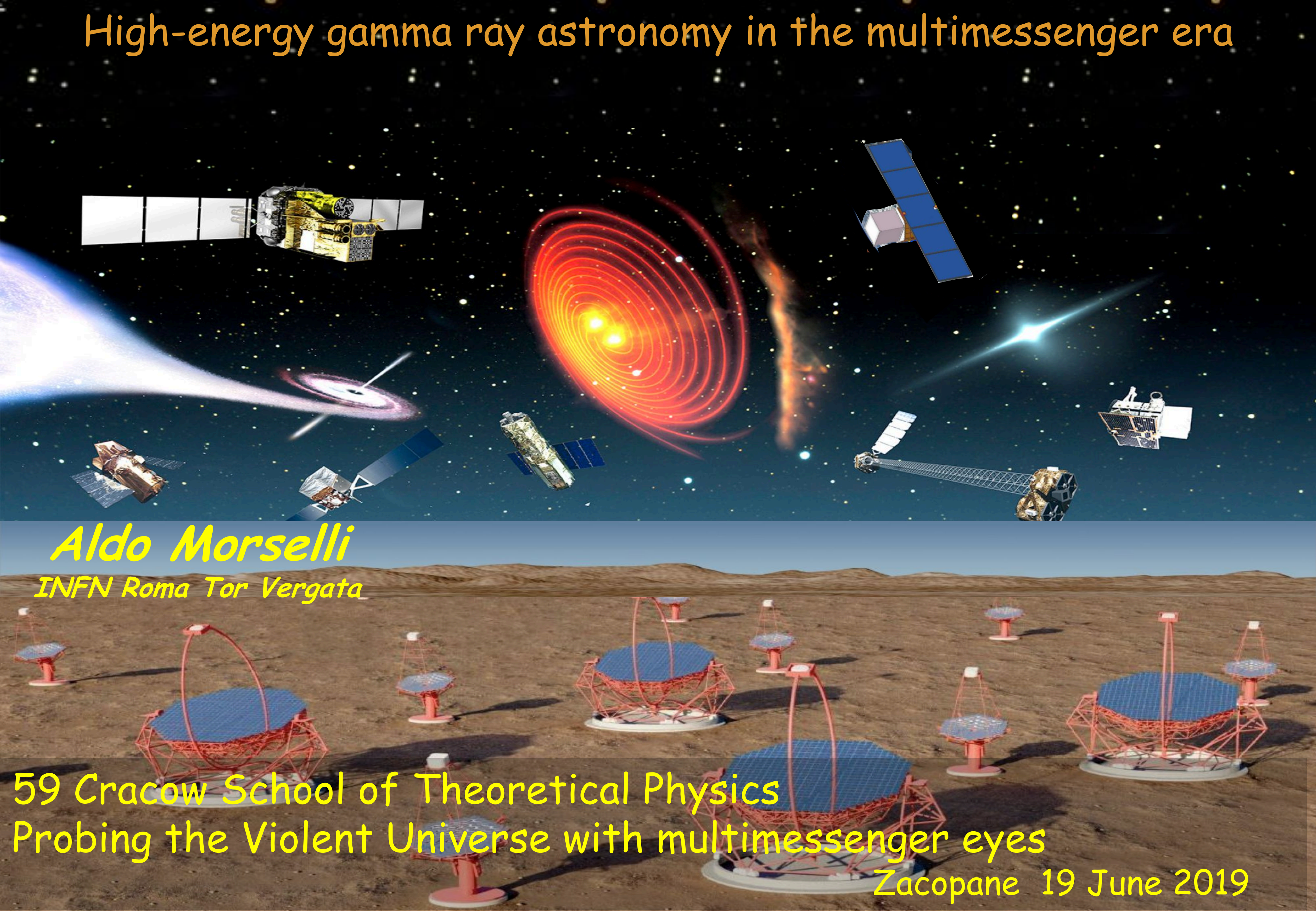
High-energy gamma ray astronomy in the multimessenger era



Aldo Morselli

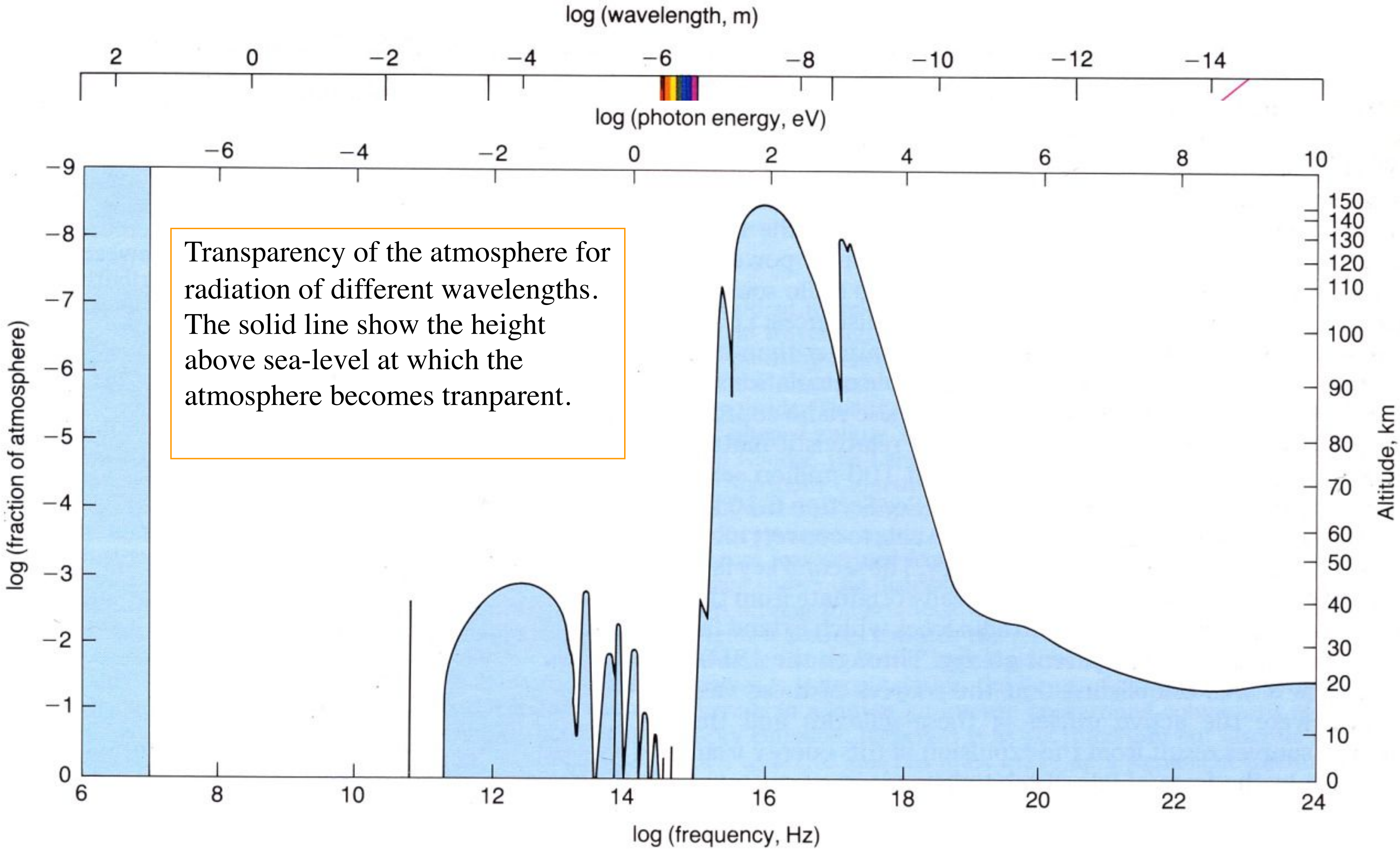
INFN Roma Tor Vergata

59 Cracow School of Theoretical Physics

Probing the Violent Universe with multimessenger eyes

Zacopane 19 June 2019

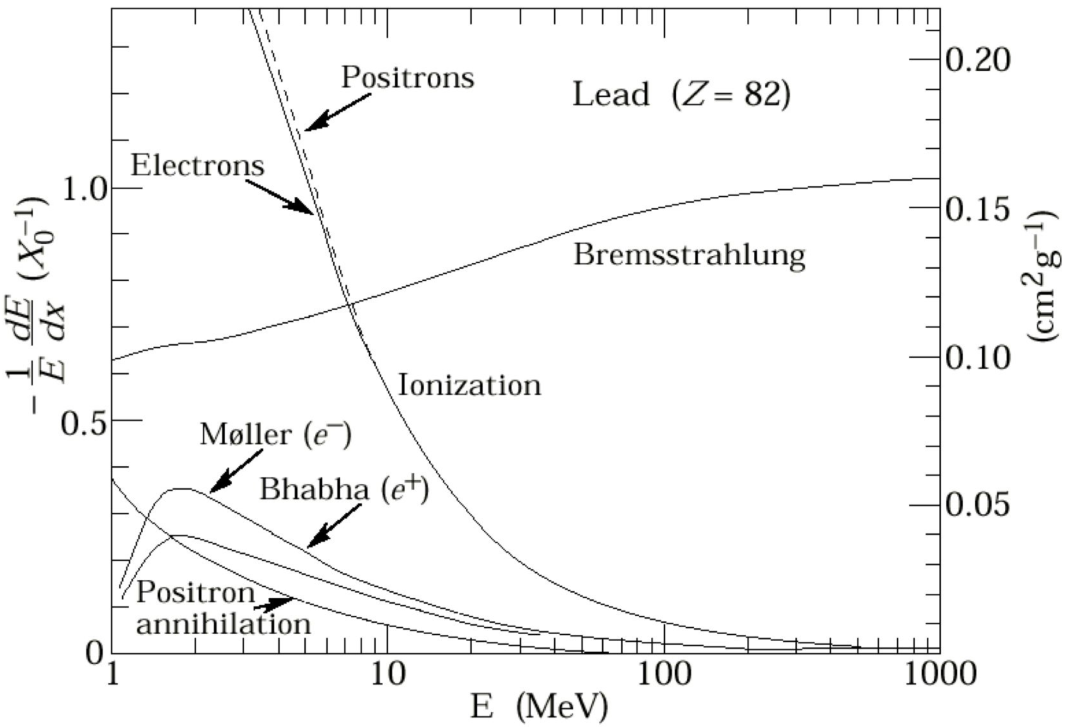
Gamma ray attenuation



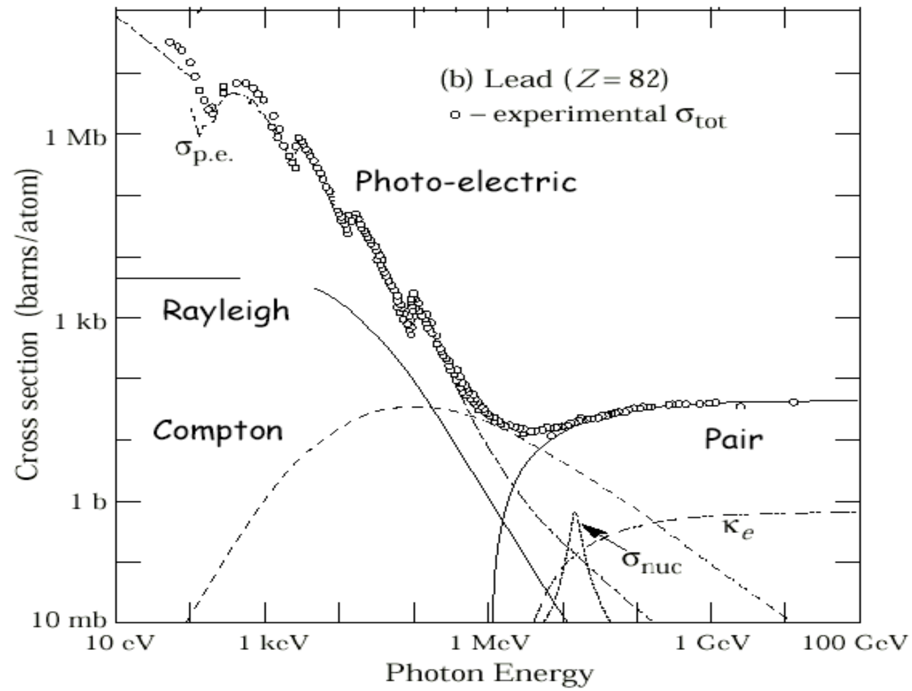
Transparency of the atmosphere for radiation of different wavelengths. The solid line show the height above sea-level at which the atmosphere becomes tranparent.

Interaction of photons with matter

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



Photon total cross sections



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

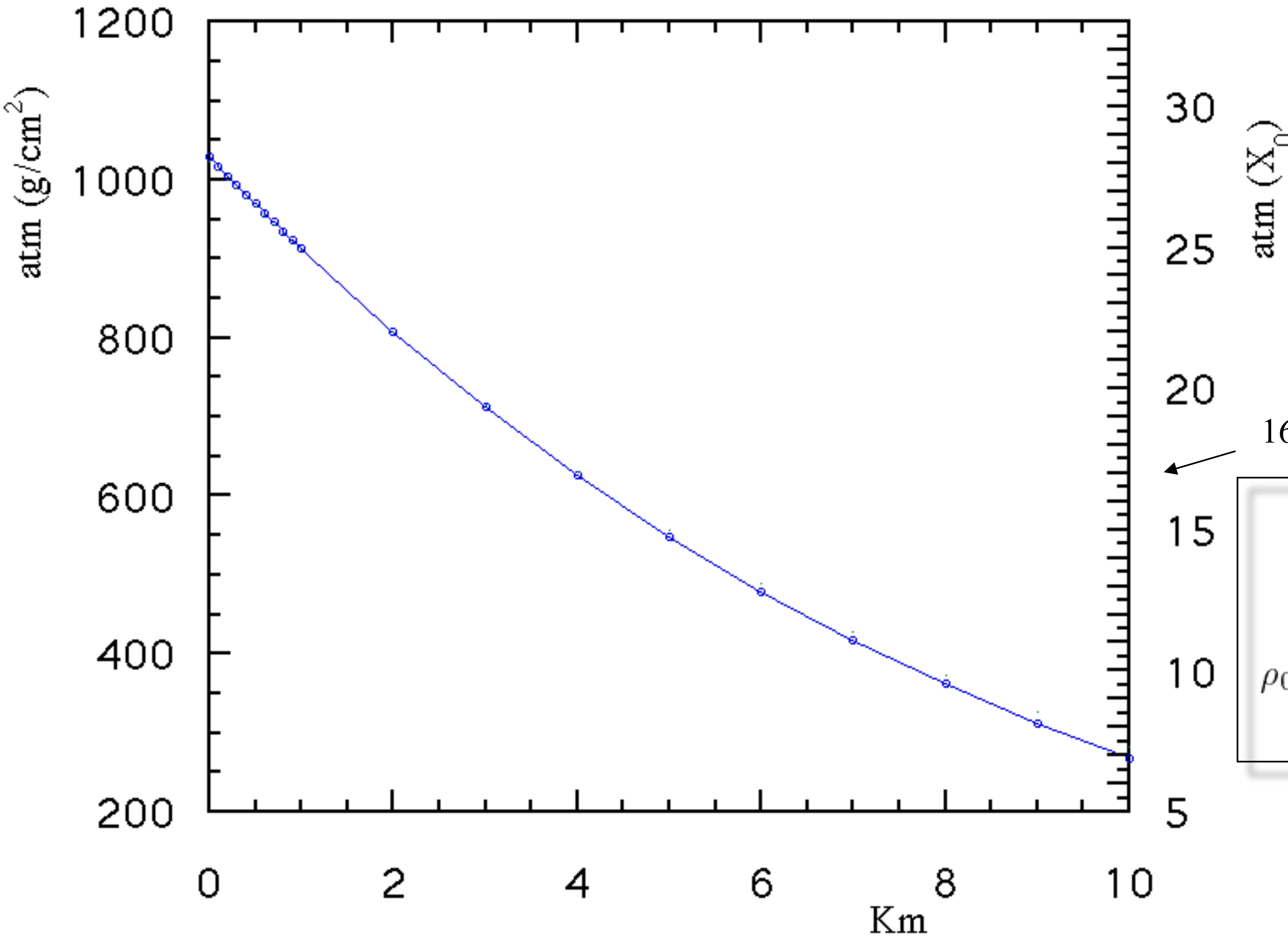
with X_0 = radiation length

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

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

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

Relation between altitude, number of Radiation Length and g/cm^2 traversed



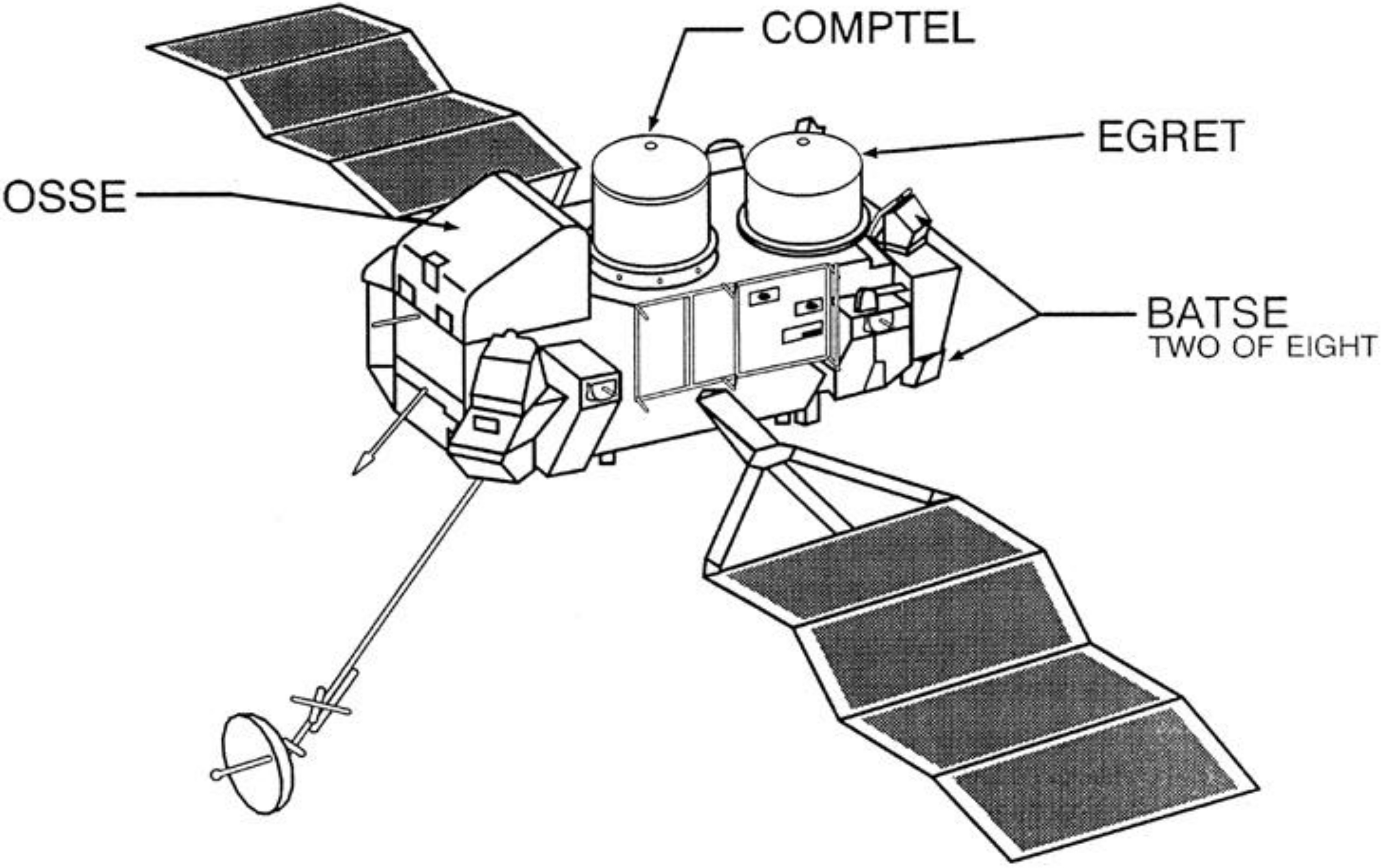
16 X_0 Yanbajiging

$$\rho = \rho_0 \; h_0 \; e^{-h/h_0}$$

$$h_0 \sim 6.4 \; Km$$

$$\rho_0 \sim 161 \; g/(cm^2 Km)$$

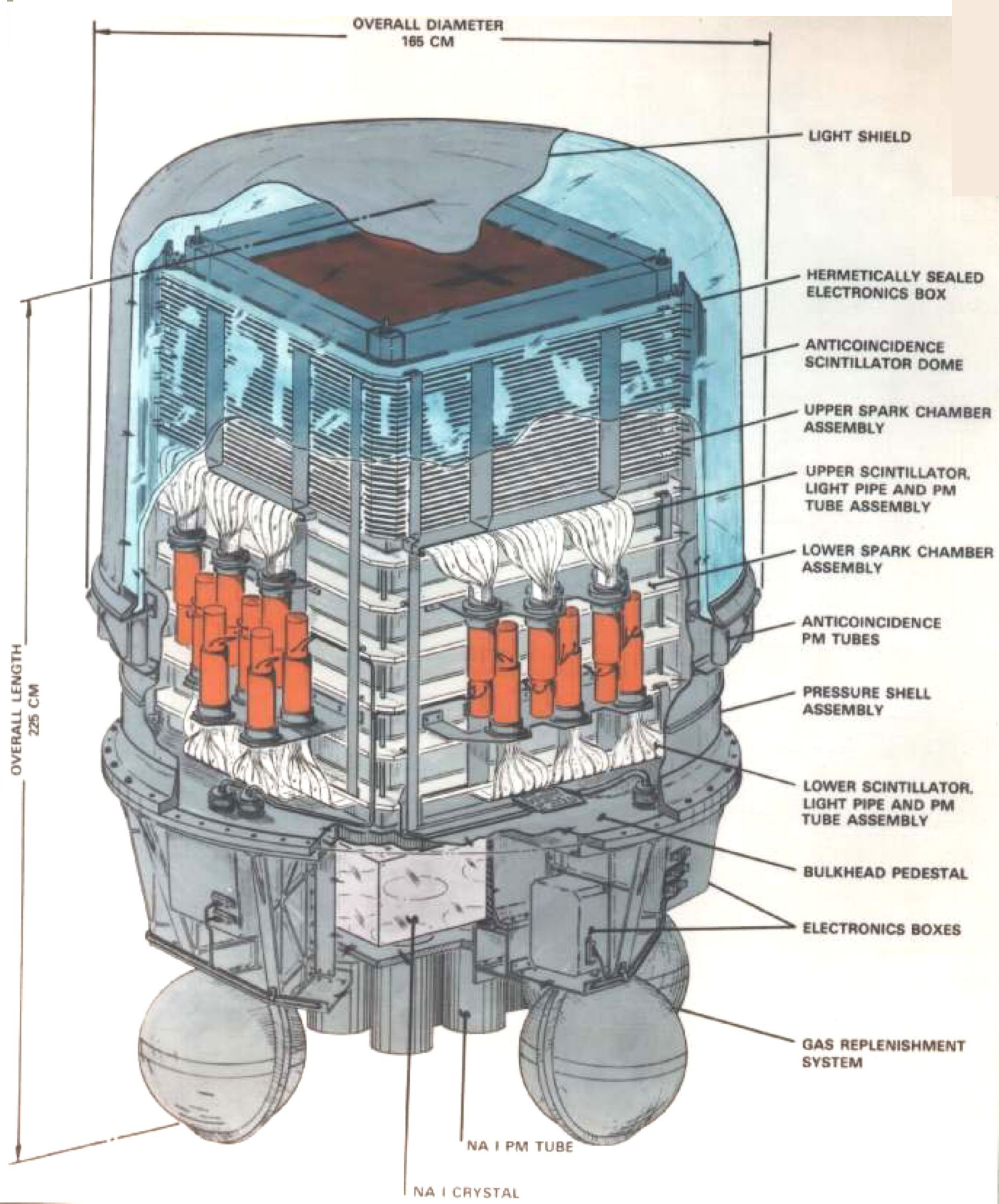
COMPTON OBSERVATORY INSTRUMENTS

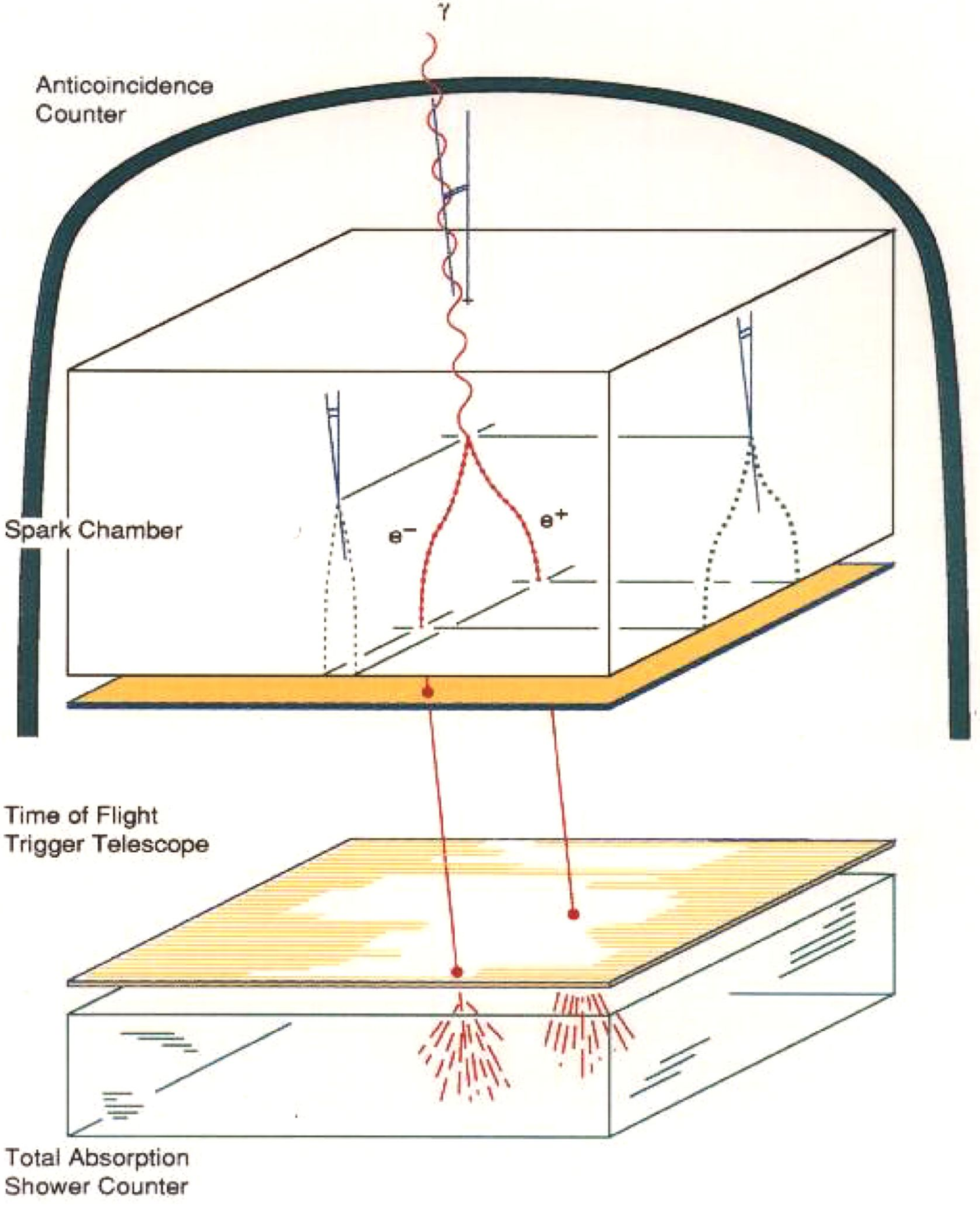


EGRET:the detector

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

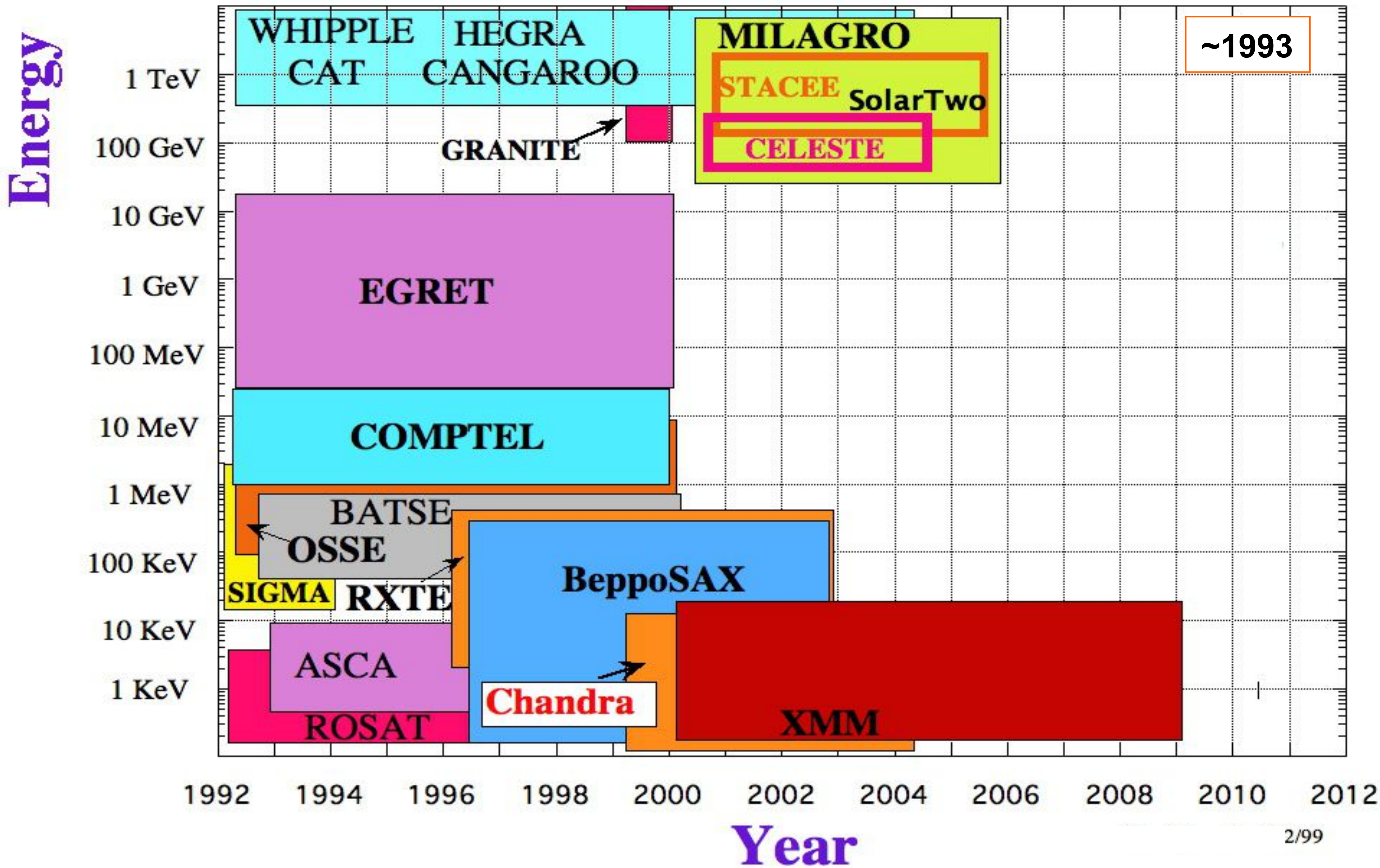
EGRET – Principle of gamma ray detection

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.

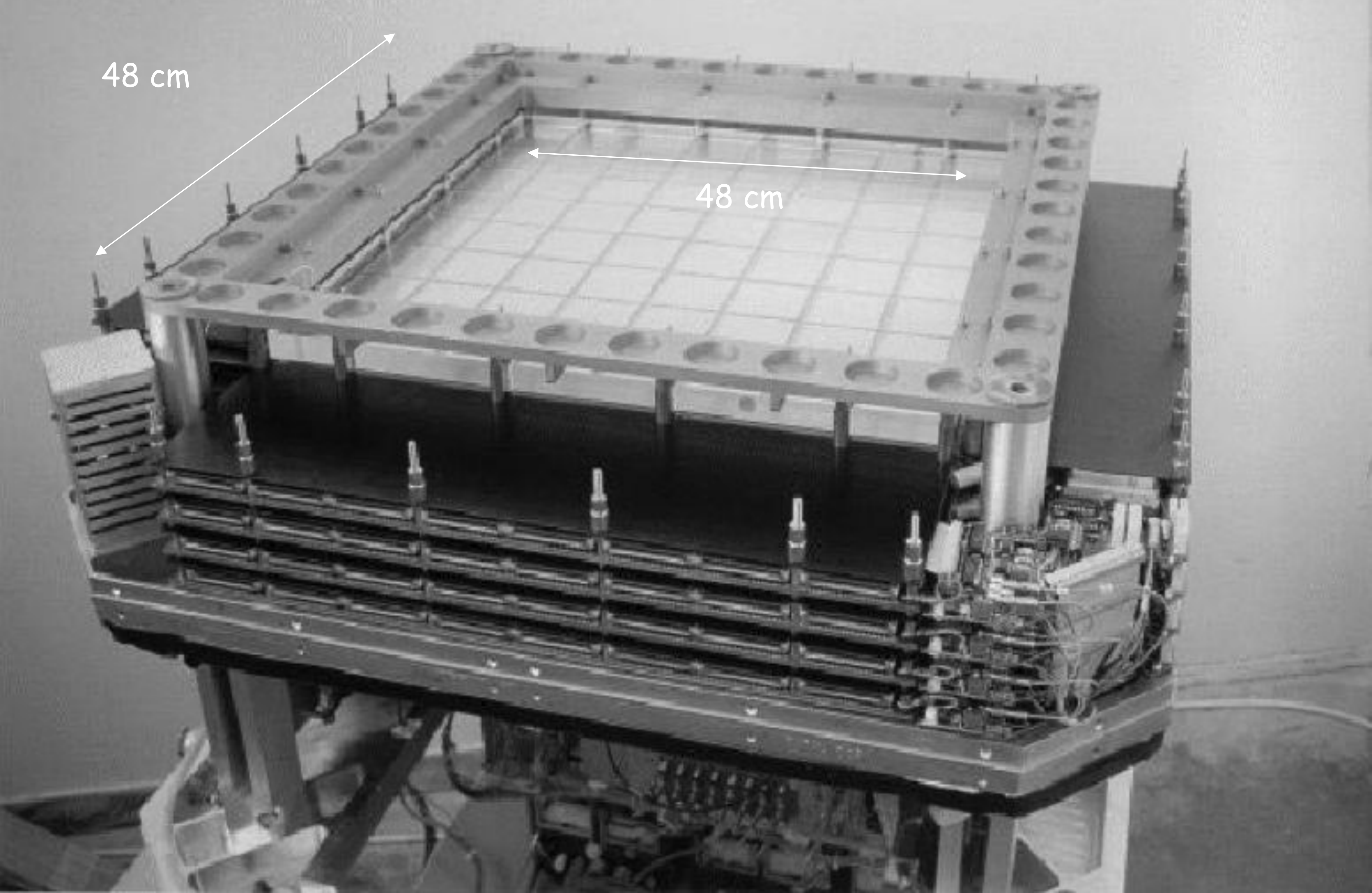
Below the conversion stack are two 4 x 4 arrays of plastic scintillation detector tiles spaced 60 cm apart which register the passage of charged particles. If the timeofflight delay indicates a downward moving particle which passed through a valid combination of upper and lower scintillator tiles, and 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.



ELSEVIER

Nuclear Instruments and Methods in Physics Research A 354 (1995) 547–552

NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH Section A

The GILDA mission: a new technique for a gamma-ray telescope in the energy range 20 MeV–100 GeV

G. Barbiellini [a], M. Boezio [a], M. Casolino [b], M. Candusso [b], M.P. De Pascale [b], A. Morselli [b,*], P. Picozza [b], M. Ricci [d], R. Sparvoli [b], P. Spillantini [c], A. Vacchi [a]

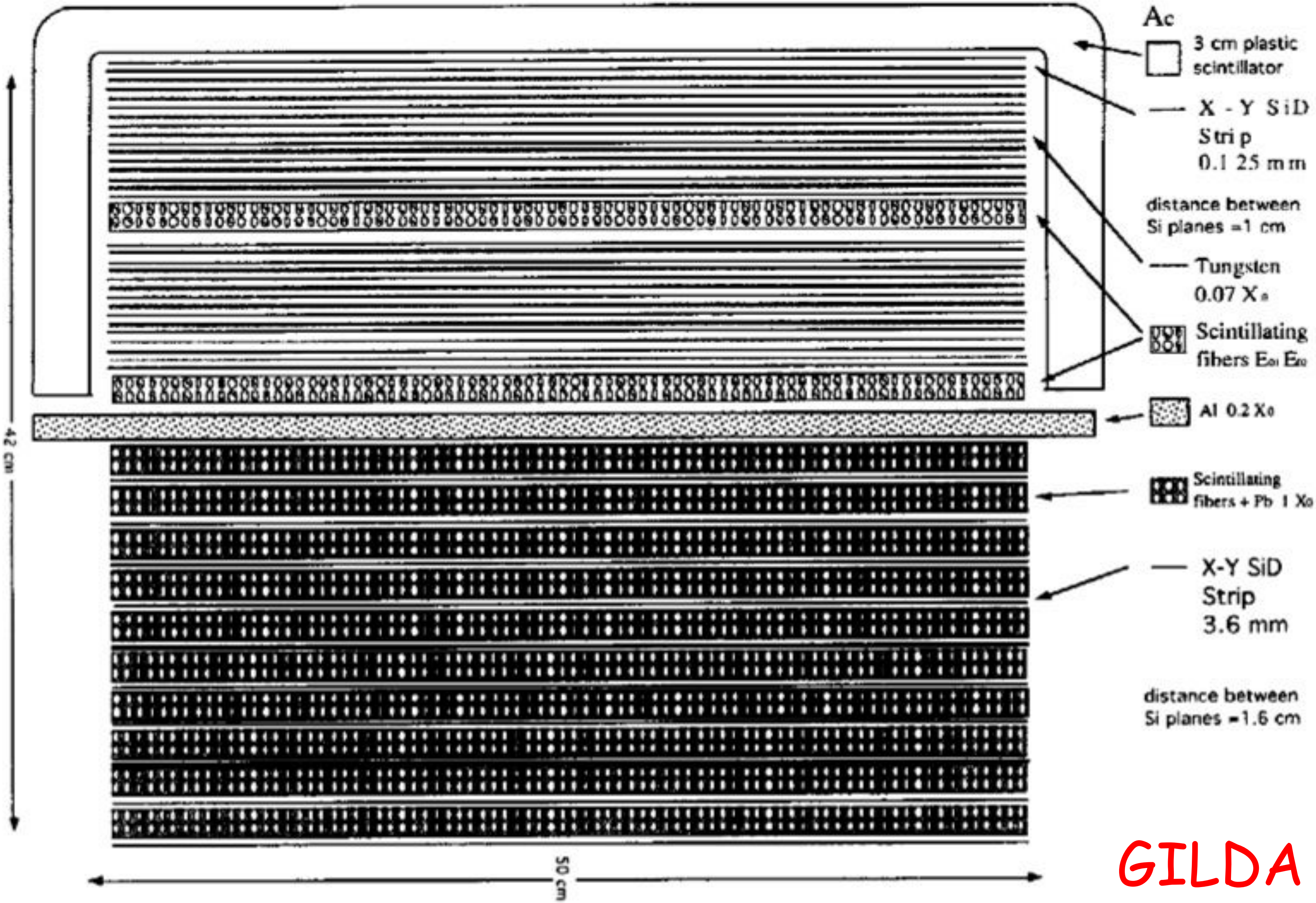
[a] *Dept. of Physics, Univ. of Trieste and INFN, Italy*
[b] *Dept. of Physics, II Univ. of Rome "Tor Vergata" and INFN, Italy*
[c] *Dept. of Physics, Univ. of Firenze and INFN, Italy*
[d] *INFN Laboratori Nazionali di Frascati, Italy*

Received 5 August 1994

Abstract

In this article a new technique for the realization of a high energy gamma-ray telescope is presented, based on the adoption of silicon strip detectors and lead scintillating fibers. The simulated performances of such an instrument (GILDA) are significatively better than those of EGRET, the last successful experiment of a high energy gamma-ray telescope, launched on the CGRO satellite, though having less volume and weight.

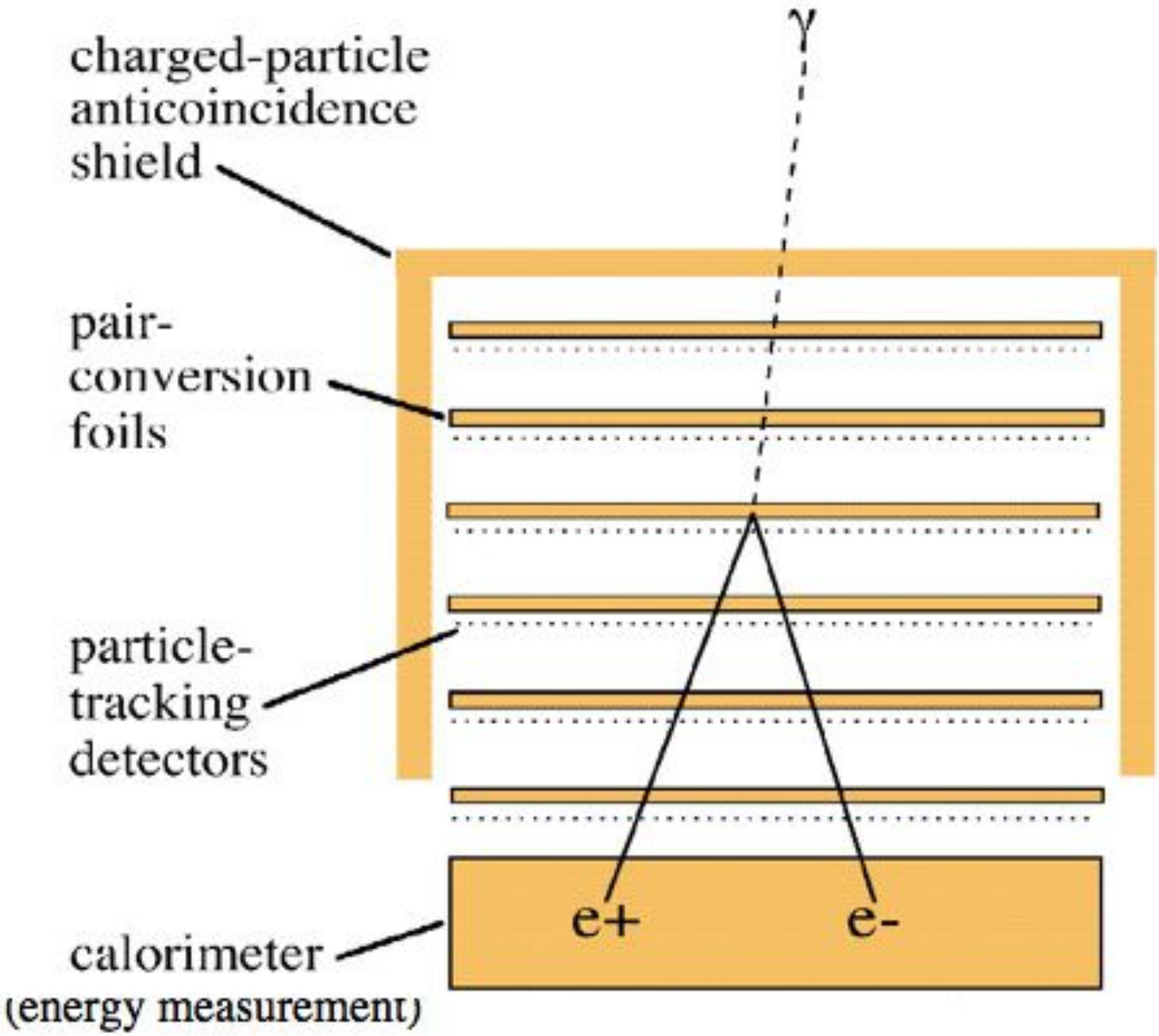
* Corresponding author.



