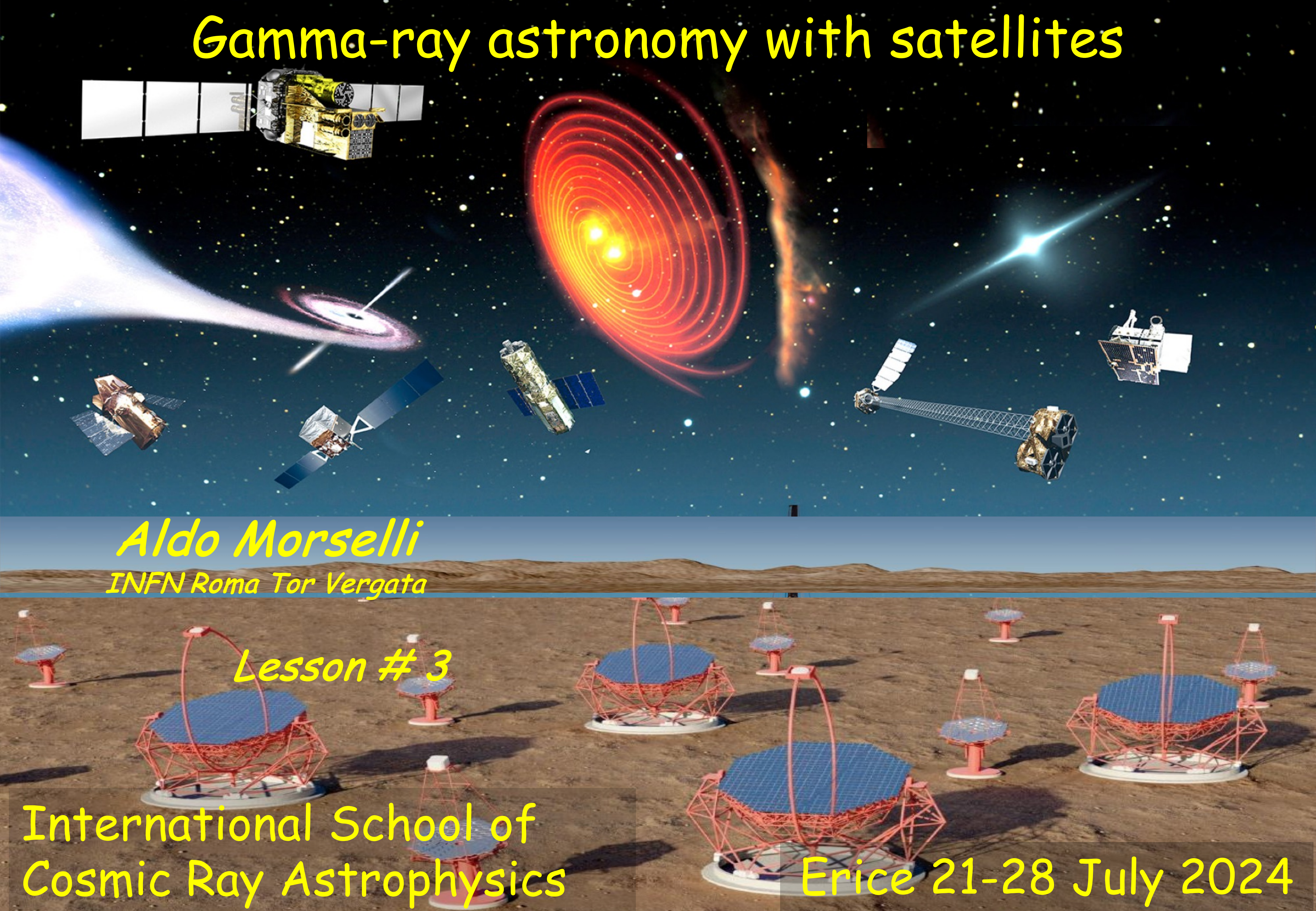
Gamma-ray astronomy with satellites



Aldo Morselli
INFN Roma Tor Vergata

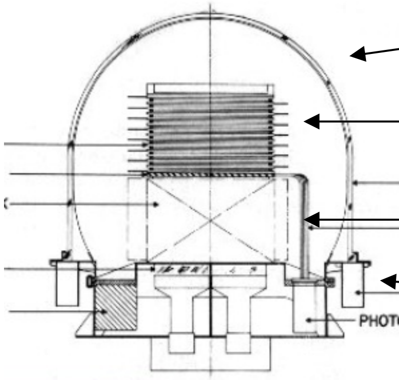
Lesson # 3

International School of Cosmic Ray Astrophysics

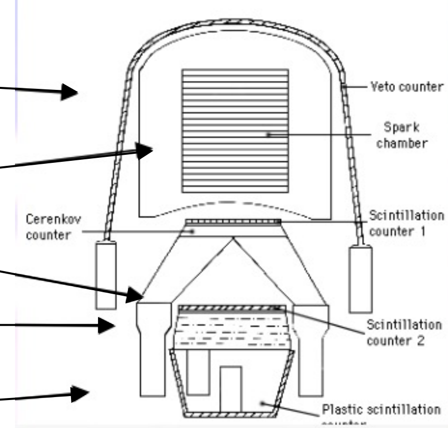
Erice 21-28 July 2024

wrap up of the previous lessons

The gamma-ray missions



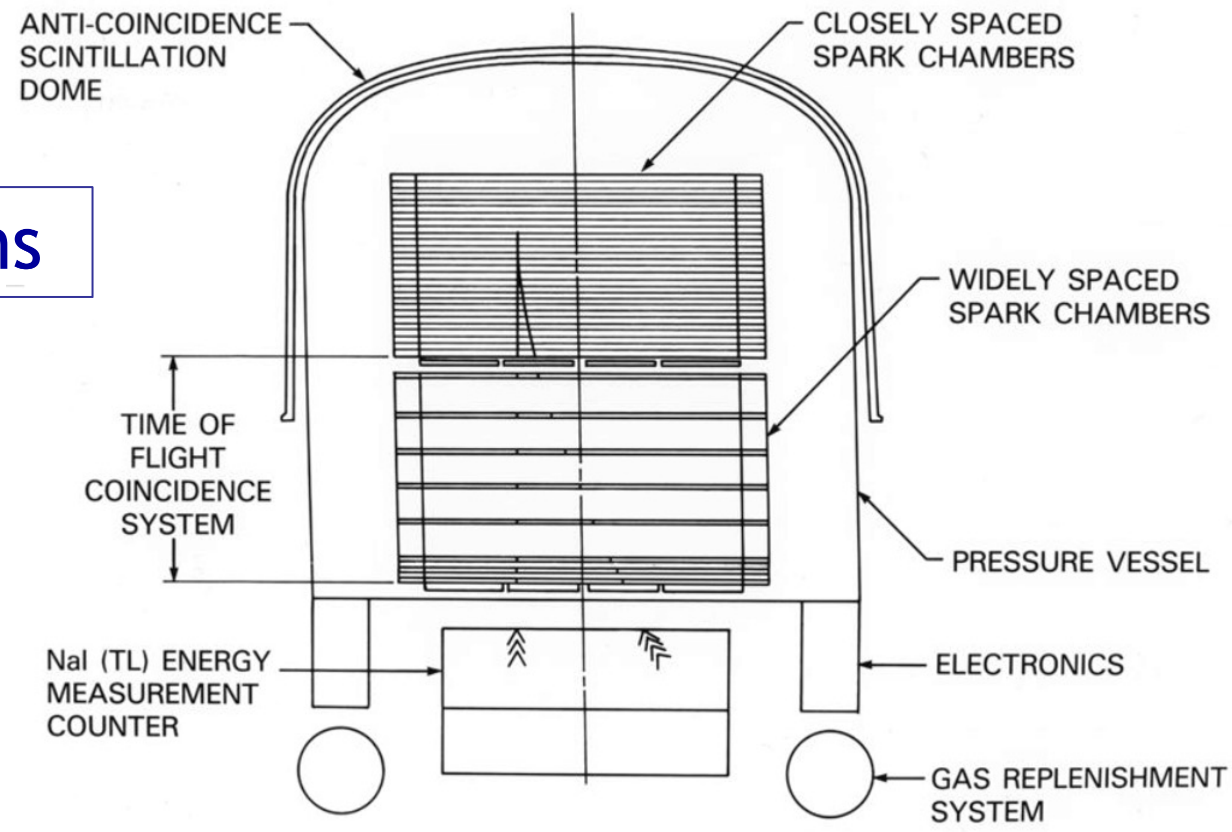
Anti-Coincidence Dome
Spark Chamber
Trigger Telescope
Cerenkov Counter
Energy Calorimeter



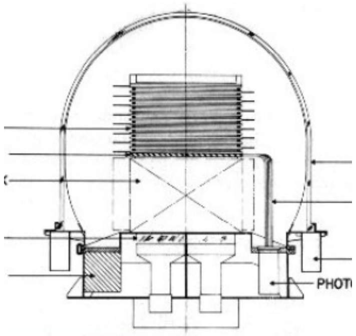
SAS-2 11/1972-7/1973

Cos-B 8/1975-4/1982

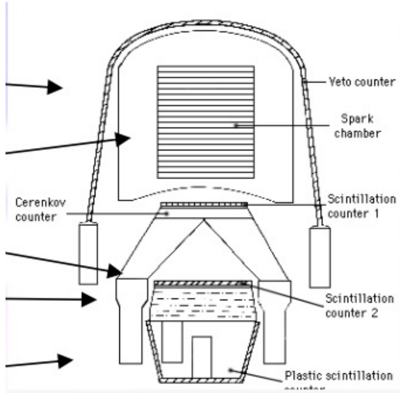
EGRET 4/1991-1999



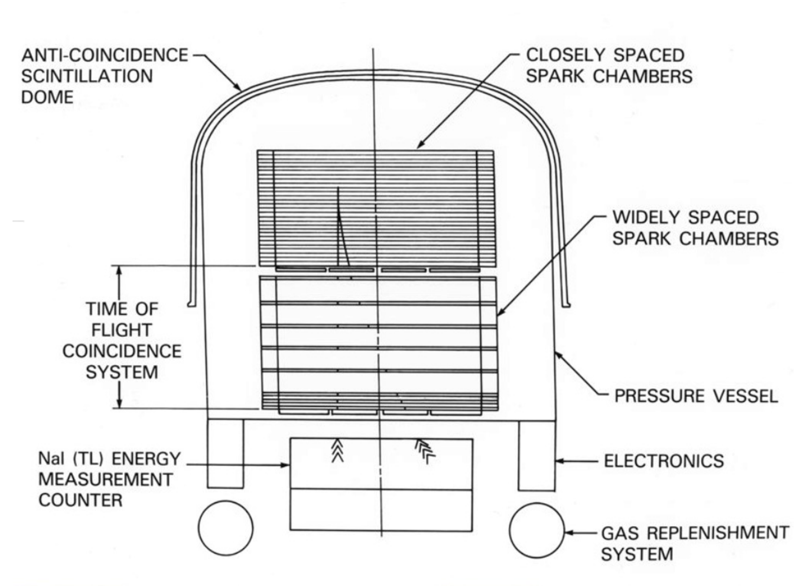
The gamma-ray missions



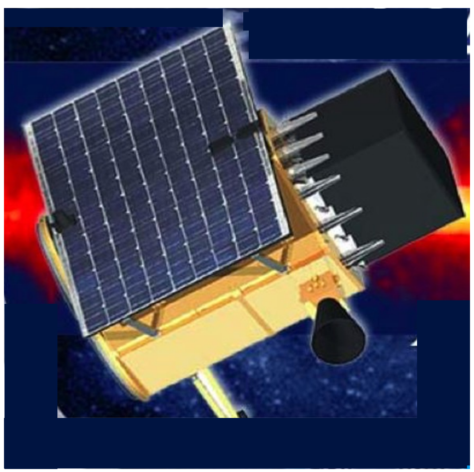
SAS-2 11/1972-7/1973



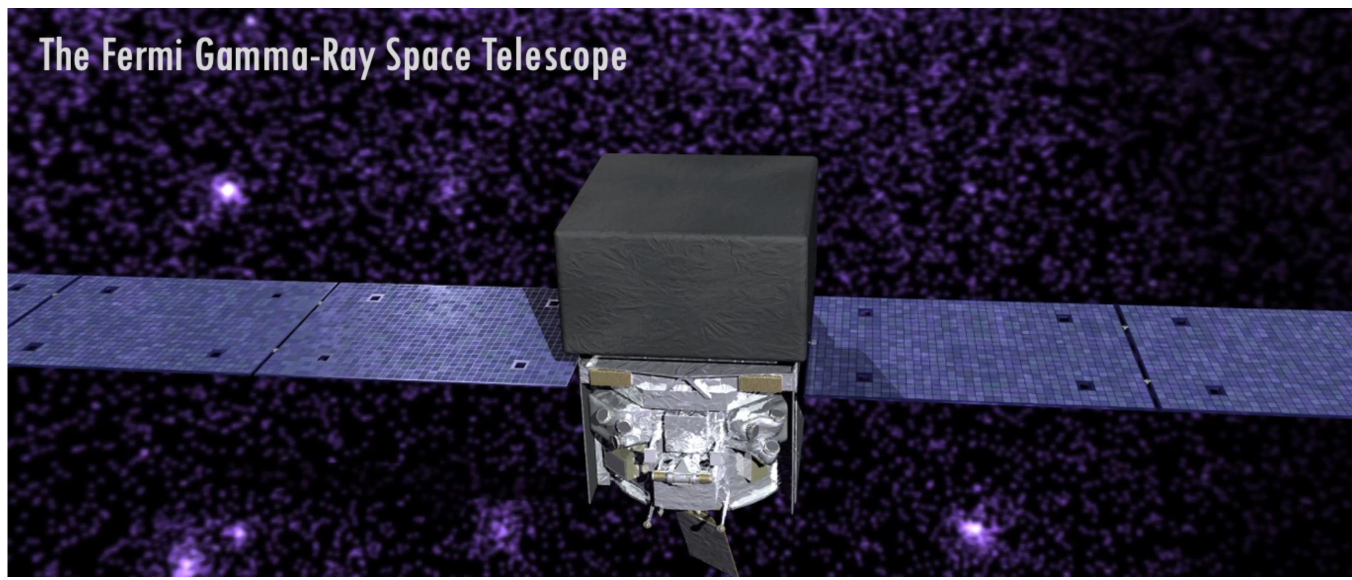
Cos-B 8/1975-4/1982



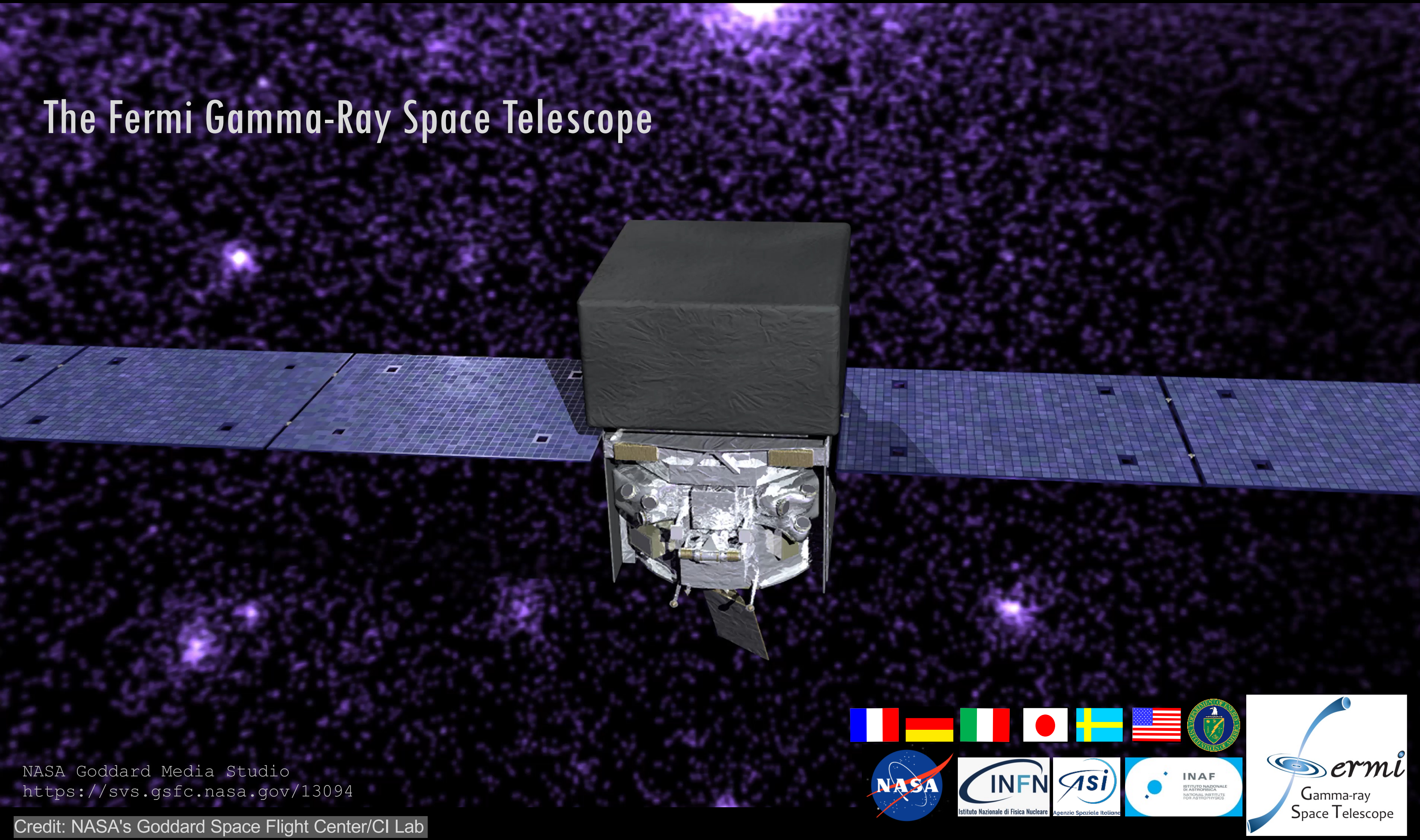
EGRET 4/1991-1999



AGILE 23/04/2007-13/02/2024

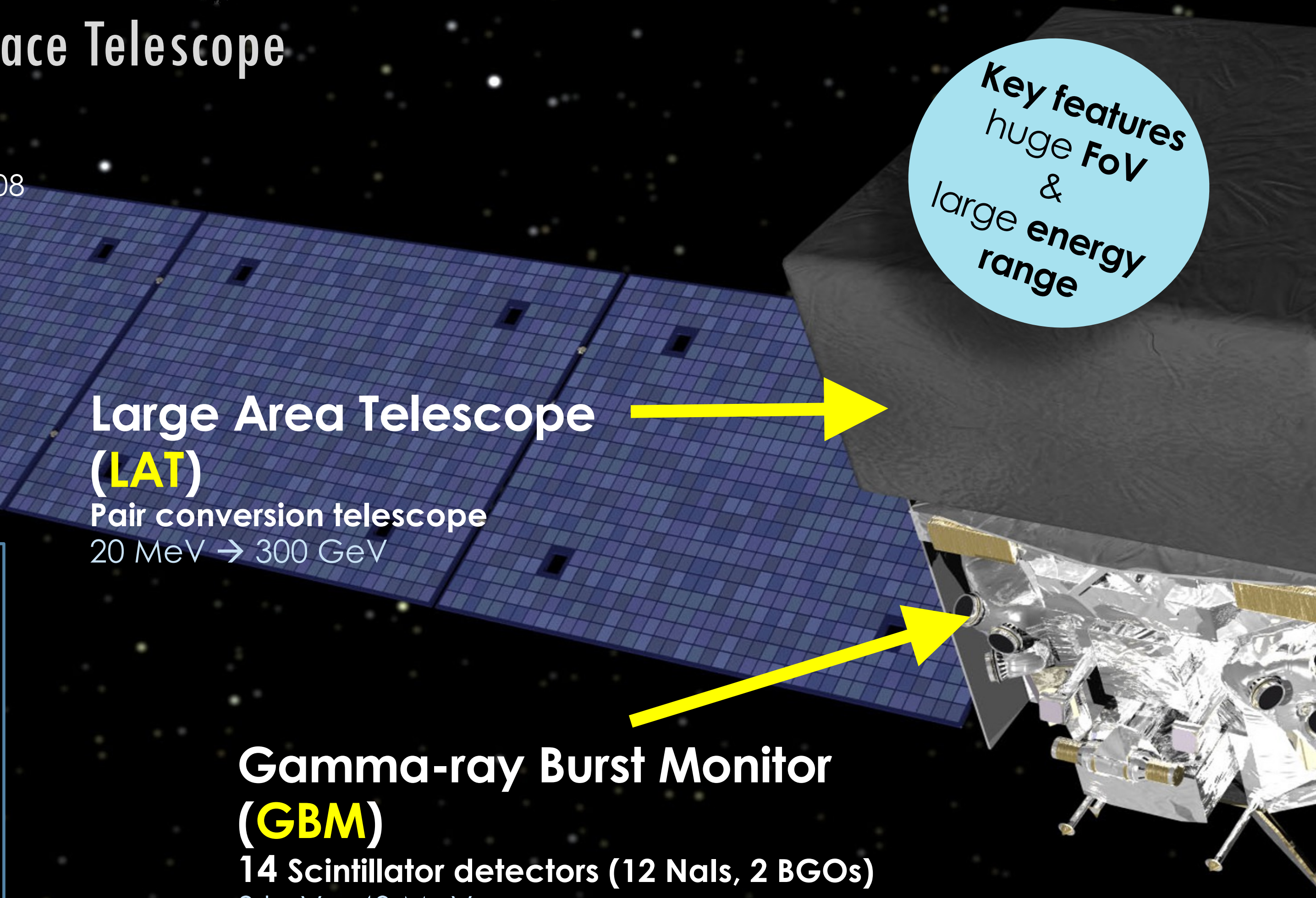


Fermi 11/06/2008----


The Fermi Gamma-Ray Space Telescope
NASA Goddard Media Studio
https://svs.gsfc.nasa.gov/13094
Credit: NASA's Goddard Space Flight Center/CI Lab
NASA
INFN
Istituto Nazionale di Fisica Nucleare
ASI
Agenzia Spaziale Italiana
INAF
Fermi
Gamma-ray
Space Telescope

The Fermi Gamma-Ray Space Telescope

Launched on June 11, 2008



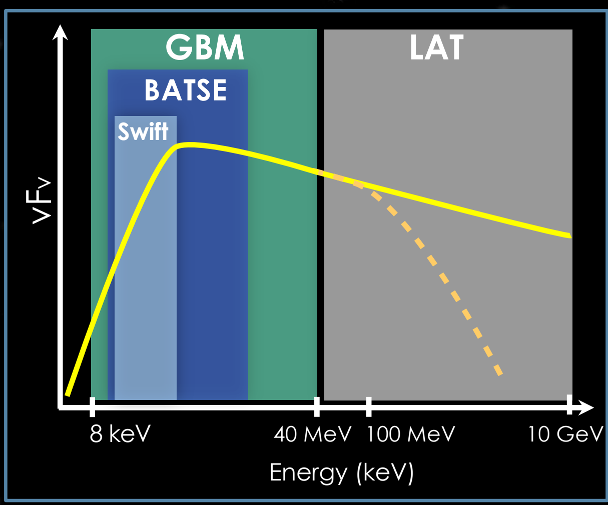
Key features
huge **FoV**
&
large **energy range**

Large Area Telescope (LAT)

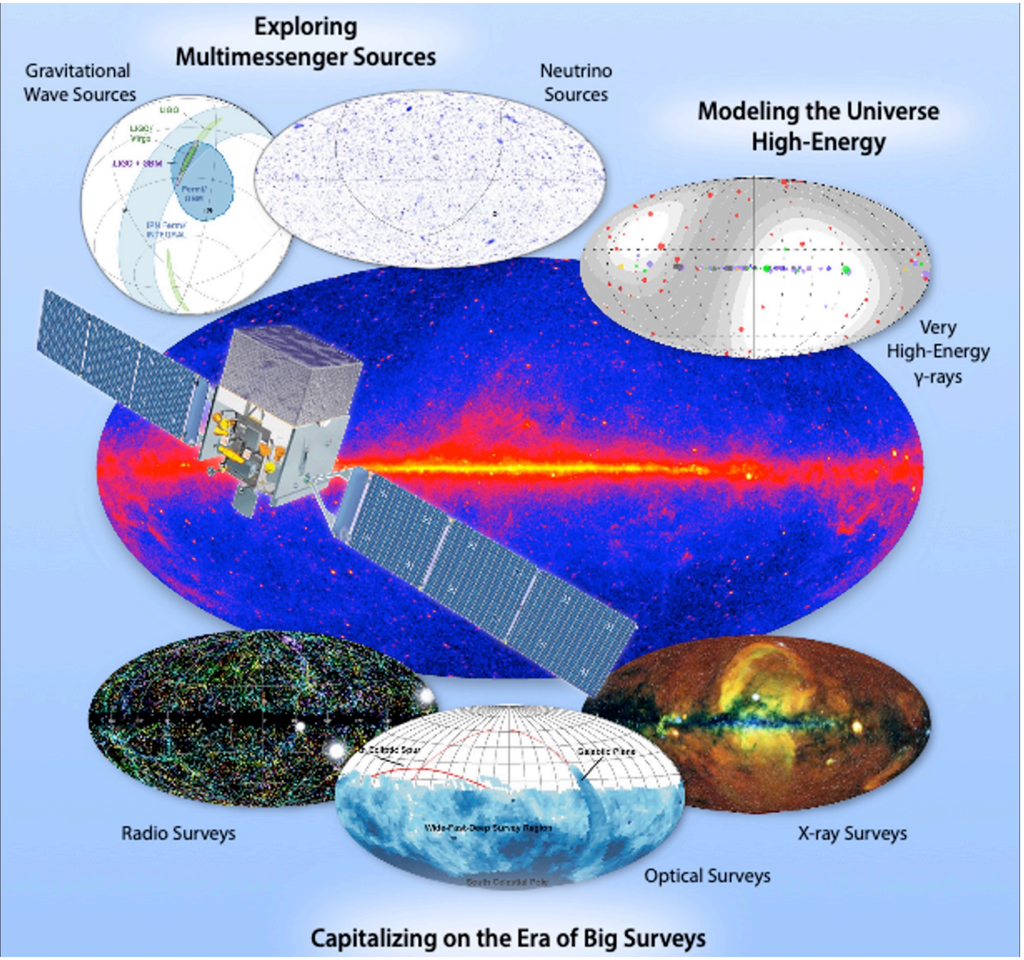
Pair conversion telescope
20 MeV → 300 GeV

Gamma-ray Burst Monitor (GBM)

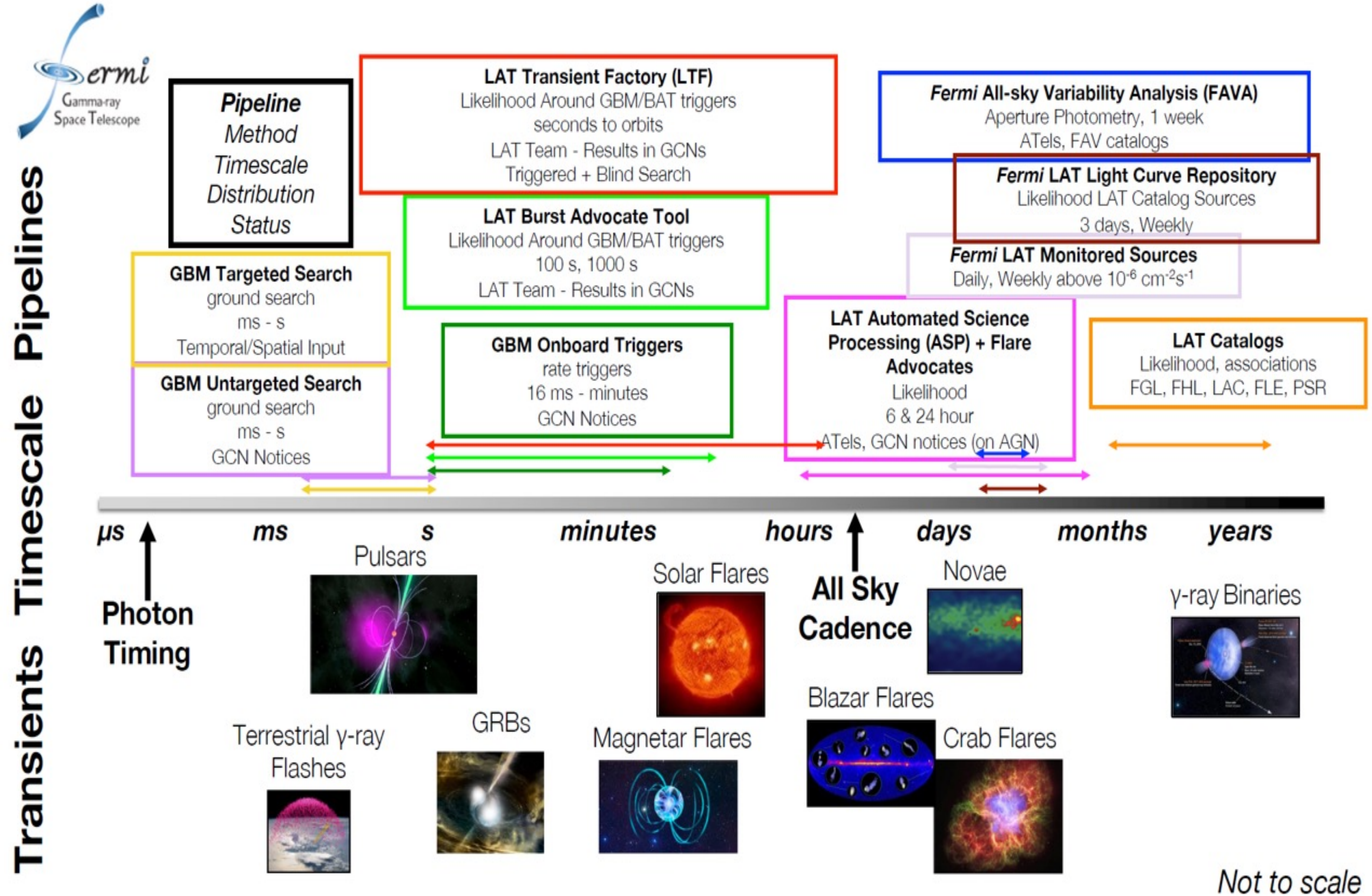
14 Scintillator detectors (12 NaIs, 2 BGOs)
8 keV – 40 MeV



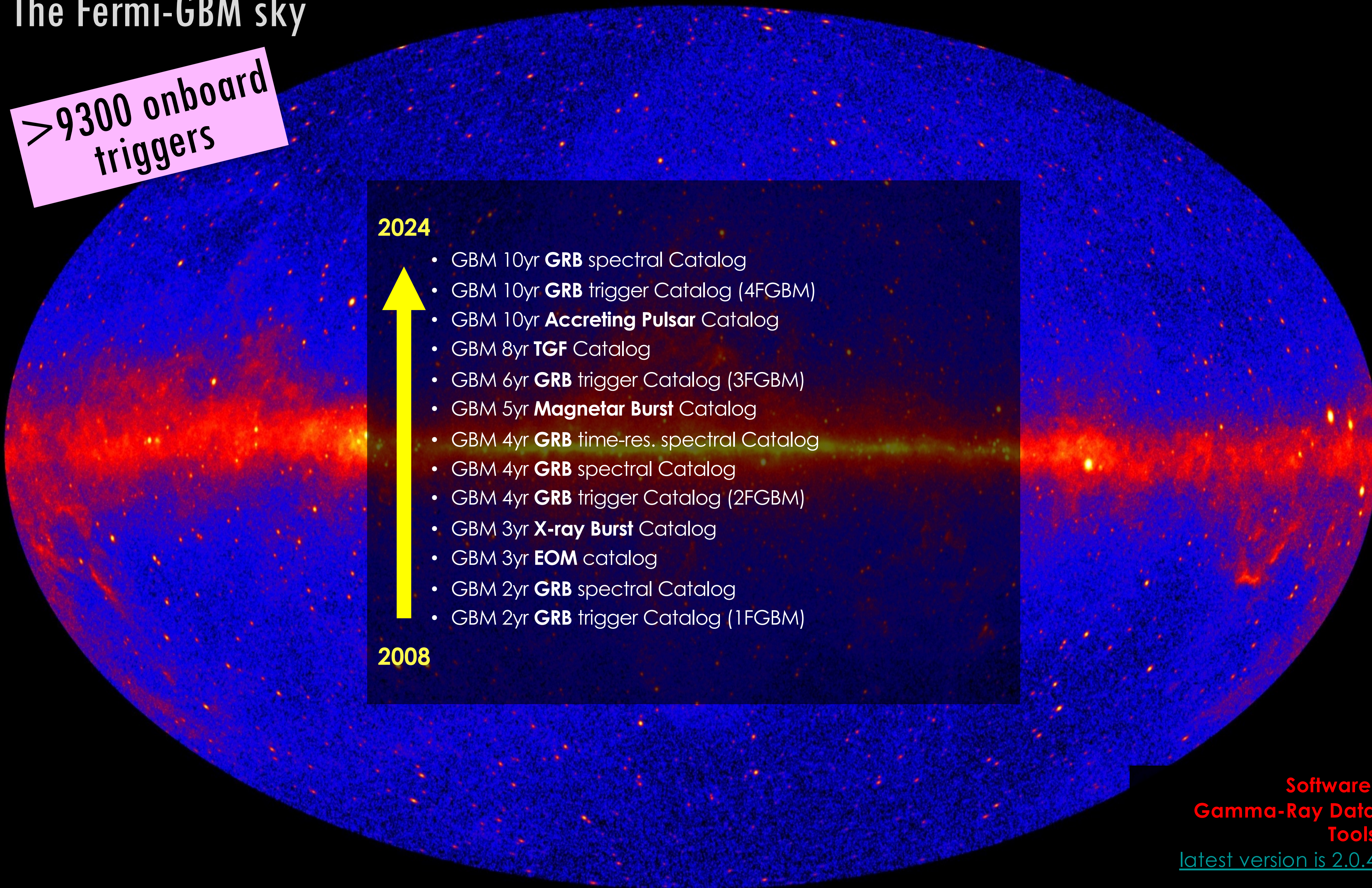
Fermi mission status and prospects



- *Spacecraft and instrument performance is excellent at 16 years*
  - *2 maneuvers (2013 and 2024) to avoid close approaches to other spacecrafts*
- Last NASA Senior Review (SR) in 2022
  - Fermi recommended for continuation for 3 years until next SR in 2025
    - *"Fermi provides unique access to the gamma-ray portion of the electromagnetic spectrum and the largest simultaneous field-of-view of any space telescope.*
      Its data give us a time-domain view of the entire gamma-ray sky and are a crucial asset for gravitational-wave and multi-messenger astrophysics."
- *Lifetime of orbit extends into the mid-2030s*


Fermi
Gamma-ray Space Telescope
Pipeline
Method
Timescale
Distribution
Status
LAT Transient Factory (LTF)
Likelihood Around GBM/BAT triggers
seconds to orbits
LAT Team - Results in GCNs
Triggered + Blind Search
Fermi All-sky Variability Analysis (FAVA)
Aperture Photometry, 1 week
ATels, FAV catalogs
Fermi LAT Light Curve Repository
Likelihood LAT Catalog Sources
3 days, Weekly
LAT Burst Advocate Tool
Likelihood Around GBM/BAT triggers
100 s, 1000 s
LAT Team - Results in GCNs
Fermi LAT Monitored Sources
Daily, Weekly above 10^-6 cm^-2s^-1
GBM Targeted Search
ground search
ms - s
Temporal/Spatial Input
GBM Onboard Triggers
rate triggers
16 ms - minutes
GCN Notices
LAT Automated Science Processing (ASP) + Flare Advocates
Likelihood
6 & 24 hour
ATels, GCN notices (on AGN)
LAT Catalogs
Likelihood, associations
FGL, FHL, LAC, FLE, PSR
GBM Untargeted Search
ground search
ms - s
GCN Notices
Pipelines
Timescale
Transients
μs
ms
s
minutes
hours
days
months
years
Photon Timing
Pulsars
Solar Flares
All Sky Cadence
Novae
γ-ray Binaries
Blazar Flares
Terrestrial γ-ray Flashes
GRBs
Magnetar Flares
Crab Flares
Not to scale

The Fermi-GBM sky



>9300 onboard triggers

2024

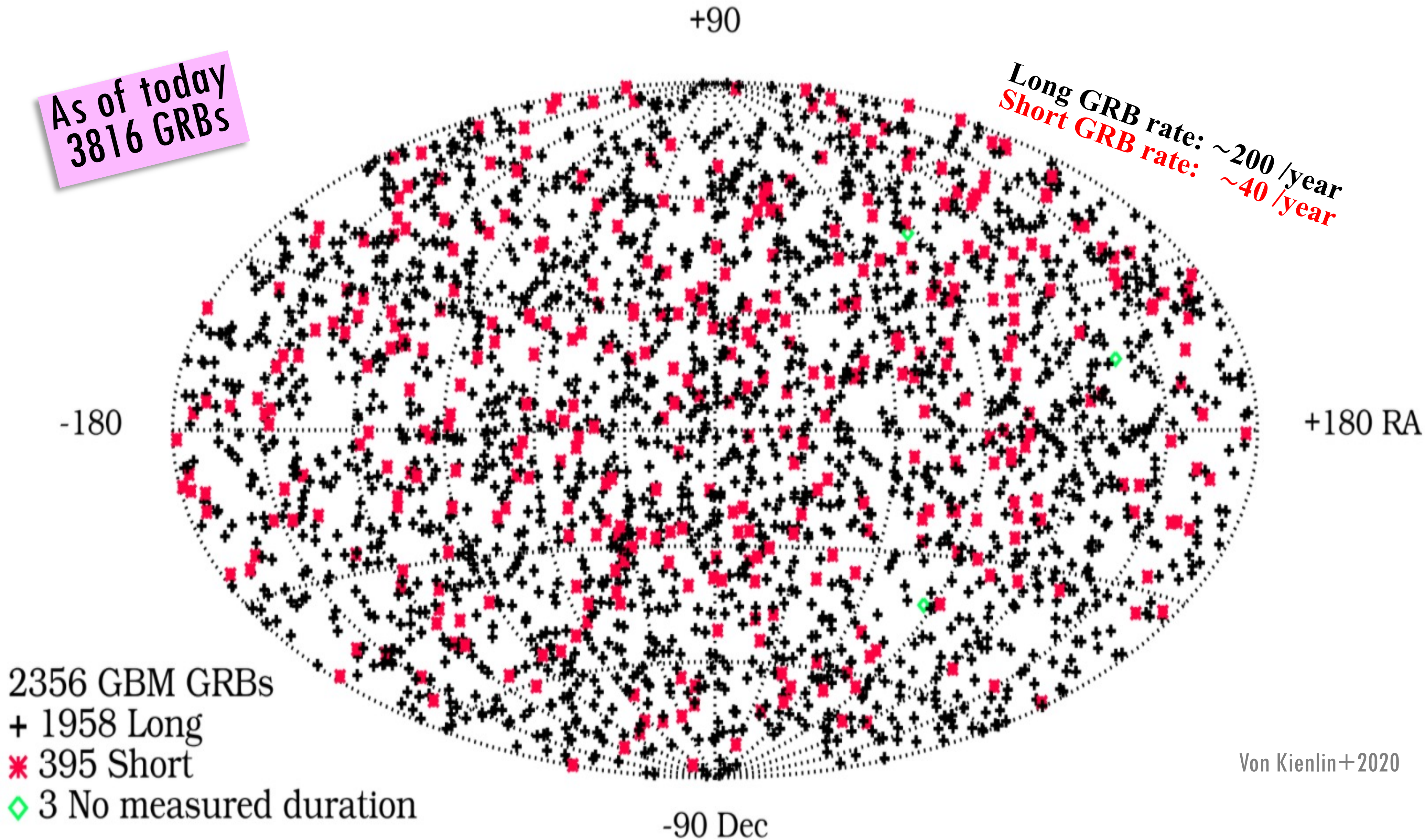
- GBM 10yr **GRB** spectral Catalog
- GBM 10yr **GRB** trigger Catalog (4FGBM)
- GBM 10yr **Accreting Pulsar** Catalog
- GBM 8yr **TGF** Catalog
- GBM 6yr **GRB** trigger Catalog (3FGBM)
- GBM 5yr **Magnetar Burst** Catalog
- GBM 4yr **GRB** time-res. spectral Catalog
- GBM 4yr **GRB** spectral Catalog
- GBM 4yr **GRB** trigger Catalog (2FGBM)
- GBM 3yr **X-ray Burst** Catalog
- GBM 3yr **EOM** catalog
- GBM 2yr **GRB** spectral Catalog
- GBM 2yr **GRB** trigger Catalog (1FGBM)

2008

Software: Gamma-Ray Data Tools

latest version is 2.0.4

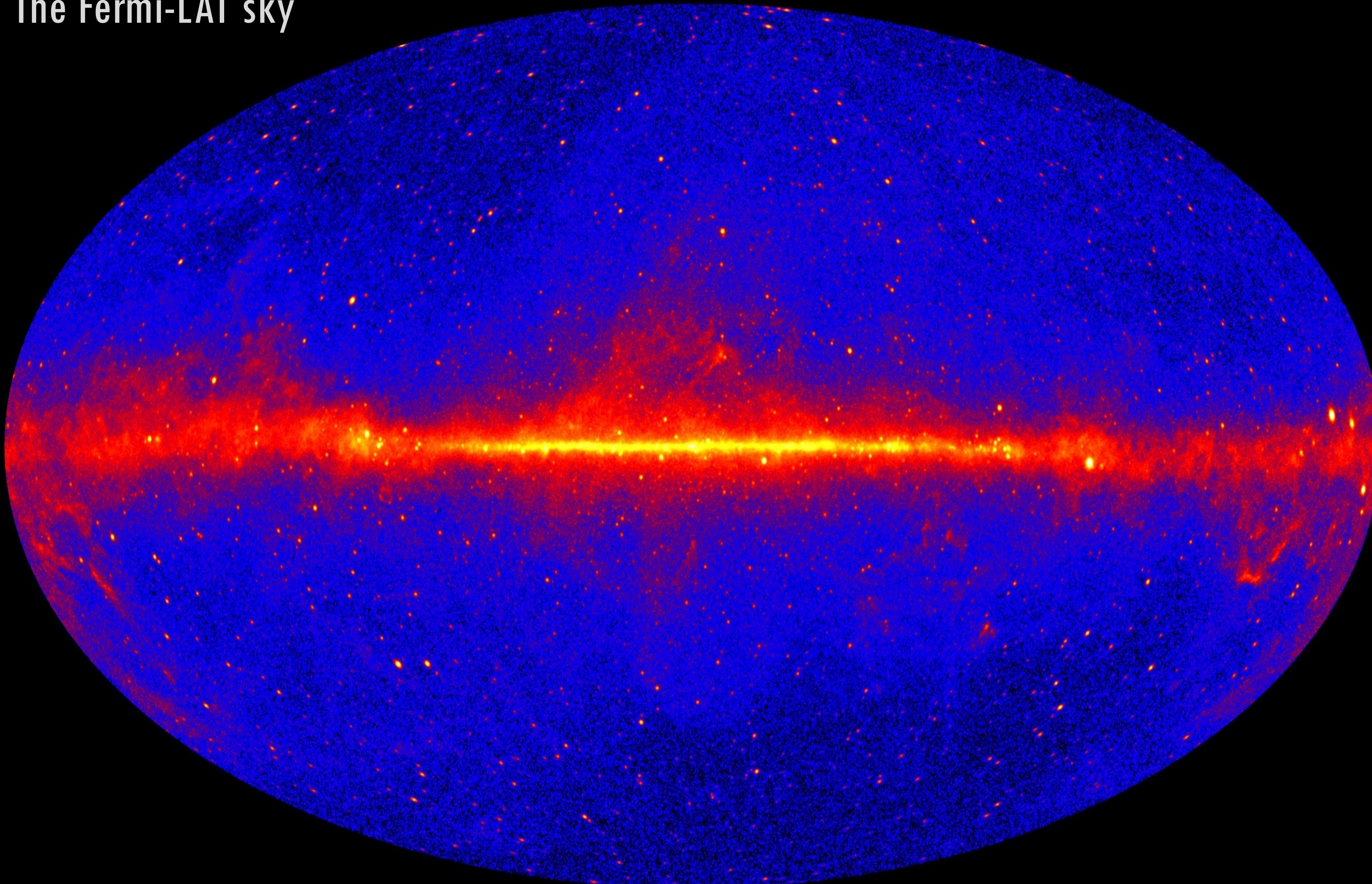
Fermi GBM GRBs in first ten years of operation



As of today 3816 GRBs

Long GRB rate: ~200 /year
Short GRB rate: ~40 /year

The Fermi-LAT sky



The Fermi-LAT sky

>939 billion triggers*

2024

- LAT 14yr **Point Source** Catalog (4FGL-DR4) **(7194 sources)**
- LAT 12yr **Pulsars** Catalog (3PC)
- LAT 12yr **Point Source** Catalog (4FGL-DR3)
- LAT 10yr **Point Source** Catalog (4FGL-DR2)
- LAT 8yr **Solar Flare** Catalog
- LAT 10yr **AGN** Catalog (4LAC)
- LAT 10yr **GRB** Catalog (2FLGC)
- LAT 8yr **Point Source** Catalog (4FGL)
- LAT 7yr **High-Energy Source** Catalog (3FHL)
- LAT **Extended Sources** in the Galactic Plane (FGES)
- LAT All-sky **Variability Analysis** Catalog (2FAV)
- LAT 6yr **High-Energy Source** Catalog (2FHL)
- LAT 4yr **Point Source** Catalog (3FGL)
- LAT 4yr **AGN** Catalog (3LAC)
- LAT 3yr **GRB** Catalog (1FLGC)
- LAT 3yr **SNR** Catalog
- LAT 3yr **Pulsars** Catalog (2PC)
- LAT 3yr **High-Energy Source** Catalog (1FHL)
- LAT 2yr **AGN** Catalog (2LAC)
- LAT 2yr **Point Source** Catalog (2FGL)
- LAT 1yr **AGN** Catalog (1LAC)
- LAT 1yr **Point Source** Catalog (1FGL)
- LAT 6month **Pulsars** Catalog (1PC)
- LAT 3month **Bright Source** List (0FGL)

2008

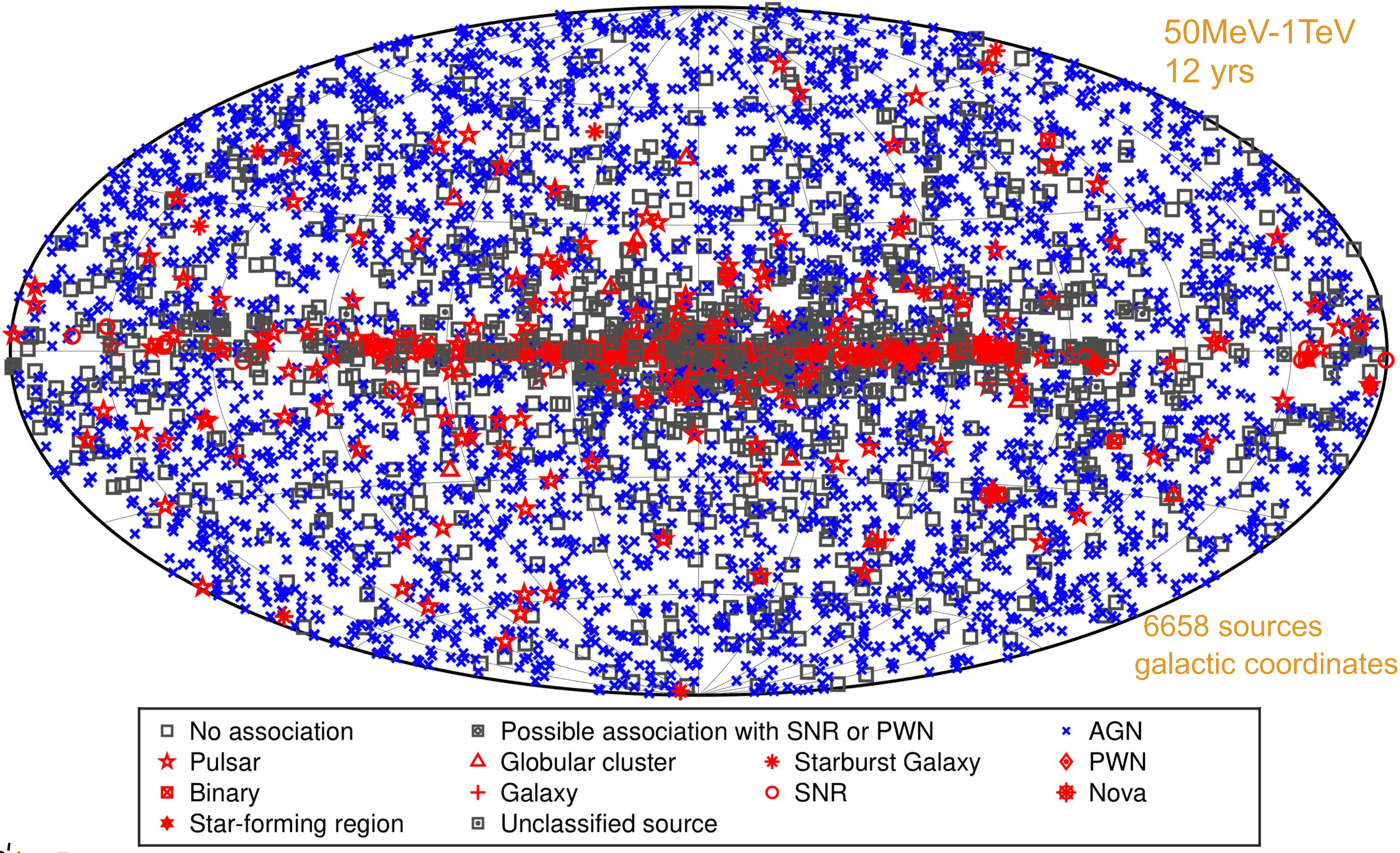
0/1/2/3/4FGL:
full energy range
(50 MeV-1 TeV)
1/2/3FHL:
high-energy only (> 10/50 GeV)

Each generation uses
improved data/calibration:
P6 → P7 → P7Rep → P8

*4.53 billion LAT events available at FSSC

Software: Fermitools
latest version is 2.2.0

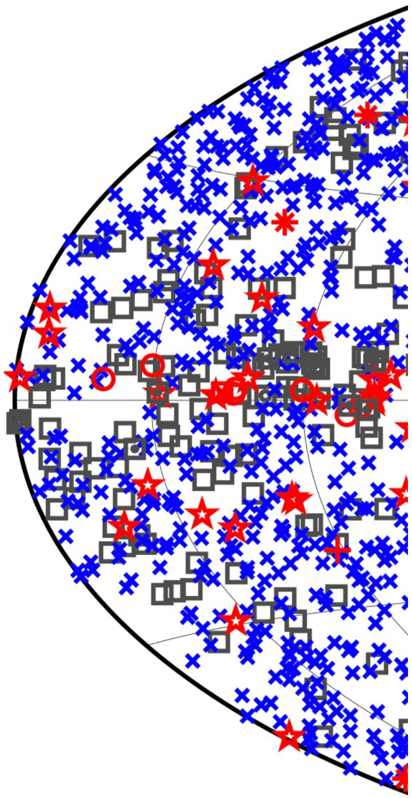
The sky in gamma-rays 4th source catalog



Incremental Fermi Fouth Source Catalog, ApJS 260, 53 (2022) [arXiv: 2201.11184]

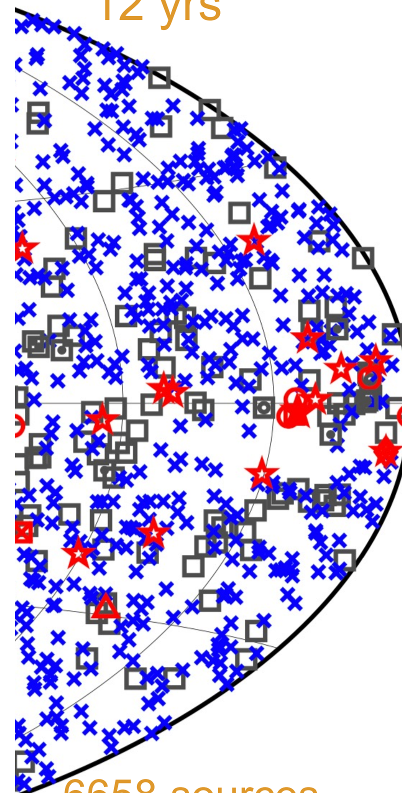
The sky in gamma-rays 4th source catalog

50MeV-1TeV
12 yrs



Description	Identified		Associated	
	Designator	Number	Designator	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

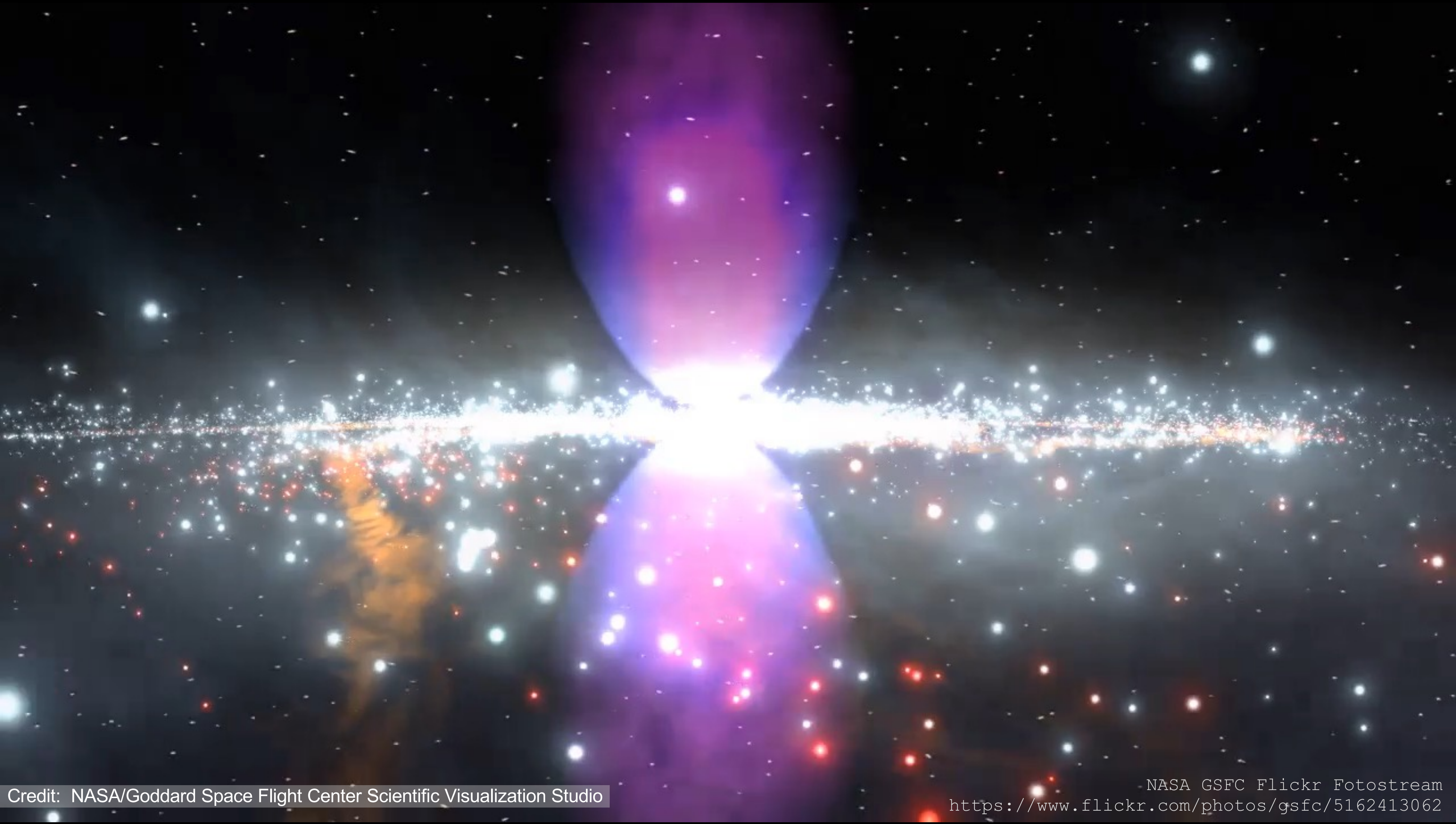
NOTE—The designation 'spp' indicates potential association with SNR or PWN. 'Unknown' are $|b| < 10°$ sources solely associated with the likelihood-ratio method from large radio and X-ray surveys. Designations shown in capital letters are firm identifications; lower-case letters indicate associations.