GILDA

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

Elements of a pair-conversion telescope

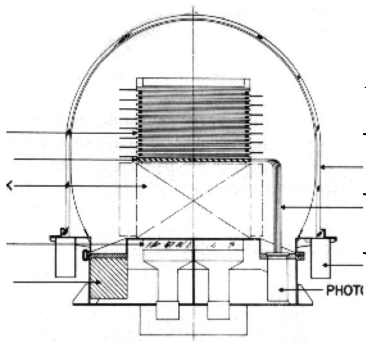


- photons materialize into matter-antimatter pairs:

  E_γ --> $m_{e+}c^2 + m_{e-}c^2$

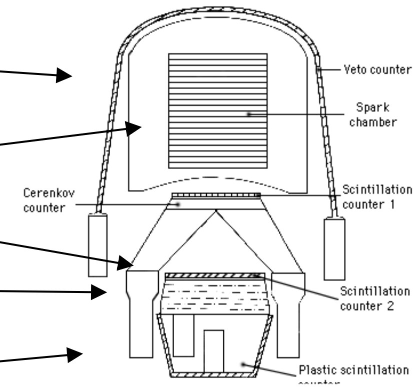
- electron and positron carry information about the direction, energy and polarization of the γ-ray

The gamma-ray missions

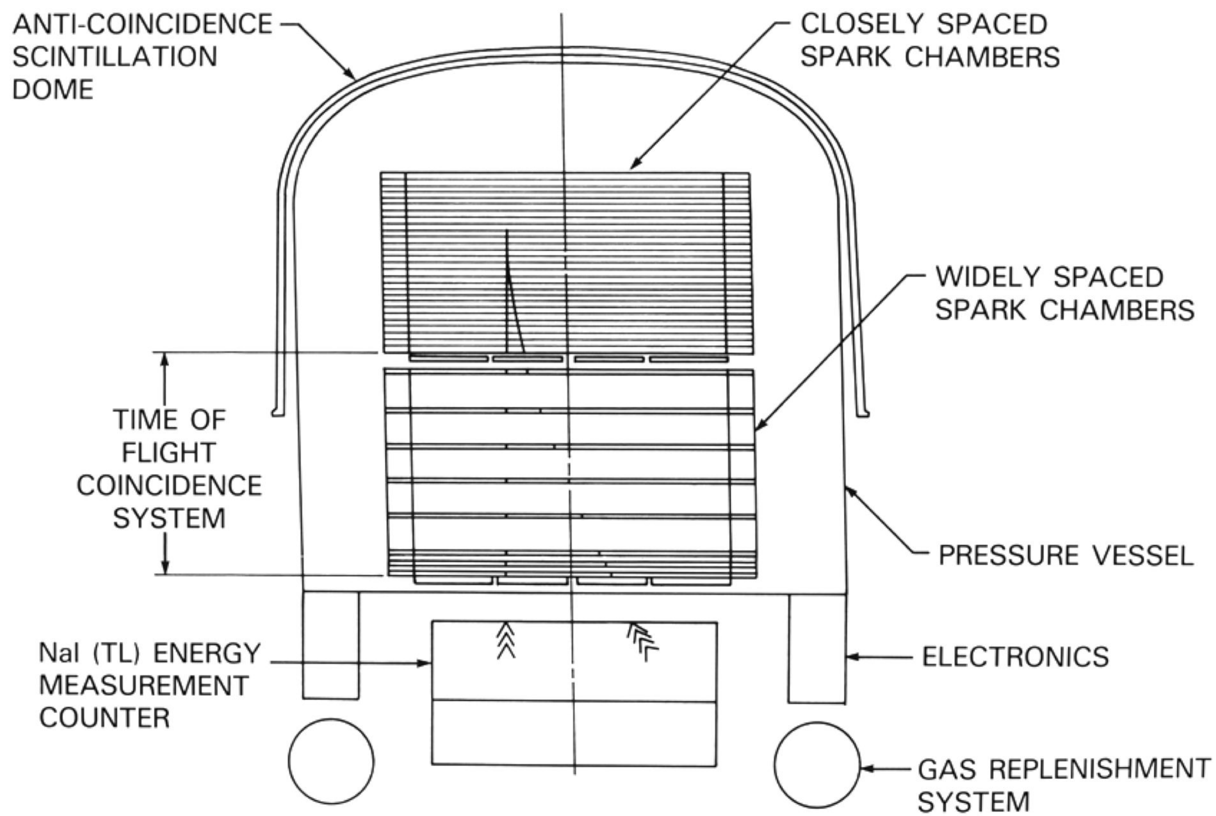


SAS-2
11/1972-7/1973

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

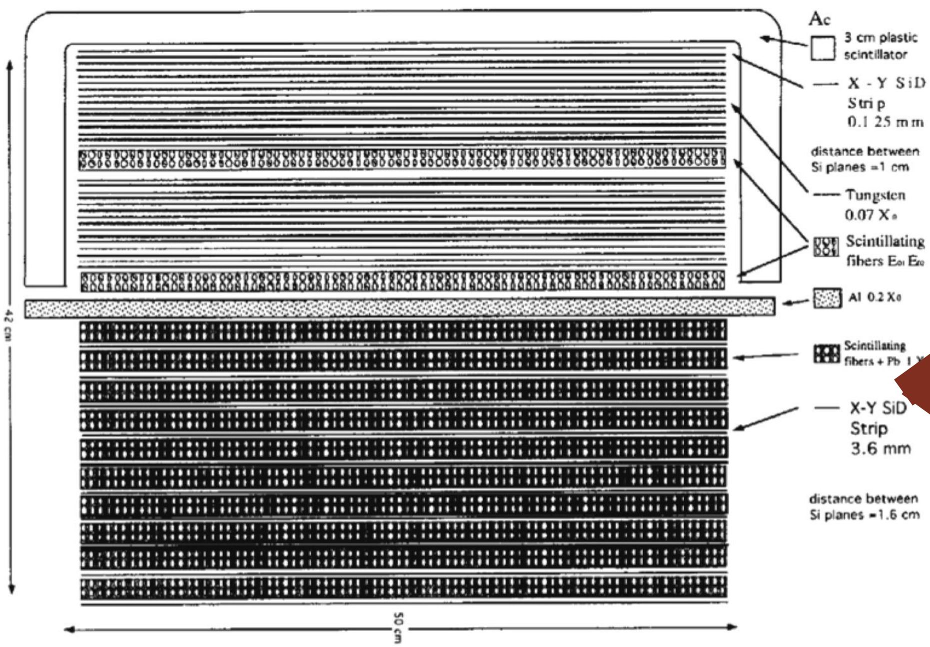


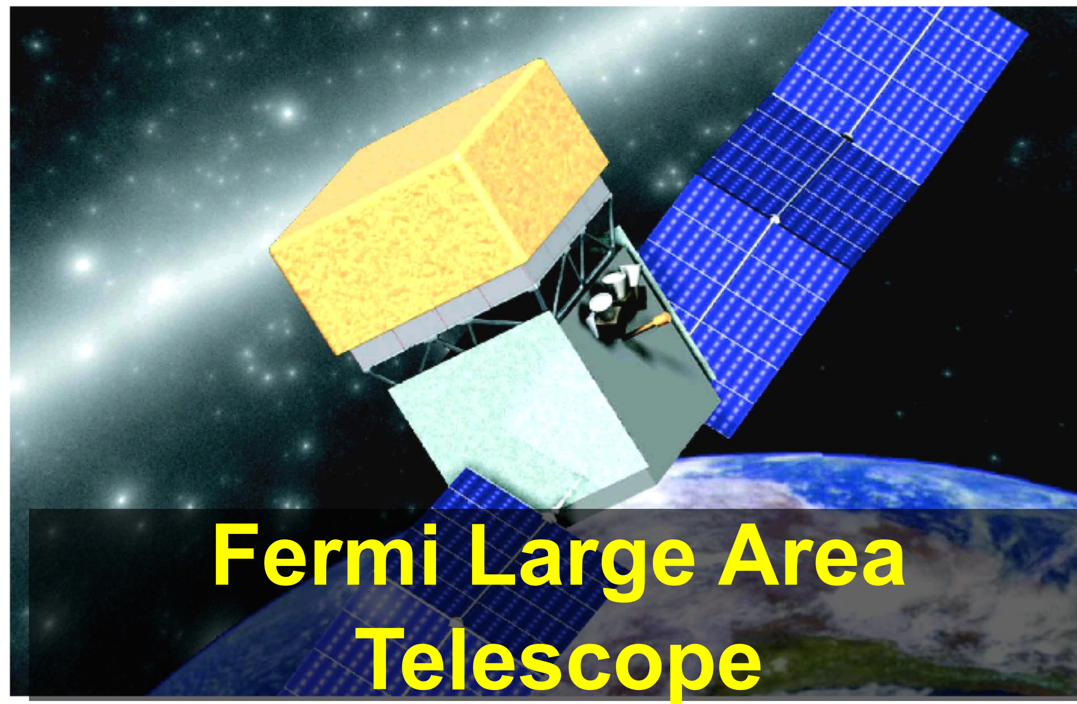
Cos-B
8/1975-4/1982



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

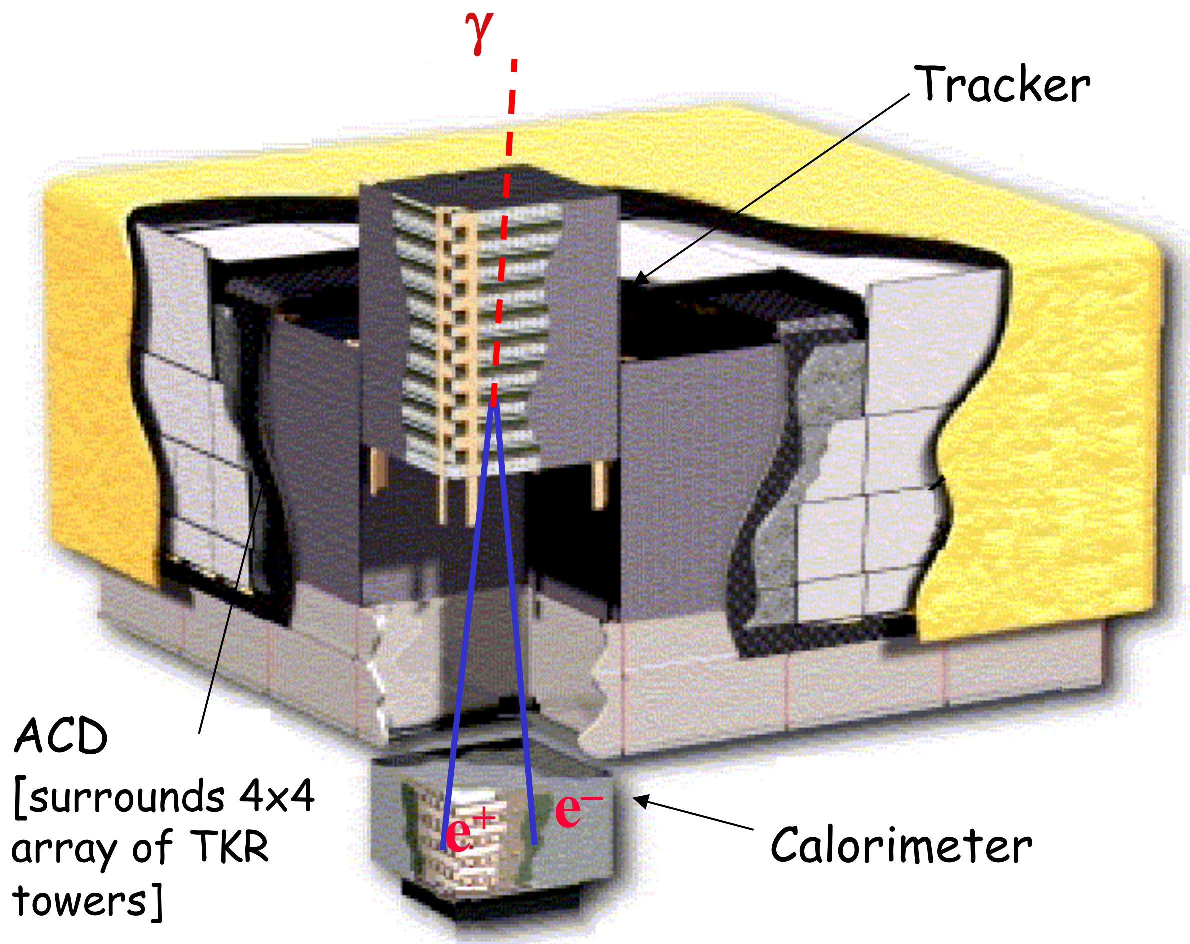
Happy 11th Birthday Fermi !!

11 June 2008

Pisa 15 March 2018

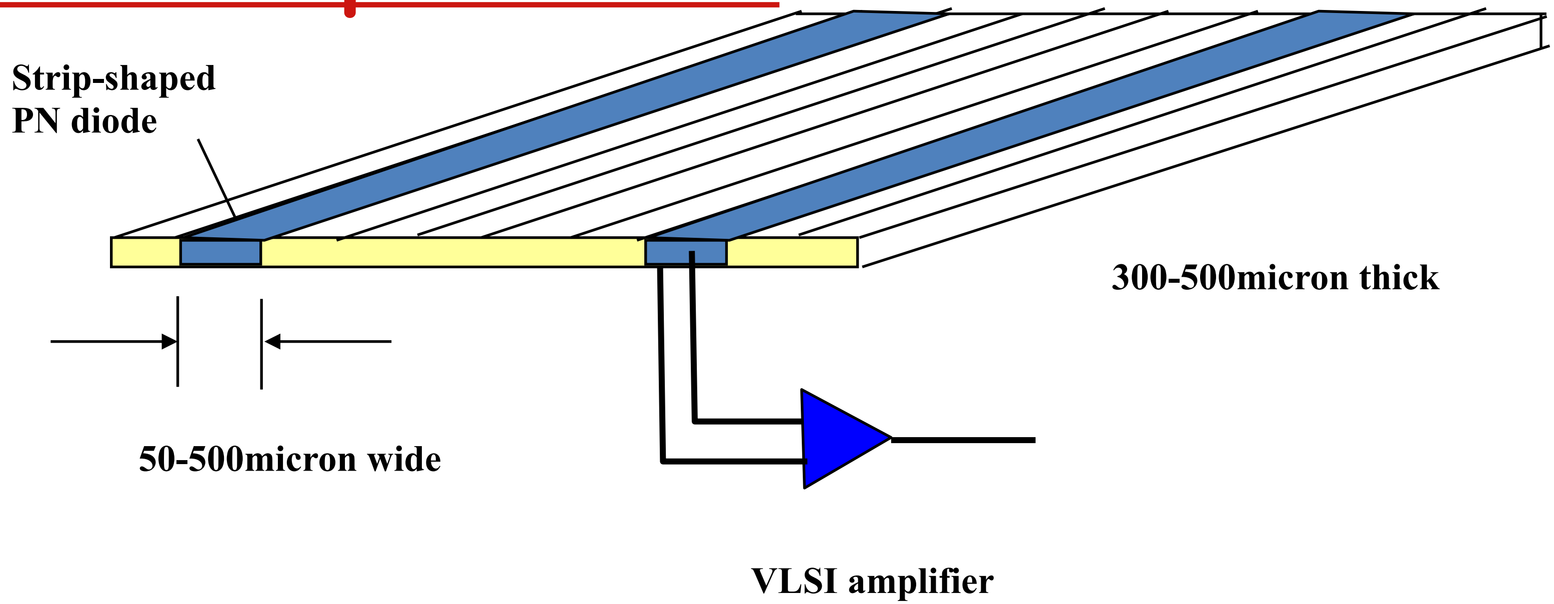
Fermi LAT: A Telescope Without Lenses

- 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

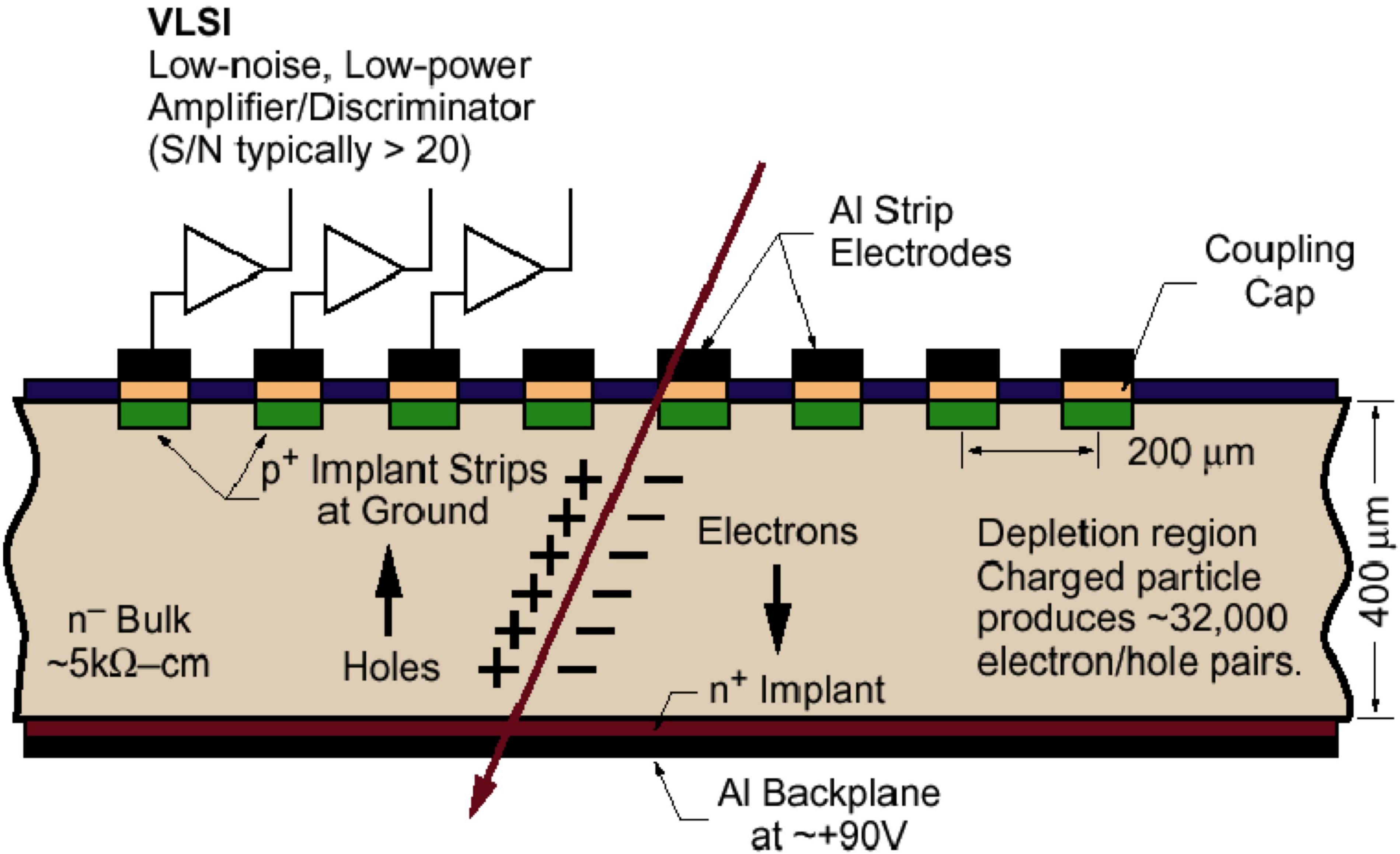
- **Silicon strip detector**



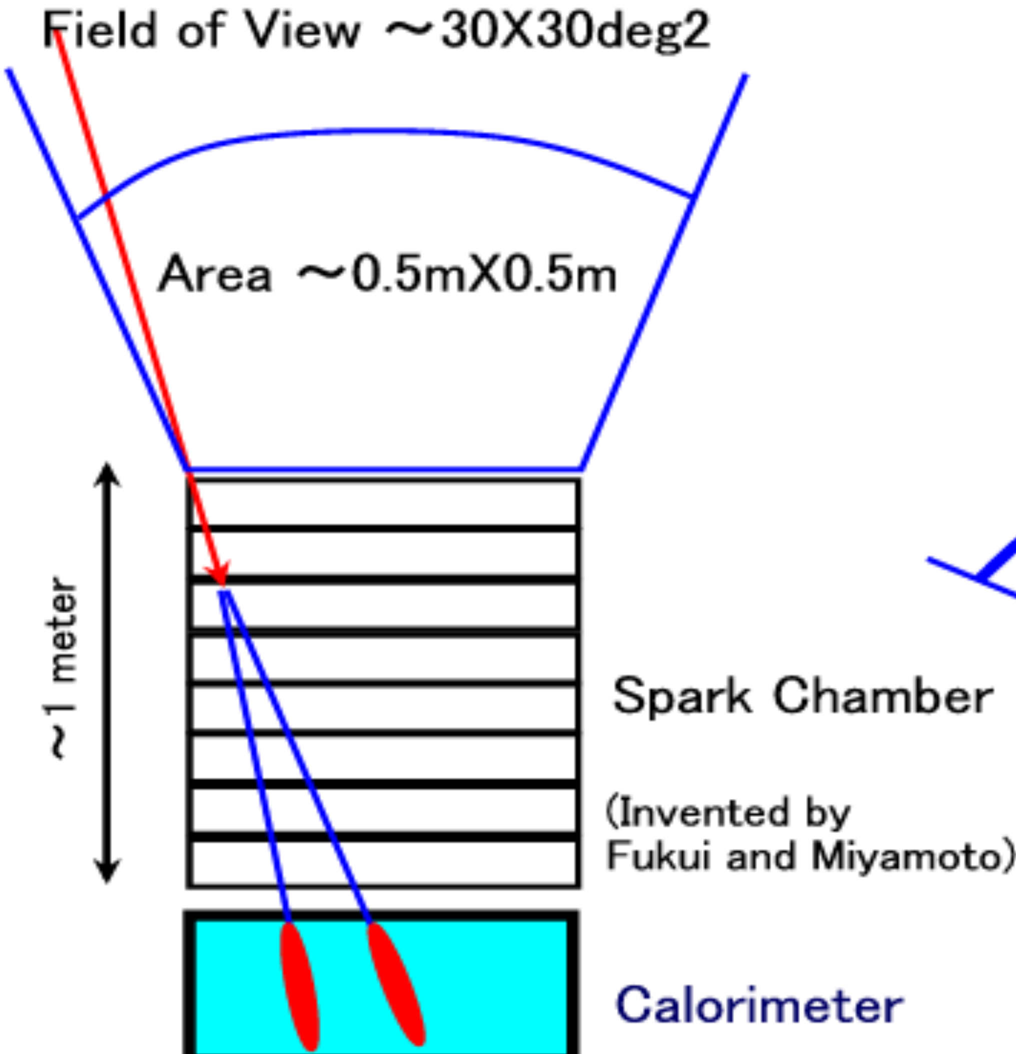
Stable particle tracker that allows micron-level tracking of gamma-rays

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)

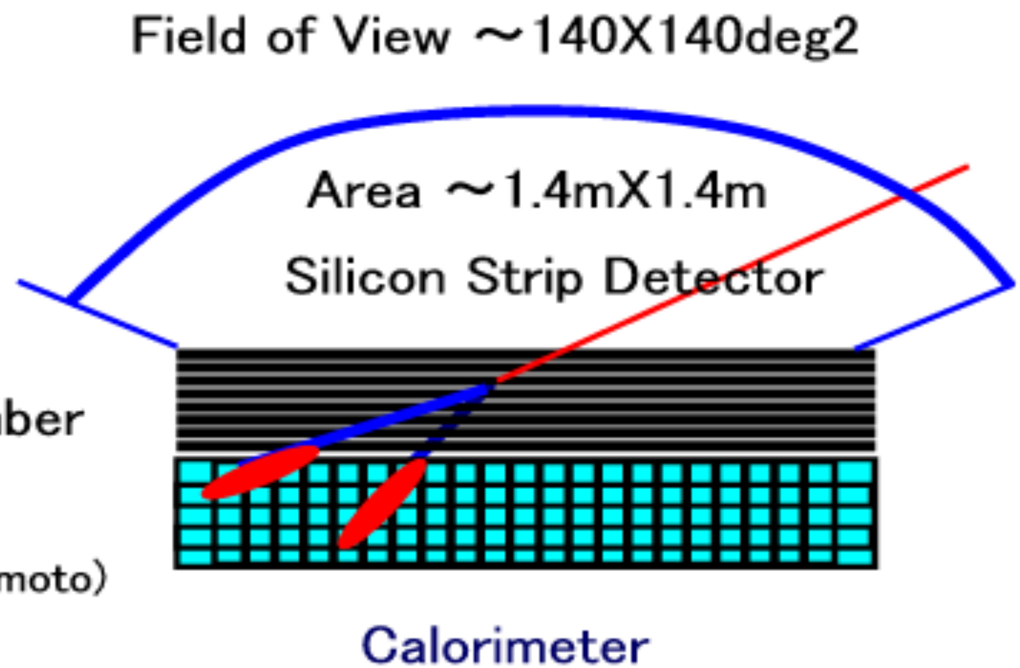
Silicon Strip Detector Principle



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



EGRET on Compton GRO
(1991-2000)



Fermi Large Area Telescope
(2008-2018)

The Fermi Observatory

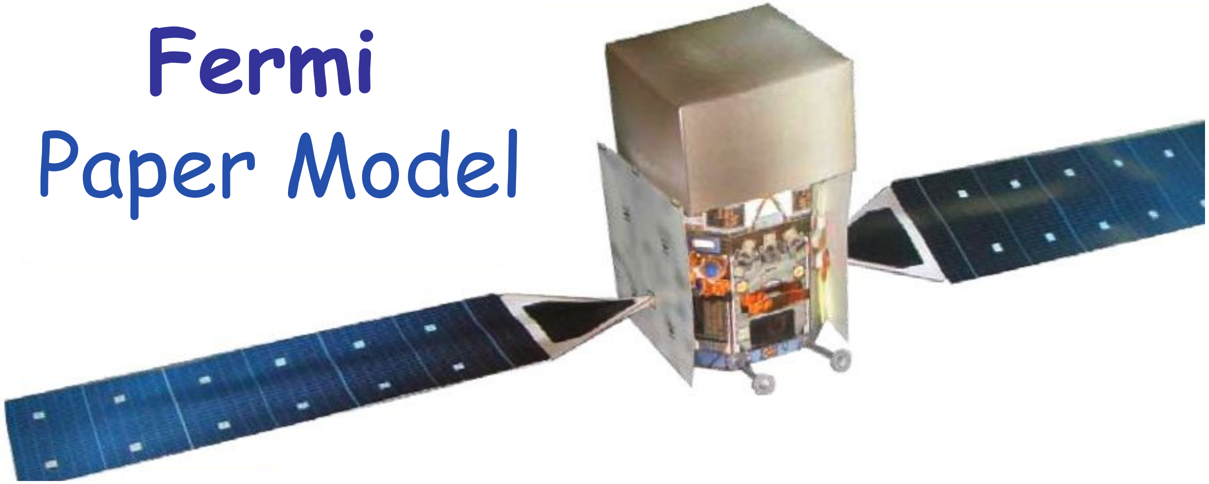
LAT
Large
Area
Telescope

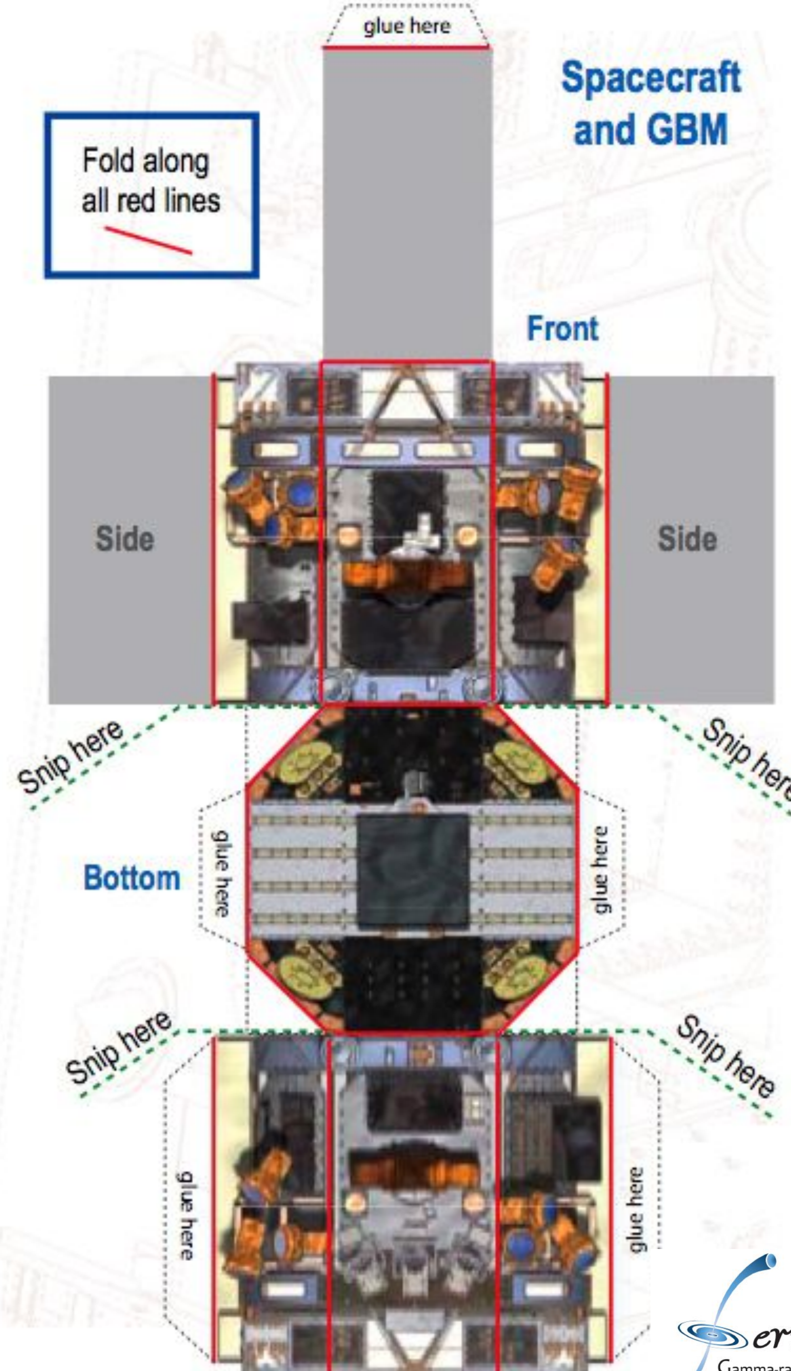
GBM
Sodium Iodide
Detector

GBM
Bismuth
Germanate
Detector

Fermi Prior to Fairing Installation

Fermi
Paper Model

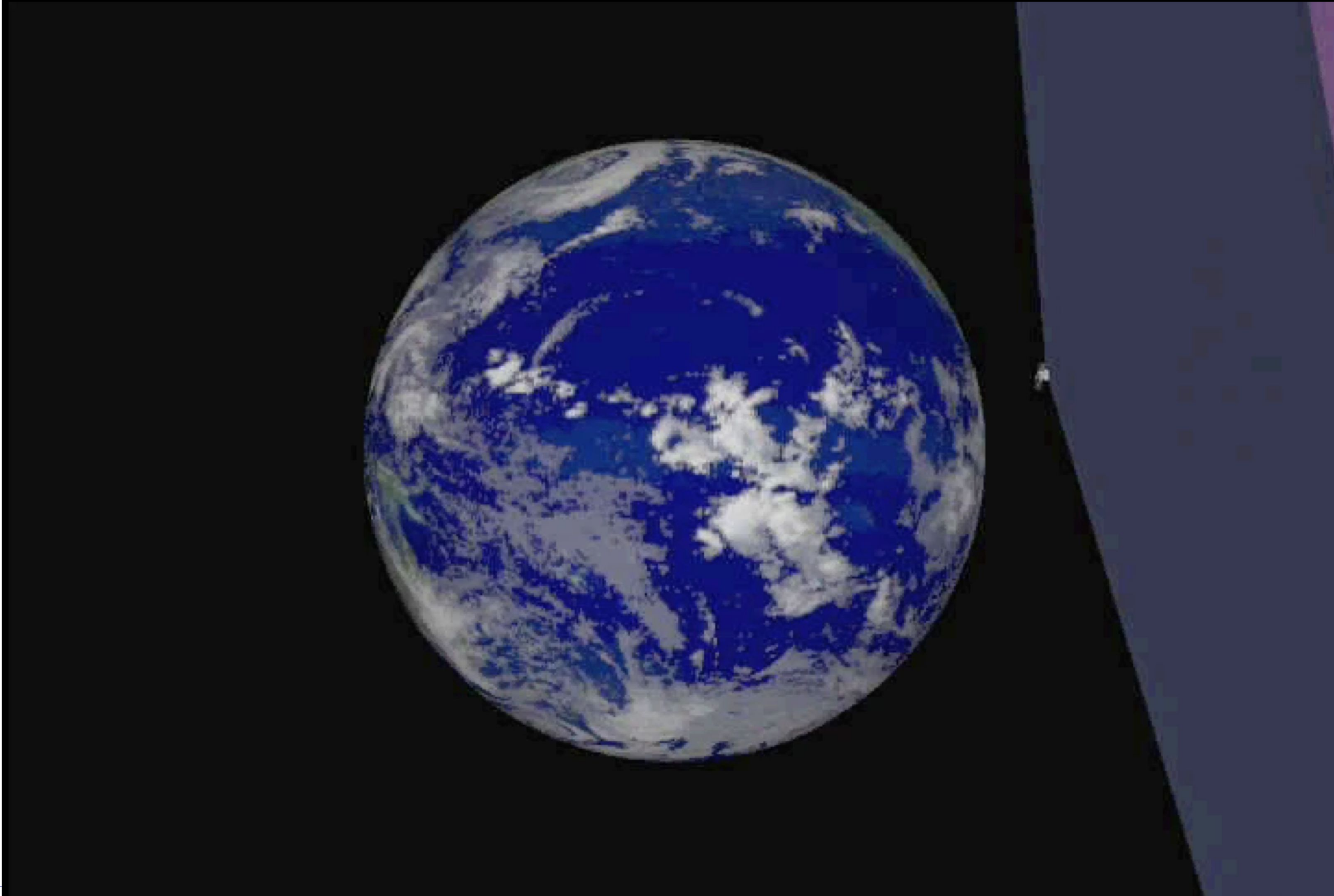




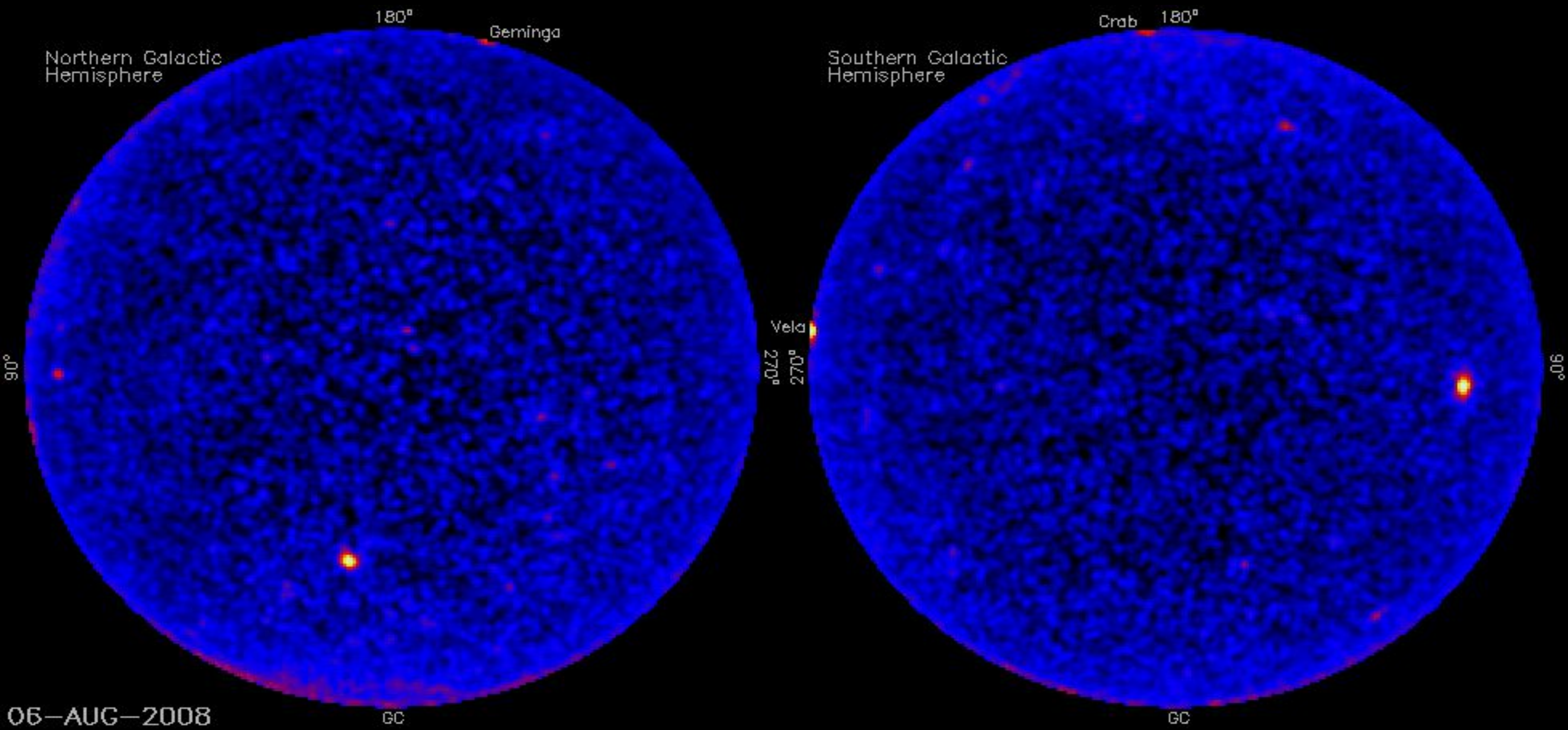
http://people.roma2.infn.it/~aldo/GLASTpaperModel.pdf

Fermi Gamma-ray Space Telescope

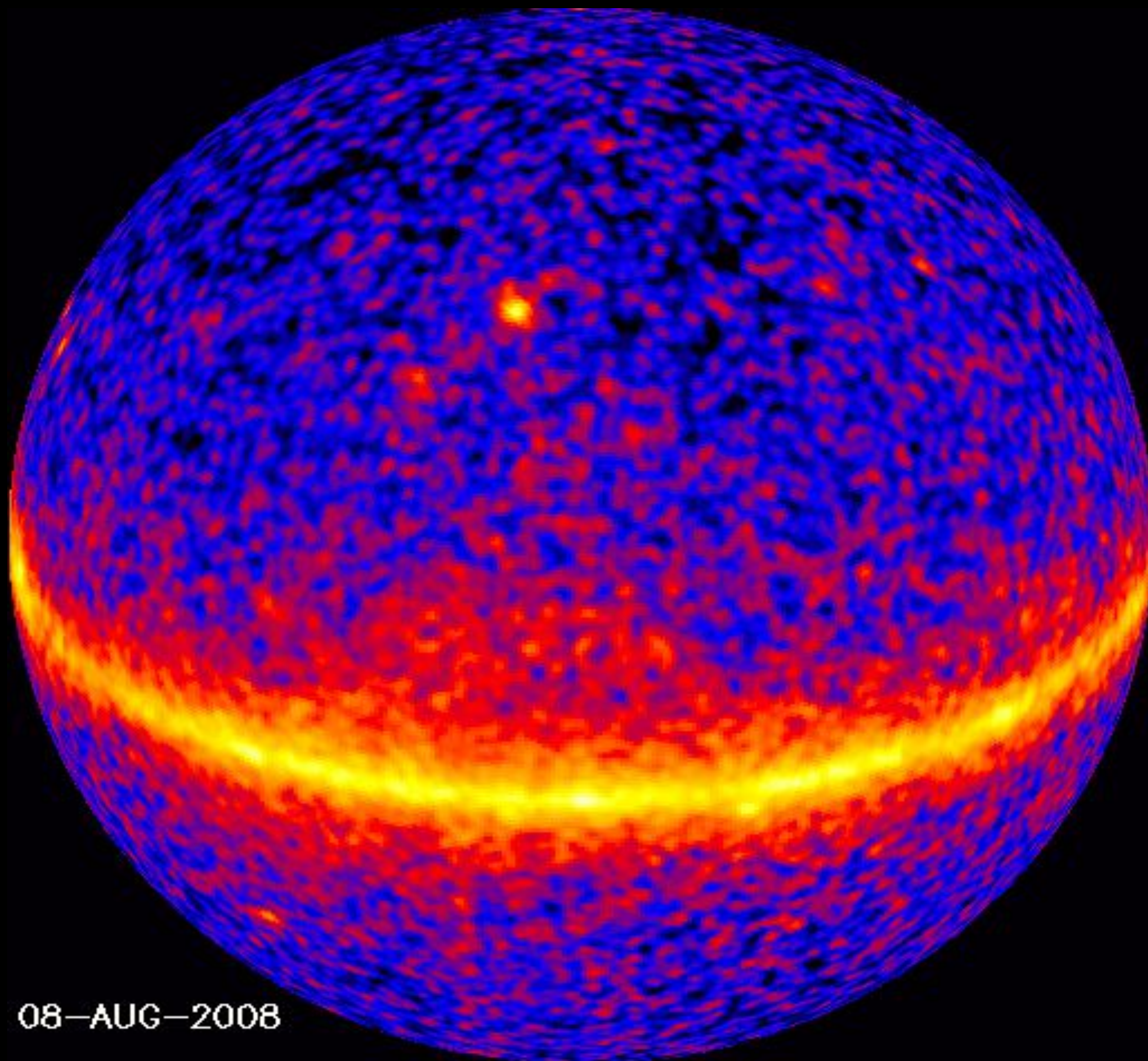

11 June 2008

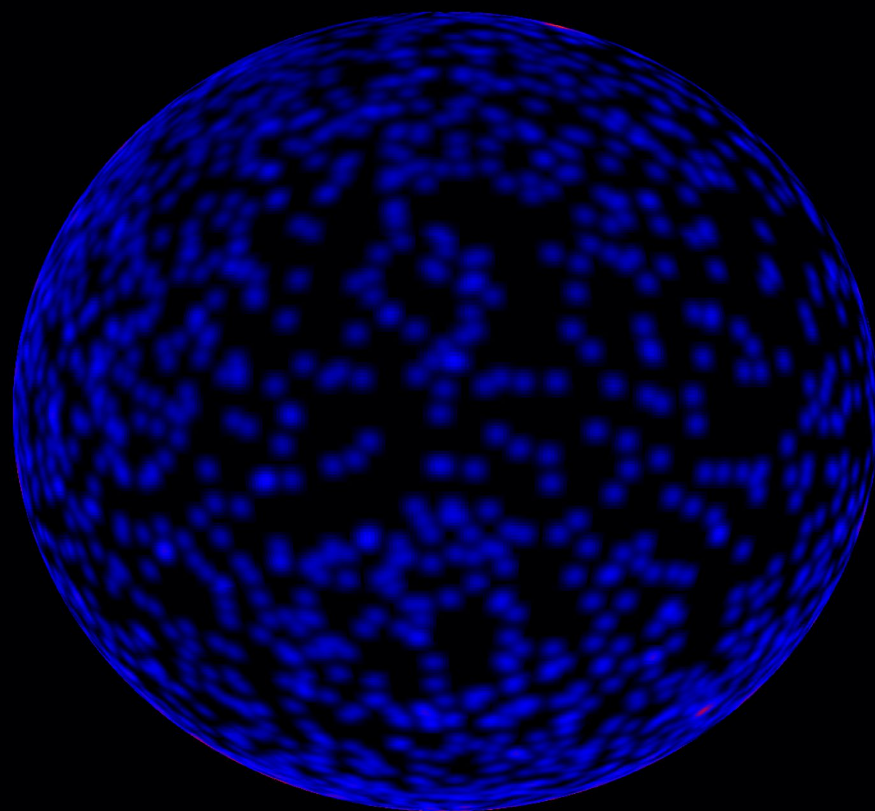


Daily Gamma-ray Sky

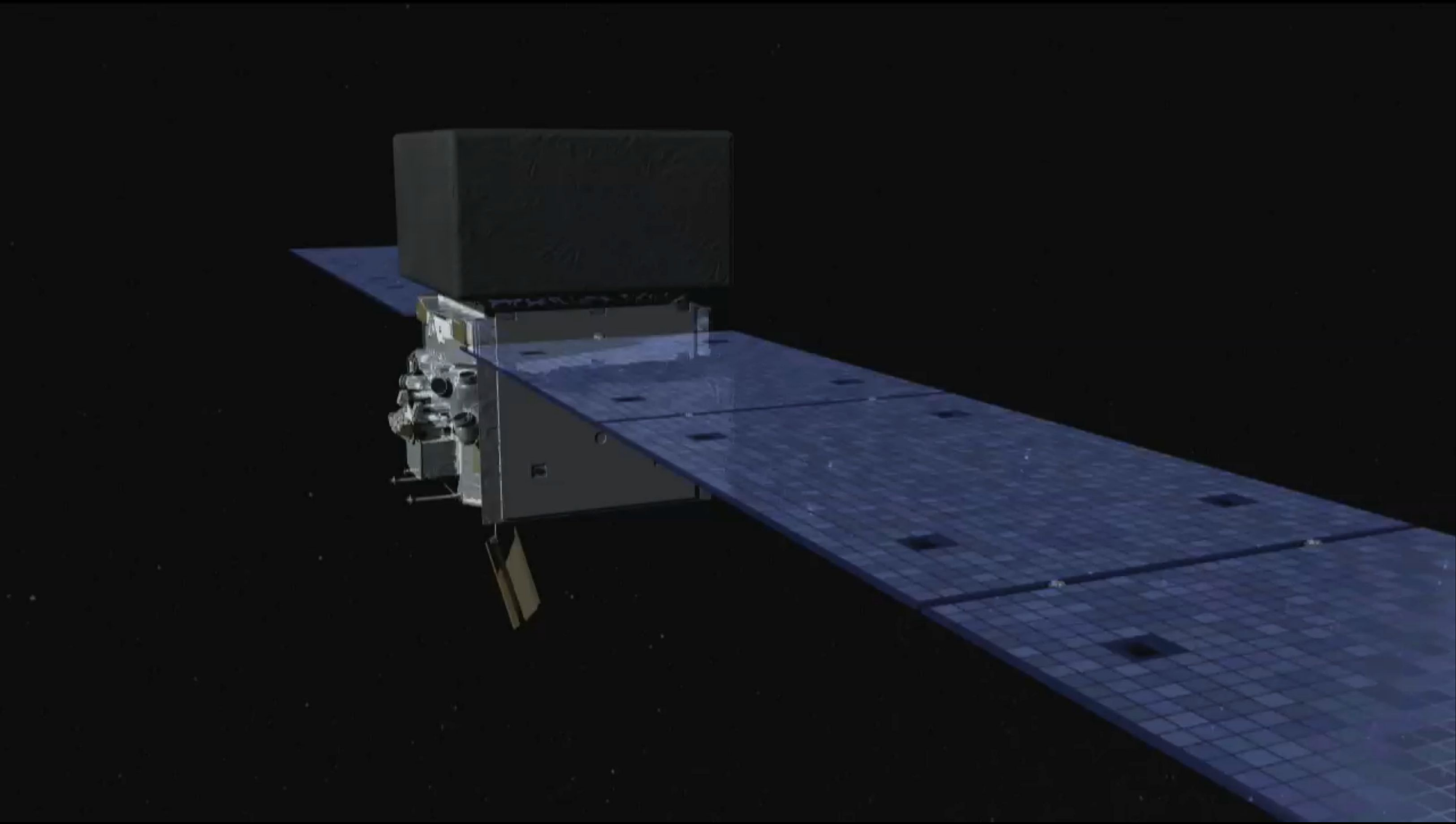


Daily Gamma-ray Sky

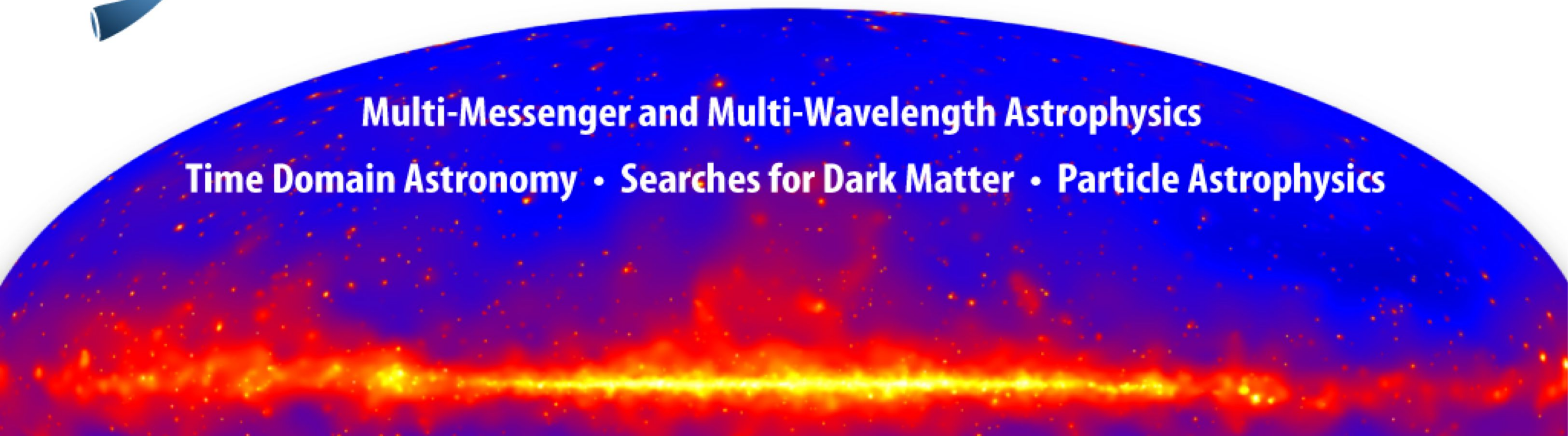


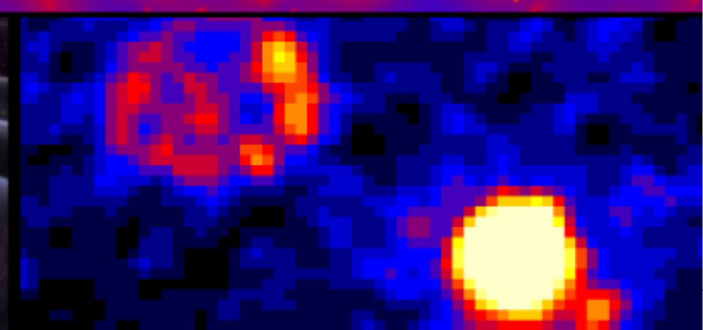


8 may 2013

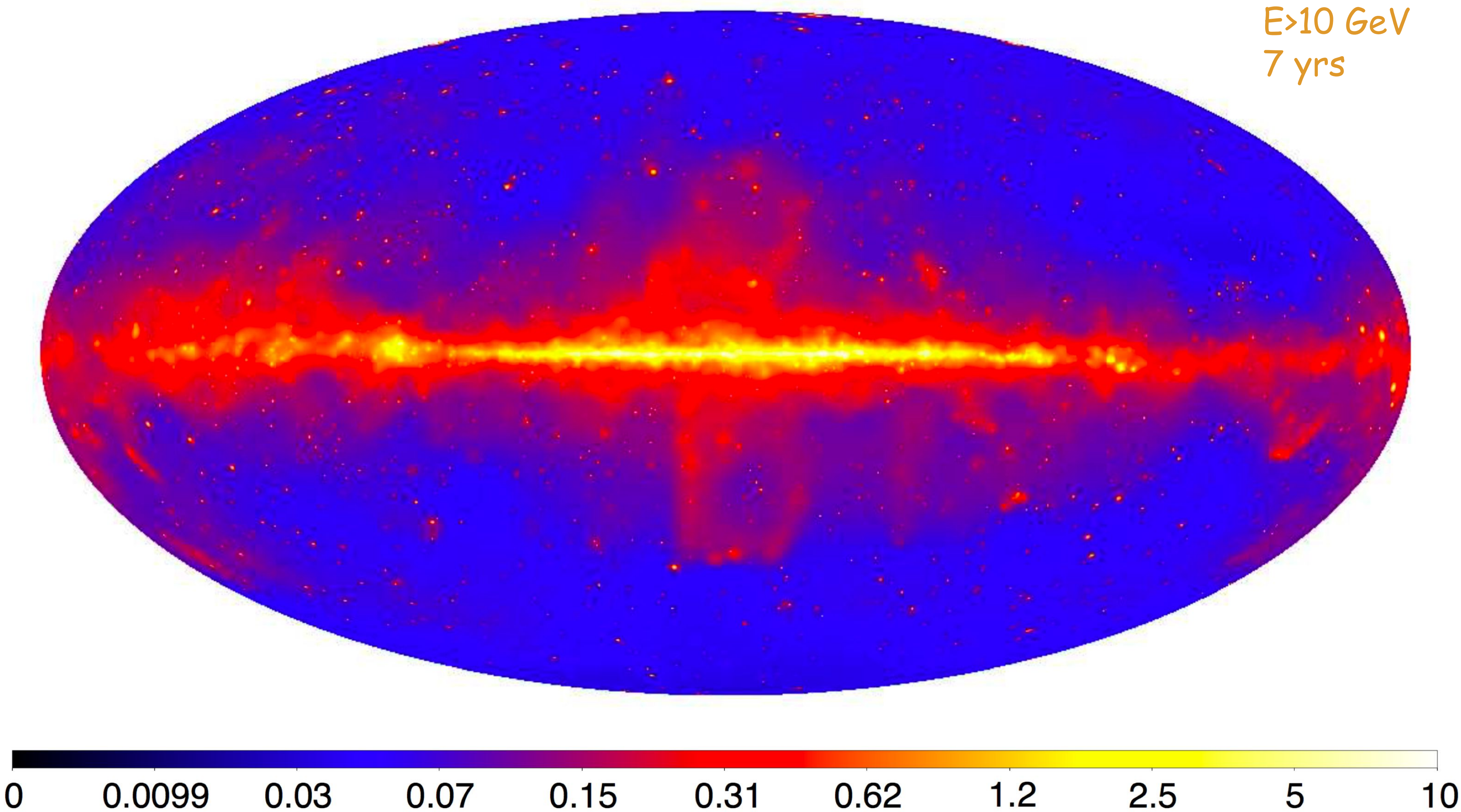


fermi Gamma-Ray Space Telescope





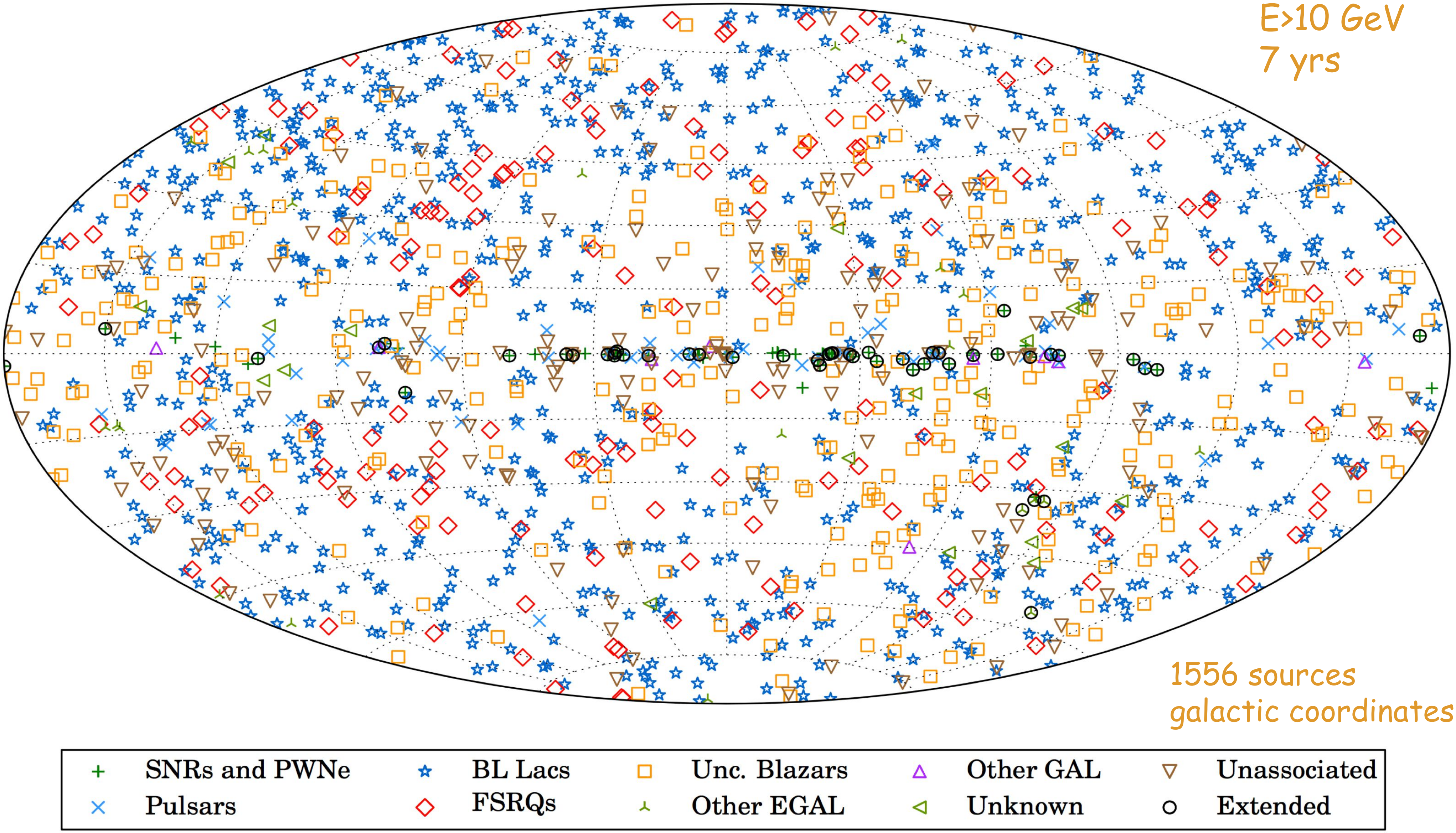
The sky in gamma-rays



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

The sky in gamma-rays

E>10 GeV
7 yrs

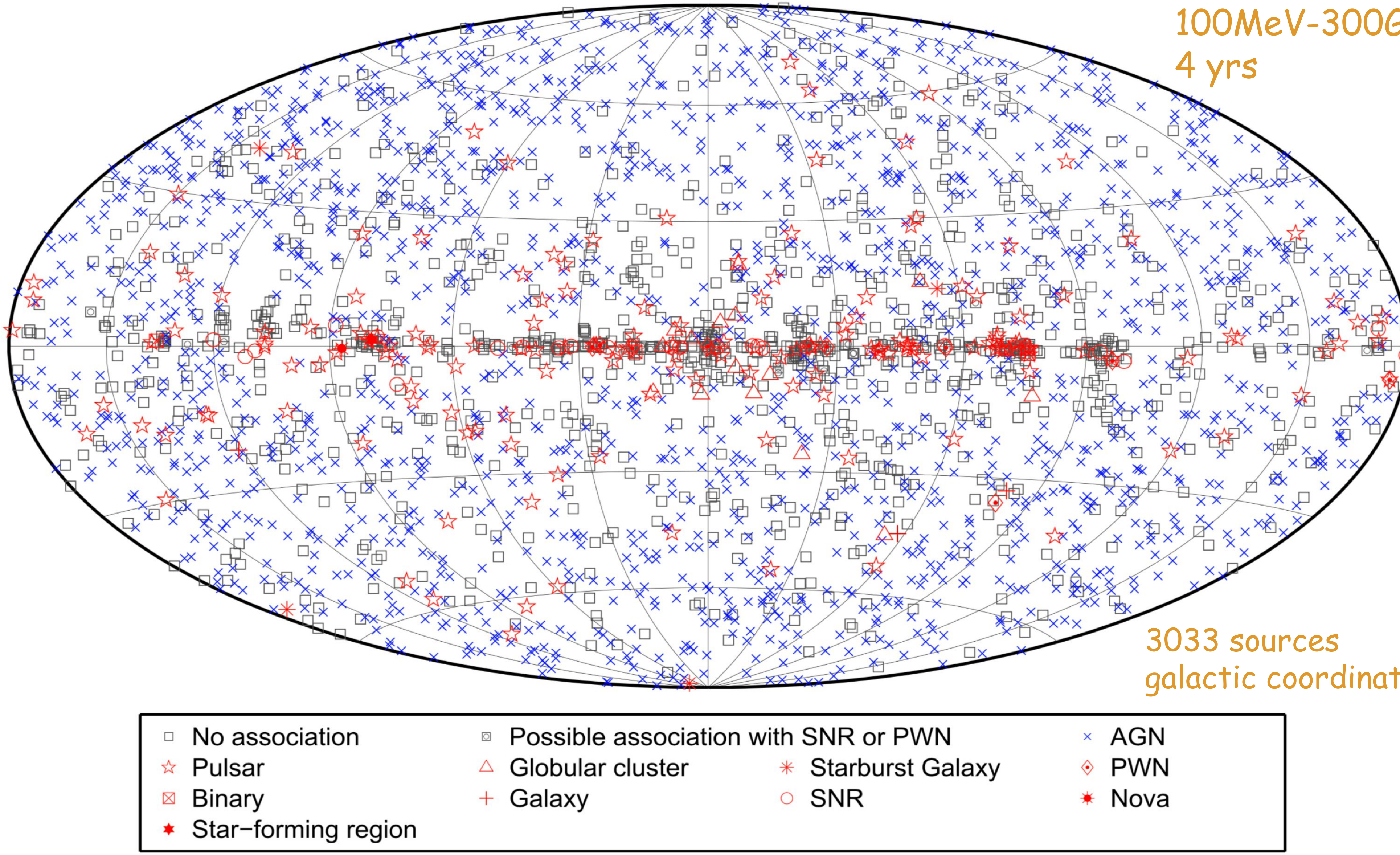


1556 sources
galactic coordinates

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 3rd source catalog

100MeV-300GeV
4 yrs

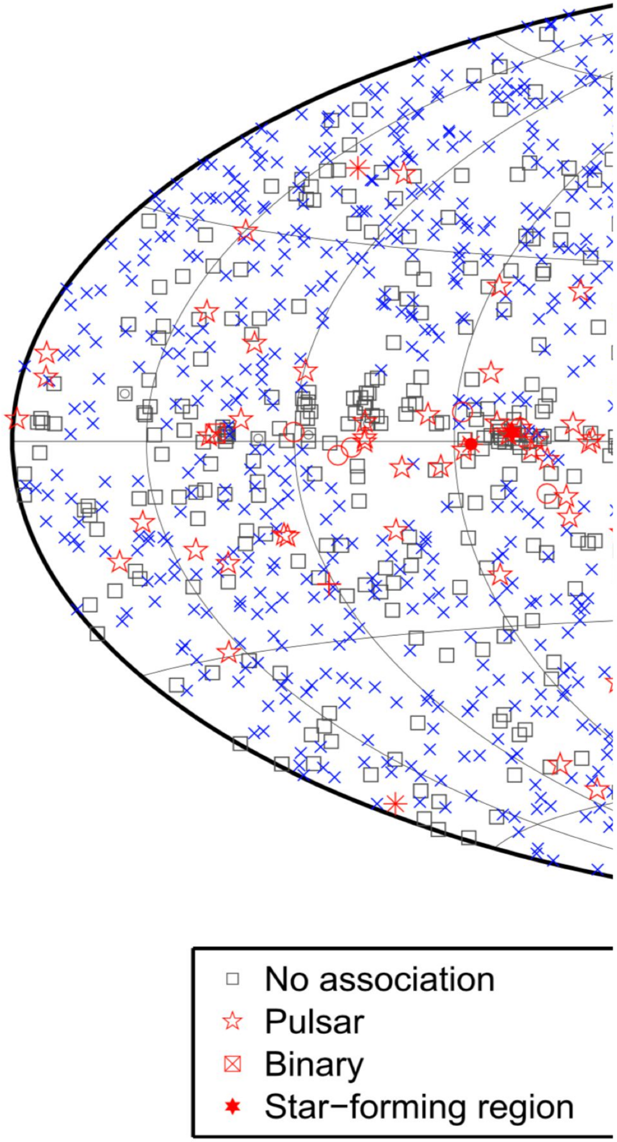


3033 sources
galactic coordinates

F.Acero et al. [Fermi Coll.] Fermi Third Catalog ApJS 2015 218 arXiv: 1501.02003

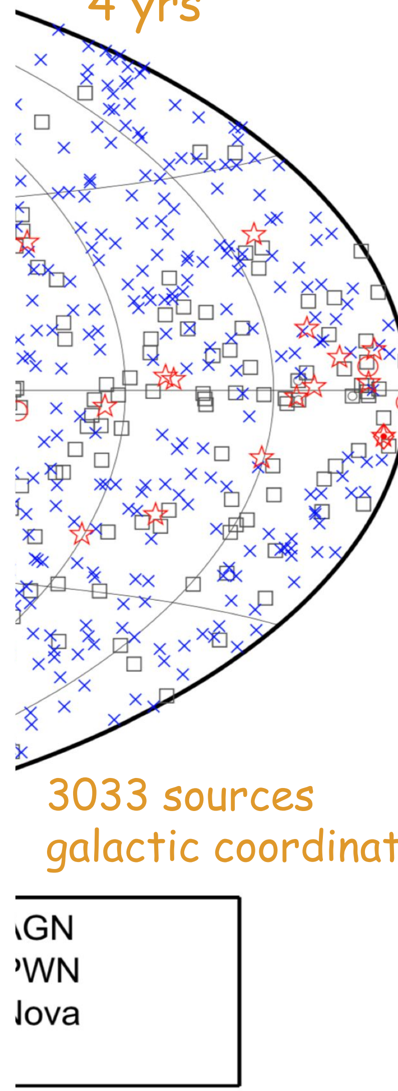
The sky in gamma-rays 3rd source catalog

100MeV-300GeV
4 yrs



LAT 3FGL Source Classes

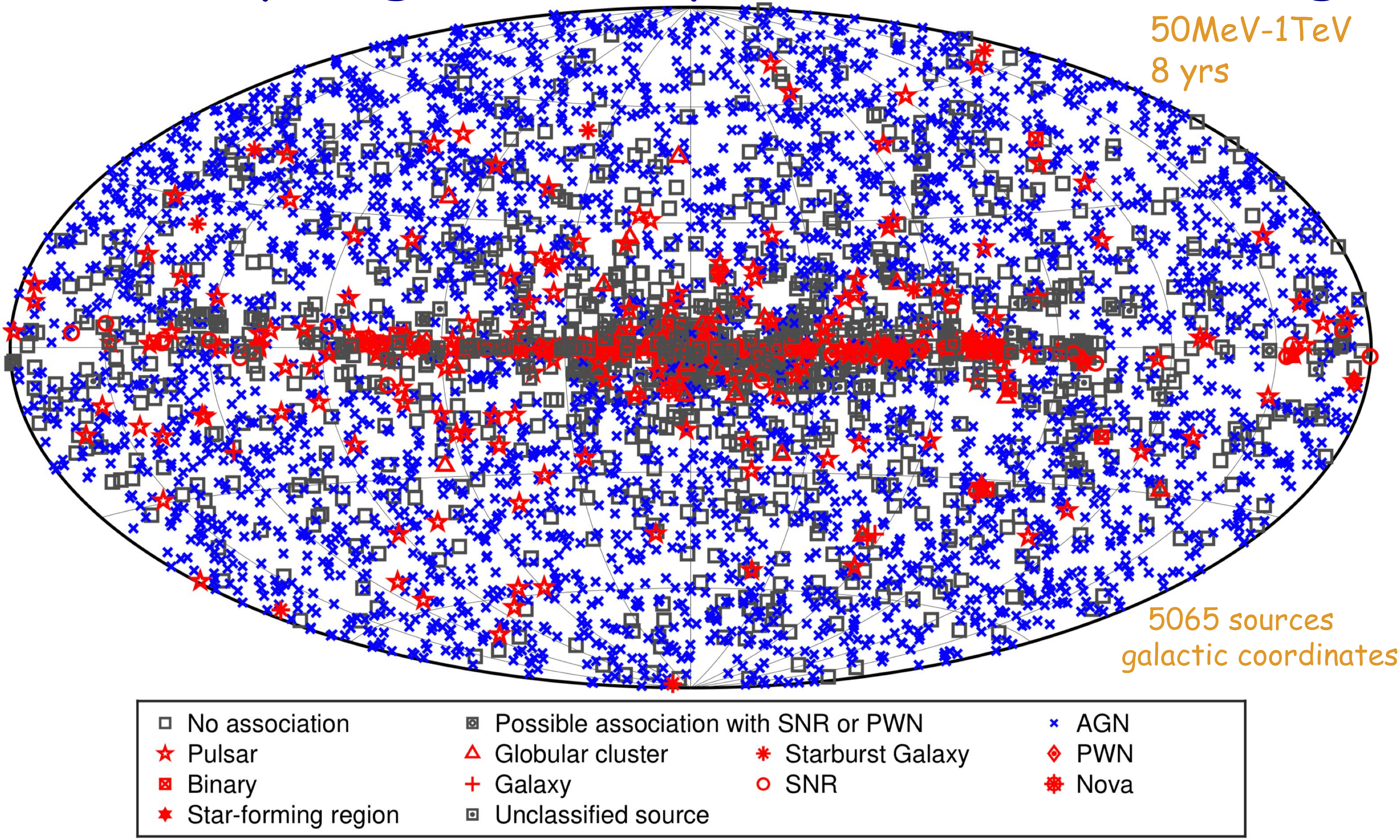
Description	Identified		Associated	
	Designator	Number	Designator	Number
Pulsar, identified by pulsations	PSR	143	...	...
Pulsar, no pulsations seen in LAT yet	...	...	psr	24
Pulsar wind nebula	PWN	9	pwn	2
Supernova remnant	SNR	12	snr	11
Supernova remnant/pulsar wind nebula	...	...	spp	49
Globular cluster	GLC	0	glc	15
High-mass binary	HMB	3	hmb	0
Binary	BIN	1	bin	0
Nova	NOV	1	nov	0
Star-forming region	SFR	1	sfr	0
Compact steep spectrum quasar	CSS	0	css	1
BL Lac type of blazar	BLL	18	bll	642
FSRQ type of blazar	FSRQ	38	fsrq	446
Non-blazar active galaxy	AGN	0	agn	3
Radio galaxy	RDG	3	rdg	12
Seyfert galaxy	SEY	0	sey	1
Blazar candidate of uncertain type	BCU	5	bcu	568
Normal galaxy (or part)	GAL	2	gal	1
Starburst galaxy	SBG	0	sbg	4
Narrow-line Seyfert 1	NLSY1	2	nlsy1	3
Soft-spectrum radio quasar	SSRQ	0	ssrq	3
Total	...	238	...	1785
Unassociated	...	...	...	1010



3033 sources
galactic coordinates

F.Acero et al. [Fermi Coll.] Fermi Third Catalog ApJS 2015 218 arXiv: 1501.02003

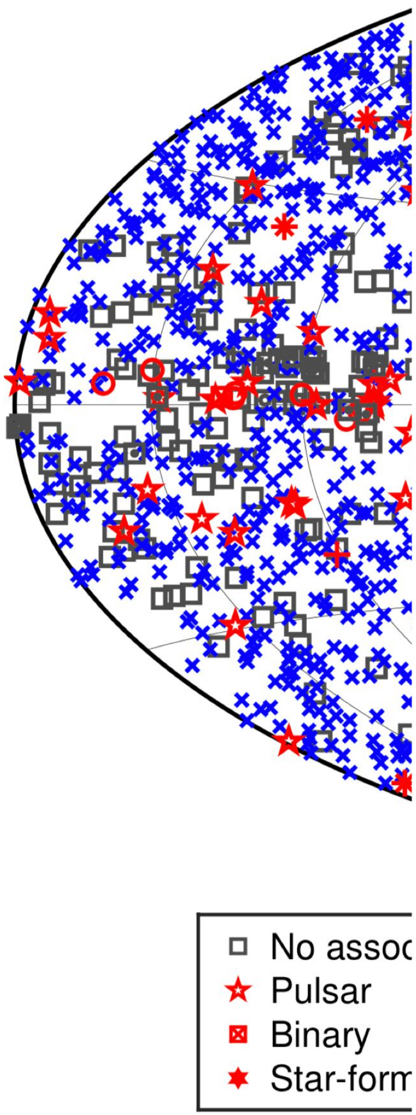
The sky in gamma-rays 4th source catalog



Fermi Fouth Source Catalog, arXiv:1902.10045_v3

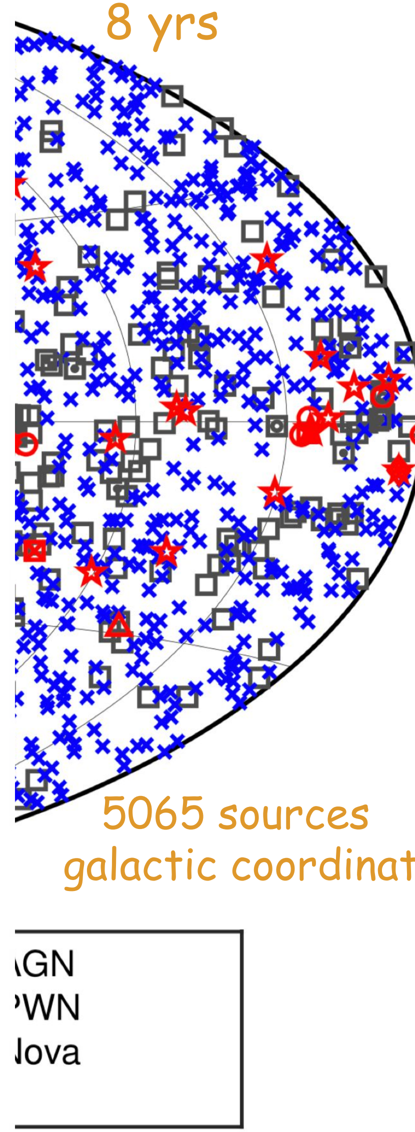
The sky in gamma-rays 4th source catalog

50MeV-1TeV
8 yrs



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

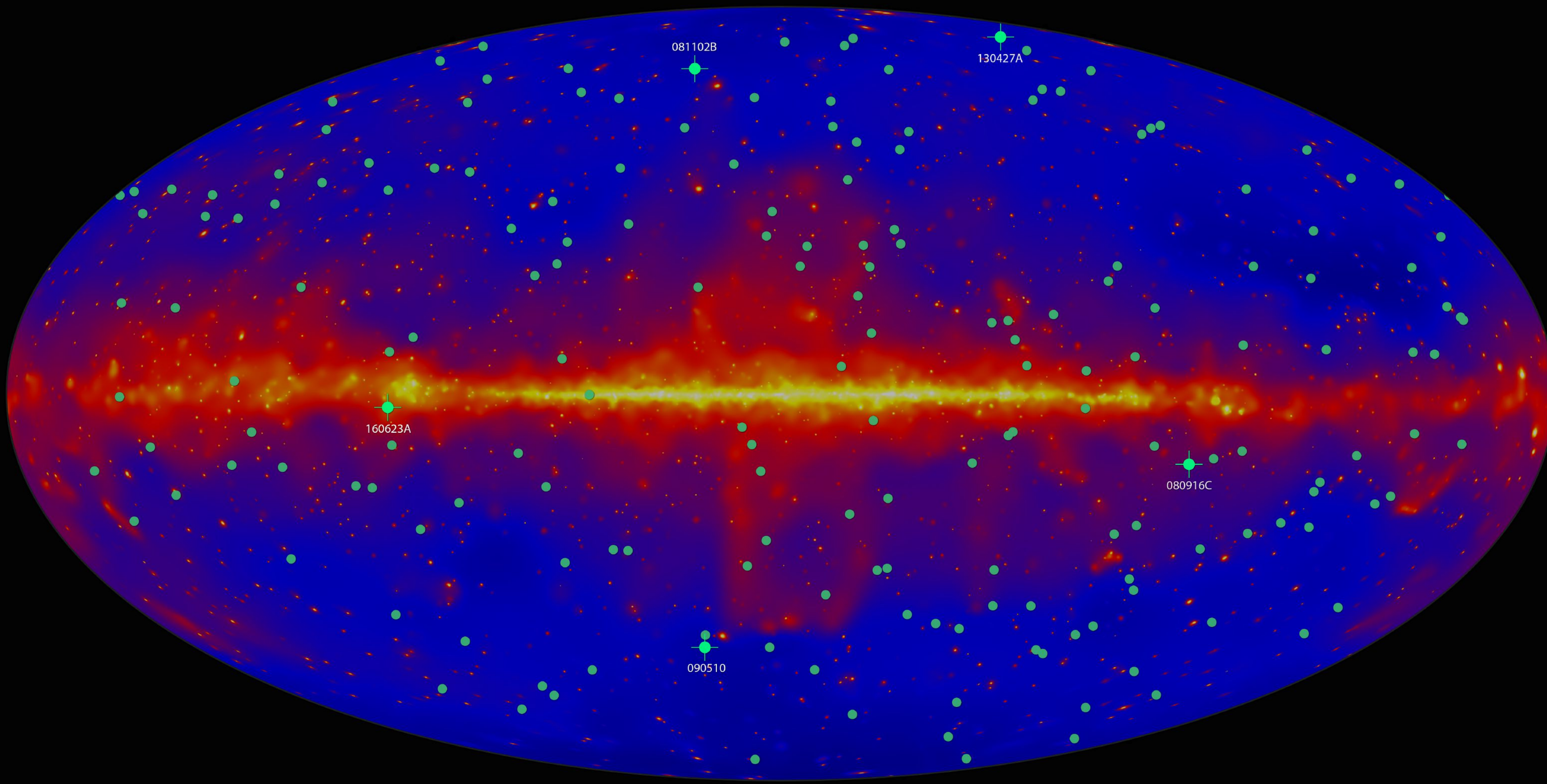
NOTE—The designation 'spp' indicates potential association with SNR or PWN. Designations shown in capital letters are firm identifications; lower case letters indicate associations.



5065 sources
galactic coordinates

Fermi Fouth Source Catalog, arXiv:1902.10045_v3

The 10 years GRB catalog



M.Ajello et al. [Fermi Coll.] A decade of Gamma-Ray Bursts observed by Fermi-LAT ApJS 878:52, 2019 June 10

[Previous | Next | ADS]

First time detection of a GRB at sub-TeV energies; MAGIC detects the GRB 190114C

ATel #12390; ***Razmik Mirzoyan on behalf of the MAGIC Collaboration***
on ***15 Jan 2019; 01:03 UT***
Credential Certification: Razmik Mirzoyan (Razmik.Mirzoyan@mpp.mpg.de)

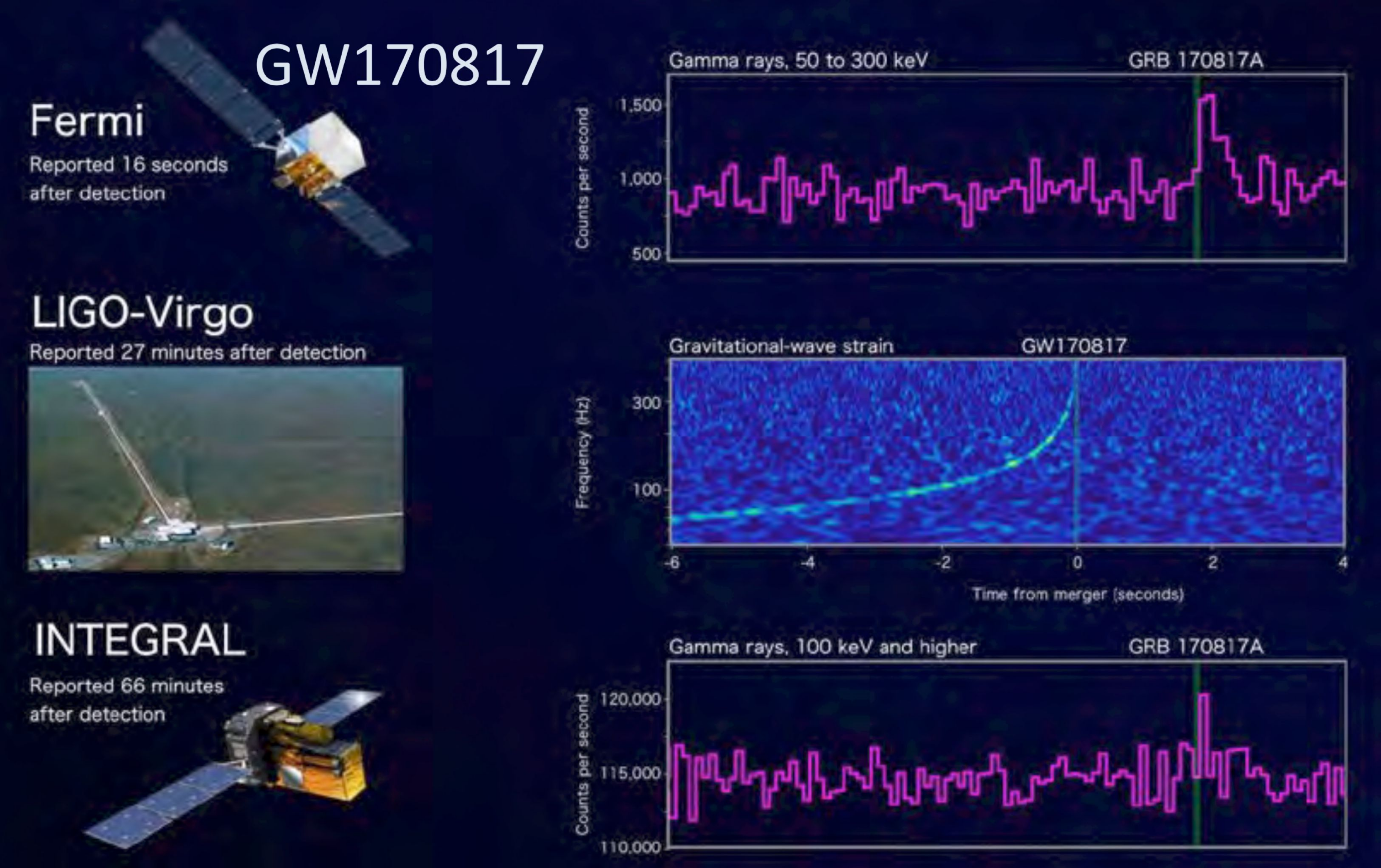
Subjects: Gamma Ray, >GeV, TeV, VHE, Request for Observations, Gamma-Ray Burst

Referred to by ATel #: 12395, 12475

Tweet

The MAGIC telescopes performed a rapid follow-up observation of GRB 190114C (Gropp et al., GCN 23688; Tyurina et al., GCN 23690, de Ugarte Postigo et al., GCN 23692, Lipunov et al. GCN 23693, Selsing et al. GCN 23695). This observation was triggered by the Swift-BAT alert; we started observing at about 50s after Swift T0: 20:57:03.19. The MAGIC real-time analysis shows a significance >20 sigma in the first 20 min of observations (starting at T0+50s) for energies >300GeV. The relatively high detection threshold is due to the large zenith angle of observations (>60 degrees) and the presence of partial Moon. Given the brightness of the event, MAGIC will continue the observation of GRB 190114C until it is observable tonight and also in the next days. We strongly encourage follow-up observations by other instruments. The MAGIC contact persons for these observations are R. Mirzoyan (Razmik.Mirzoyan@mpp.mpg.de) and K. Noda (nodak@icrr.u-tokyo.ac.jp). MAGIC is a system of two 17m-diameter Imaging Atmospheric Cherenkov Telescopes located at the Observatory Roque de los Muchachos on the Canary island La Palma, Spain, and designed to perform gamma-ray astronomy in the energy range from 50 GeV to greater than 50 TeV.

Related



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

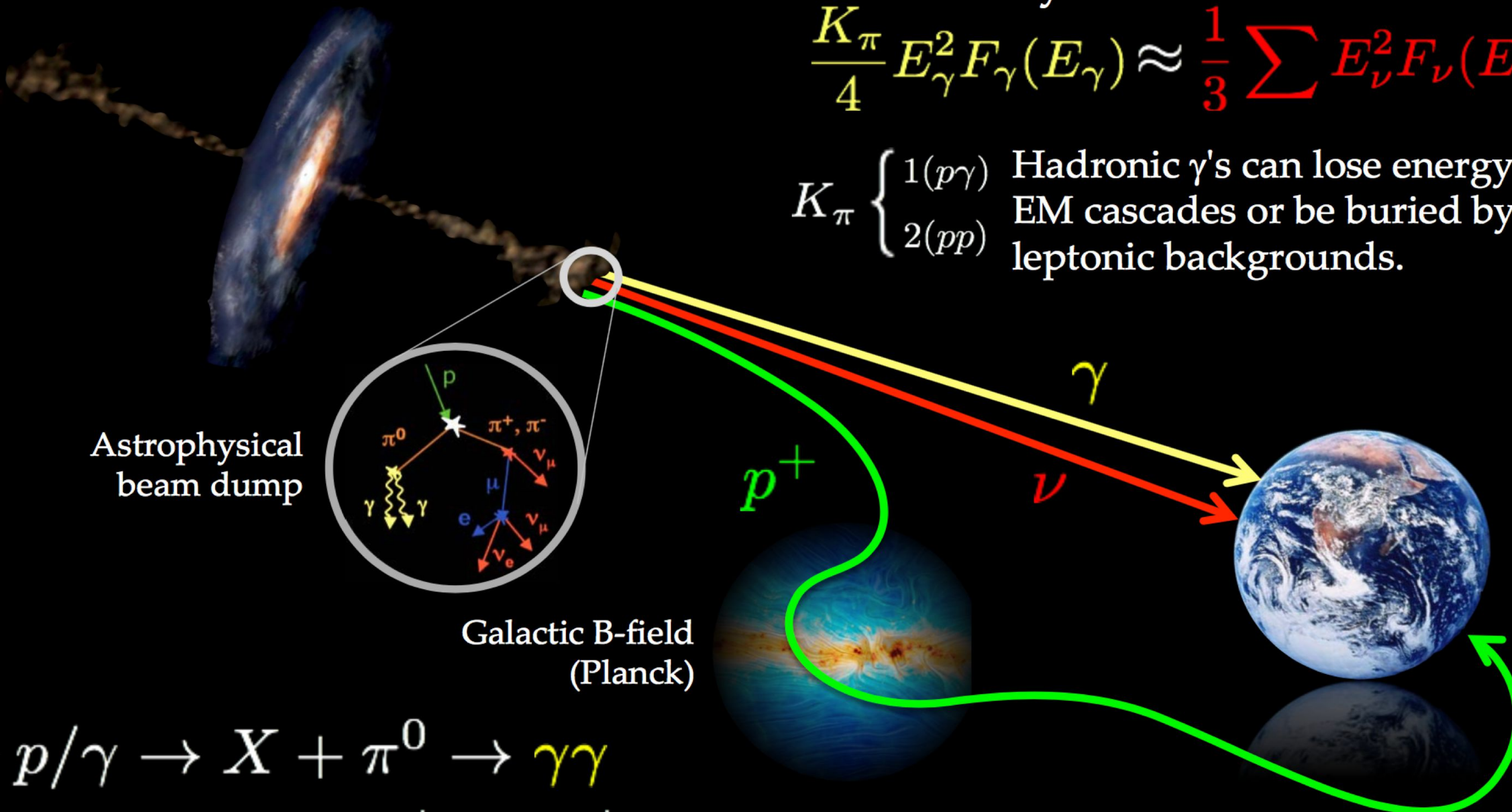
Neutrinos and Gamma Rays

Gamma-ray flux — Neutrino flux

$$\frac{K_\pi}{4} E_\gamma^2 F_\gamma(E_\gamma) \approx \frac{1}{3} \sum E_\nu^2 F_\nu(E_\nu)$$

$$K_\pi \begin{cases} 1 (p\gamma) \\ 2 (pp) \end{cases}$$

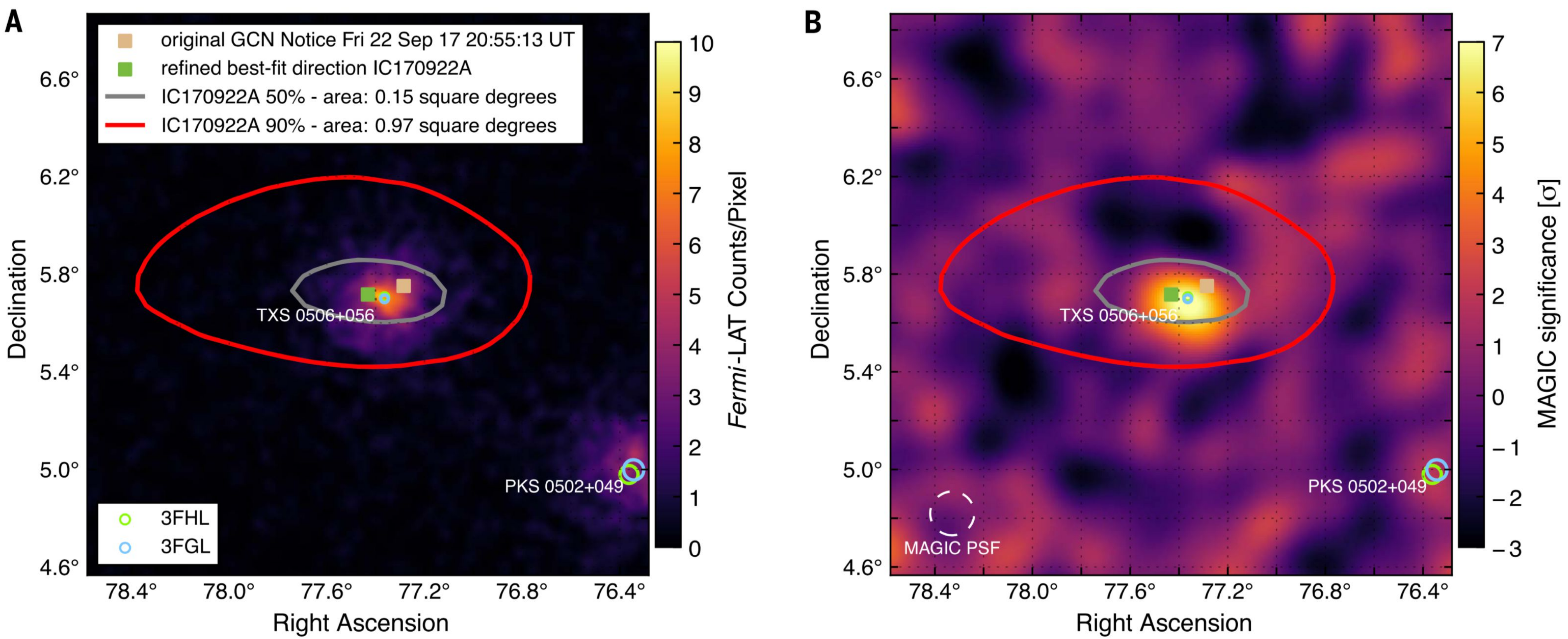
Hadronic γ's can lose energy via EM cascades or be buried by leptonic backgrounds.



$$p + p/\gamma \rightarrow X + \pi^0 \rightarrow \gamma\gamma$$
$$\rightarrow X + \pi^+ \rightarrow \mu^+ + \nu_\mu$$
$$\mu^+ \rightarrow e^+ + \nu_e + \bar{\nu}_\mu$$ (oscillates to ~1:1:1)

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

Multimessenger Astronomy: Neutrinos

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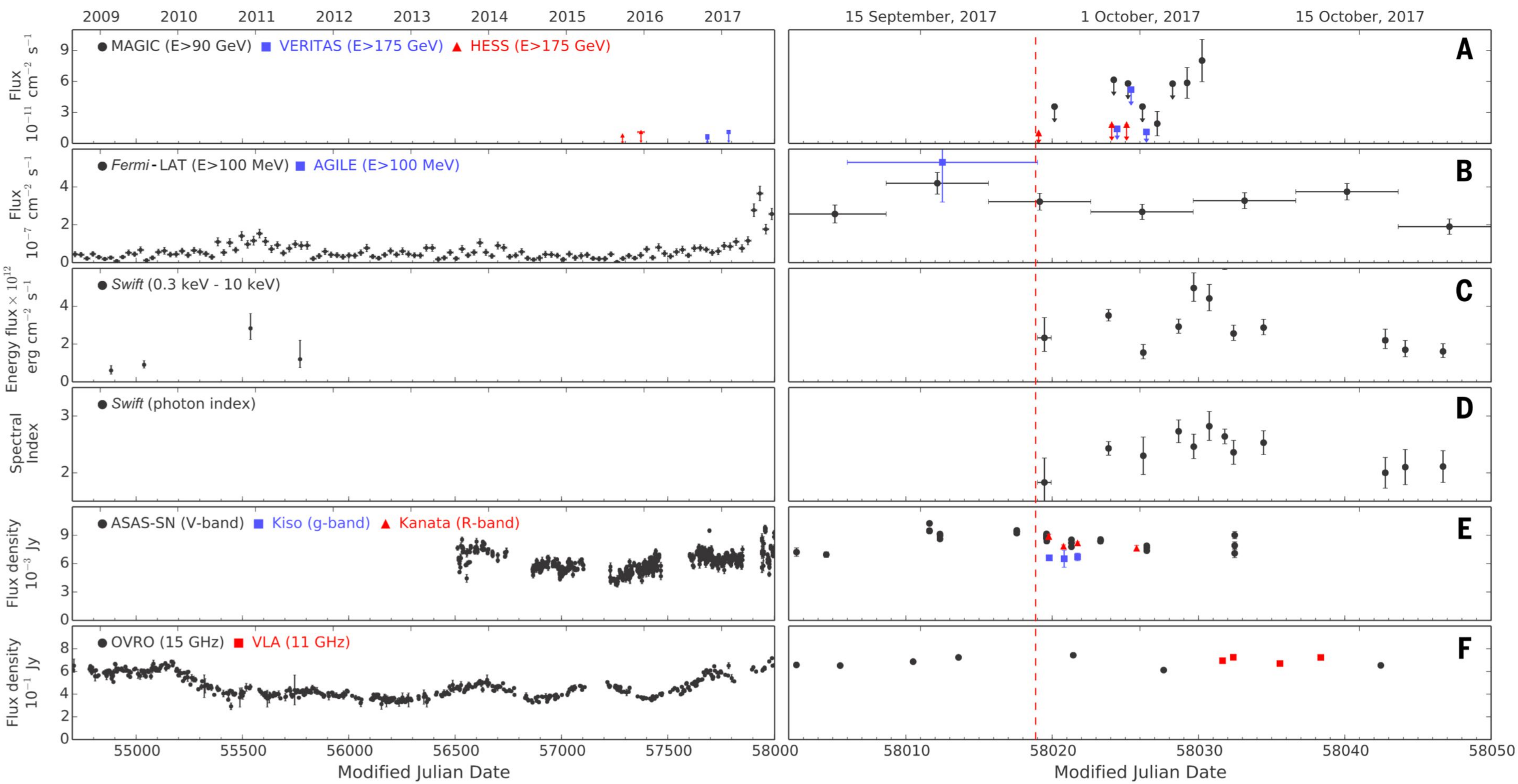
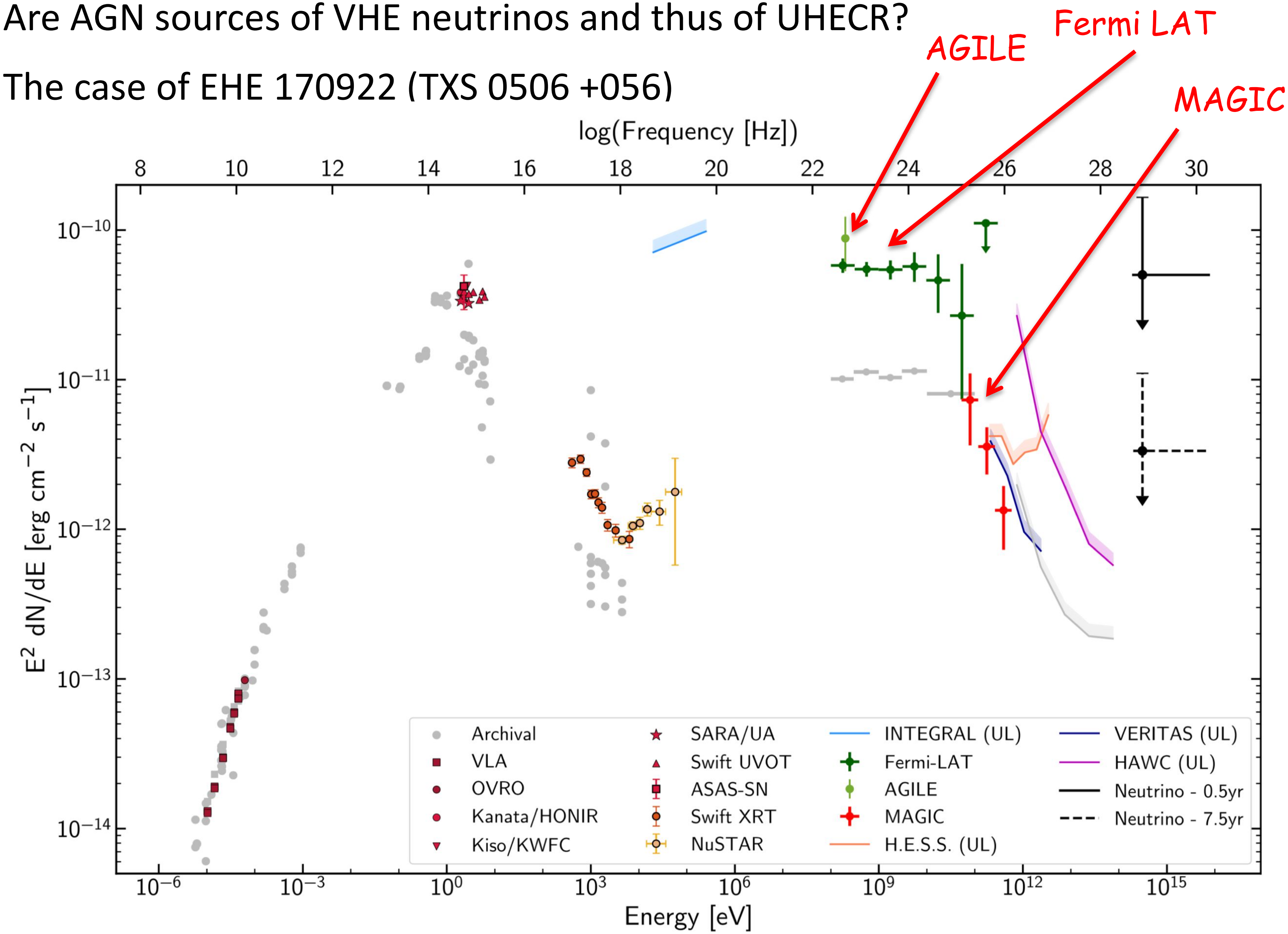


Multiwavelength observations of TXS 0506+056 before and after IceCube-170922A

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)



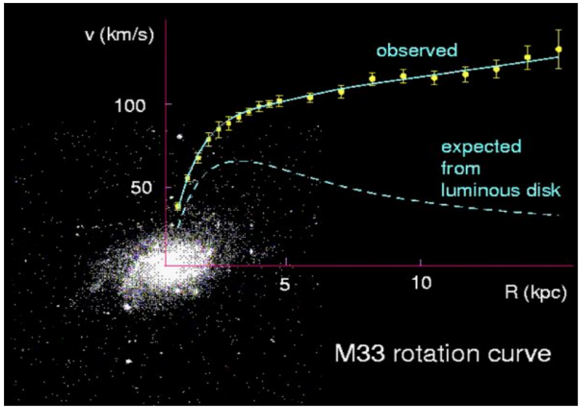
Science 361, eaat1378 (2018) 12July

Dark Matter EVIDENCE

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

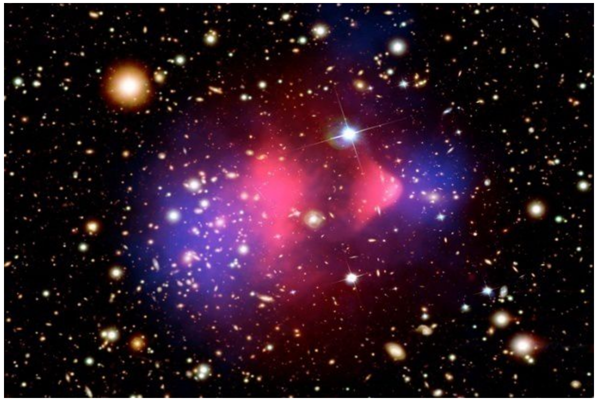
Since then, even more evidence:

Rotation curves of galaxies

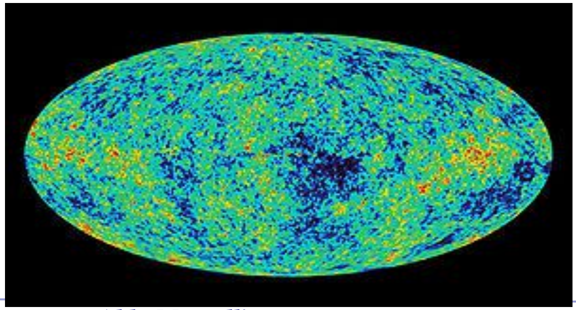


Gravitational lensing

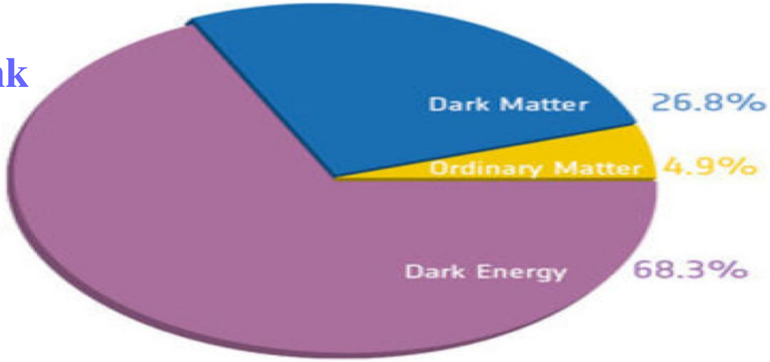
Bullet cluster



Structure formation as deduced from CMB



Data by Plank imply:



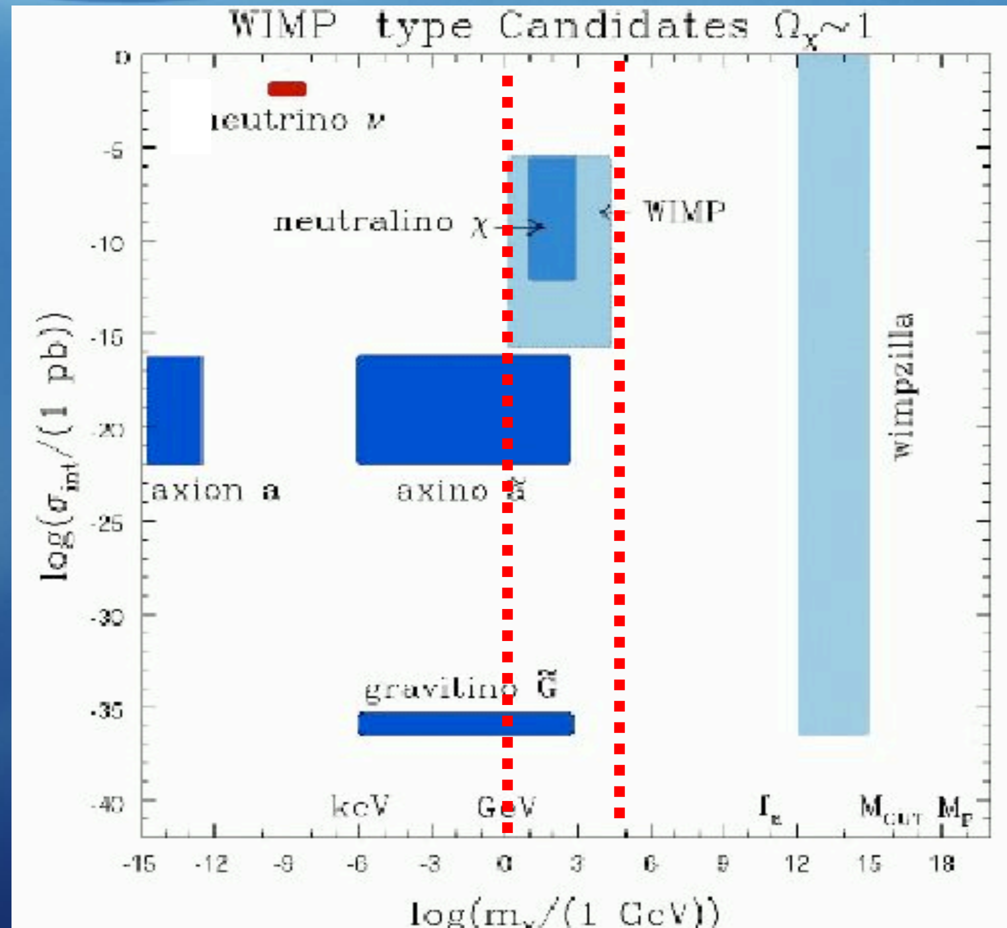
$\Omega_{Dm} \approx 26.8\%$

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

Dark Matter

Dark Matter Candidates

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



Dark Matter Candidates

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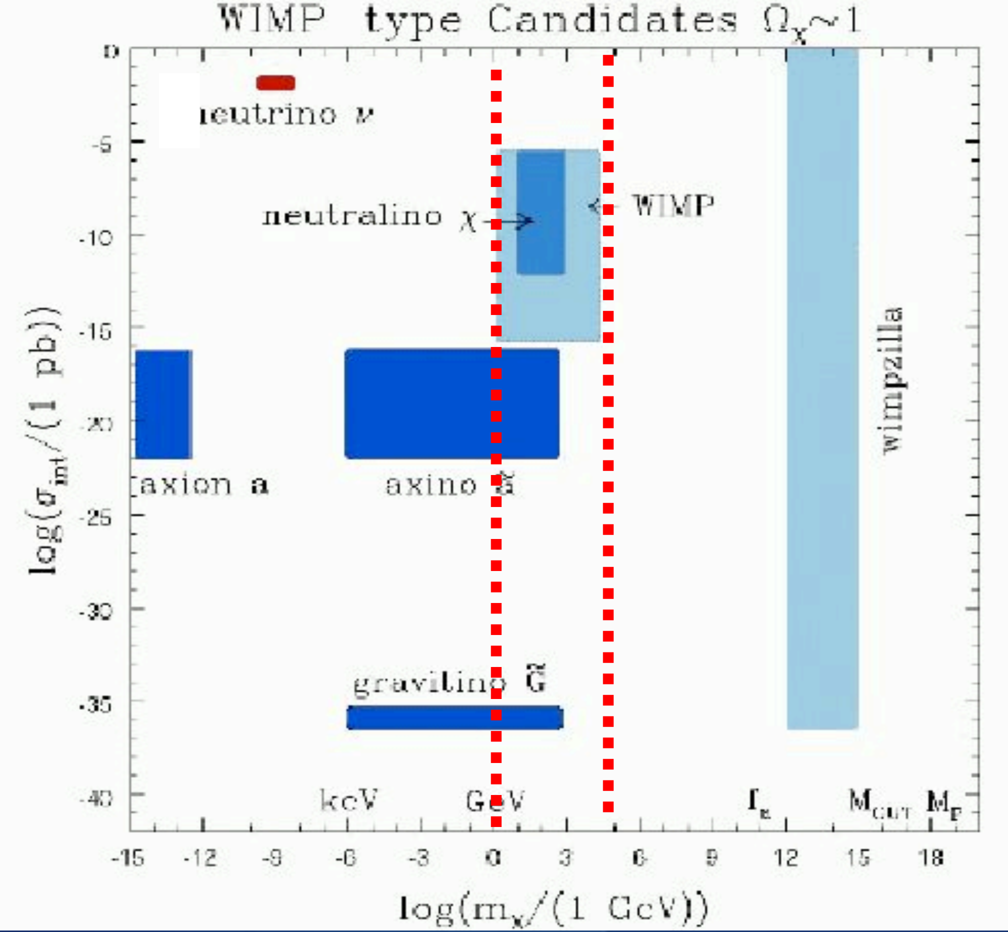
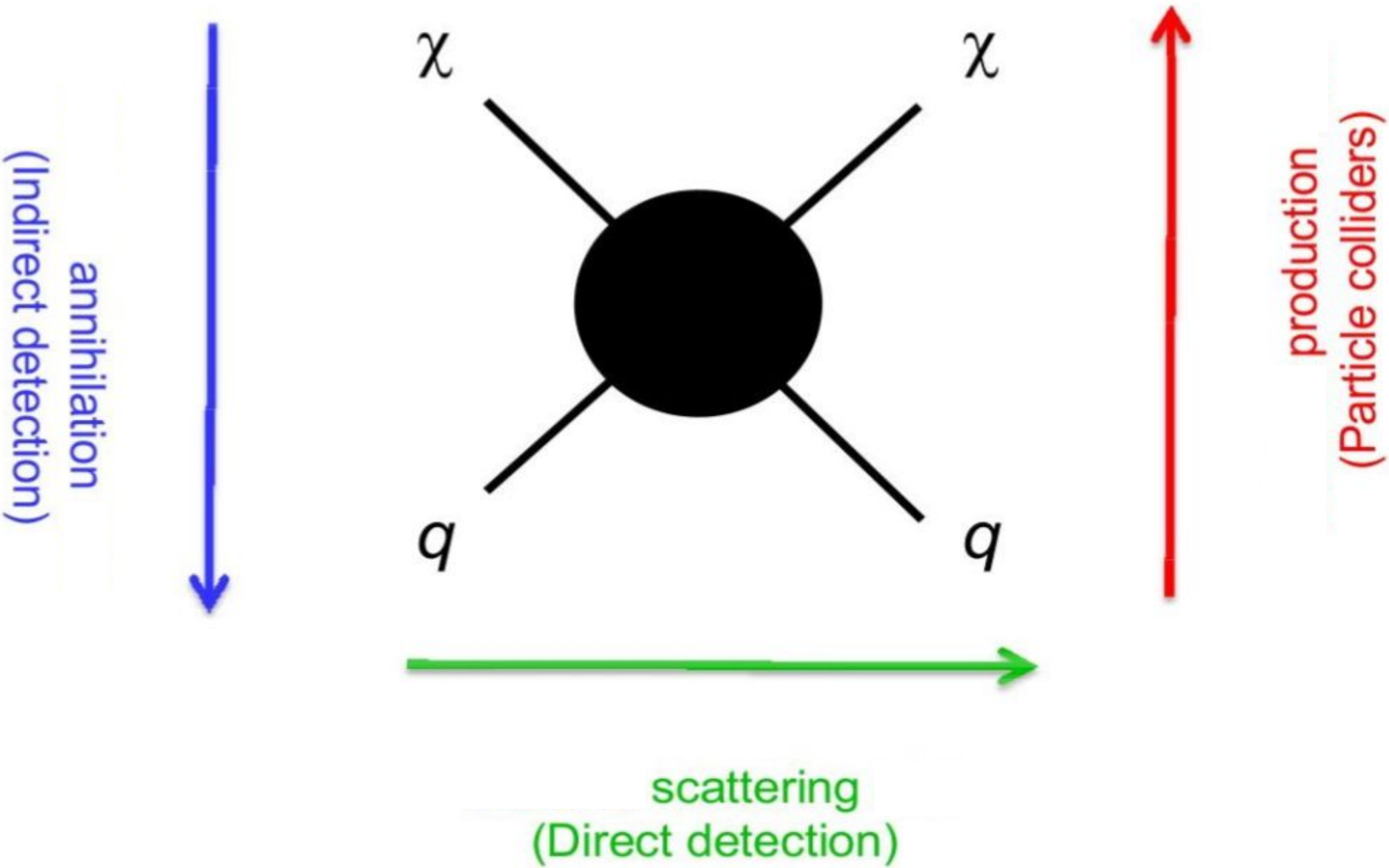
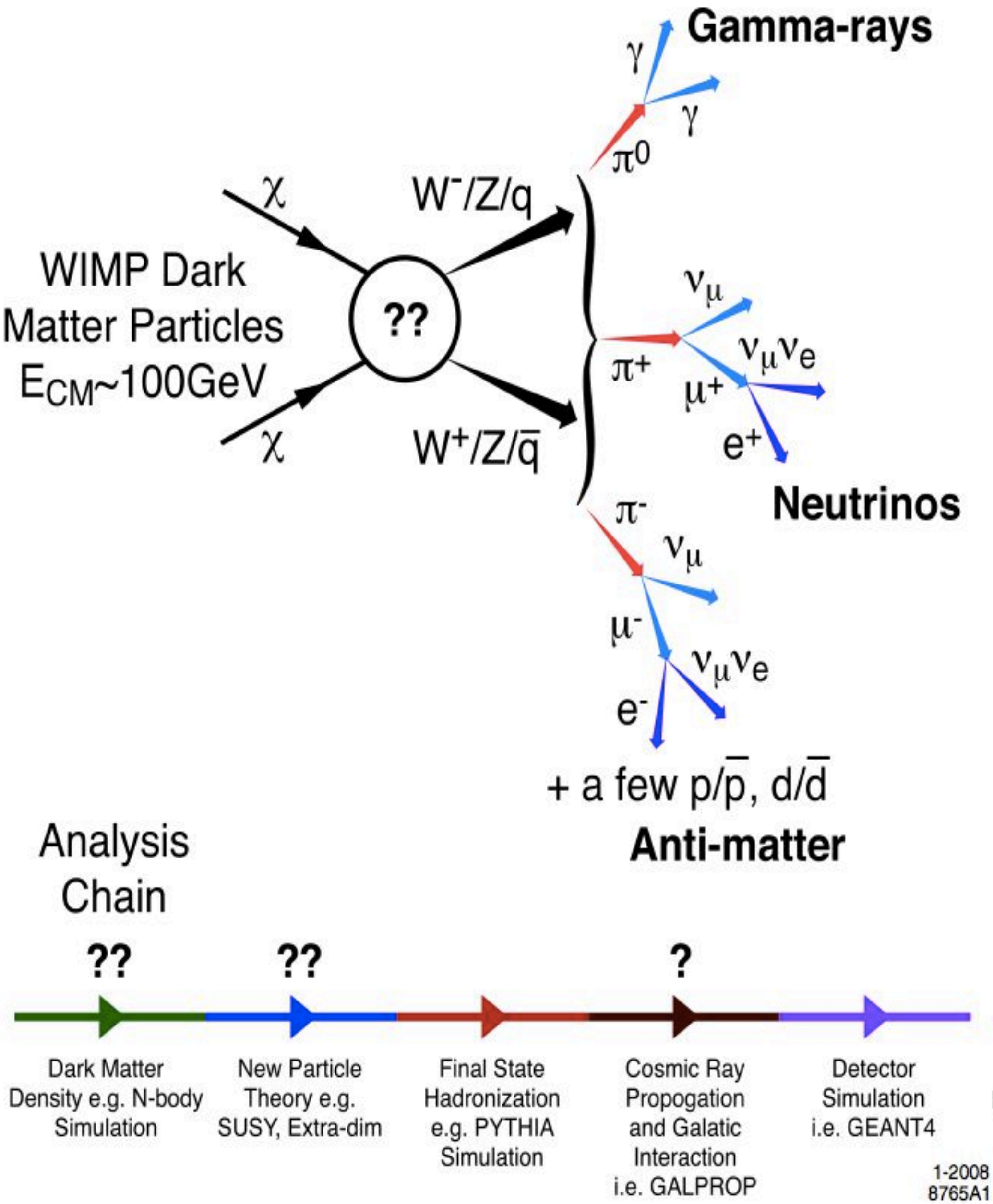
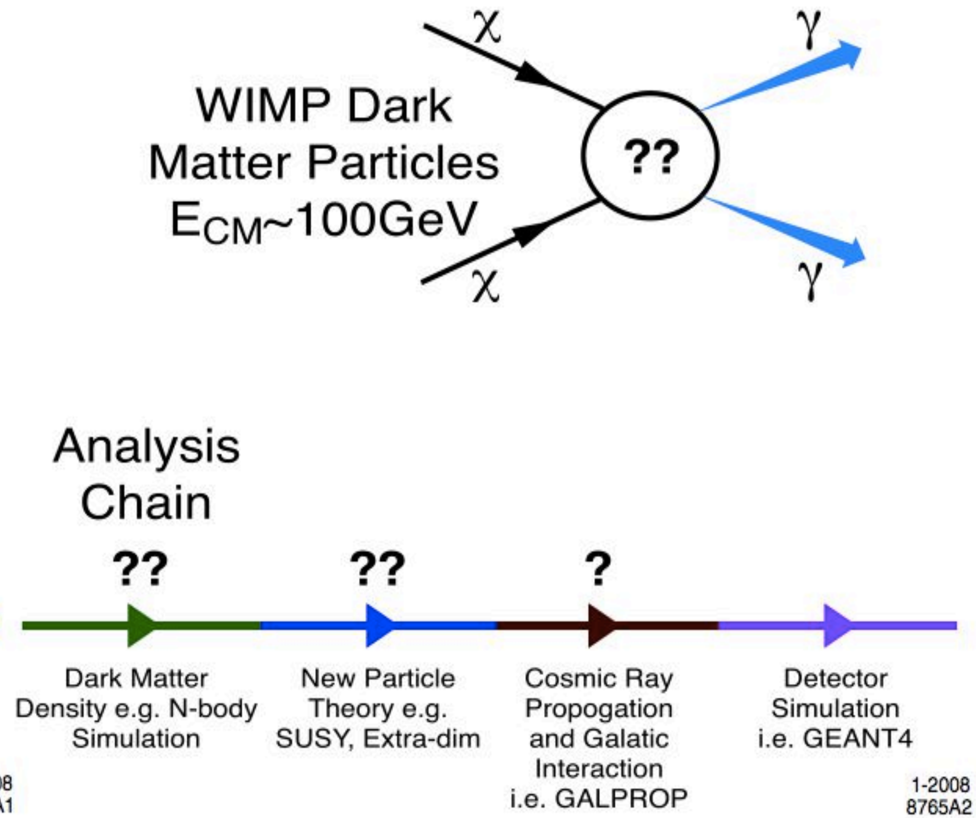


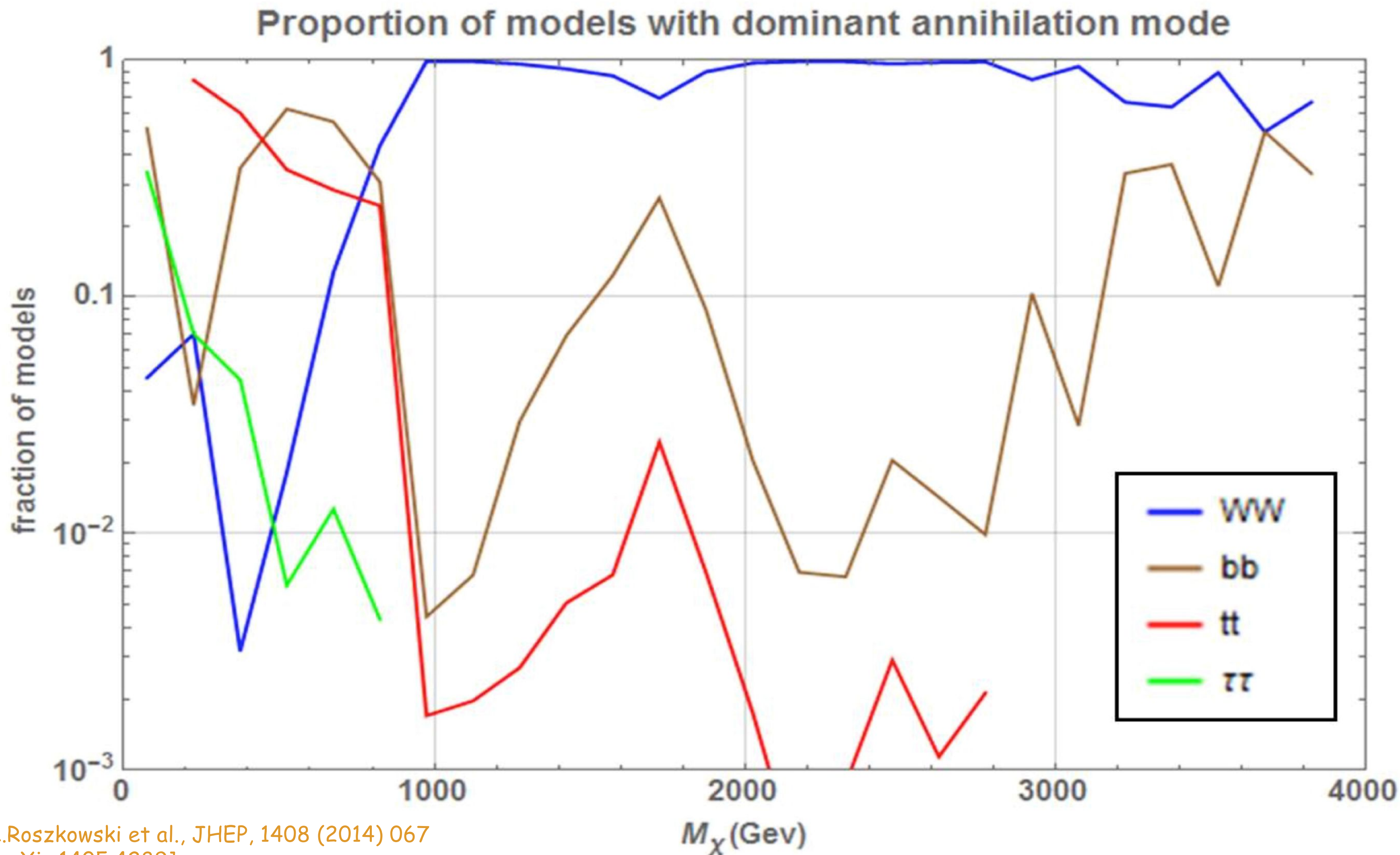

χ
χ
q
q
annihilation
(Indirect detection)
production
(Particle colliders)
scattering
(Direct detection)

Annihilation channels





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



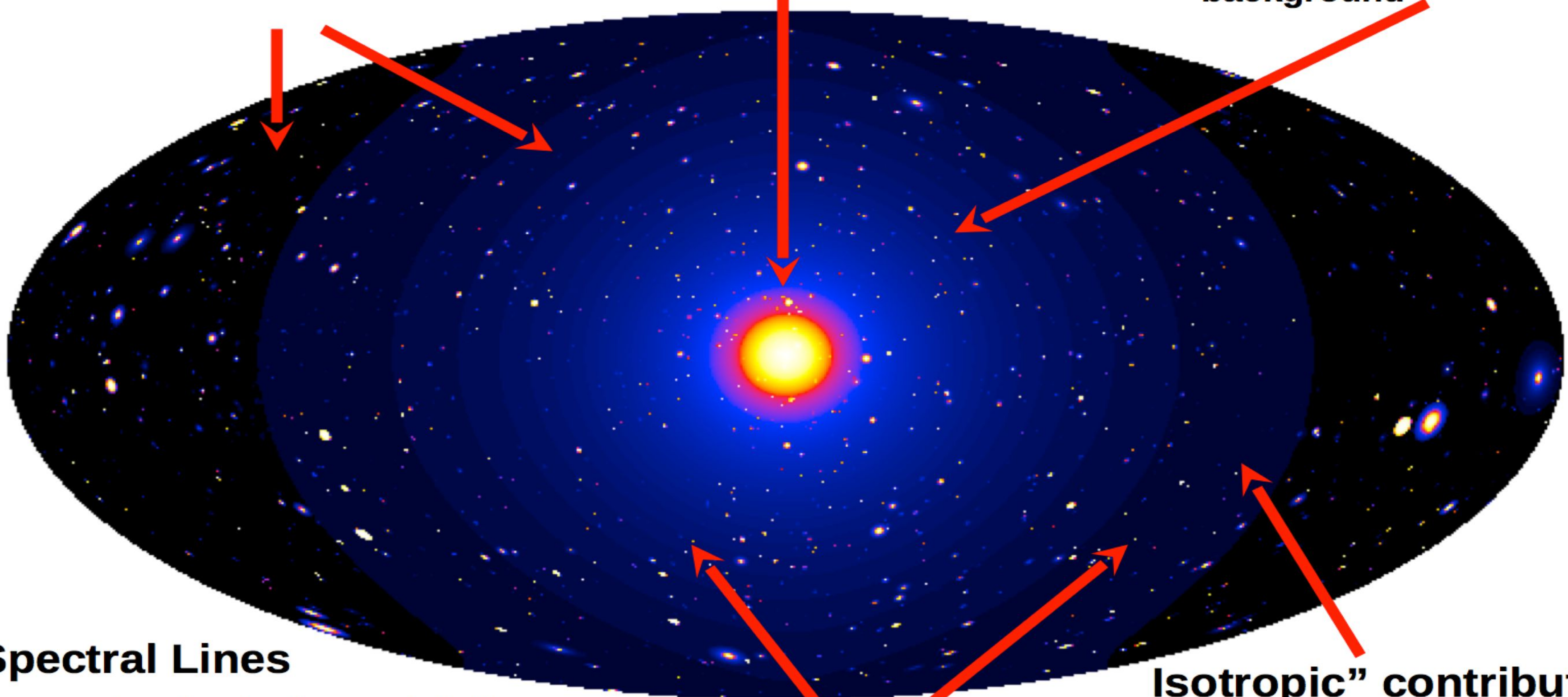
L.Roszkowski et al., JHEP, 1408 (2014) 067
[arXiv:1405.4289]

Dark Matter Search: Targets and Strategies

Satellites
Low background and good source id, but low statistics

Galactic Center
Good Statistics, but source confusion/diffuse background

Milky Way Halo
Large statistics, but diffuse background



Spectral Lines
Little or no astrophysical uncertainties, good source id, but low sensitivity because of expected small branching ratio

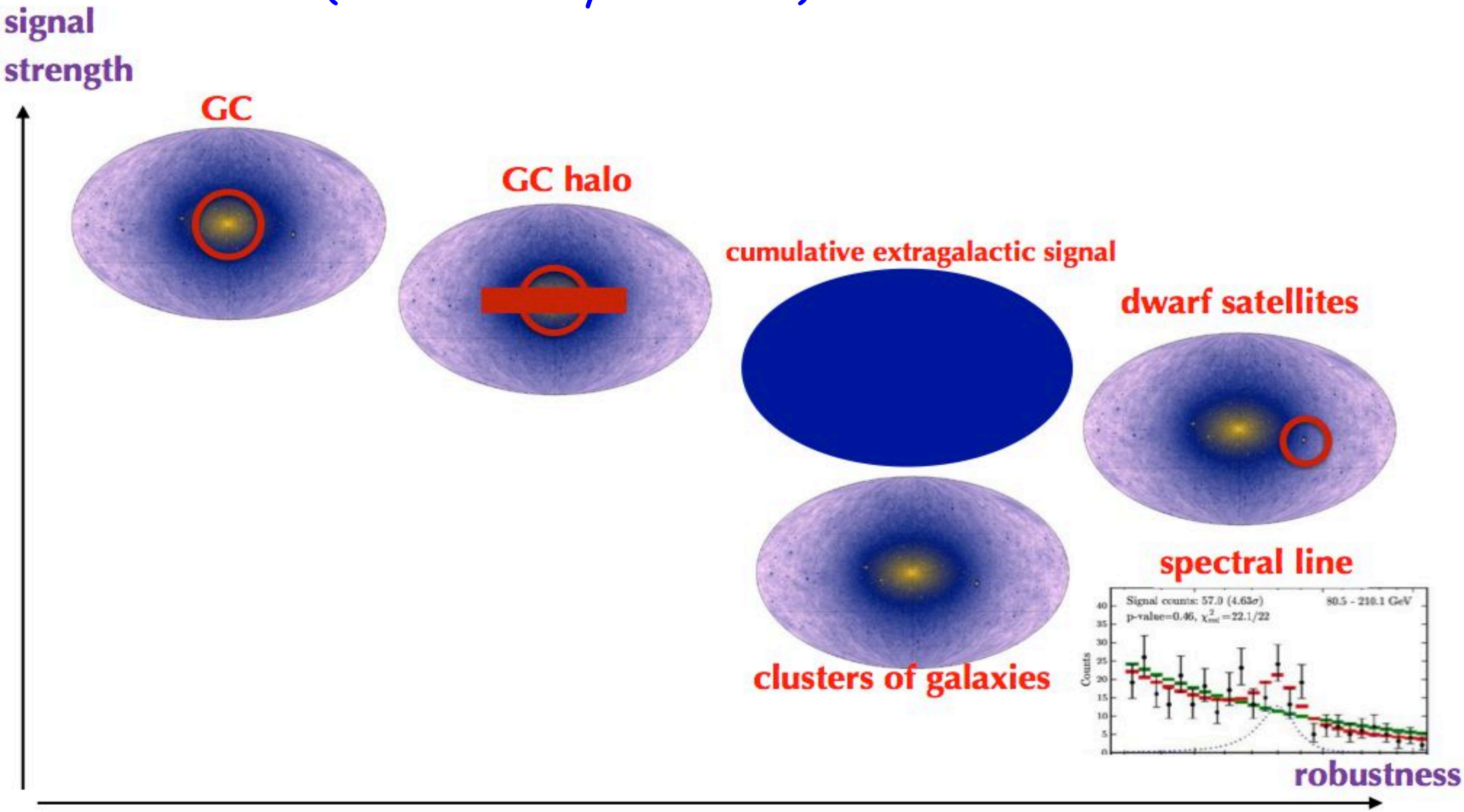
Galaxy Clusters
Low background, but low statistics

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

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

Dark Matter Search: Targets and Strategies

(Another way to see it)

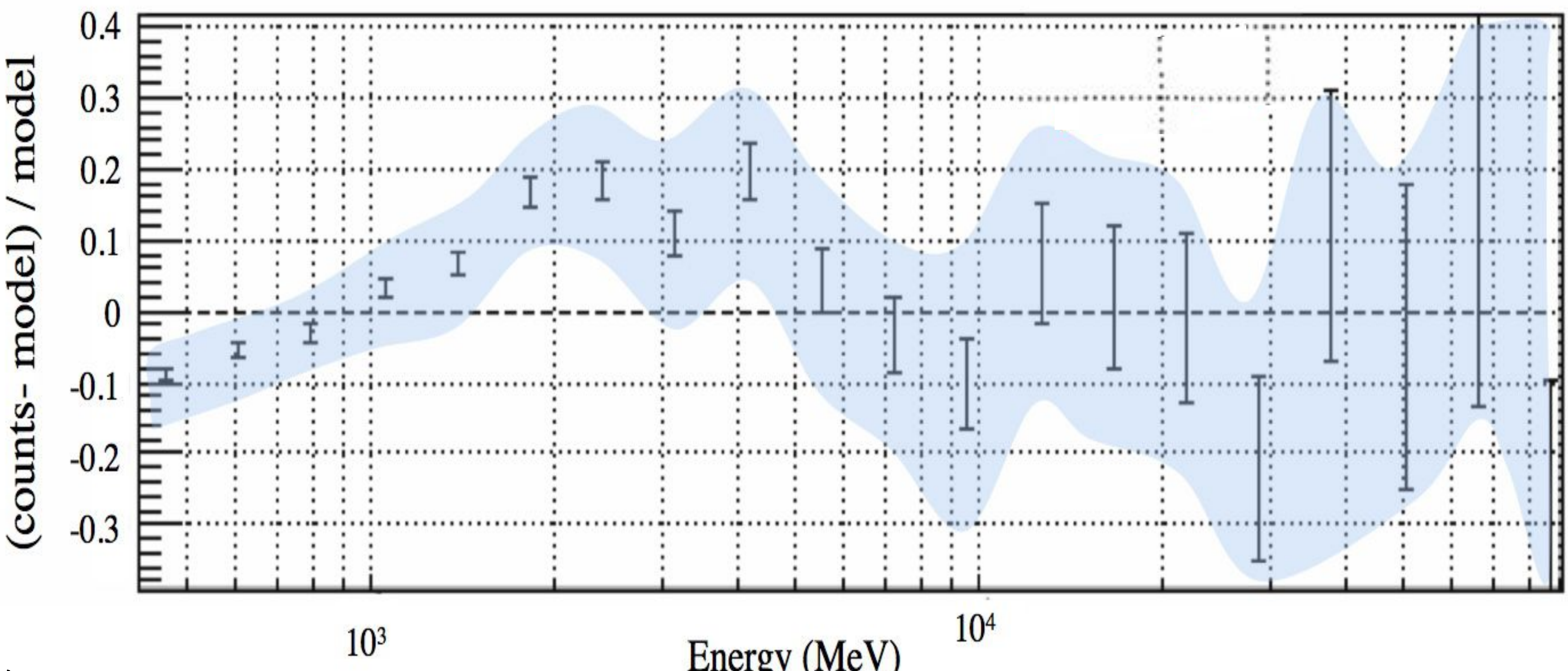


The GeV excess

7° x7° region centered on the Galactic Center

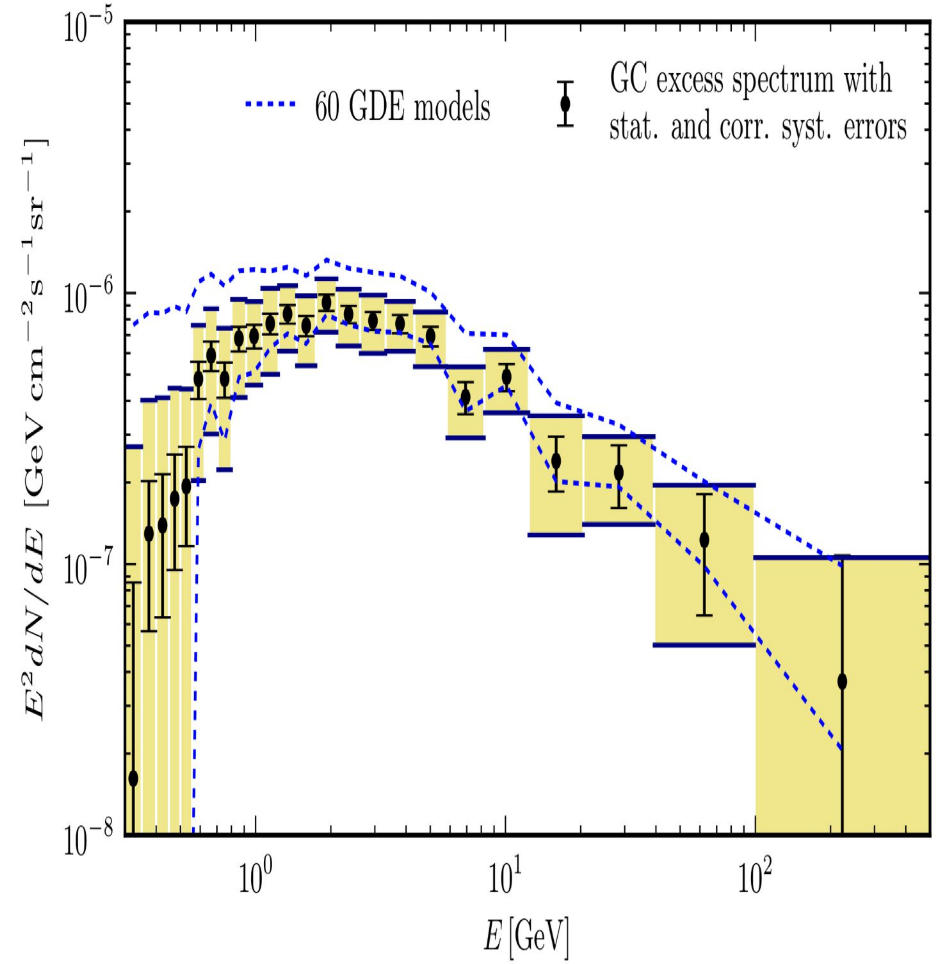
11 months of data, E >400 MeV, front-converting events analyzed with binned likelihood analysis)

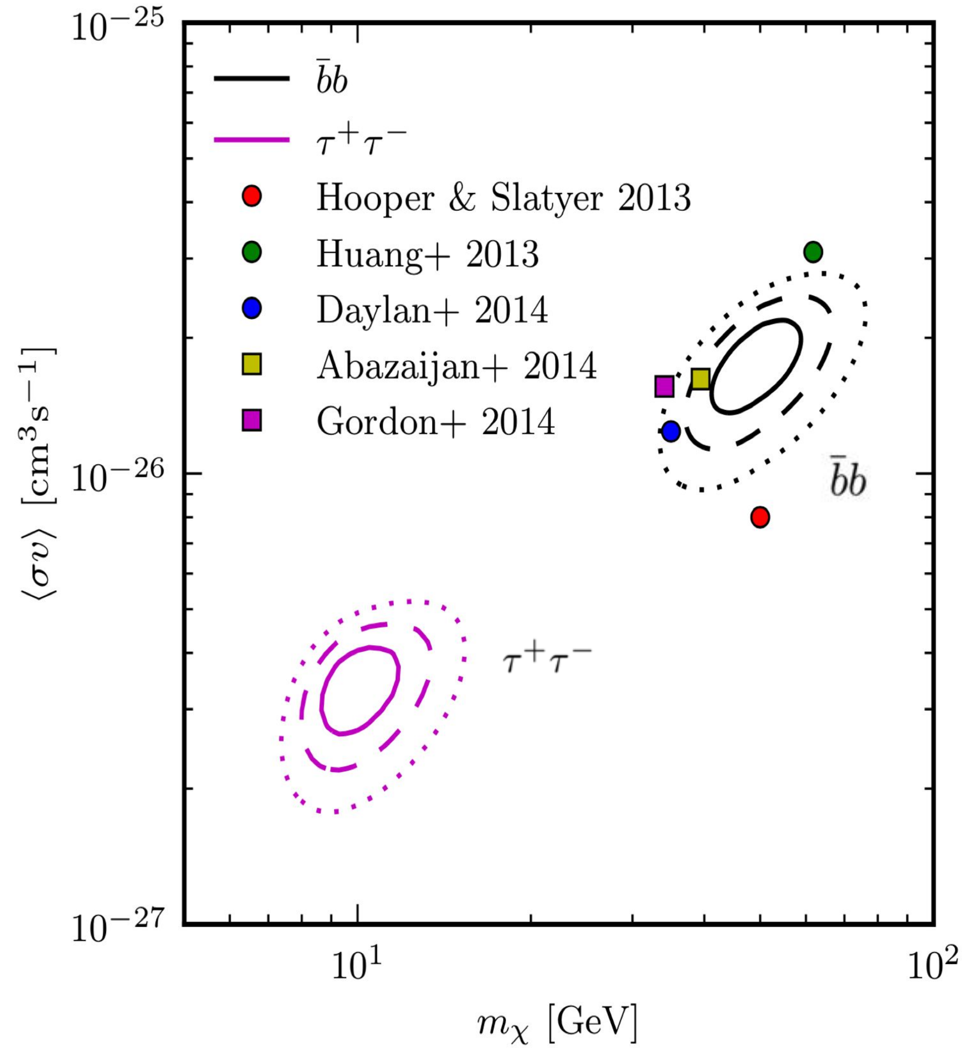
- The systematic uncertainty of the effective area (blue area) of the LAT is ~10% at 100 MeV, decreasing to 5% at 560 MeV and increasing to 20% at 10 GeV



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

The GeV excess





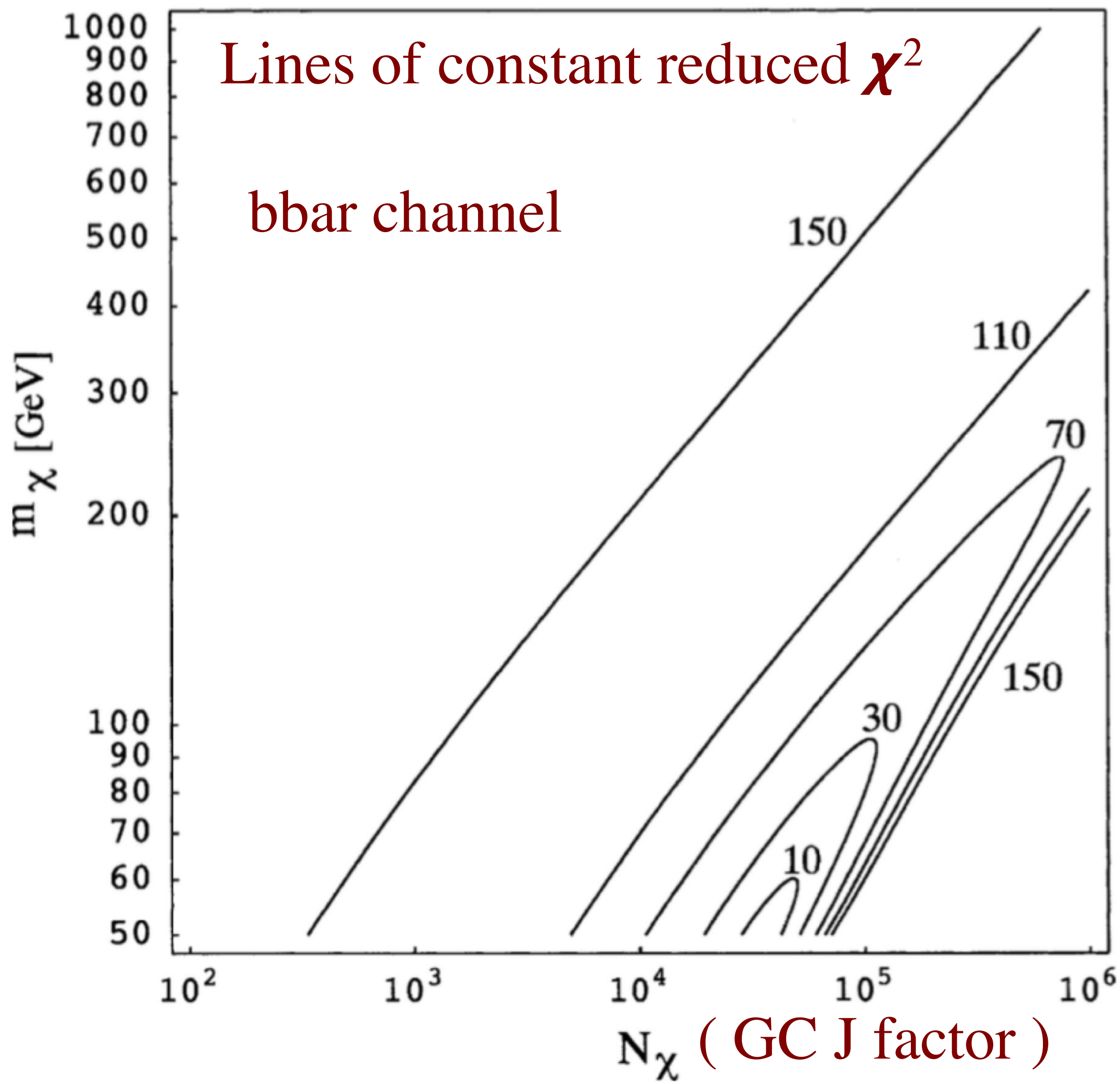
A lot of activity outside the Fermi collaboration with claims of evidence for dark matter in the Galactic Center

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 !

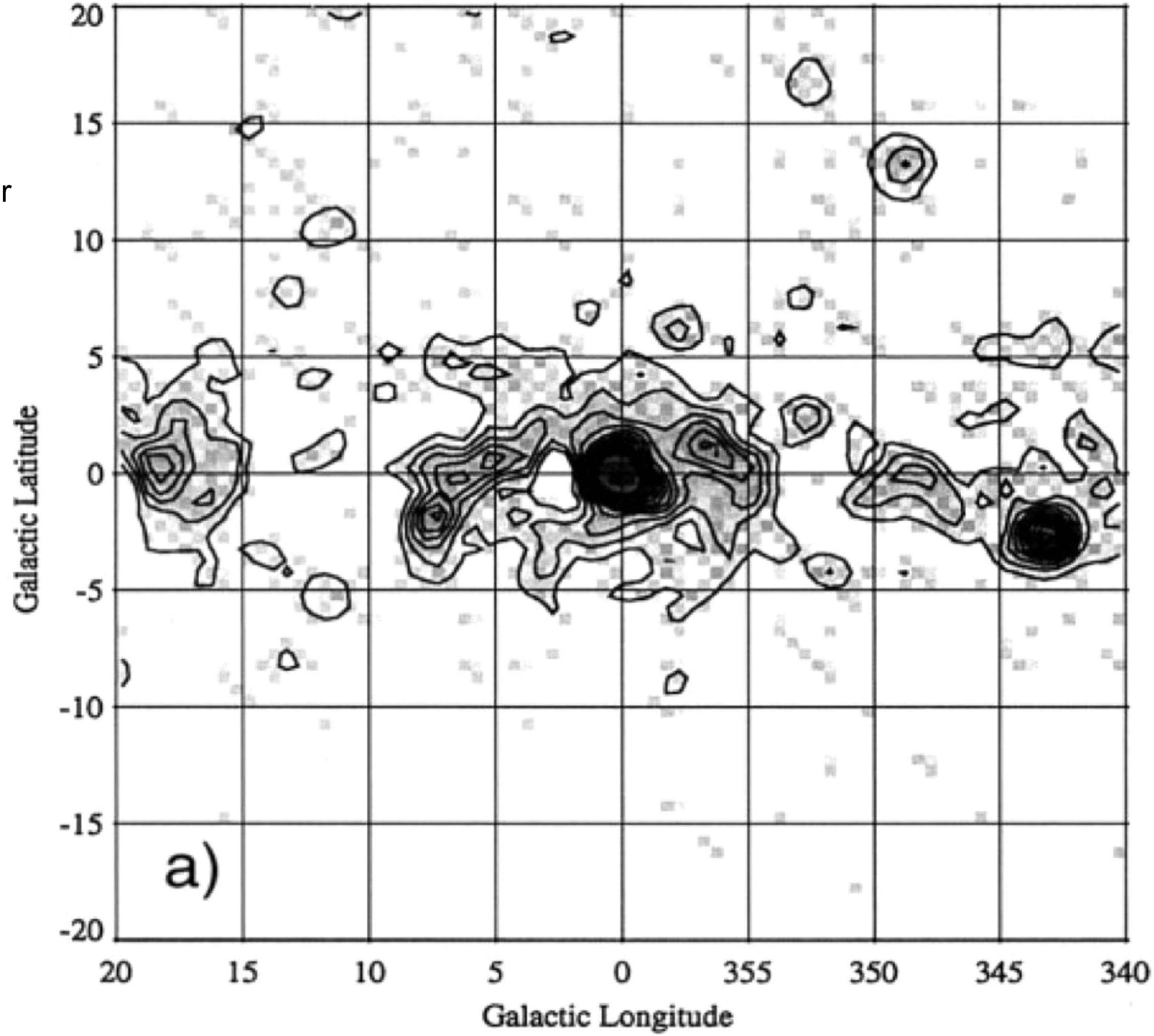
mass ~ 50- 80 GeV

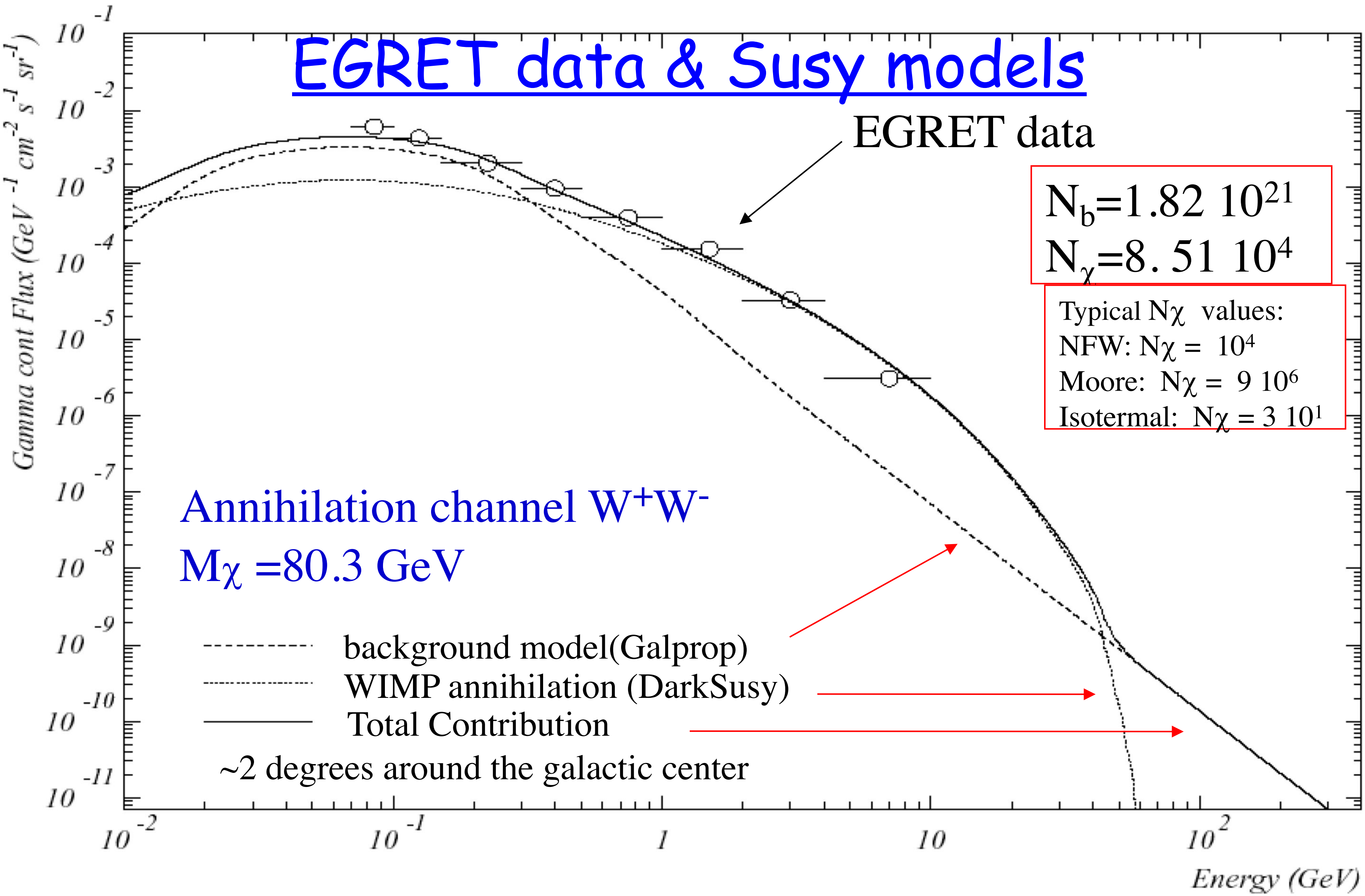


A.Cesarini, F.Fucito, A.Lionetto, A.Morselli, P.Ullio, Astroparticle Physics, 21, 267, 2004 [astro-ph/0305075]

EGRET, E > 1GeV

Mayer-Hasselwander et al, 1998





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)

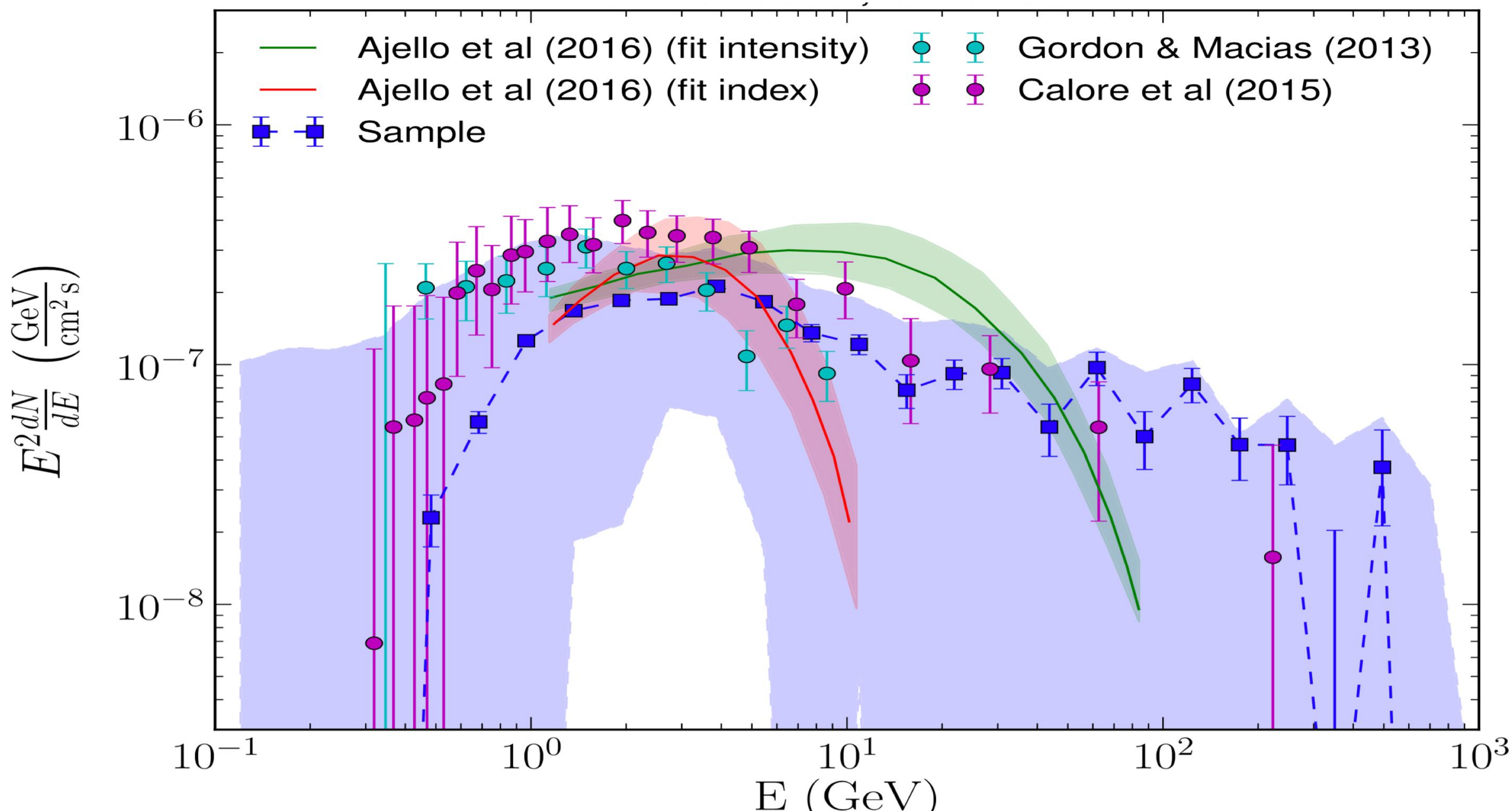
Dark Matter Annihilation in The Galactic Center As Seen by the Fermi Gamma Ray Space Telescope
Dan Hooper , Lisa Goodenough . (21 March 2011). 21 pp. **Phys.Lett. B697 (2011) 412-428**

....