6658 sources
galactic coordinates

Incremental Fermi Fouth Source Catalog, ApJS 260, 53 (2022) arXiv: 2201.11184

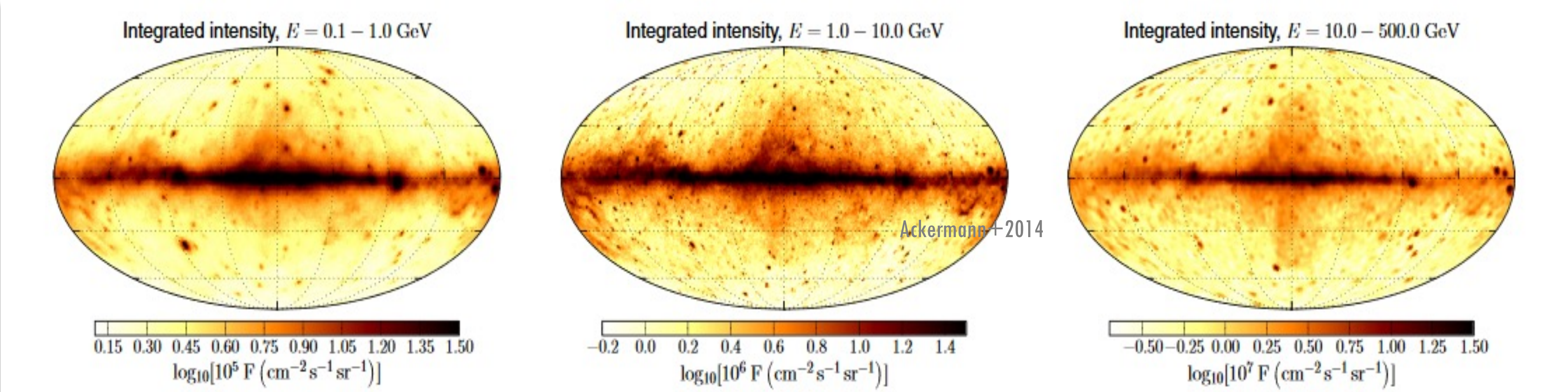
The Fermi Bubbles



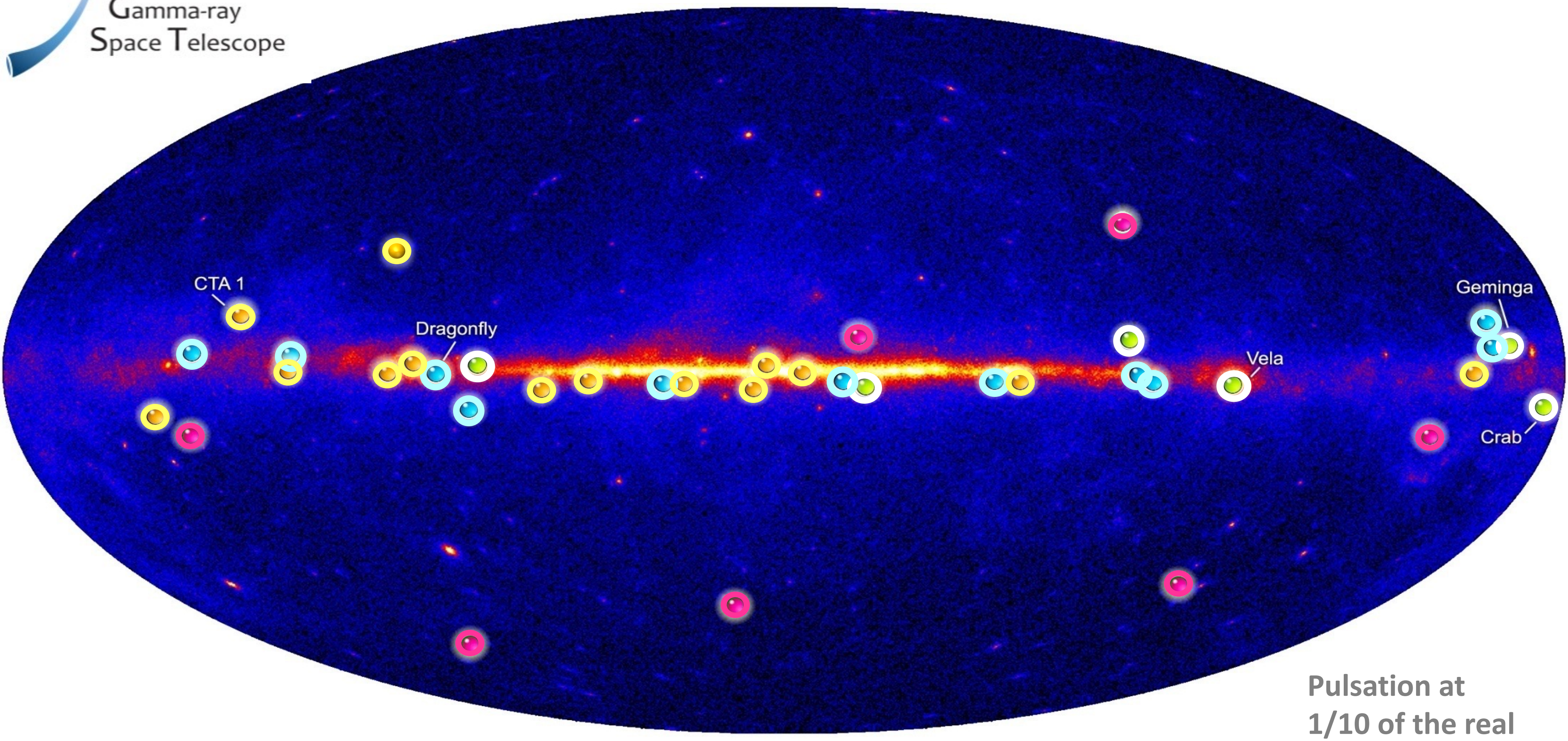
Credit: NASA/Goddard Space Flight Center Scientific Visualization Studio

The Fermi bubbles

- Excess in the diffuse emission detected between 1 GeV up to 50GeV
- Fermi Bubbles properties:
  - Extension for ~**55°** above and below the Galactic plane
  - Same morphology as the WMAP microwave haze with a magnetic field between 5 and 20 μG ➔ common origin
  - Likely created by some large energy injection in the Galactic Center, such as a past accretion event onto the central black hole SgrA in the last ~10 My



The pulsating gamma rays sky

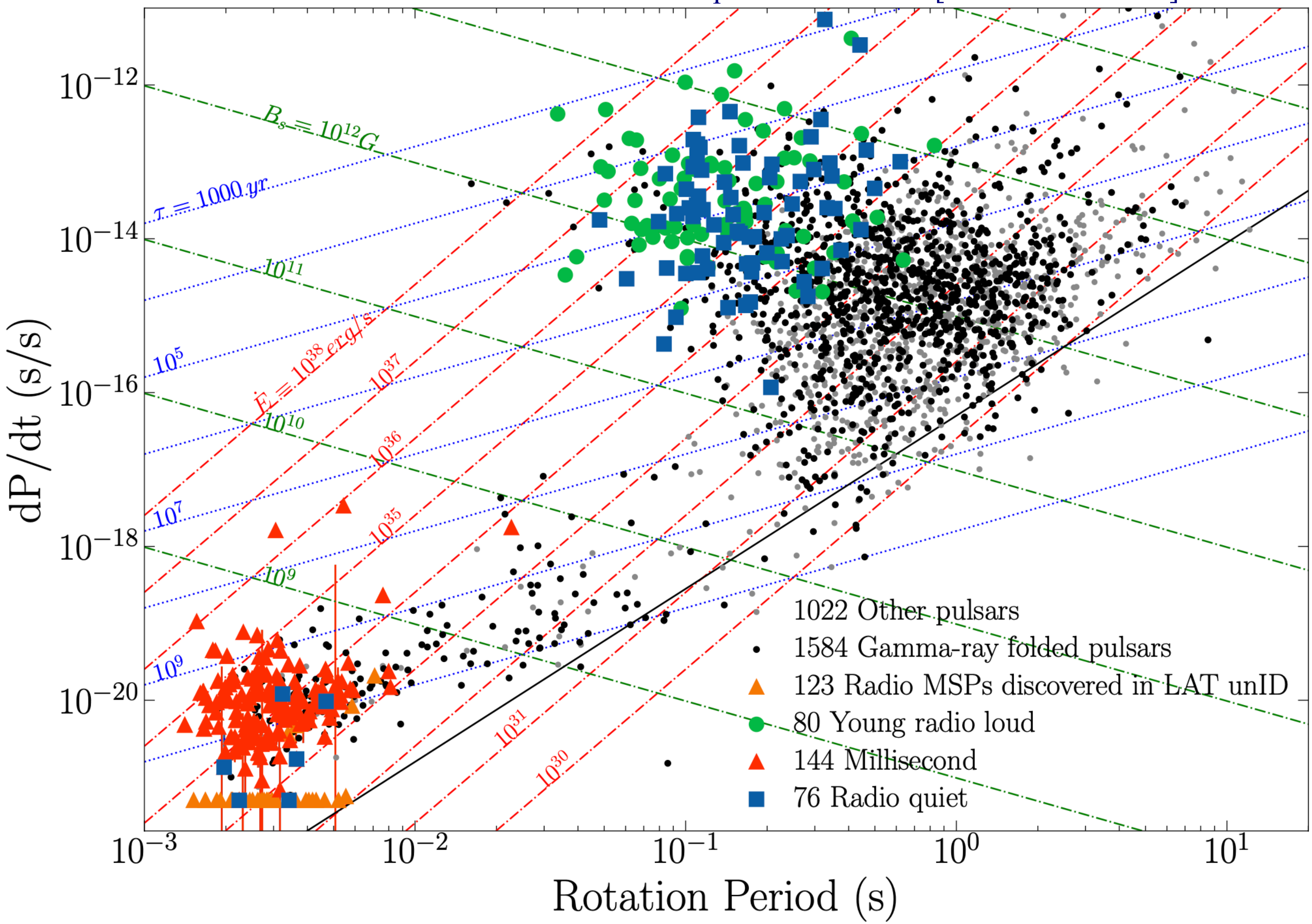


New pulsars discovered in a blind search
Millisecond radio pulsars
Young radio pulsars
Pulsars seen by Compton Observatory EGRET instrument

Pulsation at 1/10 of the real frequency

Fermi LAT pulsars

The Third Fermi Large Area Telescope Catalog of Gamma-ray Pulsars
Fermi-LAT. ApJ 2023 958 191 [arXiv:2307.11132]



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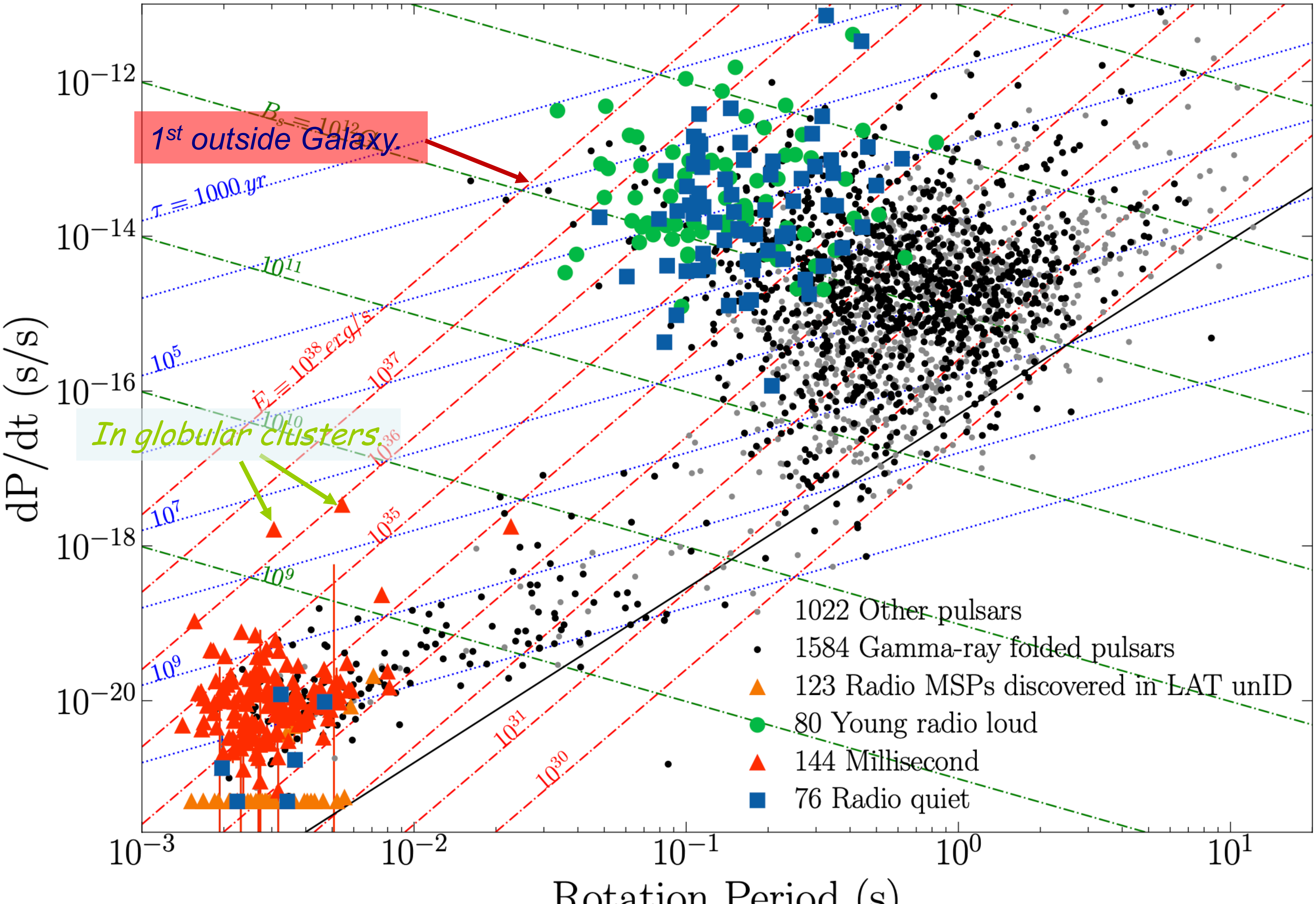

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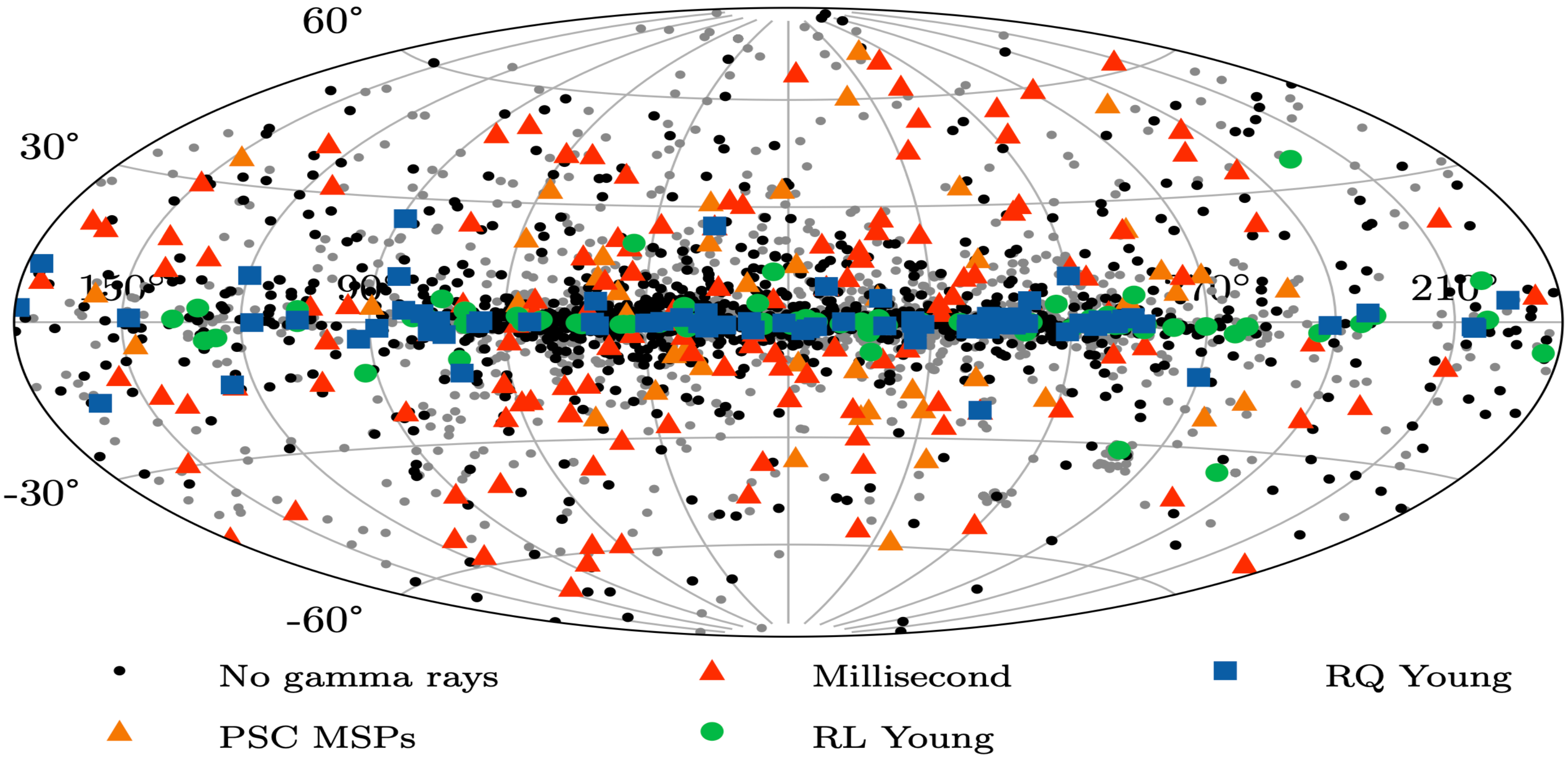


At present the LAT has detected 276 gamma-ray pulsars (Third Catalog on the way)

•Half of the gamma-ray pulsars were not known before Fermi

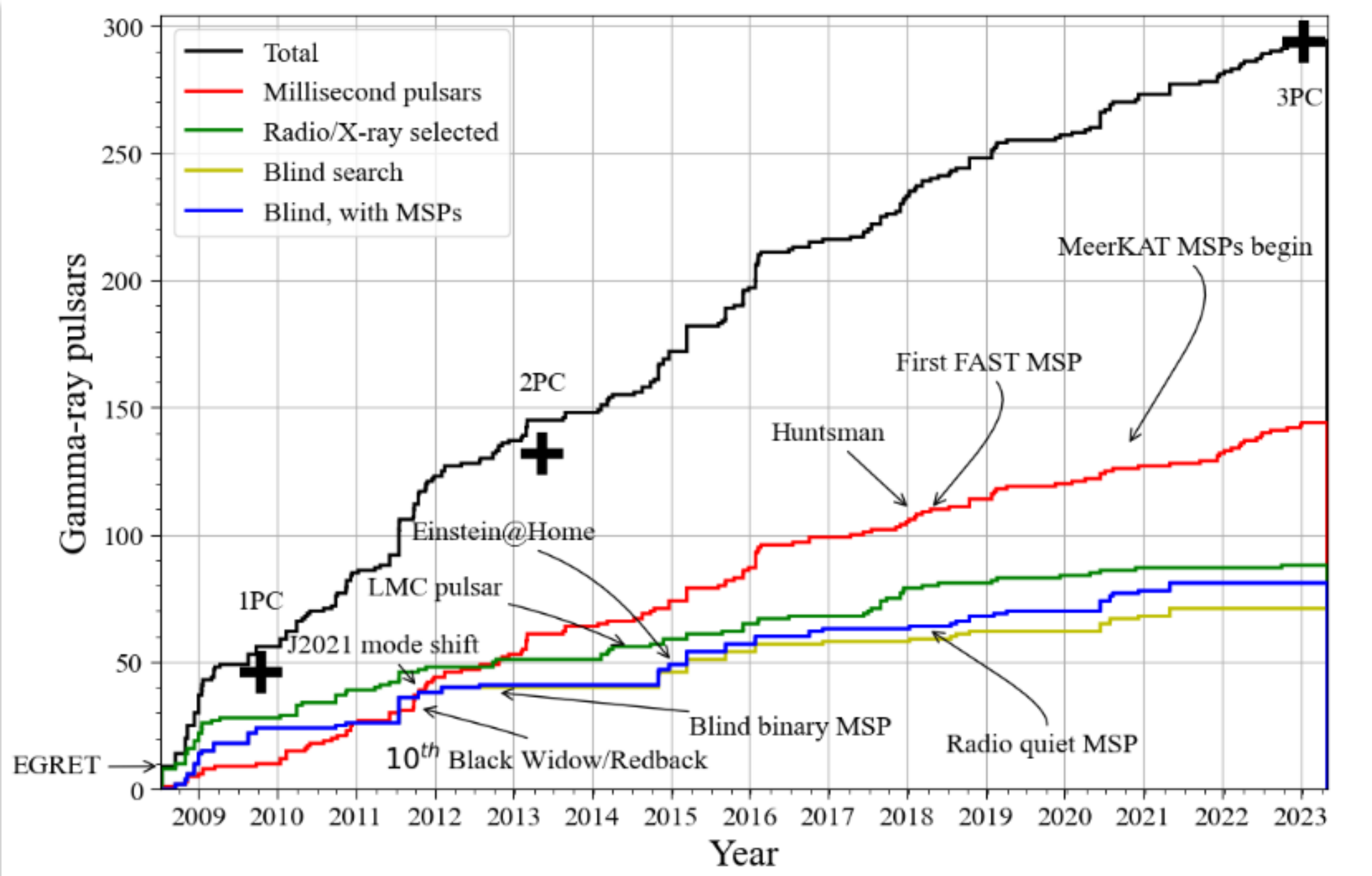
•Pulsar science represents an example of successful cooperation between radio, X-ray and gamma-ray astronomers.

• A Pulsar Search Consortium (PSC) undertook searches at radio and X-ray wavelengths at the positions of unidentified LAT gamma-ray sources.

Fermi LAT pulsars

The Third Fermi Large Area Telescope Catalog of Gamma-ray Pulsars
Fermi-LAT. ApJ 2023 958 191 [arXiv:2307.11132]

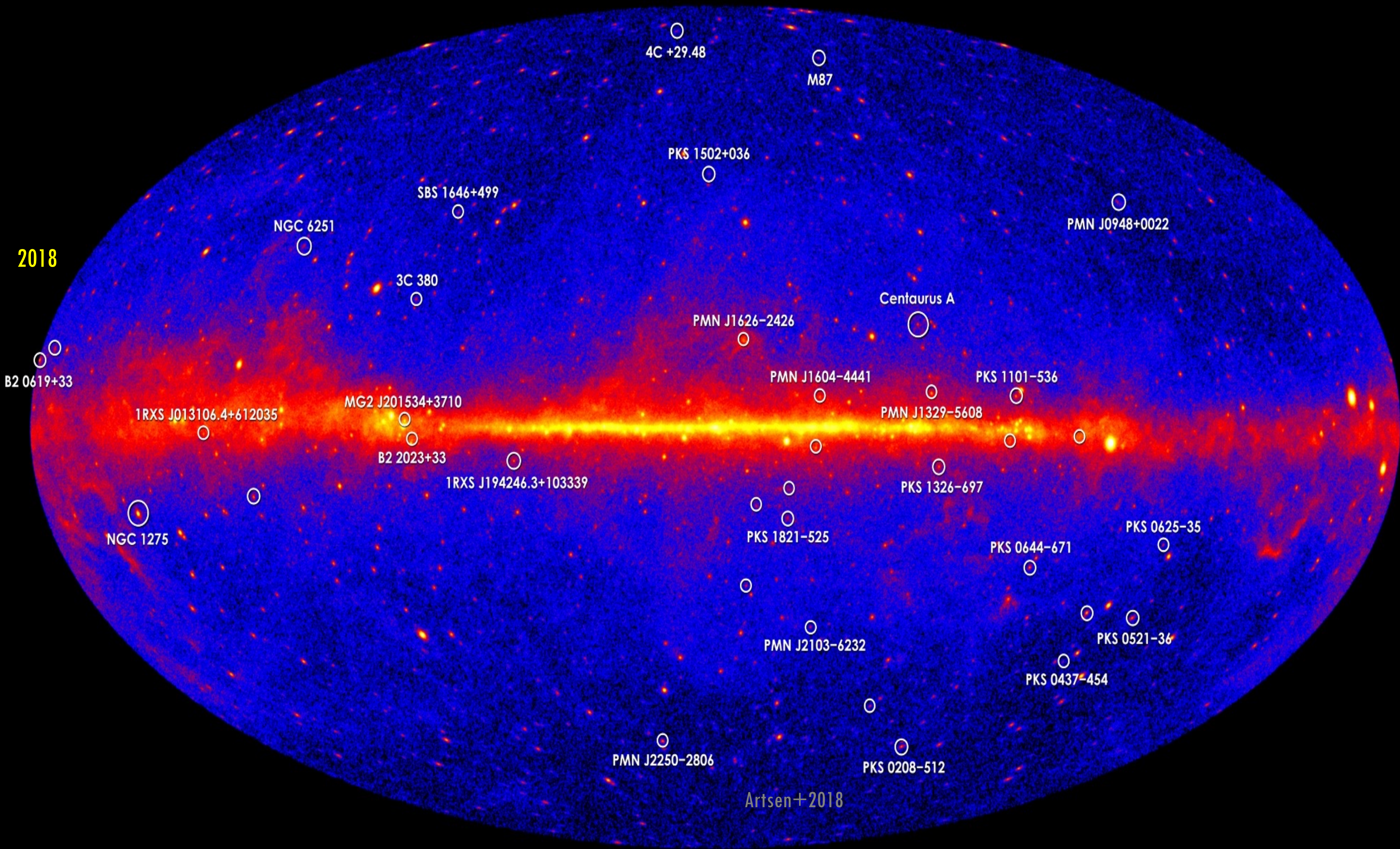
- 294 gamma-ray pulsars
  - Half of them not known before Fermi
  - Emission region location: outer-gap model preferred with respect to the polar-gap
  - Discovery of gamma-ray millisecond pulsars (MSPs)
  - Pulsars, considered stable sources, were discovered to be variable!



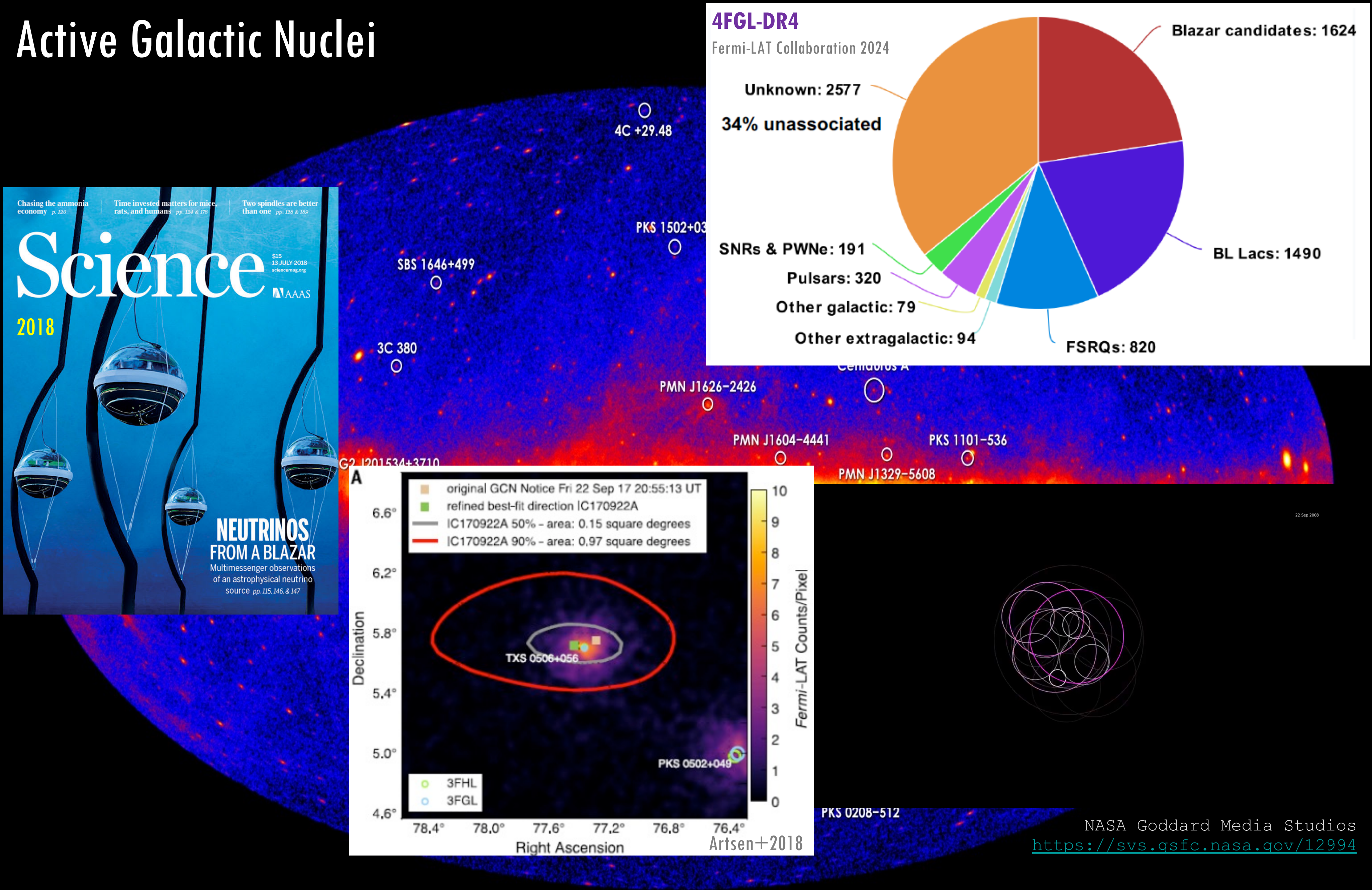
Public list of LAT pulsars

https://confluence.slac.stanford.edu/display/GLAMCOG/Public+List+of+LAT-Detected+Gamma-Ray+Pulsars

Active Galactic Nuclei



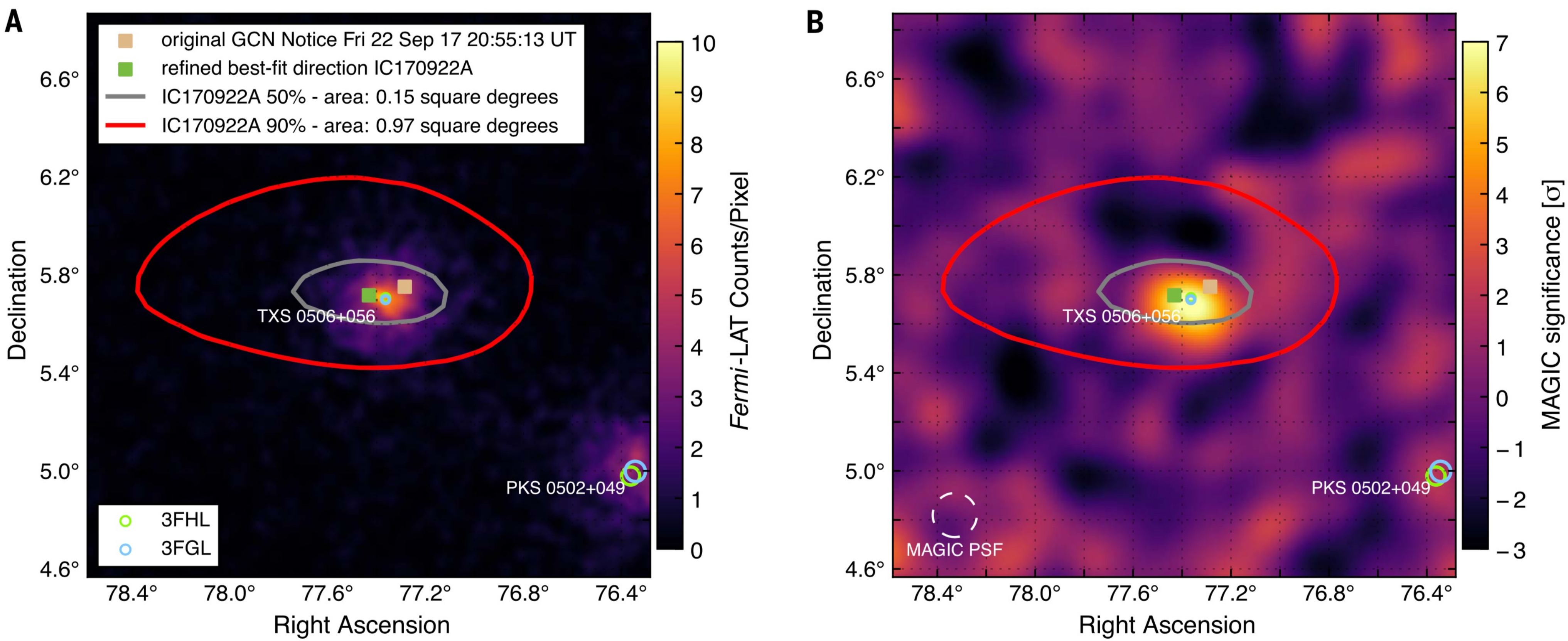
Active Galactic Nuclei



NASA Goddard Media Studios
https://svs.gsfc.nasa.gov/12994

Multimessenger Astronomy: Neutrinos

- Are AGN sources of VHE neutrinos and thus of UHECR?
- The case of EHE 170922 (TXS 0506 +056)

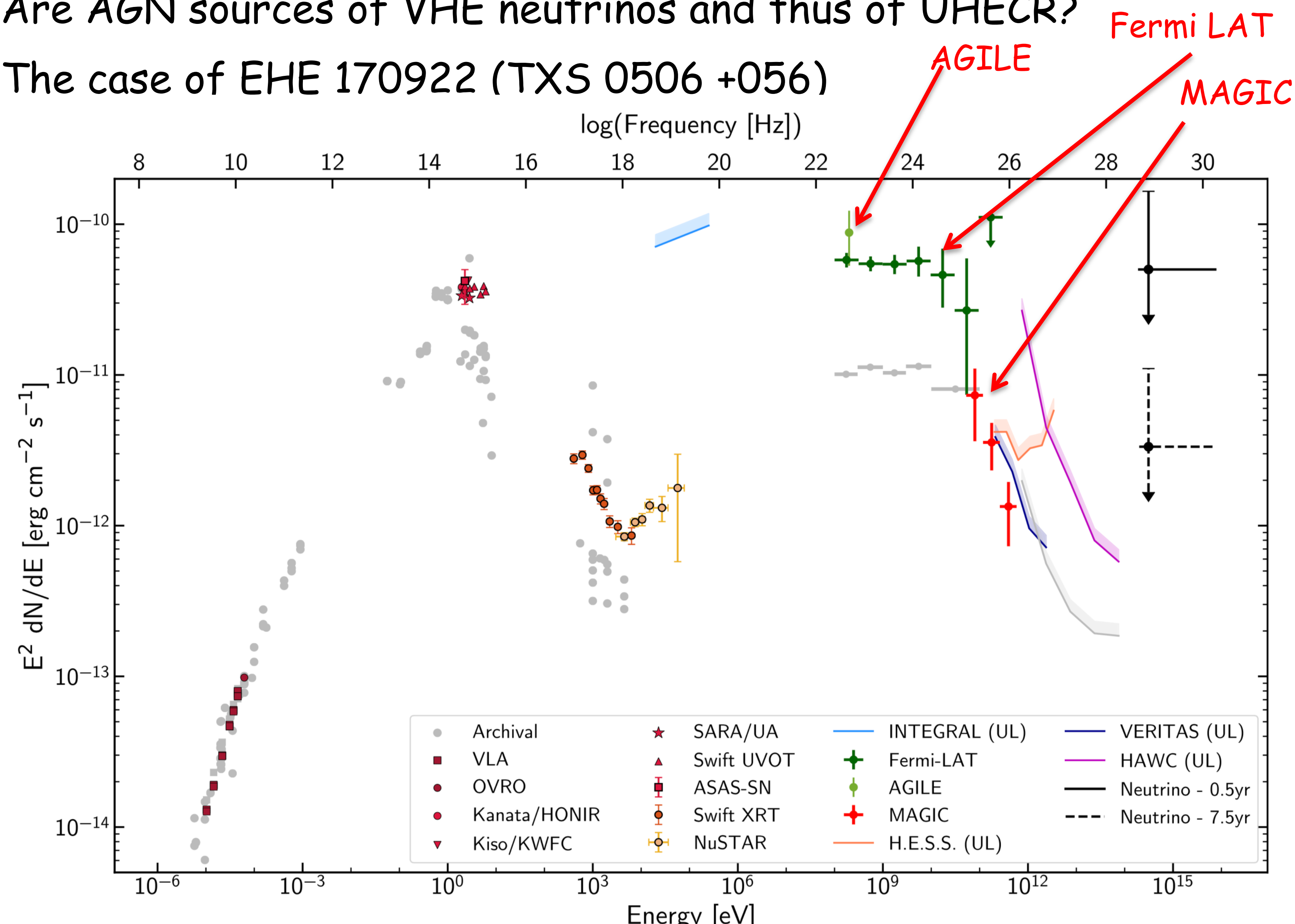


Fermi-LAT and MAGIC observations of IceCube-170922A's location.

Science 361, eaat1378 (2018) 12July

Broadband spectral energy distribution for the blazar TXS 0506+056

- Are AGN sources of VHE neutrinos and thus of UHECR?
- The case of EHE 170922 (TXS 0506 +056)



Science 361, eaat1378 (2018) 12July

Multimessenger observation of blazars with neutrinos

IC 170922A and TXS 0506+056

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NUMBER:  21916
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DATE:    17/09/23 01:09:26 GMT
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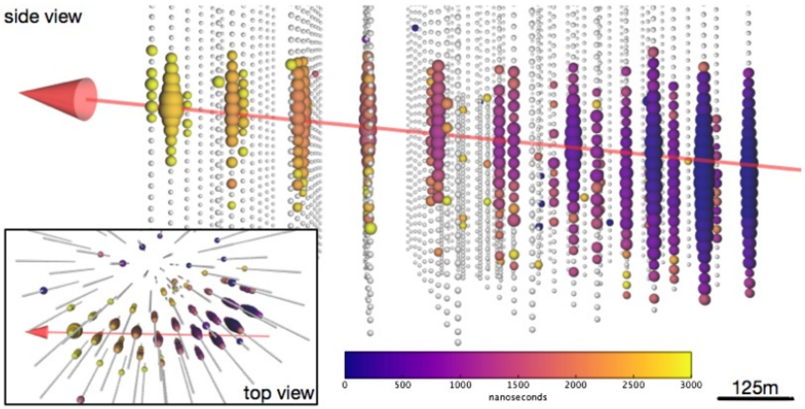
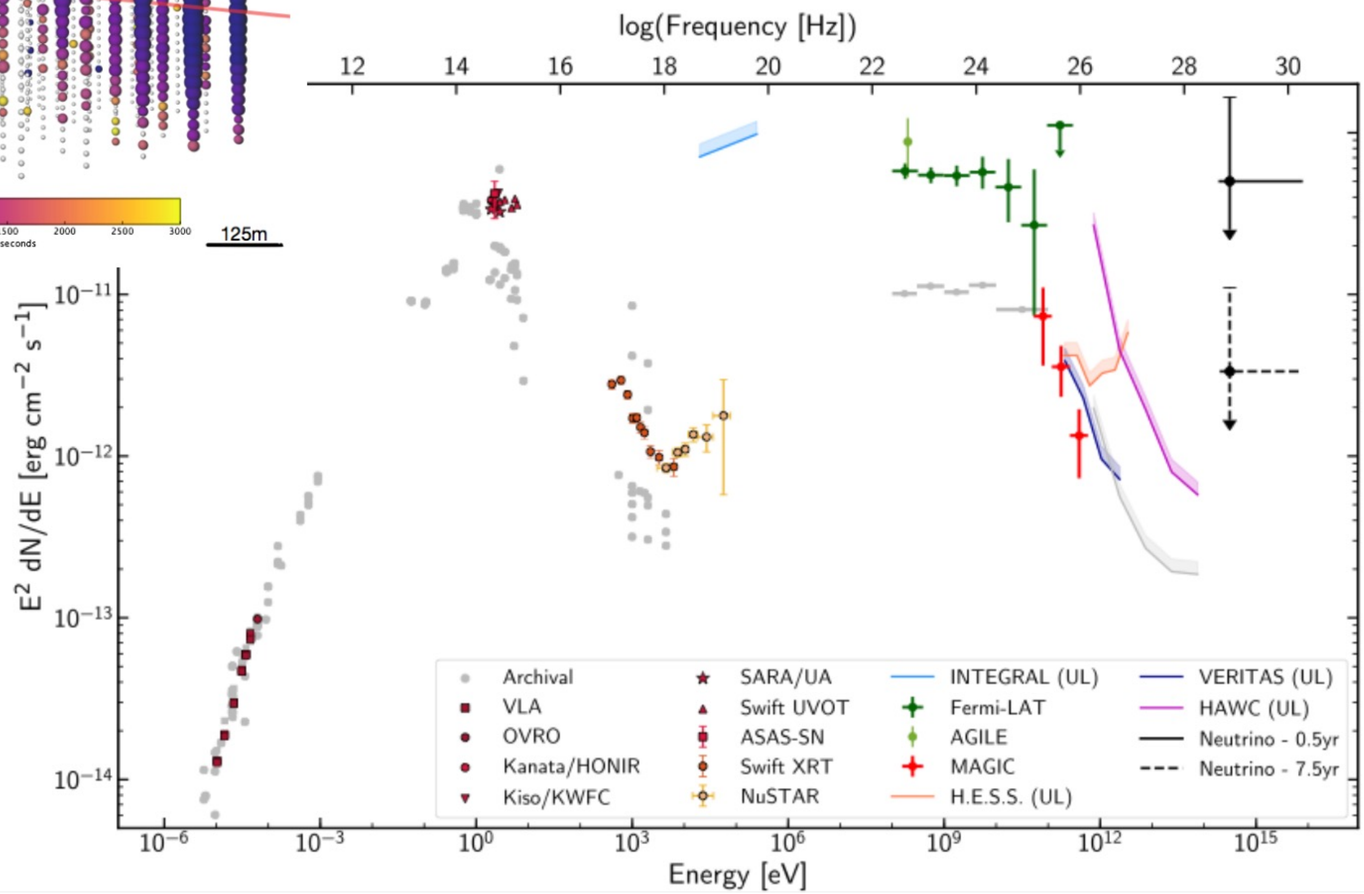
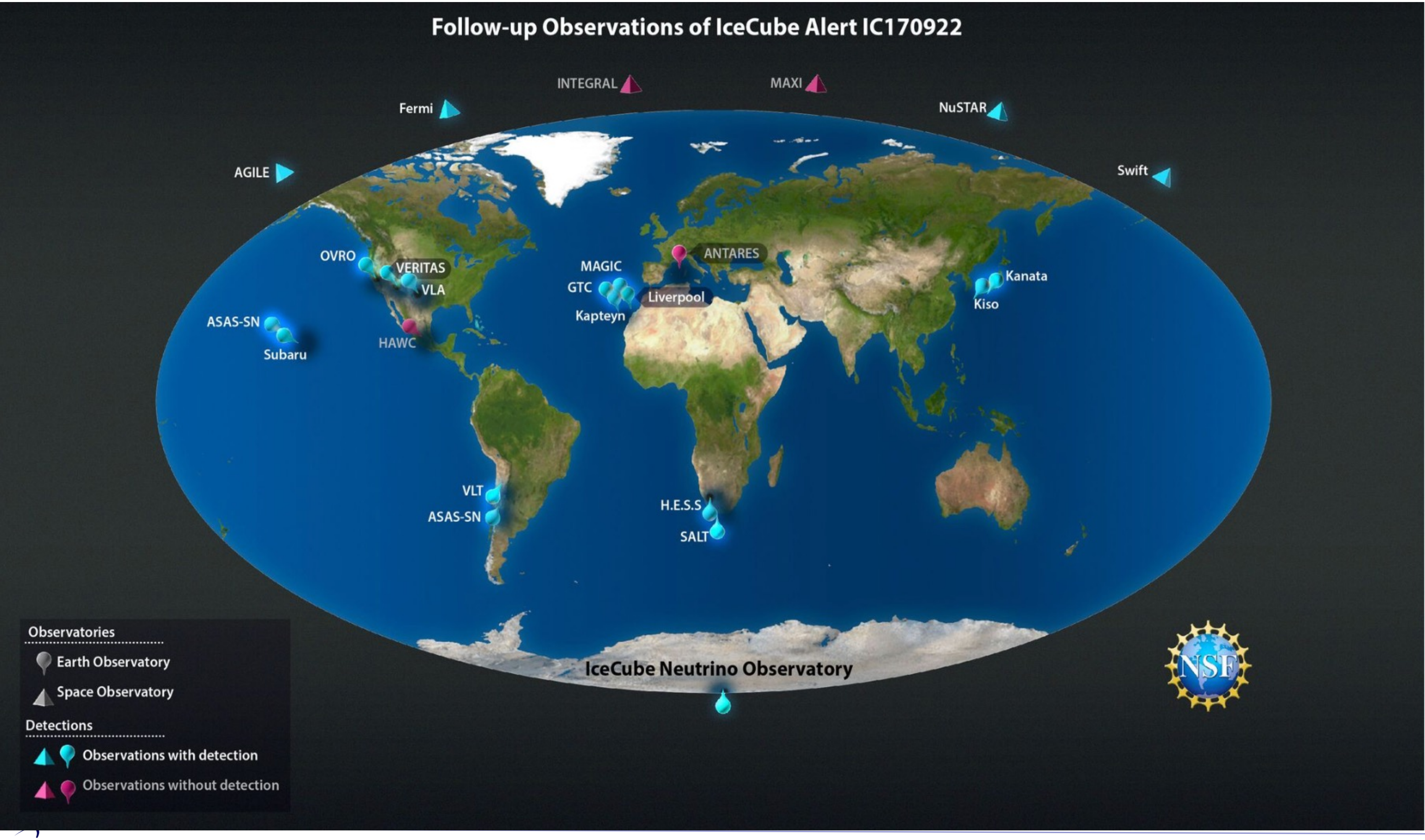




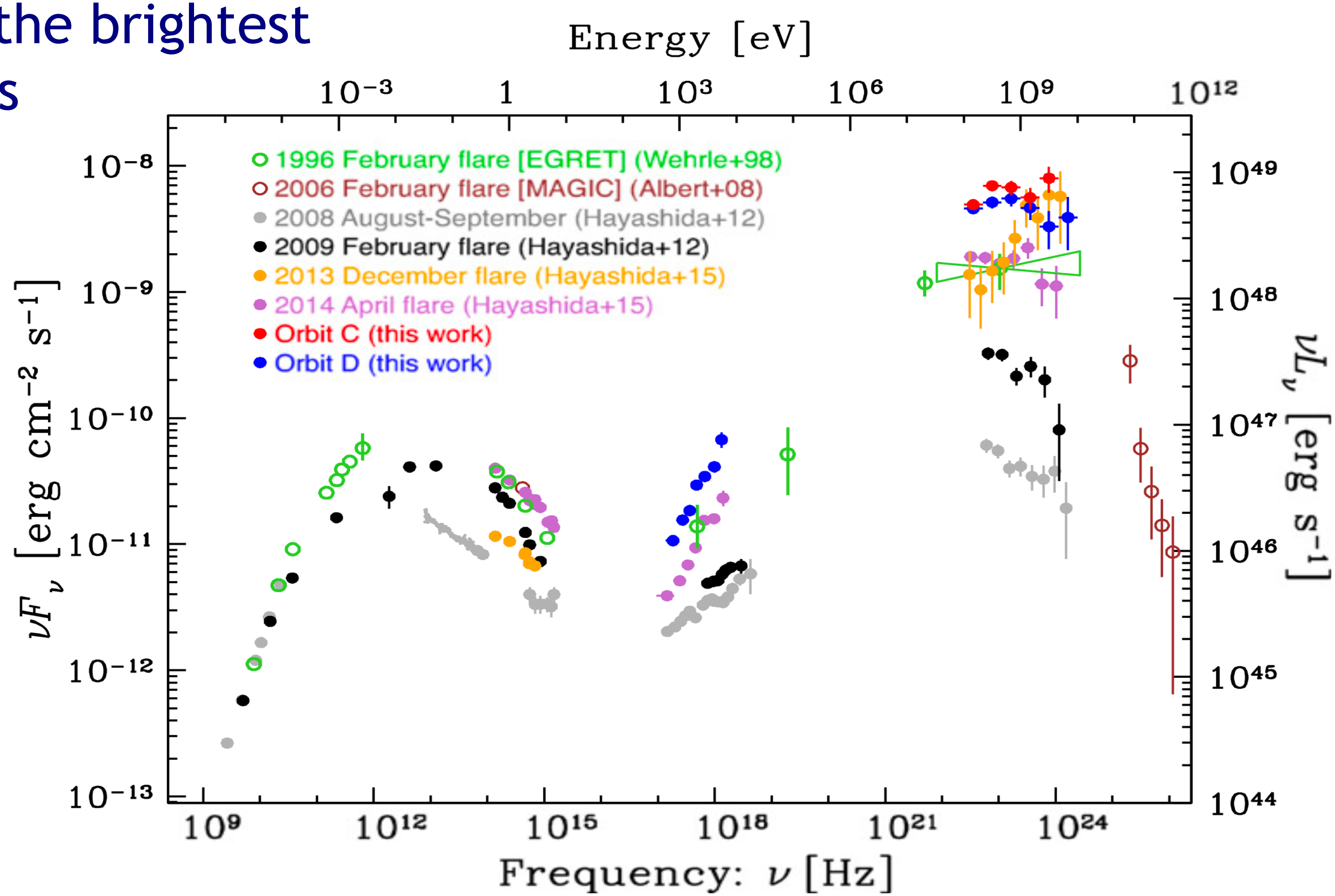
IceCube et al. 18

Multimessenger observation of blazars with neutrinos

IC 170922A and TXS 0506+056



3C 279: One of the brightest powerful blazars



the observed variability timescale constrains the characteristic size of the emitting region radius

$$R_\gamma < \mathcal{D} c t_{\rm var,obs}/(1+z) \simeq 10^{-4}(\mathcal{D}/50)\,{\rm pc}$$

Minute-Timescale >100 MeV gamma-ray variability during the giant outburst of quasar 3C 279 observed by Fermi-LAT in 2015 June
Fermi Lat Coll. ApJL 824 L20 2016 June 20 [arxiv:1605.05324]

ACTIVE GALACTIC NUCLEI and Fermi LAT

THE ASTROPHYSICAL JOURNAL SUPPLEMENT SERIES, 263:24 (9pp), 2022 December https://doi.org/10.3847/1538-4365/ac9523

CrossMark

The Fourth Catalog of Active Galactic Nuclei Detected by the Fermi Large Area Telescope: Data Release 3

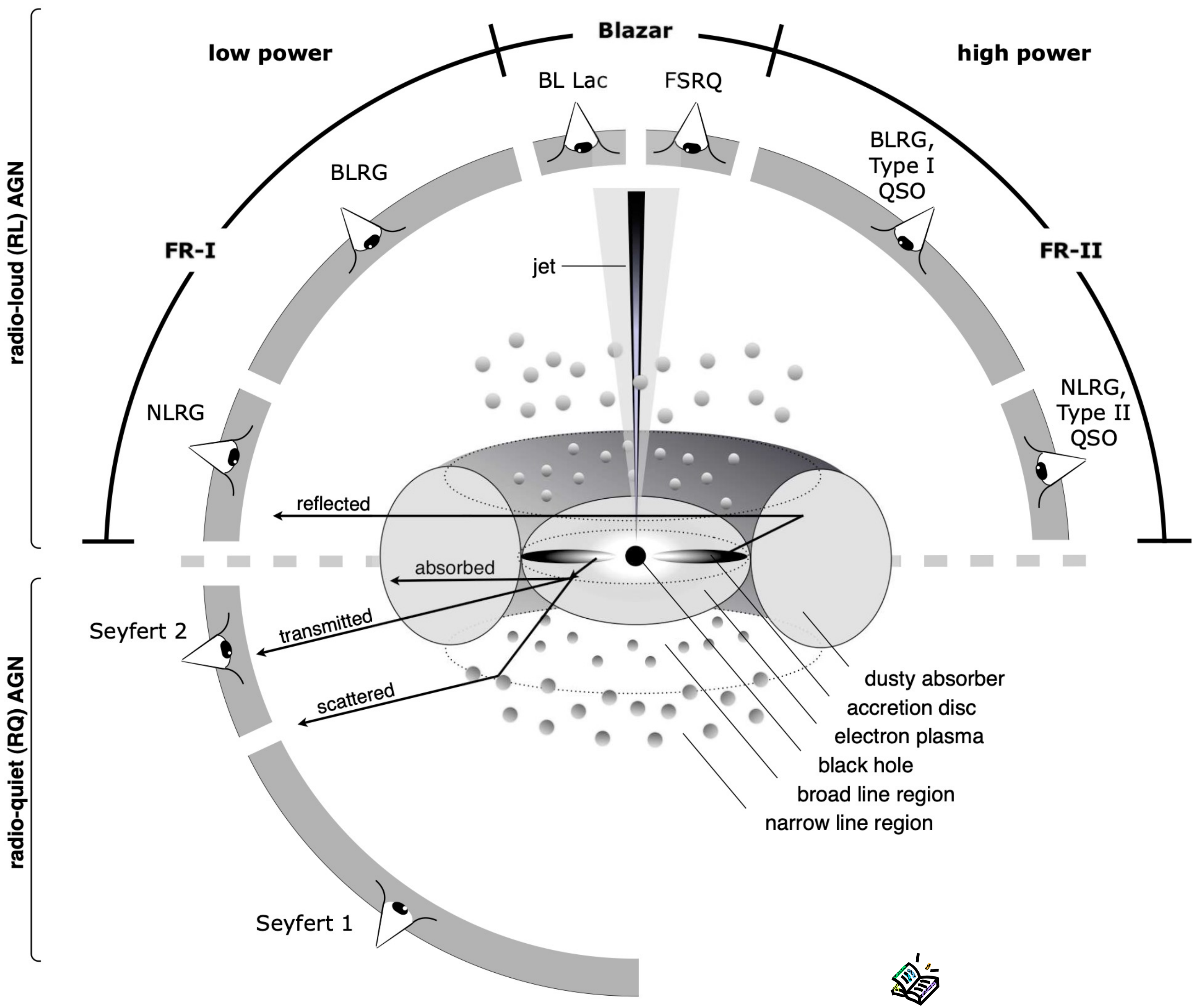
M. Ajello[1], L. Baldini[2], J. Ballet[3], D. Bastieri[4,5,6], J. Becerra Gonzalez[7], R. Bellazzini[8], A. Berretta[9], E. Bissaldi[10,11], R. Bonino[12,13], A. Brill[14,68], P. Bruel[15], S. Buson[16], R. Caputo[14], P. A. Caraveo[17], C. C. Cheung[18], G. Chiaro[17], N. Cibrario[12,13], S. Ciprini[19,20], M. Crnogorcevic[14,21], S. Cutini[22], F. D'Ammando[23], S. De Gaetano[10,11], N. Di Lalla[24], L. Di Venere[10,11], A. Domínguez[25], V. Fallah Ramazani[26], E. C. Ferrara[14,21,27], A. Fiori[2], Y. Fukazawa[28], S. Funk[29], P. Fusco[10,11], V. Gammaldi[30], F. Gargano[11], S. Garrappa[31], D. Gasparrini[19,20], N. Giglietto[10,11], F. Giordano[10,11], M. Giroletti[23], D. Green[32], I. A. Grenier[3], S. Guiriec[14,33], D. Horan[15], X. Hou[34,35], T. Kayanoki[28], M. Kuss[8], S. Larsson[36,37], L. Latronico[12], T. Lewis[14], J. Li[38,39], I. Liodakis[40], F. Longo[41,42], F. Loparco[10,11], B. Lott[43], M. N. Lovellette[44], P. Lubrano[22], G. M. Madejski[24], S. Maldera[12], A. Manfreda[2], G. Martí-Devesa[45], M. N. Mazziotta[11], I. Mereu[9,22], P. F. Michelson[24], N. Mirabal[14,46], W. Mitthumsiri[47], T. Mizuno[48], M. E. Monzani[24,49], A. Morselli[19], I. V. Moskalenko[24], M. Negro[27,46], R. Ojha[14], M. Orienti[23], E. Orlando[24,50], J. F. Ormes[51], Z. Pei[5], H. Peña-Herazo[12,13,52,53,54], M. Persic[42,55], M. Pesce-Rollins[8], V. Petrosian[24], R. Pillera[10,11], H. Poon[28], T. A. Porter[24], G. Principe[23,41,42], S. Rainò[10,11], R. Rando[4,5,6], B. Rani[14,56,57], M. Razzano[2], S. Razzaque[58], A. Reimer[45], O. Reimer[45], L. Scotton[59], D. Serini[11], C. Sgrò[8], E. J. Siskind[60], G. Spandre[8], P. Spinelli[10,11], D. J. Suson[61], H. Tajima[24,62], D. F. Torres[63,64,65], J. Valverde[14,46], H. Yassin[66], and G. Zaharijas[67]

587 blazar and four radio galaxies

- The Fourth Catalog of Active Galactic Nuclei Detected by the Fermi Large Area Telescope -- Data Release 3
  Apj S 263 24 DOI 10.3847/1538-4365/ac9523 [arXiv:2209.12070]

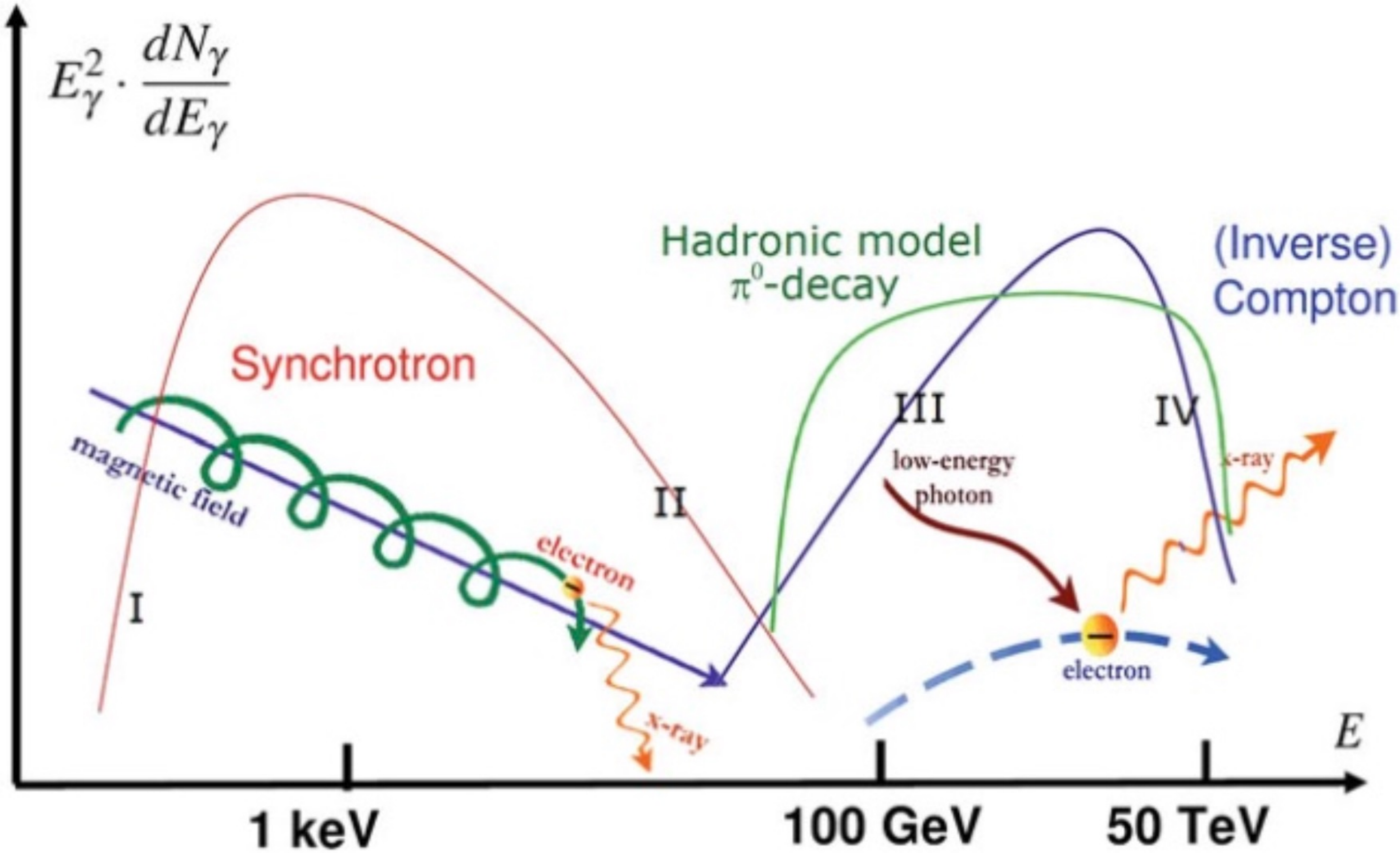
- The Fourth Catalog of Active Galactic Nuclei Detected by the Fermi Large Area Telescope The Fermi-LAT Coll.
  Apj, 892:105 (23pp), 2020 April 1 [arXiv:1905.10771]