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

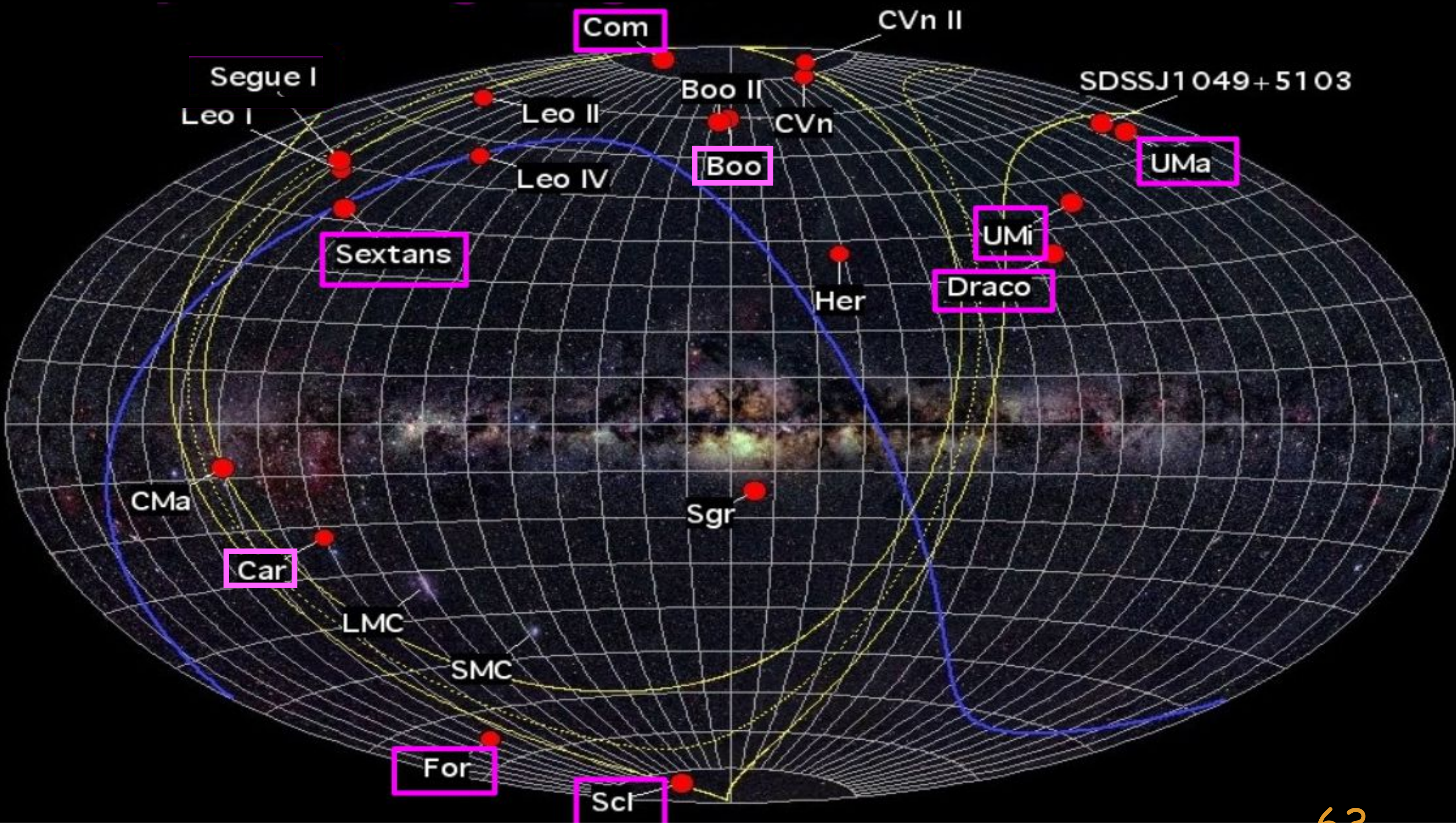
- Variation of GALPROP models – Distribution of gas along the line of sight

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

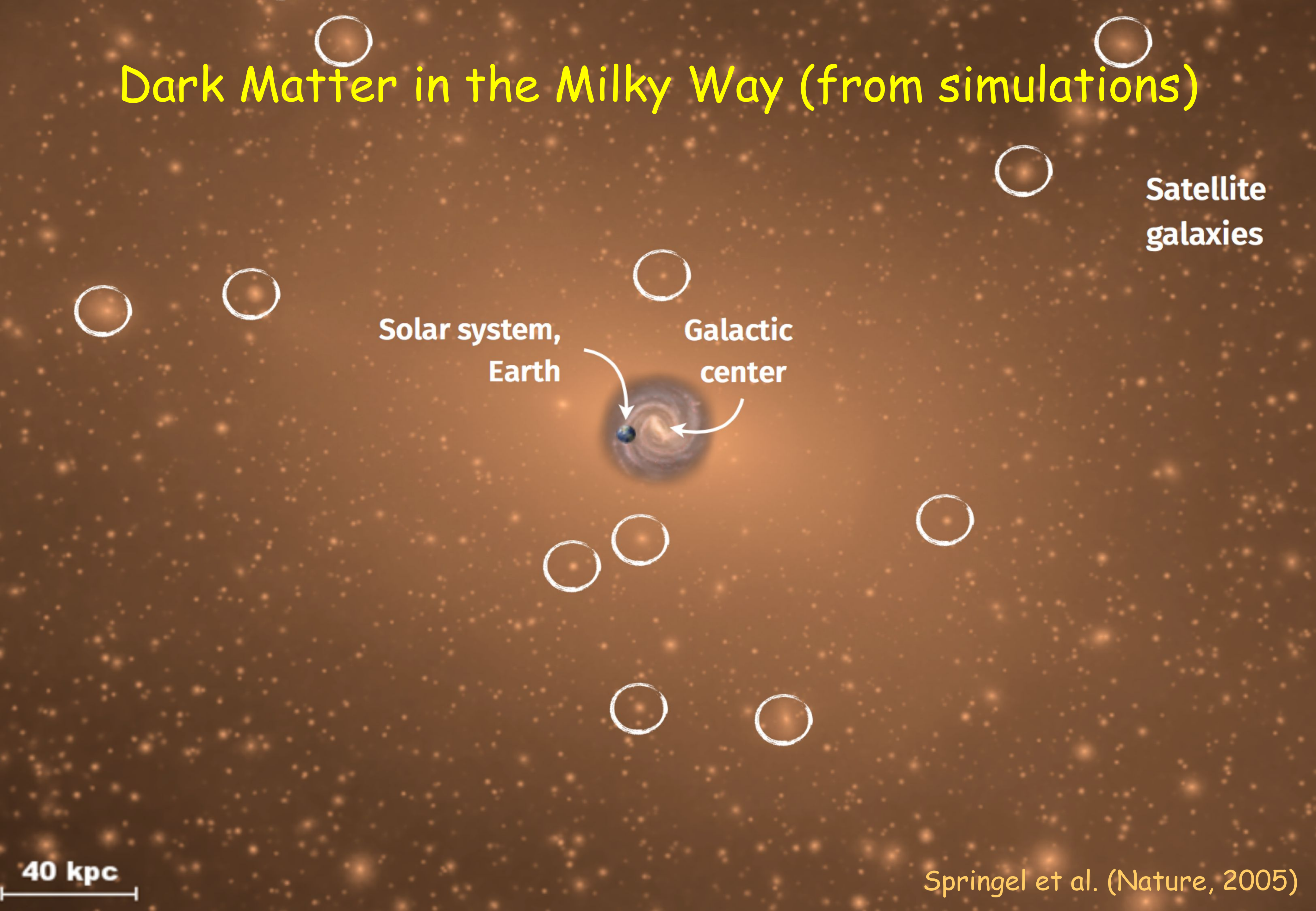
- Fermi bubbles morphology at low latitude – Sources of CR electrons near the GC

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

Classical Dwarf spheroidal galaxies: promising targets for DM detection

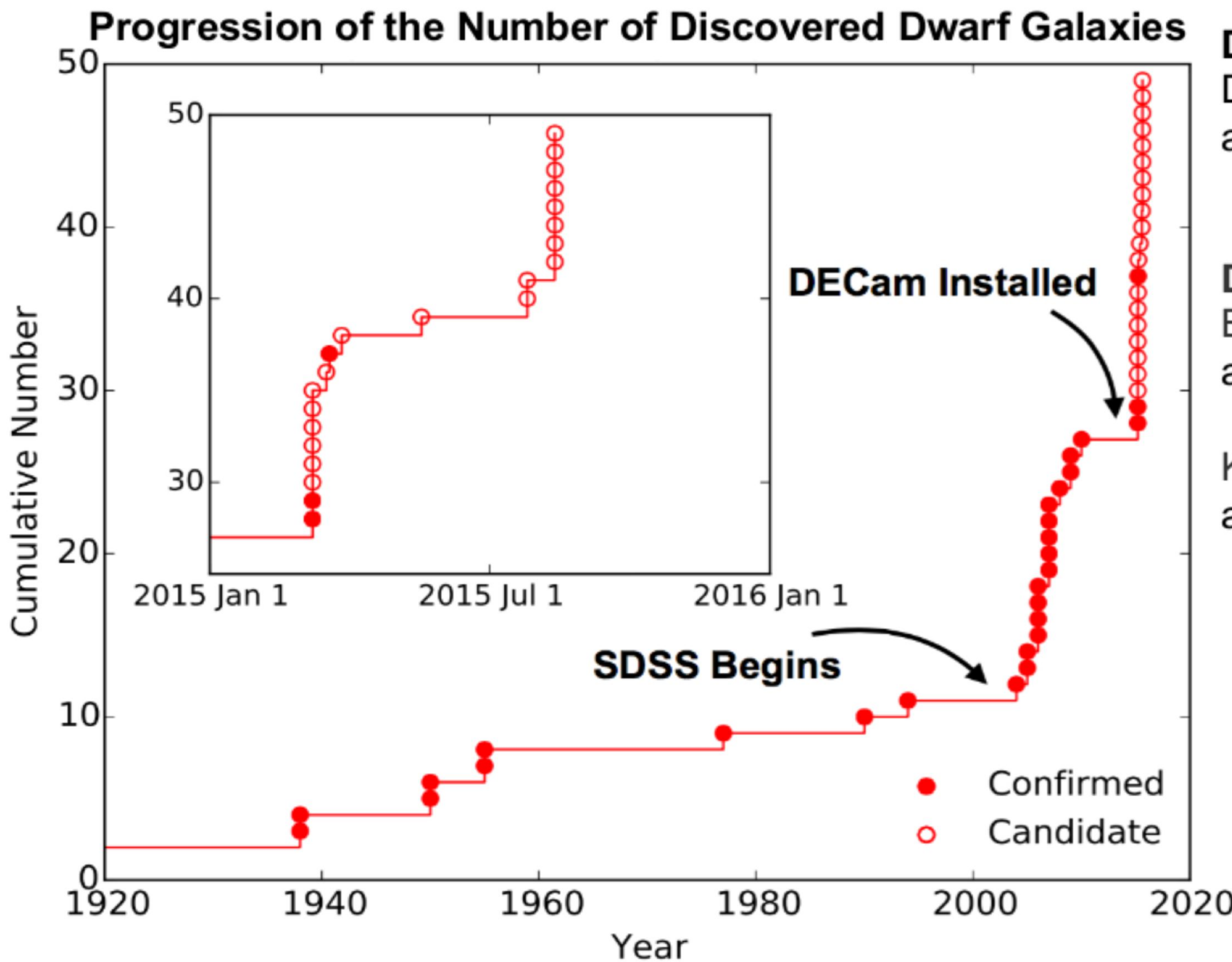


Dark Matter in the Milky Way (from simulations)



Springel et al. (Nature, 2005)

Dwarf Spheroidal Galaxies: Growing number of known targets

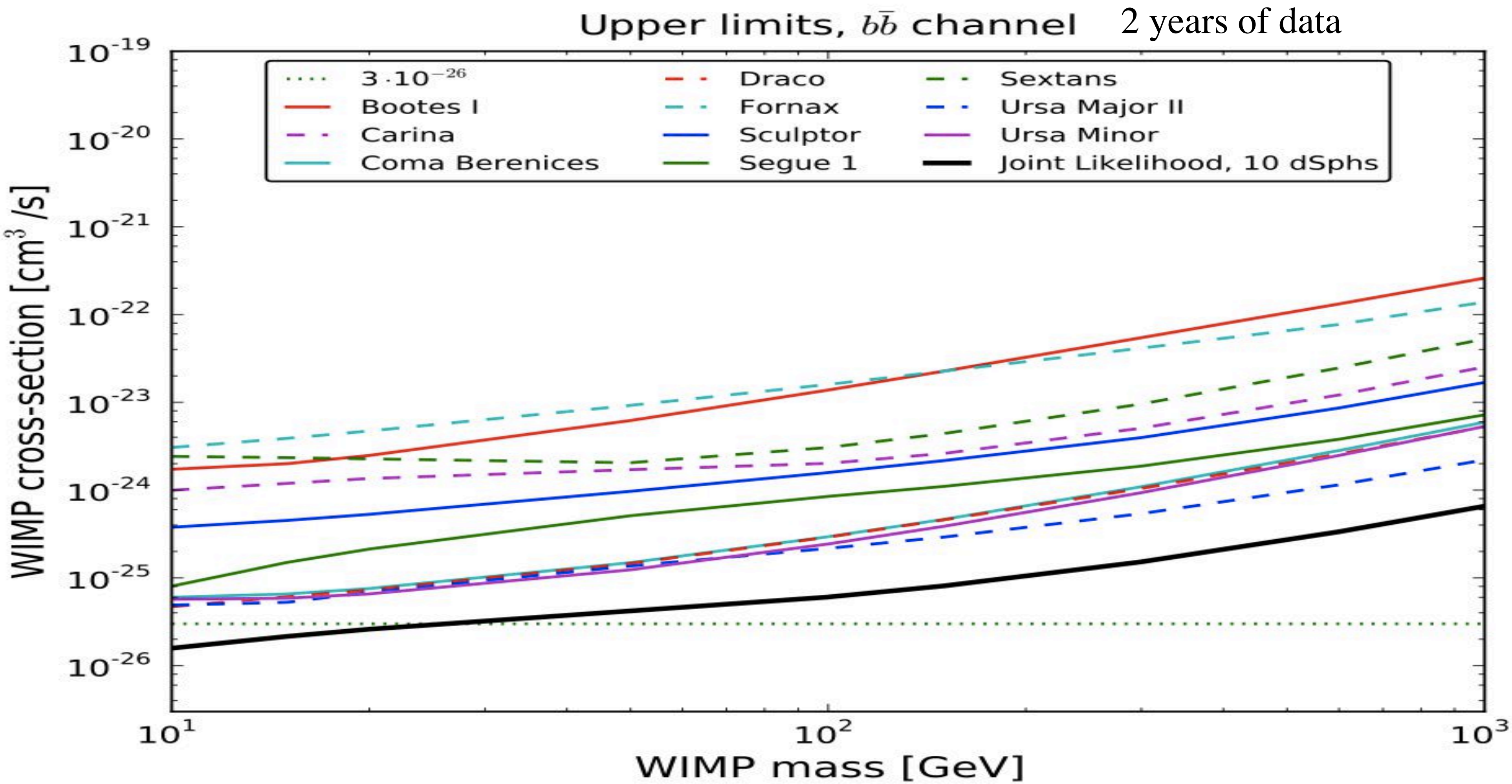


DES Year 2 Data:
Drlica-Wagner+,
arXiv:1508.03622

DES Year 1 Data:
Bechtol+:
arXiv:1503.02584

Koposov+:
arXiv:1503.02079

Dwarf Spheroidal Galaxies combined analysis

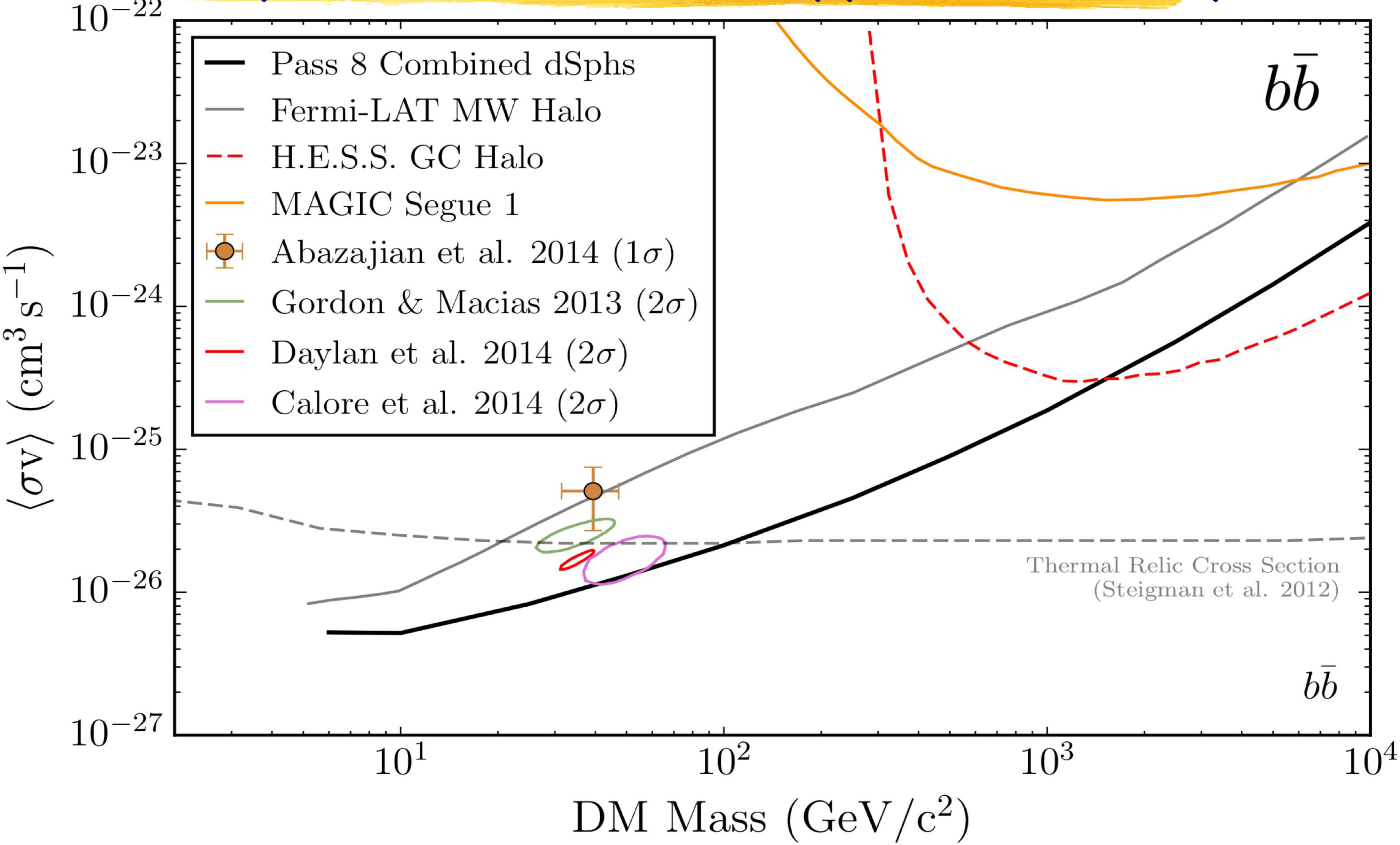


robust constraints including J-factor uncertainties from the stellar data statistical analysis

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

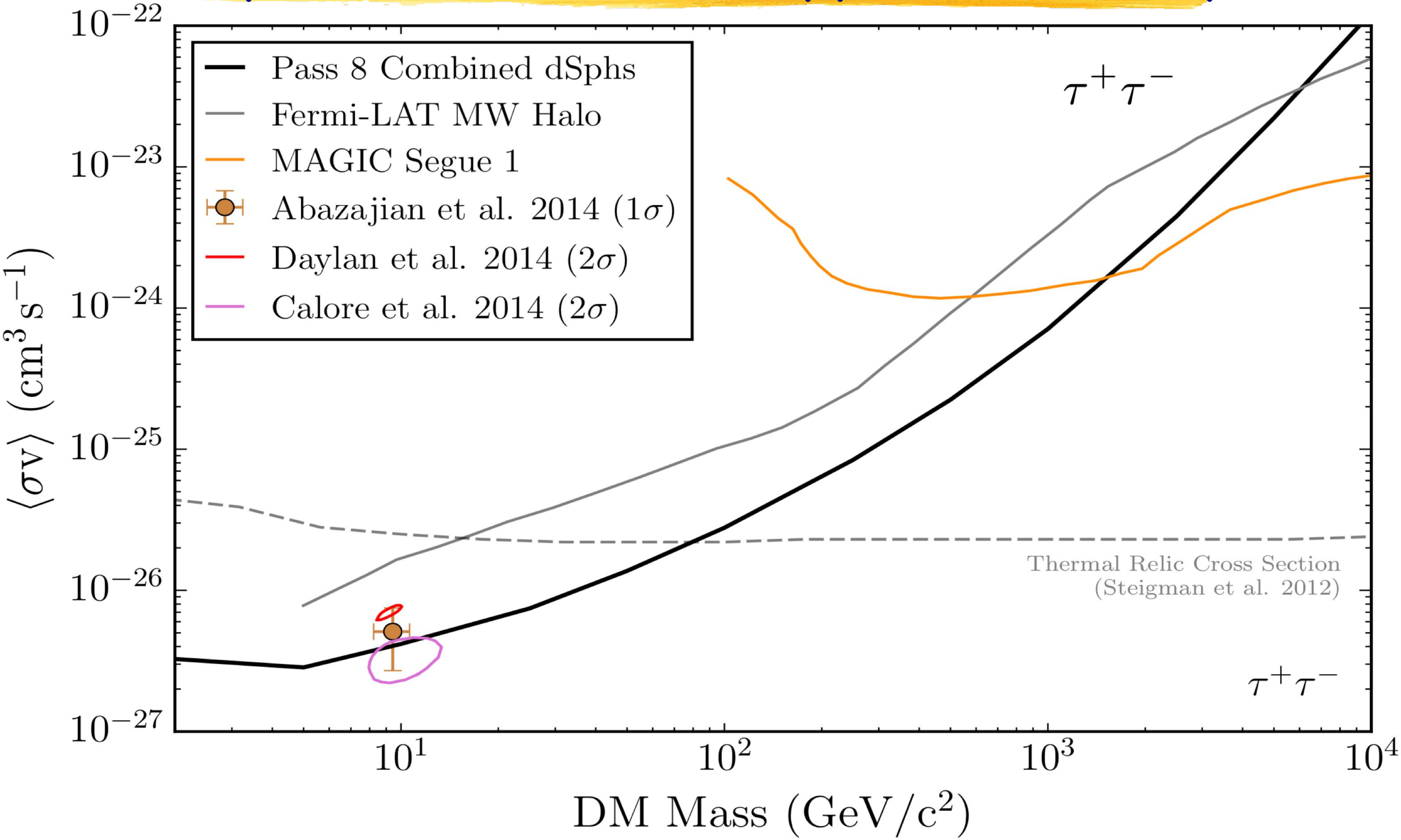
Fermi Lat Coll., PRL 107, 241302 (2011) [arXiv:1108.3546]

Dwarf Spheroidal Galaxies upper-limits (6 years)



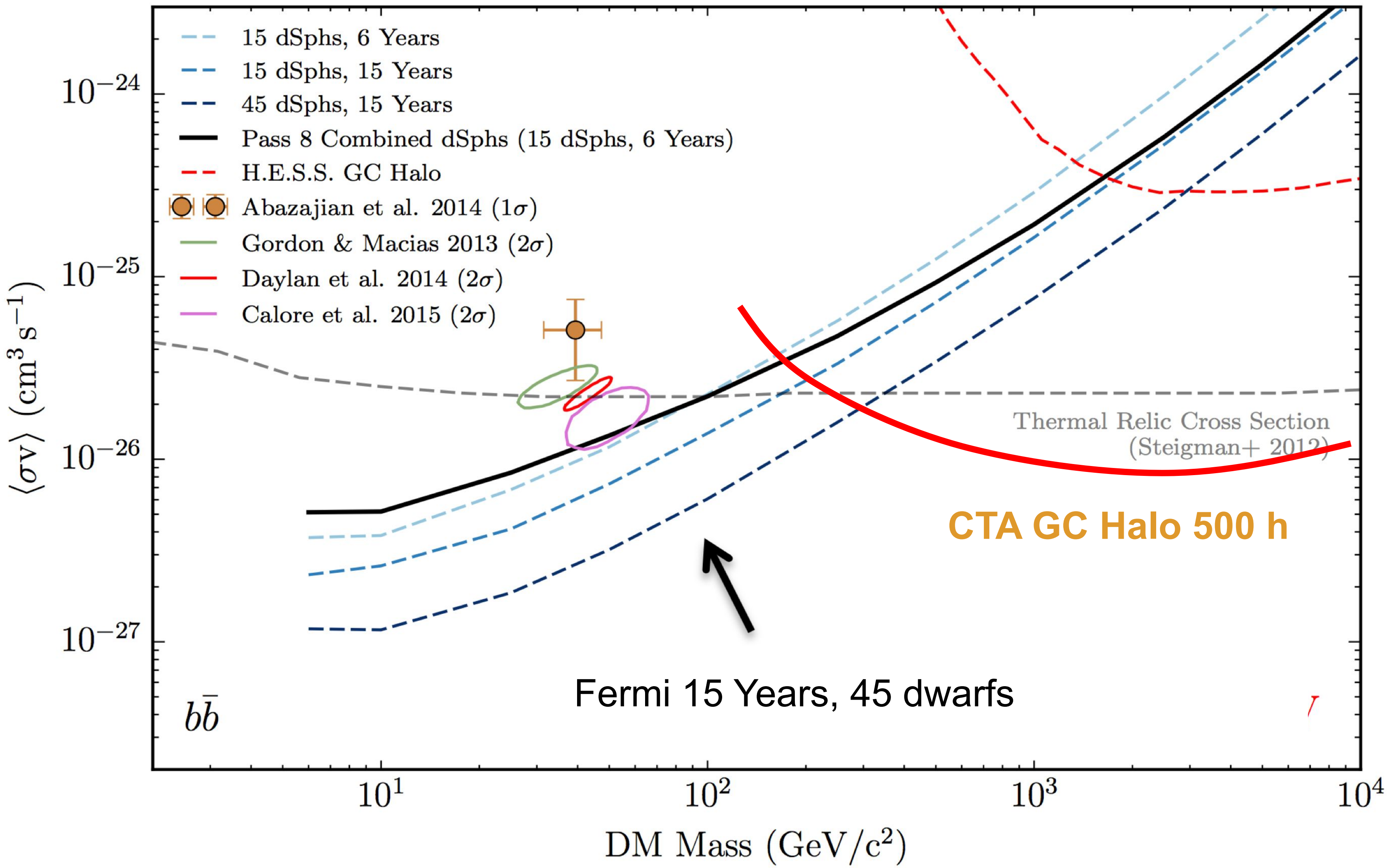
M.Ackermann et al., [Fermi Coll.] PRL 115, 231301 (2015) [arXiv:1503.02641]

Dwarf Spheroidal Galaxies upper-limits (6 years)

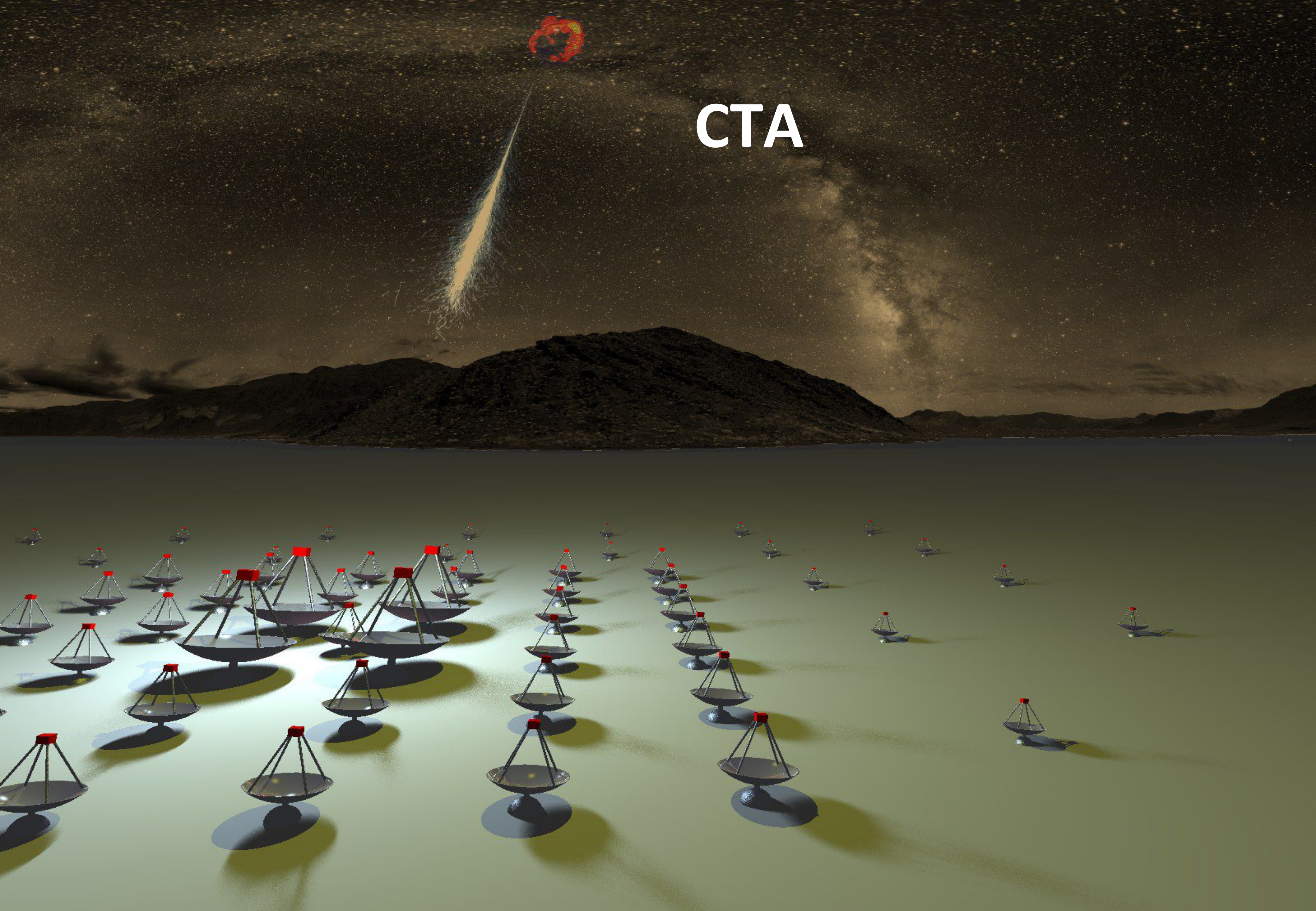


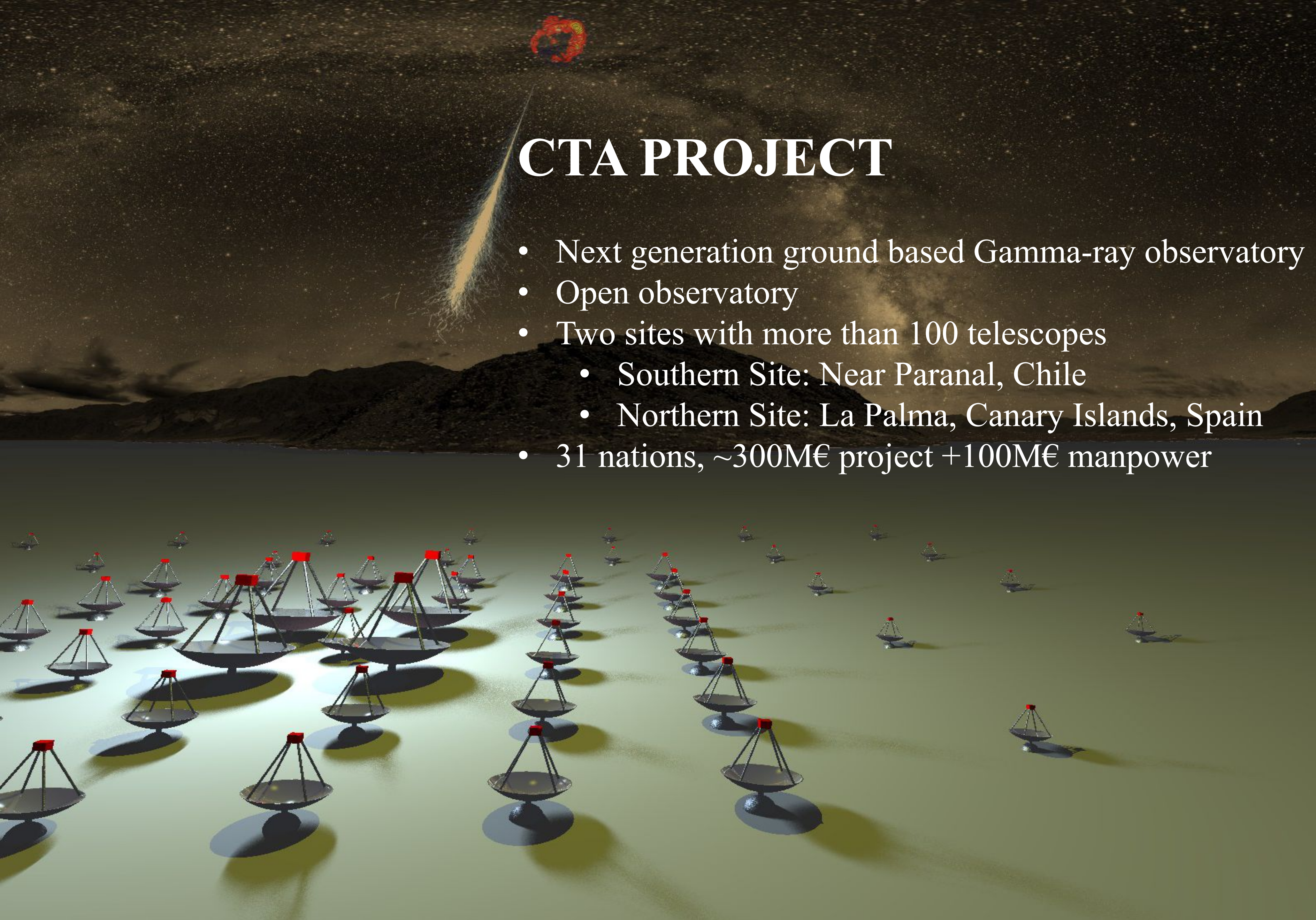
M.Ackermann et al., [Fermi Coll.] PRL 115, 231301 (2015) [arXiv:1503.02641]

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



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


CTA

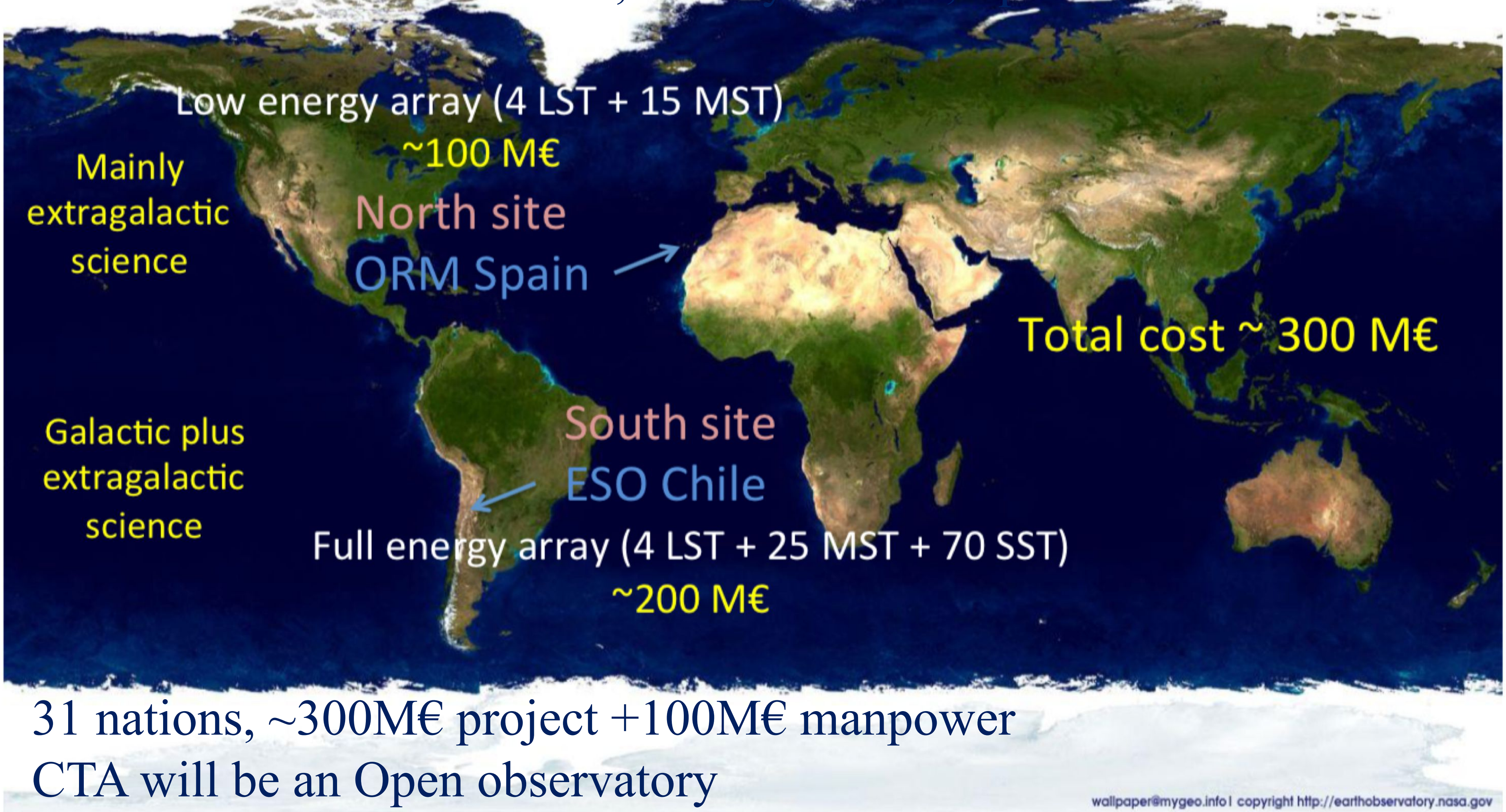


CTA PROJECT

- Next generation ground based Gamma-ray observatory
- Open observatory
- Two sites with more than 100 telescopes
  - Southern Site: Near Paranal, Chile
  - Northern Site: La Palma, Canary Islands, Spain
- 31 nations, ~300M€ project +100M€ manpower

All-sky coverage: two observatories

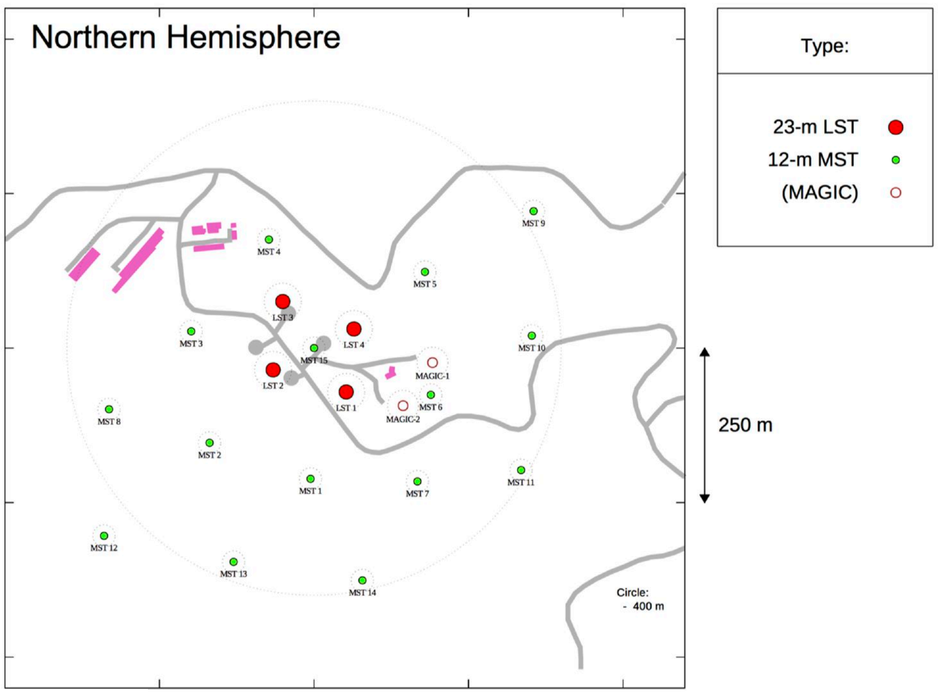
- Two sites with more than 100 telescopes
  - Southern Site: Near Paranal, Chile
  - Northern Site: La Palma, Canary Islands, Spain



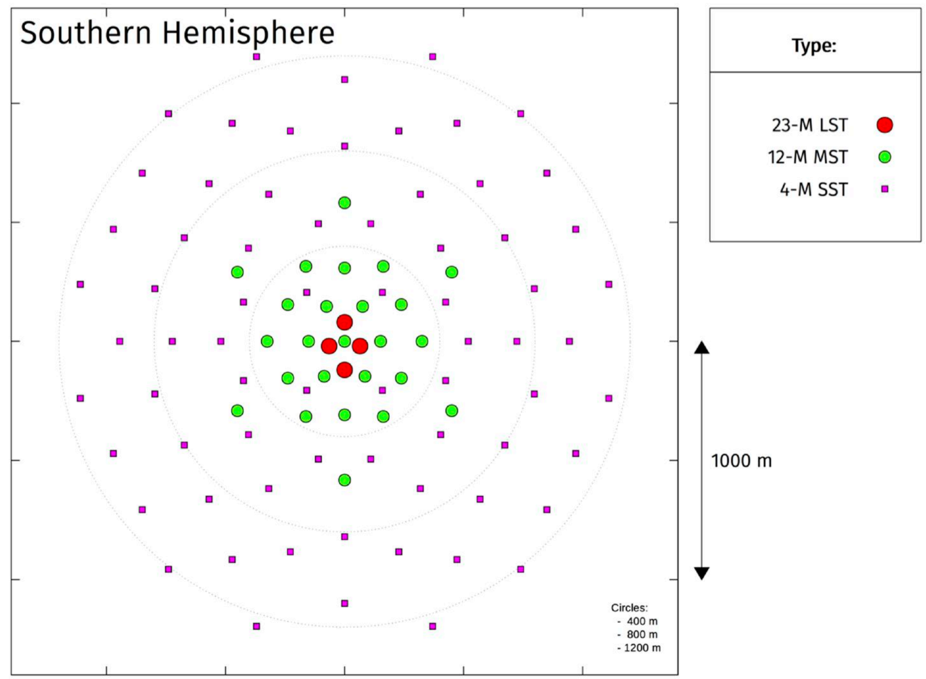
31 nations, ~300M€ project +100M€ manpower

CTA will be an Open observatory

CTA sites and proposed telescope layouts



4 Large-Sized (LST), 15 Medium-Sized (MST) telescopes



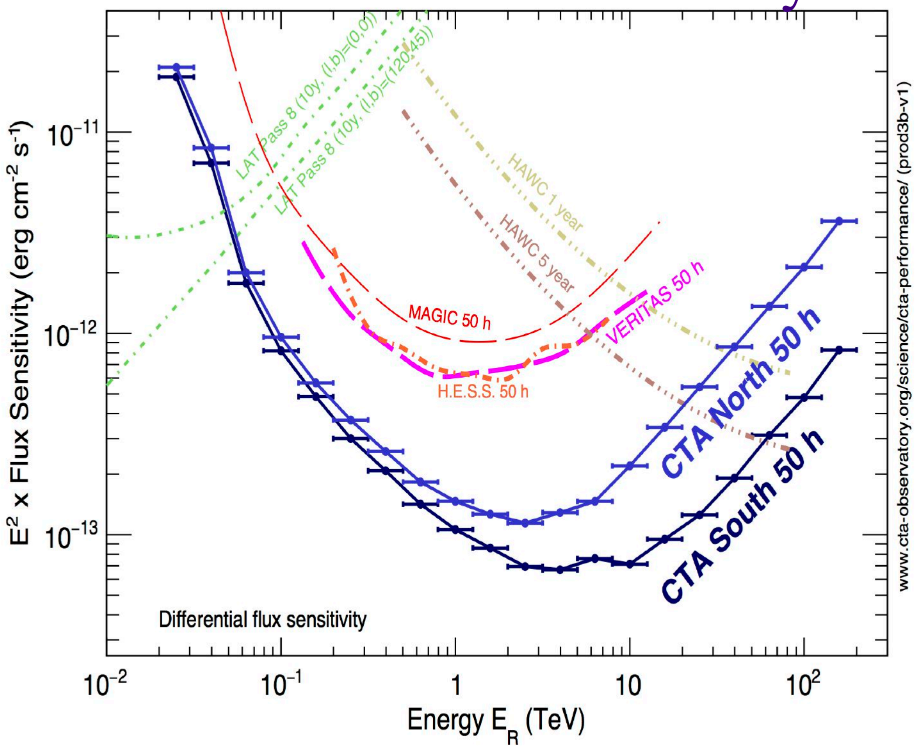
4 Large-Sized (LST), 25 Medium-Sized (MST), 70 Small-Sized (SST) telescopes

CTA PERFORMANCE

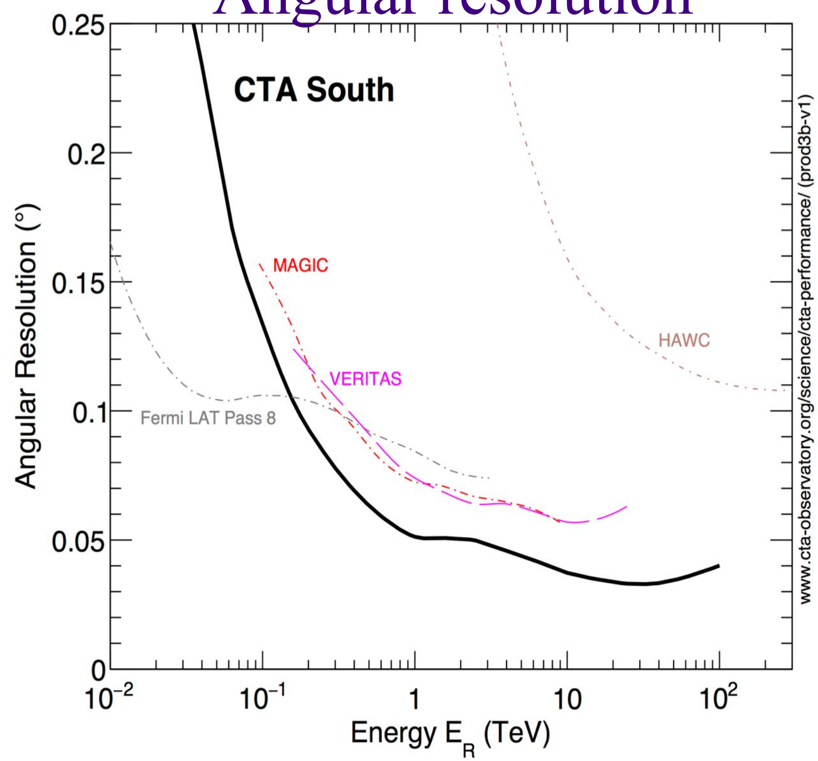
Southern Site:
- 4 Large-size telescopes
- 25 Medium-size telescopes
- 70 Small-size telescopes