ACTIVE GALACTIC NUCLEI



Blazars:
- FSRQ
- BL Lacertae Objects

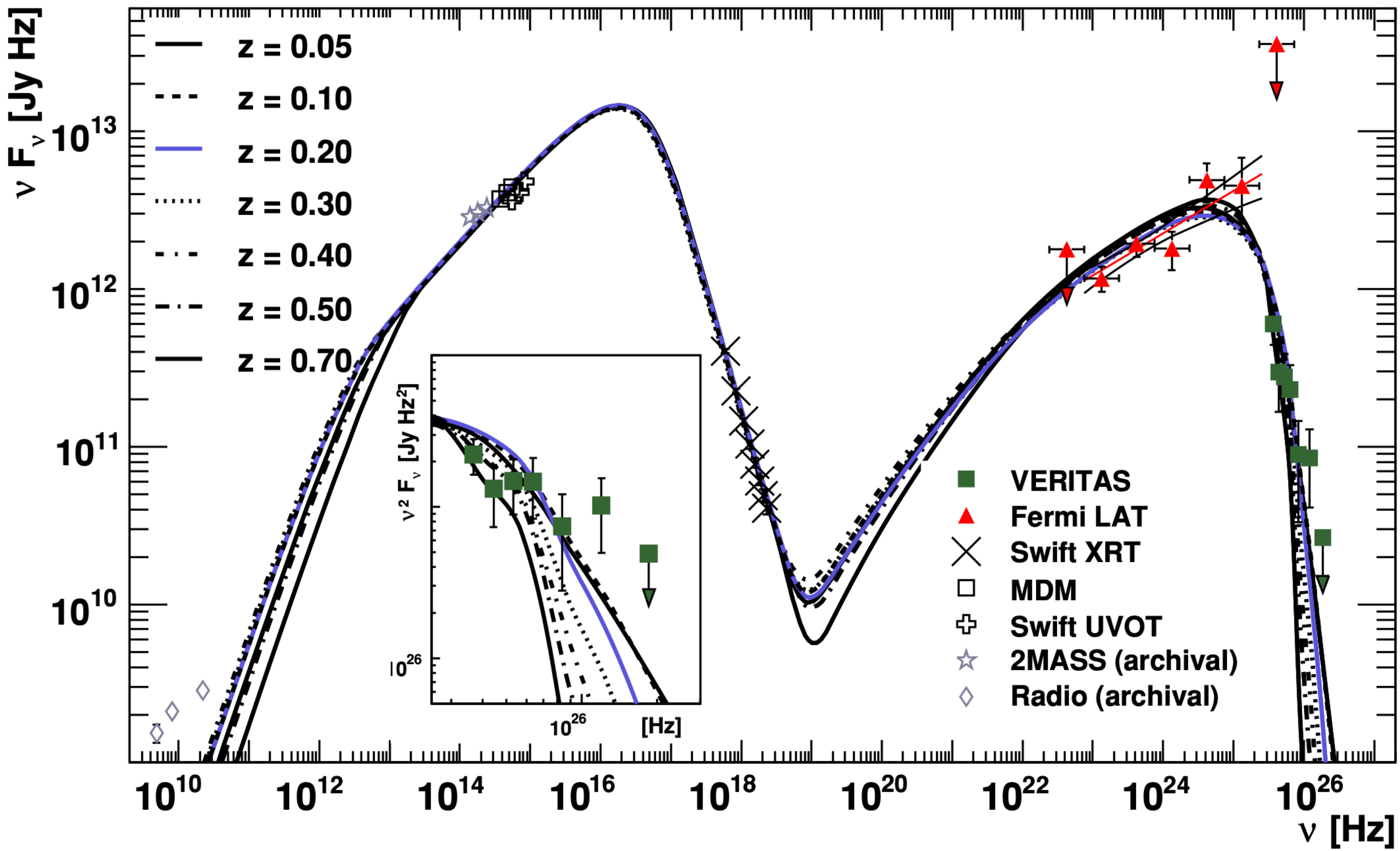
Model of blazar emission



Spectral energy distribution of photons produced in leptonic/hadronic models. Synchrotron radiation is caused by relativistic electrons accelerated in a magnetic field. Photons from synchrotron emission represent also the target for inverse Compton scattering of the parent electrons. When hadrons interact with matter or ambient photons, a distribution of γ-rays from π^0 decays as indicated by the *green* curve could be obtained. Superimposition of γ-rays from both leptonic and hadronic mechanisms is assumed in case of mixed models

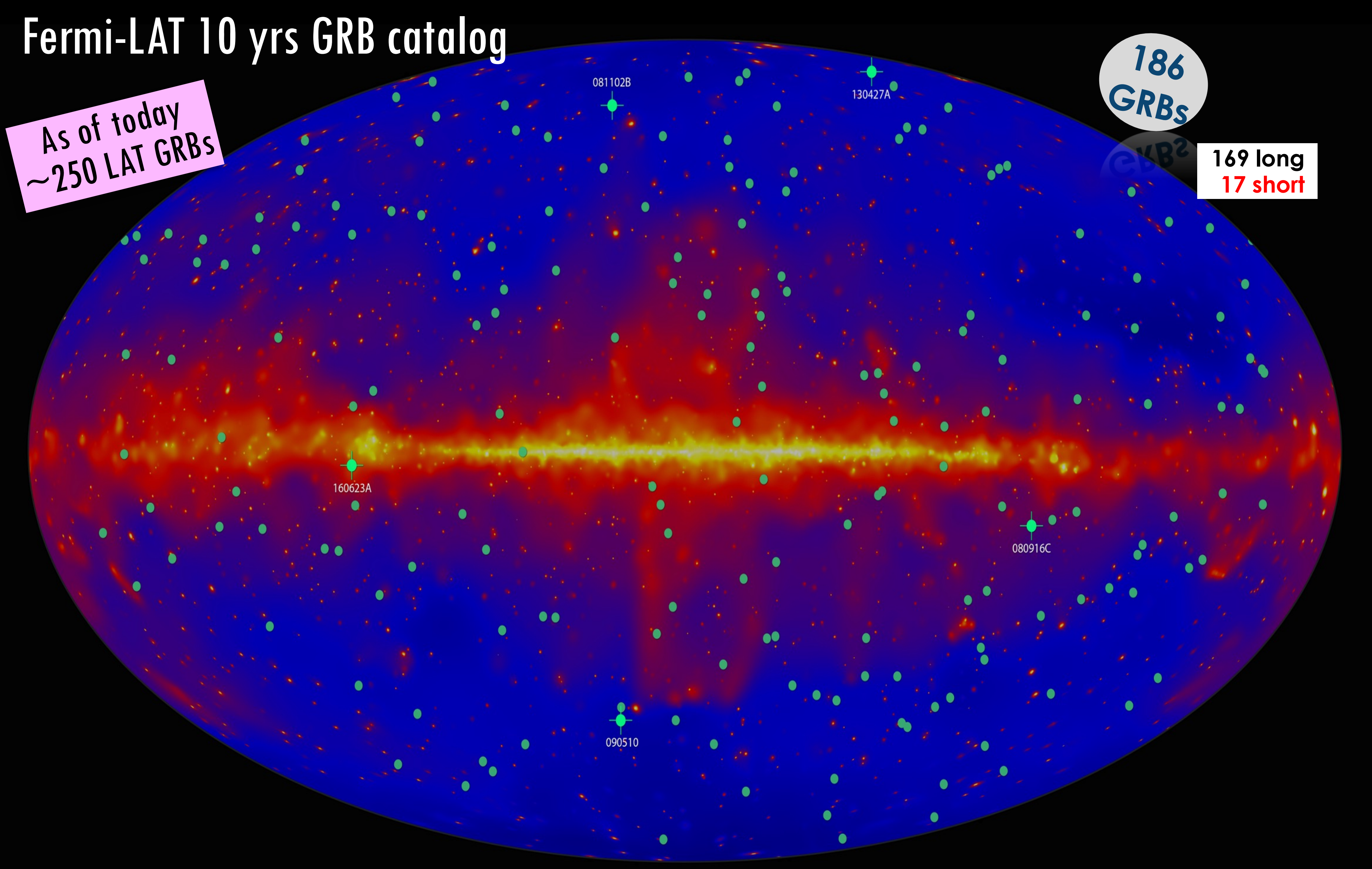
Blazars - BL Lac

Leptonic model provide a good fits to many blazars



Discovery of Very High Energy Gamma Rays from PKS 1424+240 and Multiwavelength Constraints on Its Redshift, Fermi Coll. ApJL, 708(2010) L100-106

Fermi-LAT 10 yrs GRB catalog



https://heasarc.gsfc.nasa.gov/W3Browse/fermi/fermilgrb.html

GW170817

Fermi

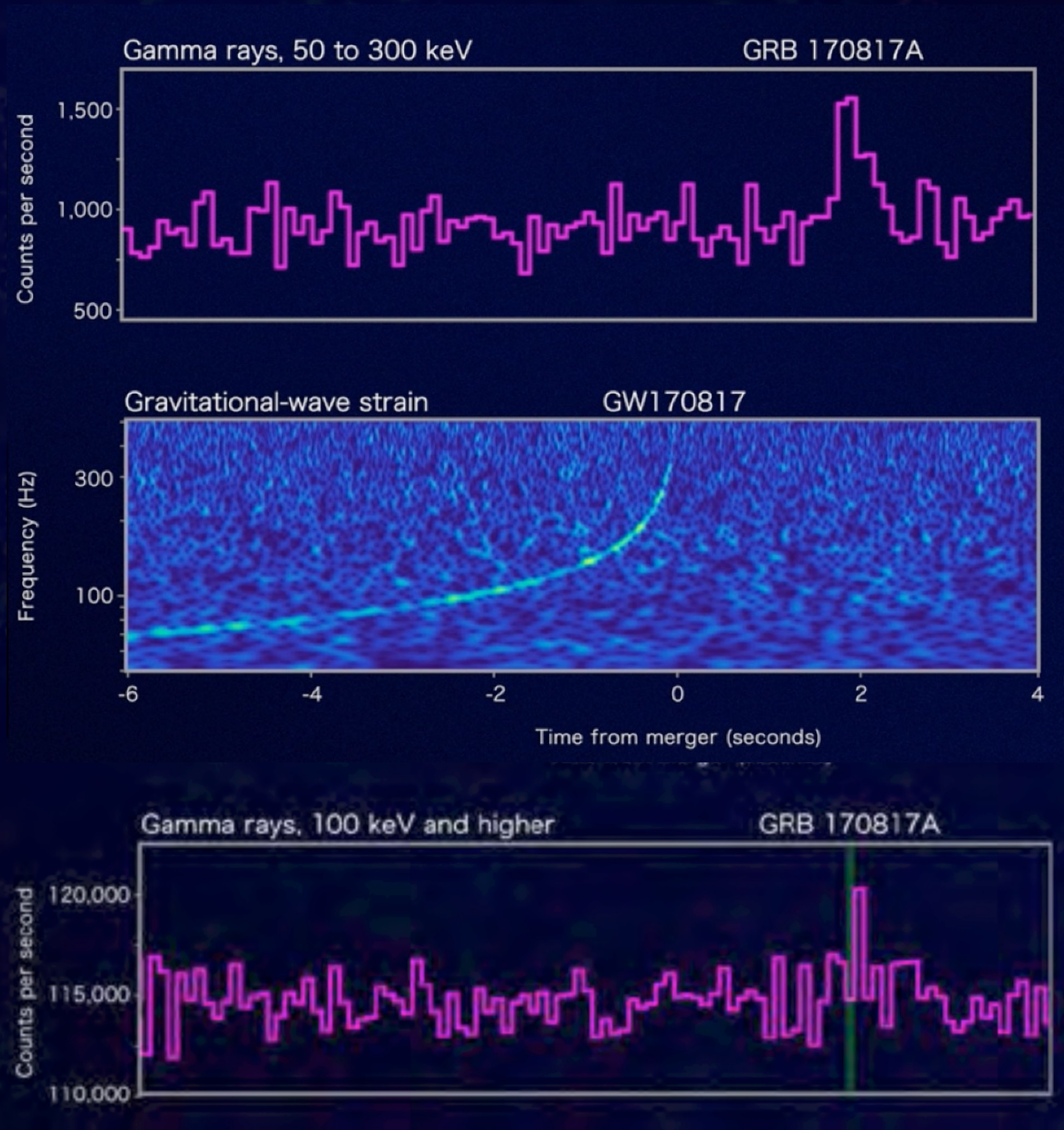
Reported 16 seconds
after detection

LIGO-Virgo

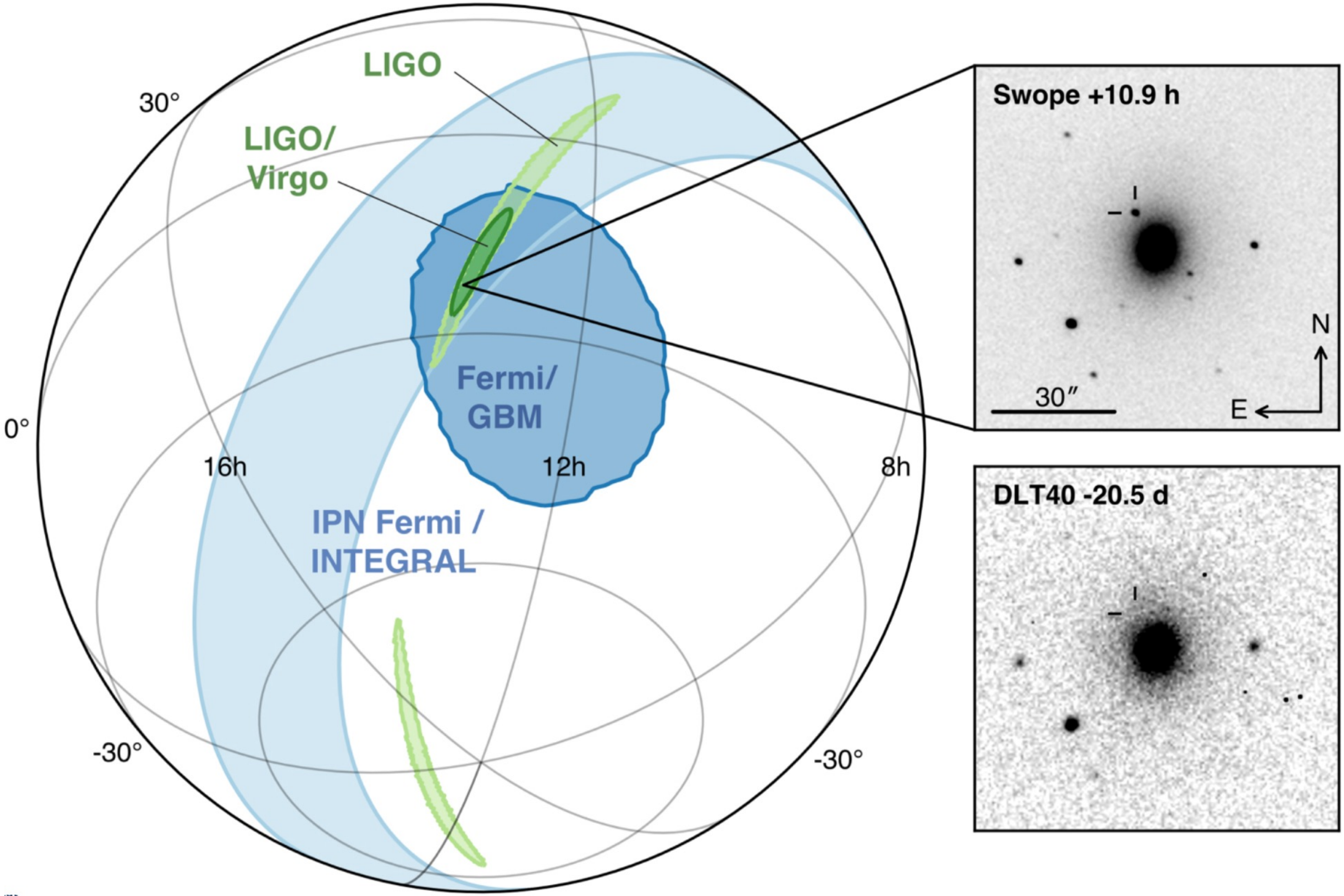
Reported 27 minutes after detection

INTEGRAL

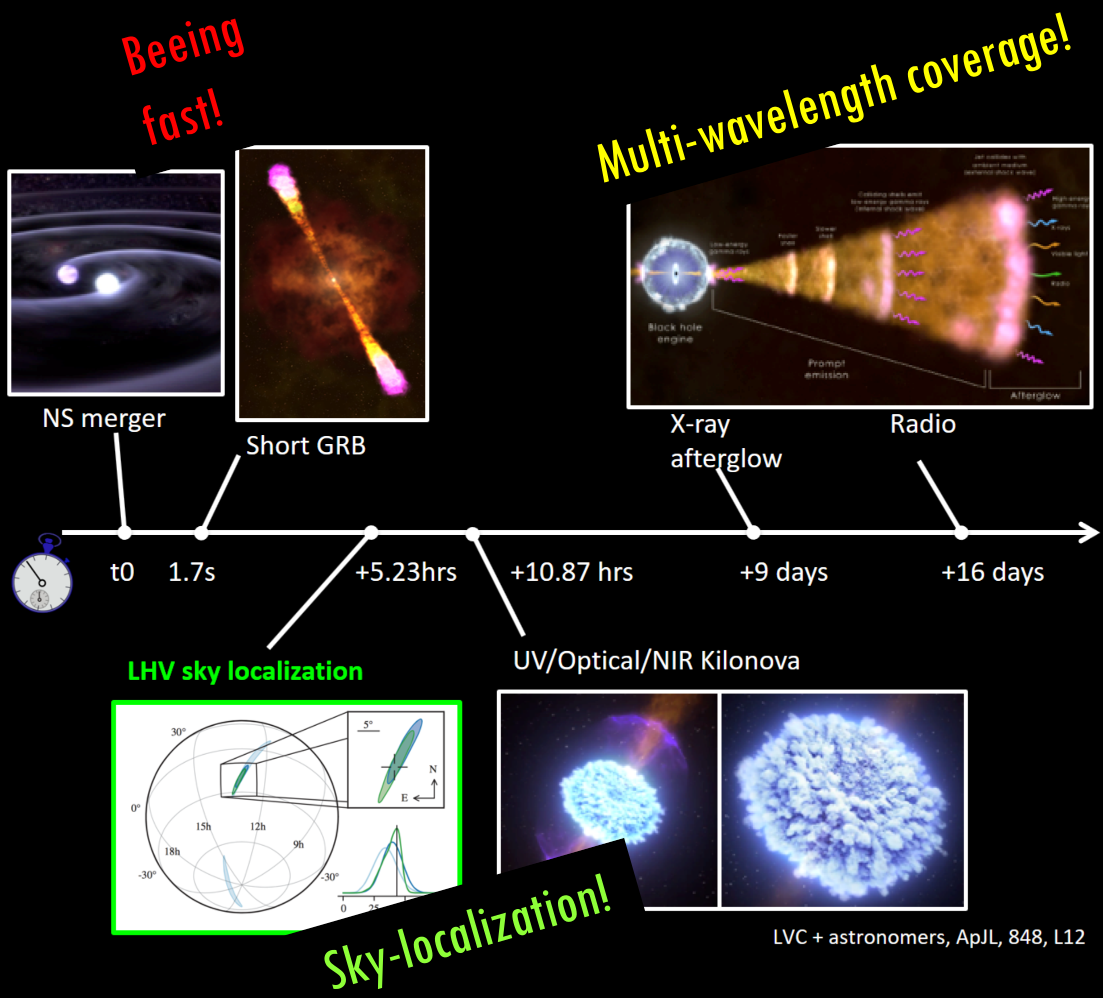
Reported 66 minutes
after detection



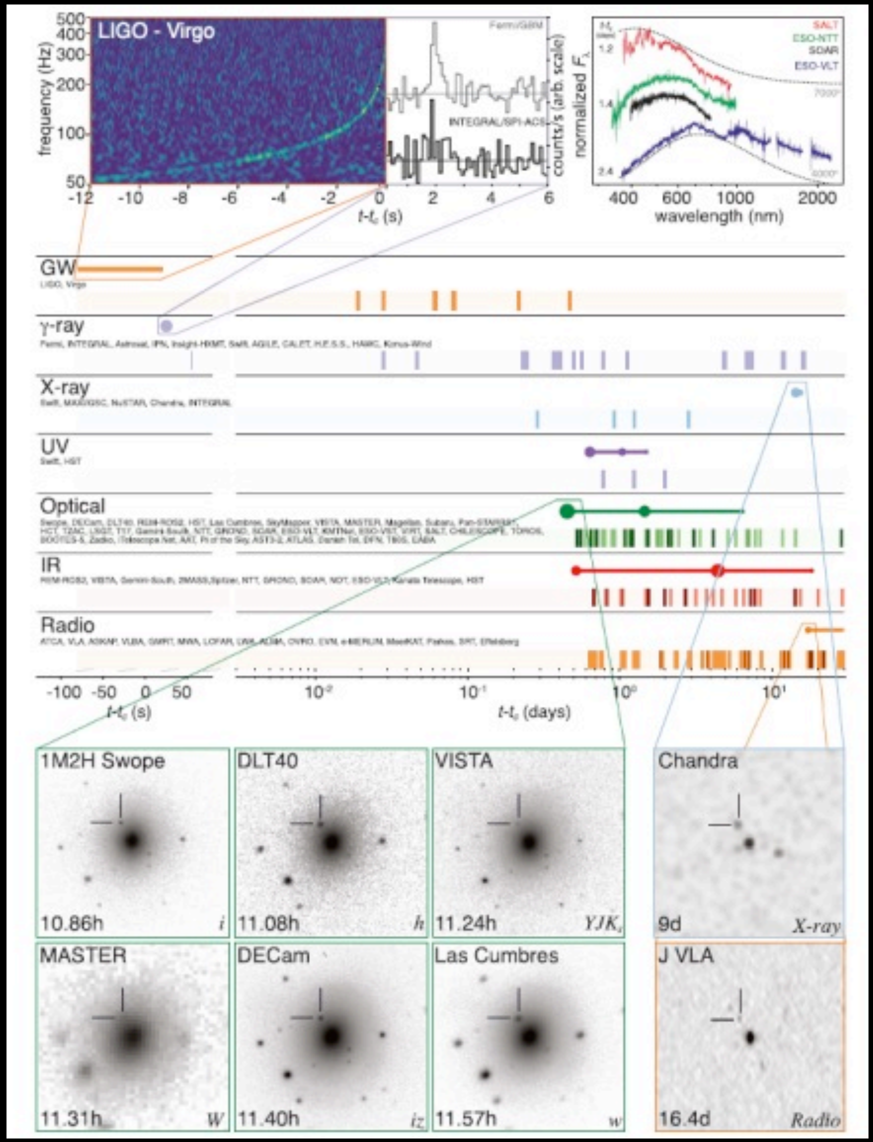
THE MULTI-MESSENGER EVENT GRB170817A, GW170817



THE MULTI-MESSENGER EVENT GW170817, GRB 170817A



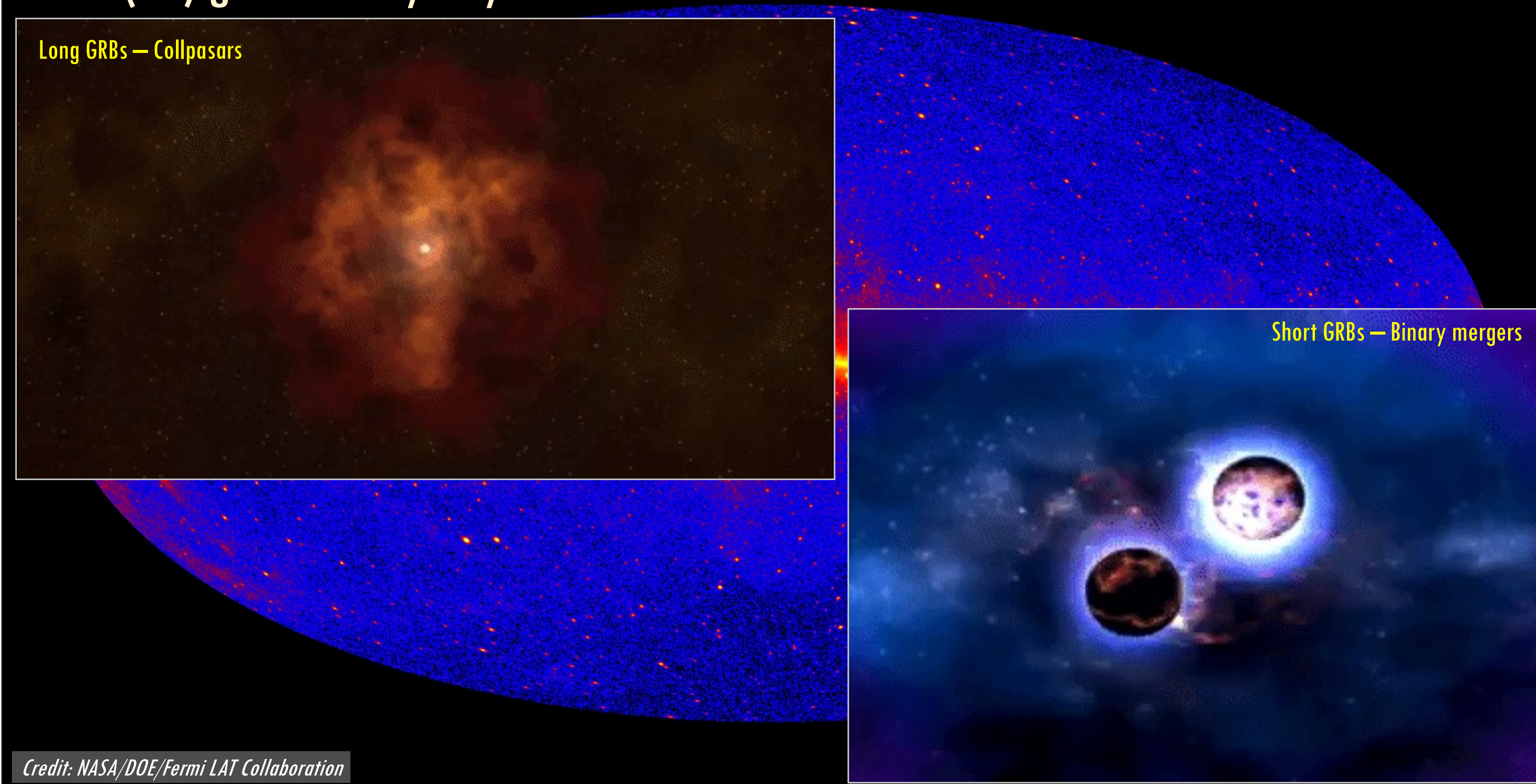
LVC + astronomers, ApJL, 848, L12



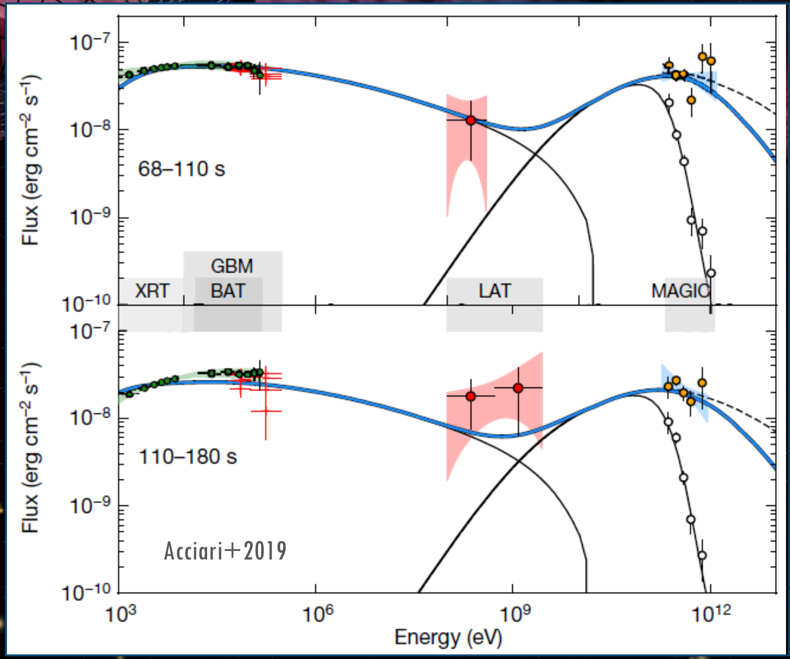
Multi-messenger Observations of a Binary Neutron Star Merger ApjL 848 L12 2017 [arXiv:1710.05833] 3656 authors !

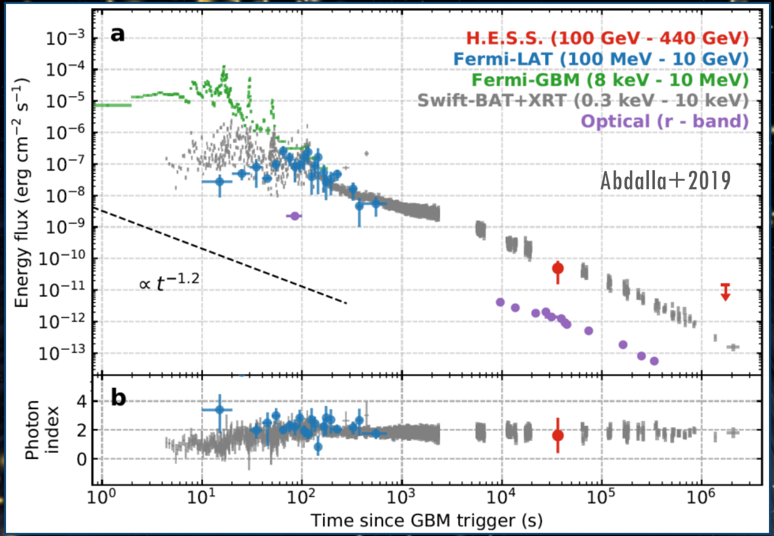
Credit: Dana Berry/SkyWorks Digital, Inc./Harvard-Smithsonian Center for Astrophysics

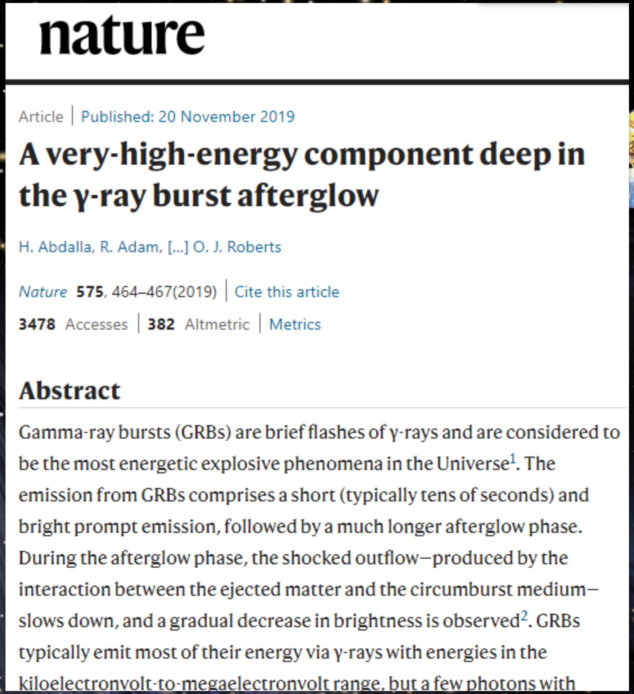
The (HE) gamma-ray sky



2019: GRBs at TeV energies







nature

Article | Published: 20 November 2019

A very-high-energy component deep in the γ-ray burst afterglow

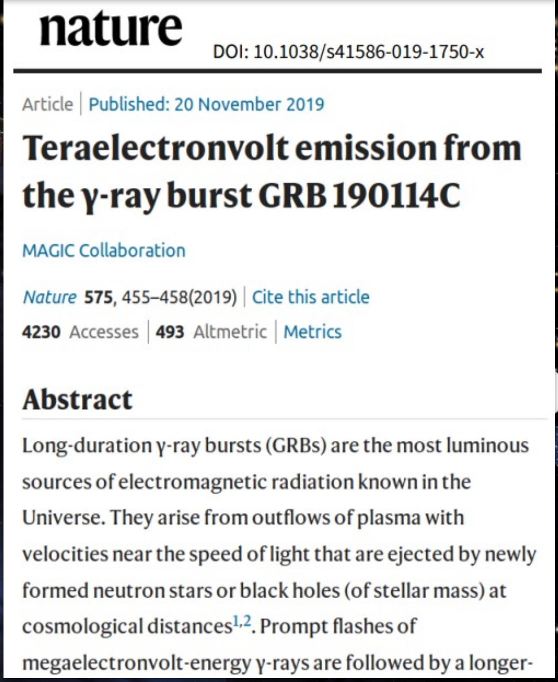
H. Abdalla, R. Adam, [...] O. J. Roberts

Nature **575**, 464–467(2019) | Cite this article

3478 Accesses | **382** Altmetric | Metrics

Abstract

Gamma-ray bursts (GRBs) are brief flashes of γ-rays and are considered to be the most energetic explosive phenomena in the Universe[1]. The emission from GRBs comprises a short (typically tens of seconds) and bright prompt emission, followed by a much longer afterglow phase. During the afterglow phase, the shocked outflow—produced by the interaction between the ejected matter and the circumburst medium—slows down, and a gradual decrease in brightness is observed[2]. GRBs typically emit most of their energy via γ-rays with energies in the kiloelectronvolt-to-megaelectronvolt range, but a few photons with



nature

DOI: 10.1038/s41586-019-1750-x

Article | Published: 20 November 2019

Teraelectronvolt emission from the γ-ray burst GRB 190114C

MAGIC Collaboration

Nature **575**, 455–458(2019) | Cite this article

4230 Accesses | **493** Altmetric | Metrics

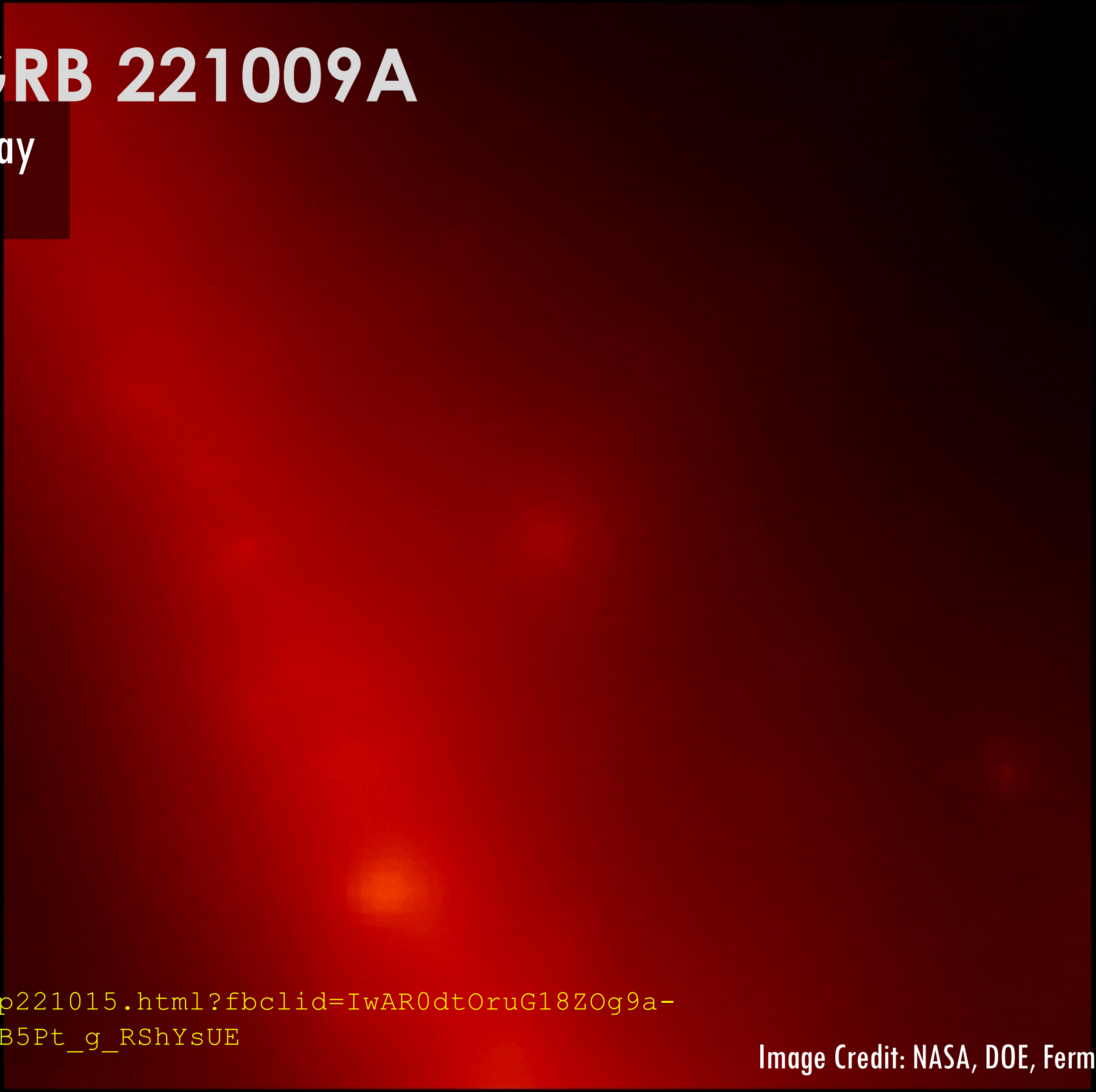
Abstract

Long-duration γ-ray bursts (GRBs) are the most luminous sources of electromagnetic radiation known in the Universe. They arise from outflows of plasma with velocities near the speed of light that are ejected by newly formed neutron stars or black holes (of stellar mass) at cosmological distances[1,2]. Prompt flashes of megaelectronvolt-energy γ-rays are followed by a longer-

The «BOAT» GRB 221009A

Astronomy Picture of the Day

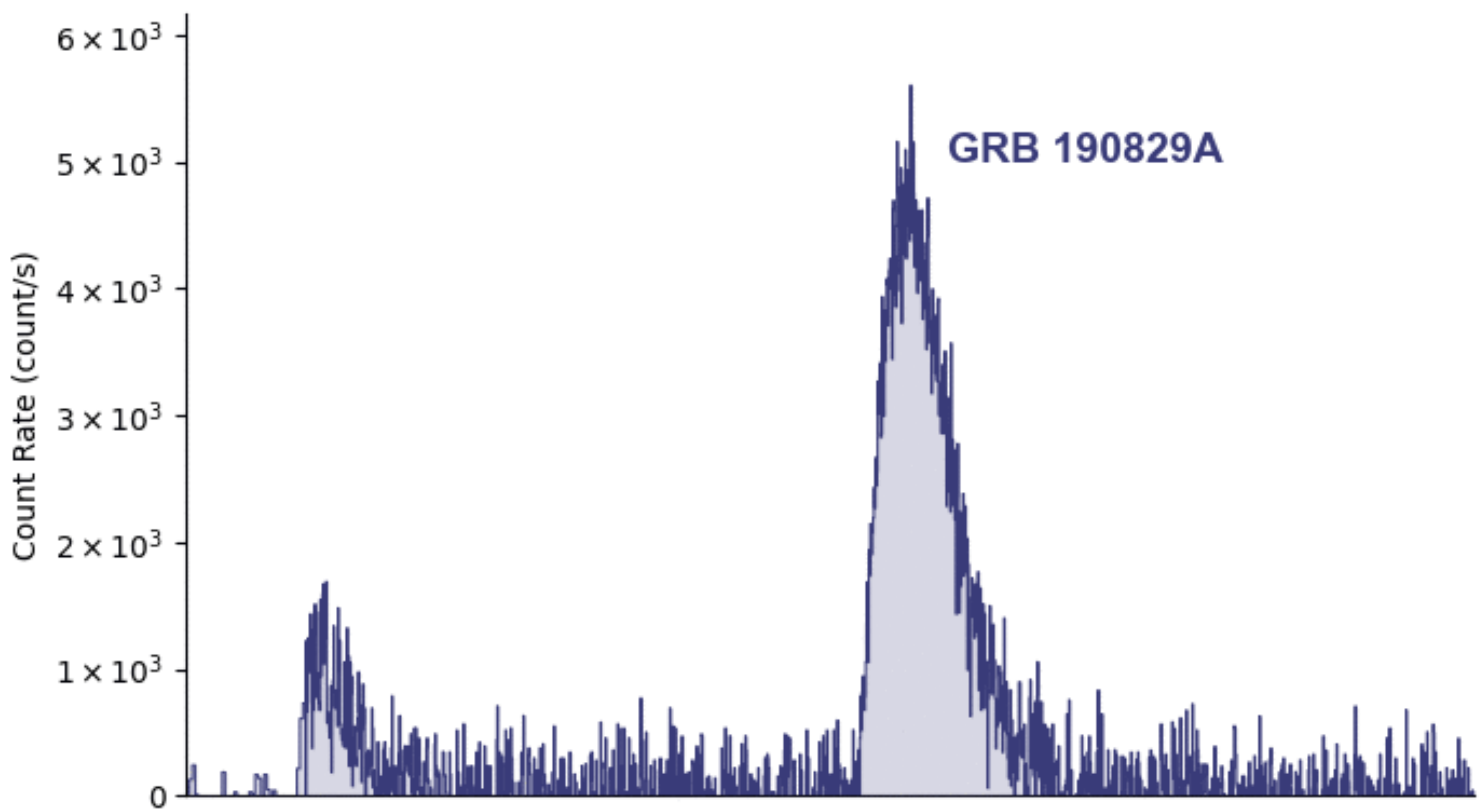
15 October 2022



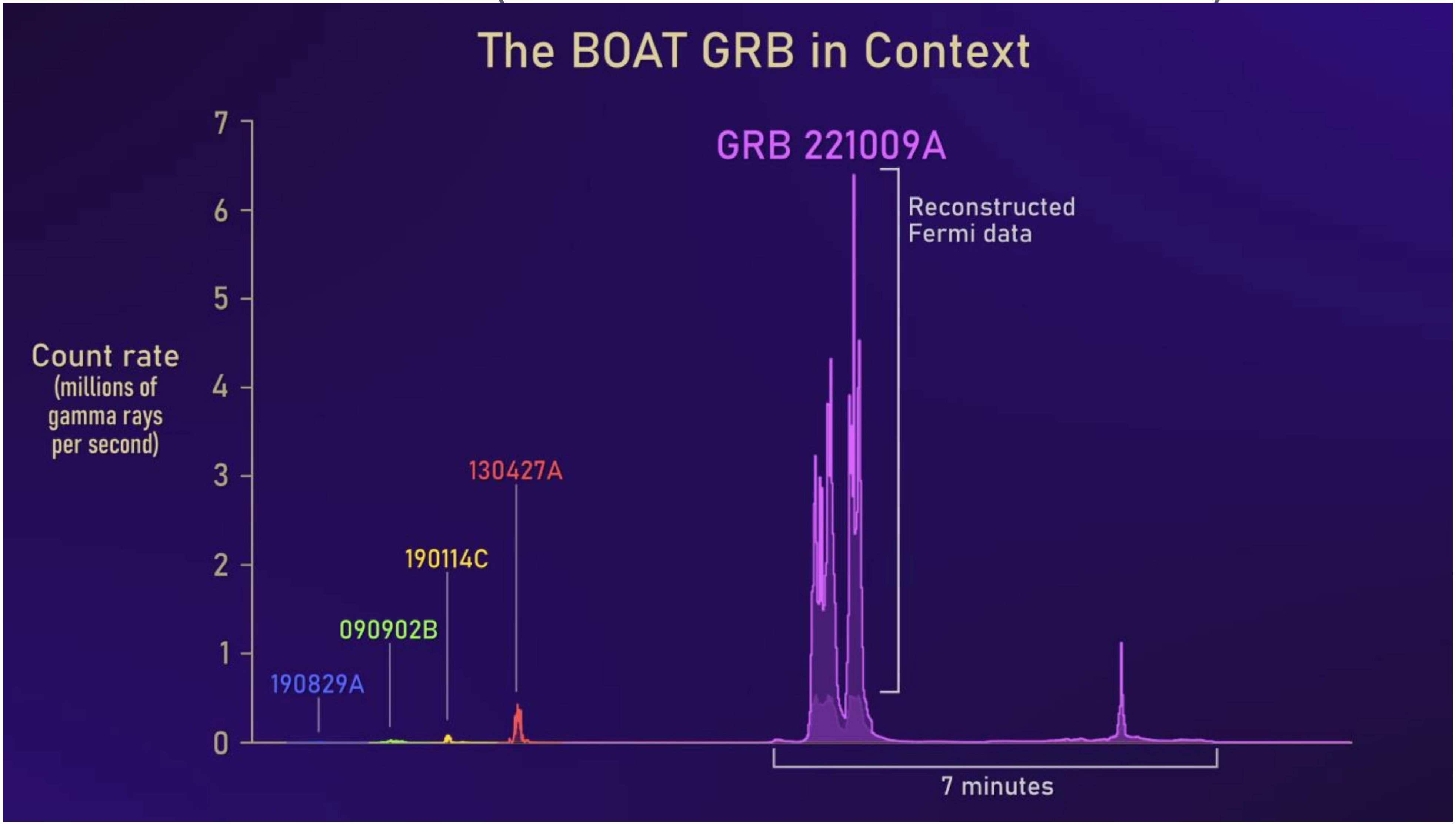
https://apod.nasa.gov/apod/ap221015.html?fbclid=IwAR0dtOruG18ZOg9a-AhjcLkfPfvsok_C5Dvn-sjK7YpBQB5Pt_g_RShYsUE

Image Credit: NASA, DOE, Fermi LAT Collaboration, R.Pillera

THE BOAT (BRIGHTEST OF ALL TIMES)



THE BOAT (BRIGHTEST OF ALL TIMES)



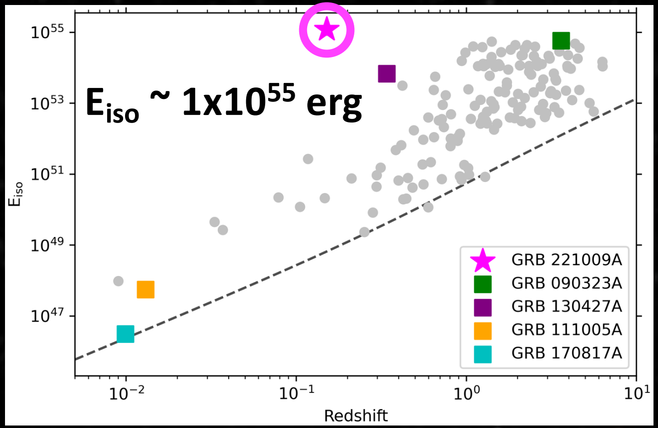
1-in-10000 year event ➢ Detected by Fermi GBM

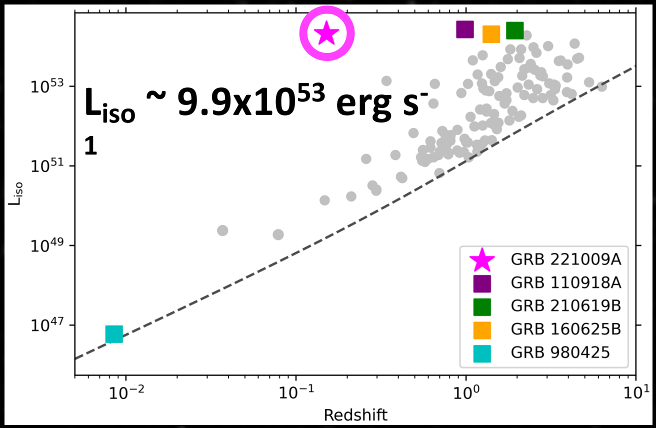
➢ Severe saturation in GBM and LAT in main phase (Region IV)

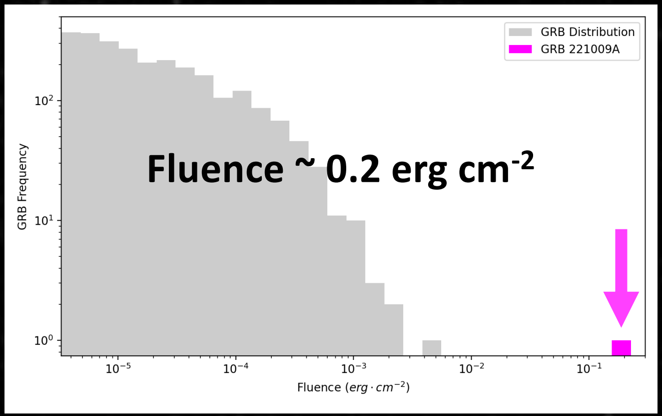
➢ Detected by LHAASO and HAWC (IACTs: full moon)

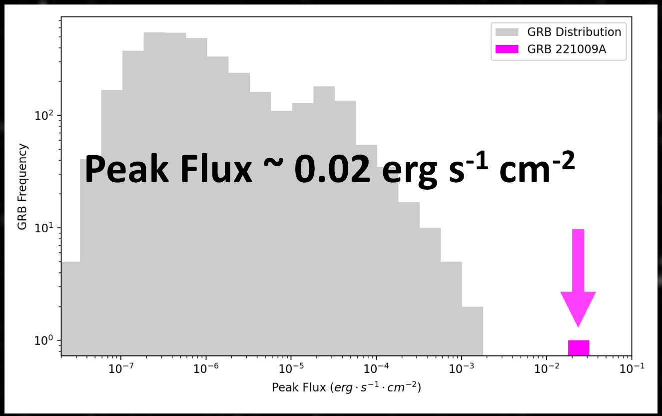
Is it the B.O.A.T.?

(4 measures)









55 years of data

Burns+2023

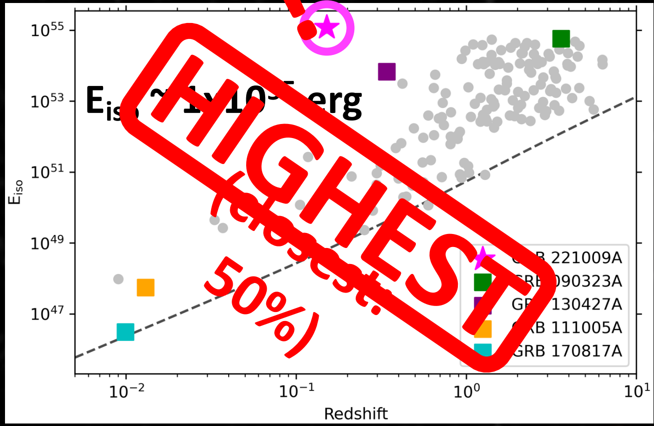
Slide courtesy of S. Lesage, *Fermi*-GBM | GRB50

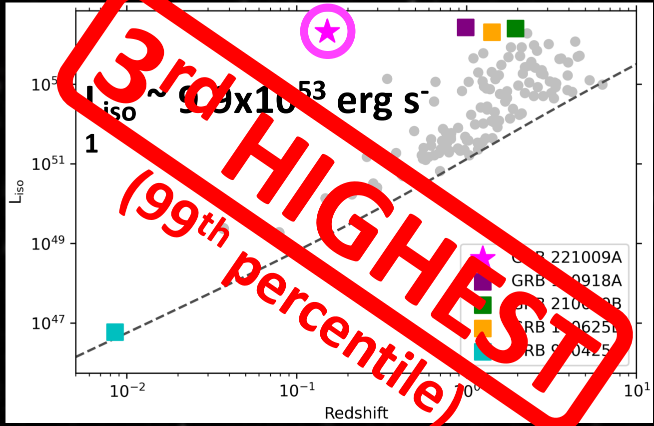
Is it the B.O.A.T.?

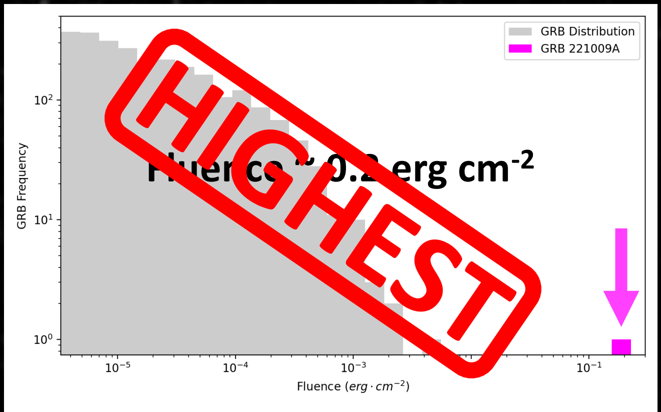
(4 measures)

YES!

YES!



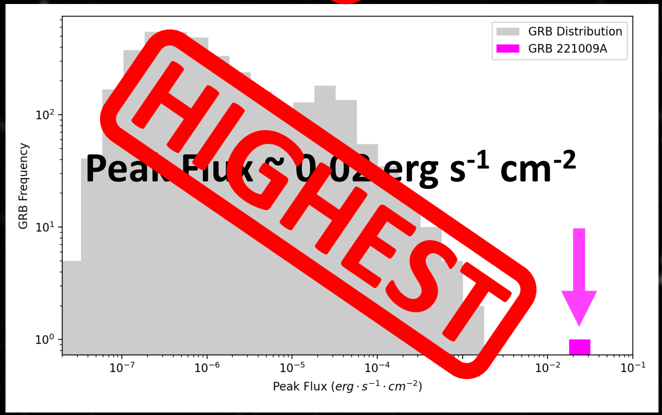




¾ measures of brightness

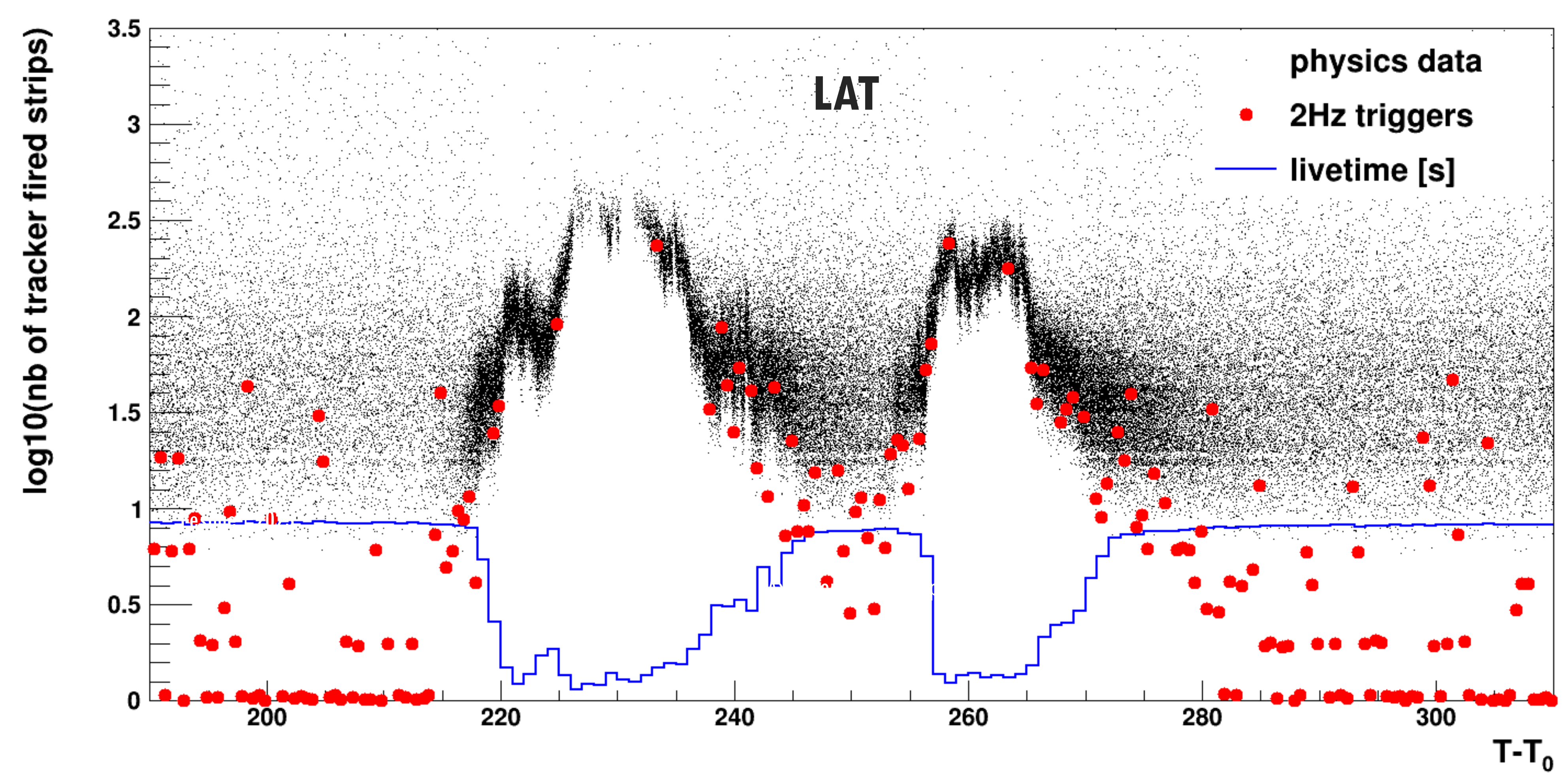
55 years of data

Burns+2023



Slide courtesy of S. Lesage, *Fermi*-GBM | GRB50

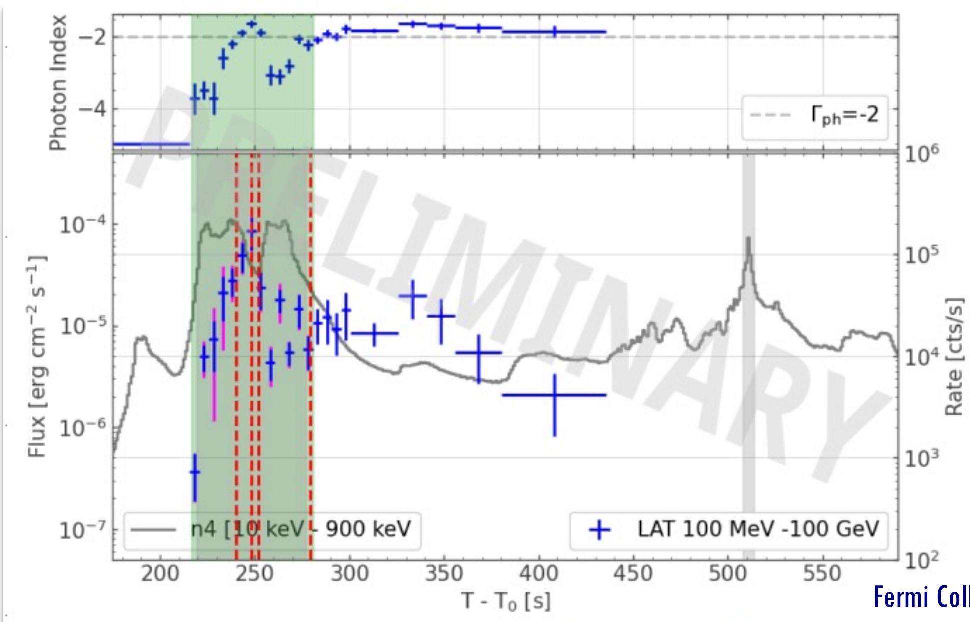
GRB 221009A – Fermi data issues



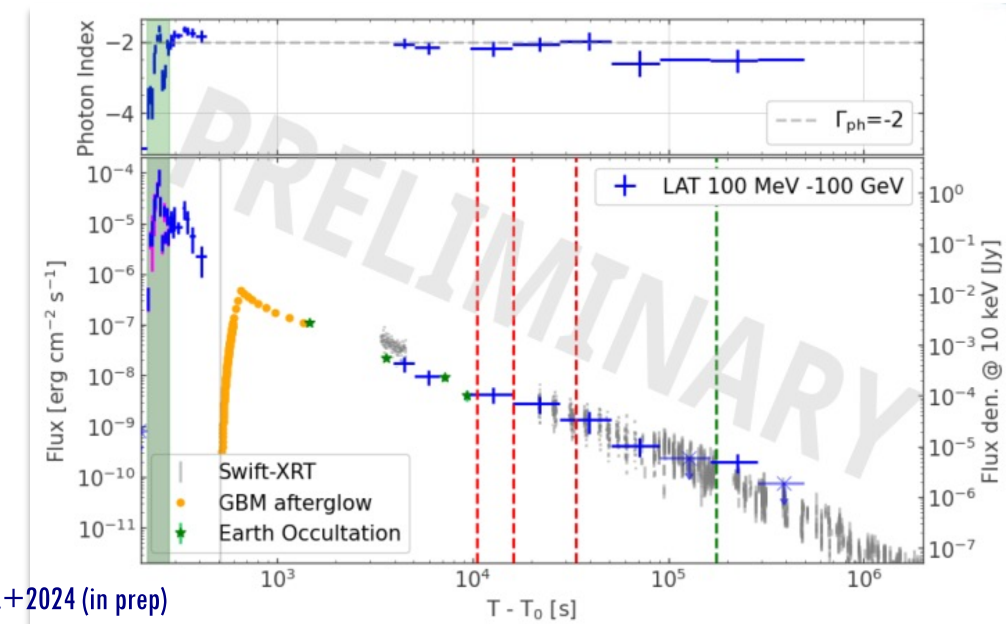
- **Normal data taking conditions** Before T_0+217 s and after T_0+280 s
- **Bad Time Intervals** No standard analysis possible

`All caveats can be found here:`
[`https://fermi.gsfc.nasa.gov/ssc/data/analysis/grb221009a.html`](https://fermi.gsfc.nasa.gov/ssc/data/analysis/grb221009a.html)

GRB 221009A – High-energy emission analysis



Fermi Coll.+2024 (in prep)



Early times LLE+LAT analysis

- Estimate flux maximum in the BTI
- Bulk Lorentz factor estimation from opacity arguments: **Γ>450**

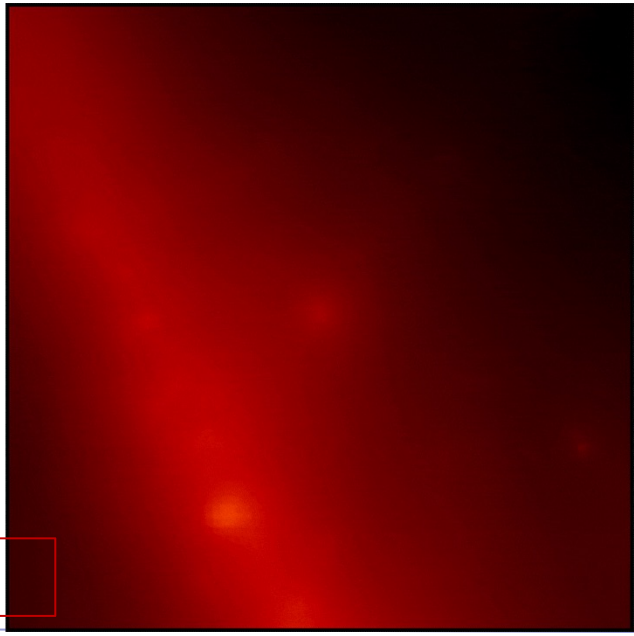
Late times LAT analysis

- GRB duration: **180 ks** (**2 days: record!**)
- Afterglow flux PL decay (index ~ **−1.3**)
- $t_{peak,\,ag} \gtrsim t_0$+280 s consistent with LHAASO
-

Oct 9, 2022 **Swift and Fermi Missions Detect Exceptional Cosmic Blast**

GRB 221009A

Sequence constructed from Fermi Large Area Telescope data reveals the sky in gamma rays centered on the location of GRB 221009A. Each frame shows gamma rays with energies greater than 100 MeV, ~ 10 hours of observations. The glow from the midplane of our Milky Way galaxy appears as a wide diagonal band. The image is about 20 degrees across.