Northern Site:
- 4 Large-size telescopes
- 15 Medium-size telescopes

Differential sensitivity



Angular resolution



CTA PERFORMANCE

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

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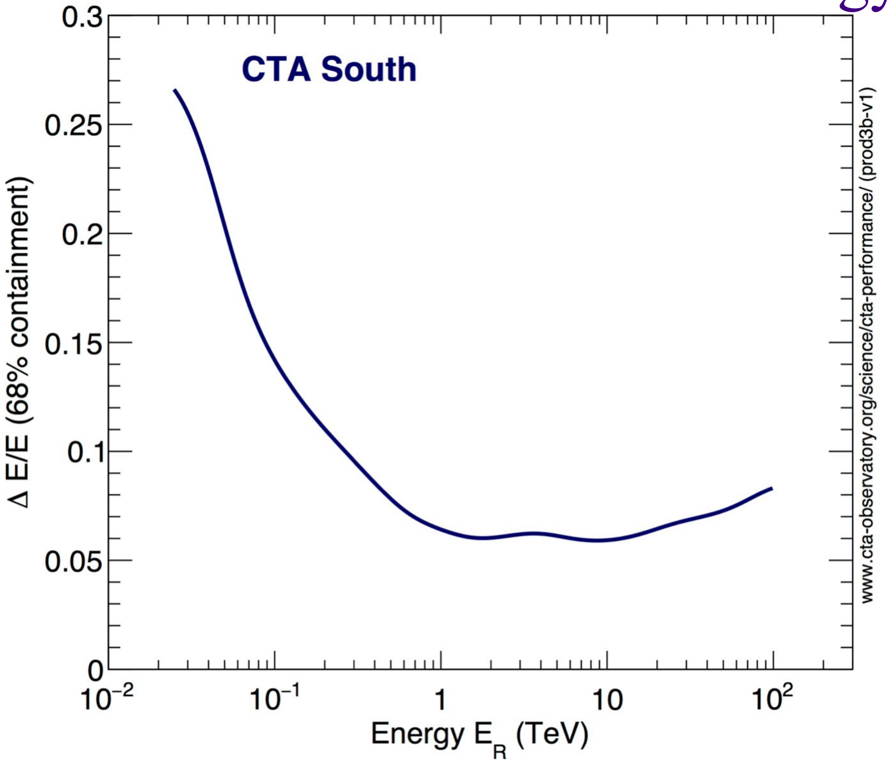
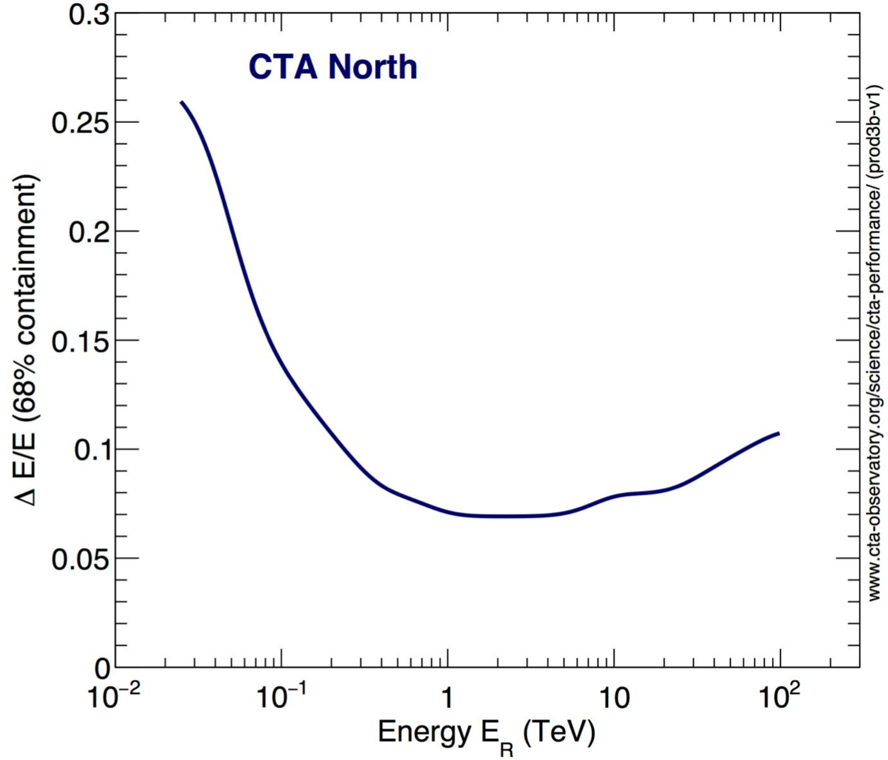
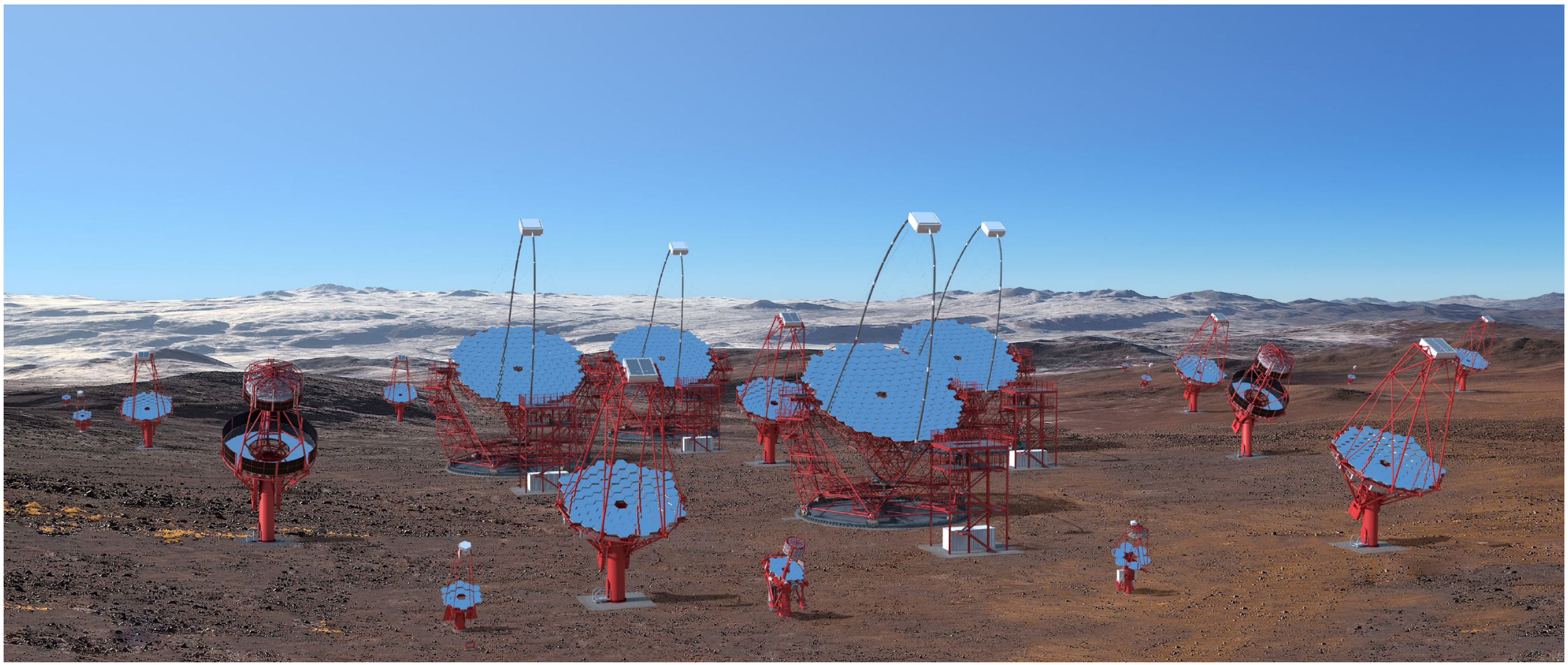
Energy Resolution





Final Agreements Signed for CTA's Southern Hemisphere Site in Chile

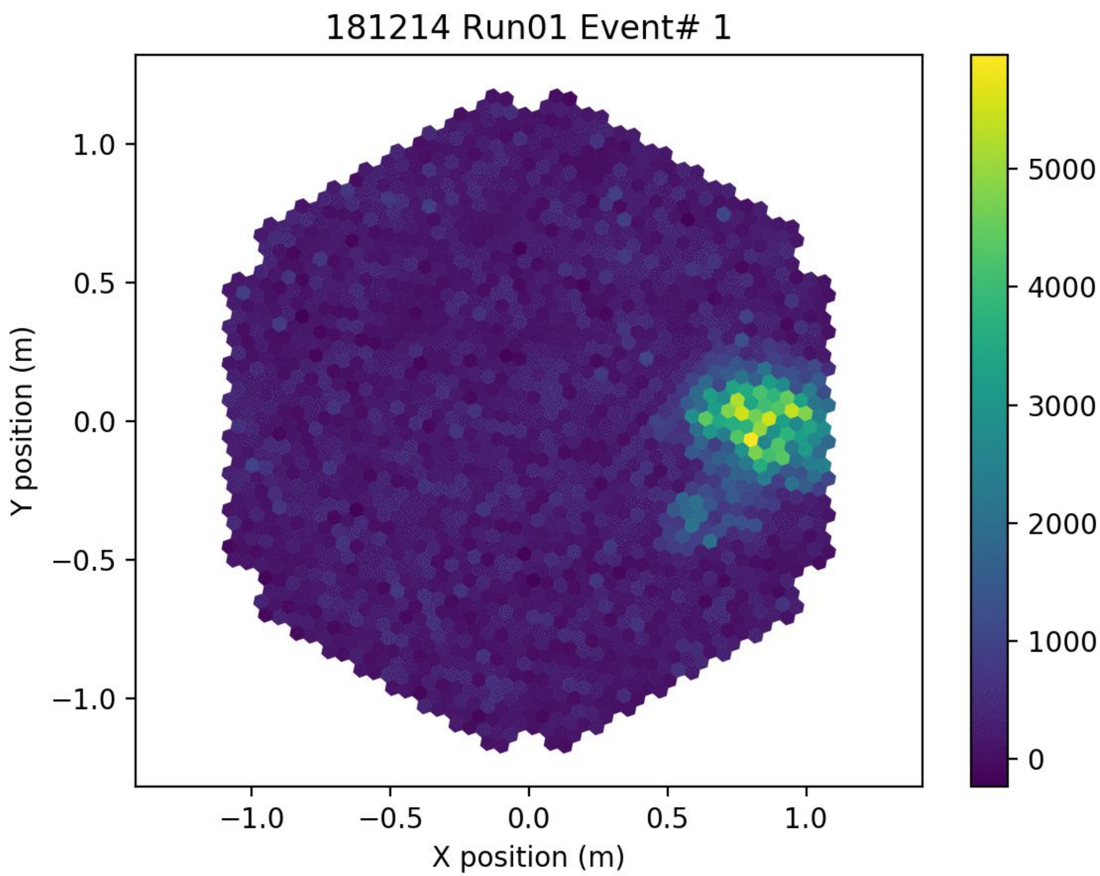
Santiago, Chile – On 19 December 2018, the Cherenkov Telescope Array Observatory (CTAO) and the European Southern Observatory (ESO) signed the final agreements needed for CTA's southern hemisphere array to be hosted near ESO's Paranal Observatory in Chile. Construction on both the northern and southern arrays is expected to begin in 2020.



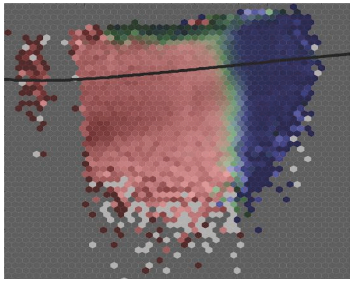
Rendering of the South Site

Large-Sized Telescope Prototype records its First Light

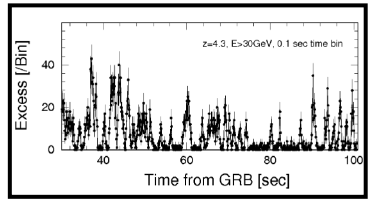
On the night of 14-15 December 2018, the Large-SizedTelescope (LST) prototype recorded its first Cherenkov light on the northern site of the Cherenkov Telescope Array (CTA), located at the Instituto de Astrofísica de Canarias' (IAC's) Observatorio del Roque de los Muchachos (ORM), on the Canary island of La Palma



Key Science Projects (KSPs)

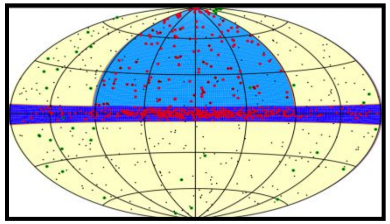


Dark Matter Programme



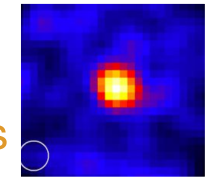
Transients

Extragalactic



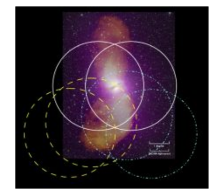
ExGal Survey

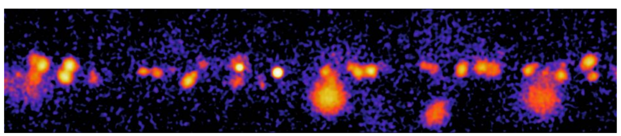
Galaxy Clusters



Star Forming Systems

AGN

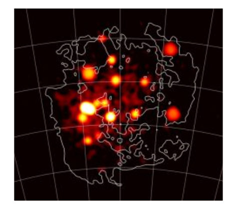




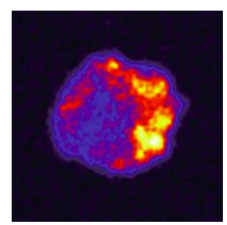
Galactic Plane Survey

Galactic

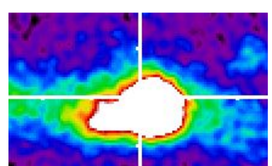
LMC Survey



PeVatrons

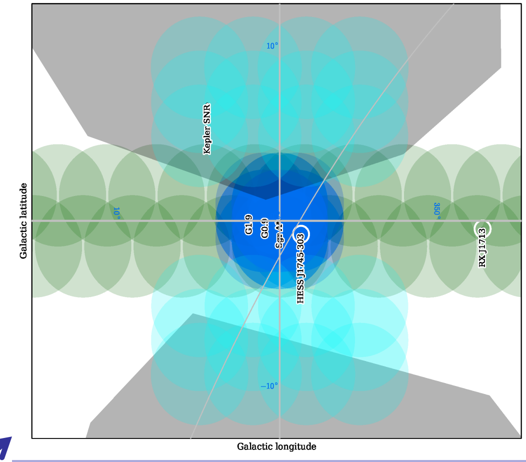


Galactic Centre

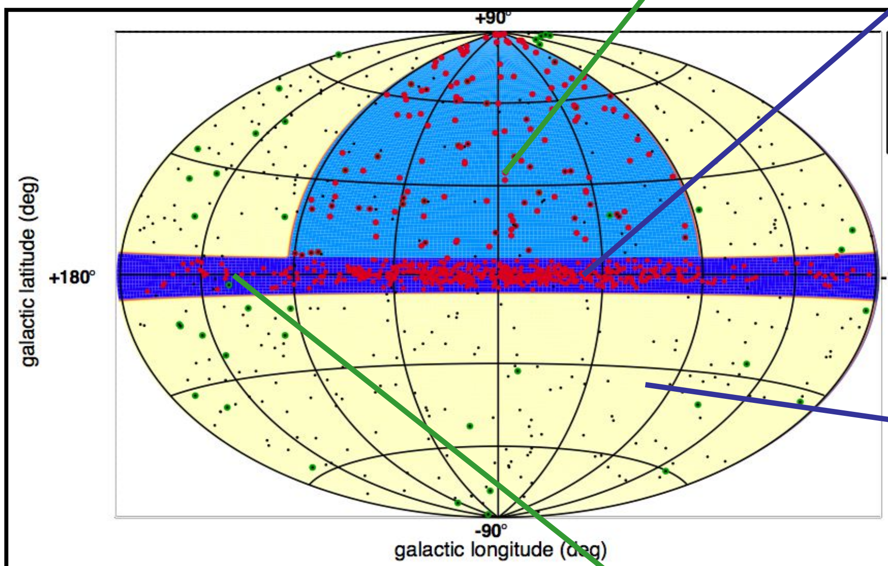


Science with the Cherenkov Telescope Array
World Scientific
https://doi.org/10.1142/10986
[arXiv:1709.07997] ~364 pp.

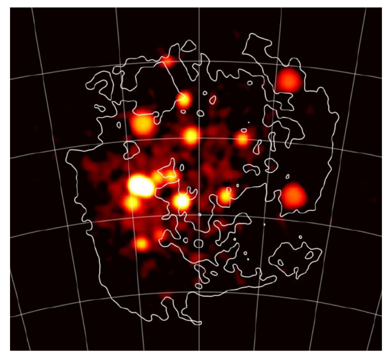
The Survey Key Science Projects



Extragalactic Survey:
Unbiased survey of ¼ sky to ~6 mCrab
VHE population study, duty cycle
New, unknown sources; 1000 h



Galactic Centre Survey:
ID of the central source
Spectrum, morphology of diffuse emission
Deep DM search
Central exposure: 525 h, 10°x10° : 300 h

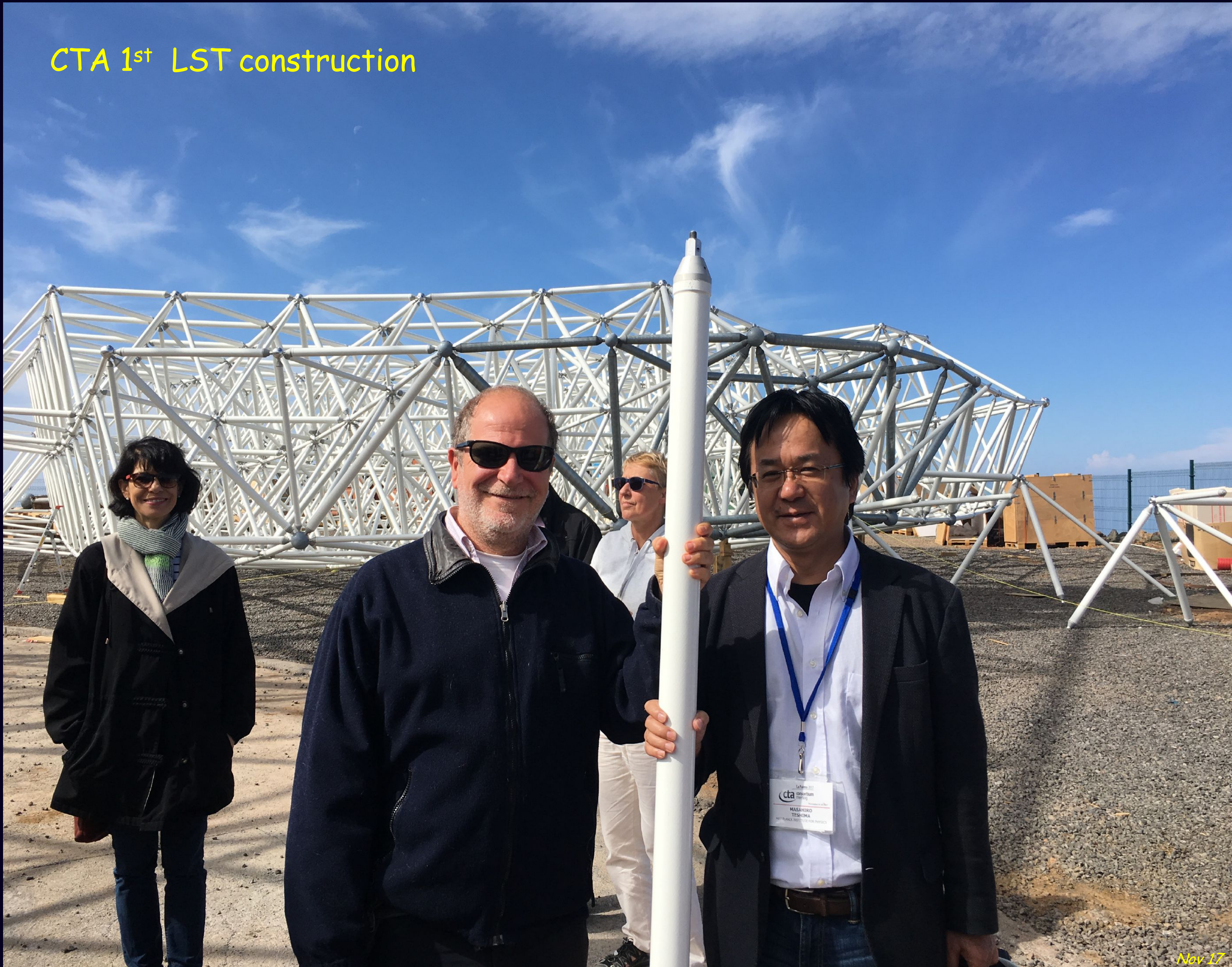


Science with the Cherenkov Telescope Array
World Scientific
https://doi.org/10.1142/10986
[arXiv:1709.07997] ~364 pp.

Galactic Plane Survey:
Survey of entire plane to ~2 mCrab
Galactic source population: SNRs, PWNe, etc.
PeVatron candidates, early view of GC, 1620 h

Large Magellanic Cloud Survey:
Face-on satellite galaxy with high SFR
Extreme Gal. sources, diffuse emission (CRs)
DM search; 340 h in six pointings

CTA 1st LST construction



Nov 17

CTA 1st LST construction

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

CTA 1st LST construction

CTA 1st LST construction

Camera Support Structure Installed
21 June

CTA 1st LST construction

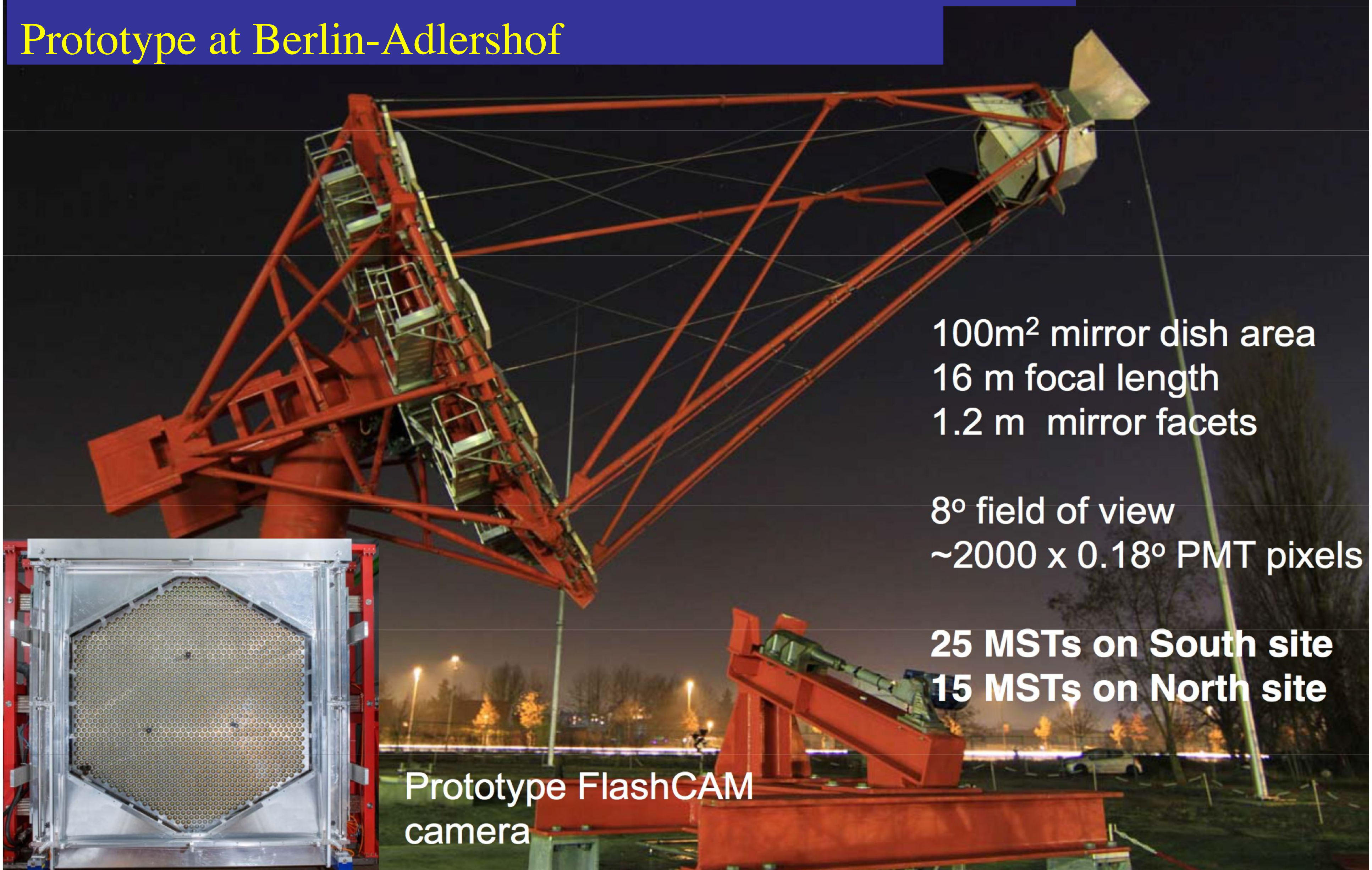
Inauguration 10 October 2018

CTA 1st LST construction

Inauguration 10 October 2018

Medium-Sized Telescope

Prototype at Berlin-Adlershof



Medium-Sized 2-mirror Telescope

Prototype SCT at Whipple Obs, Arizona

Schwarzschild-Couder Telescope (SCT)

9.7 m primary
5.4 m secondary
5.6 m focal length, f/0.58
50 m^2 mirror dish area
PSF better than 4.5′
across 8° FOV

8° field of view
11328 x 0.07° Si-PM pixels

➜ Improved γ-ray angular resolution

Small-Sized Telescopes

cherenkov
telescope
array

- 3 different prototype designs
- 2 designs use two-mirror approaches (Schwarzschild-Couder design)
- All use Si-PM photosensors
- 8-10 m^2 mirror area, FOV > 9^o

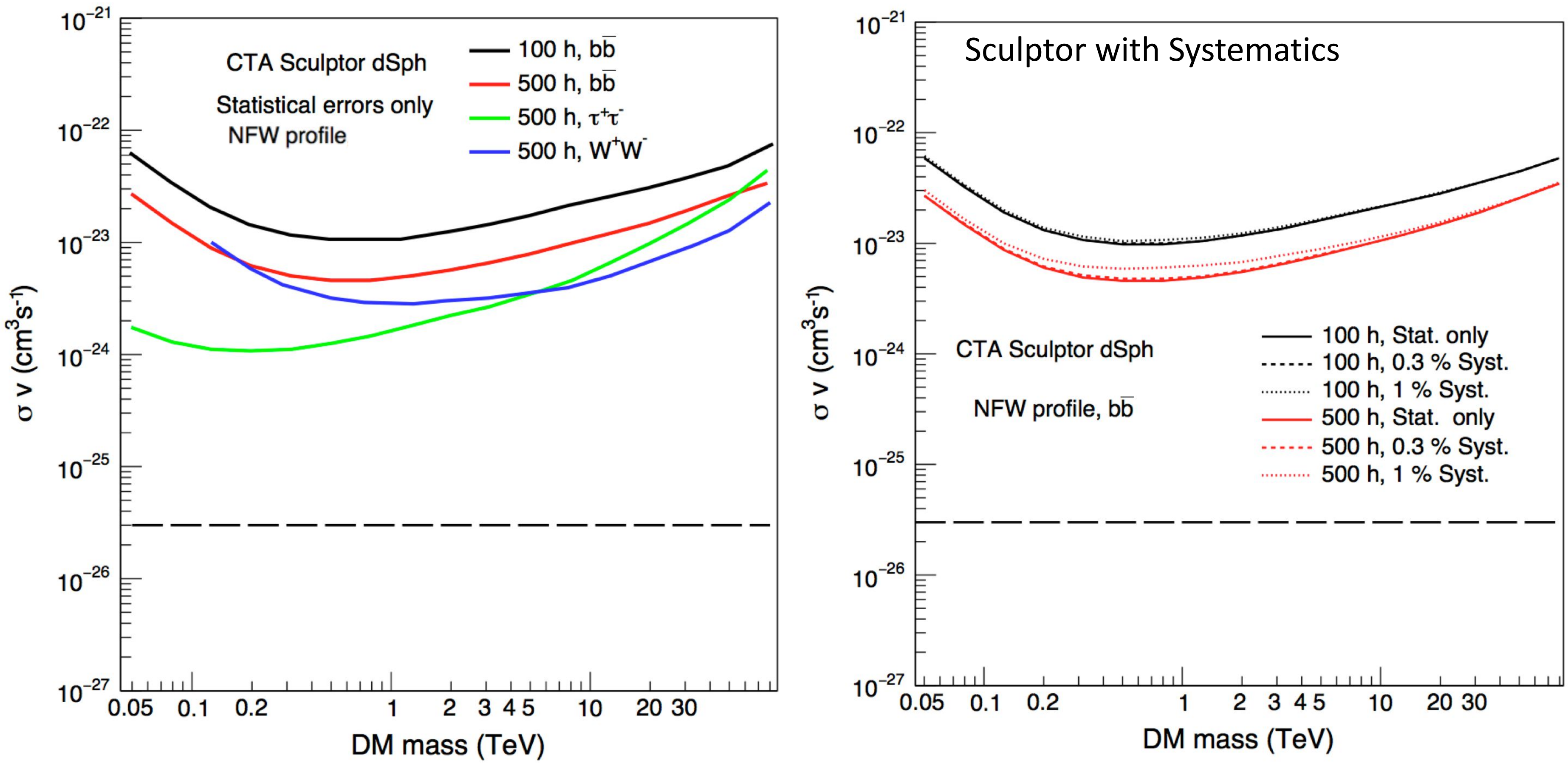
SST-1M
Krakow, Poland

SST-2M ASTRI
Mt. Etna, Italy

first light May 17

SST-2M GCT
Meudon, France

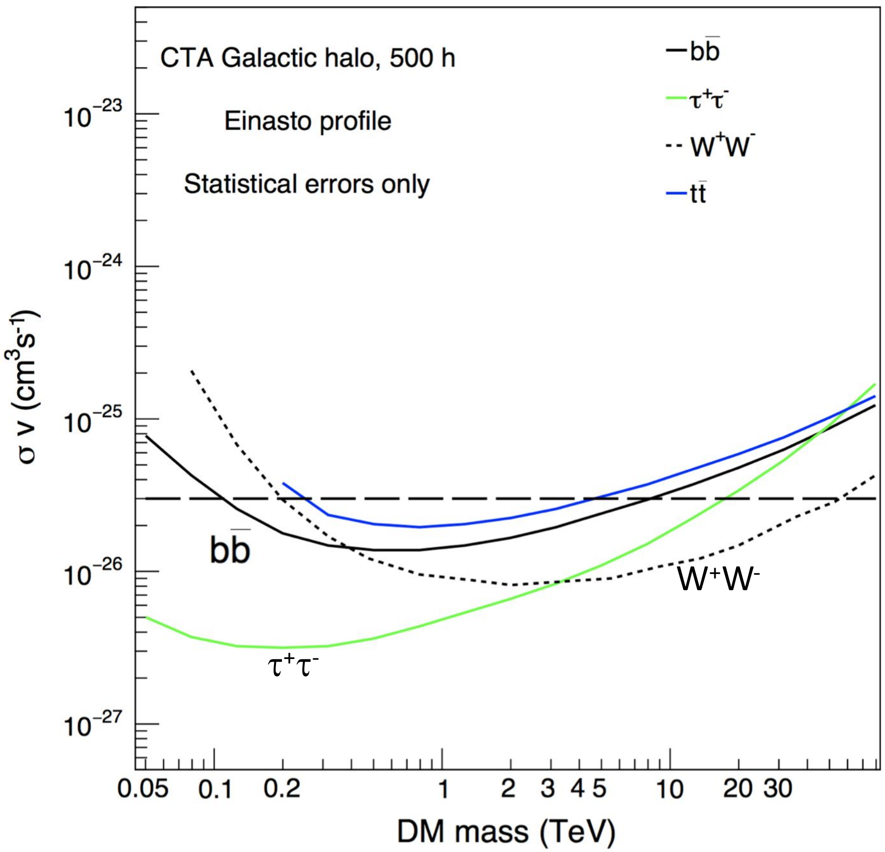
Dwarf Spheroidal Galaxies: CTA Sensitivity

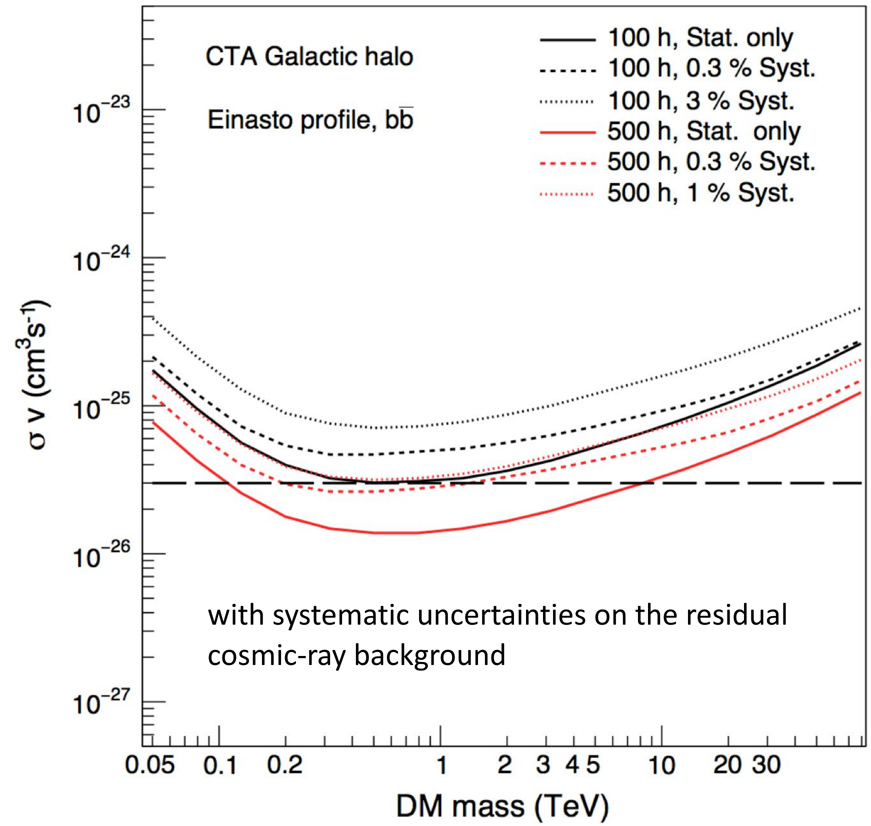


There are several of the newly discovered dSph that have a better case for being a promising target,

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

CTA Galactic Halo DM upper-limits

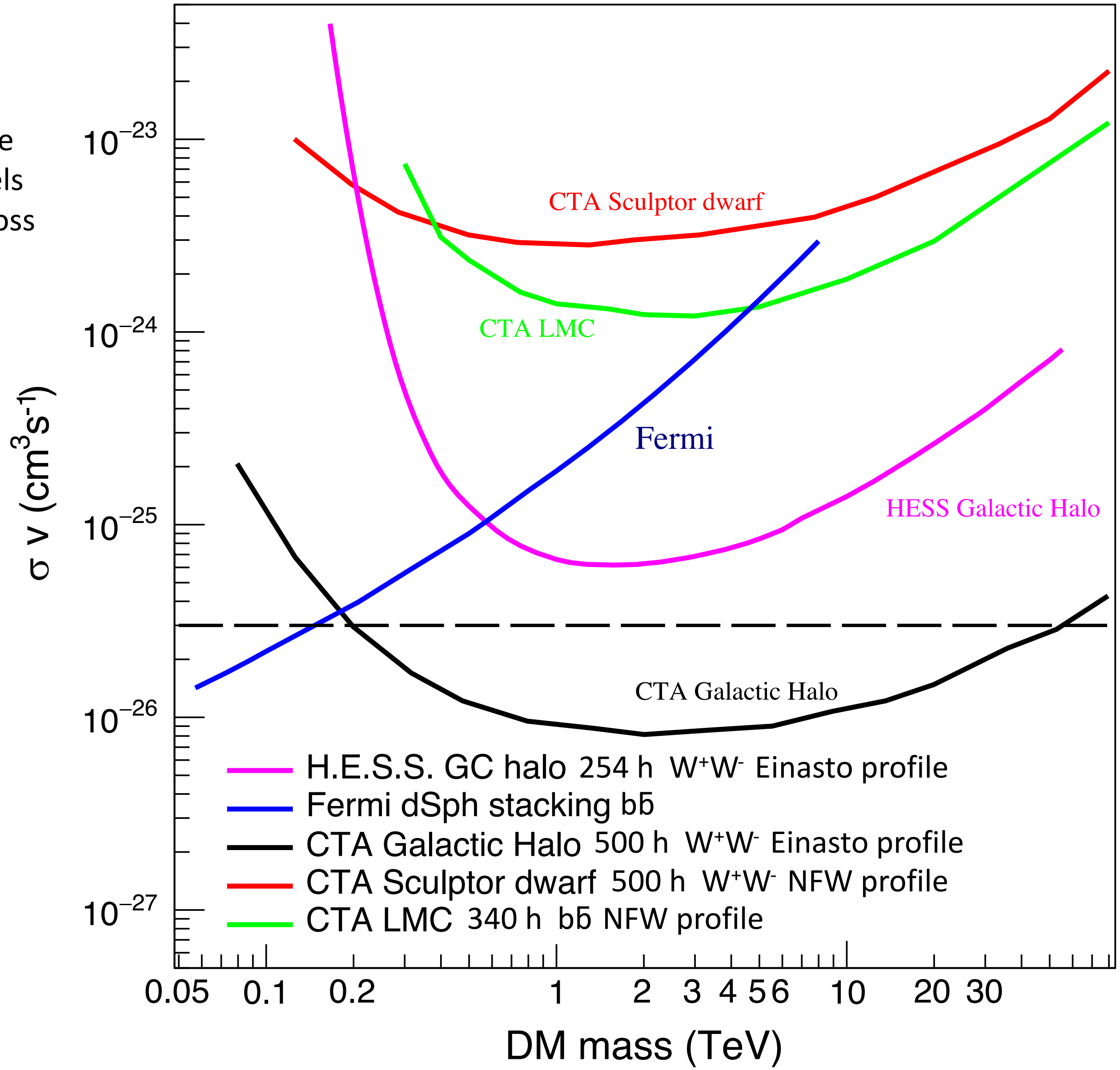




The predictions shown here can be considered optimistic, even when systematics errors are included, as we do not consider the effect of the Galactic diffuse emission as background for DM searches that can affect the results by ~ 50%
This will be investigated in detail in a forthcoming publication by the CTA Consortium.

CTA, 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, HESS, FERMI, PLANK DM upper-limits

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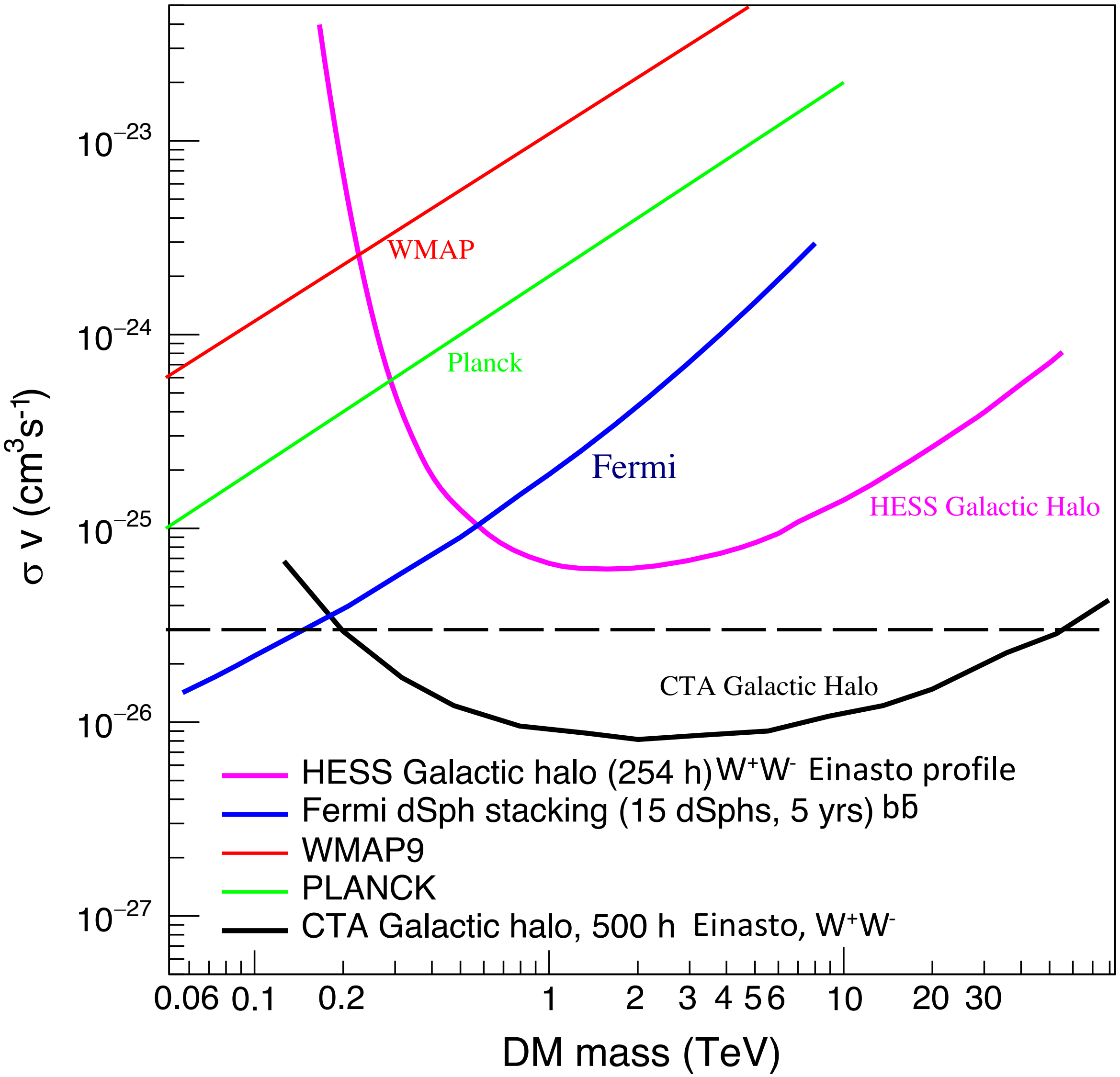


CTA DM Detection Strategy

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.

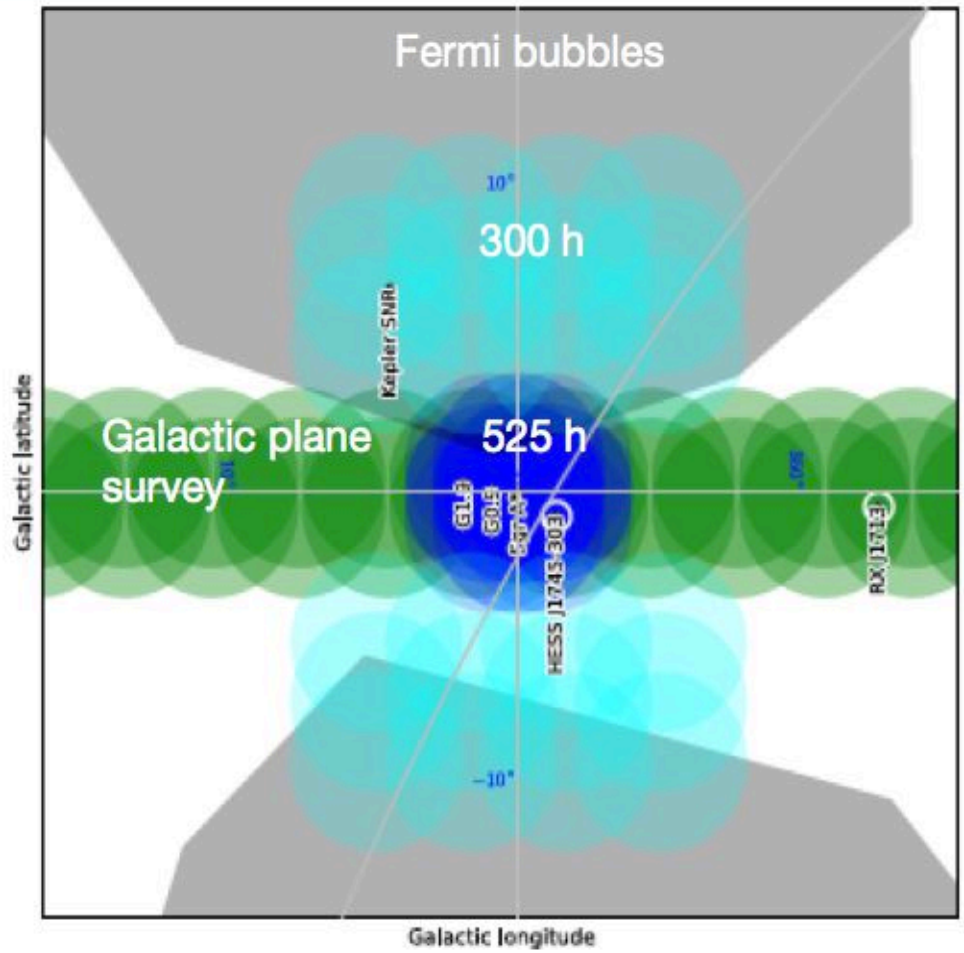
DEEP OBSERVATIONS OF GC REGION

Deep 525 h exposure in the inner 5° around Sgr A*;

Extended 300 h survey of 10°x10° region;

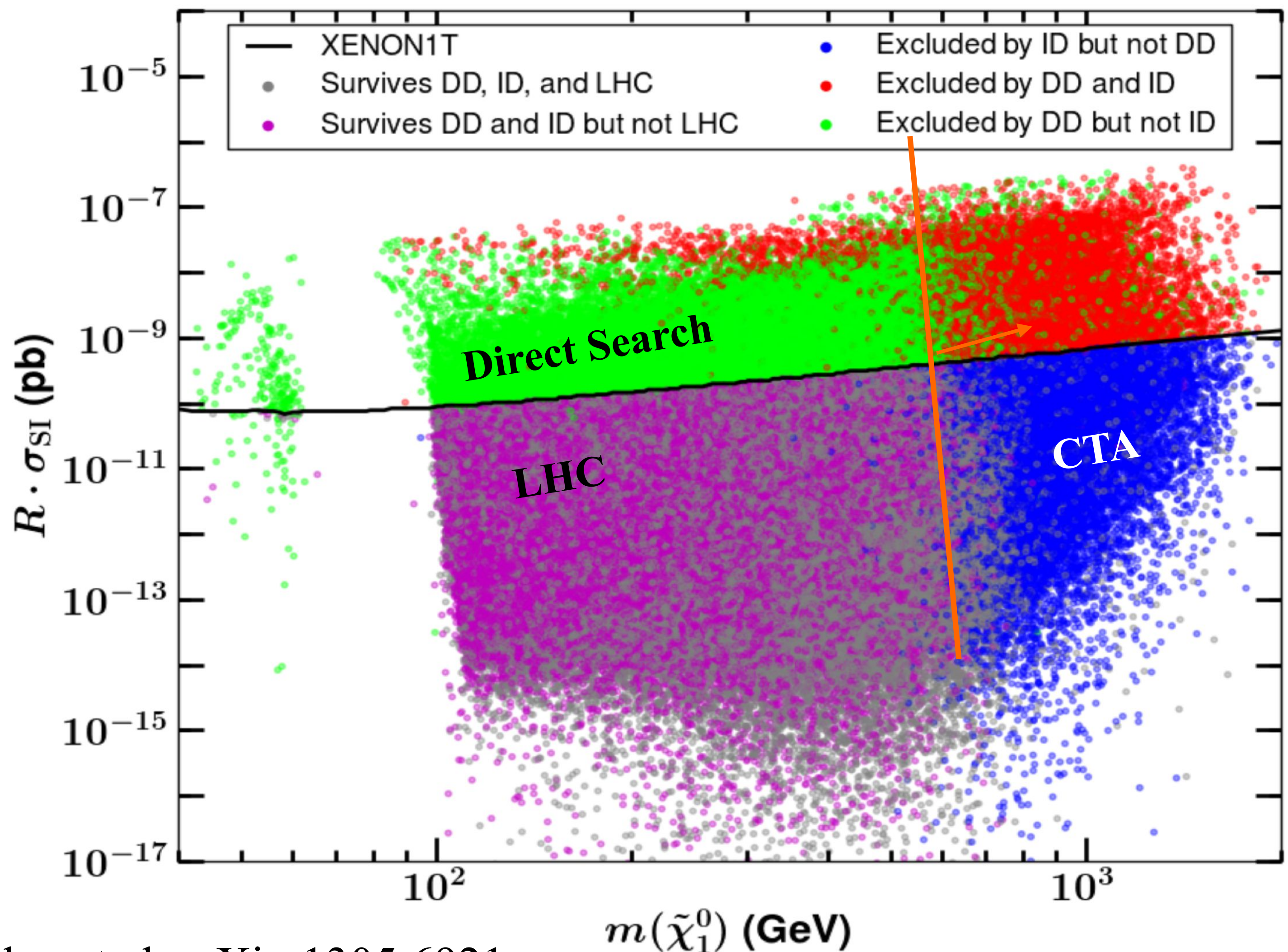
Produce CTA legacy data set for large range of scientific topics, which include

- GC and GC DM halo
- Understand "backgrounds" pin down VHE sources and map diffuse emission
- Astrophysics of SNRs (multiple sources, e.g. G1.9, …)
- Astrophysics of PWNe and Pulsars
- Extended objects such as Central Radio lobes (central ±1°) and arc features.



CTA legacy data set

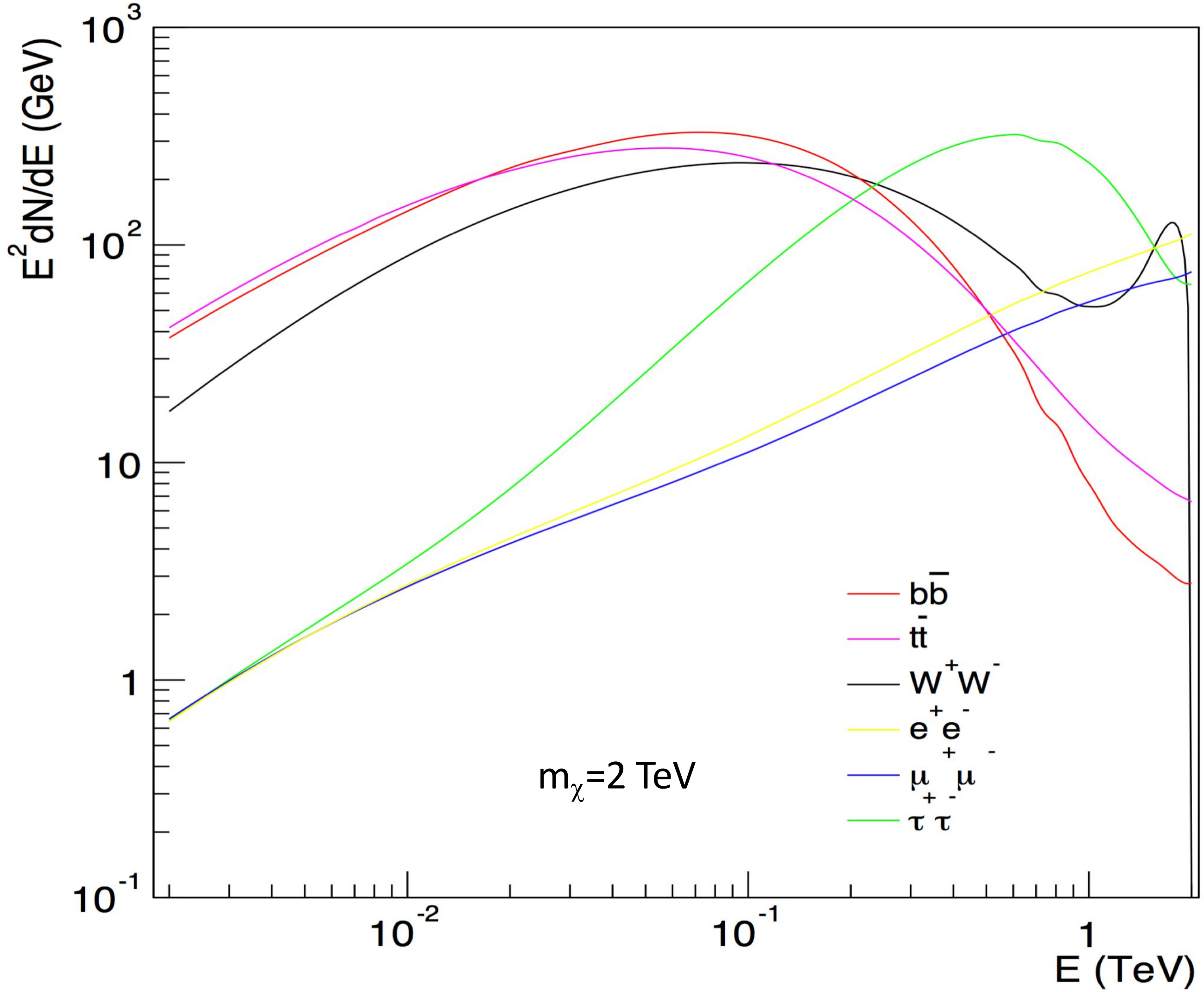
Complementarity and Searches for Dark Matter in the pMSSM



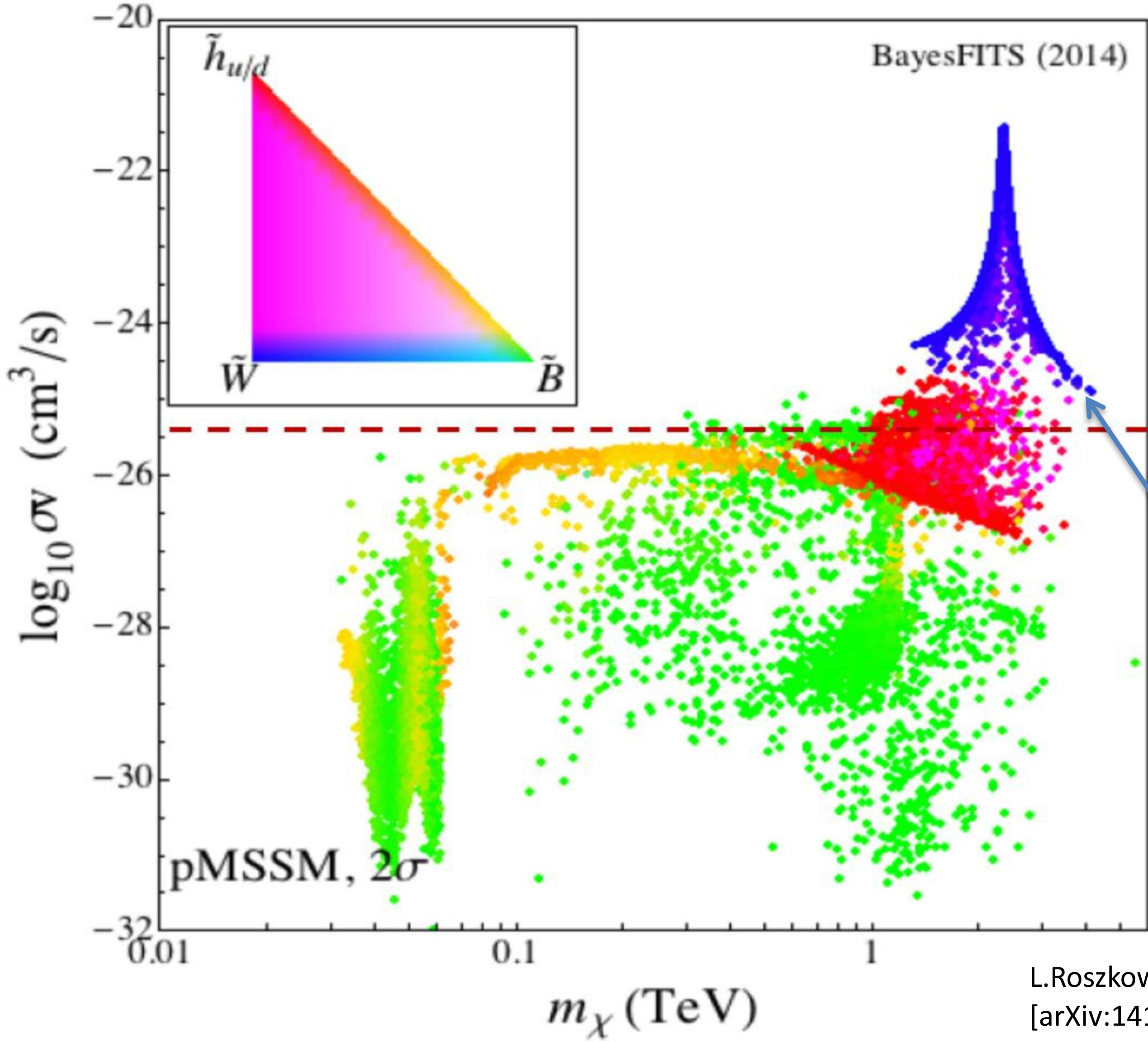
Cahill-Rowley et al. arXiv:1305.6921

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

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



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

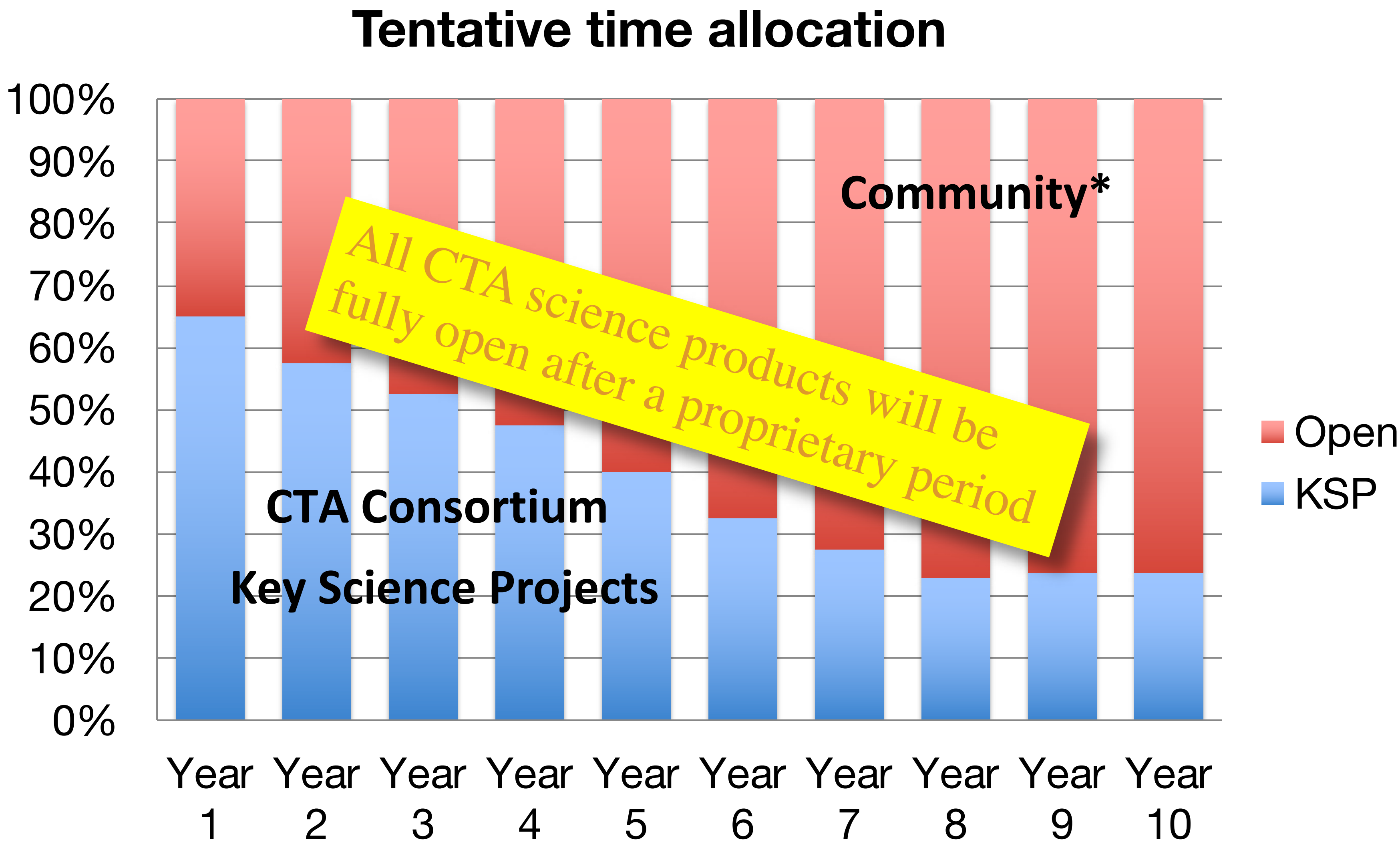


Example: Annihilation cross-section points from a 19 dimensional pMSSM fit

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

L.Roszkowski et al., JHEP 1502 (2015) 014 [arXiv:1411.5214]

Time Allocation & Community Access



*of scientists from nations contributing to CTA construction and operations and from site host nations

CTA: Analysis Software

A high-level data analysis package for gamma-ray astronomy

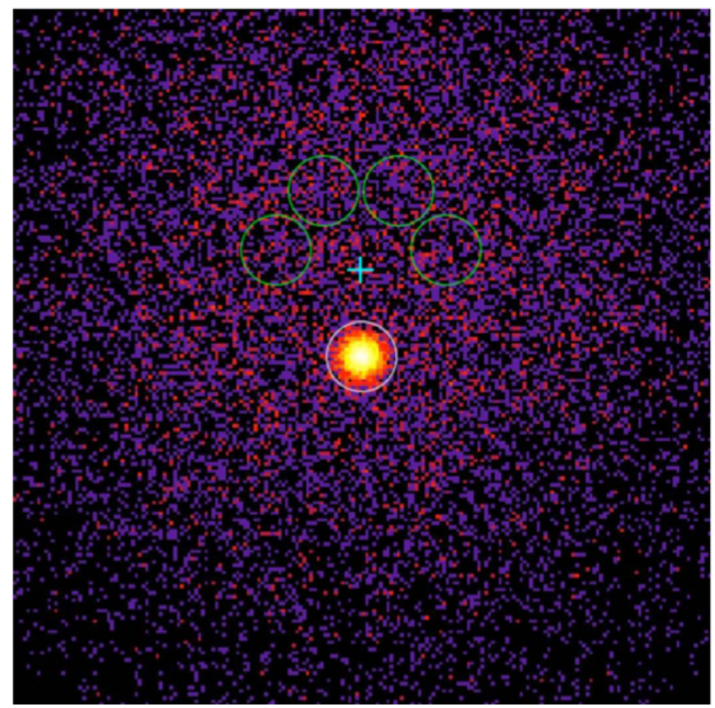
- **GammaLib-CTOOLS:**
  – COMPTEL
  – Fermi/LAT
  – Cherenkov telescopes (CTA, H.E.S.S., MAGIC, VERITAS)
- **Gammapy:**
  – Fermi/LAT
  – Cherenkov telescopes (CTA, H.E.S.S., MAGIC, VERITAS)

CTA: Analysis Software

- All tools needed to generate images, spectra, light and phase curves from CTA DL3 data

– Support for unbinned, binned and stacked 3D/4D maximum likelihood analysis

– Support for classical On/Off IACT analysis (ring background sky maps, reflected region spectra)



Download & Documentation

GammaLib-CTOOLS:
http://gammalib.sourceforge.net/

Gammapy:
http://gammapy.org/
Both have also regular coding sprints for user and developers

GammaLib+CTOOLS and Gammapy are a high-level data analysis package for gamma-ray astronomy

Both are work in progress

They are very well documented

Gammapy is a python library

CTOOLS is a set of user-friendly command-lines tools that also support python

They are being used in the first Data Challenge

This first Data Challenge is used to comparer both frameworks

And also to improve their analysis algorithms, debugging, ecc.

The Low Energy Frontier

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

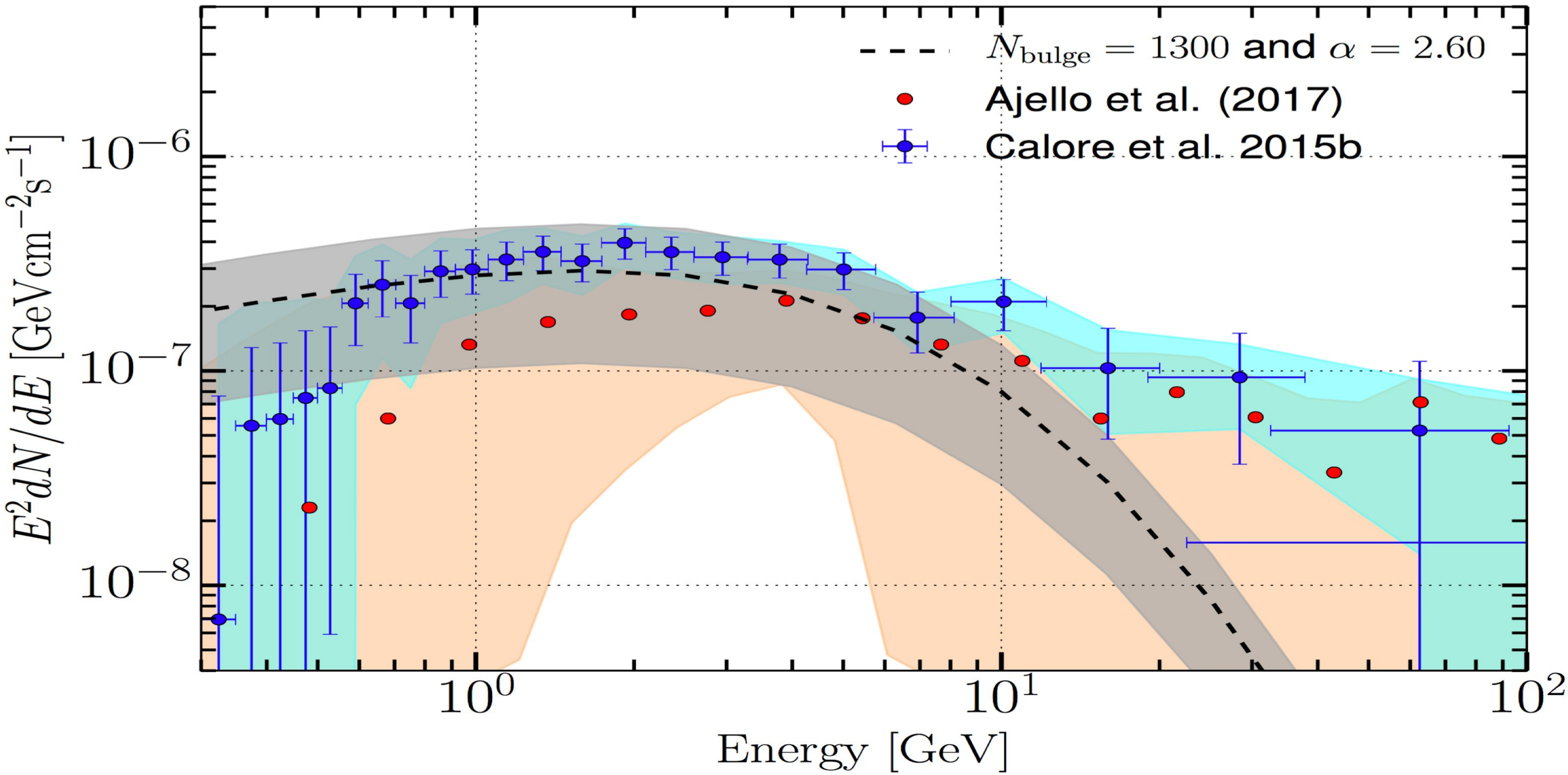
e.g. , Yuan and Zhang arXiv:1404.2318v1, Lee et al. arXiv:1506.05124, Bartels et.al. 1506.05104

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

....

How to discriminate between different hypothesis ?

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

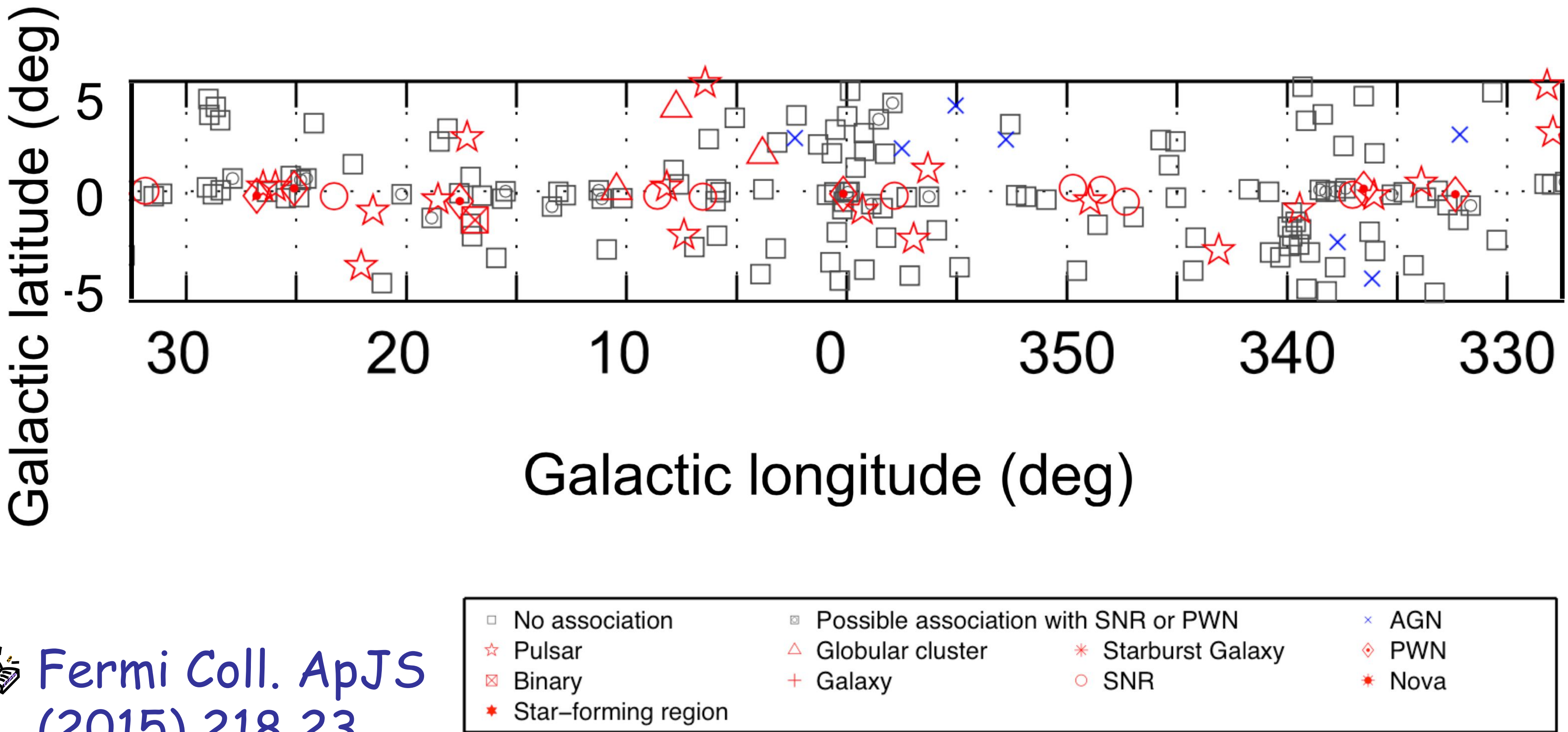
- Diffuse emission modeling
- Analysis of point sources near the GC

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

The Fermi LAT 3FGL Inner Galactic Region

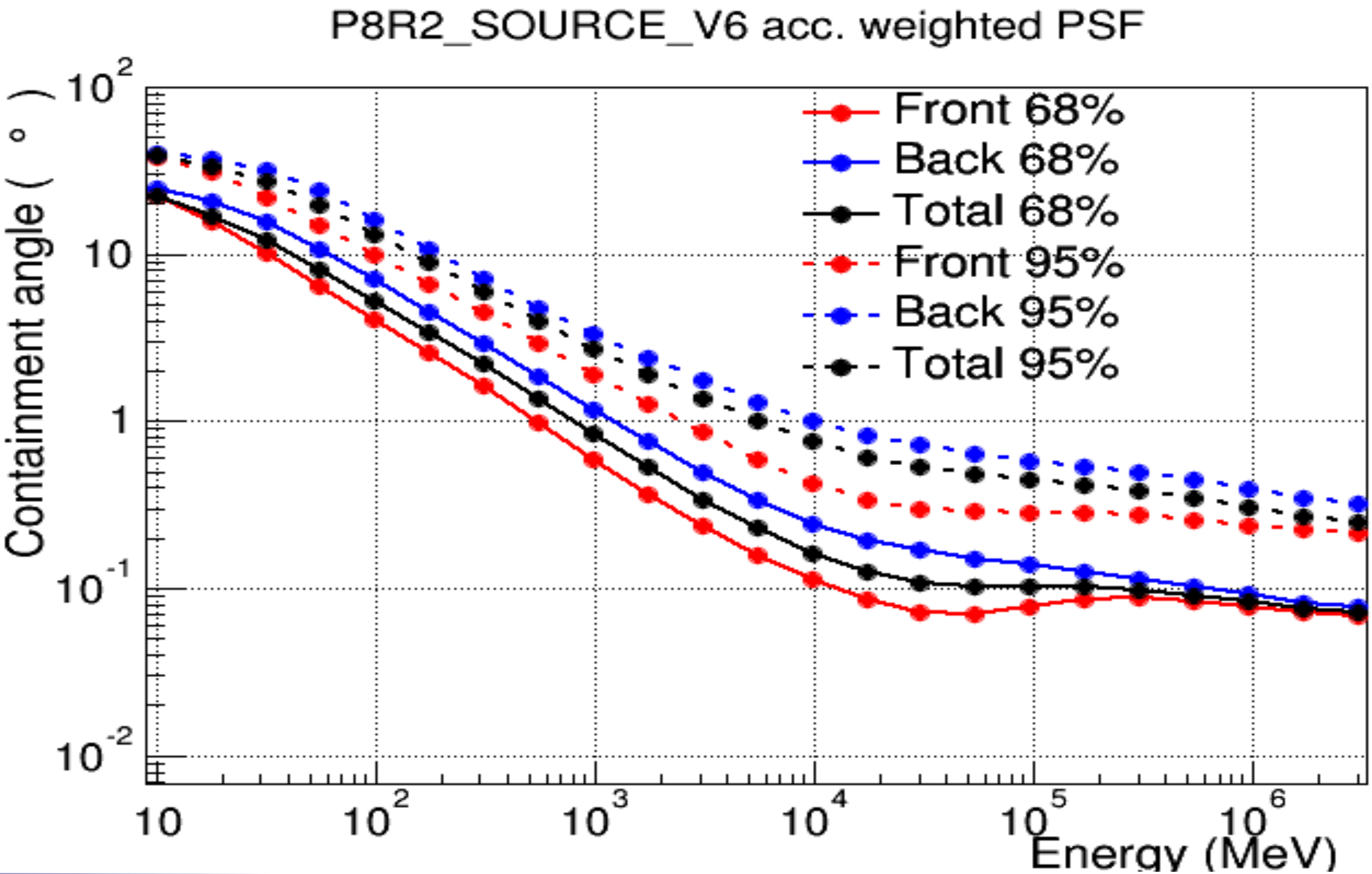
August 4, 2008, to July 31, 2010

100 MeV to 300 GeV energy range

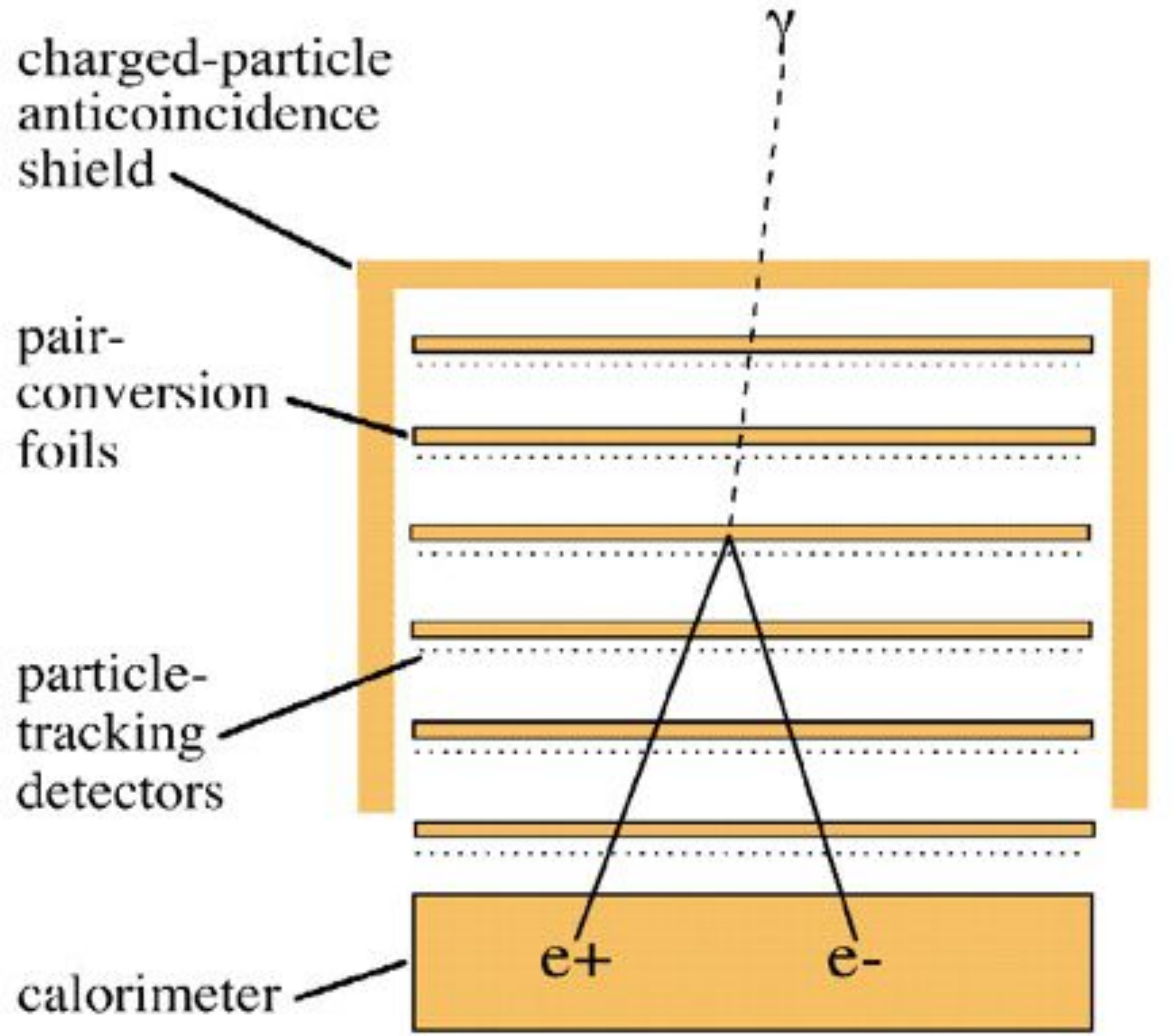


Fermi Coll. ApJS (2015) 218 23 arXiv:1501.02003

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



Elements of a pair-conversion telescope



(energy measurement)

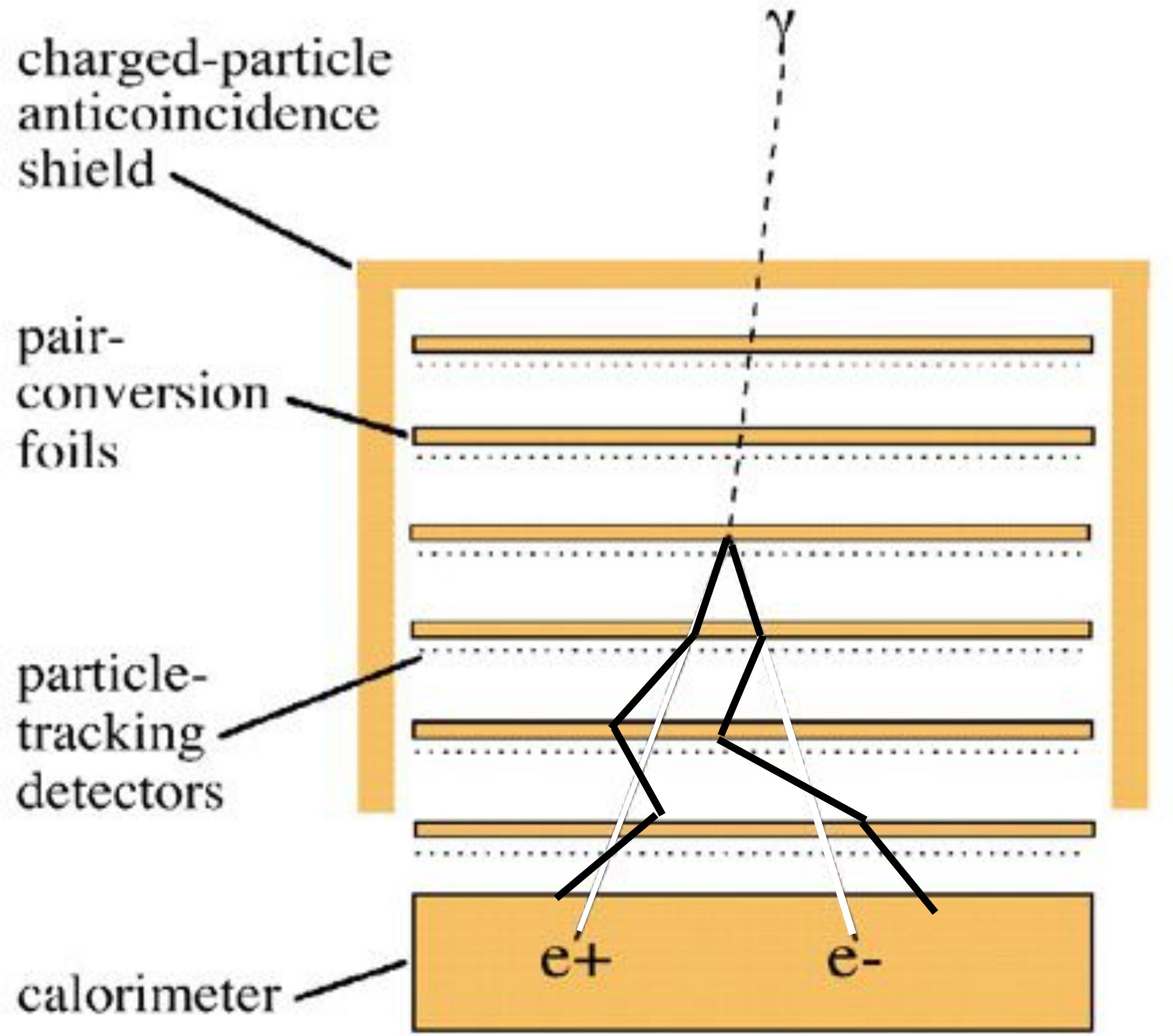
- photons materialize into matter-antimatter pairs:

  E_γ --> $m_{e^+}c^2 + m_{e^-}c^2$

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

Elements of a pair-conversion telescope

(more realistic scheme)



(energy measurement)

- photons materialize into matter-antimatter pairs:

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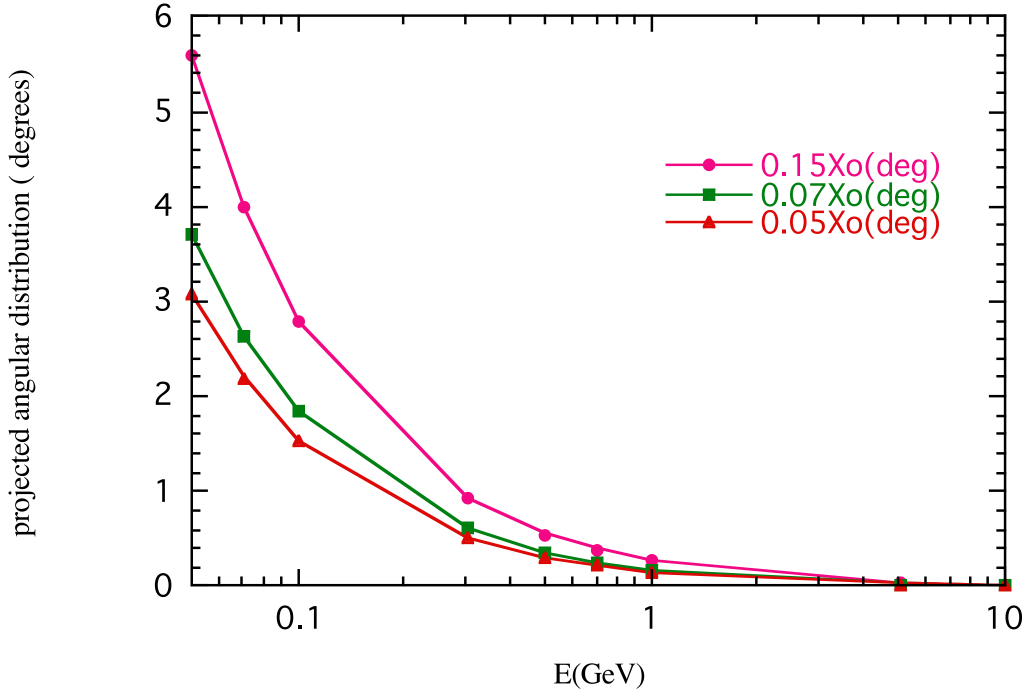
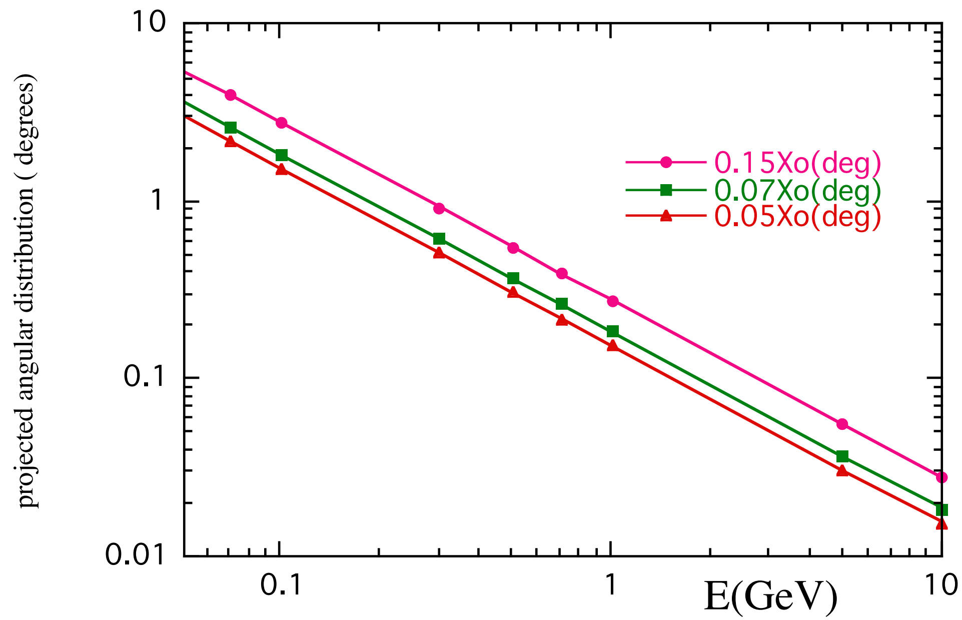
Multiple Scattering

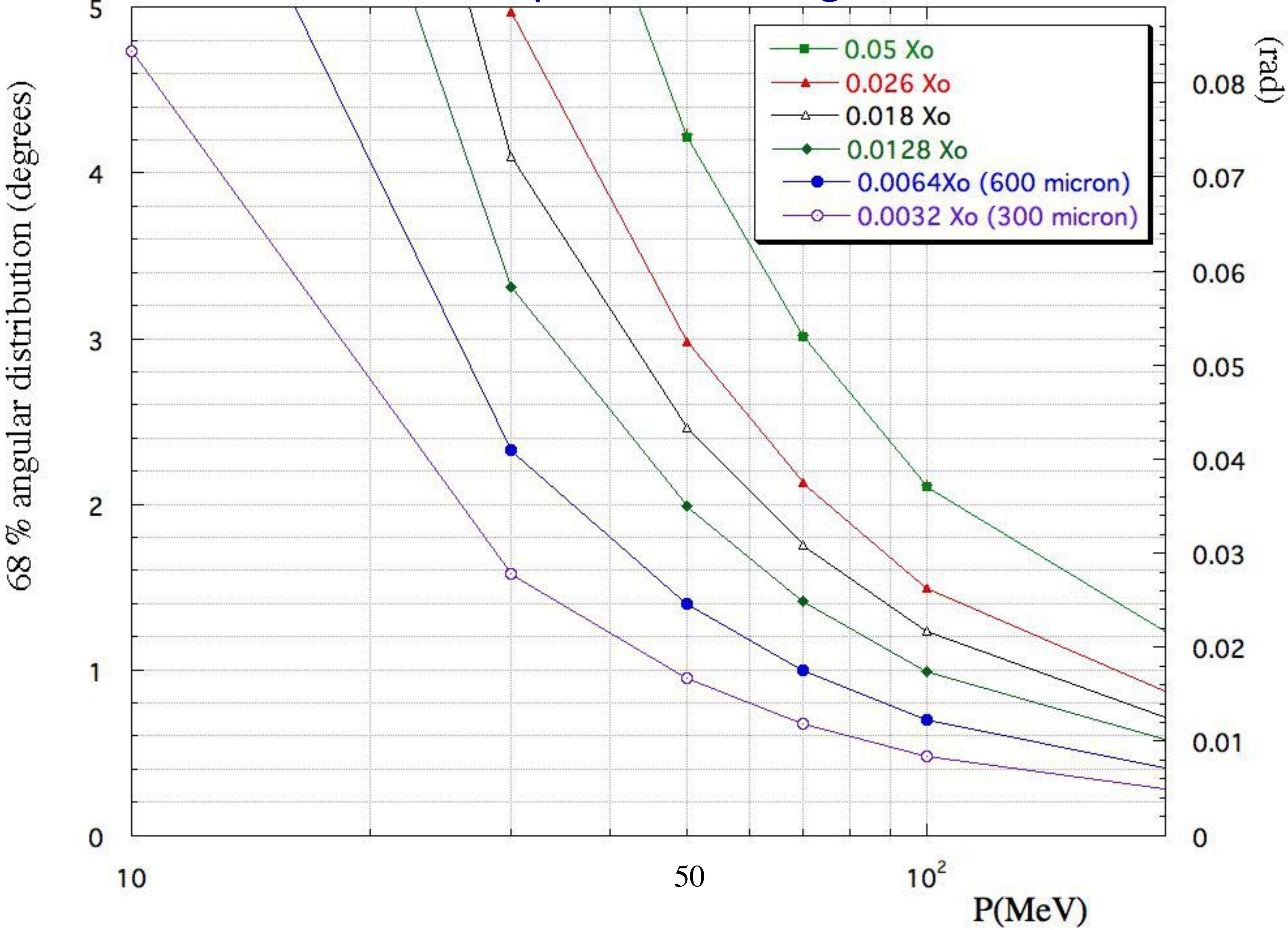




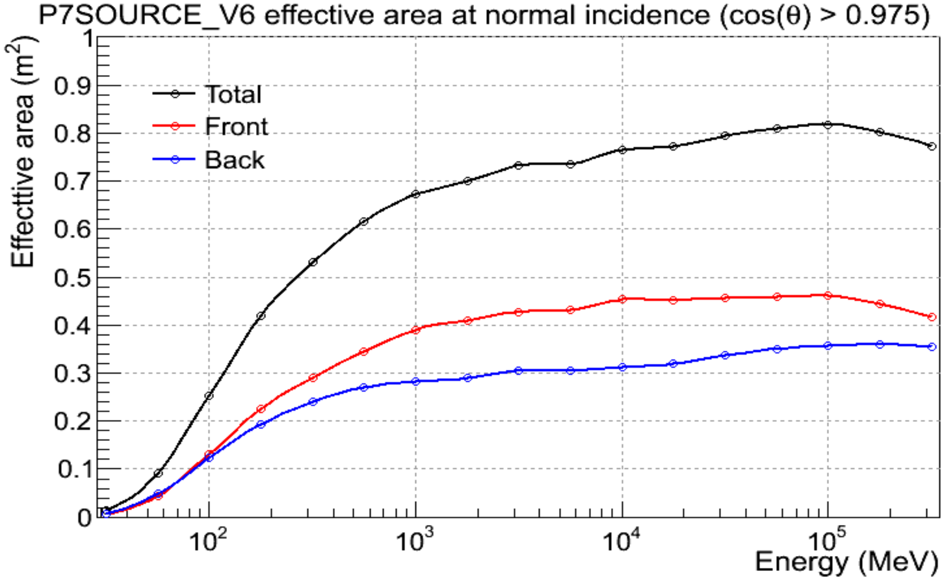
$$\theta_0 = \theta^{rms}_{plane} = \frac{1}{\sqrt{2}}\theta^{rms}_{space}$$

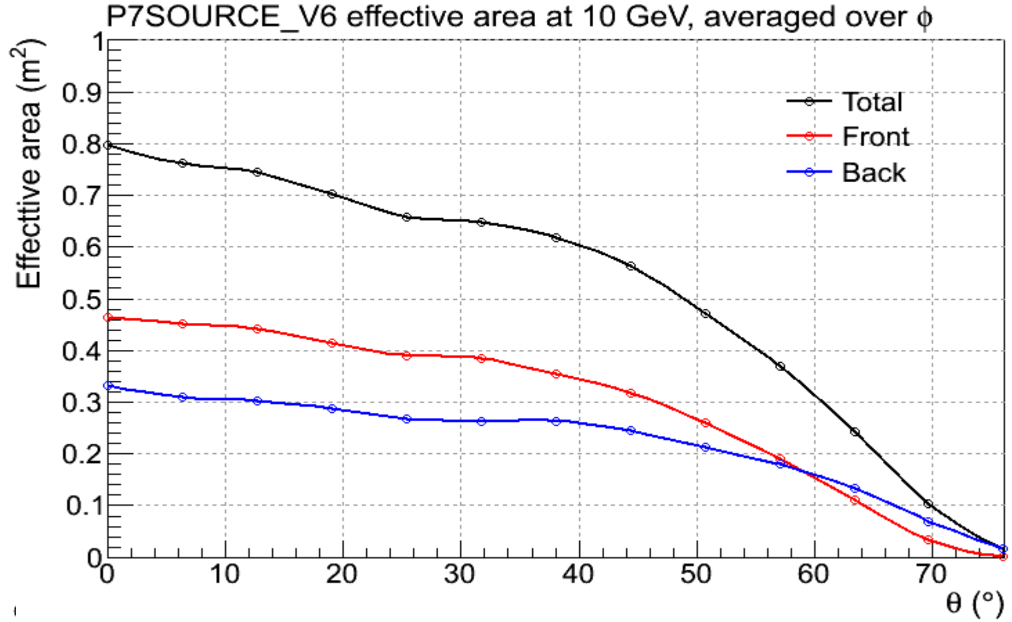
$$\theta_0 = \frac{13.6MeV}{\beta cp} z\sqrt{x/X_0}\,[1 + 0.038\ln(x/X_0)]$$