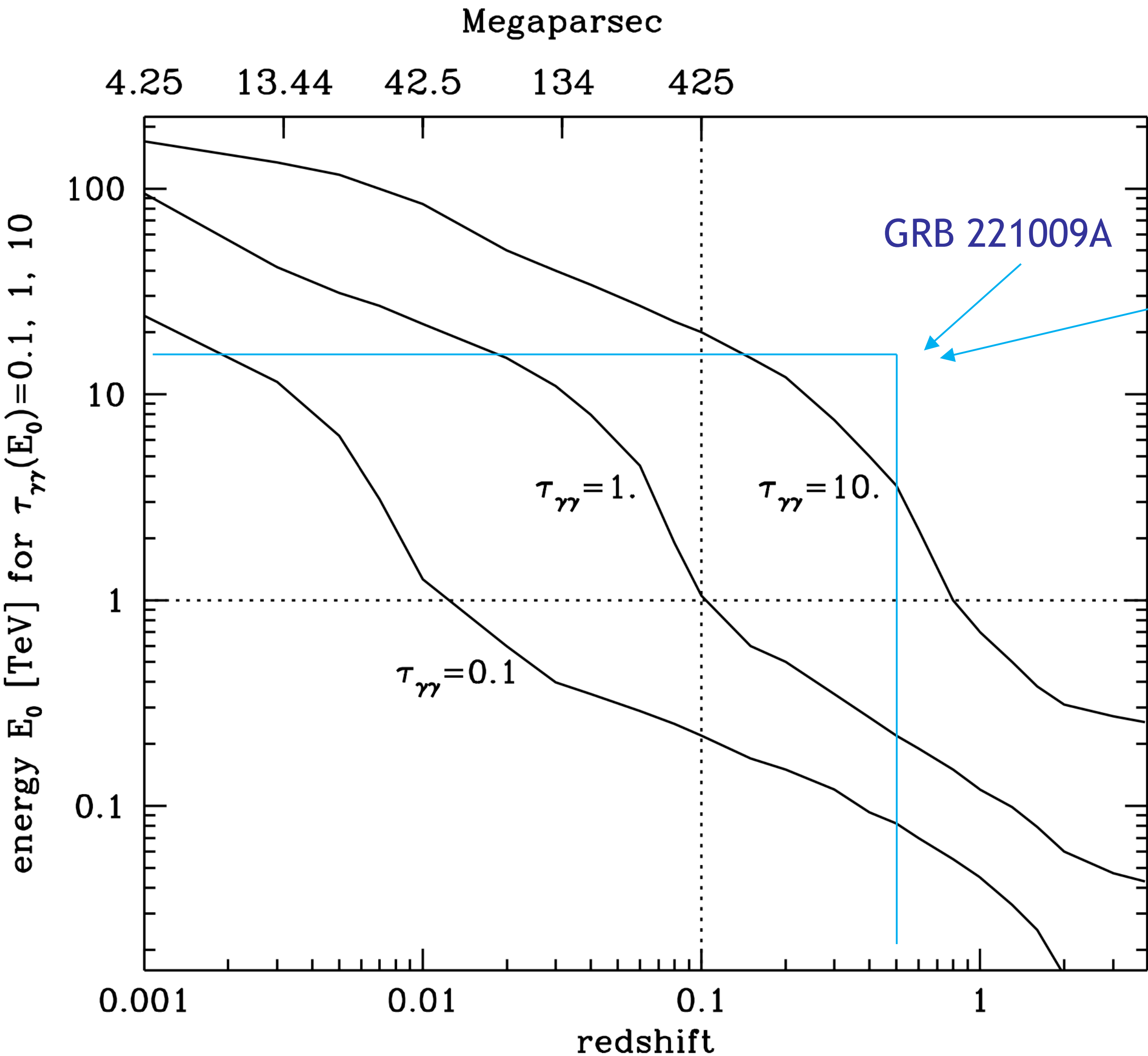


Gemini South telescope observation on 14 of October

Z=0,51

and Lhaaso in 2000 s detected ~5000 gammas with E > TeV up to ~10 TeV

The energies corresponding to optical depth values of different for photon-photon collisions, as a function of the redshift distance of the source



$\tau_{\rm CP} \simeq 14$

photon survival probability

$$P(\gamma \to \gamma; E)_{\rm CP} = e^{-\tau_{\rm CP}} \simeq 8.5 \cdot 10^{-7}$$

New Physics?
LIV or Axion-like conversion

or some instrumental effect:
- cosmic rays identified as gammas)

* energy lower than 18 TeV

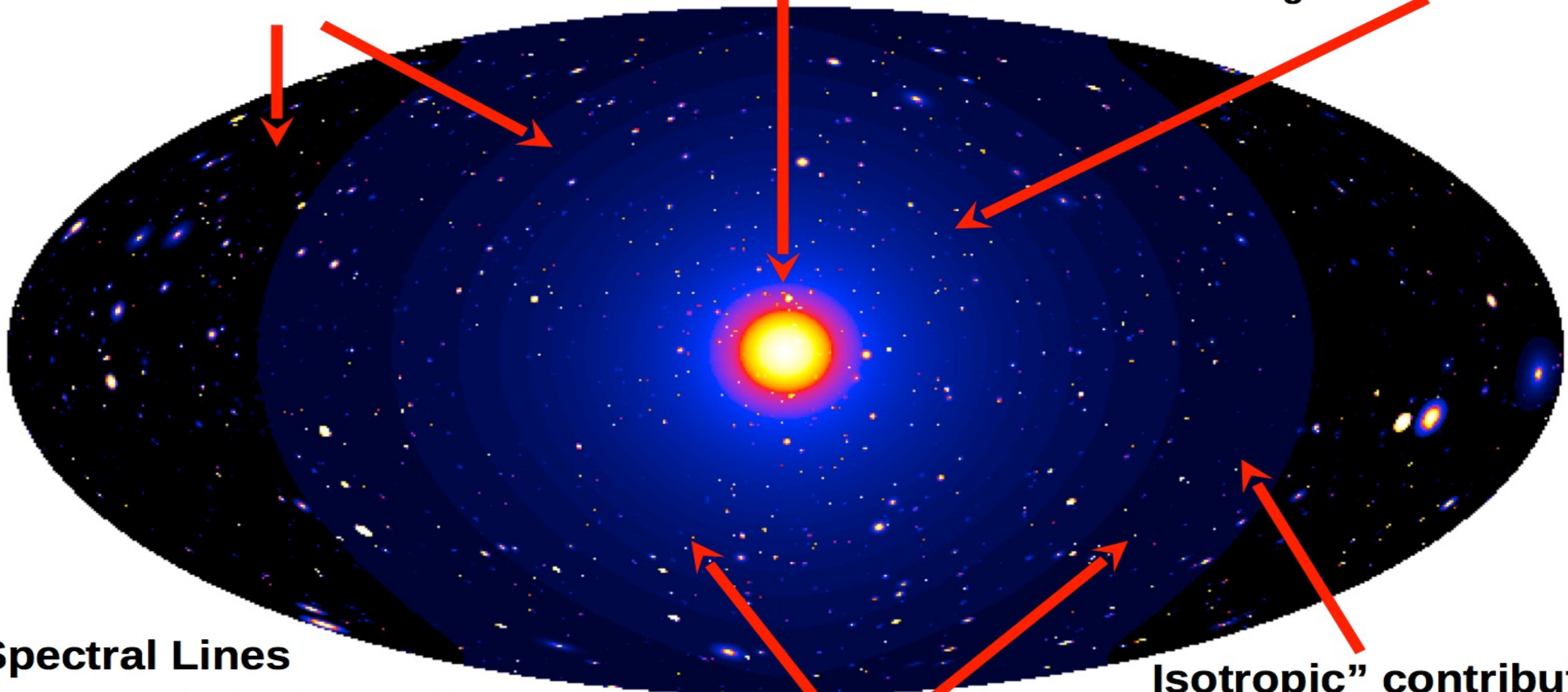
extragalactic background light revisited, Franceschini Rodighiero 1705.10256

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

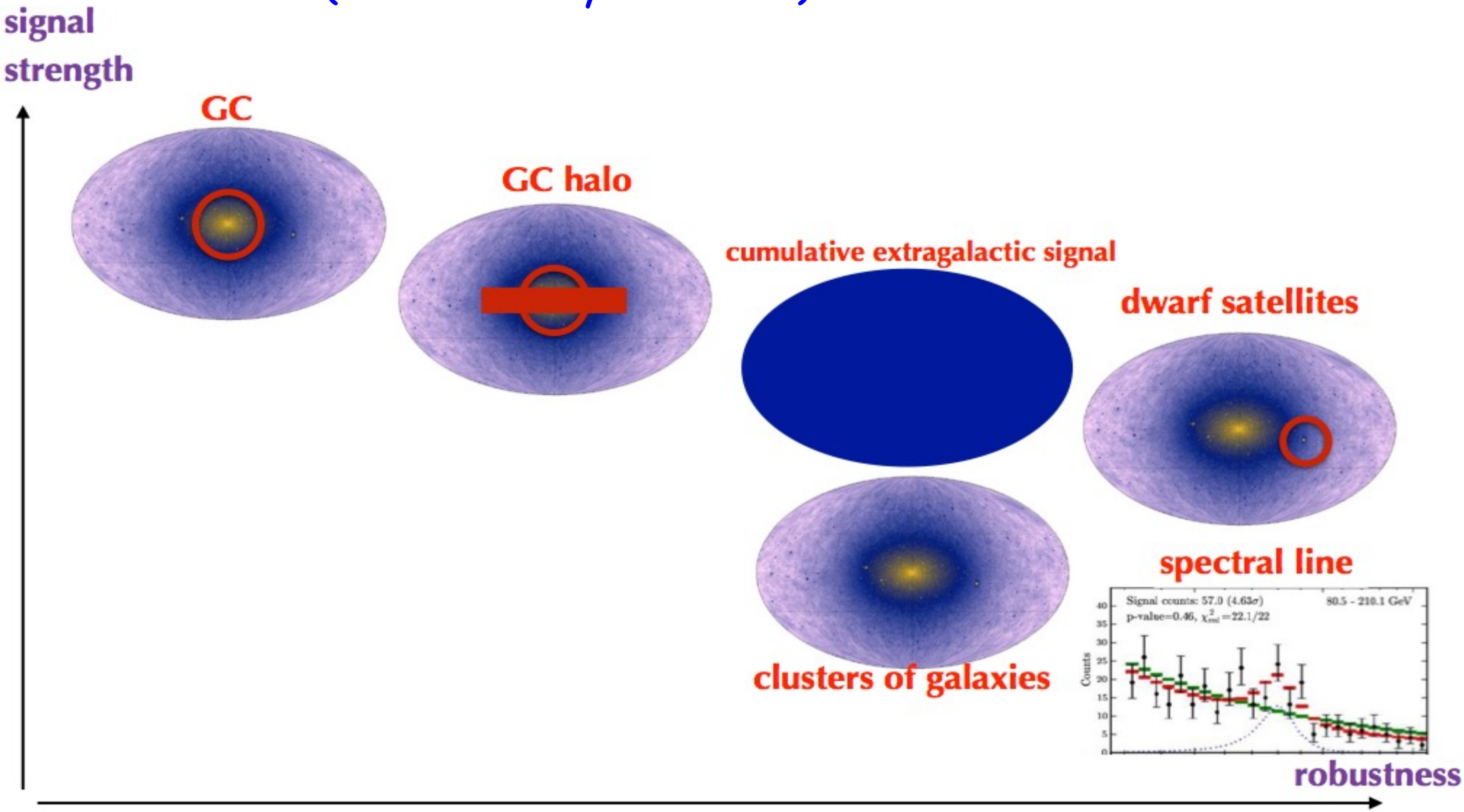
Galaxy Clusters
Low background, but low statistics

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

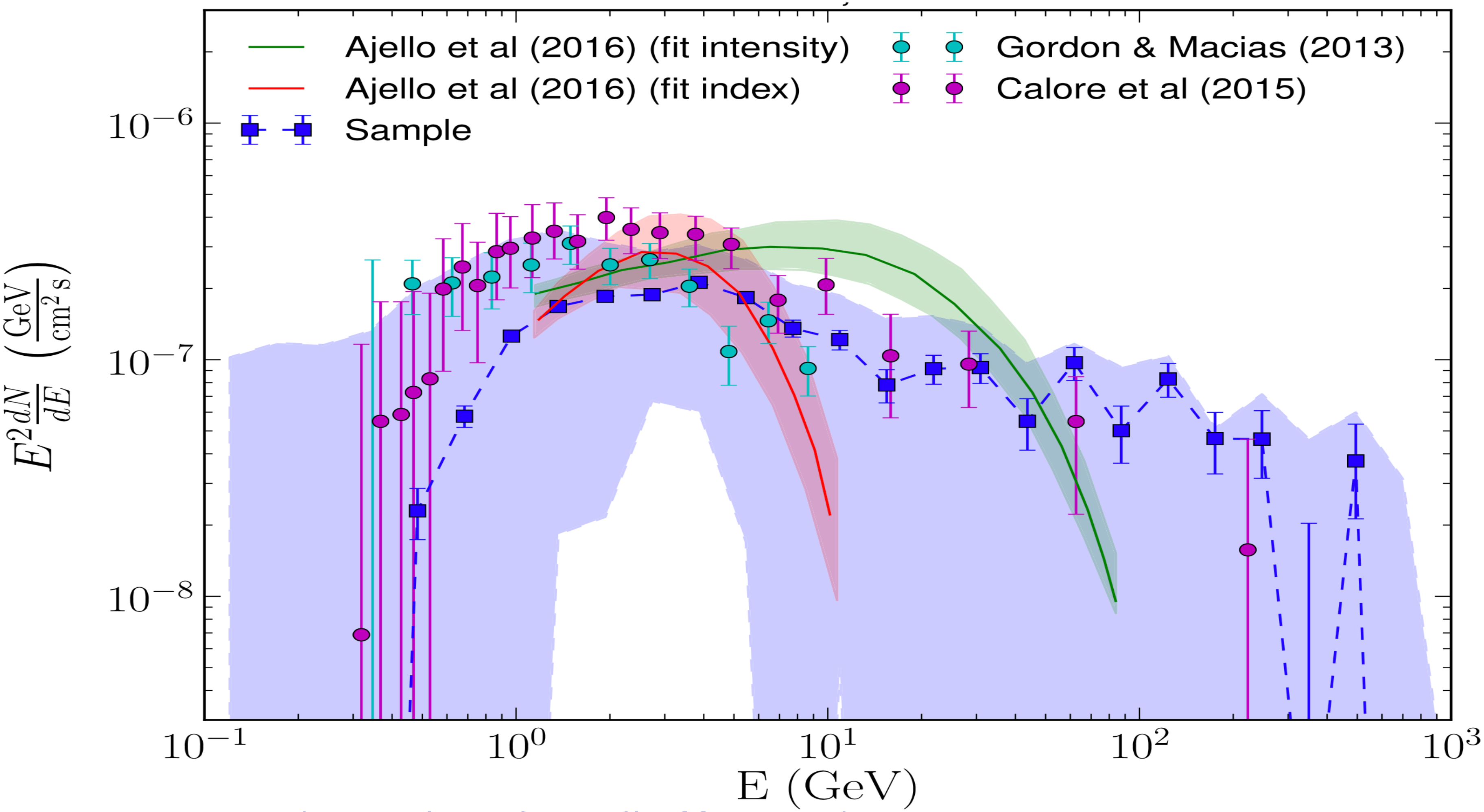
Dark Matter simulation:
Pieri+(2009) arXiv:0908.0195

Dark Matter Search: Targets and Strategies

(Another way to see it)



The GeV excess (Pass8 analysis)



following uncertainties have relatively small effect on the excess spectrum

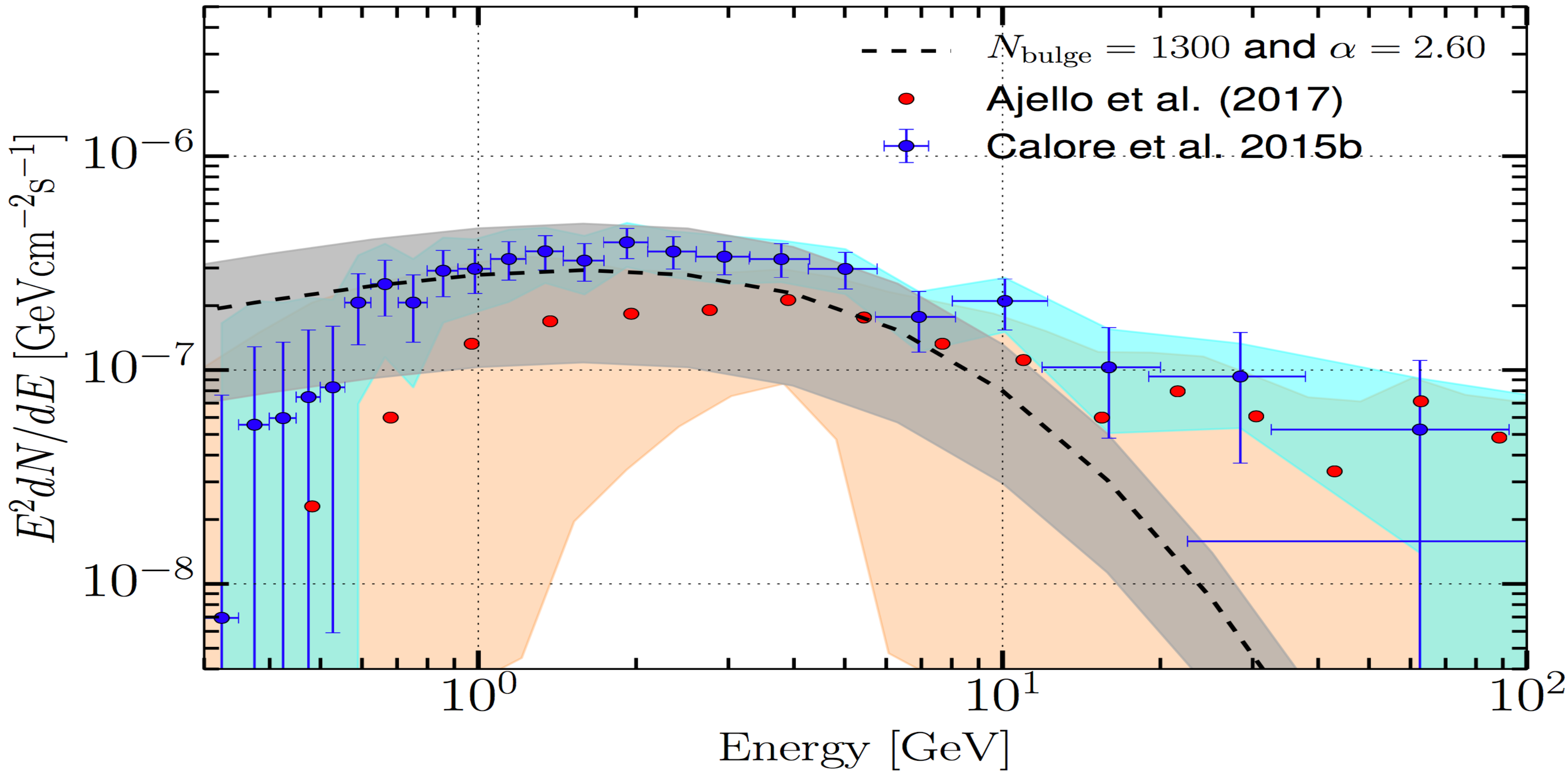
– Variation of GALPROP models – Distribution of gas along the line of sight

- **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

Population of pulsars in the Galactic bulge and the GeV excess



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

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

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

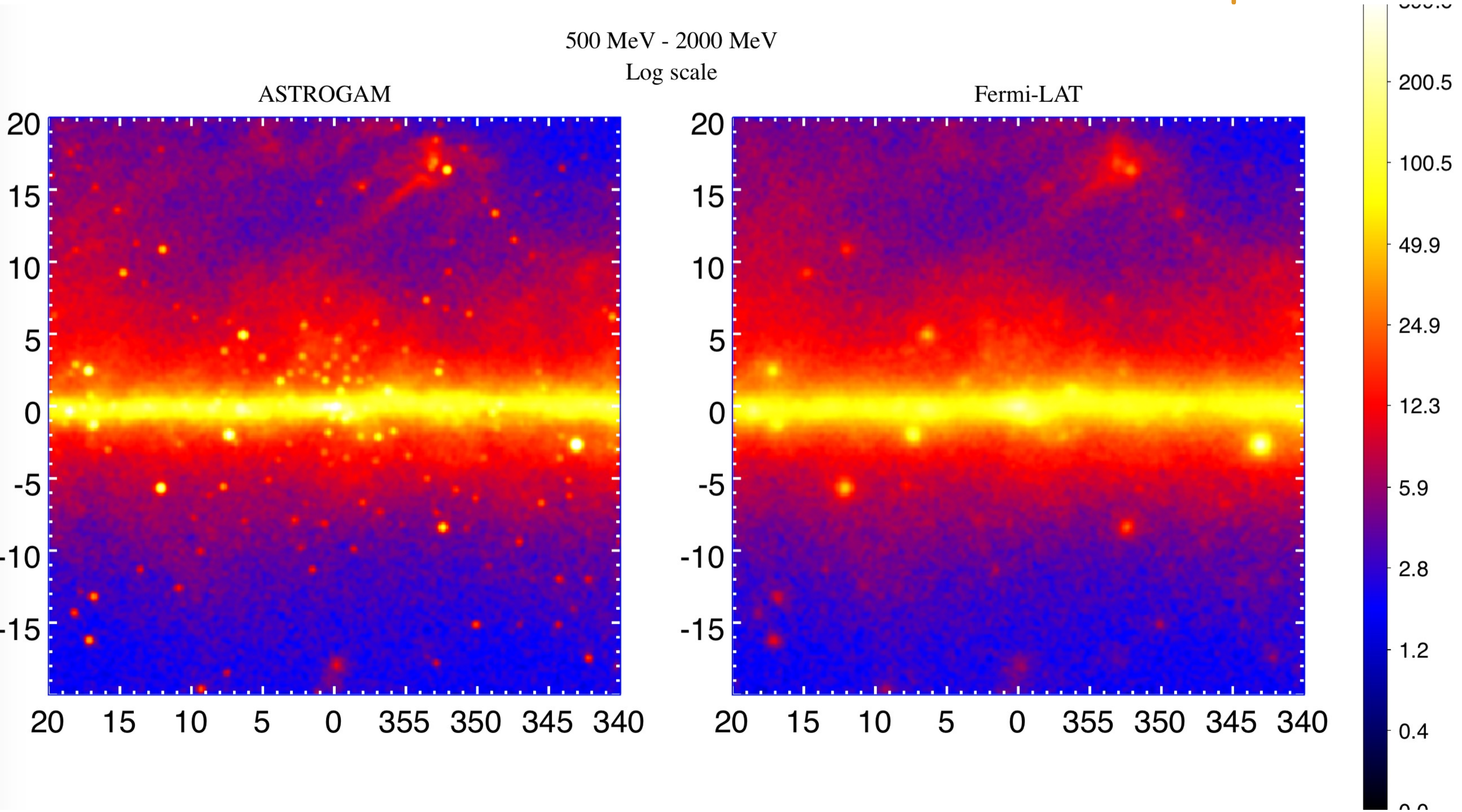
More Fermi LAT analysis

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

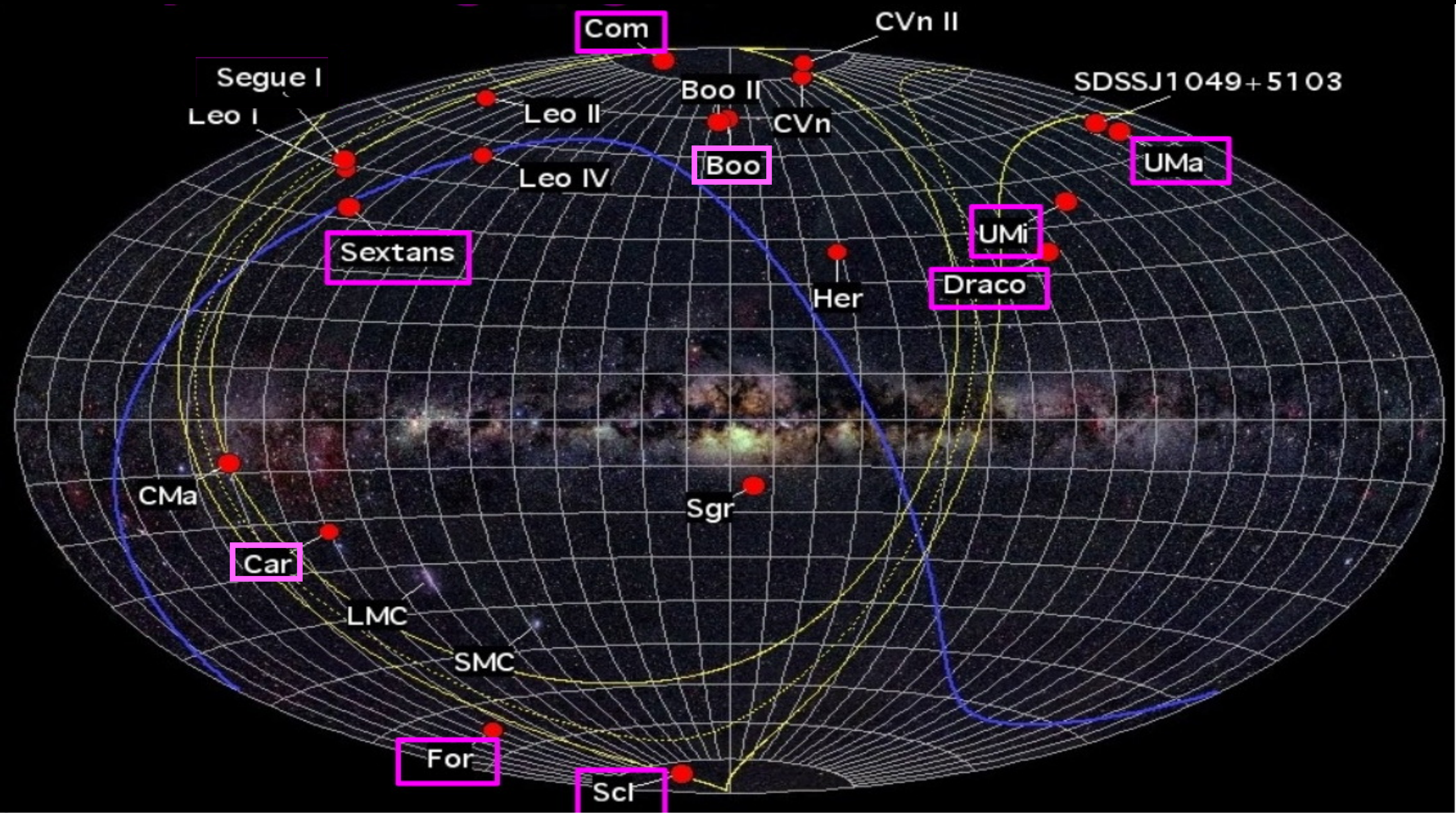
But ultimately We need a new experiment with better angular resolution below 100 MeV

Galactic Center Region 0.5-2 GeV

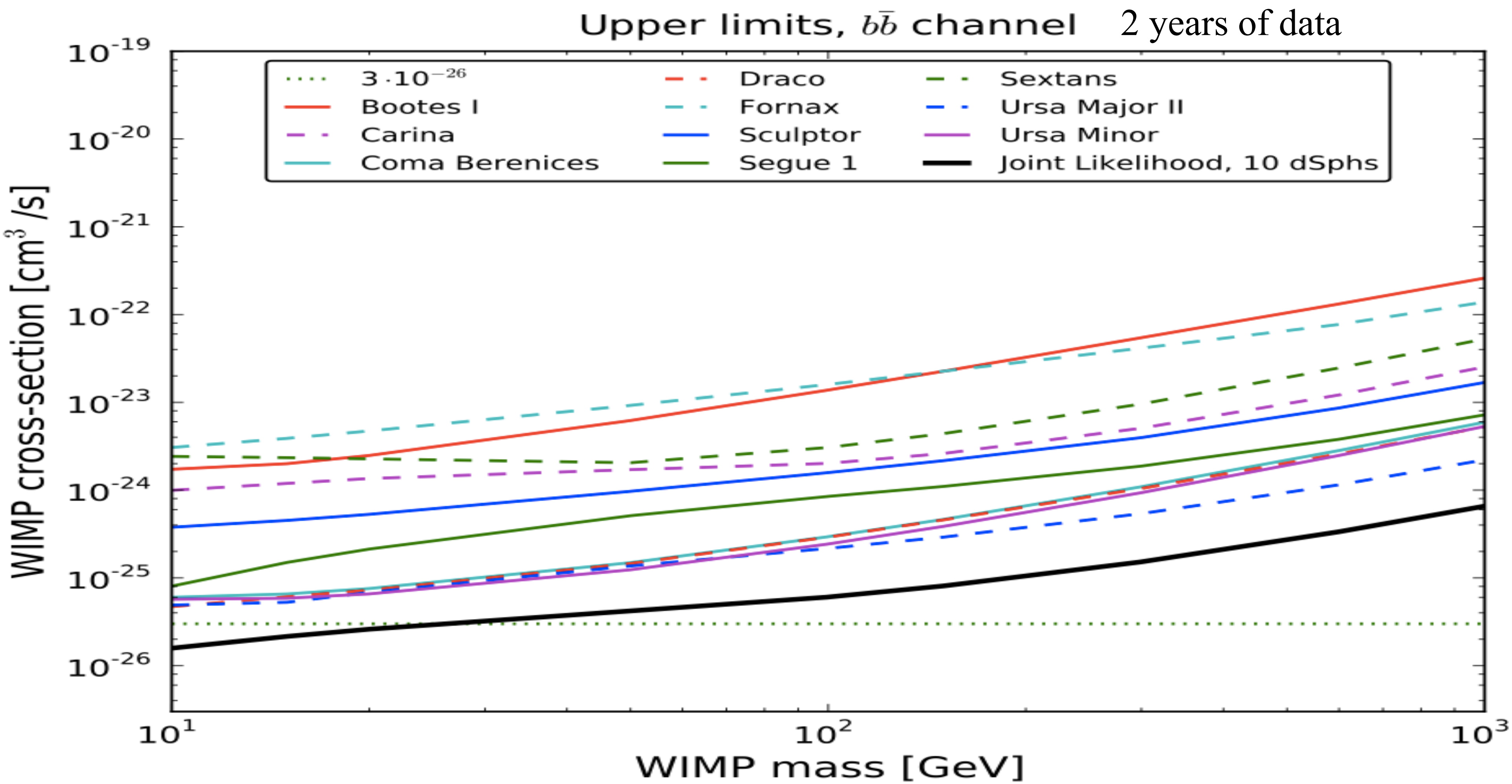
Fermi PSF Pass7 rep v15 source



Classical Dwarf spheroidal galaxies: promising targets for DM detection



Dwarf Spheroidal Galaxies combined analysis

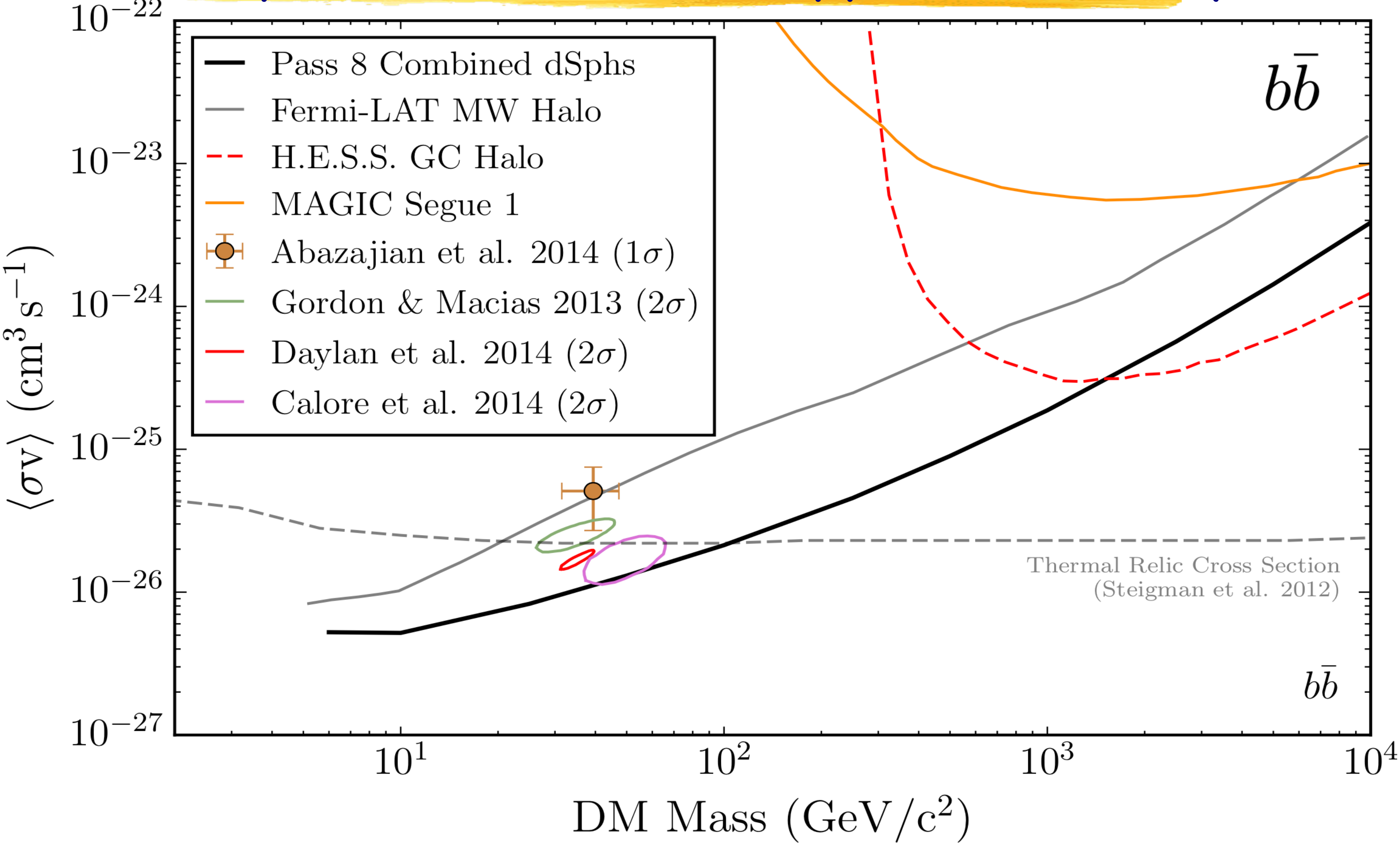


robust constraints including J-factor uncertainties from the stellar data statistical analysis

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

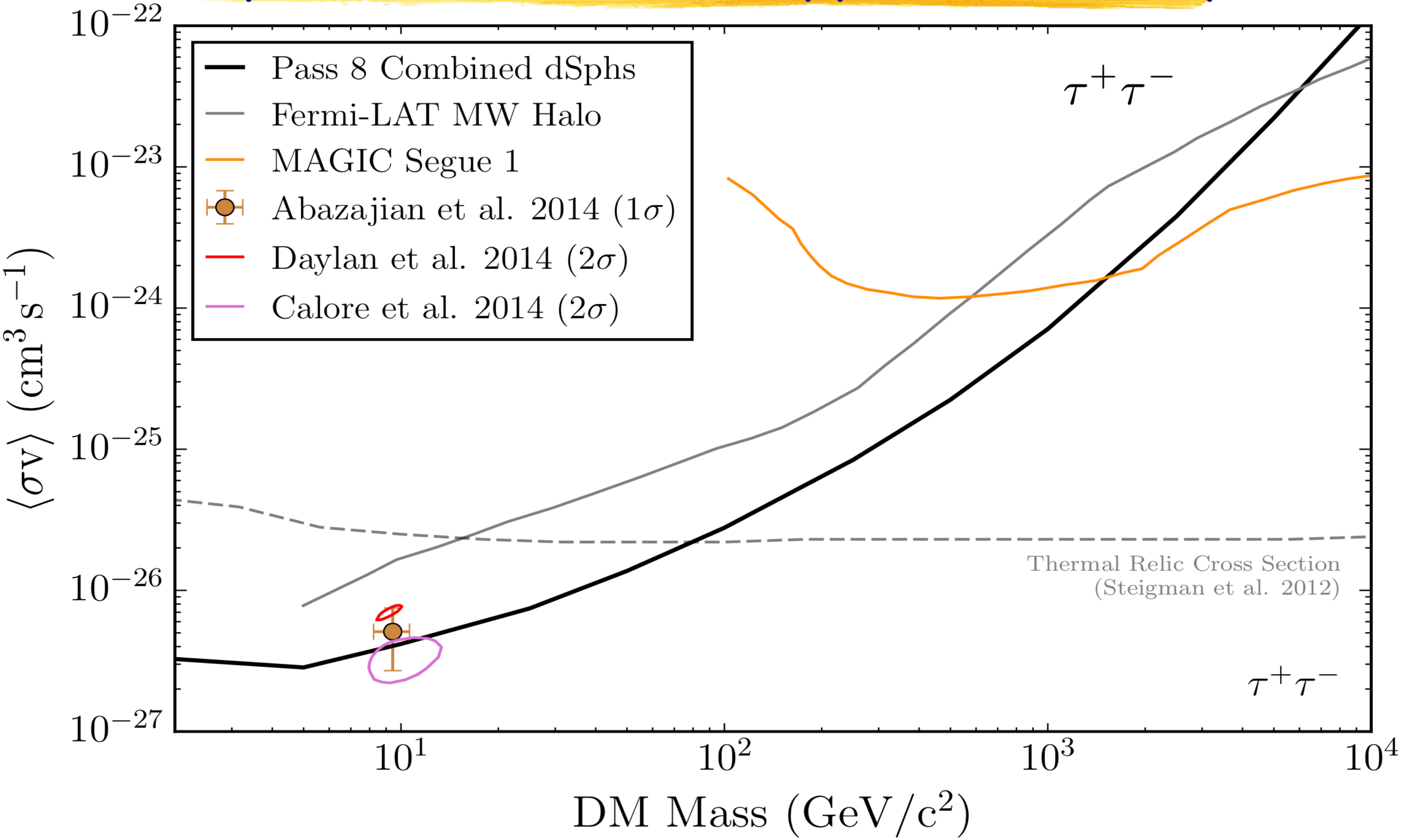
Fermi Lat Coll., PRL 107, 241302 (2011) [arXiv:1108.3546]

Dwarf Spheroidal Galaxies upper-limits (6 years)



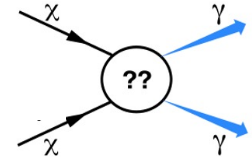
M.Ackermann et al., [Fermi Coll.] PRL 115, 231301 (2015) [arXiv:1503.02641]

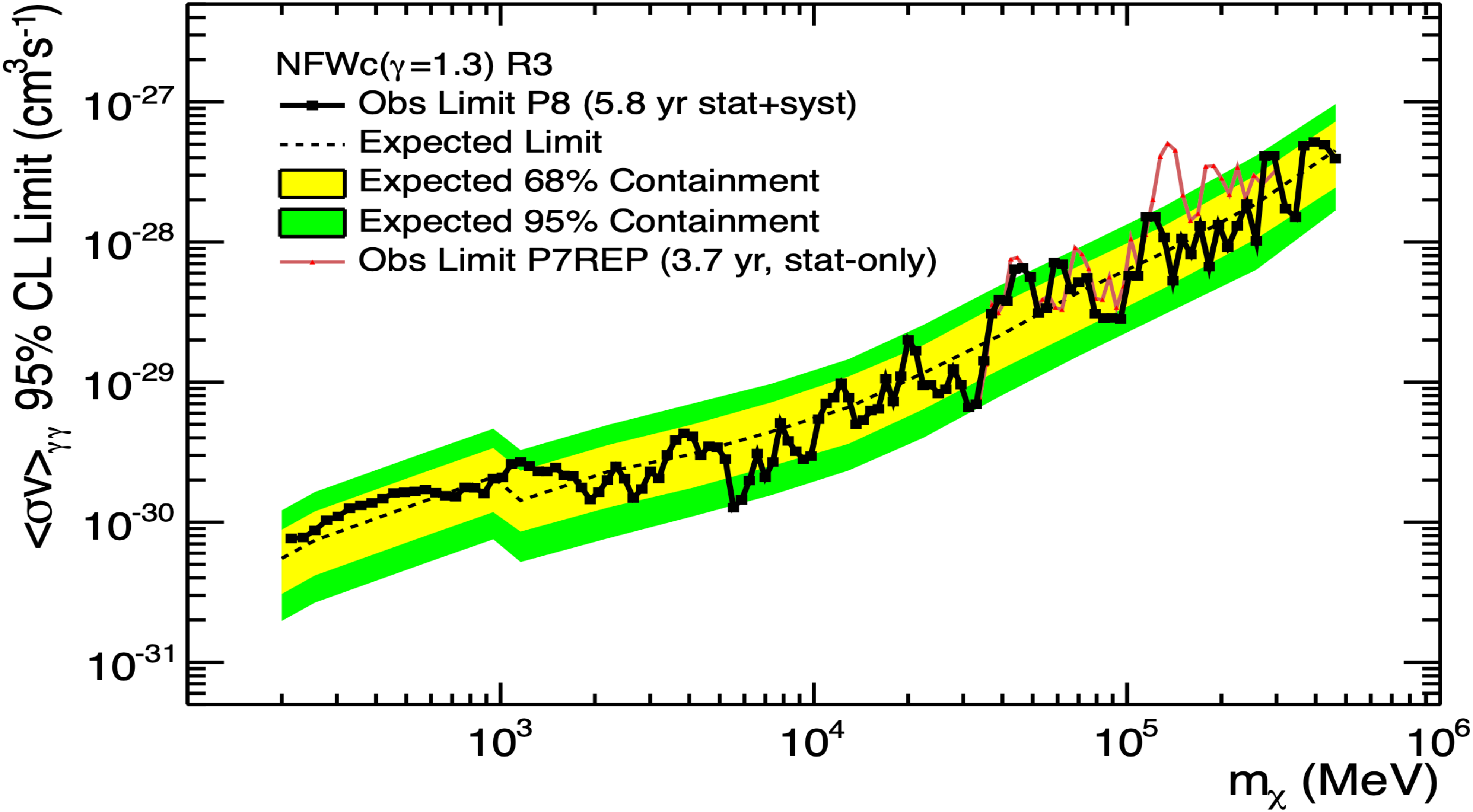
Dwarf Spheroidal Galaxies upper-limits (6 years)



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

Lines searches with Fermi-LAT



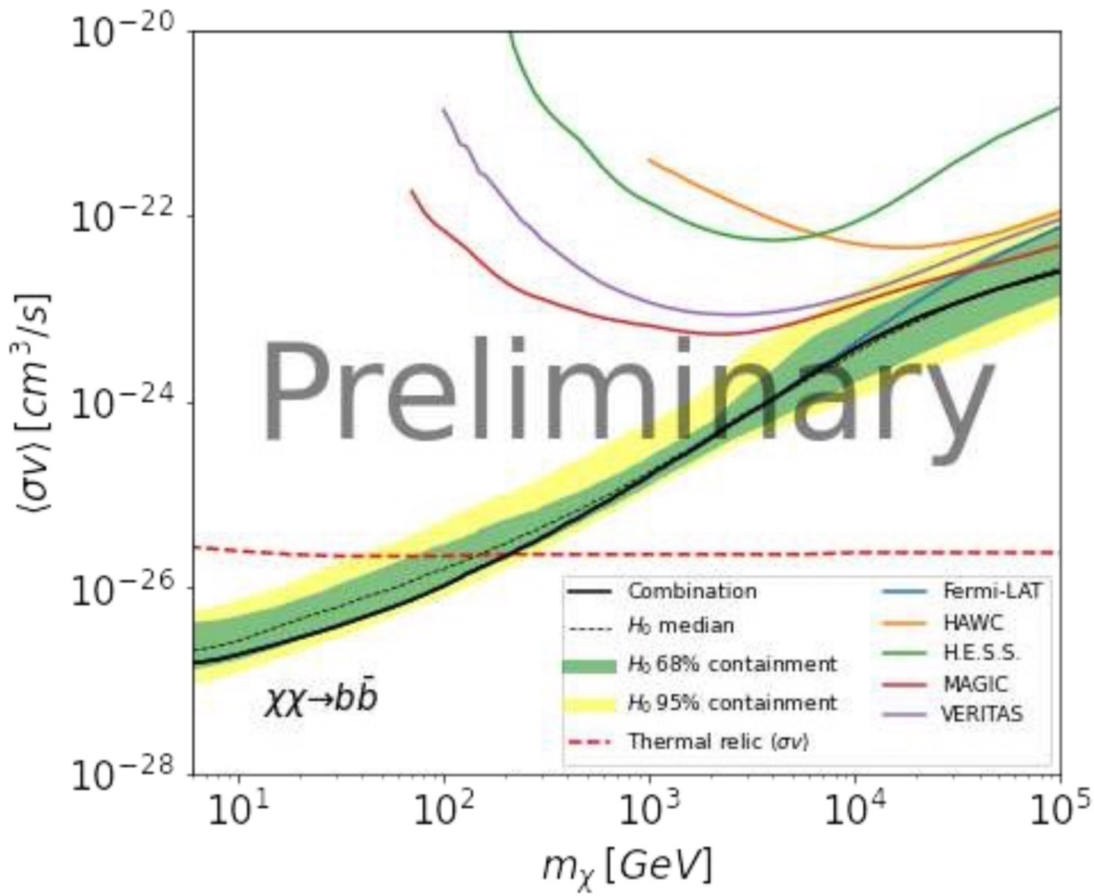


Fermi LAT Coll. Phys. Rev., D91, 2015, 122002 [arXiv:1506.00013]

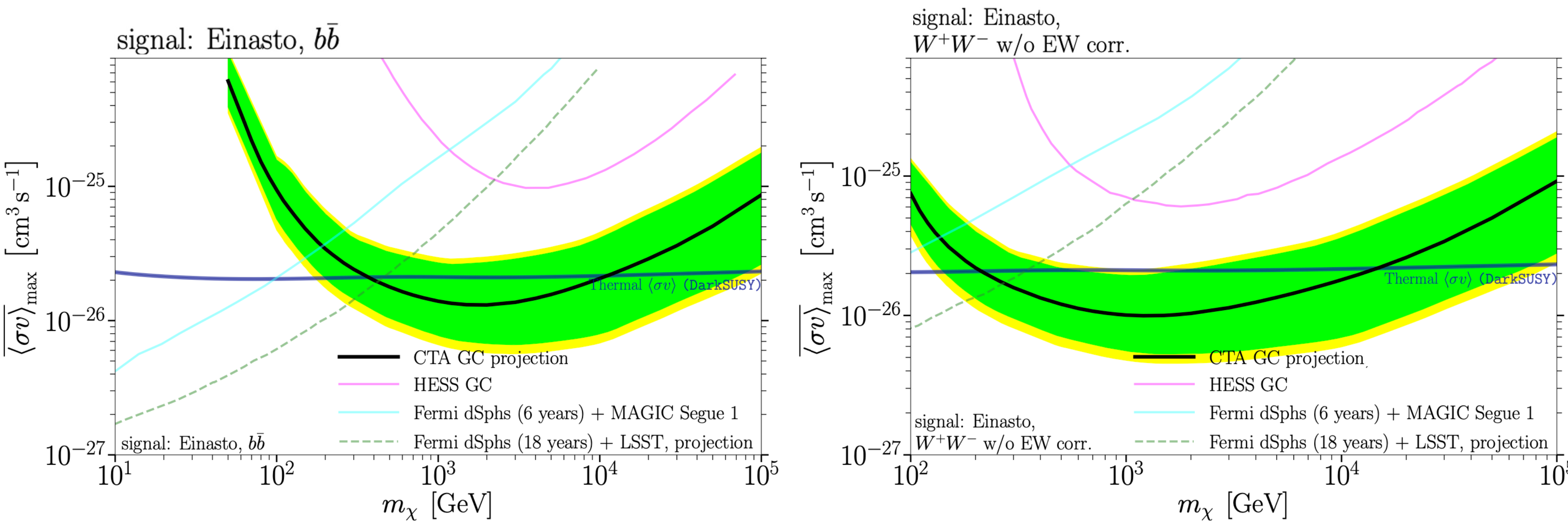
Combining all dSph observations

• 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



Galactic center CTA Sensitivity



- Einasto profile

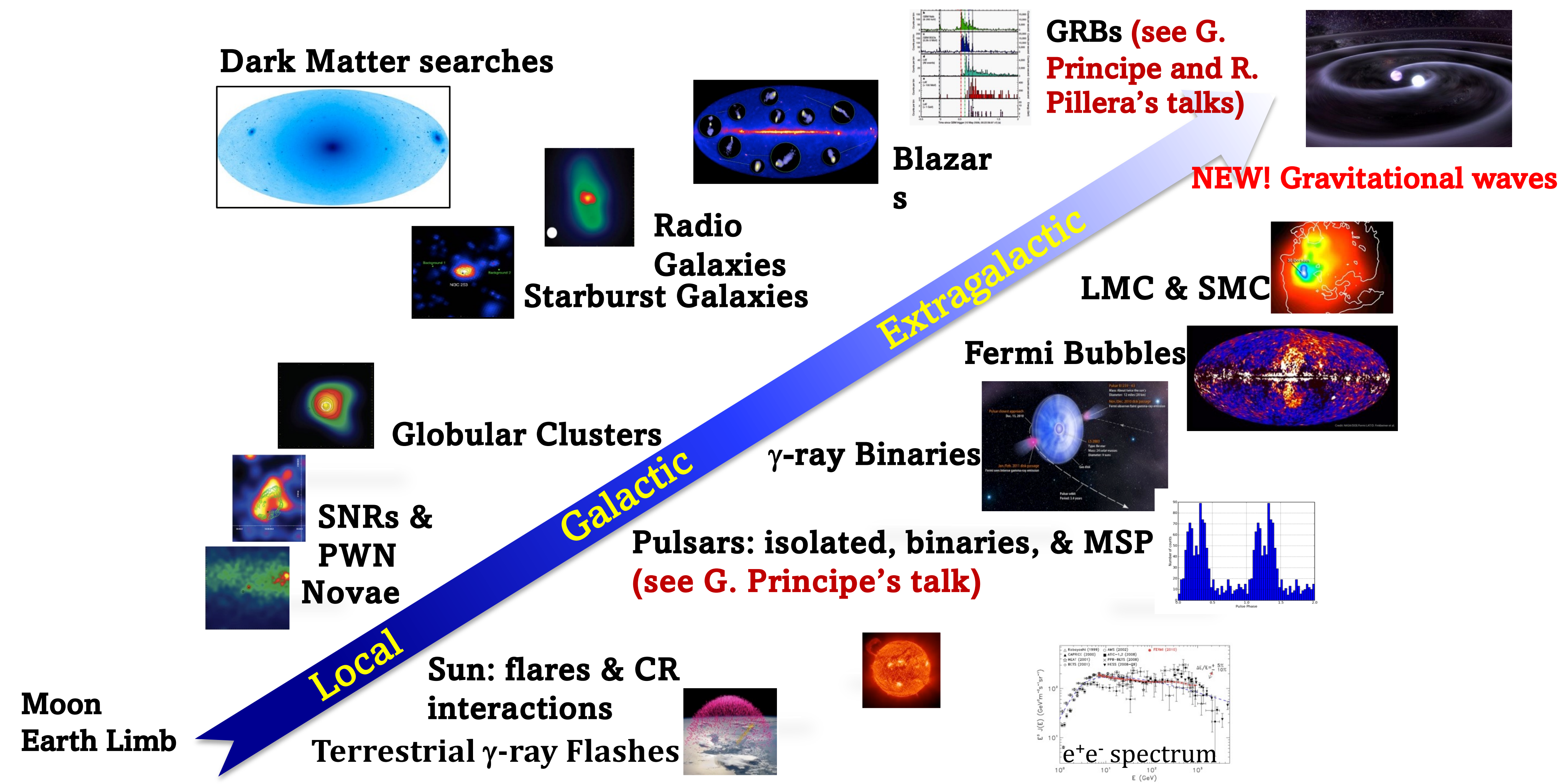
525 h

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

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

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

Science with the Fermi-LAT

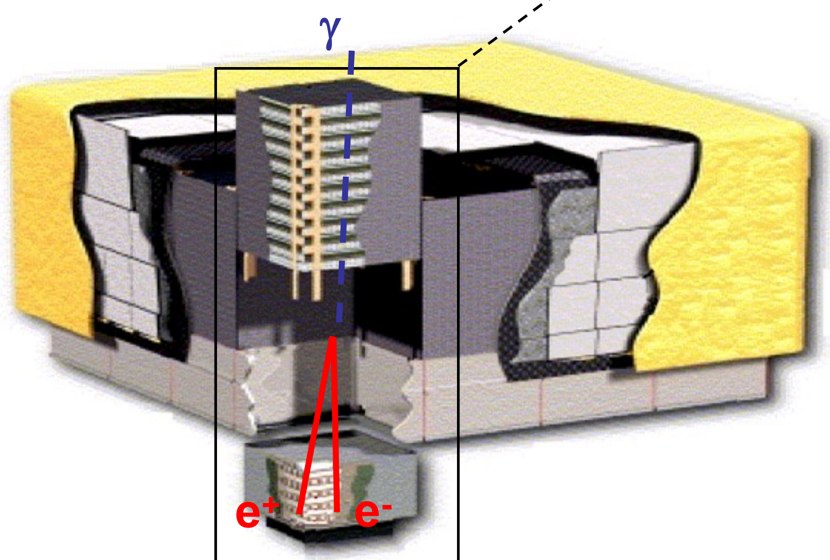


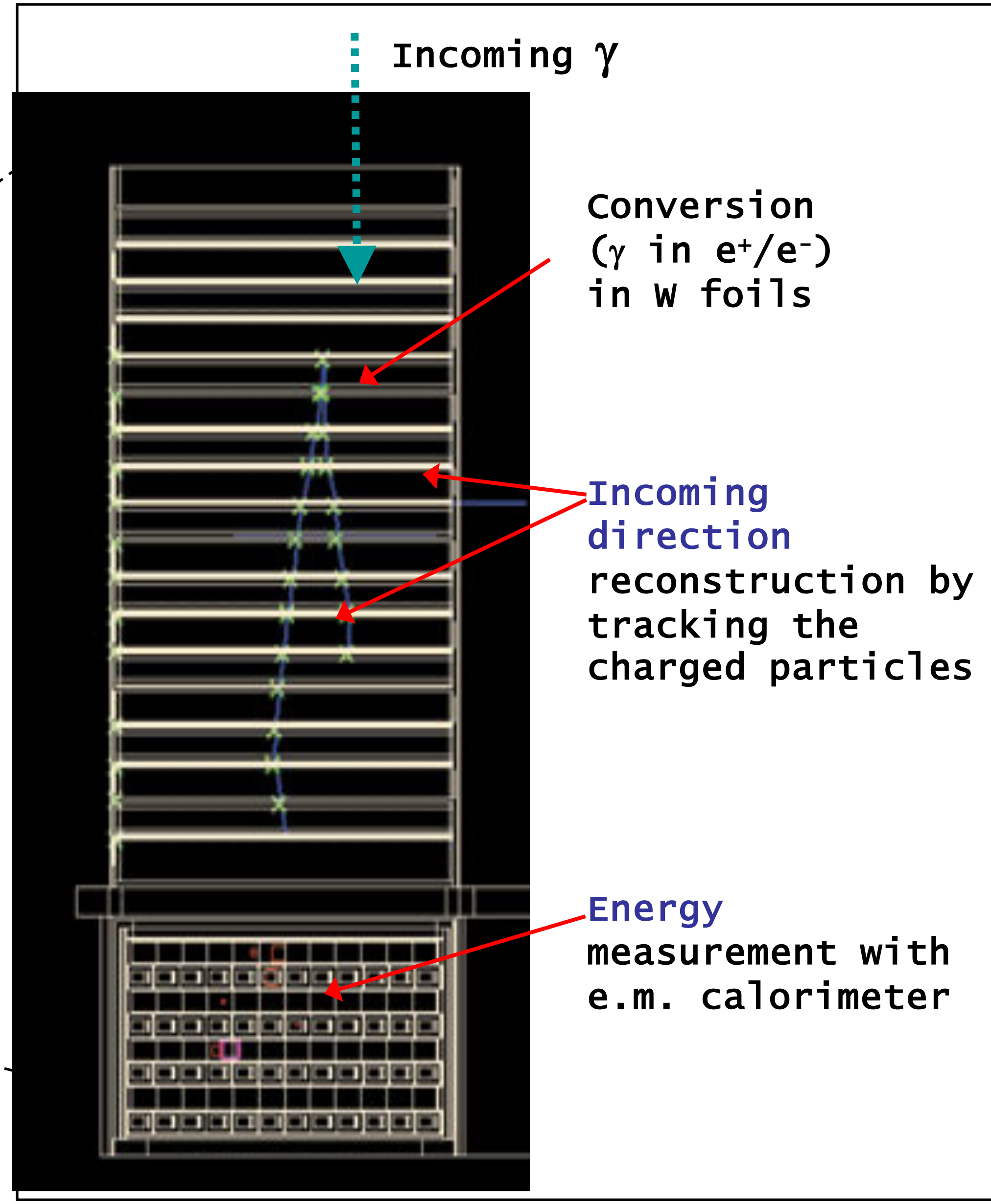
The Low Energy Frontier

How Fermi LAT detects gamma rays

4 x 4 array of identical towers with:

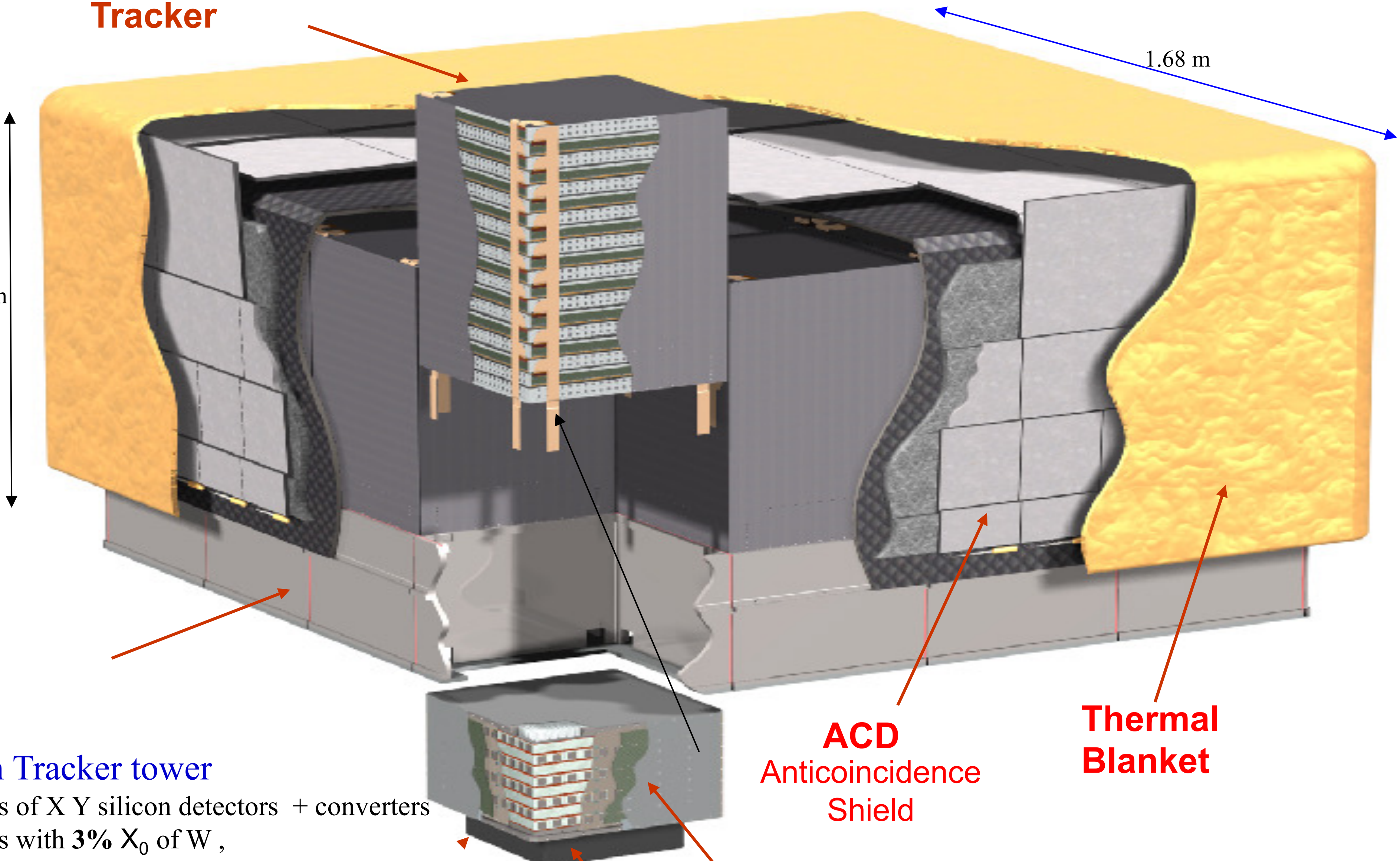
- Precision Si-strip tracker (TKR)
  - With W converter foils
- Hodoscopic CsI calorimeter (CAL)
- DAQ and Power supply box





An anticoincidence detector around the telescope distinguishes gamma-rays from charged particles

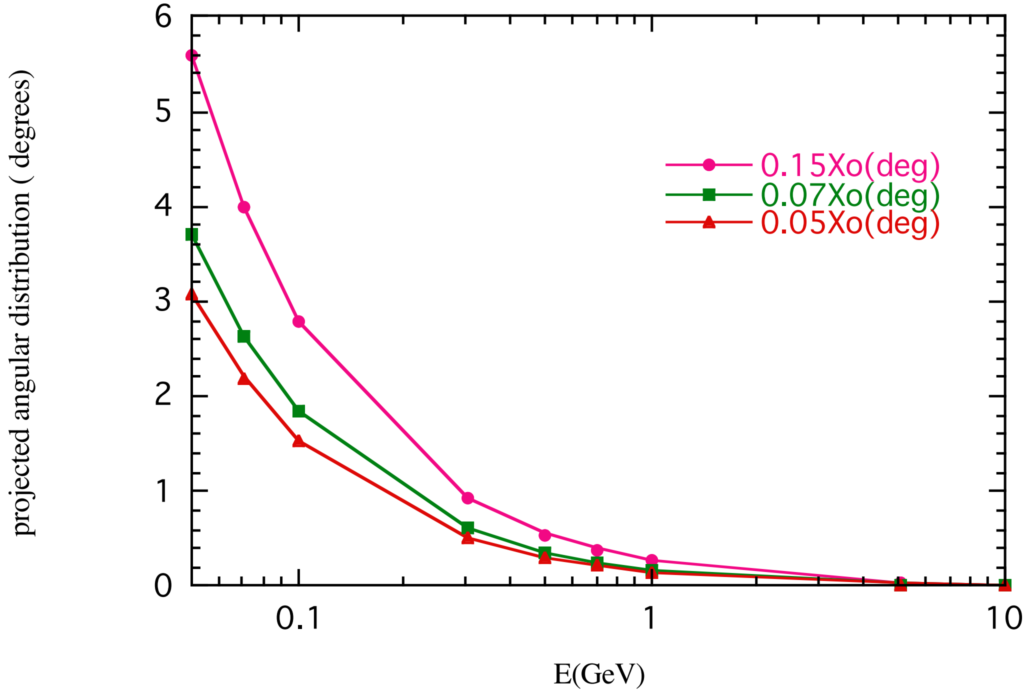
Fermi Gamma-Ray Large Area Space Telescope

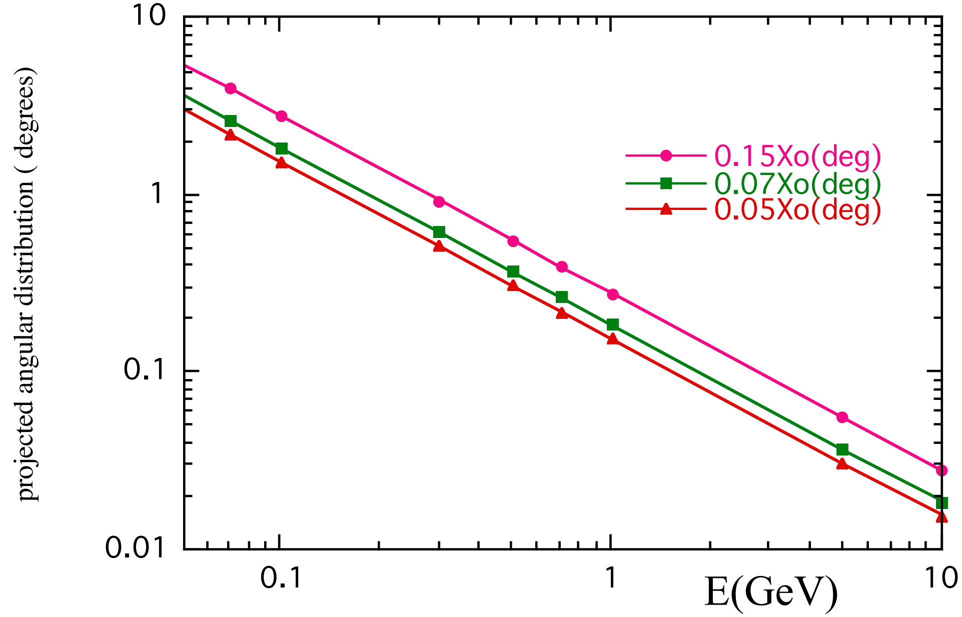


Silicon Tracker tower

18 planes of X Y silicon detectors + converters
12 planes with **3%** X_0 of W ,
4 planes with **18%** X_0
2 planes without converters

Multiple Scattering



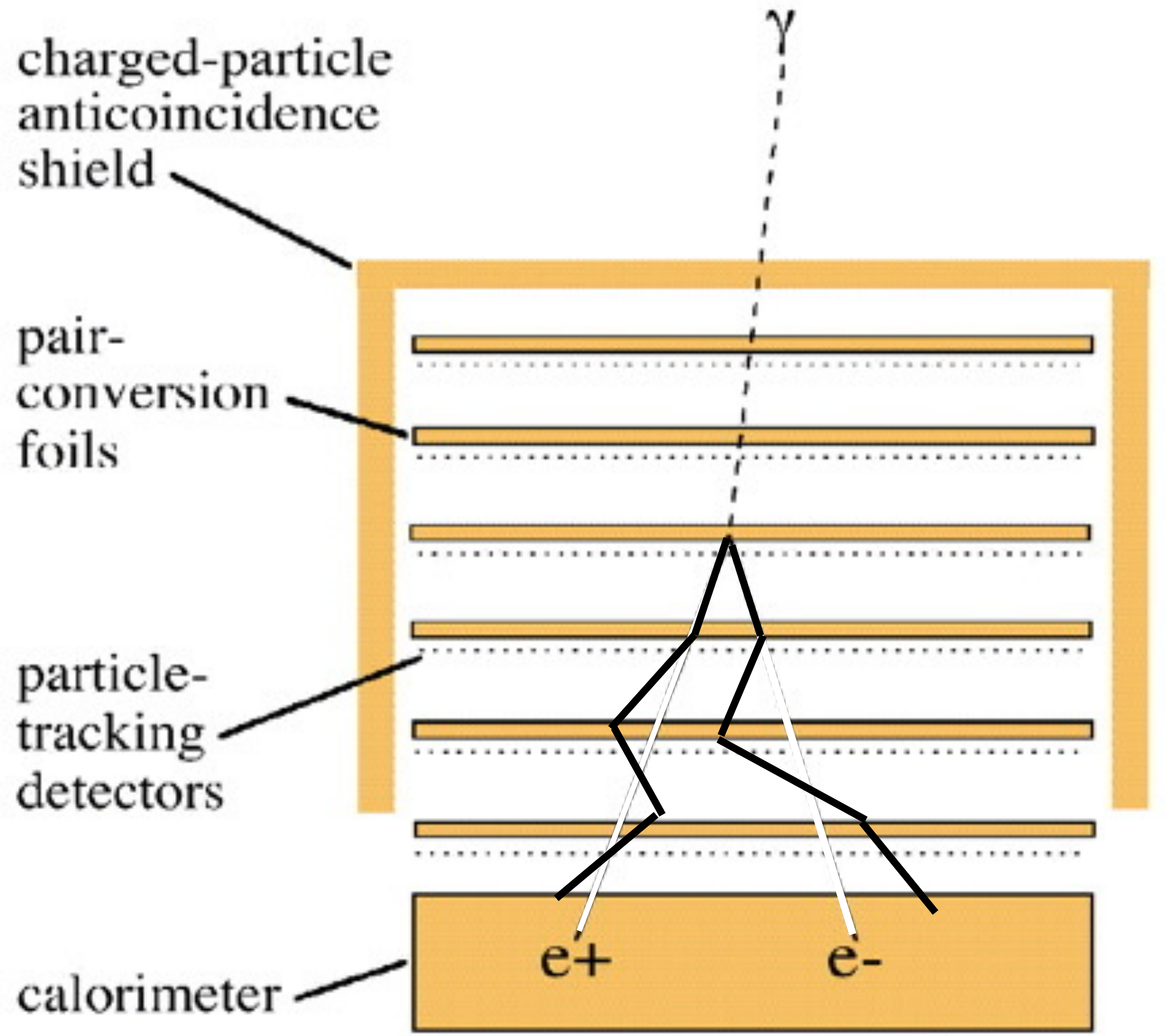


$$\theta_0 = \theta_{plane}^{rms} = \frac{1}{\sqrt{2}}\theta_{space}^{rms}$$

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

Elements of a pair-conversion telescope

(more realistic scheme)



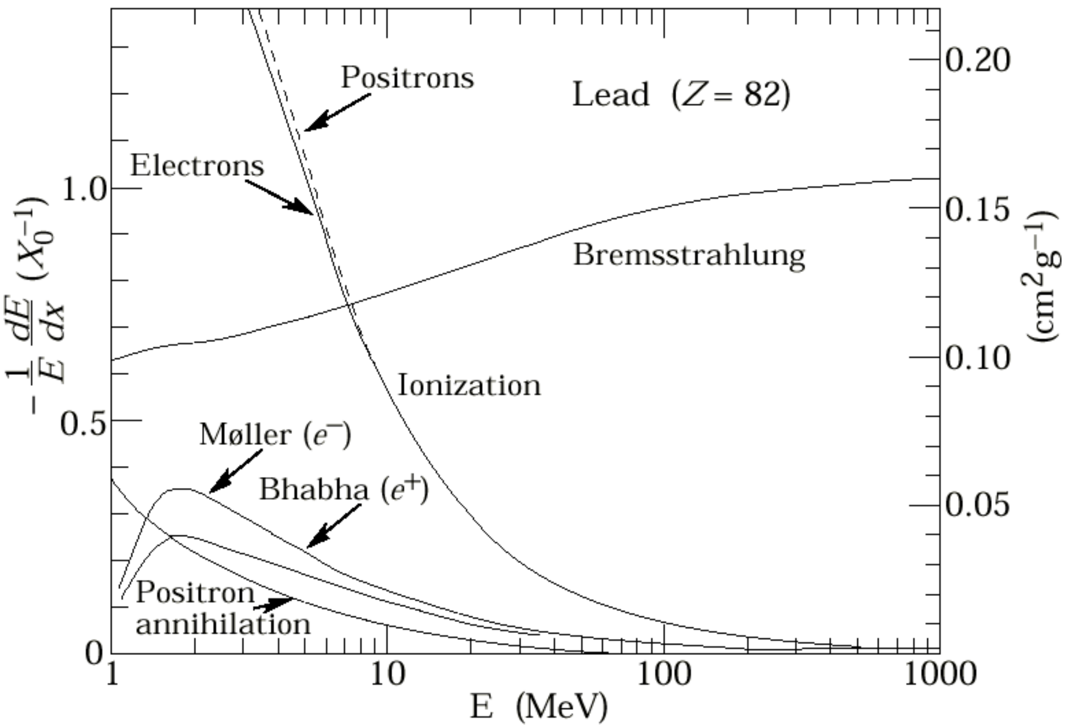
(energy measurement)

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

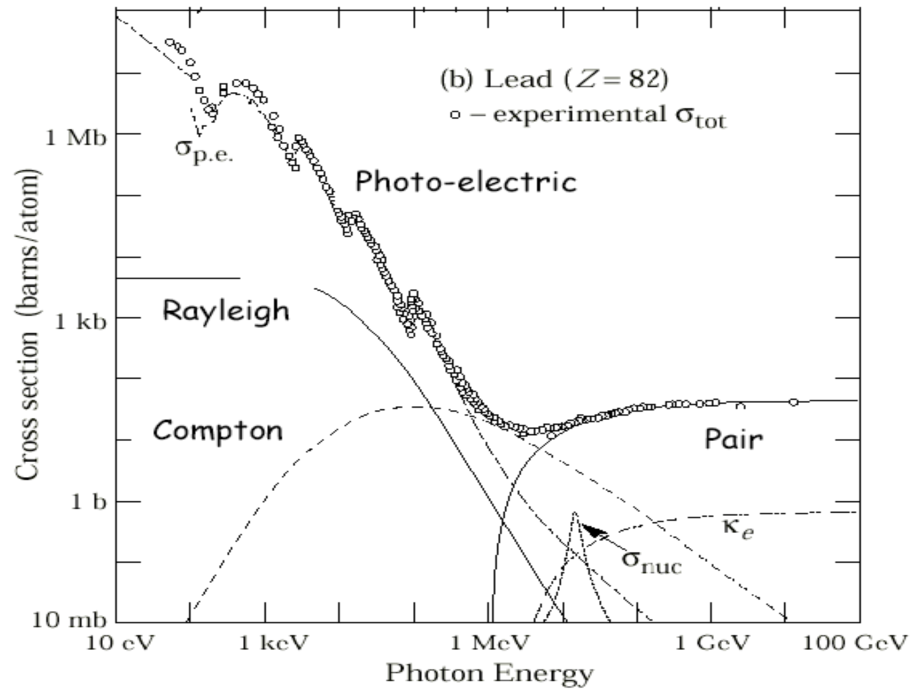
- electron and positron carry information about the direction, energy and polarization of the γ-ray

Interaction of photons with matter

Fractional energy loss for e^+ and e^- in lead



Photon total cross sections



$$\left.\frac{dE}{dx}\right._{Brems} = -\frac{E}{X_0} \Rightarrow E(x) = e^{-\frac{x}{X_0}}$$

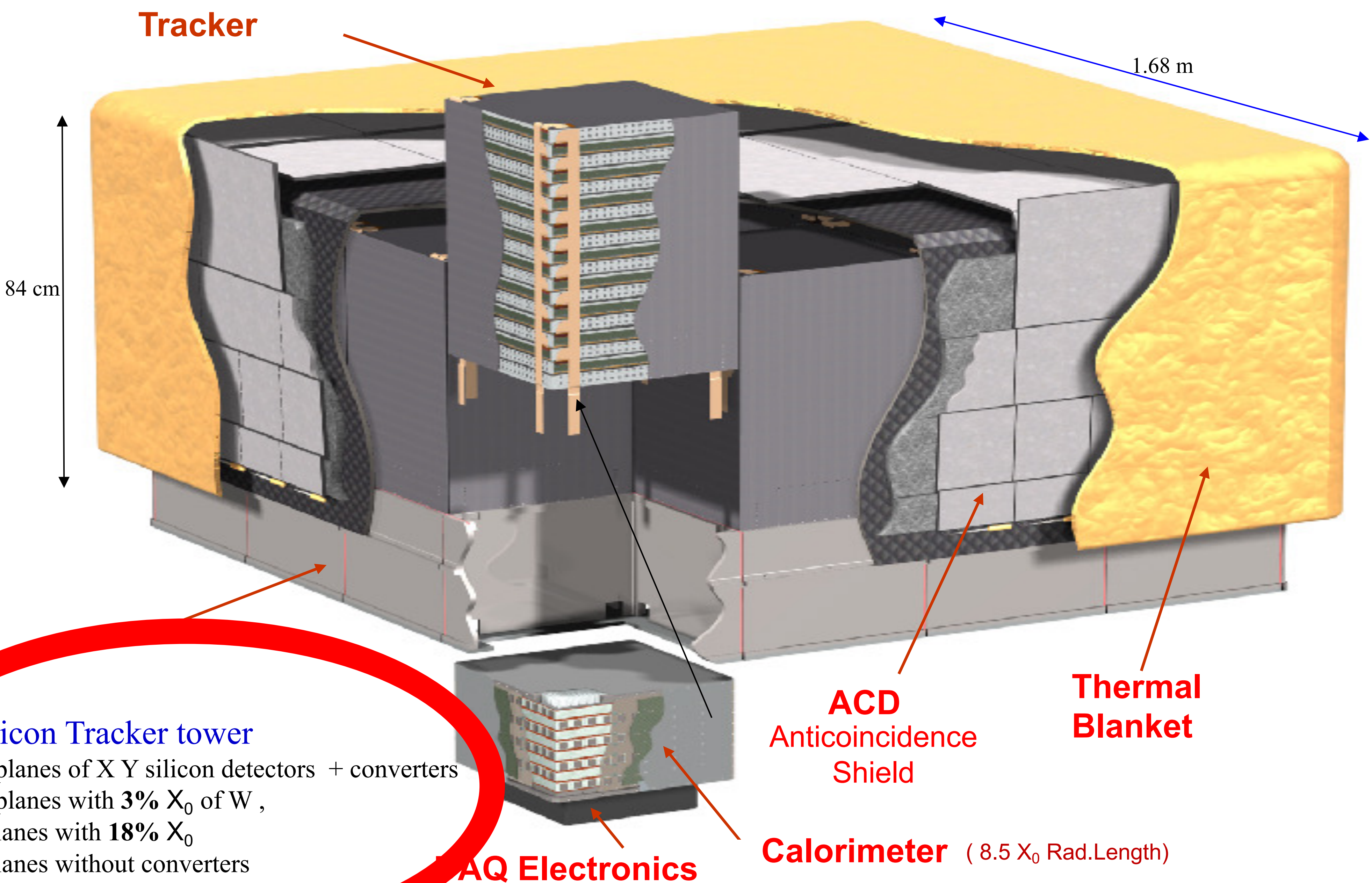
with X_0 = radiation length

$$X_0 = 716.4 \text{ g cm}^{-2} \frac{A}{Z(Z+1)\ln\frac{287}{\sqrt{Z}}}$$

$$\text{Prob. of Int.} = 1 - \exp^{-\frac{7}{9}\frac{x}{X_0}}$$

x/X_0	Prob Int.
0.5	0.40
1	0.54
2	0.79
7	0.995

Fermi Gamma-Ray Large Area Space Telescope



Silicon Tracker tower

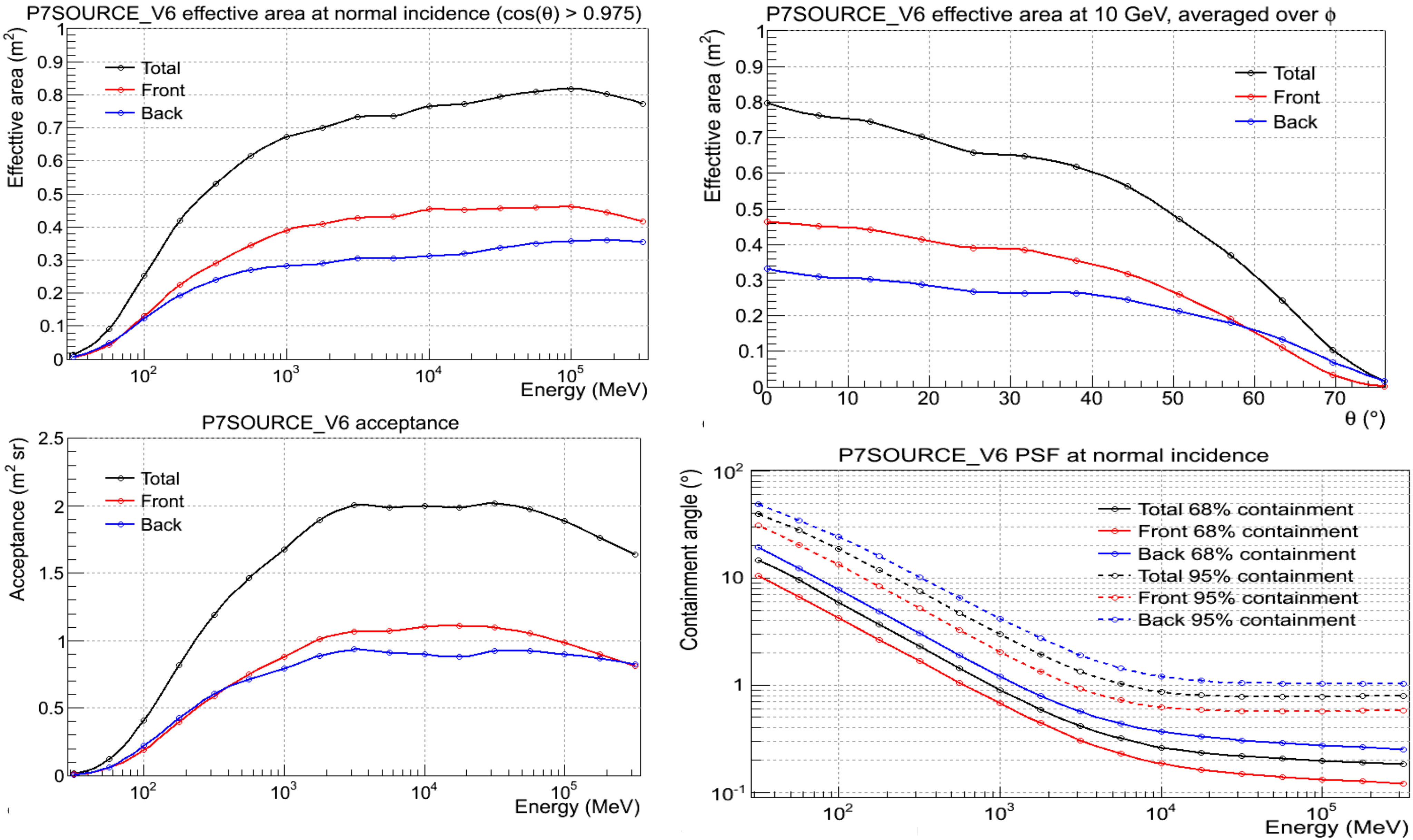
18 planes of X Y silicon detectors + converters

12 planes with **3%** X_0 of W ,

4 planes with **18%** X_0

2 planes without converters

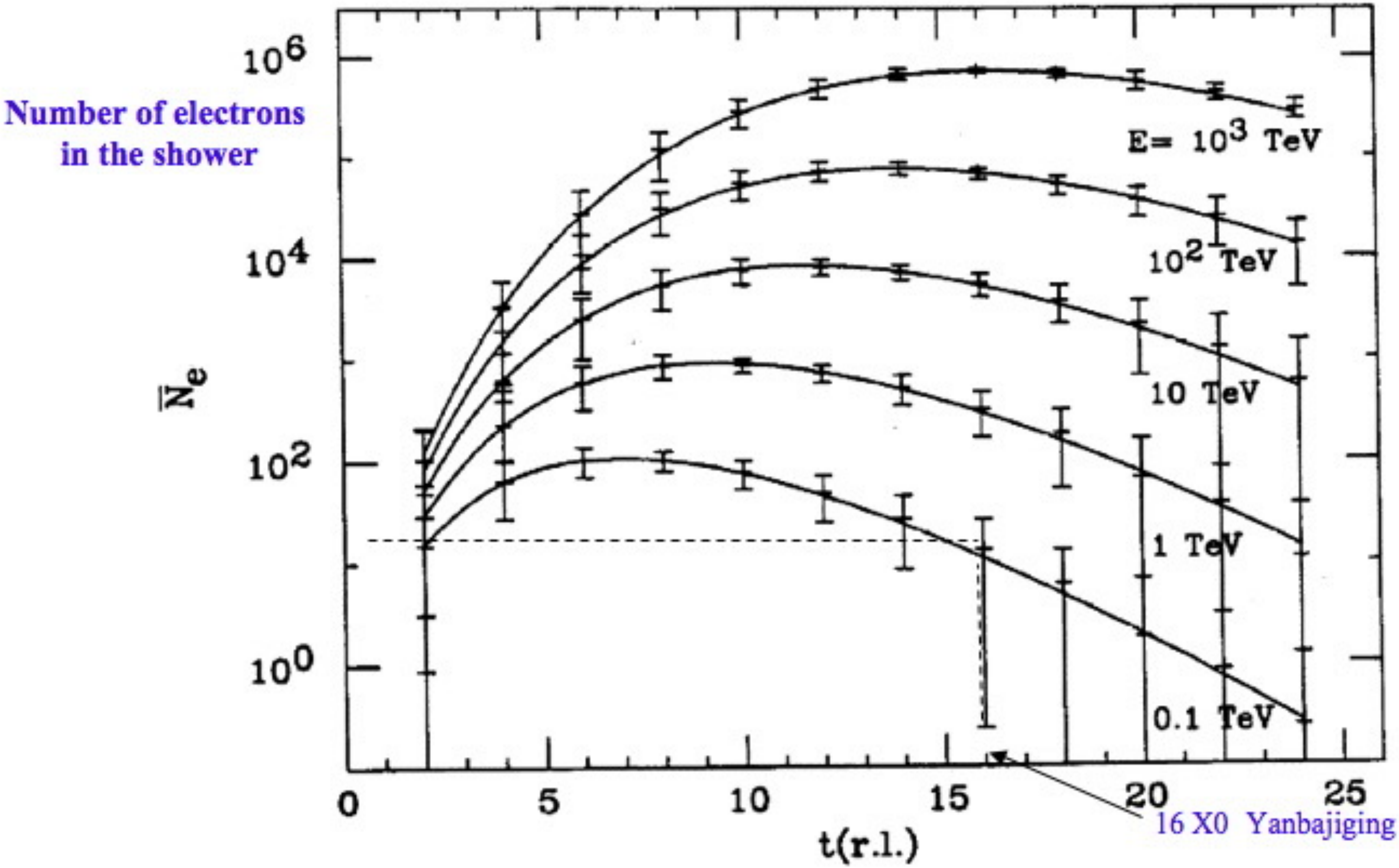
Fermi Instrument Response Function



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

Longitudinal development of the electron component of photon initiated shower

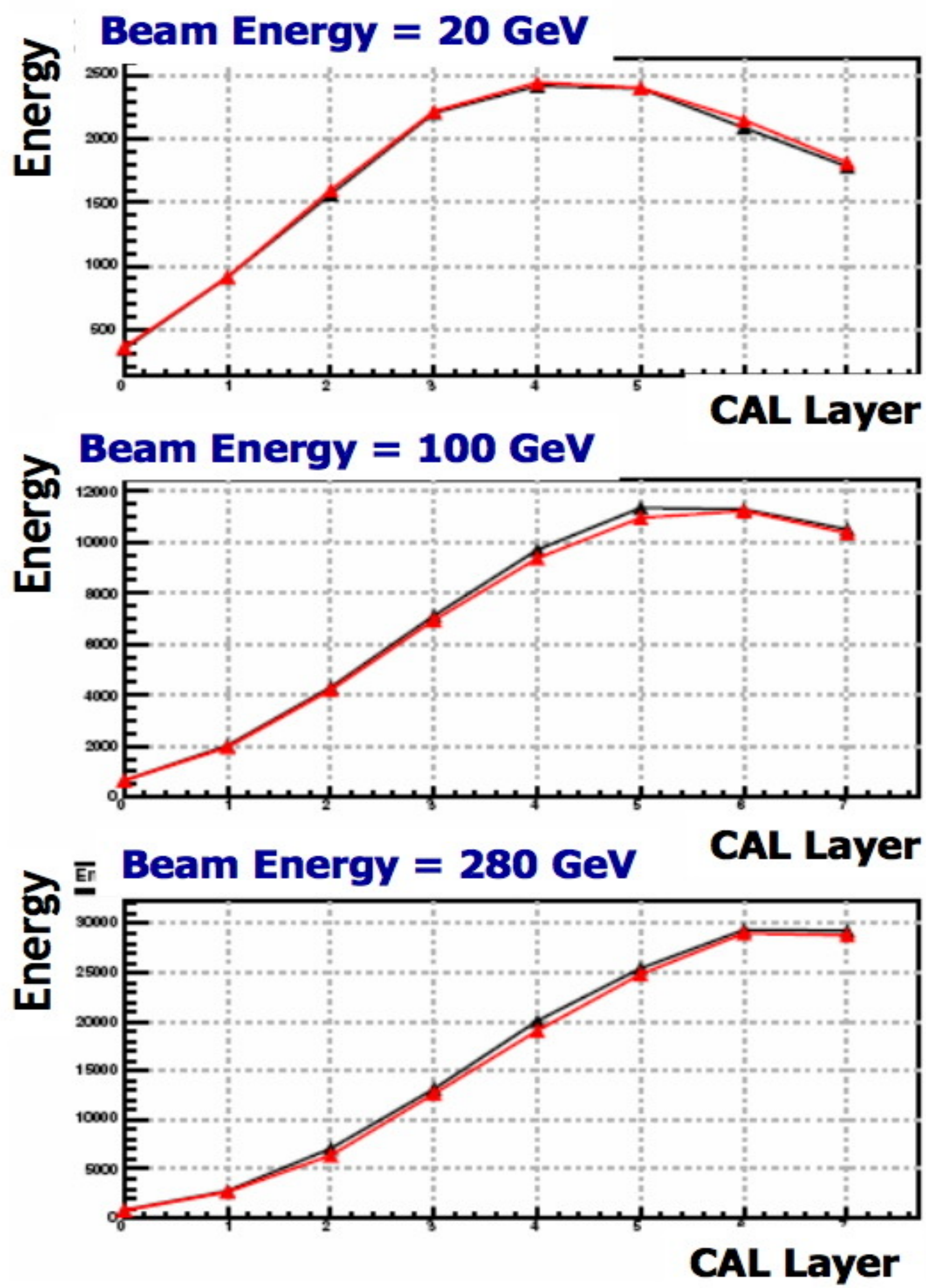
(with electron threshold energy of 5 MeV and fluctuations superimposed)



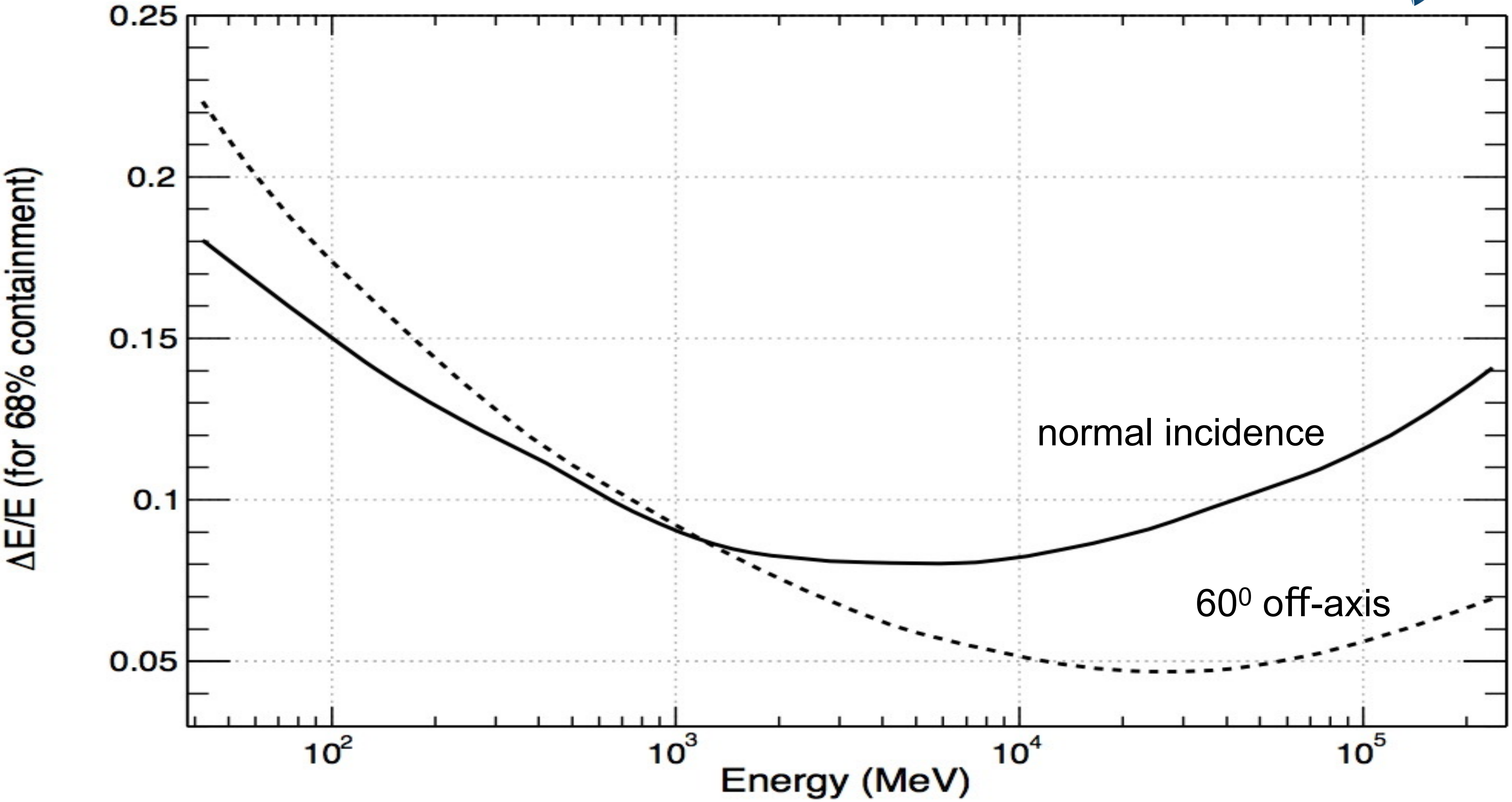
Energy reconstruction

Reconstruction of the most probable value for the event energy:
- based on calibration of the response of each of 1536 calorimeter crystals
- energy reconstruction is optimized for each event
-calorimeter imaging capability is heavily used for fitting shower profile -
-tested at CERN beams up to 280 GeV with the LAT Calibration Unit

Very good agreement between shower profile in beam test data (red) and Monte Carlo (black)



Energy Resolution



The LAT sensitivity extends to higher energies (> 300 GeV) than that of any previous space-based gamma-ray mission, opening the unexplored energy range above 30 GeV. The energy range of the LAT will overlap those of the next generation ground-based TeV gamma-ray instruments, allowing for inter-calibration between the LAT and these instruments.

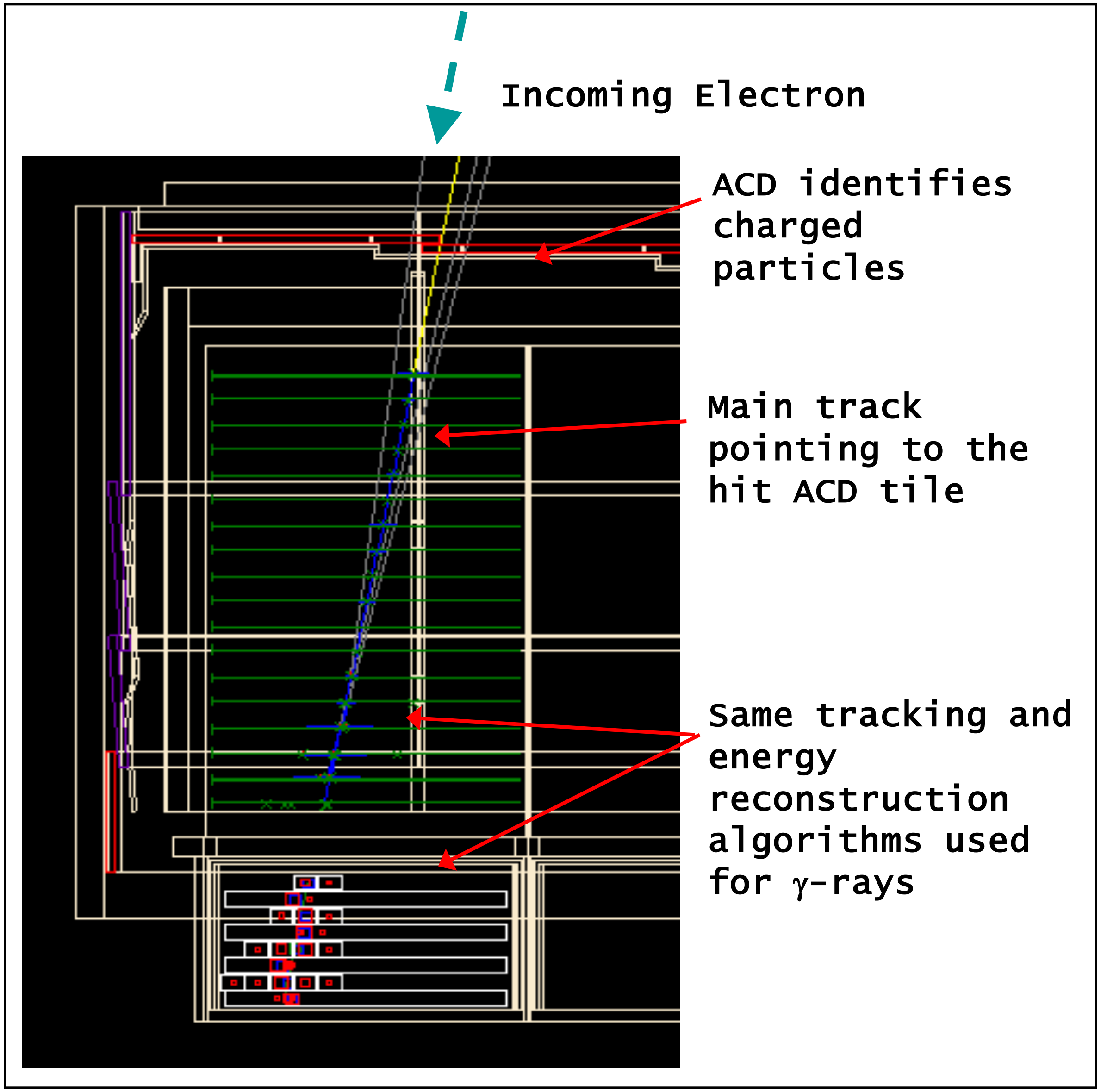
How Fermi LAT detects electrons

Trigger and downlink

- LAT triggers on (almost) every particle that crosses the LAT
  - ~ 2.2 kHz trigger rate
- On board processing removes many charged particles events
  - But keeps events with more that 20 GeV of deposited energy in the CAL
  - ~ 400 Hz downlink rate
- Only ~1 Hz are good γ-rays

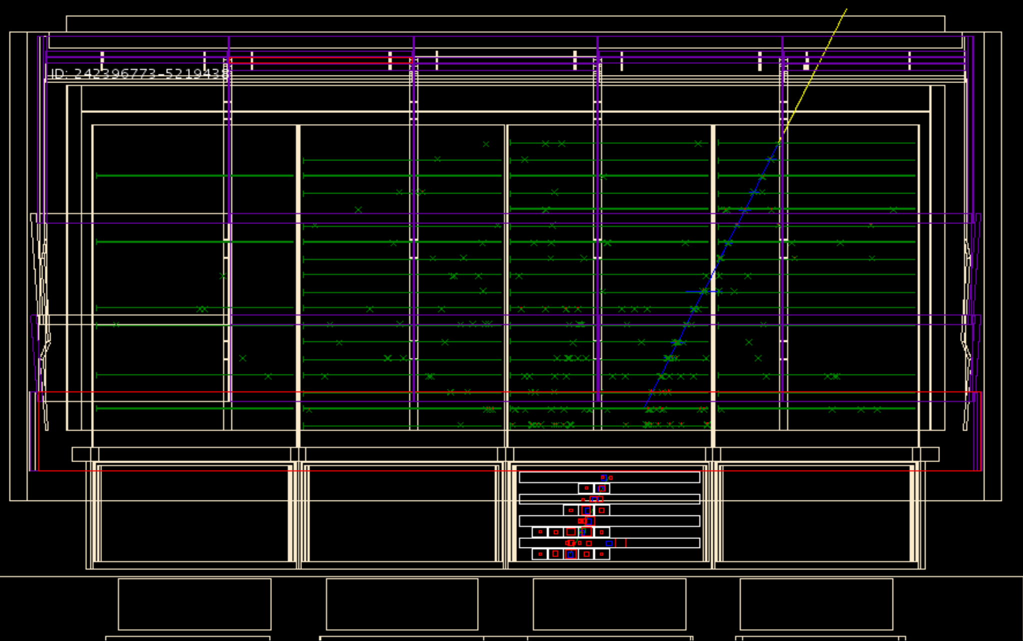
Electron identification

- The challenge is identifying the good electrons among the proton background
  - Rejection power of 10^3 - 10^4 required
  - Can not separate electrons from positrons

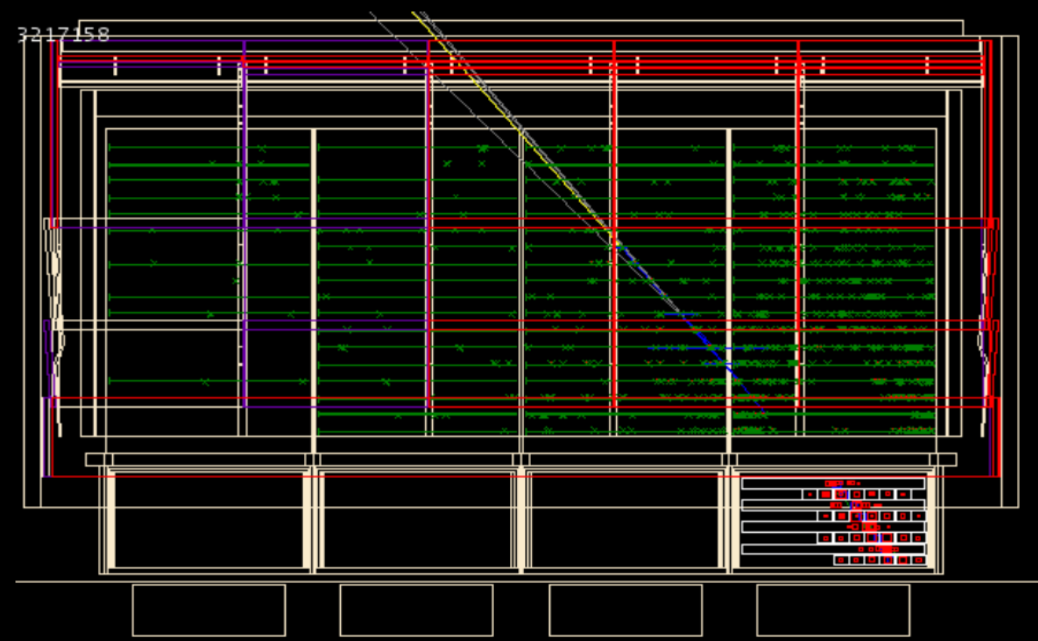


Event topology

A candidate electron
(recon energy 844 GeV)



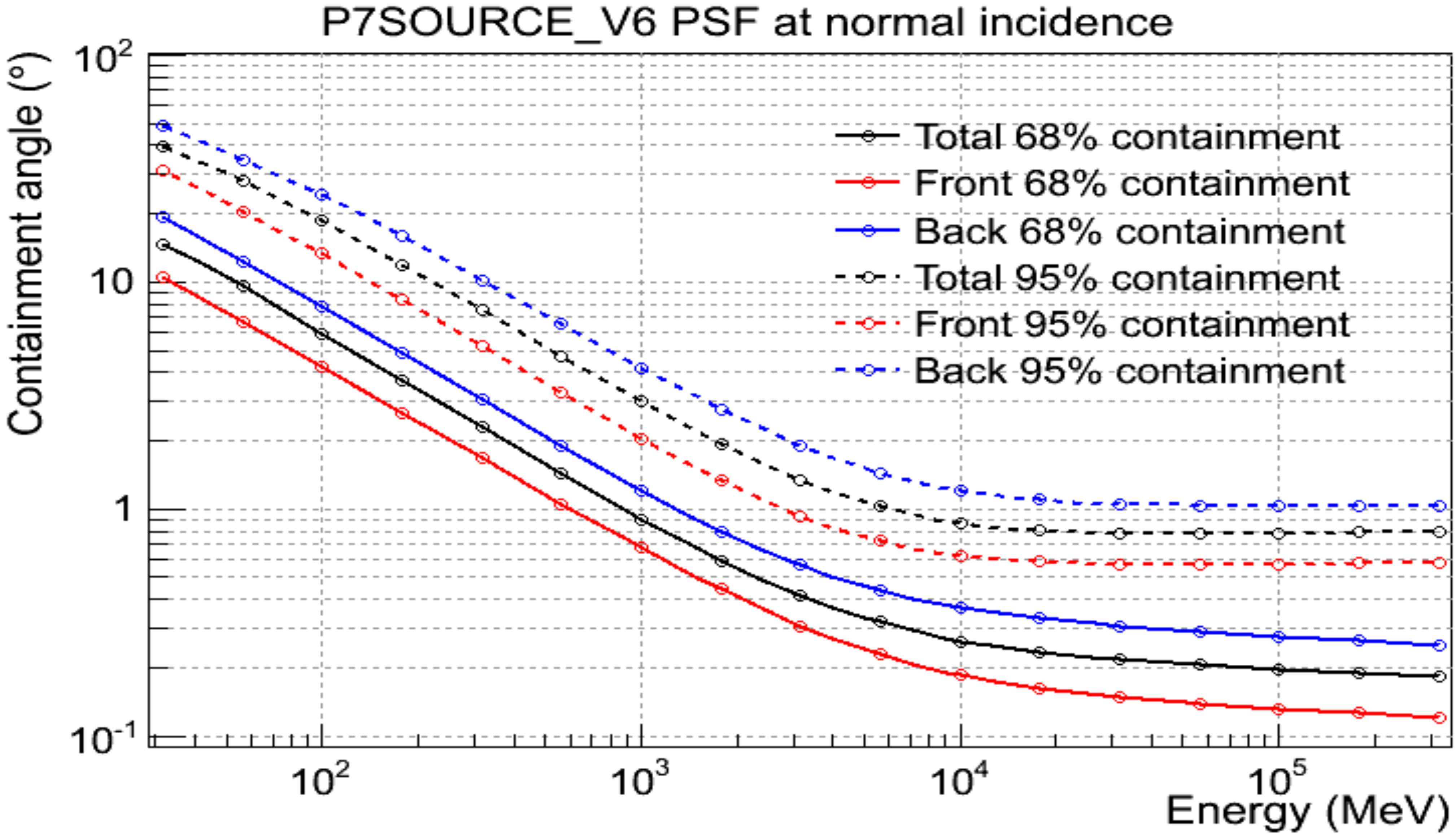
A candidate hadron
(raw energy > 800 GeV)



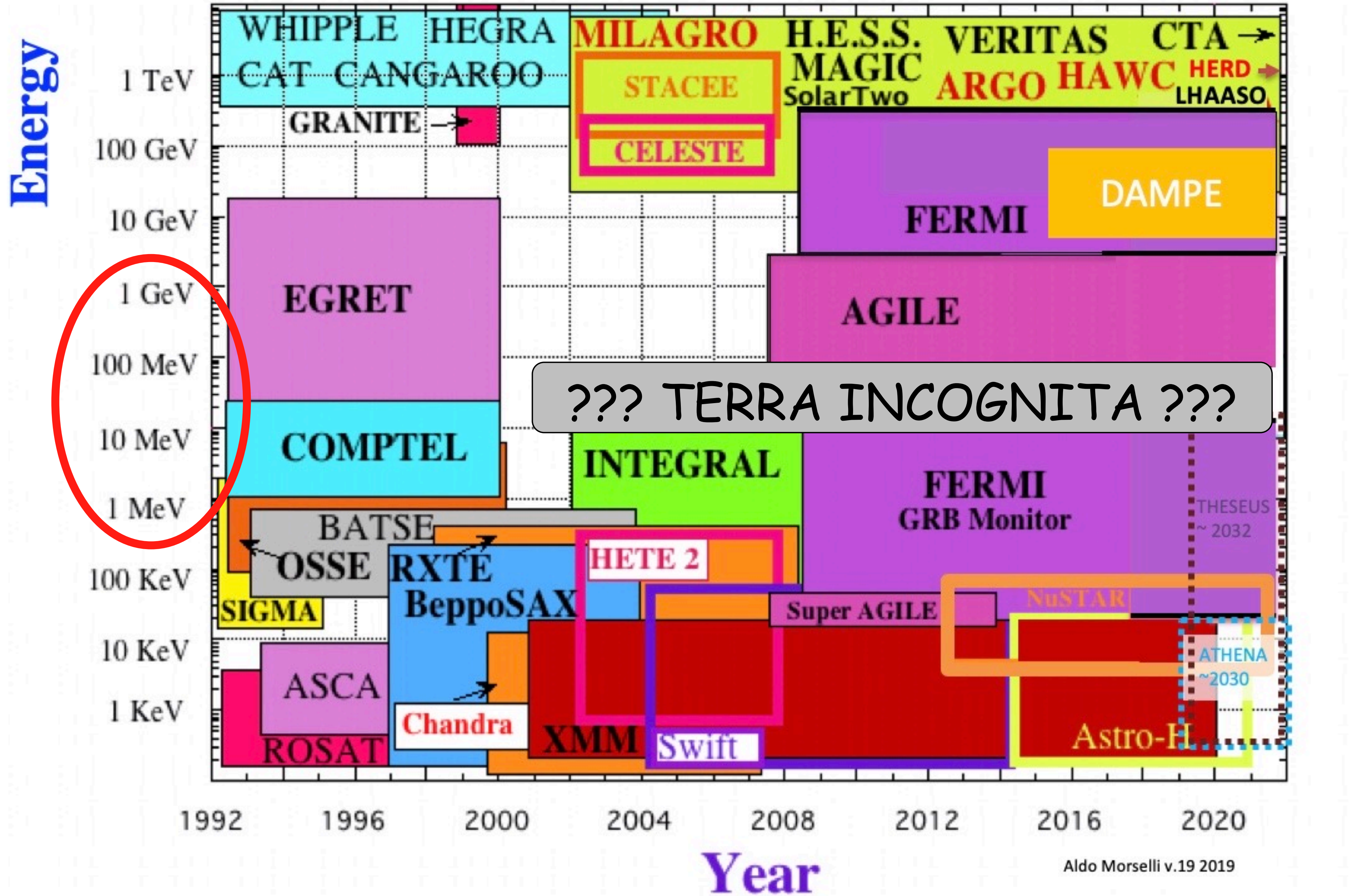
- TKR: clean main track with extra-clusters very close to the track
- CAL: clean EM shower profile, not fully contained
- ACD: few hits in conjunction with the track

- TKR: small number of extra clusters around main track
- CAL: large and asymmetric shower profile
- ACD: large energy deposit per tile

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
DAMPE
FERMI
EGRET
AGILE
??? TERRA INCOGNITA ???
COMPTEL
INTEGRAL
FERMI
GRB Monitor
THESEUS
~ 2032
BATSE
OSSE
SIGMA
RXTE
BeppoSAX
HETE 2
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

$N\gamma_s$= 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

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

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

Sensitivity

number of σ

depends on angular resolution

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

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

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

good detector

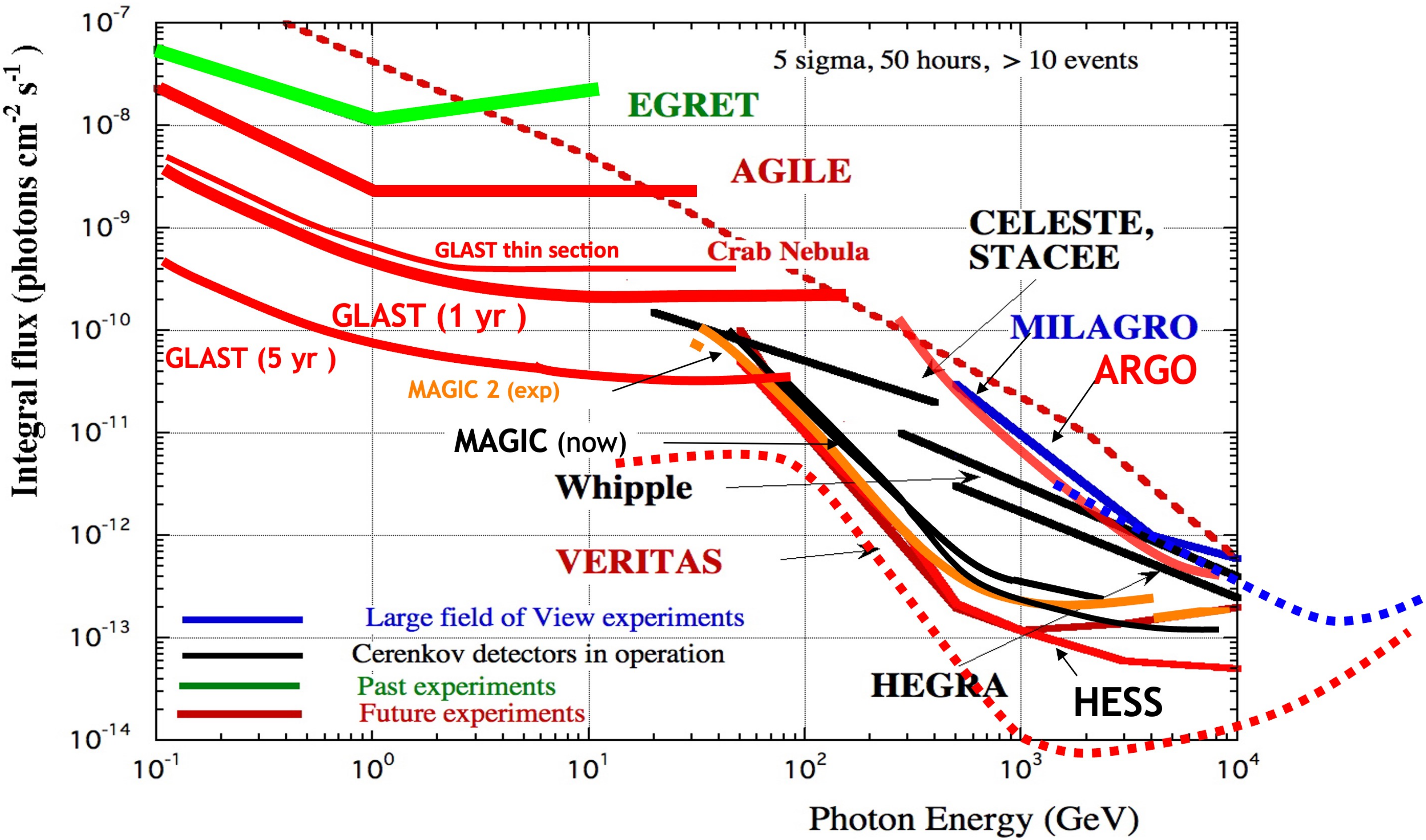
small converter plane

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

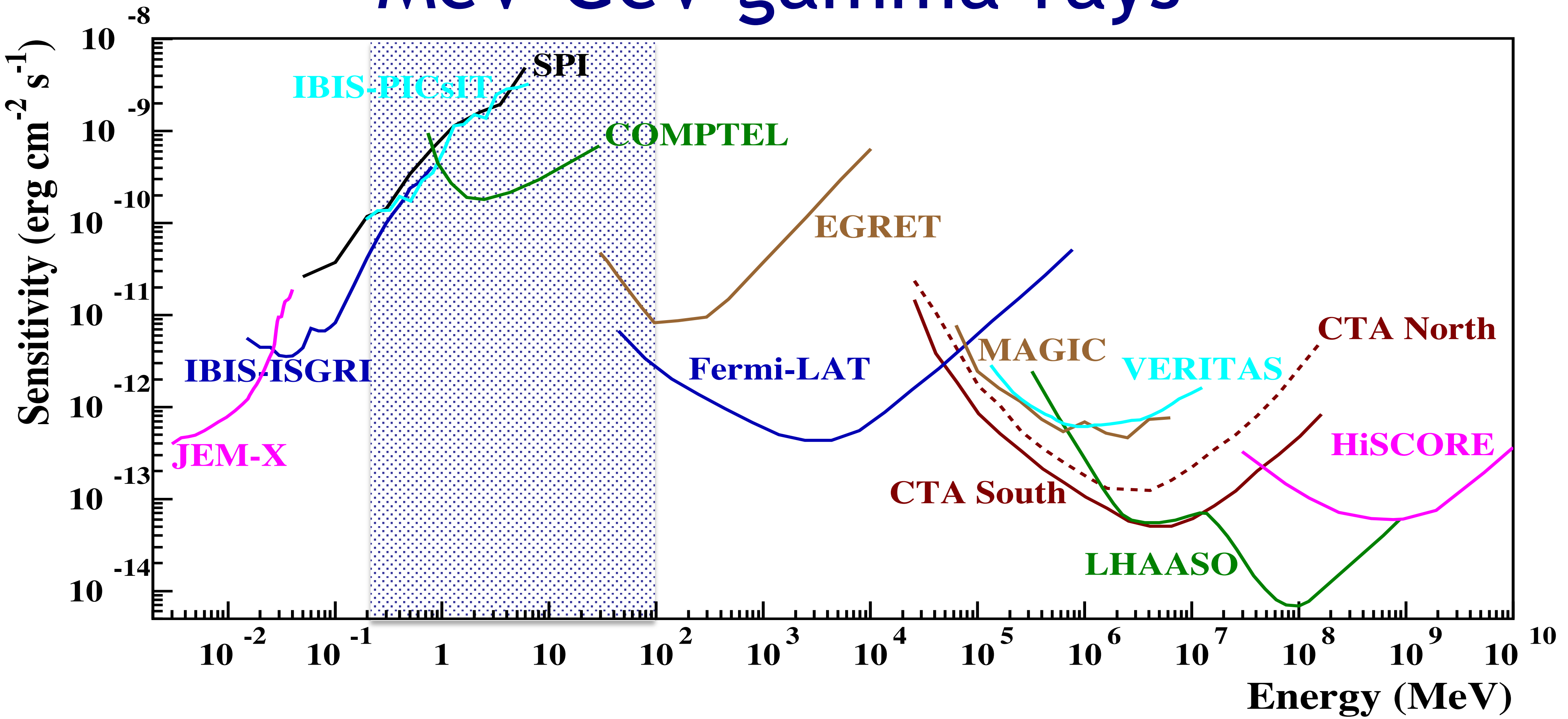
large effective area
(large geometric area and large total conversion efficiency)

large field of view

Sensitivity of γ-ray detectors

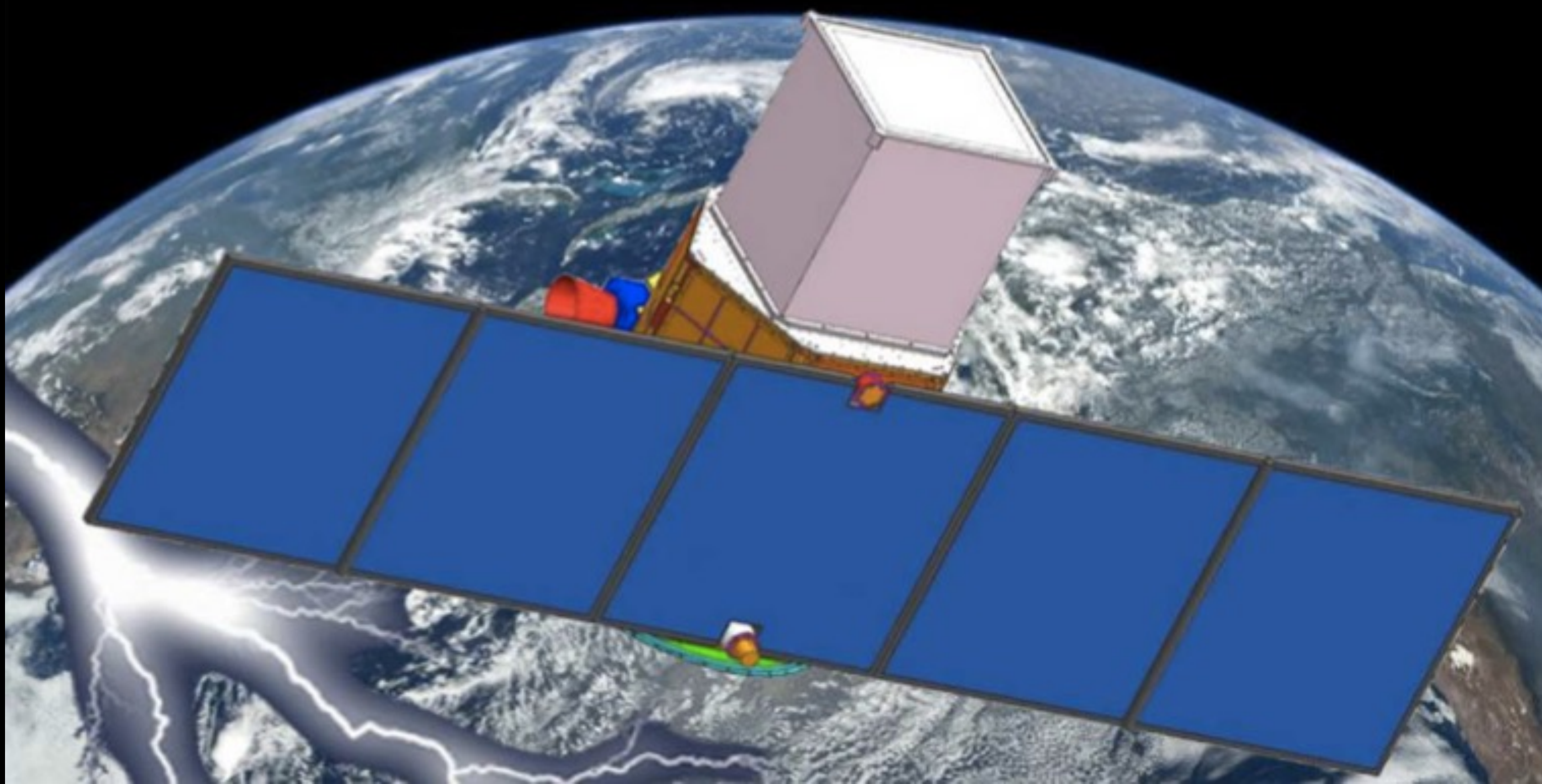


MeV-GeV gamma-rays



- 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)

Gamma-Light



Gamma-light scheme

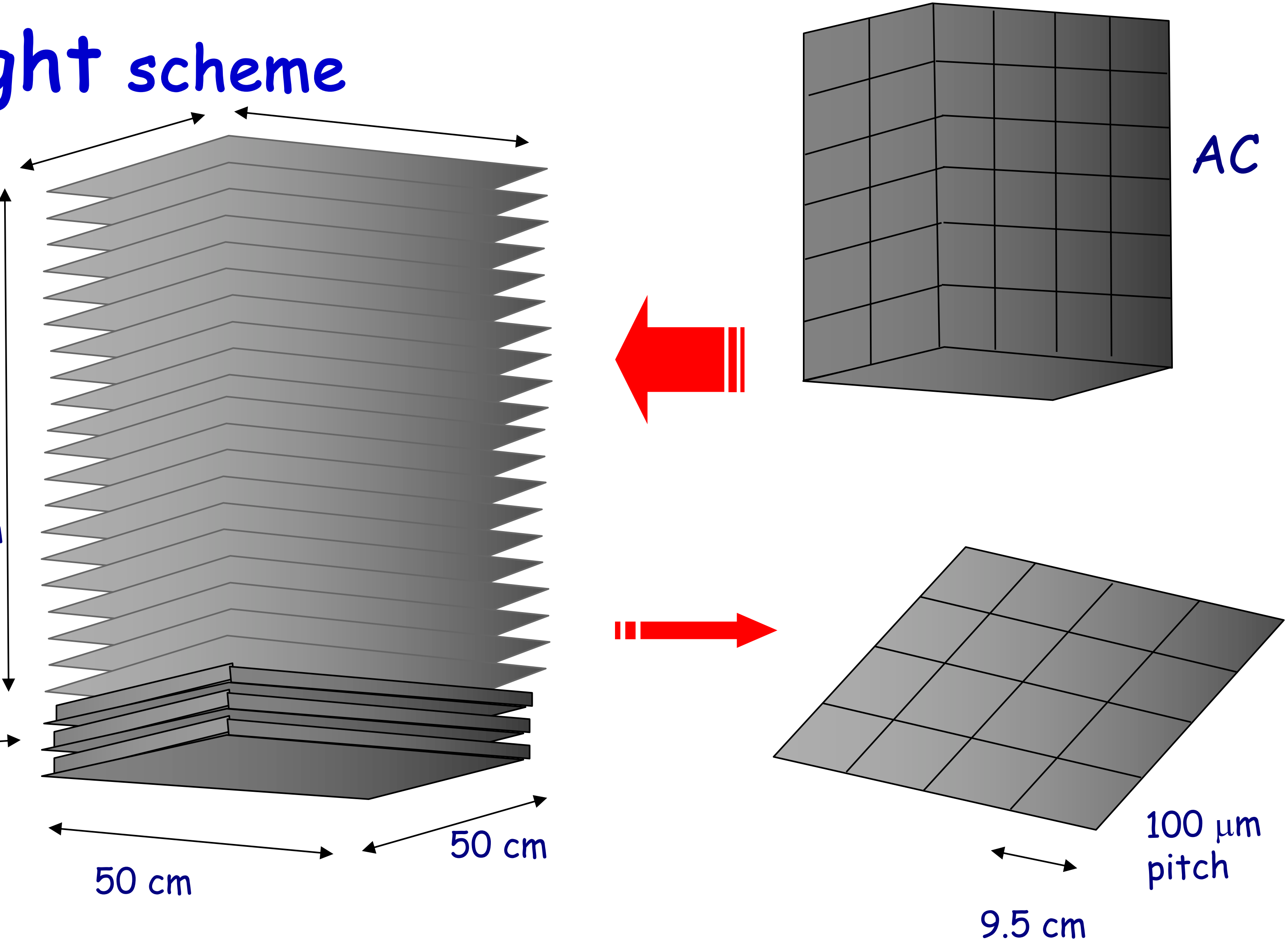
40+1 x-y planes
100 μm pitch
each
~0.025 X_0

Tot~ 1 X_0

54.7 cm

height of a plane 1.3 cm

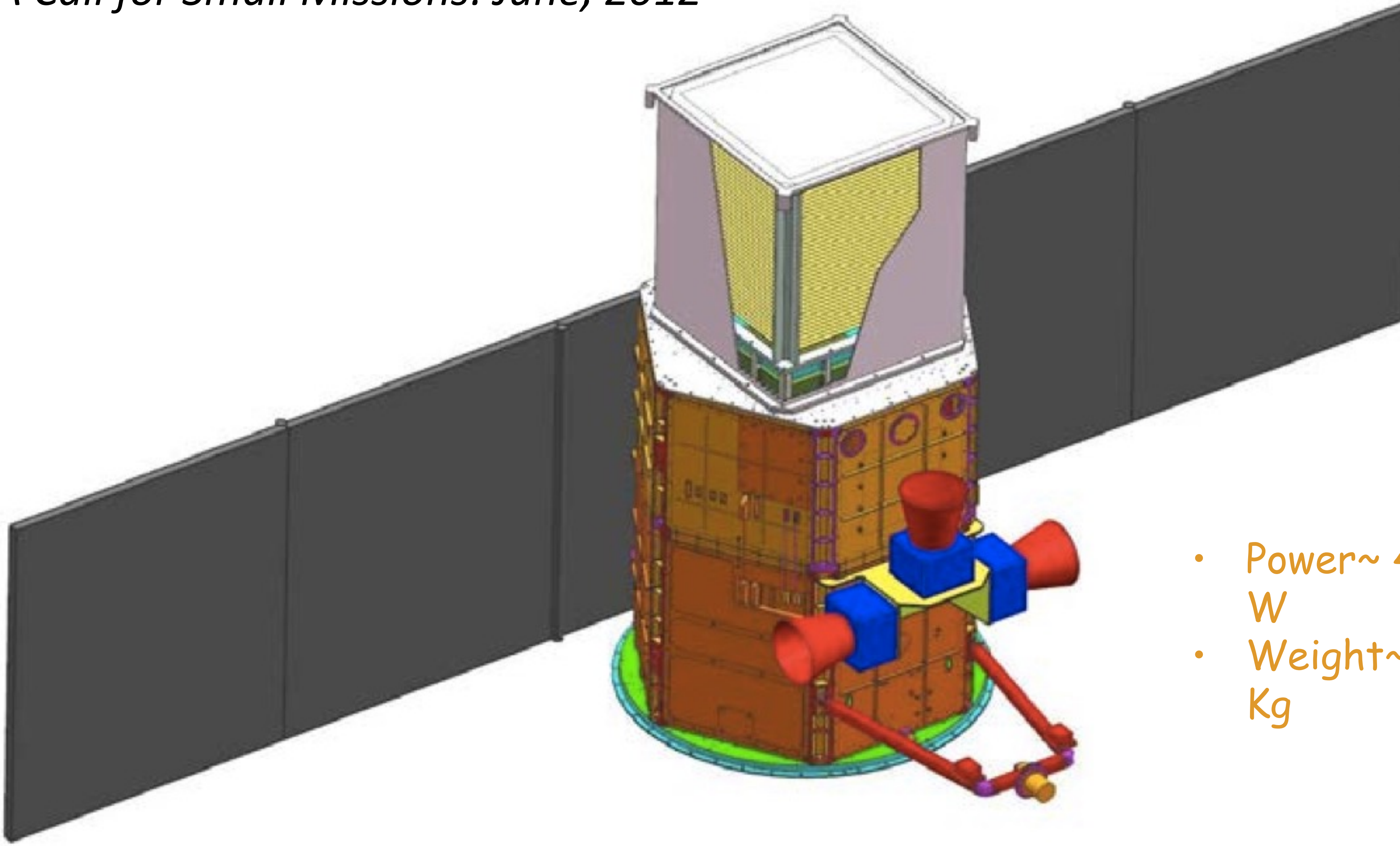
2 Xo Calorimiter



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

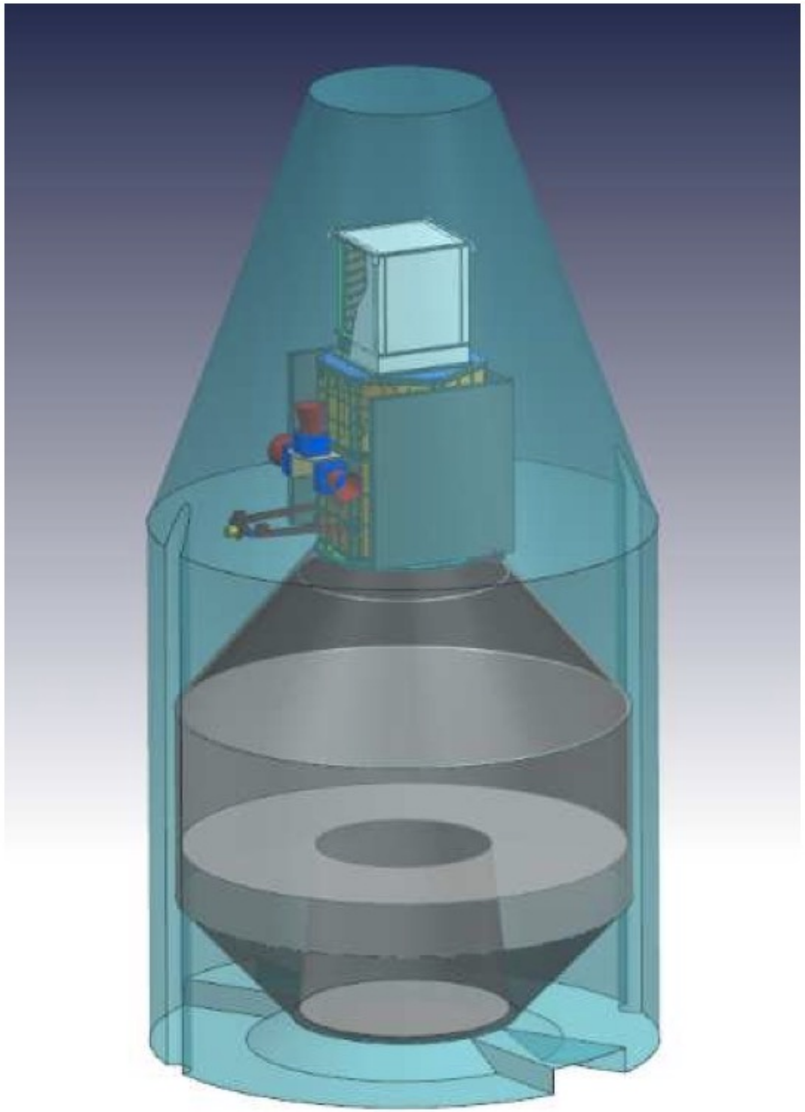
Gamma-light payload

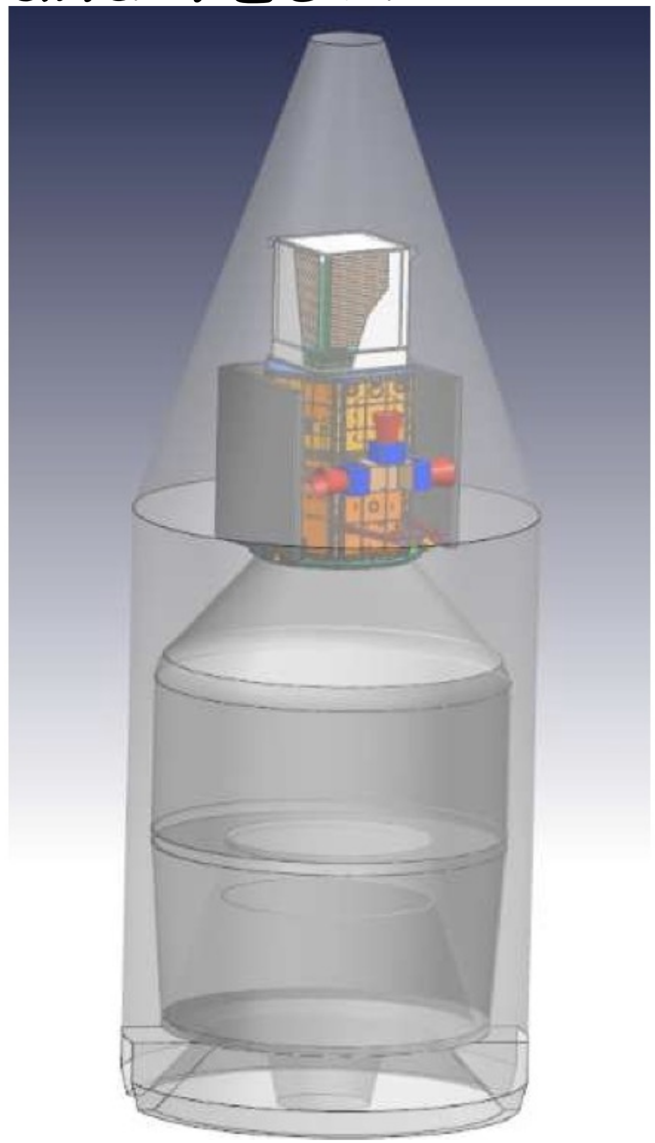
ESA Call for Small Missions: June, 2012



- Power~ 400 W
- Weight~600 Kg

GAMMA-LIGHT satellite launch configurations for the PSLV and VEGA

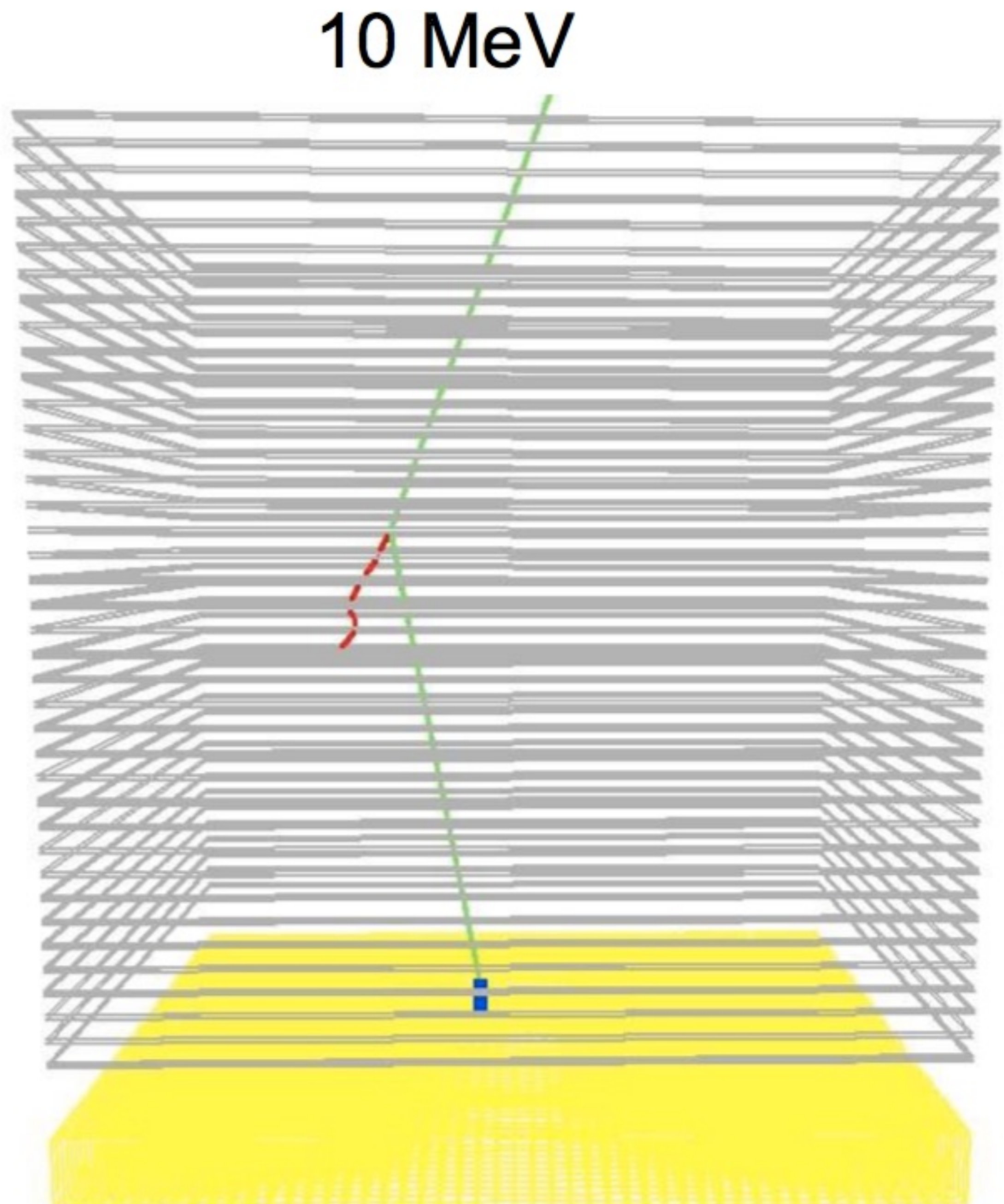




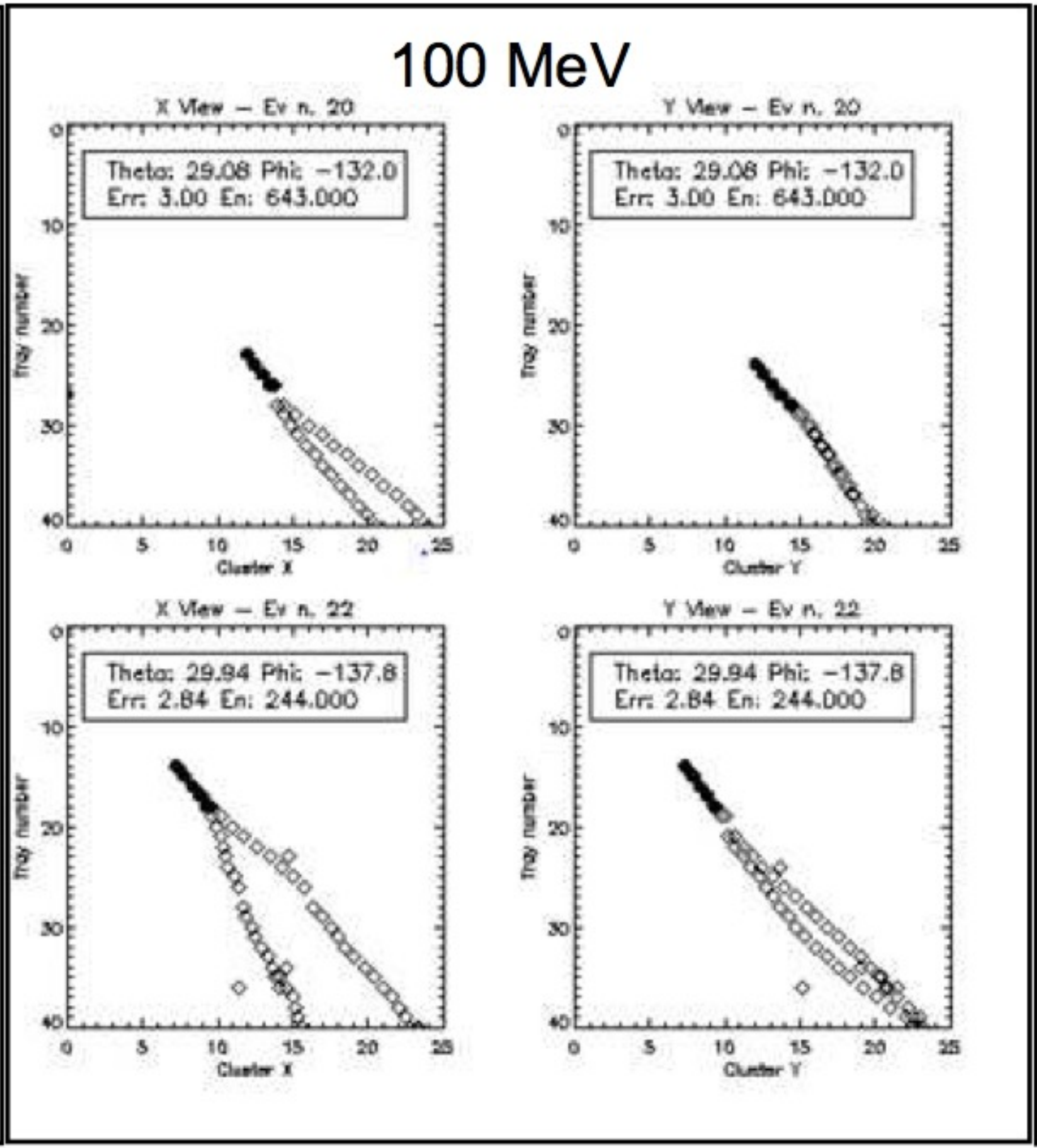
- a companion satellite similar to G-LIGHT can be accomodated.

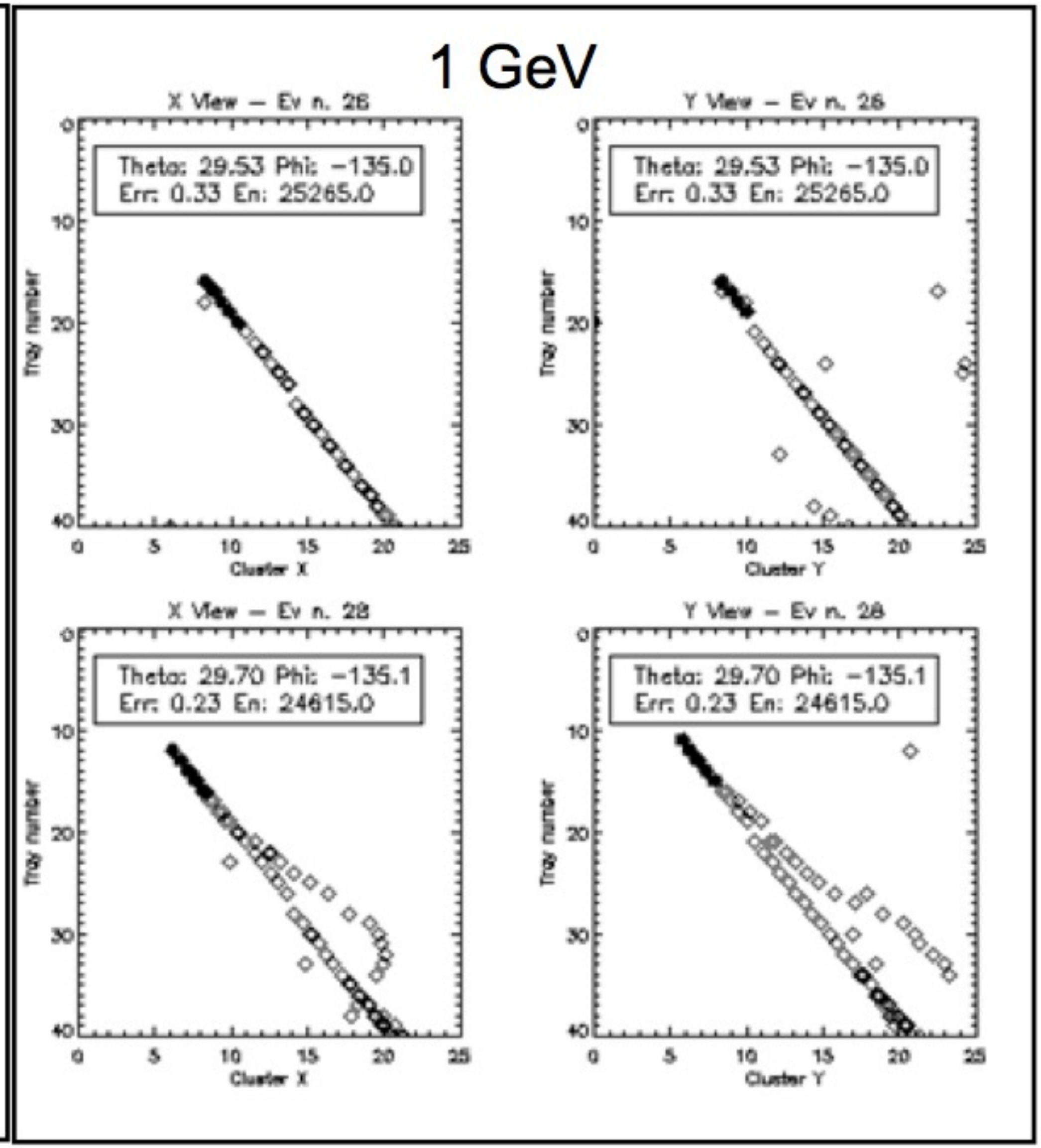
G-LIGHT Simulation

- 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

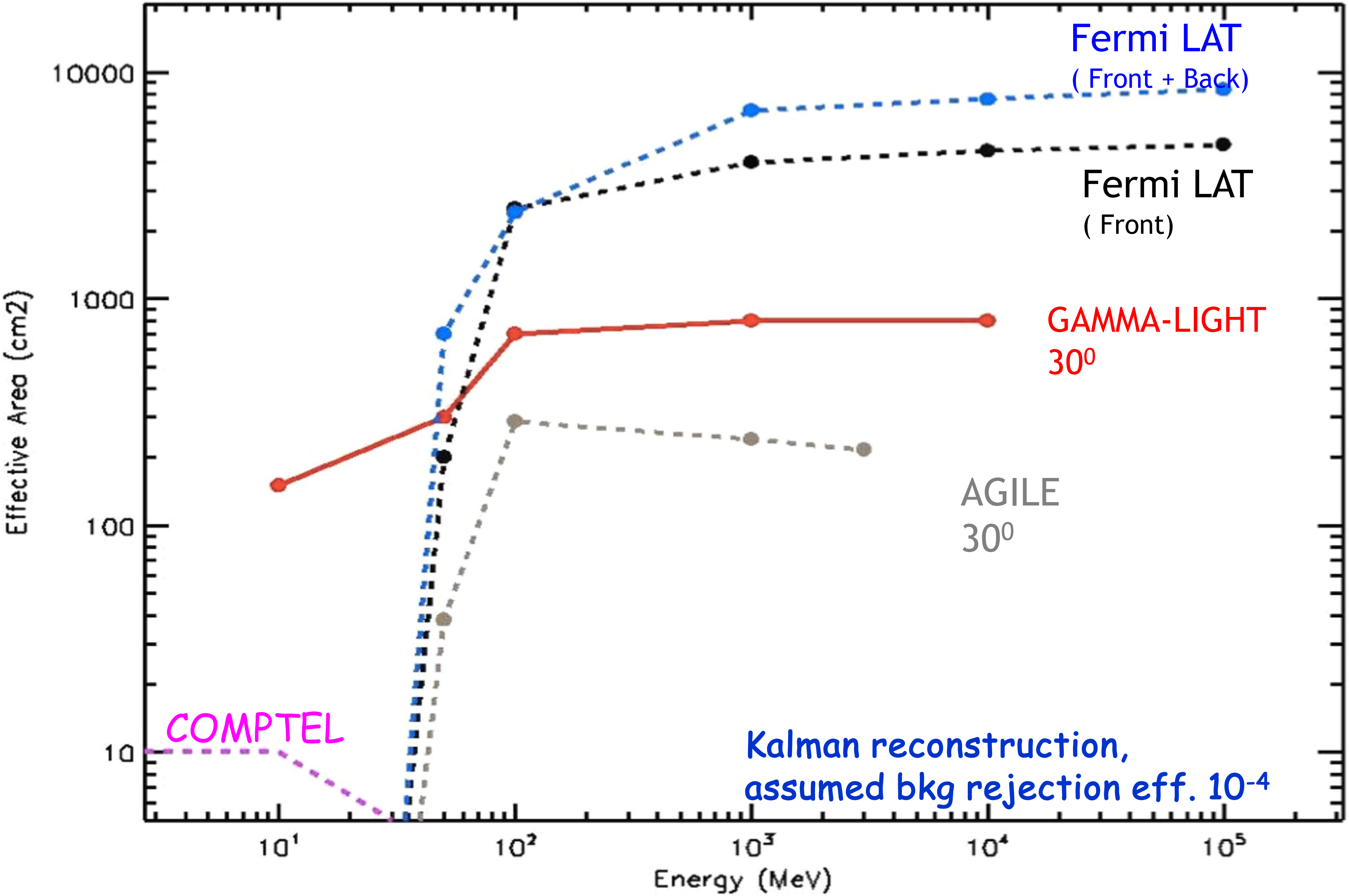


Gamma-light *Simulation*



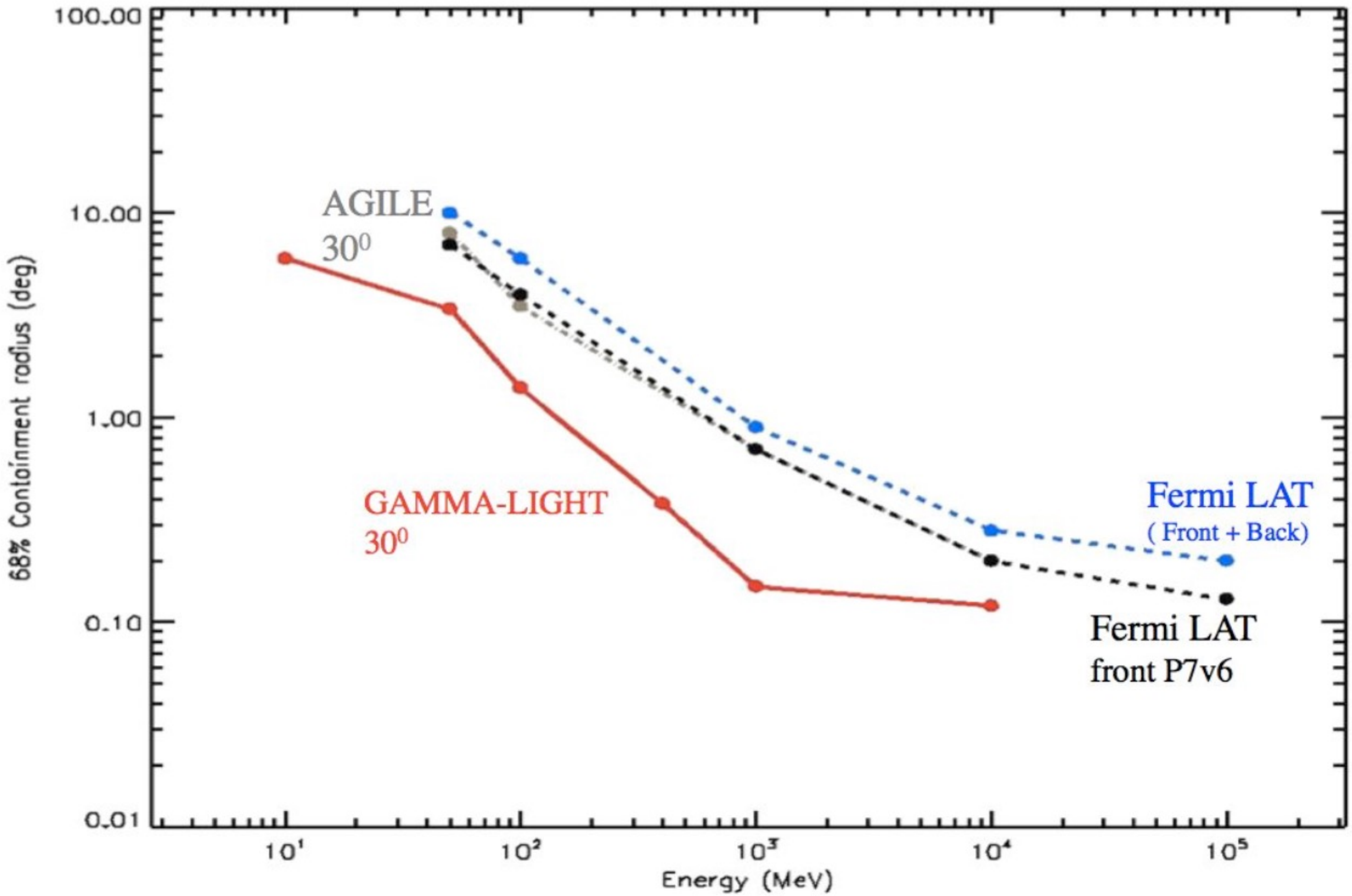


Effective area



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

PSF (68% containment radius)



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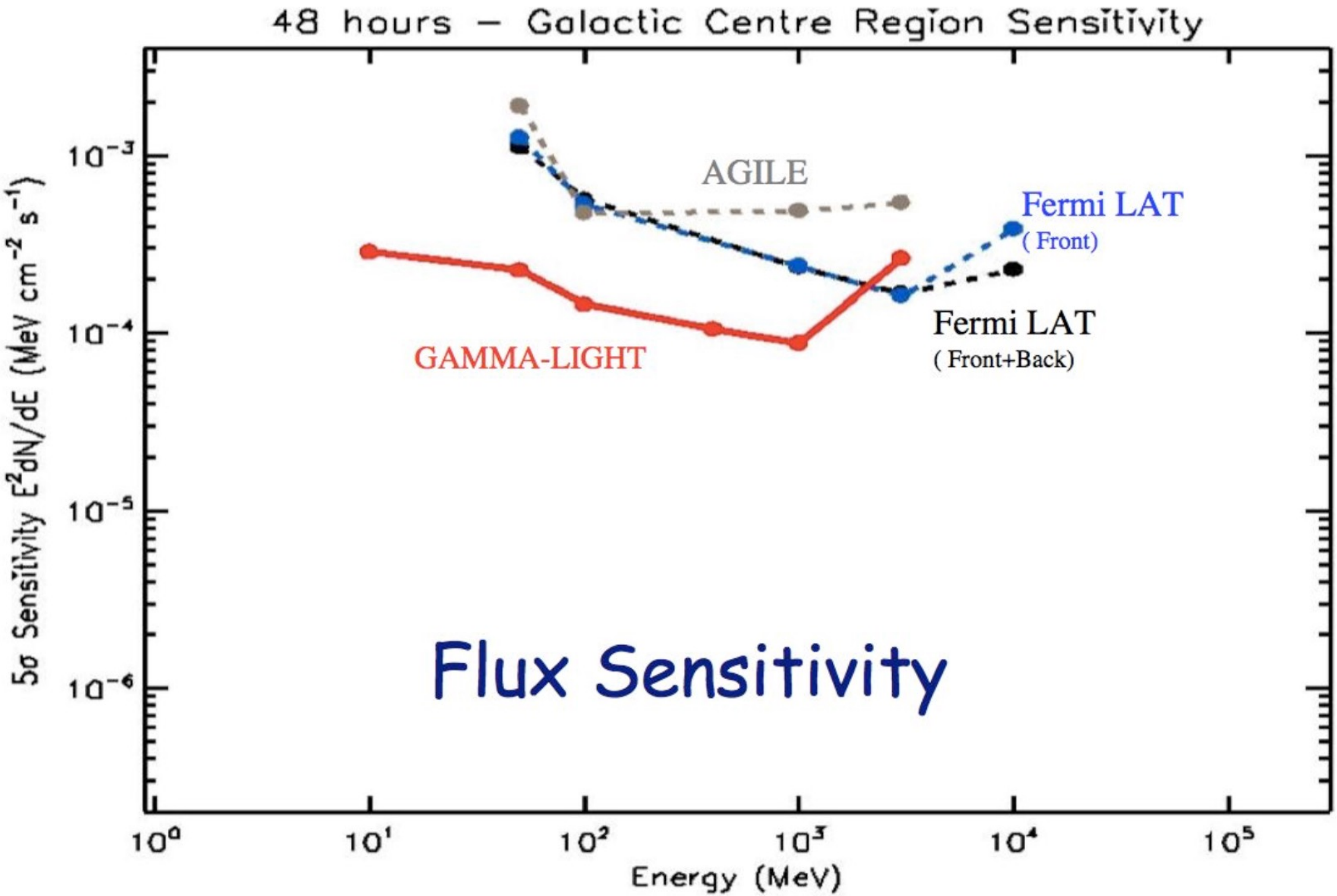
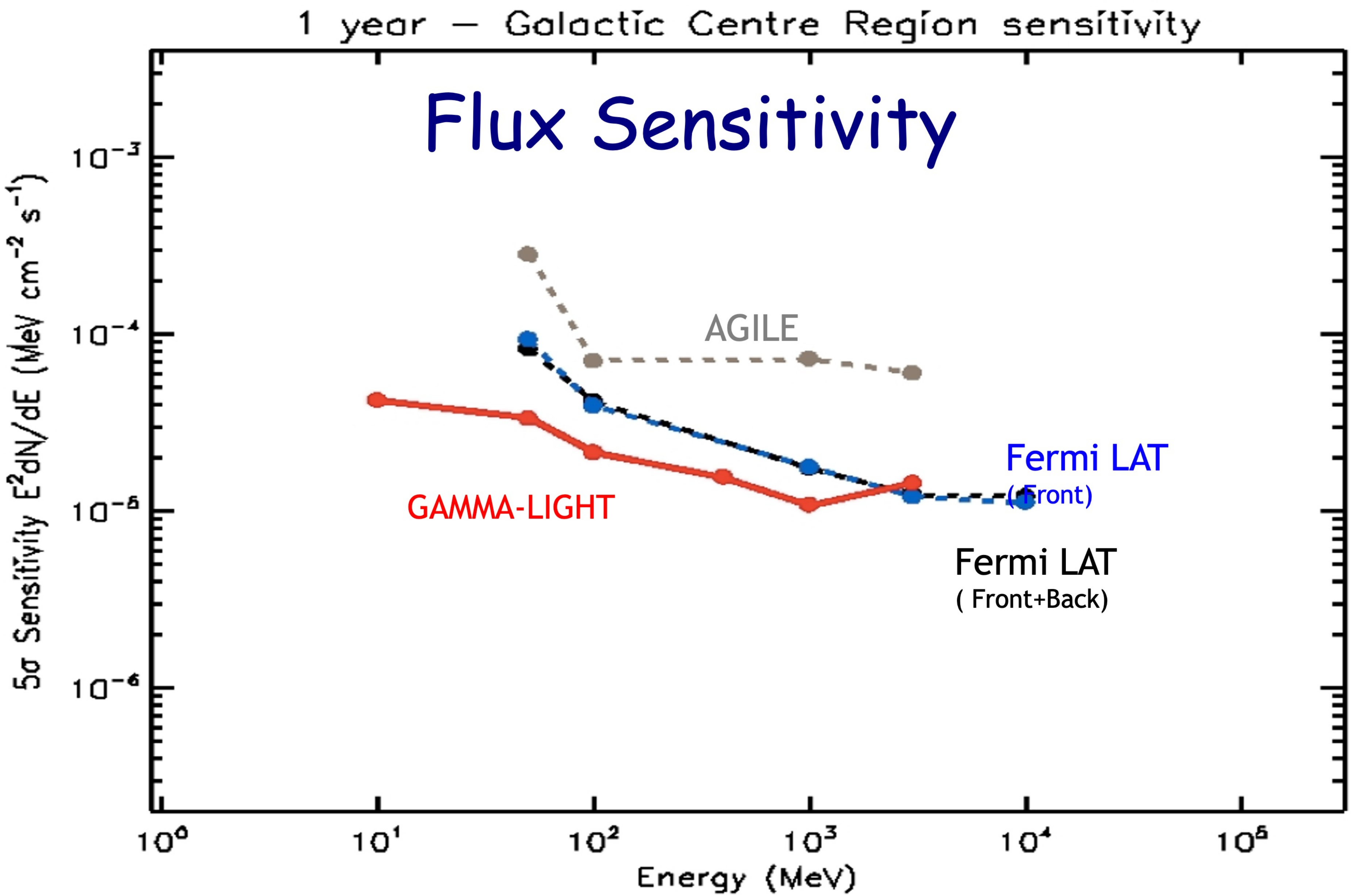


A.Morselli et al. Nuclear Physics B 239–240 (2013) 193-198 [arXiv:1406.1071]

Flux Sensitivity



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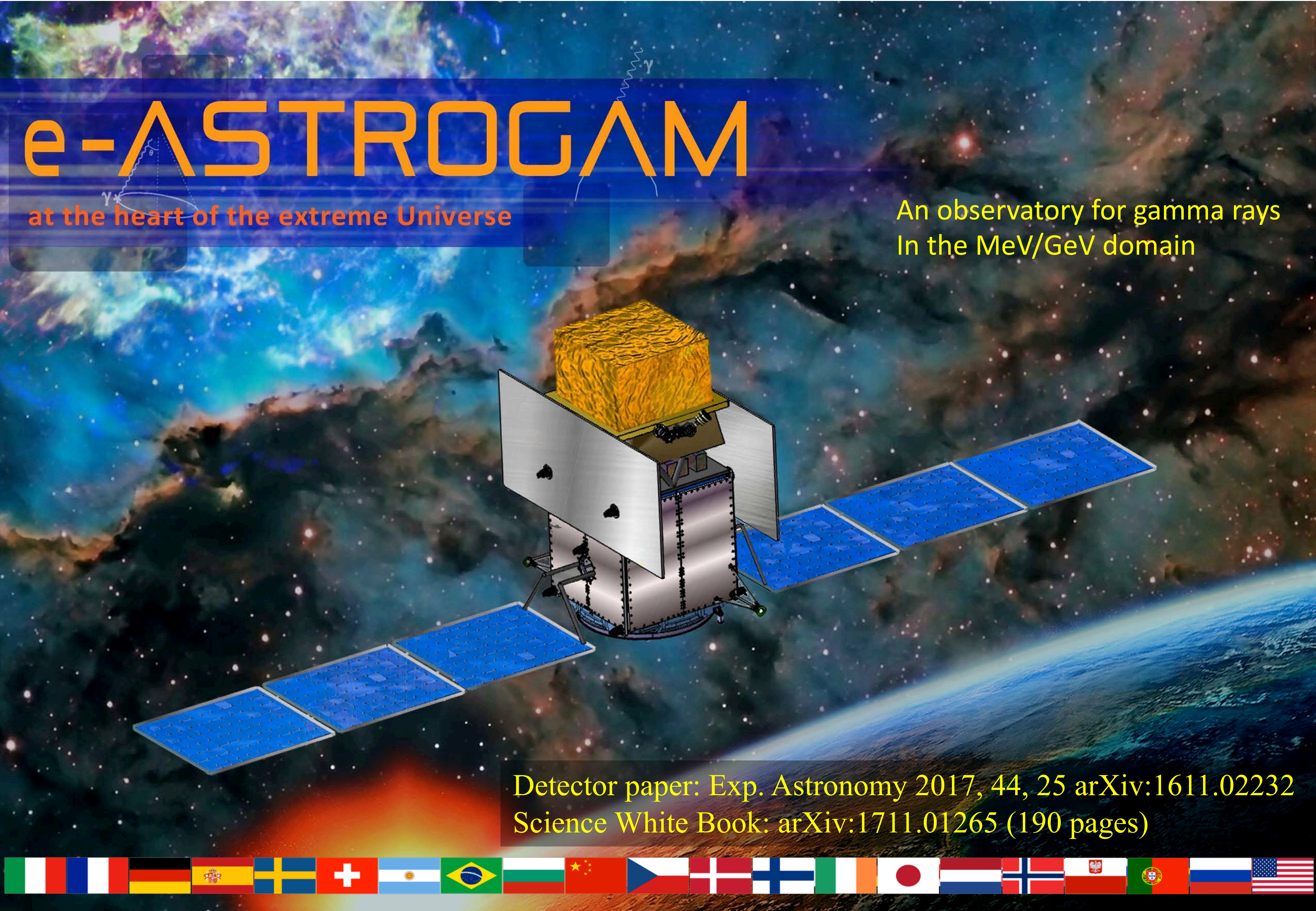
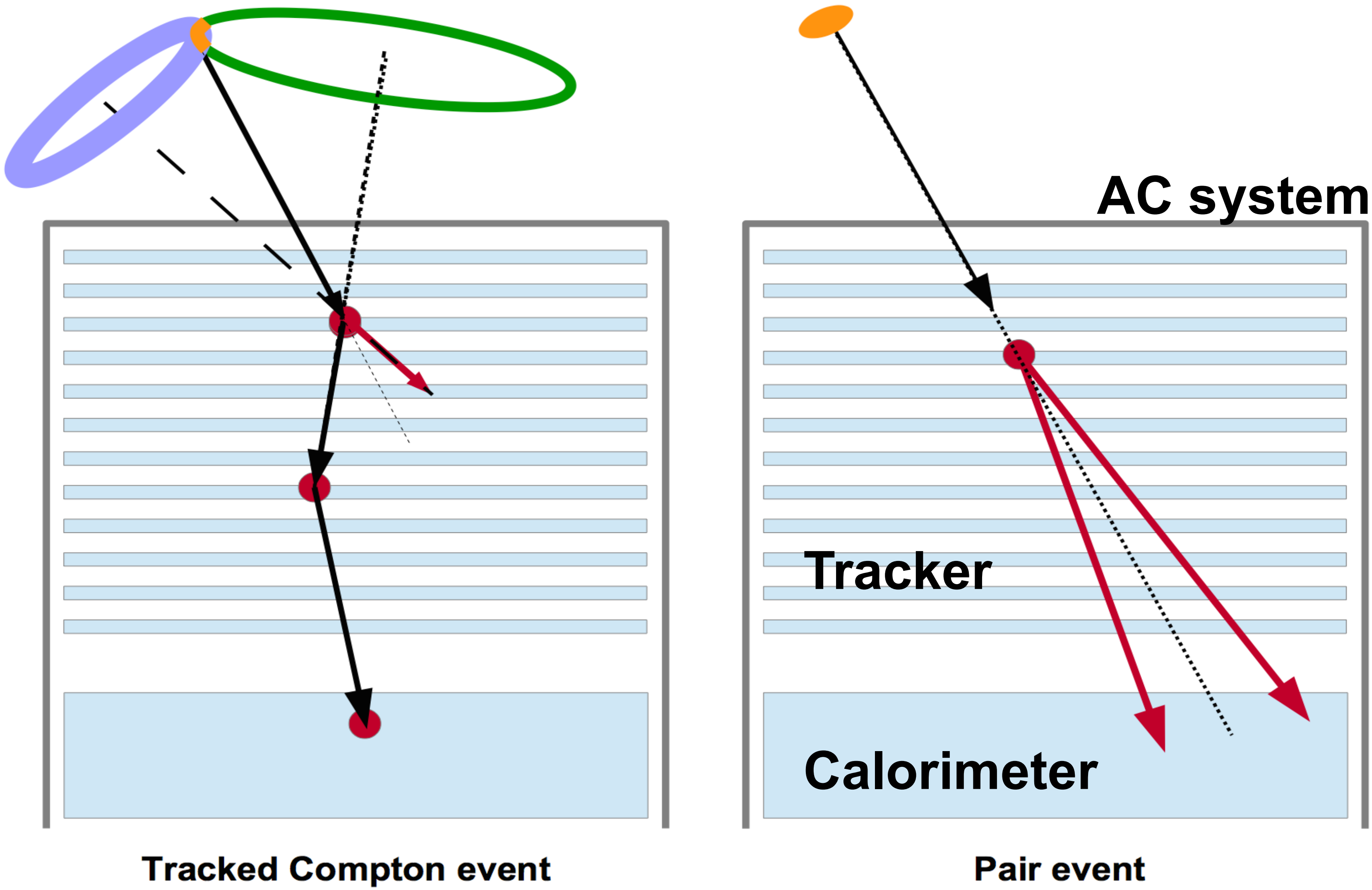
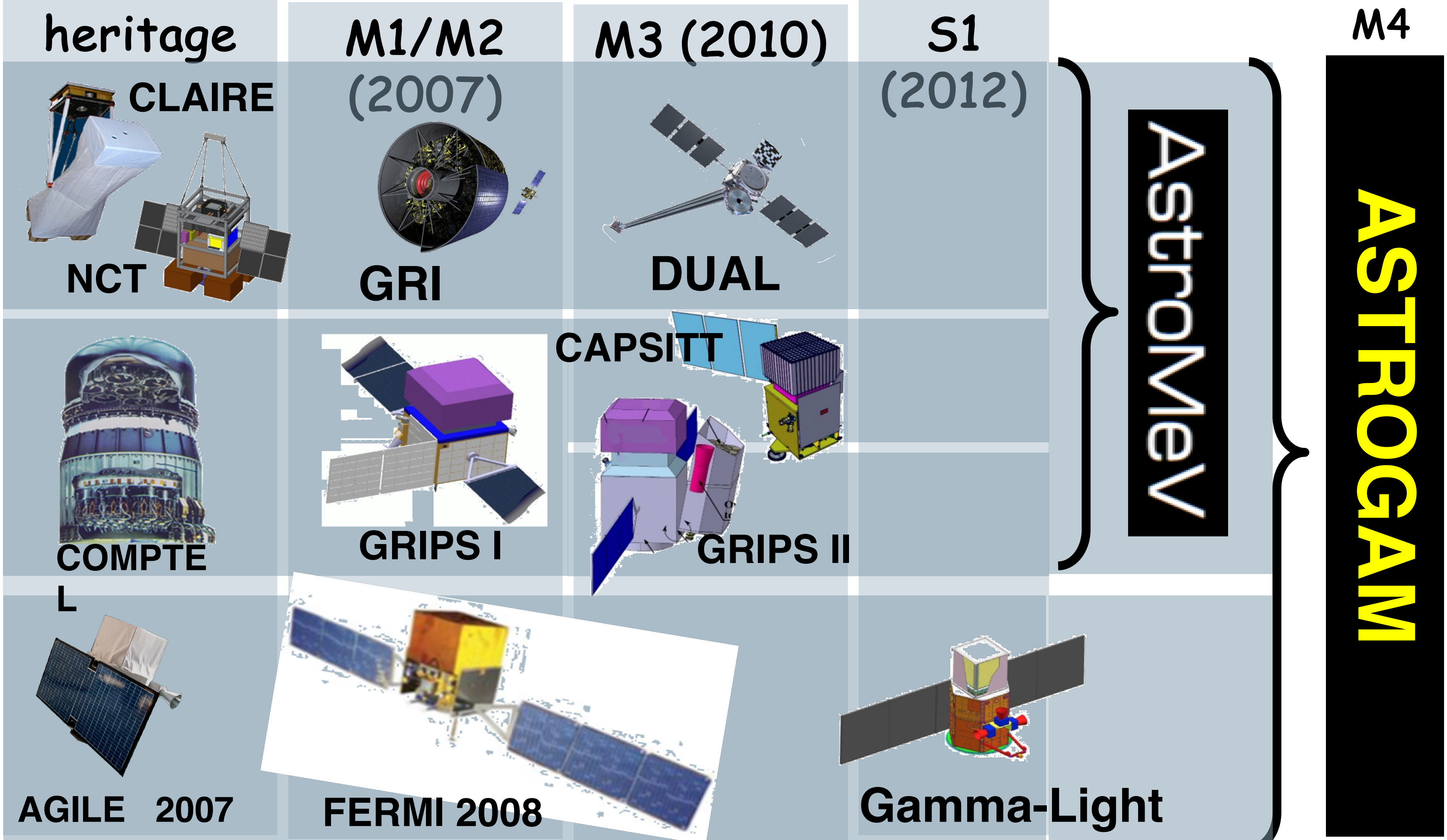

e-ASTROGAM
at the heart of the extreme Universe
An observatory for gamma rays
In the MeV/GeV domain
Detector paper: Exp. Astronomy 2017, 44, 25 arXiv:1611.02232
Science White Book: arXiv:1711.01265 (190 pages)

An instrument that combine two detection techniques

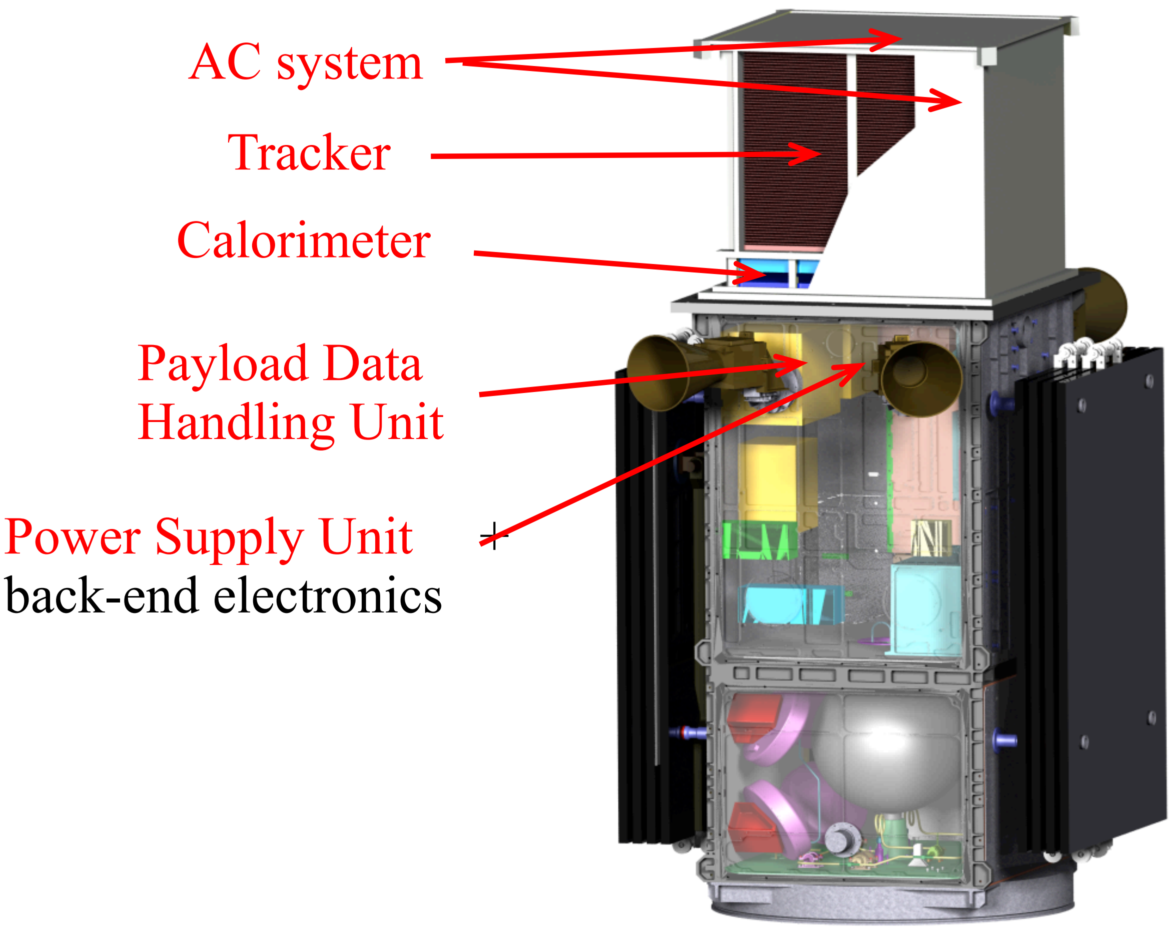


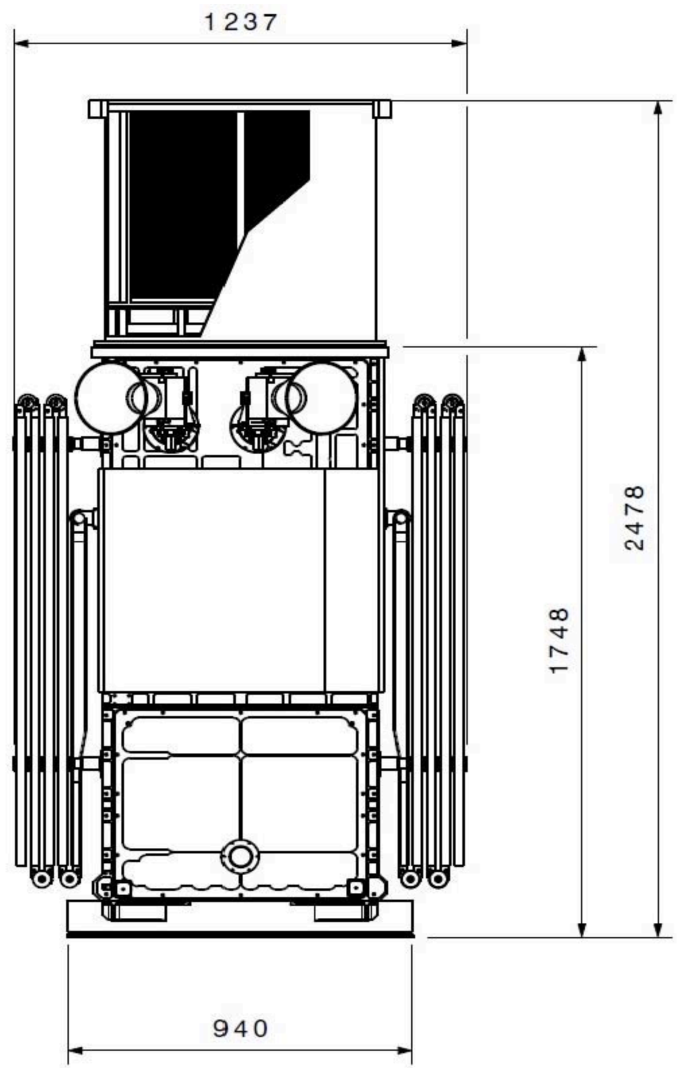
ASTROGAM a unified proposal from the entire gamma-ray community



ASTROGAM Payload

- **ESA guidelines for the M4 Call interpreted at face value ⇒ ASTROGAM payload (single instrument) designed to be 300 kg**



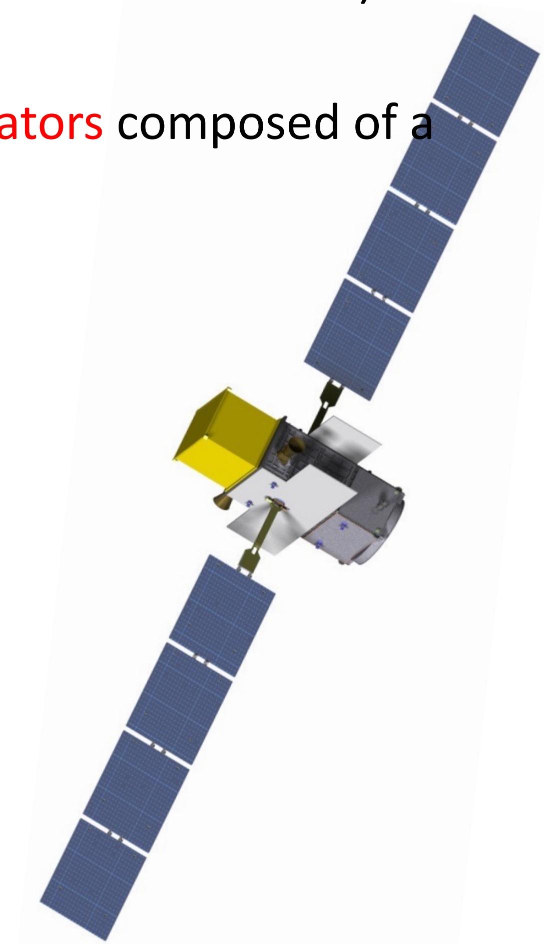


ASTROGAM Spacecraft

- Platform SB 500 developed by OHB CGS S.p.A. (heritage: AGILE, PRISMA)
- 3-axis stabilized (4 reaction wheels), pointing accuracy (± 1°), stability (0.01° /s) and altitude knowledge (1 arcmin) from standard class sensors and actuators
- Deployable and steerable solar panels of ~ 9.5 m^2 (required power at EoL ~ 1900 W) + Li-Ion rechargeable battery (BoL capacity of 110 Ah)
- Thermal control system (P/L detectors < 0° C) comprising two radiators composed of a fixed and a deployable part, for a total radiative area of ~3 m^2
- Precise timing of the P/L data (1 μs at 3σ) obtained with a GPS unit

	Predicted Mass [kg]	Predicted mass + maturity margin [kg]
PLATFORM	**430.9***	**484.1***
PAYLOAD	**262.7**	**301.4**
SATELLITE DRY MASS	**625.6**	**717.6**
System margin 20%		143.5
SATELLITE DRY MASS WITH SYSTEM MARGIN		**861.1**
SATELLITE MASS AT LAUNCH (WET MASS)		**929.1**

* Including 68 kg of hydrazine for collision avoidance (6 kg) and direct re-entry (62 kg)



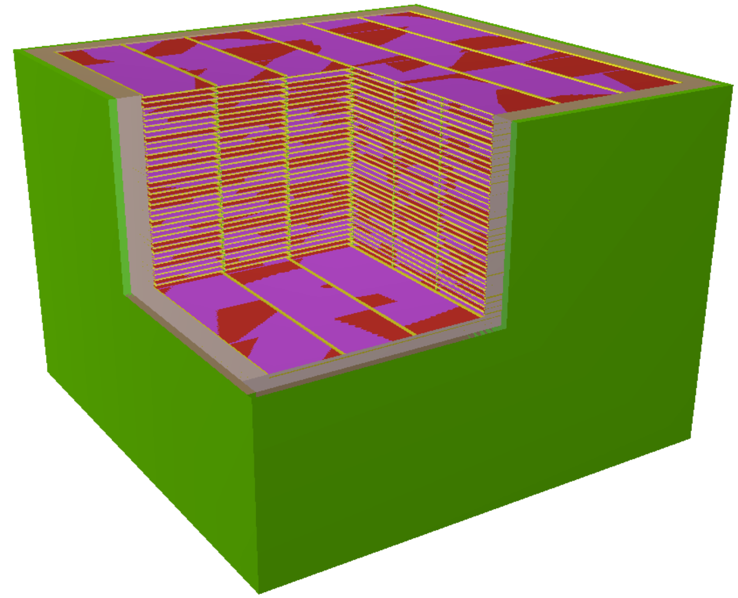
ASTROGAM Silicon Tracker

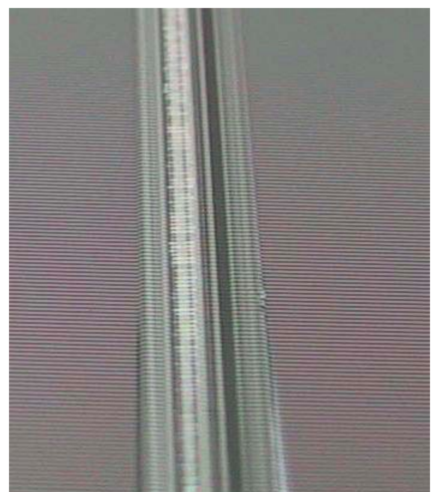
- 70 layers of 6 × 6 double sided Si strip detectors = 2520 DSSDs
- Each DSSD has a total area of 9.5 × 9.5 cm^2, a thickness of 400 μm, a strip width of 100 μm and pitch of 240 μm (384 strips per side), and a guard ring of 1.5 mm
- Spacing of the Si layers: 7.5 mm
- The DSSDs are wire bonded strip to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

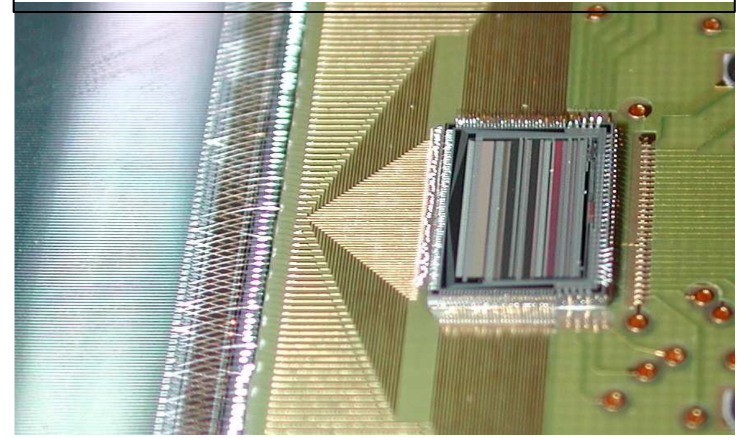
⇒ 10 080 ASICs total





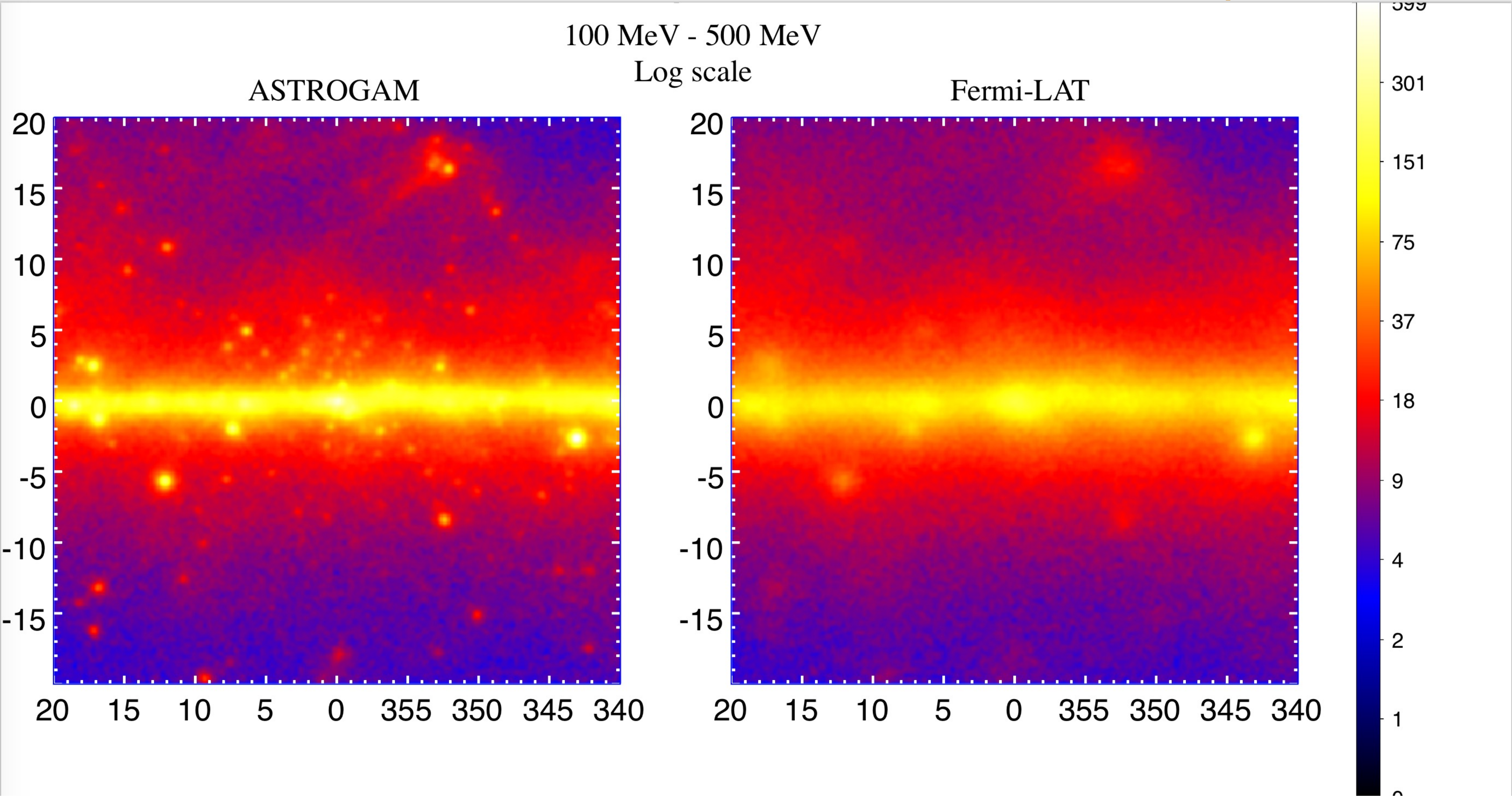
Si strip bounding in Fermi/LAT

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

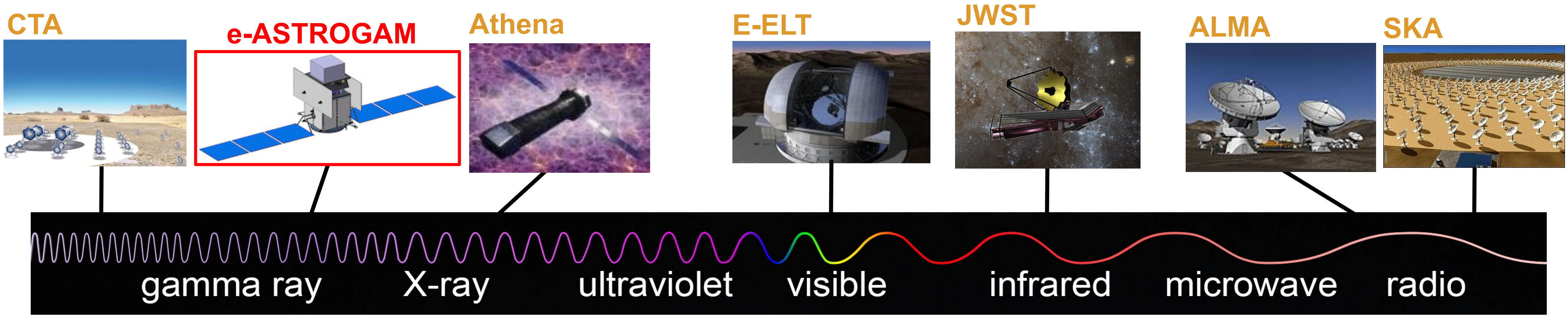


ASTROGAM view of the Galactic Center Region

100-500 MeV   Fermi PSF Pass7 rep v15 source

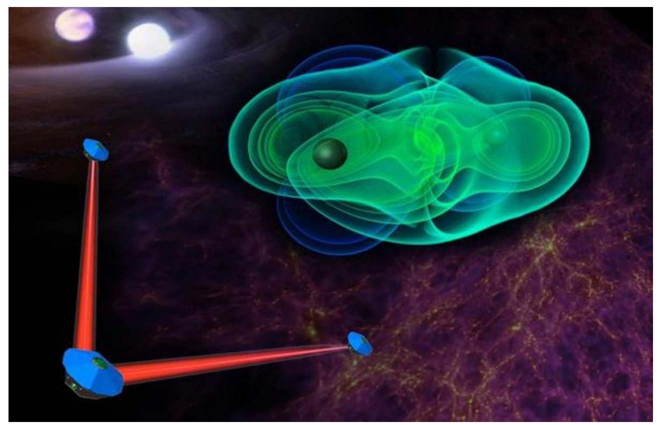


e-ASTROGAM: γ-ray astronomy in context

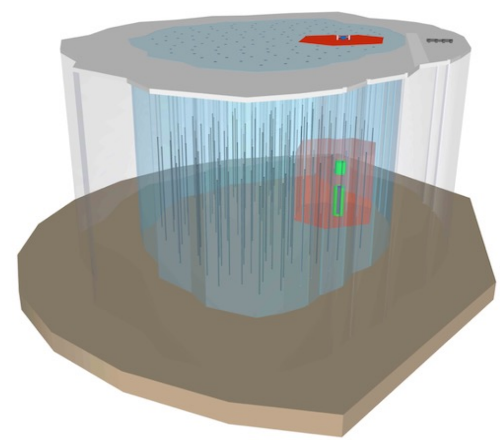


New Astronomies:
gravitational waves
neutrinos

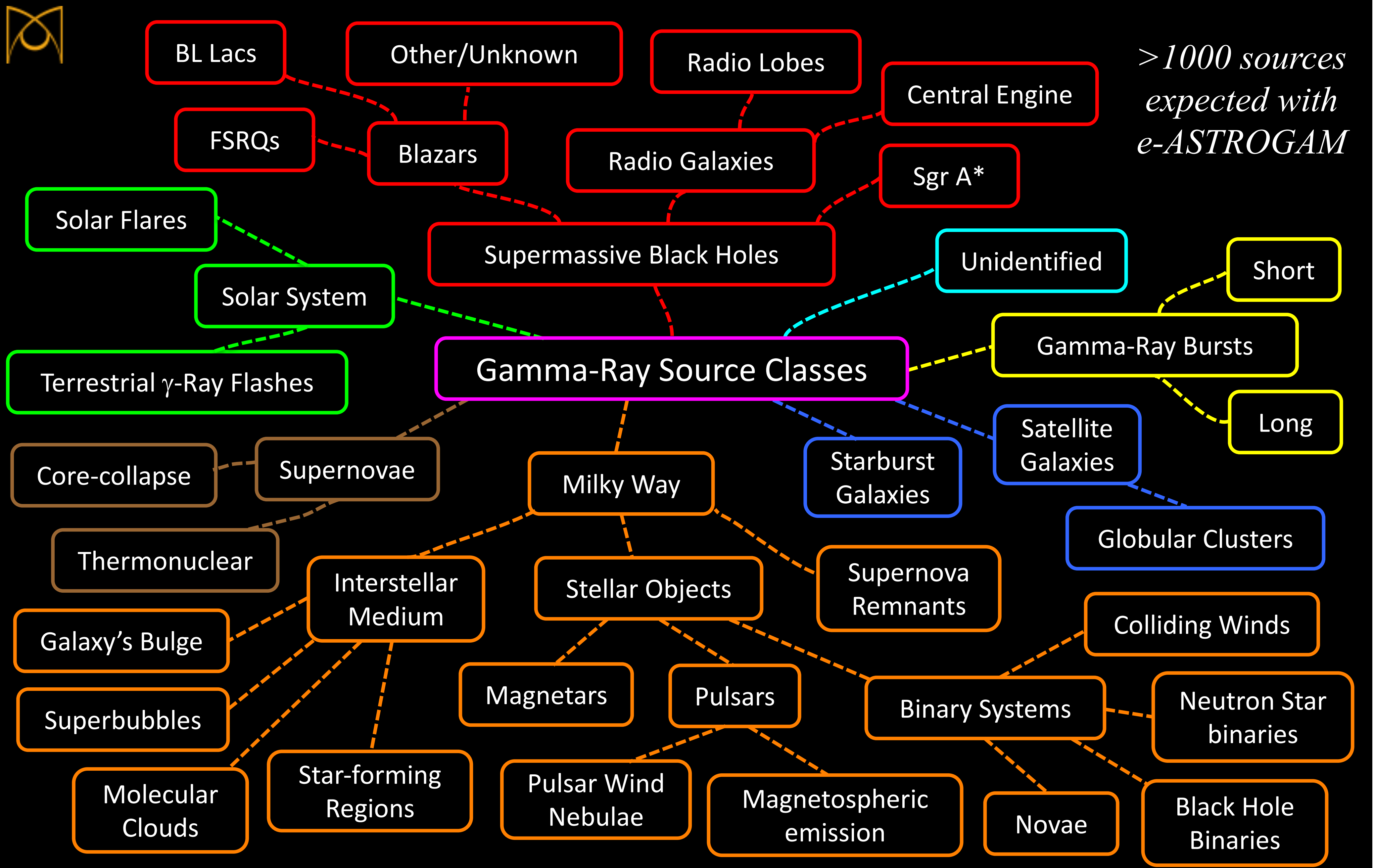
eLISA – Gravitational waves



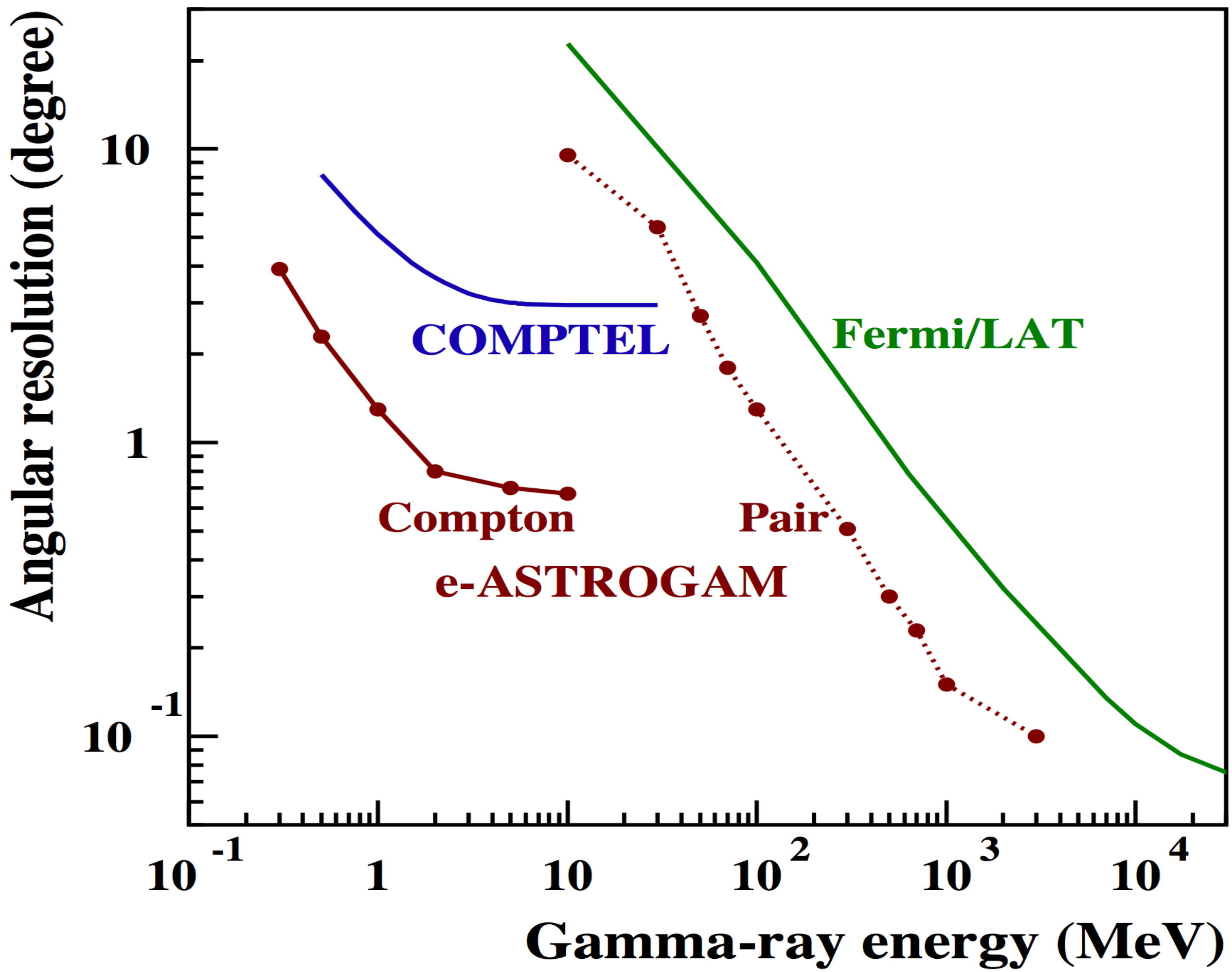
Km3Net/IceCube-Gen2 - ν



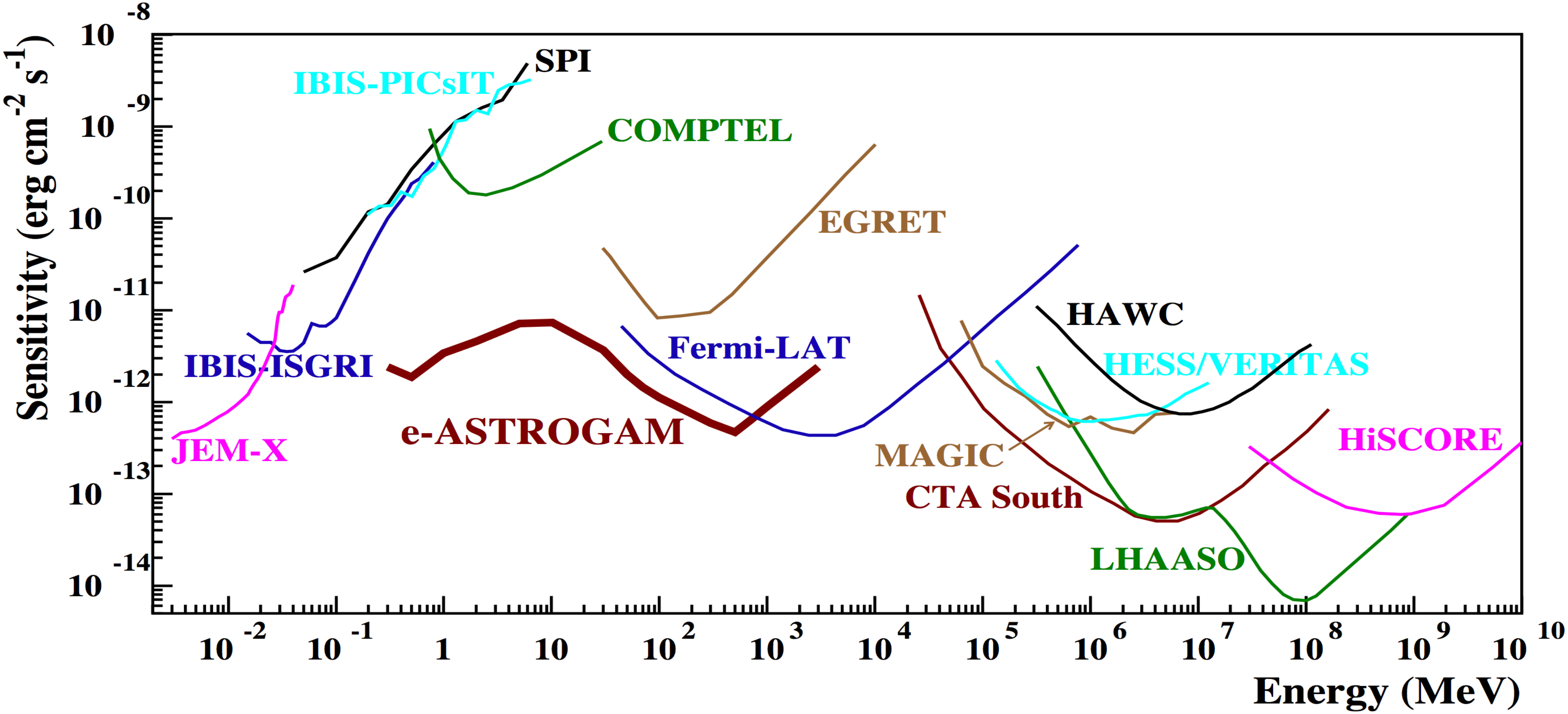
- e-ASTROGAM will be a sensitive, wide-field γ-ray space observatory operating at the same time as facilities like SKA and CTA, as well as eLISA and neutrino detectors, to get a coherent picture of the transient sky and the sources of gravitational waves and high-energy neutrinos

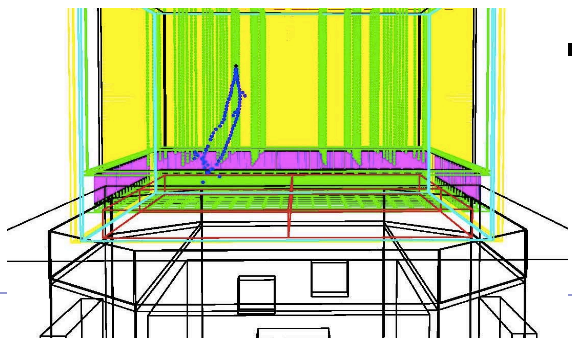

BL Lacs
Other/Unknown
Radio Lobes
Central Engine
>1000 sources expected with e-ASTROGAM
FSRQs
Blazars
Radio Galaxies
Sgr A*
Solar Flares
Supermassive Black Holes
Unidentified
Short
Solar System
Gamma-Ray Bursts
Terrestrial γ-Ray Flashes
Gamma-Ray Source Classes
Long
Satellite Galaxies
Core-collapse
Supernovae
Milky Way
Starburst Galaxies
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



Performance assessment





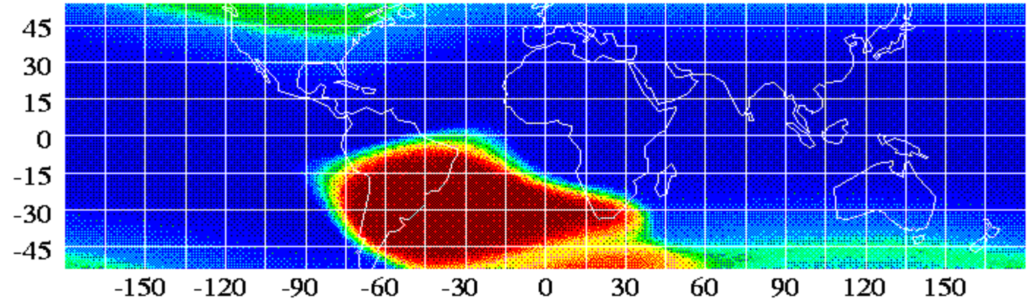
- e-ASTROGAM performance evaluated with **MEGAlib** and BoGem both tools based on Geant4 – and a detailed numerical mass model of the gamma-ray instrument

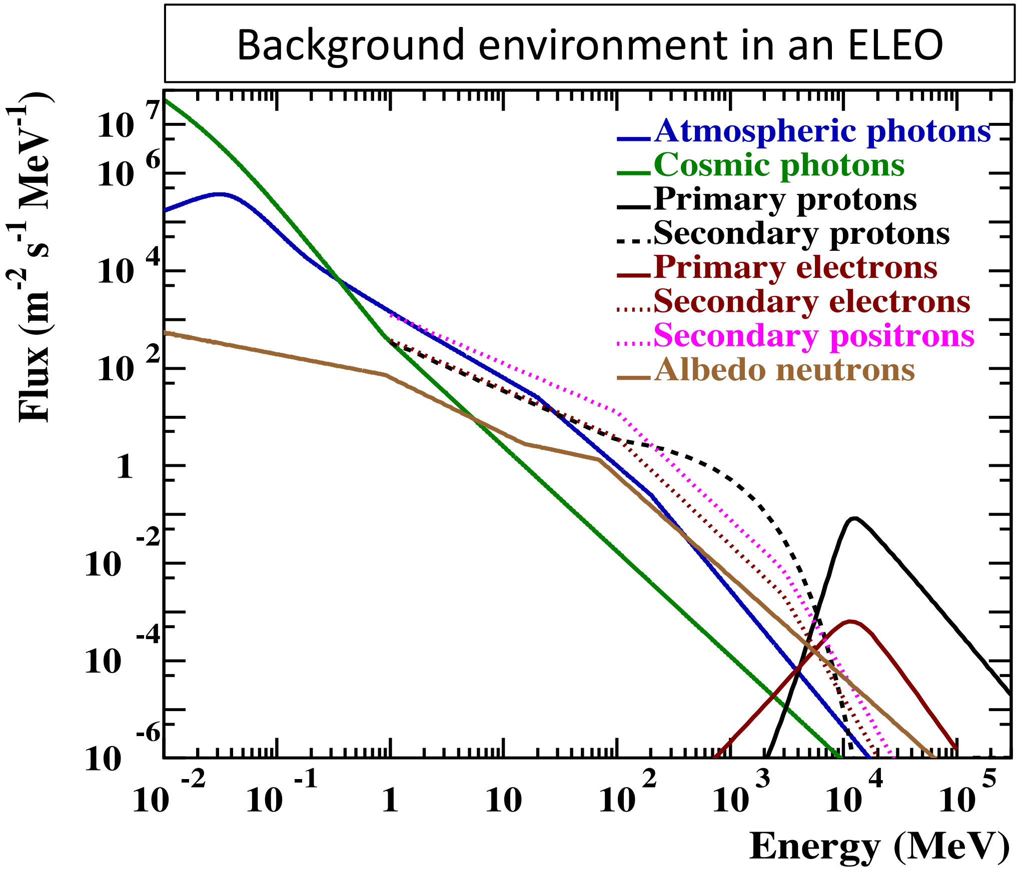
e-Astrogam: arXiv:1711.01265

103

e-ASTROGAM Mission profile

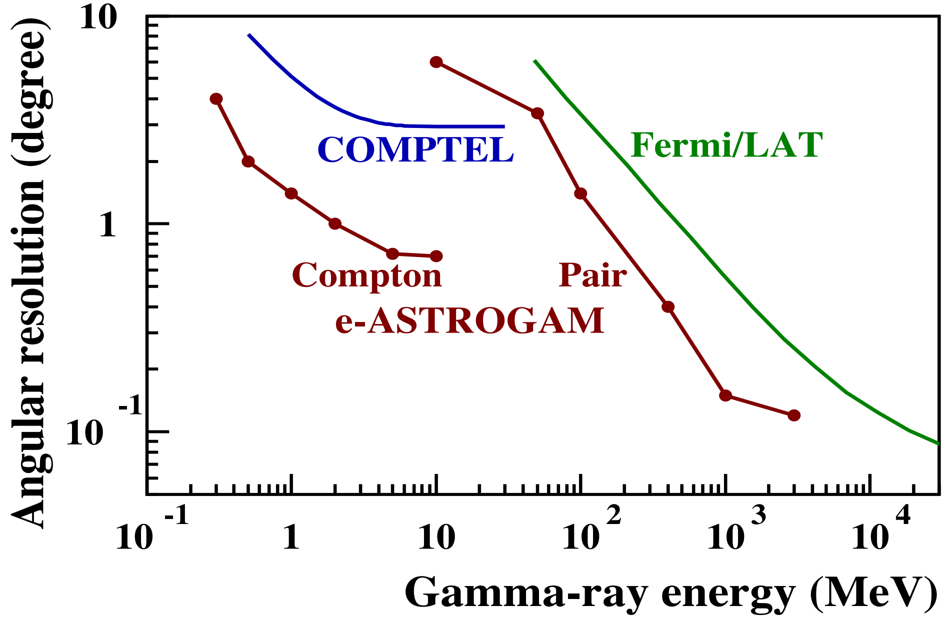
- **Orbit** – Equatorial (inclination $i < 2.5°$, eccentricity $e < 0.01$) low-Earth orbit (altitude in the range 550 - 600 km)
- **Launcher** – Ariane 6.2
- **Satellite communication** – ESA ground station at Kourou + ASI Malindi station (Kenya)
- **Data transmission** – via X-band (available downlink of 10 Mbps)
- **Observation modes** – (i) zenith-pointing sky-scanning mode, (ii) nearly inertial pointing, and (iii) fast repointing to avoid the Earth in the field of view
- **In-orbit operation** – 3 years duration + provisions for a 2+ year extension



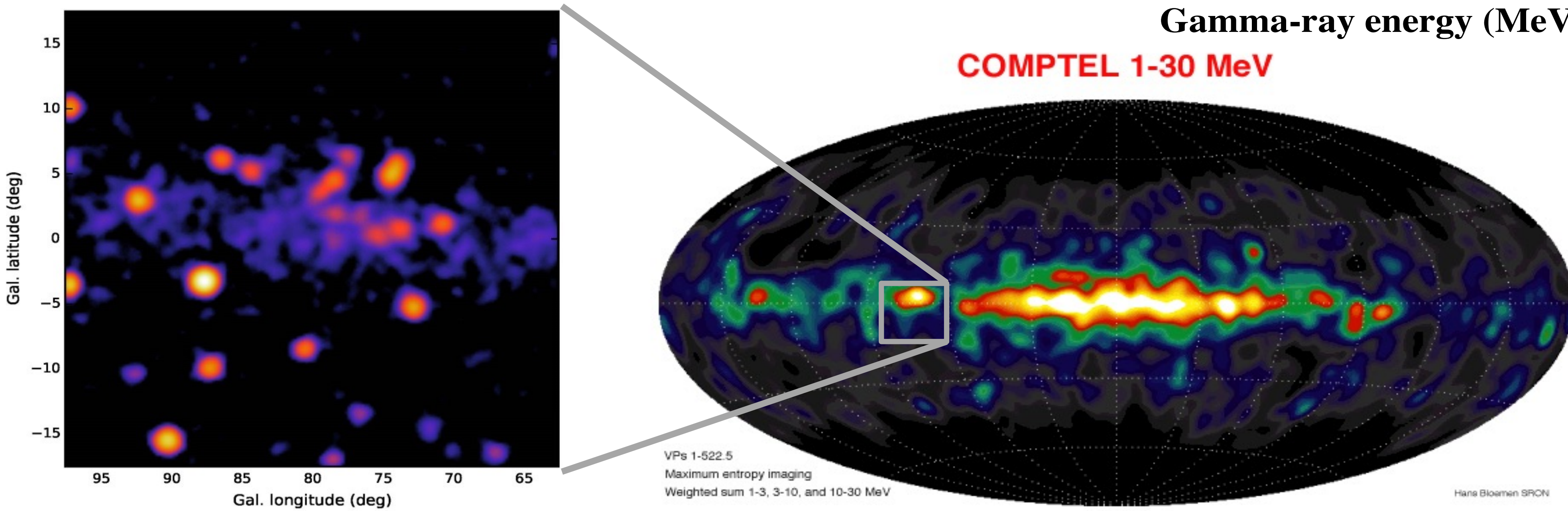


Angular resolution

- Angular resolution needs to be improved close to the physical limits (Doppler broadening, nuclear recoil)

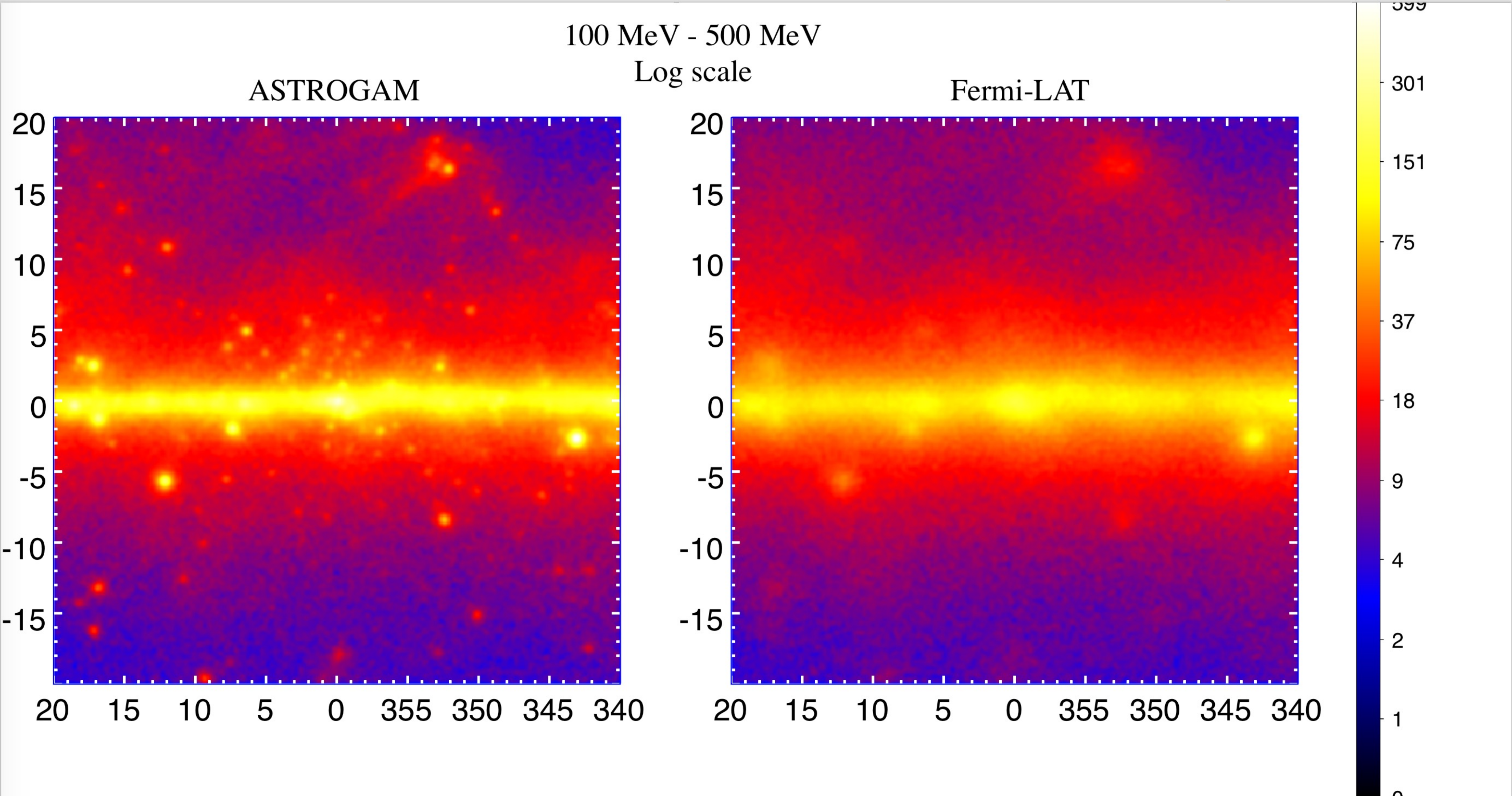


Cygnus region in the 1 - 3 MeV energy band with the e-ASTROGAM PSF (extrapolation of the 3FGL source spectra to low energies)



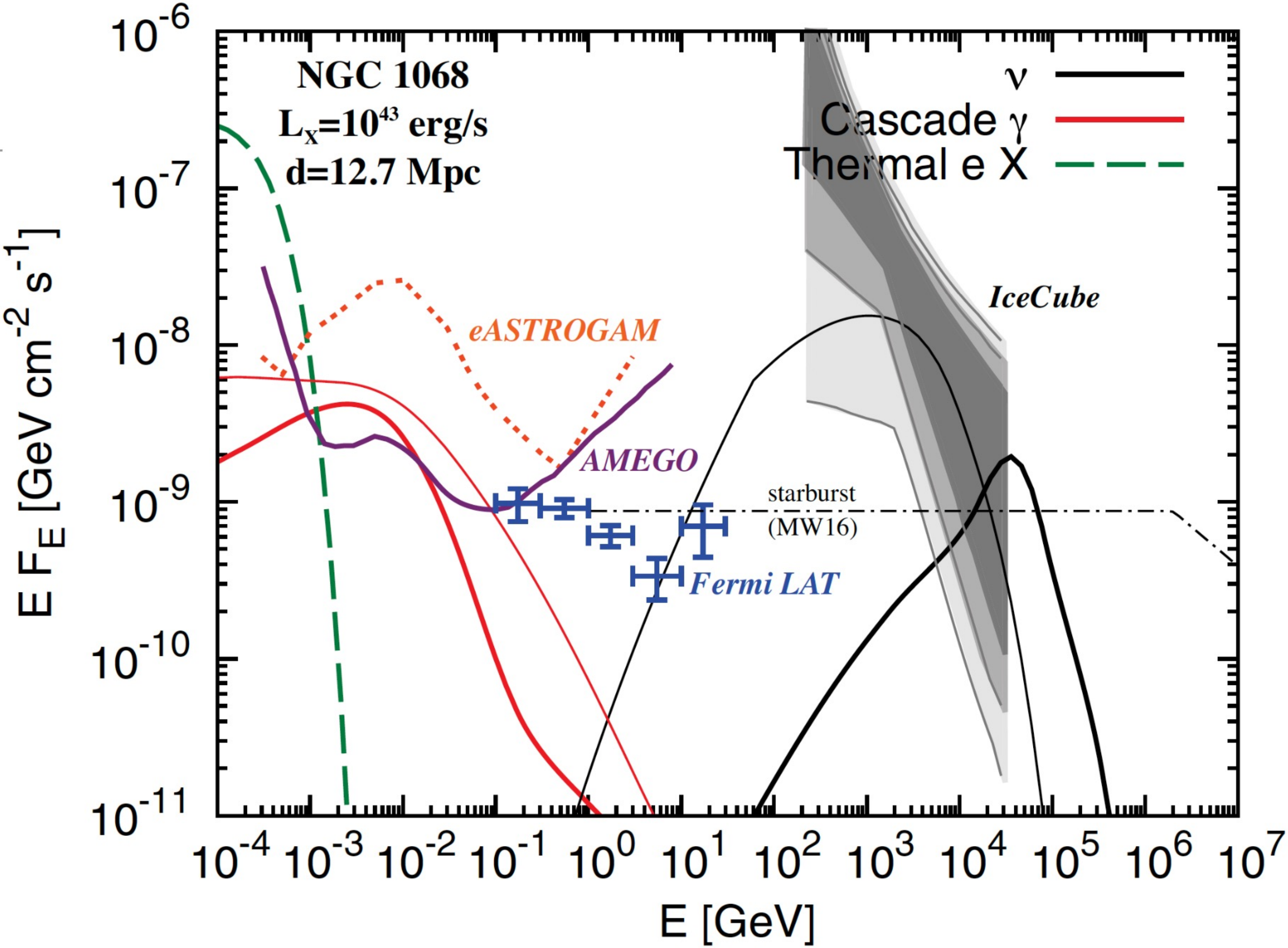
ASTROGAM view of the Galactic Center Region

100-500 MeV Fermi PSF Pass7 rep v15 source



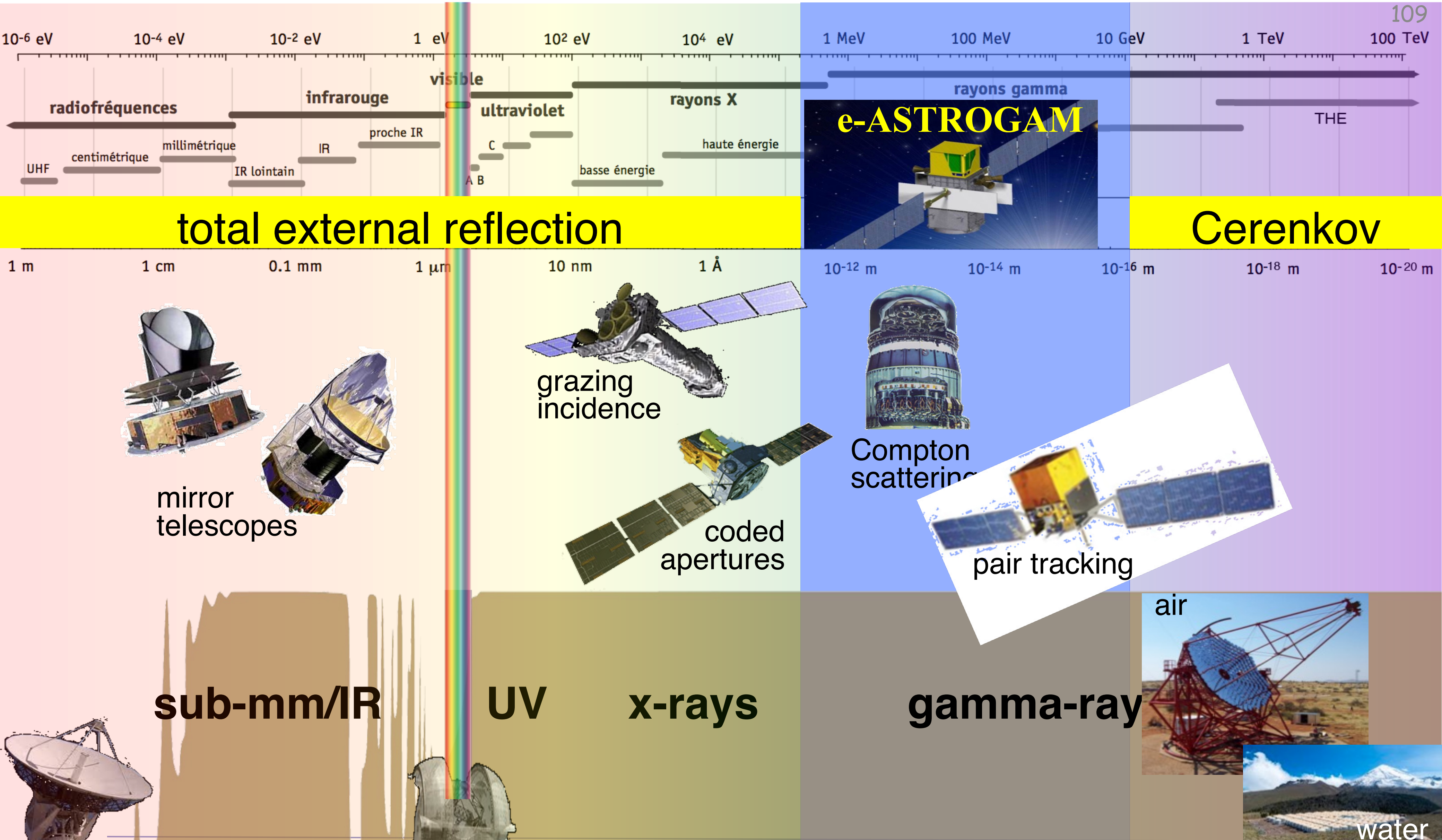
Why eAstrogam is important for IceCube and KM3Net

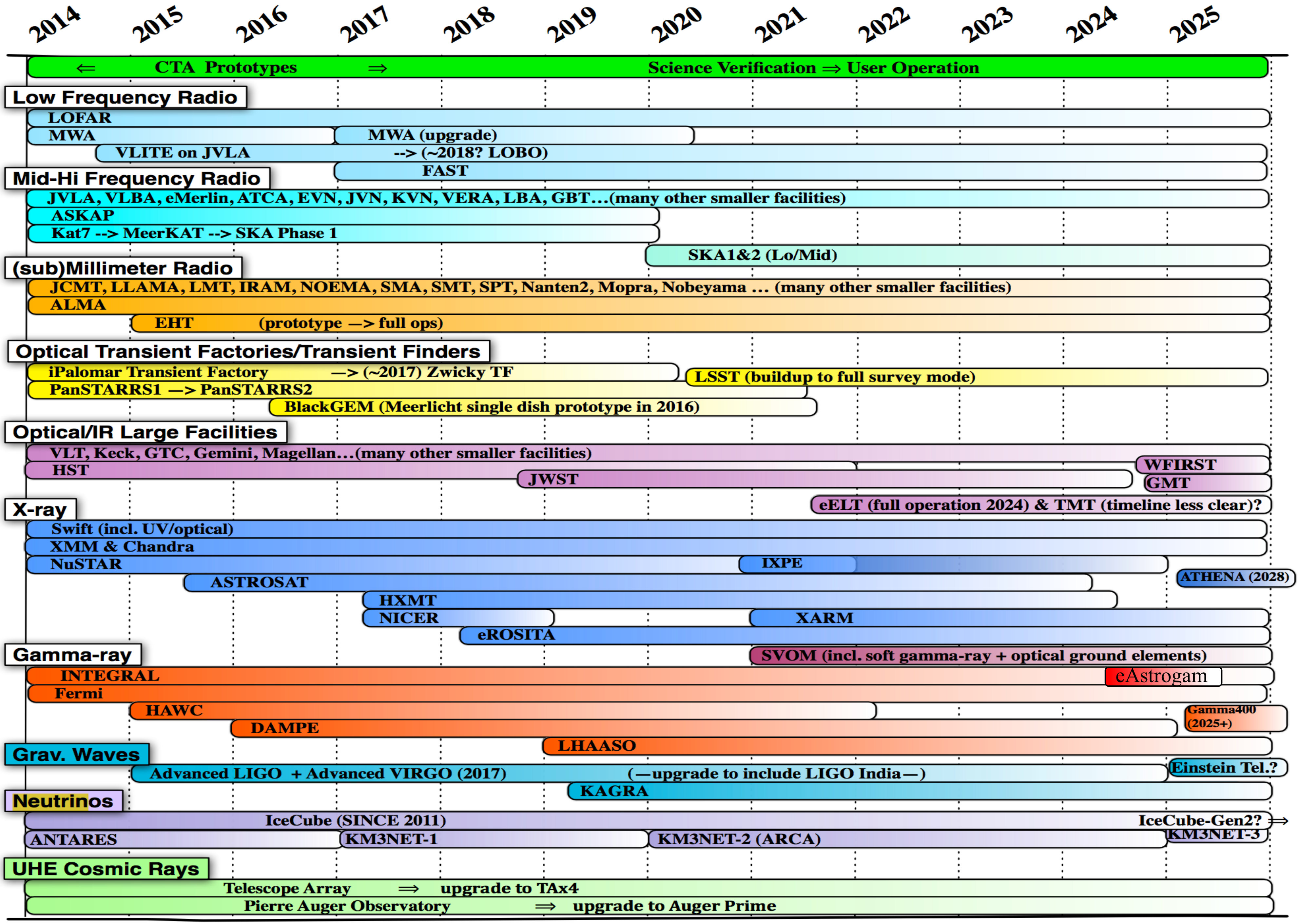
- Wide FoV (> 2.5 sr at 10 MeV) in survey mode.
- Sources of astrophysical neutrinos detected by IceCube may be opaque to 1–100 GeV gamma-rays but bright in the MeV domains (expecially if the neutrino flux originates from photo-hadronic processes)
- eAstrogam can select the best blazar candidates for 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 pγ or pp processes



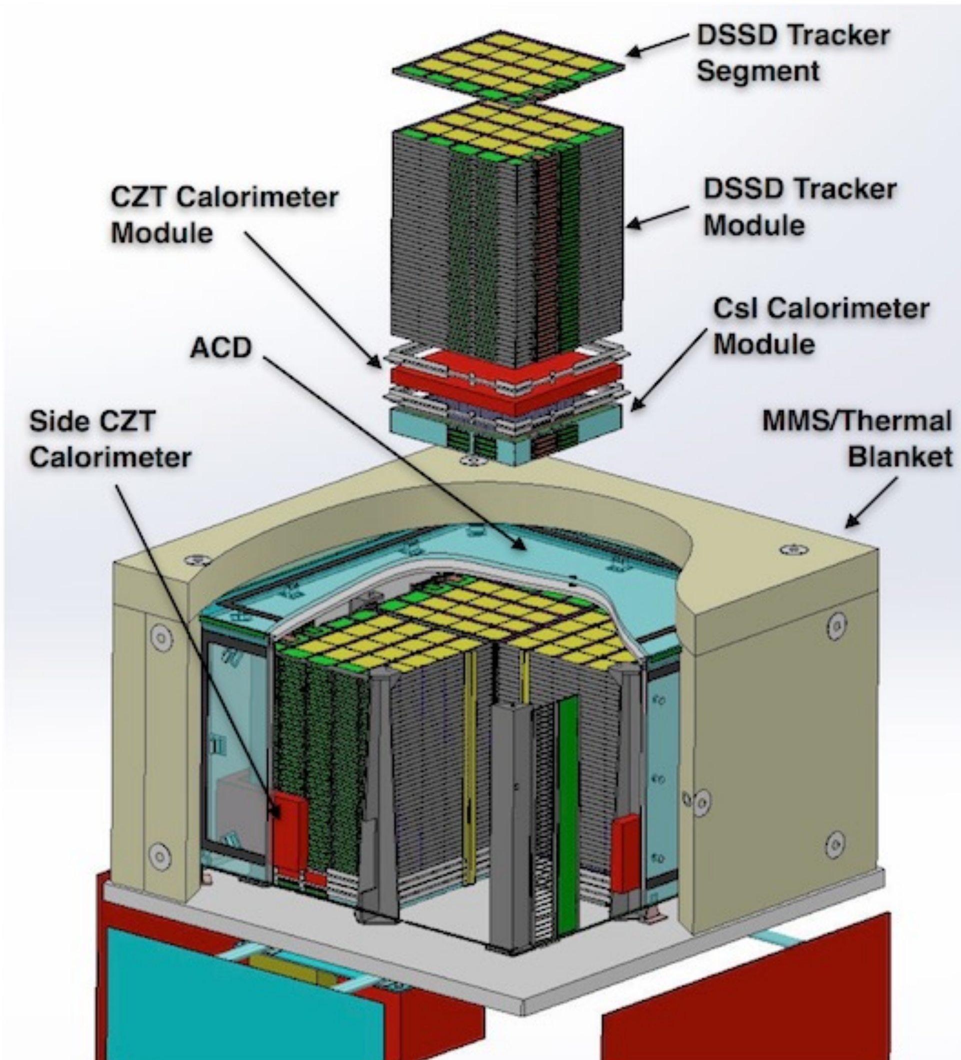
NGC 1068
L_X=10^43 erg/s
d=12.7 Mpc
ν
Cascade γ
Thermal e X
IceCube
eASTROGAM
AMEGO
starburst
(MW16)
Fermi LAT
E F_E [GeV cm^-2 s^-1]
E [GeV]

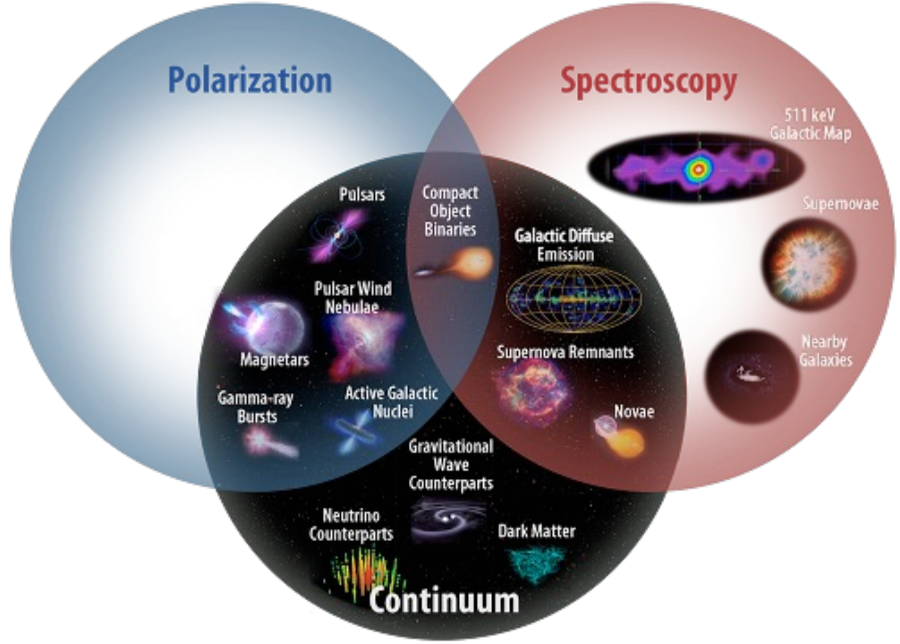
An instrument to complete the coverage of the electromagnetic spectrum




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)
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)

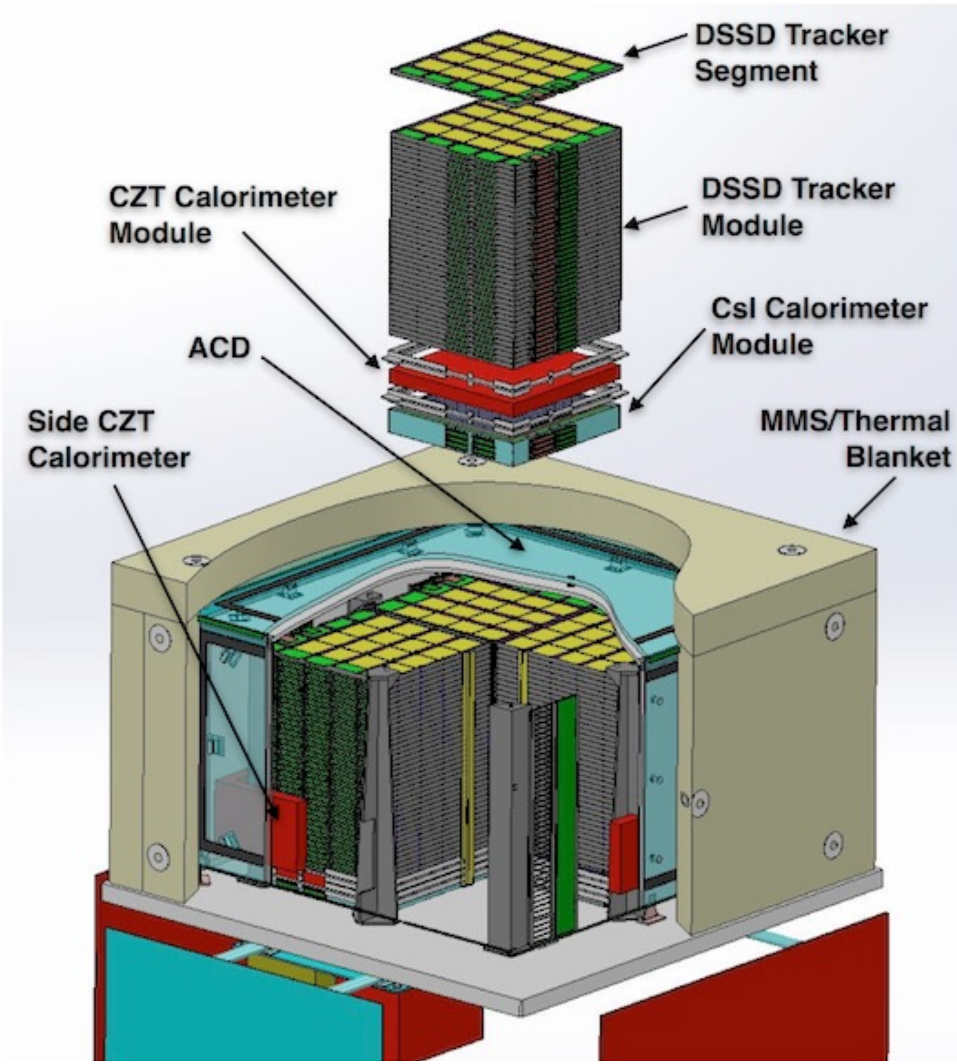




- ~20% smaller tracker
- CZT calorimeter layer

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

Our sister experiment: AMEGO (NASA)

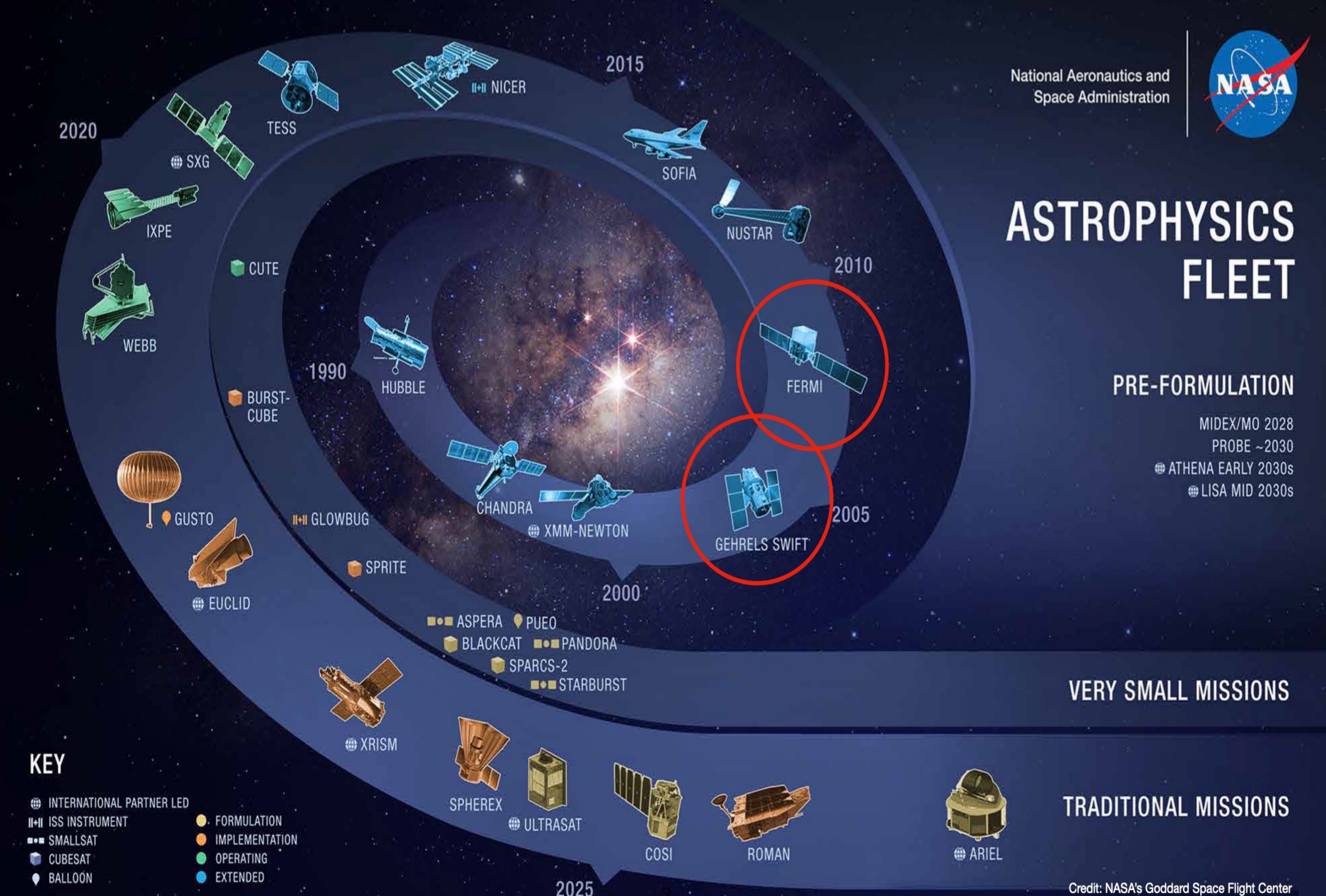


Status and Plans :
Resubmit in the next MIDEX round (~2027)

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



Updated June 2022

COSI The Compton Spectrometer and Imager

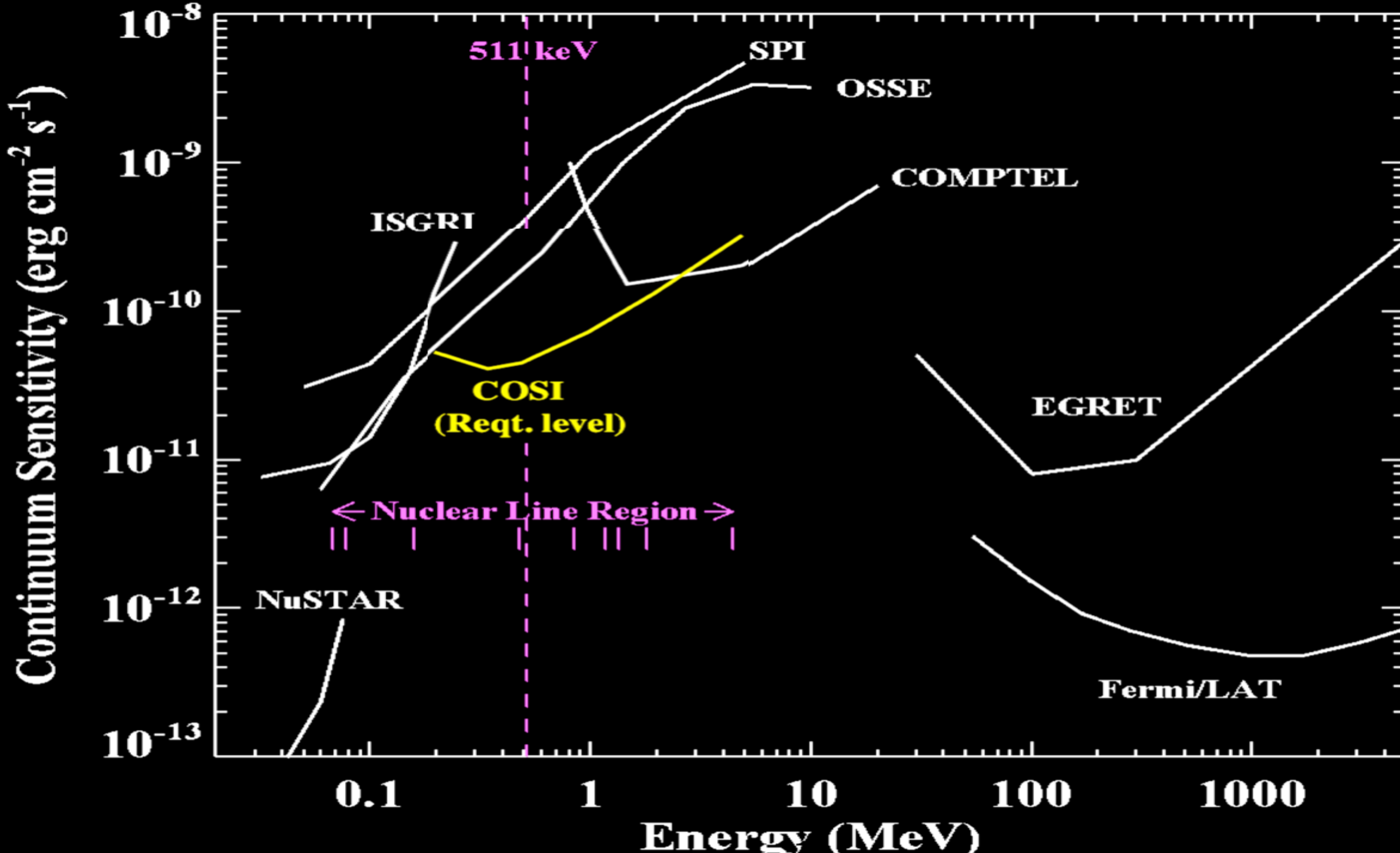
- COSI has been selected by NASA as a SMEX to launch in 2027

- 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

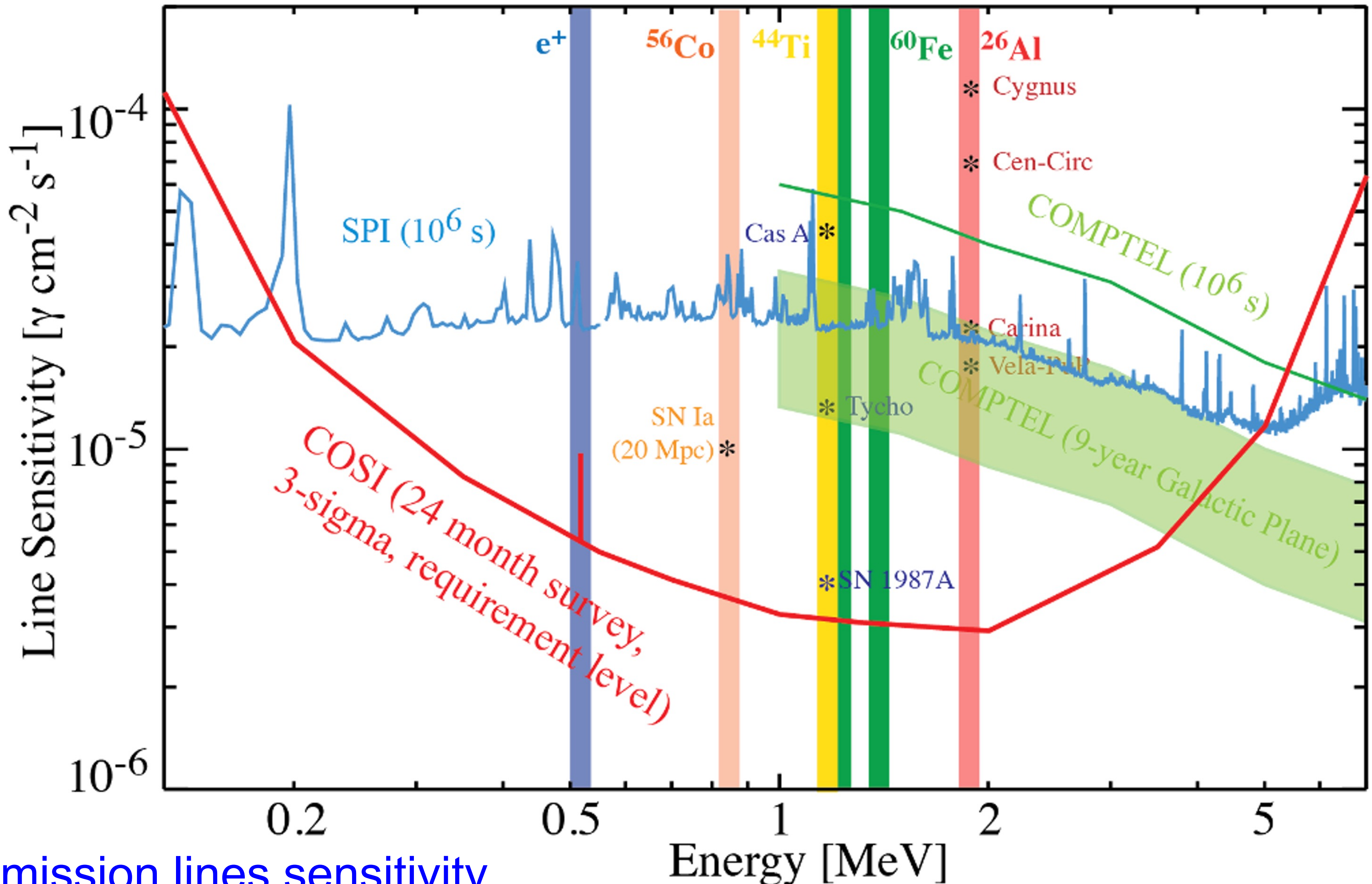
- Goal D emphasizes the connection to gravitational waves
- ▪Detects short gamma-ray bursts (GRBs) from merging neutron stars
  ▪Localizations to ~1° accuracy
  ▪Public alerts in <1 hour

COSI



continuum emission sensitivity

COSI The Compton Spectrometer and Imager

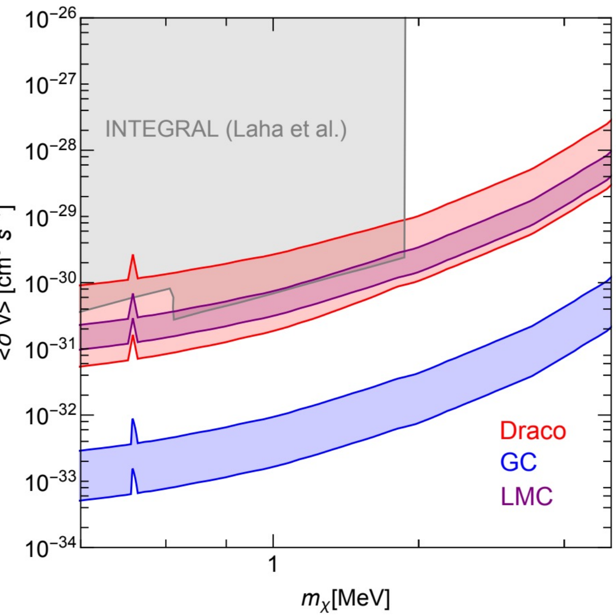


emission lines sensitivity

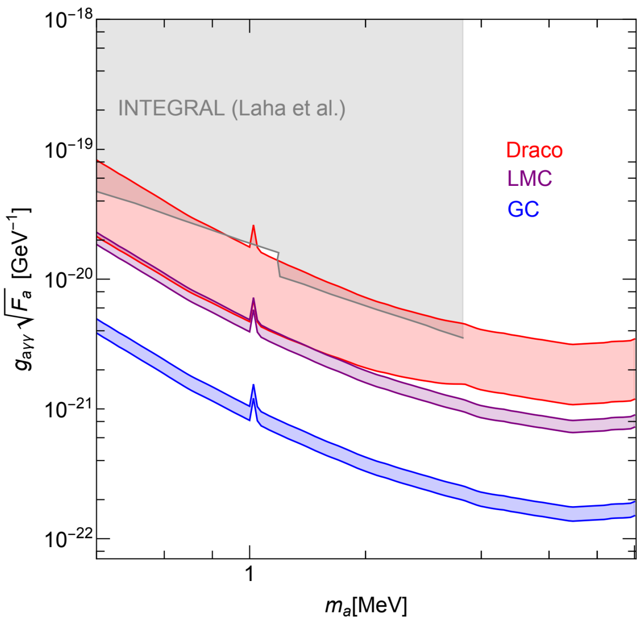
Dark Matter Studies with COSI

- COSI will provide limits on annihilating/decaying DM, Axion like particles and primordial black holes

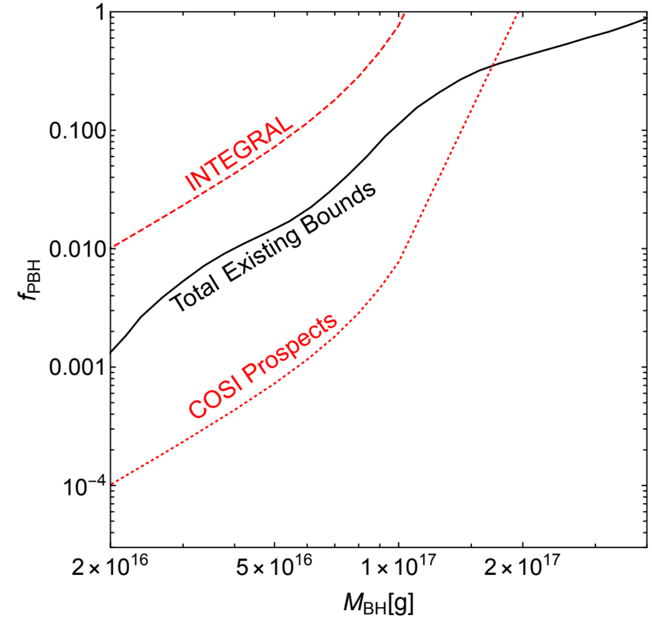
Annihilating Dark Matter



ALPs

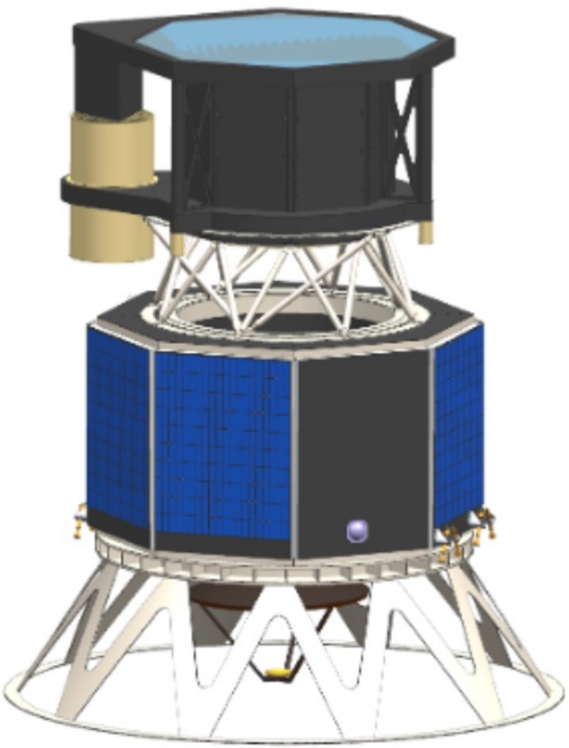


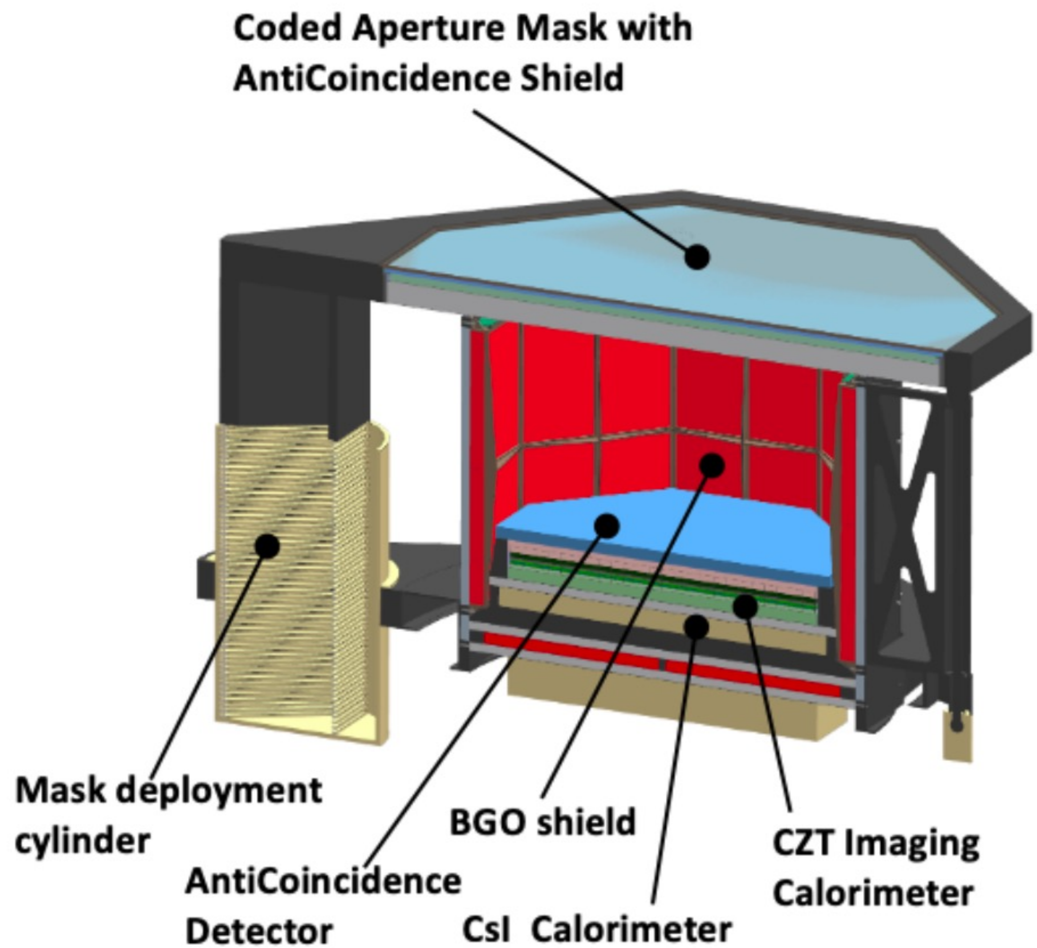
Primordial Black Holes



Caputo et al. 2023 arXiv2210.09310

GECCO The Galactic Explorer with a Coded Aperture Mask Compton Telescope

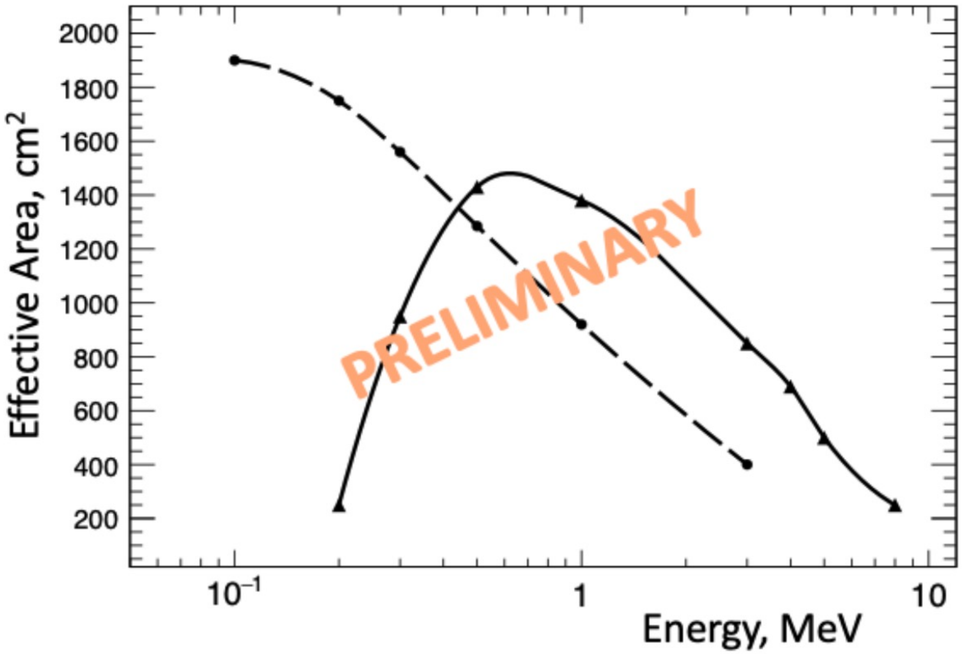




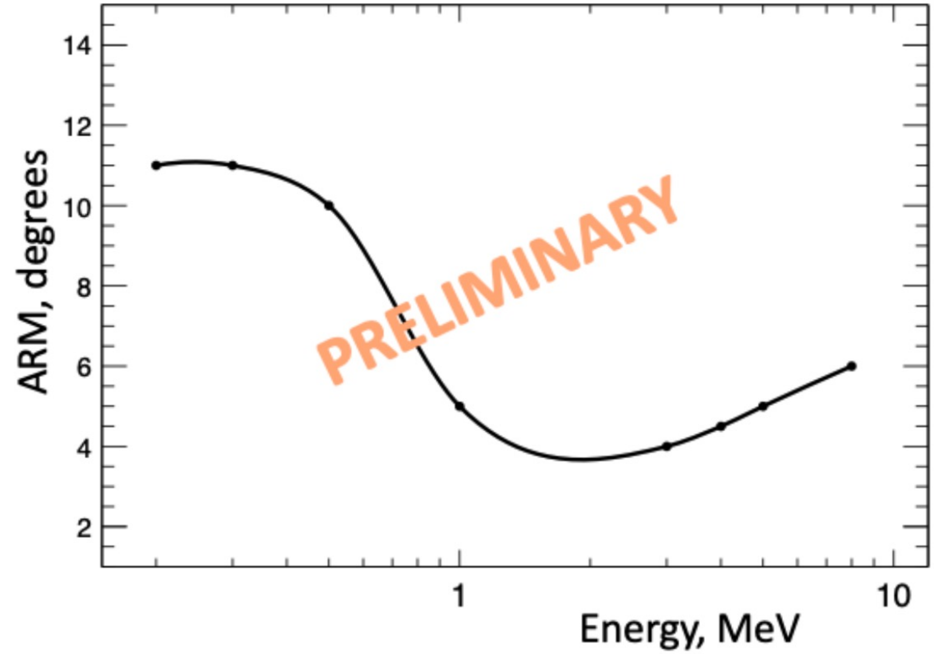
conceptual design | mask in stowed position | cutaway | diameter =90 cm

GECCO Team, JCAP07(2022)036 arXiv:2112.07190

GECCO The Galactic Explorer with a Coded Aperture Mask Compton Telescope



effective area for the CA mask imaging; the solid line is for Compton pointing used, and the dashed line is for classical mask analysis.

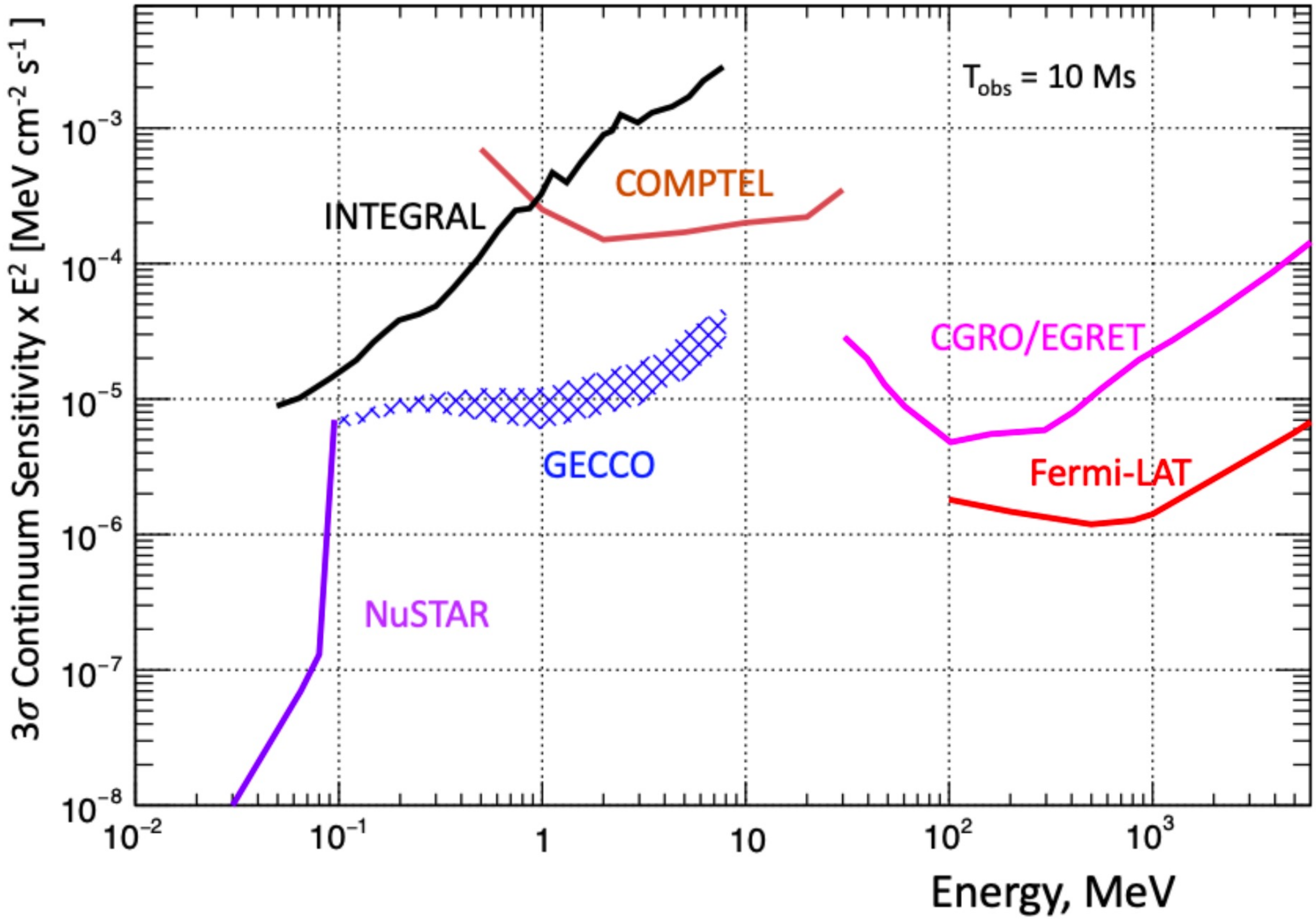


ARM (angular resolution measure) for the ImCal standalone Compton telescope.

GECCO Team, in preparation

GECCO The Galactic Explorer with a Coded Aperture Mask Compton Telescope

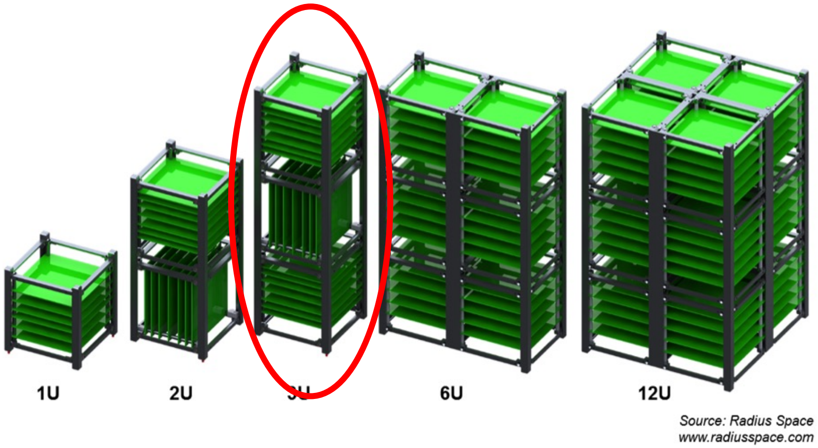
Sensitivity



GECCO Team, JCAP07(2022)036 arXiv:2112.07190

COMCUBE Nanosat sub-WP

Development of a 3U (?) Compton nanosat for the polarimetry of GRBs + qualification of the e-ASTROGAM technologies

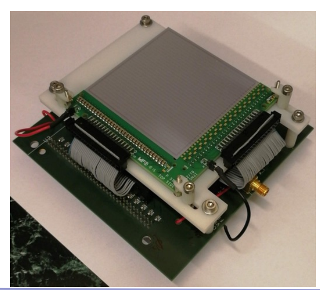


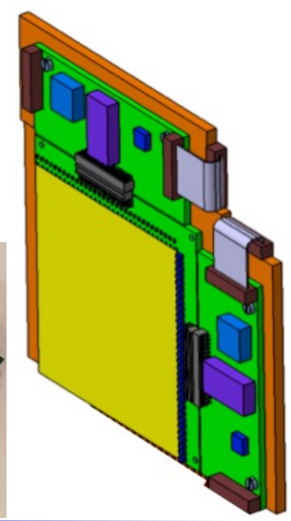
Si DSSD (1.5 mm?) +
IDeF-X ASICs (CEA)

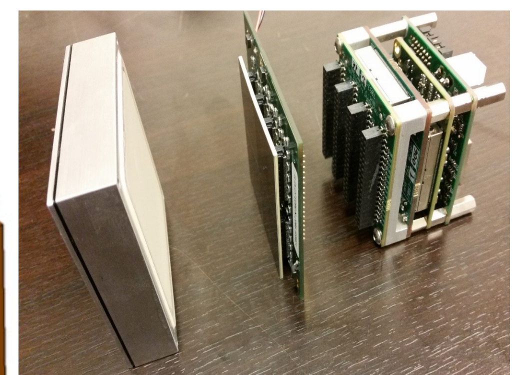
Si DSSD (1.5 mm?) +
VATA ASICs (Ideas)

Thick scintillator + SiPM array

- Cubesat : standard unit ⇒ 1U
- Size : 10 x 10 x 10 cm
- Weight : 1kg
- Power : ~ 1.3 W







Summary

- The Gamma-ray sky has been observed since 1972 with Sas2, Cos-B, CGRO and then followed with Swift, Fermi, INTEGRAL , AGILE

- Gamma-ray observations have enabled huge discoveries over the past ~2 decades and most recently as we have entered the era of multi-messenger astrophysics
- • The next generation of discoveries in astrophysics need all-sky gamma- ray observatories to go with the all-sky GW and neutrino observatories

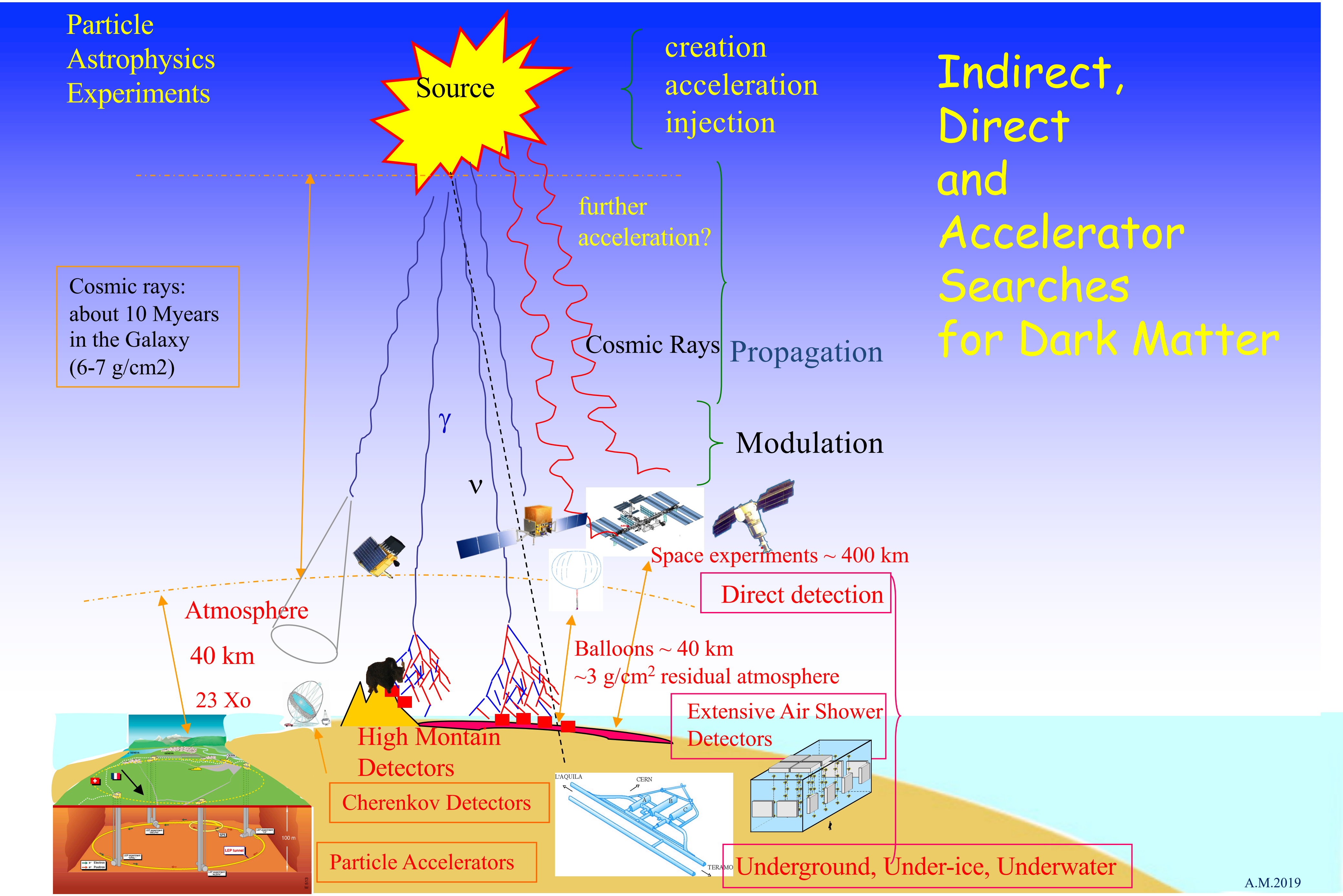
Summary

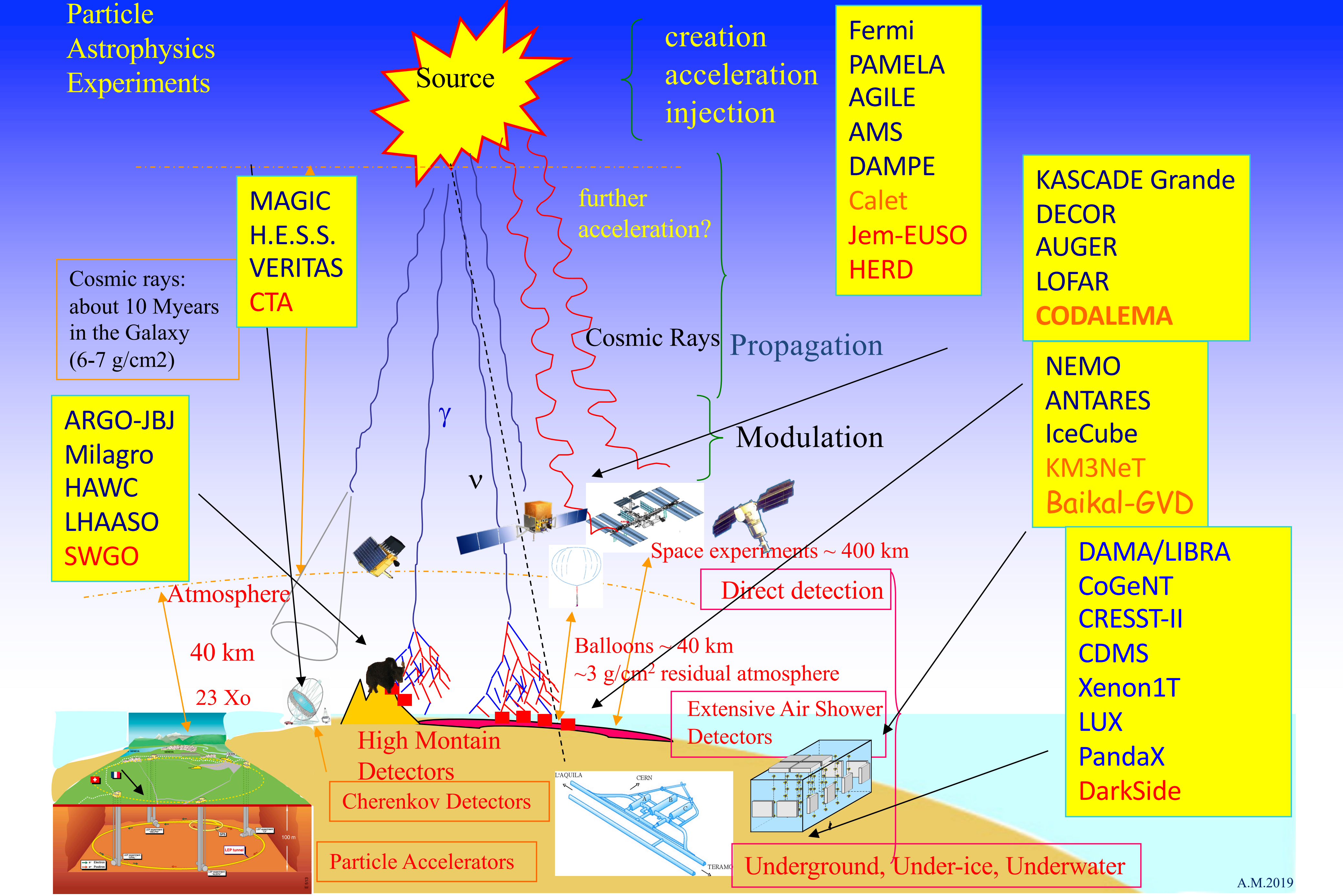
- AGILE ended data taking on 13 Feb 2024
- It was a very helpful mission for multimessanger observation
- Fermi is still in orbit but we need a new mission

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

- Because the flux is high it can be at the AGILE

scale (like Gamma-Light) i.e. also a National Space Agency (or two) can support the development and launch


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
Jem-EUSO
HERD
MAGIC
H.E.S.S.
VERITAS
CTA
further acceleration?
KASCADE Grande
DECOR
AUGER
LOFAR
CODALEMA
Cosmic rays: about 10 Myears in the Galaxy (6-7 g/cm2)
Cosmic Rays
Propagation
NEMO
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ARGO-JBJ
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HAWC
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γ
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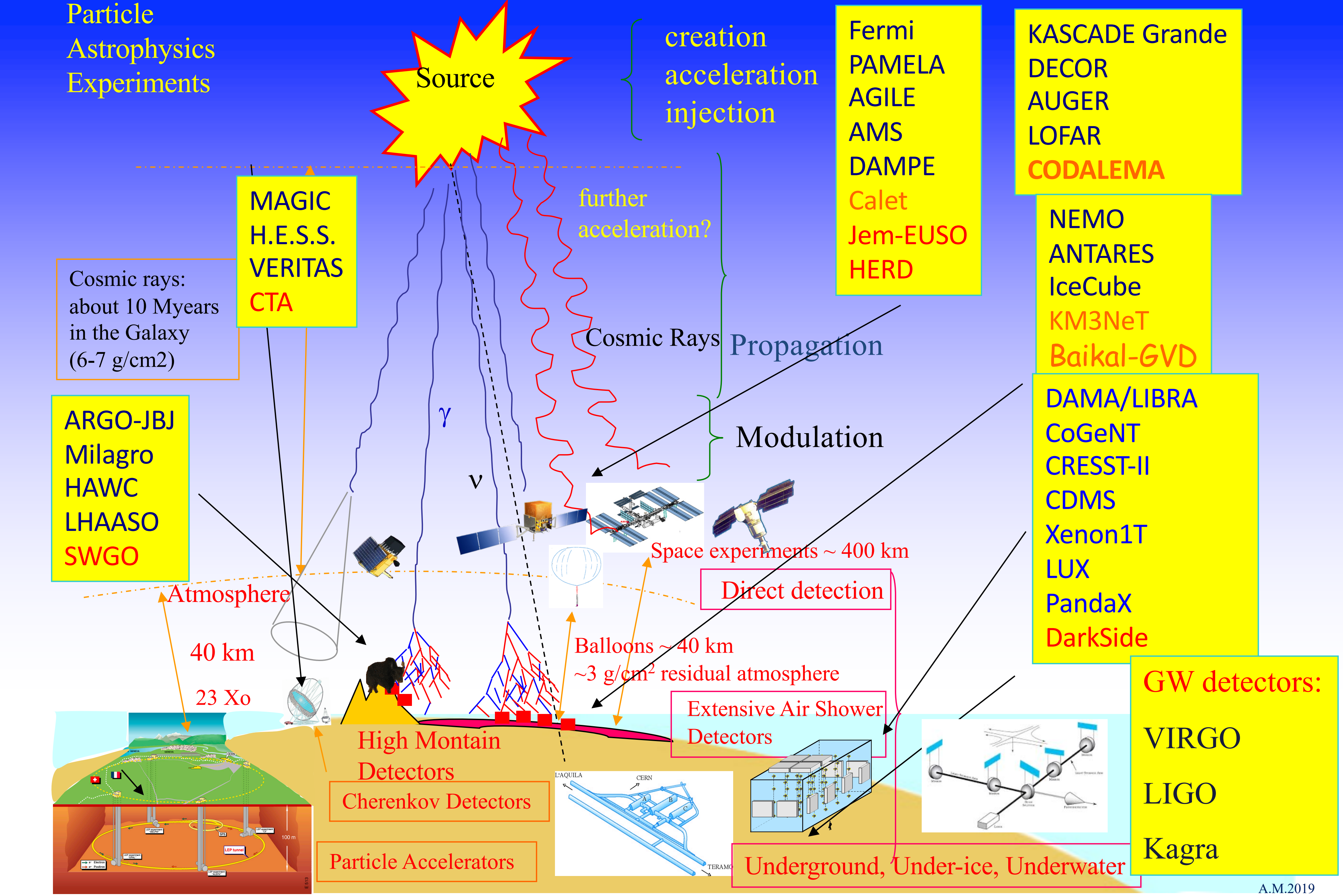
Particle
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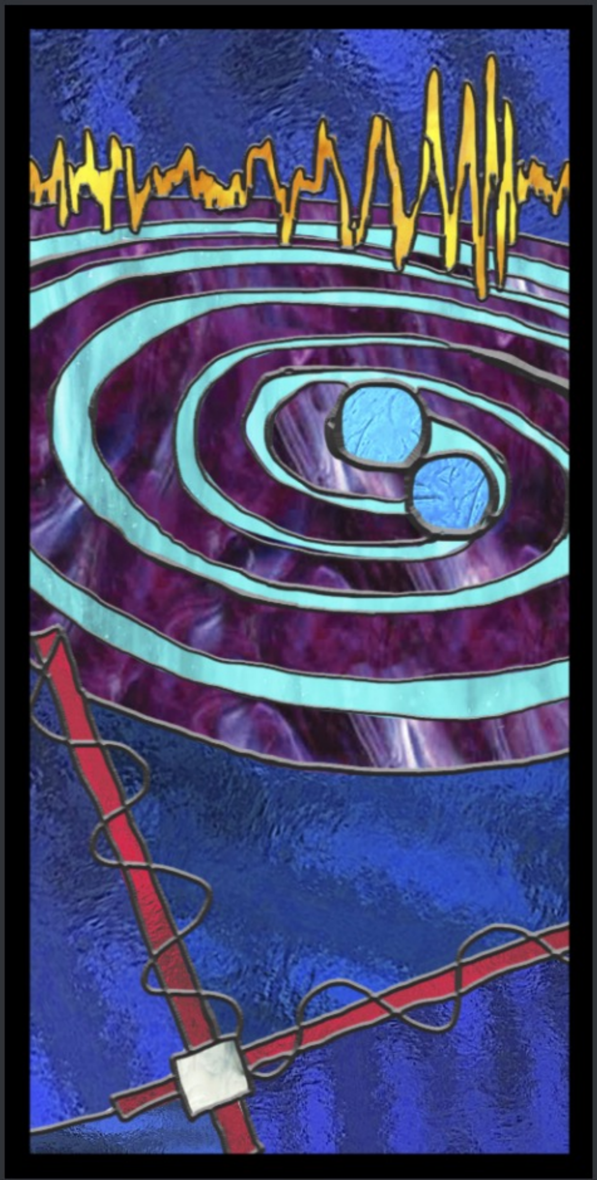
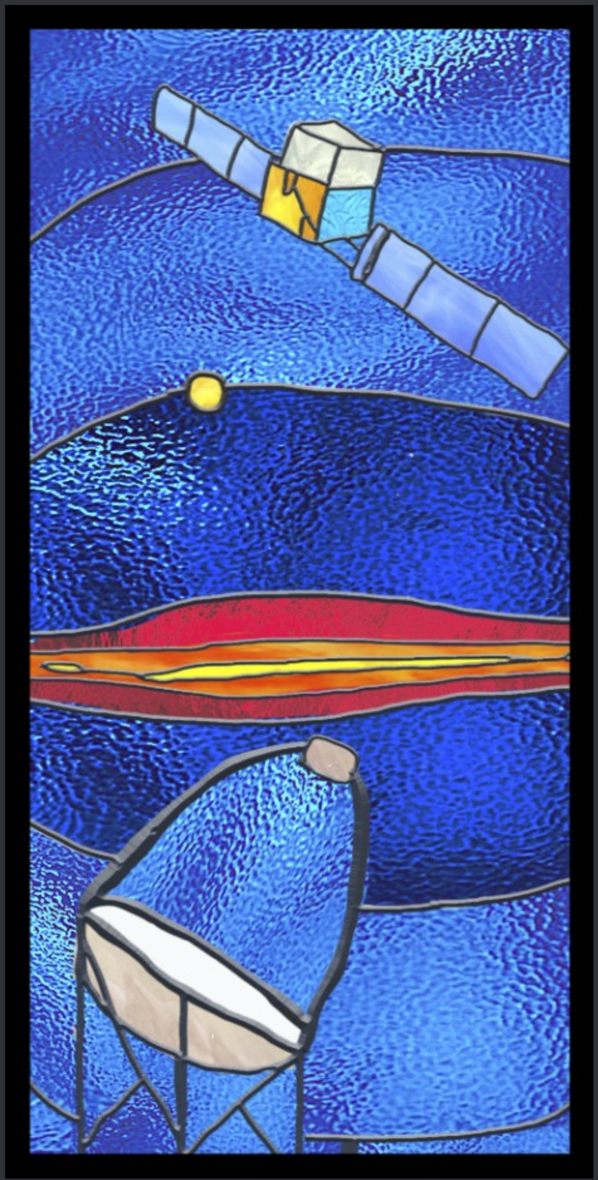
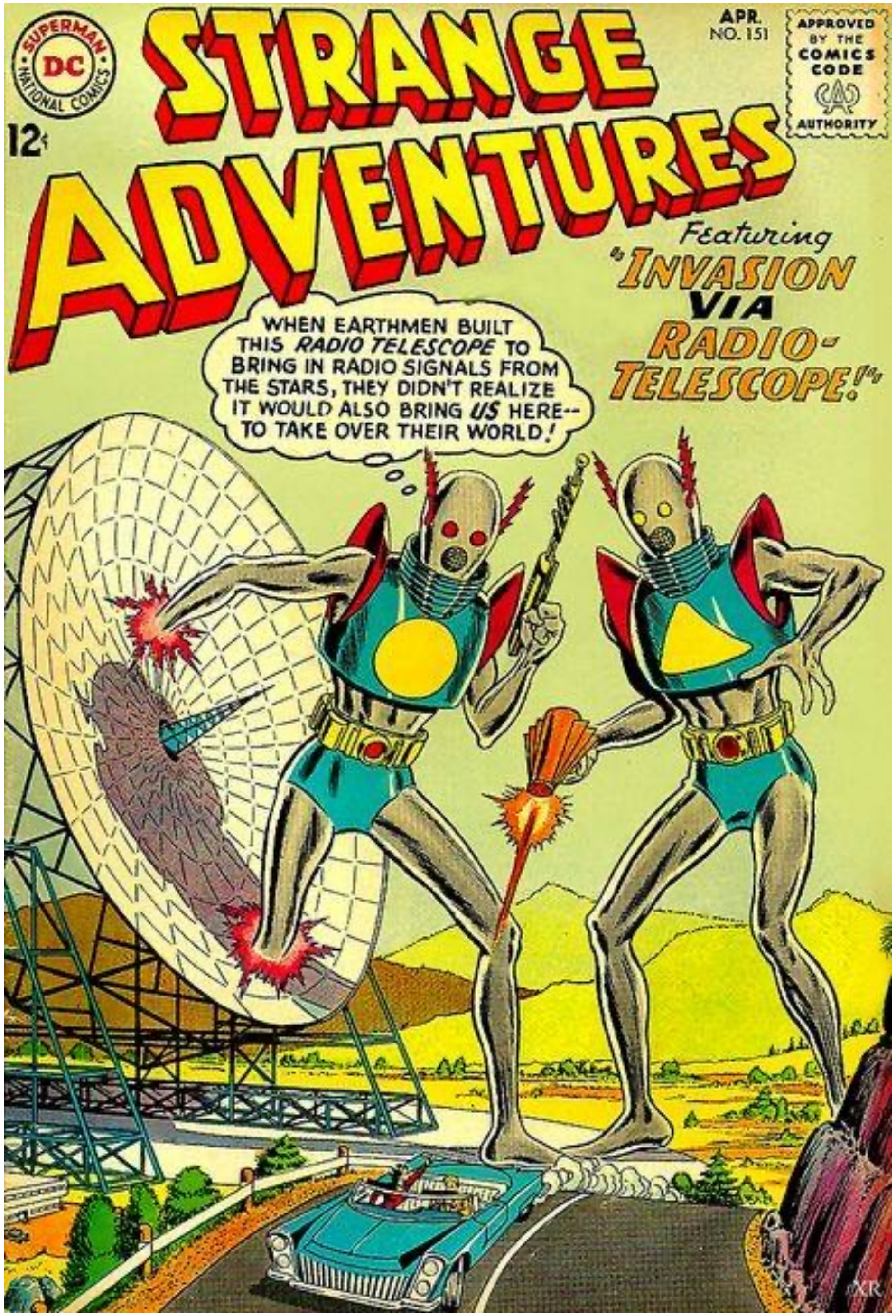
Underground, Under-ice, Underwater
A.M.2019

the multi-messanger era





there is always a risk ..



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

23–27 Sept 2024 see you in Villa Tuscolana (Frascati) for

RICAP-24 Roma International Conference on AstroParticle Physics

https://agenda.infn.it/event/35353/ poster submissione deadline July 30

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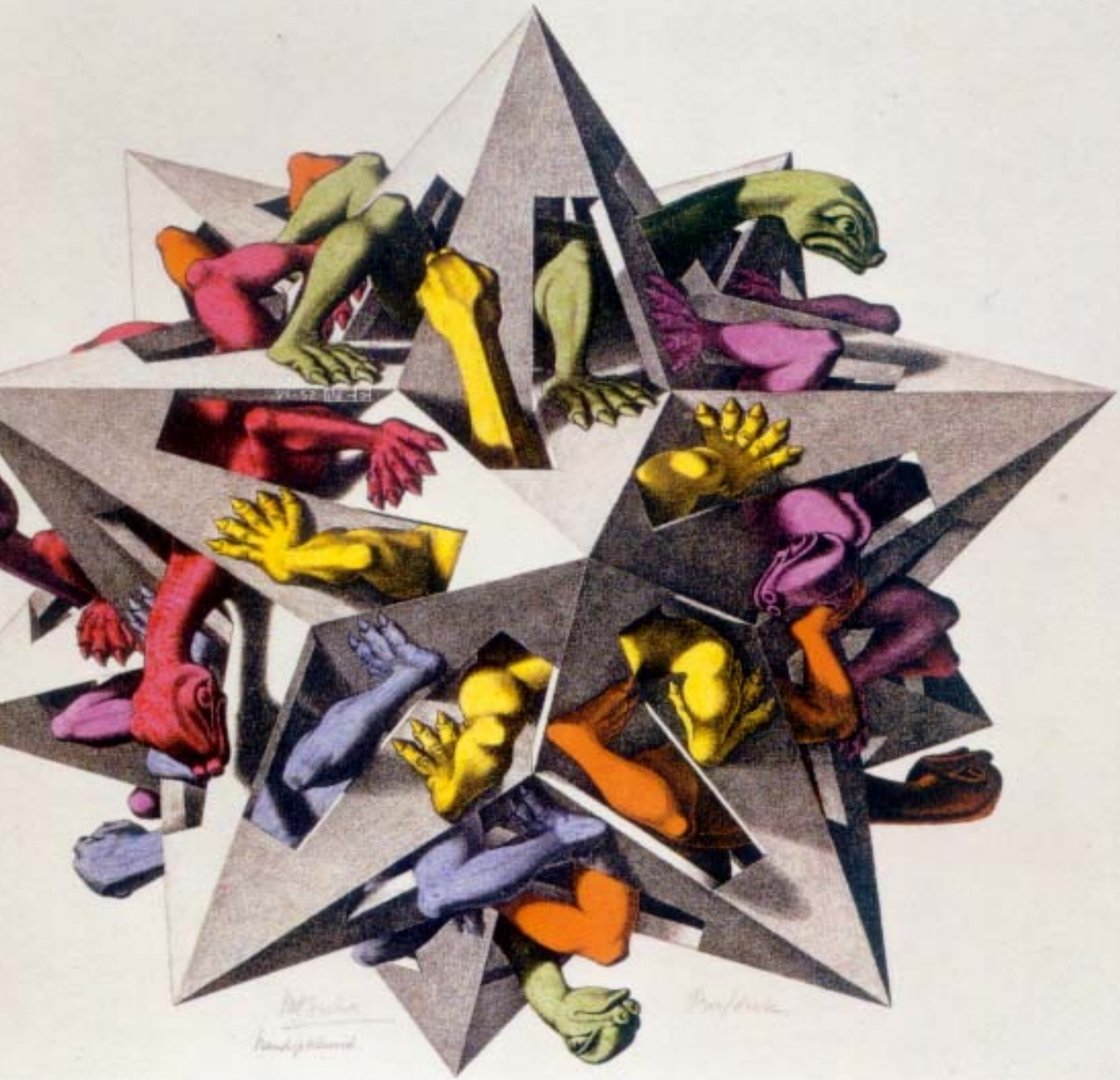
Through most of history, the cosmos has been viewed as eternally tranquil

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




The future?
Thank you !