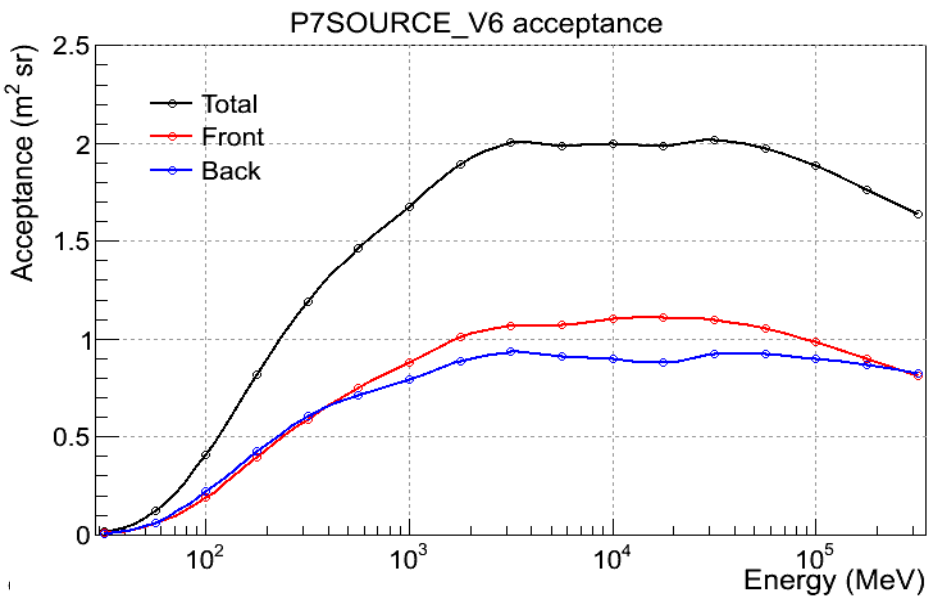
Multiple Scattering

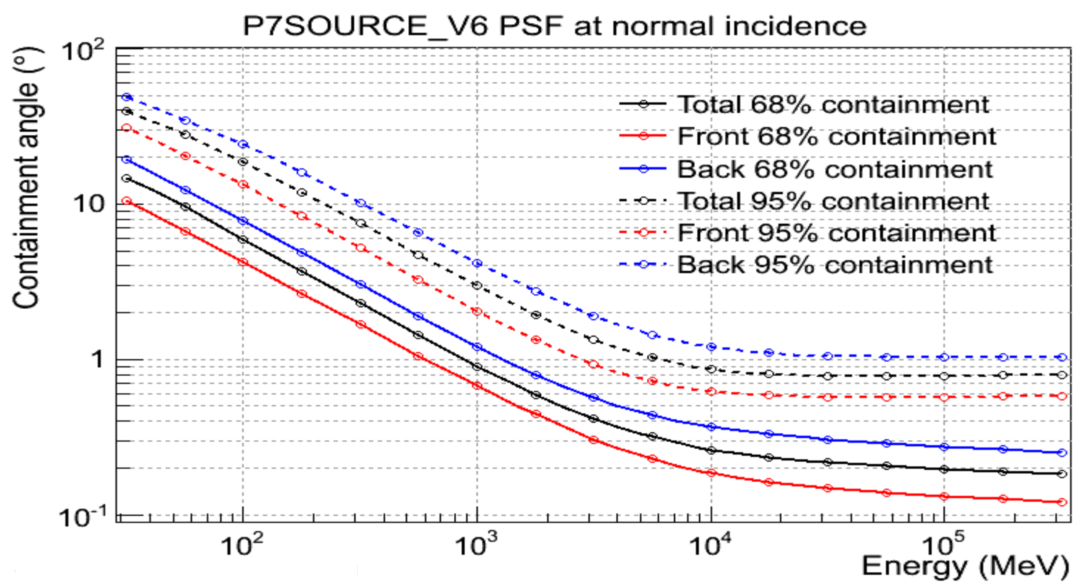


Fermi Instrument Response Function



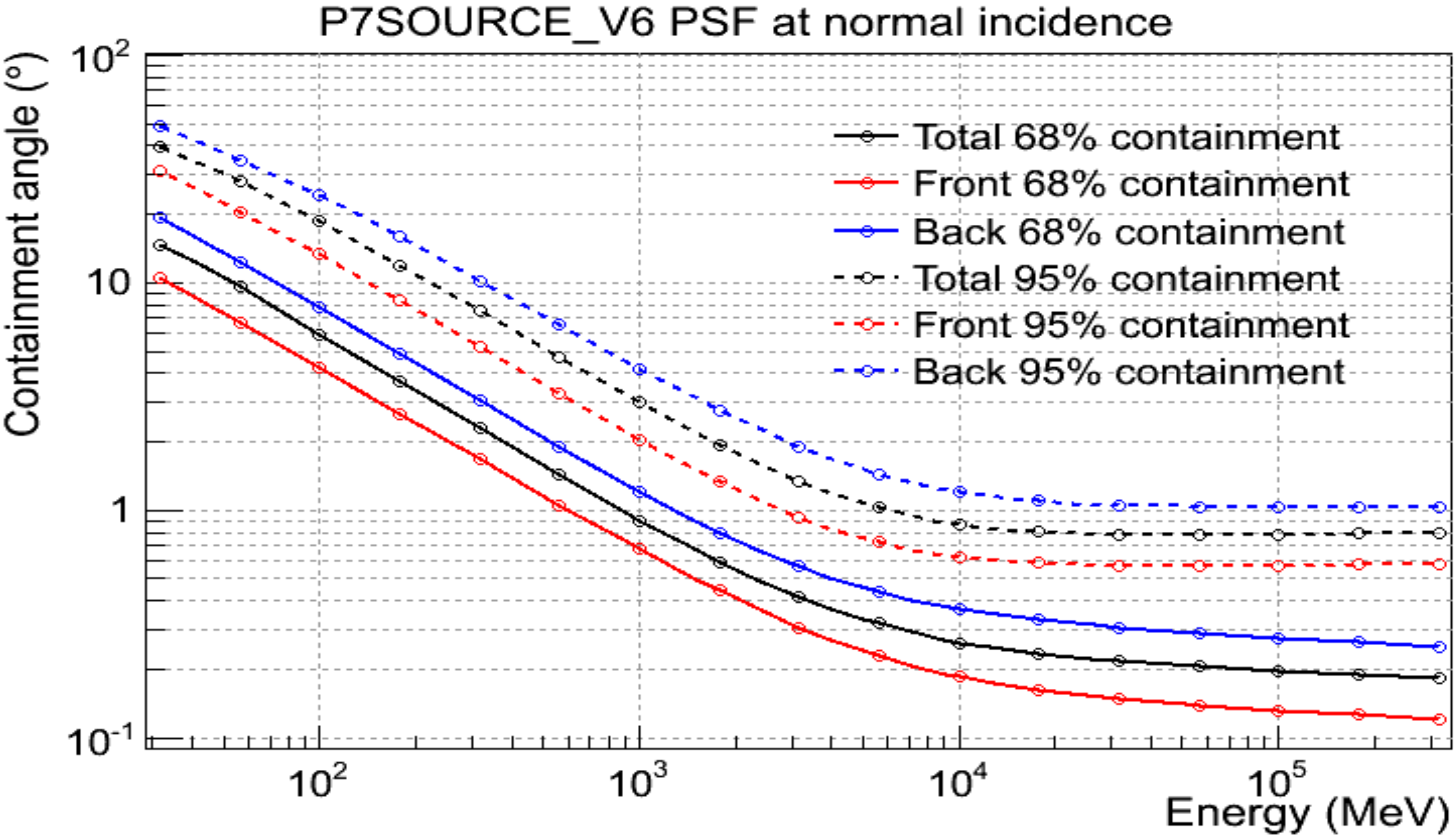






http://www.slac.stanford.edu/exp/glast/groups/canda/lat_Performance.htm

Fermi Instrument Response Function



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

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

Sensitivity

depends on field of view

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

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

depends on angular resolution

Sensitivity

number of σ

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

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

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

good detector

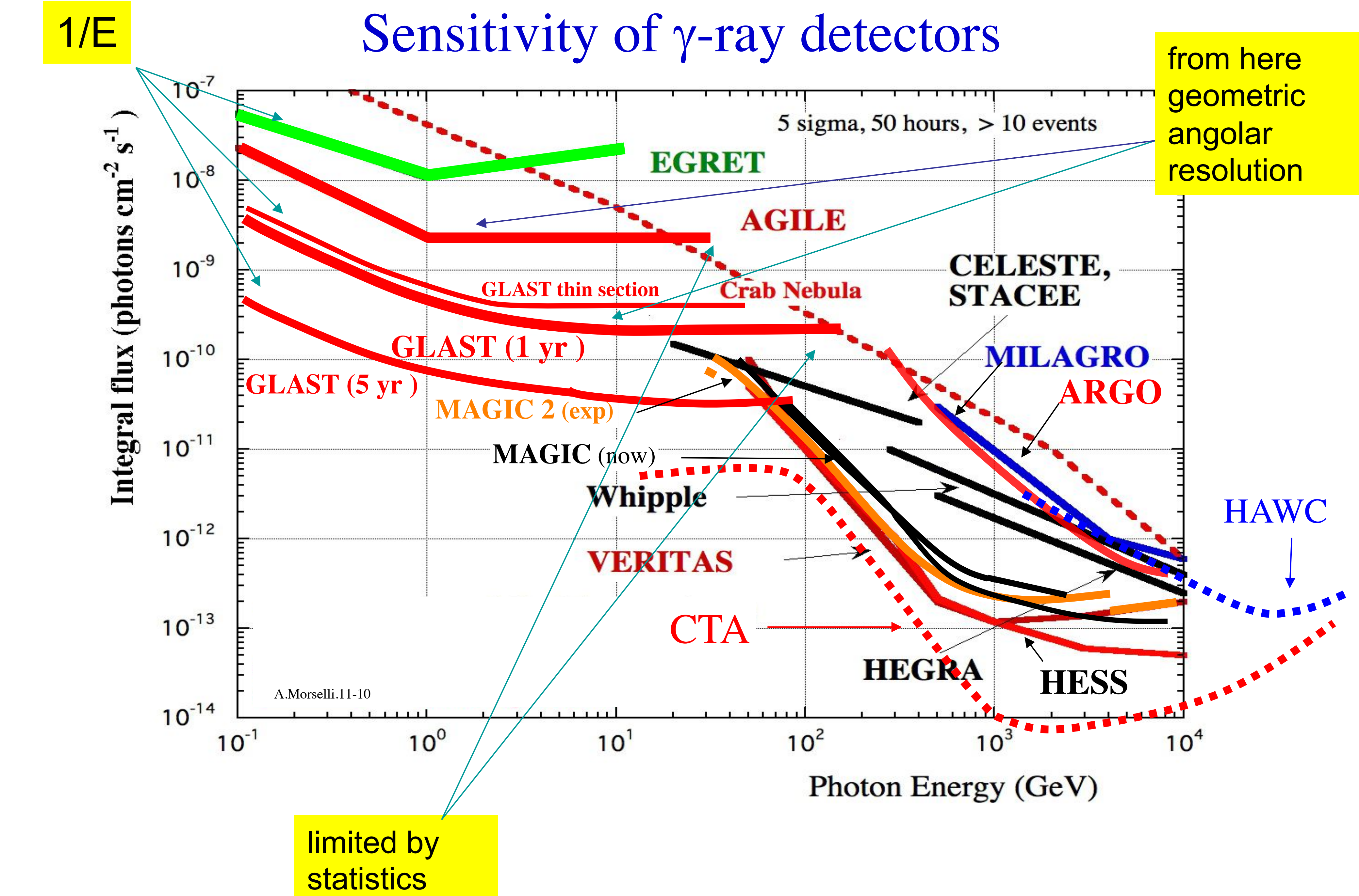
small converter plane

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

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

large field of view

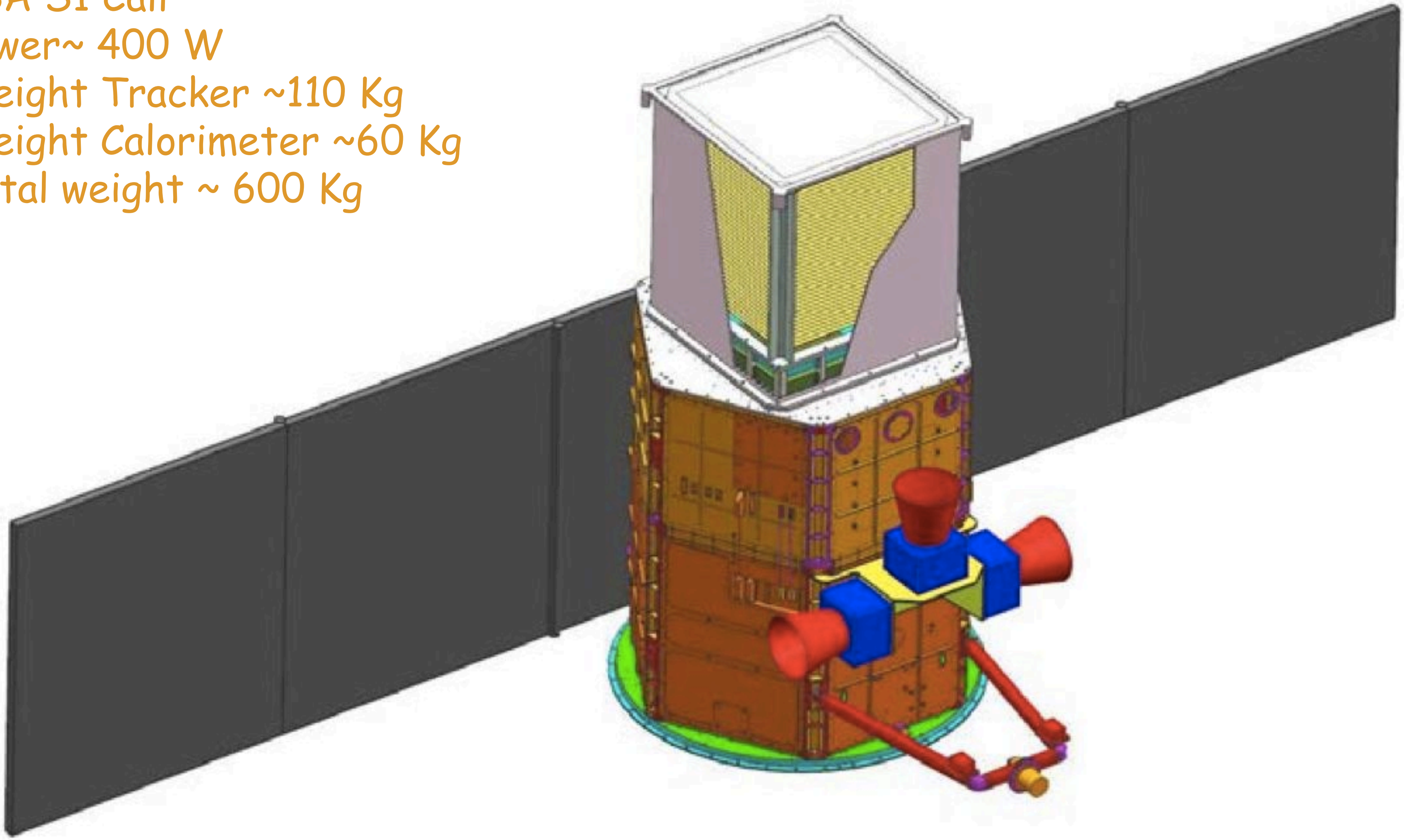
Sensitivity of γ-ray detectors



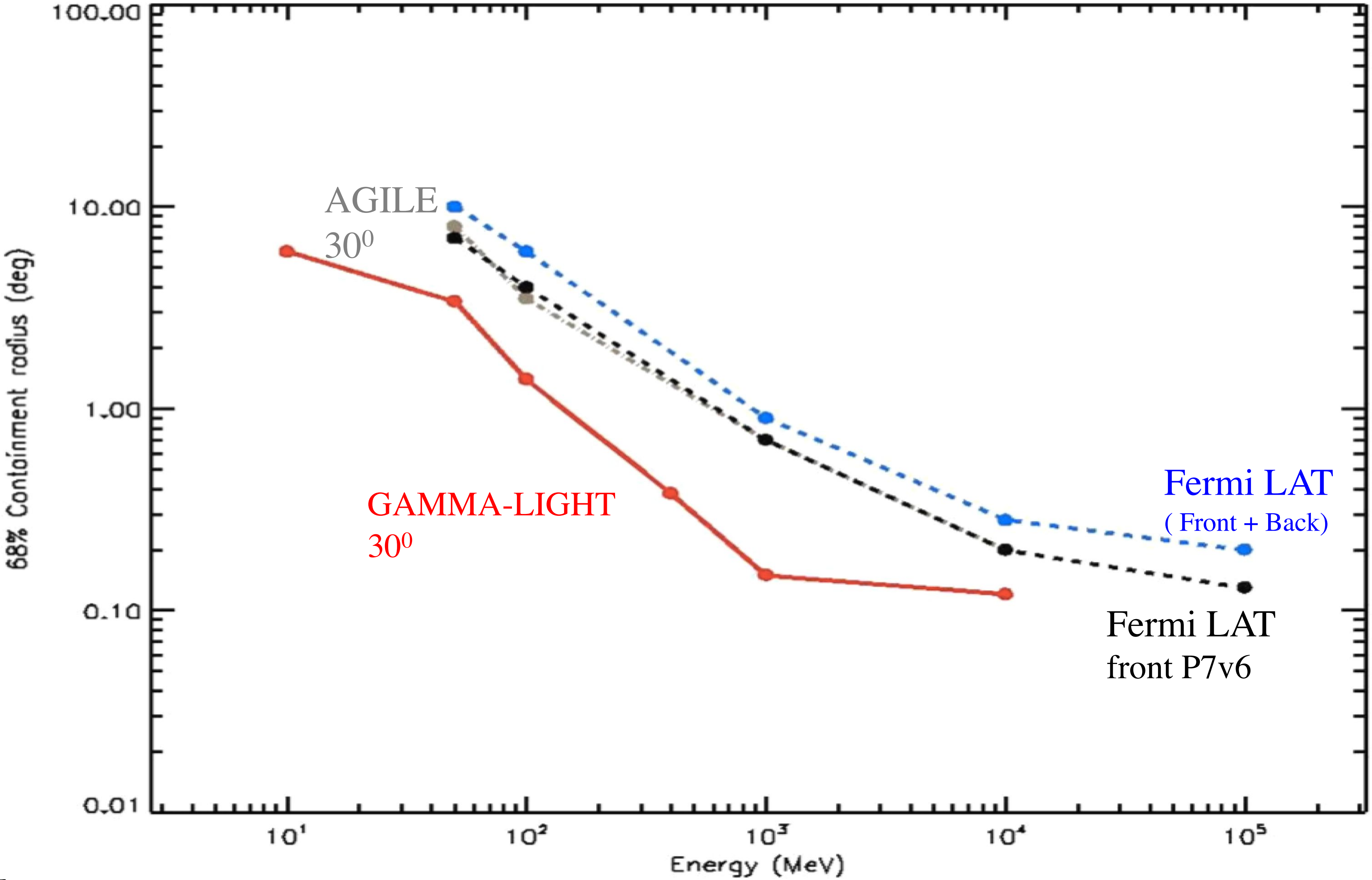
- 1-100 MeV unexplored domain for
  - Dark Matter searches
  - Galactic compact stars and nucleosynthesis
  - Cosmic rays
  - Relativistic jets, microquasars
  - Blazars
  - Gamma-Ray Bursts
  - Solar physics
- and…
  - Terrestrial Gamma-Ray Flashes

Gamma-light project

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

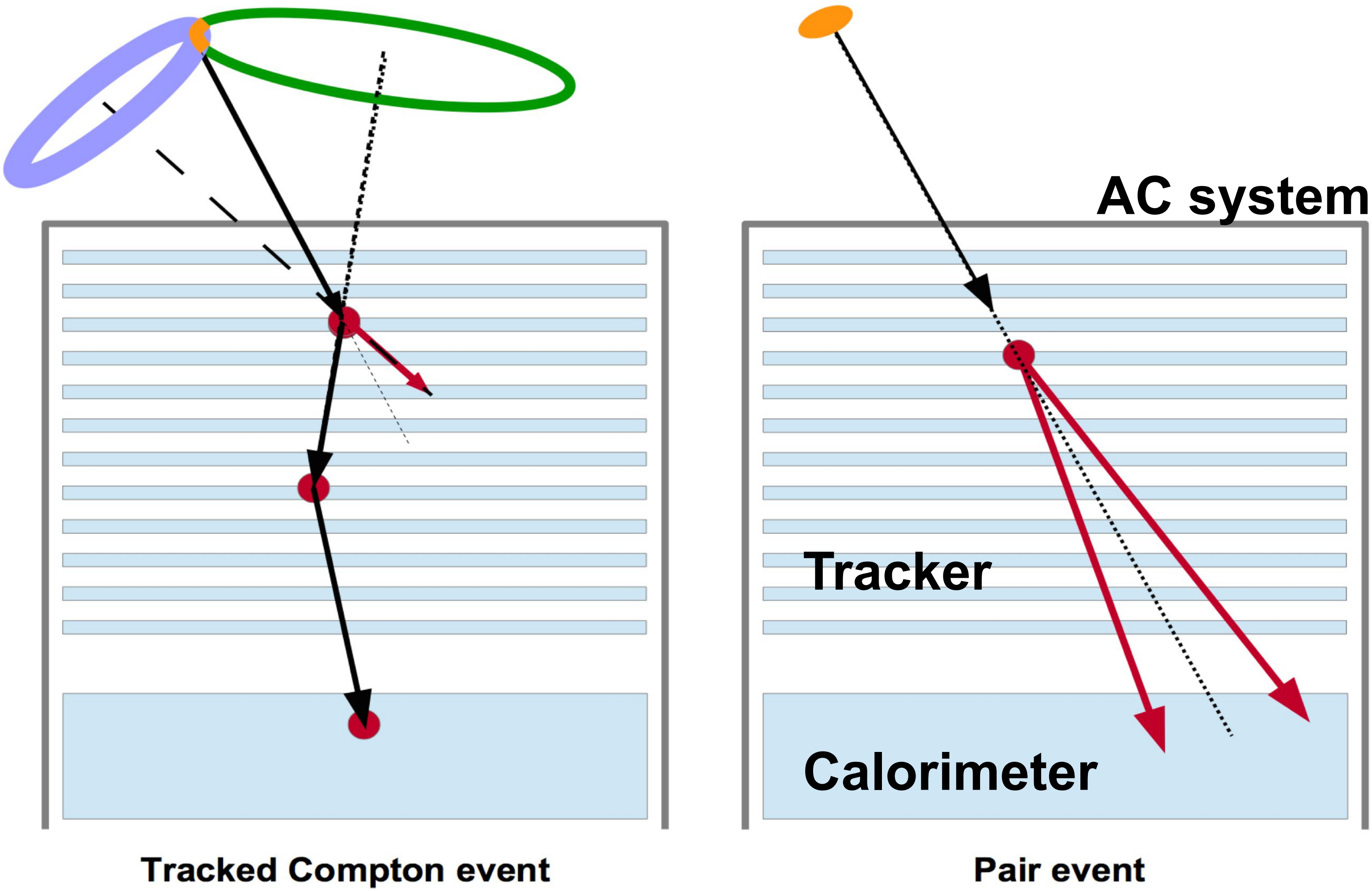


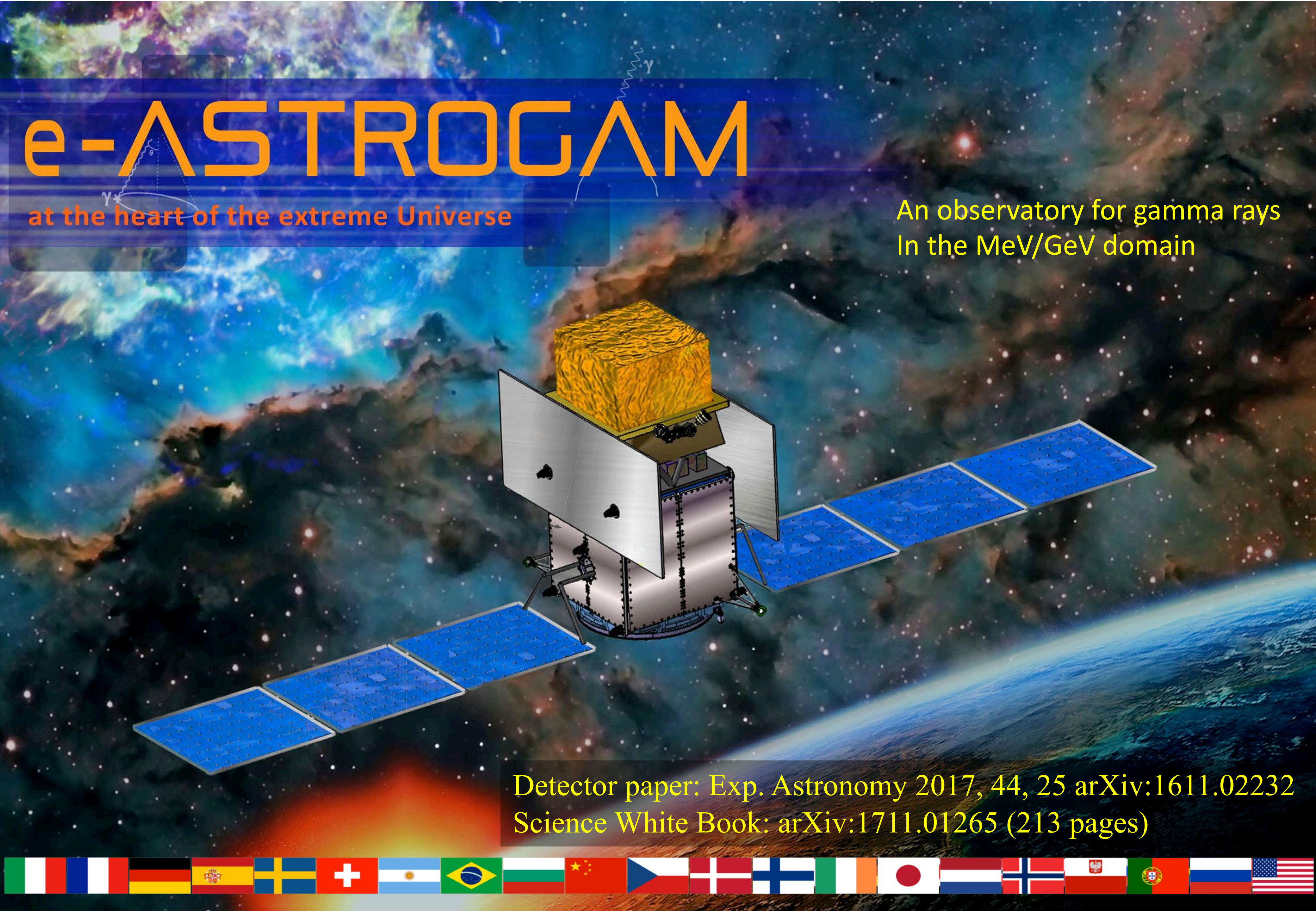
Gamma-Light Point Spread Function (angular resolution)



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

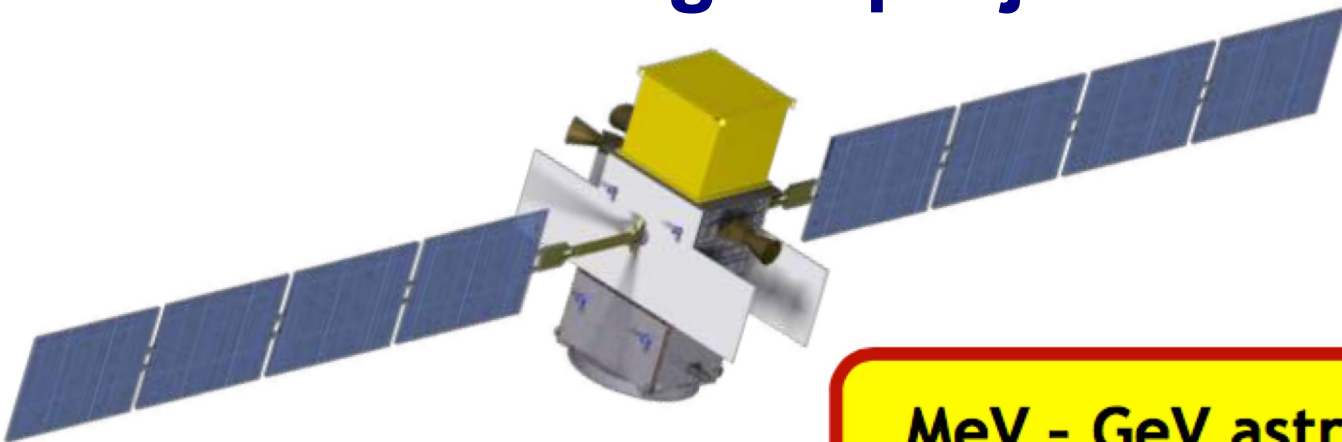
An instrument that combine two detection techniques

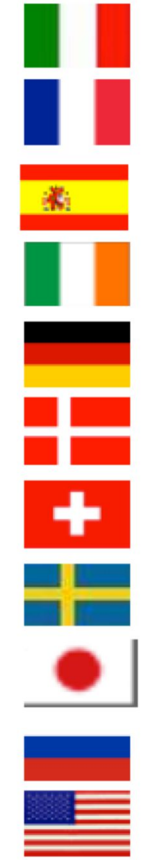



e-ASTROGAM
at the heart of the extreme Universe
An observatory for gamma rays
In the MeV/GeV domain
Detector paper: Exp. Astronomy 2017, 44, 25 arXiv:1611.02232
Science White Book: arXiv:1711.01265 (213 pages)

The next gamma-ray MeV-GeV mission:

the e-Astrogam project

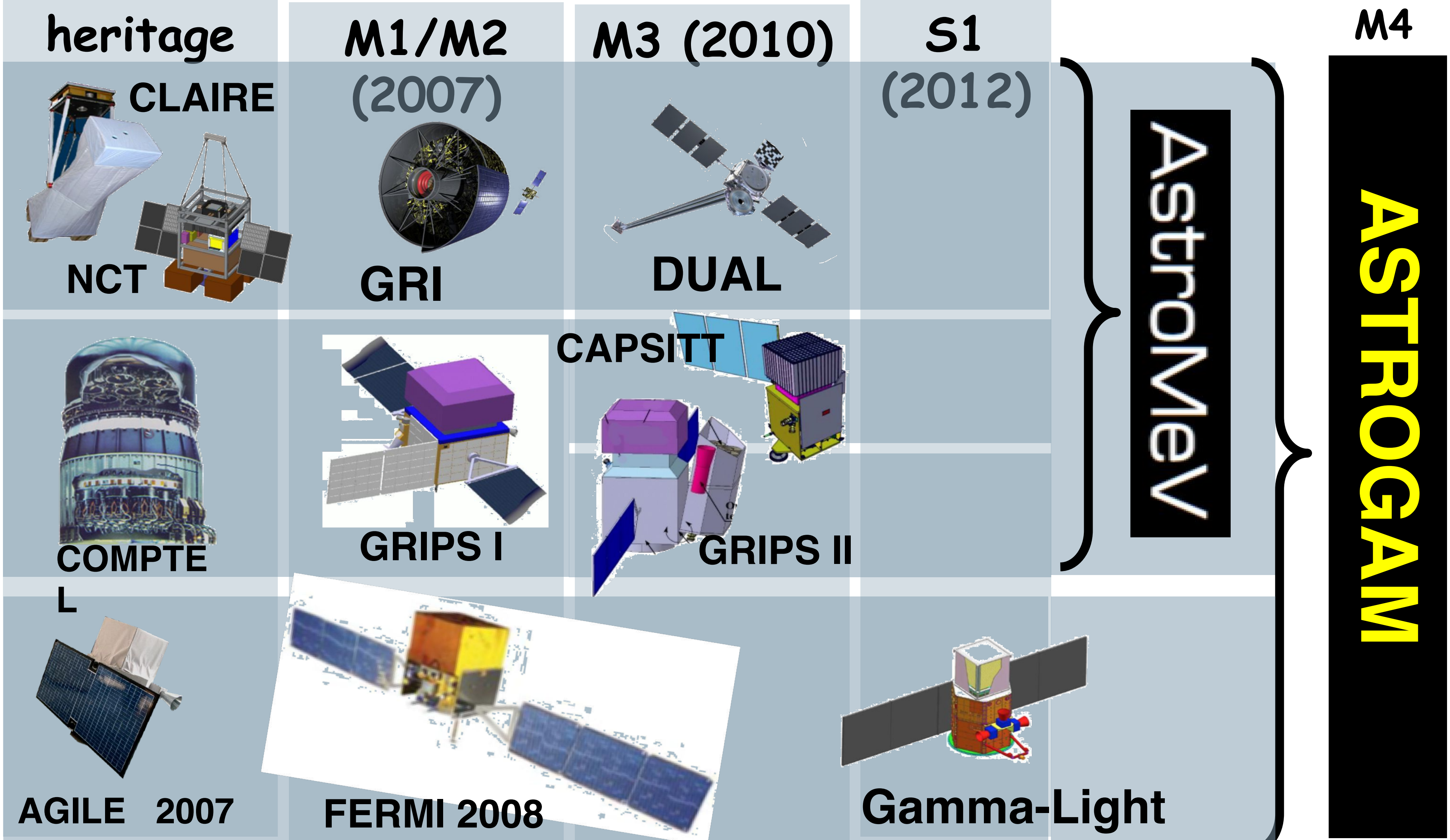




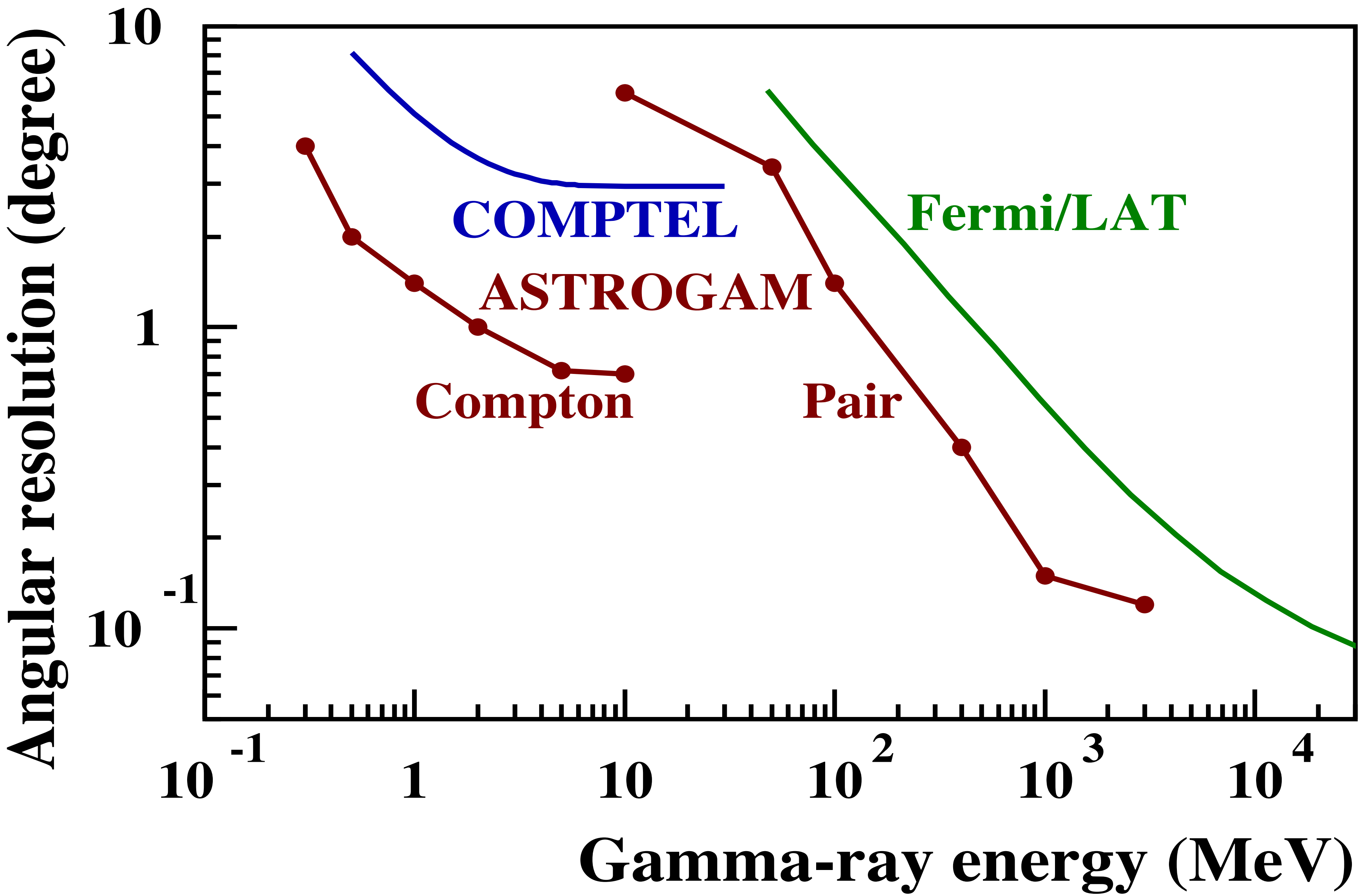
MeV - GeV astrophysics
MeV - GeV community

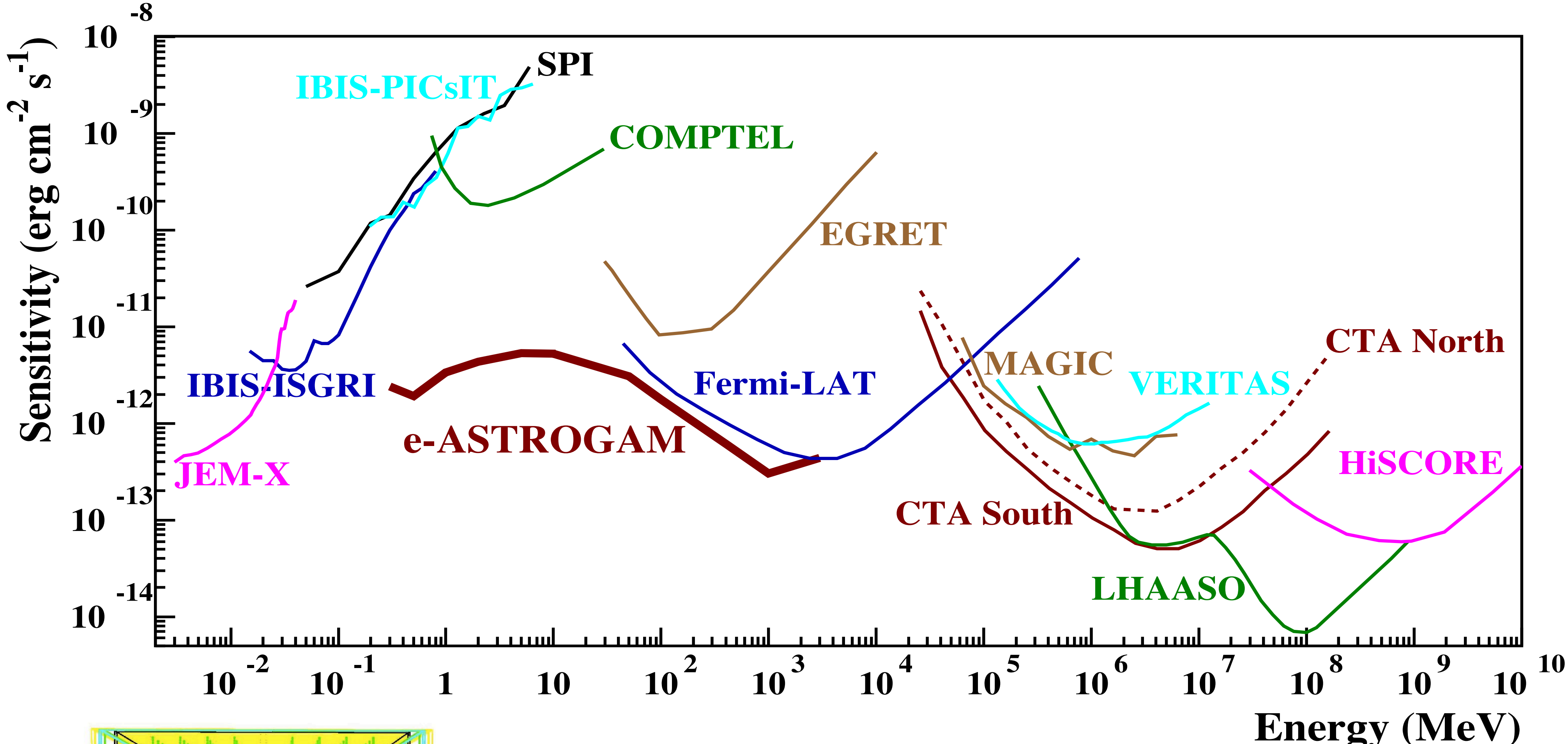
e-ASTROGAM is focused on gamma-ray astrophysics in the range 0.3-100 MeV.

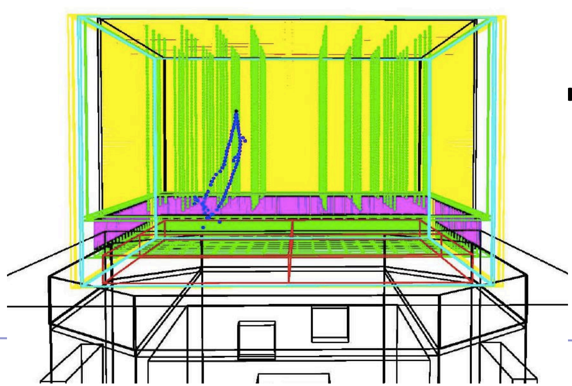
ASTROGAM a unified proposal from the entire gamma-ray community



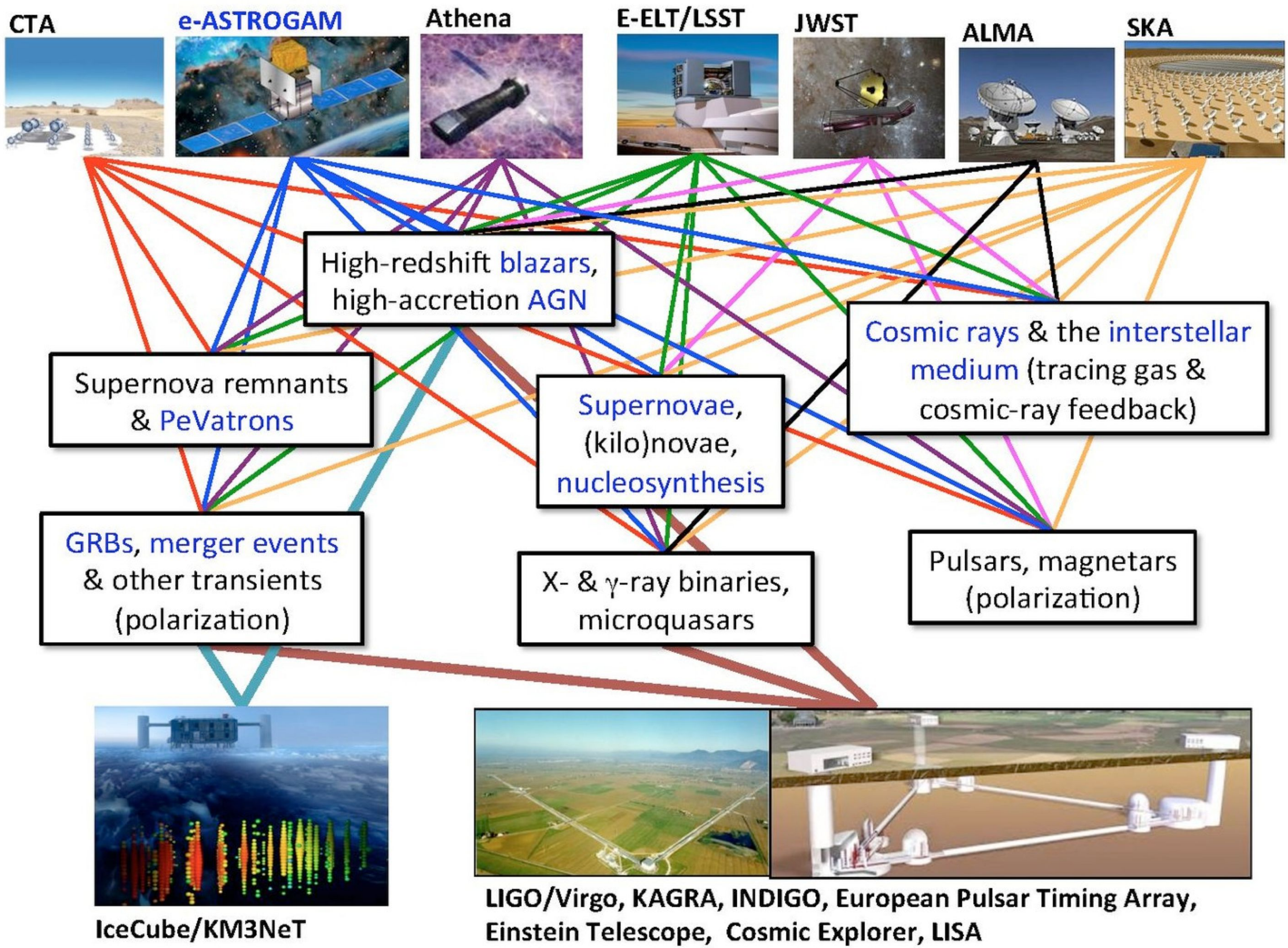
ASTROGAM Angular Resolution







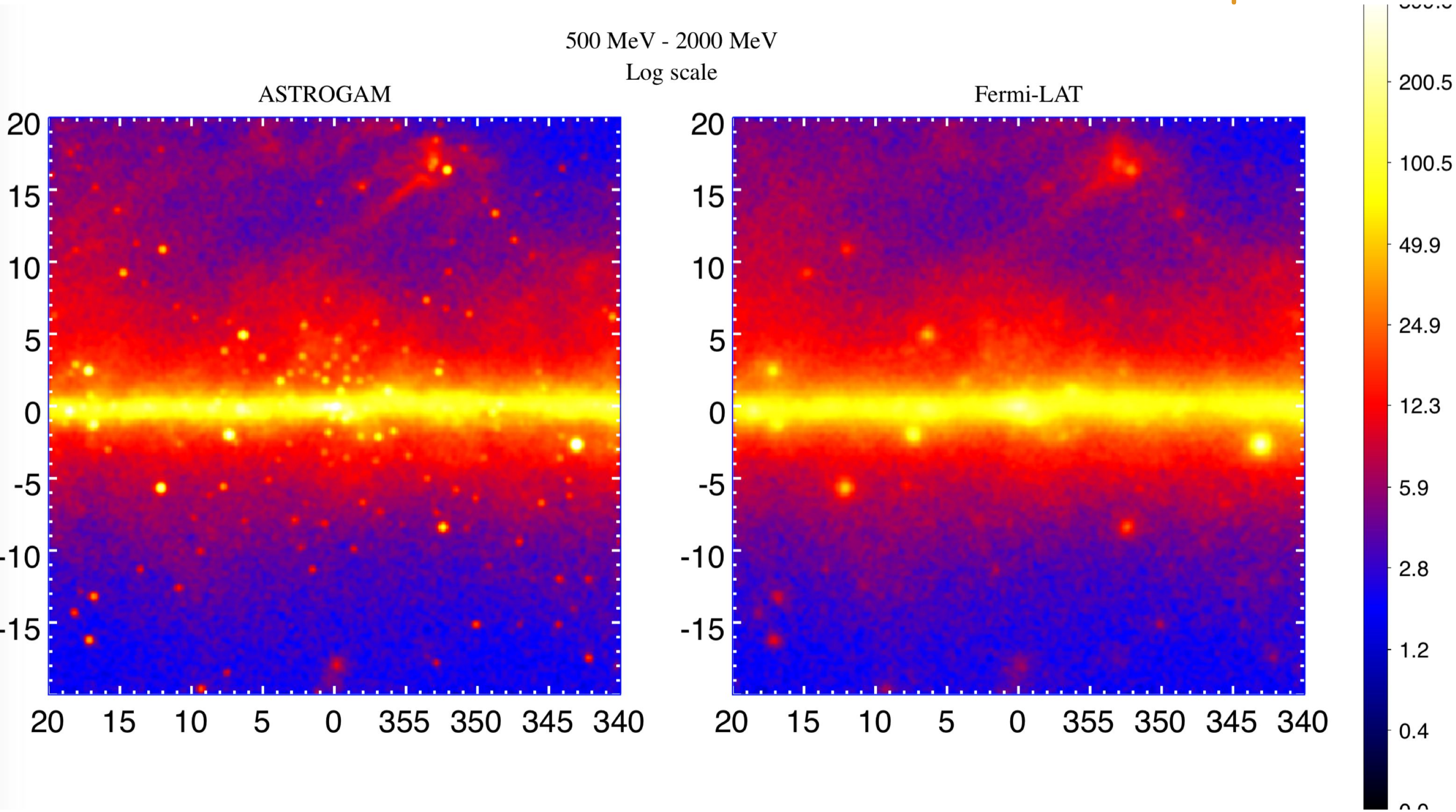
- e-ASTROGAM performance evaluated with **MEGAlib** and – both tools based on Geant4 – and a detailed numerical mass model of the gamma-ray instrument
  - e-Astrogam: arXiv:1611.02232



CTA
e-ASTROGAM
Athena
E-ELT/LSST
JWST
ALMA
SKA
High-redshift blazars, high-accretion AGN
Supernova remnants & PeVatrons
Supernovae, (kilo)novae, nucleosynthesis
Cosmic rays & the interstellar medium (tracing gas & cosmic-ray feedback)
GRBs, merger events & other transients (polarization)
X- & γ-ray binaries, microquasars
Pulsars, magnetars (polarization)
IceCube/KM3NeT
LIGO/Virgo, KAGRA, INDIGO, European Pulsar Timing Array, Einstein Telescope, Cosmic Explorer, LISA

Galactic Center Region 0.5-2 GeV

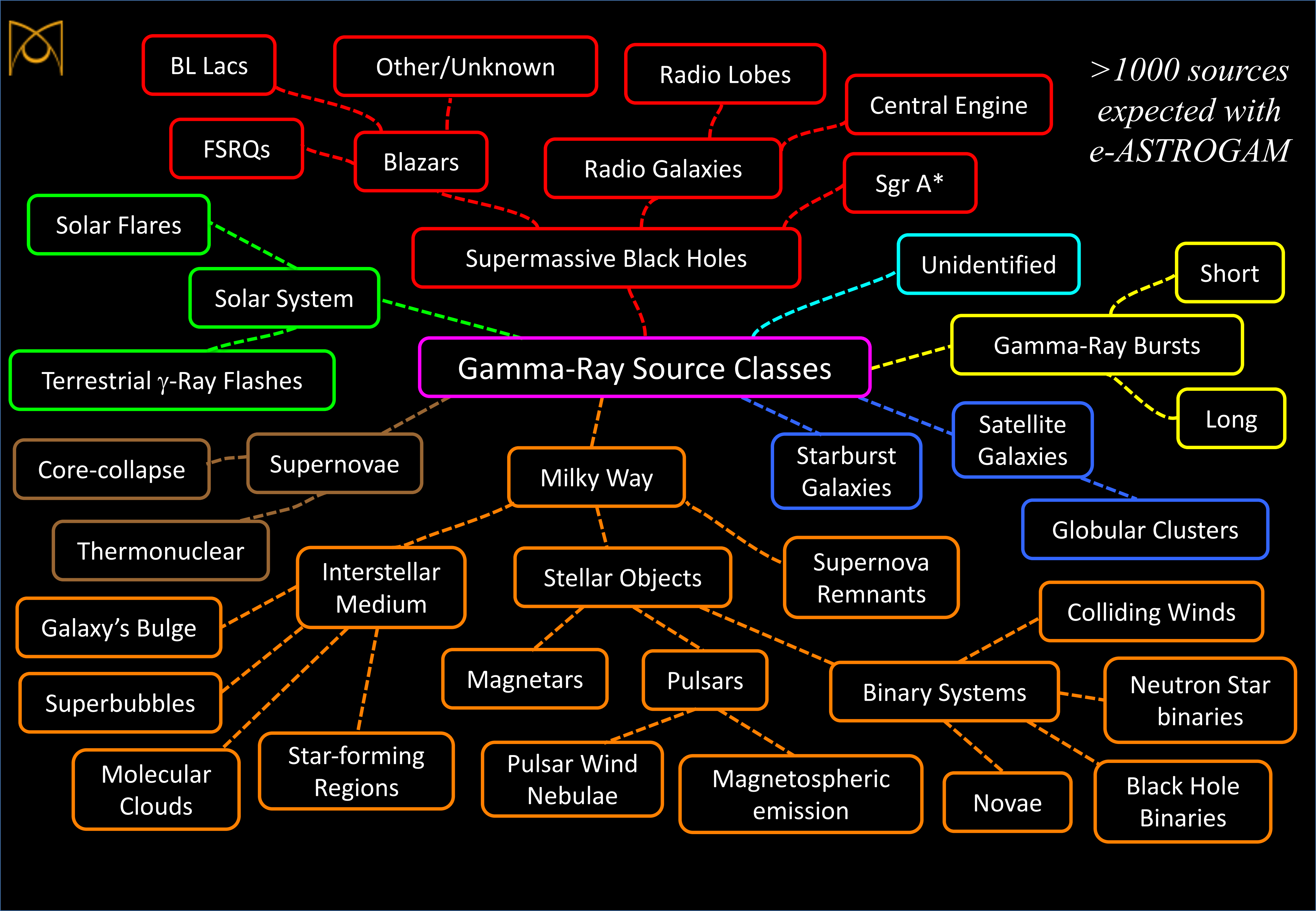
Fermi PSF Pass7 rep v15 source



Morselli, Gomez Vargas, preliminary

Why eAstrogam is important for IceCube and KM3Net

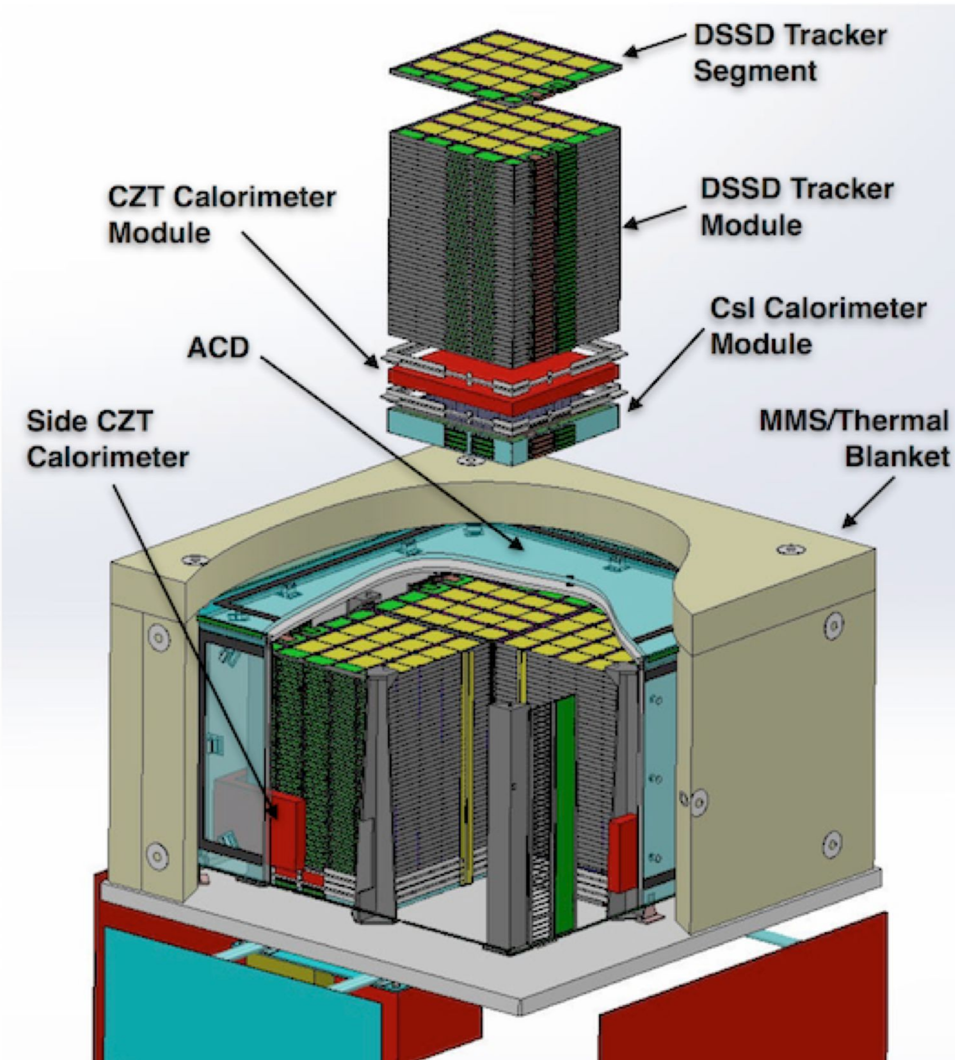
- Wide FoV (> 2.5 sr at 10 MeV) in survey mode.
- Sources of astrophysical neutrinos detected by IceCube may be opaque to 1–100 GeV gamma-rays but bright in the MeV domains (expecially if the neutrino flux originates from photo-hadronic processes)
- eAstrogam can select the best blazar candidates for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

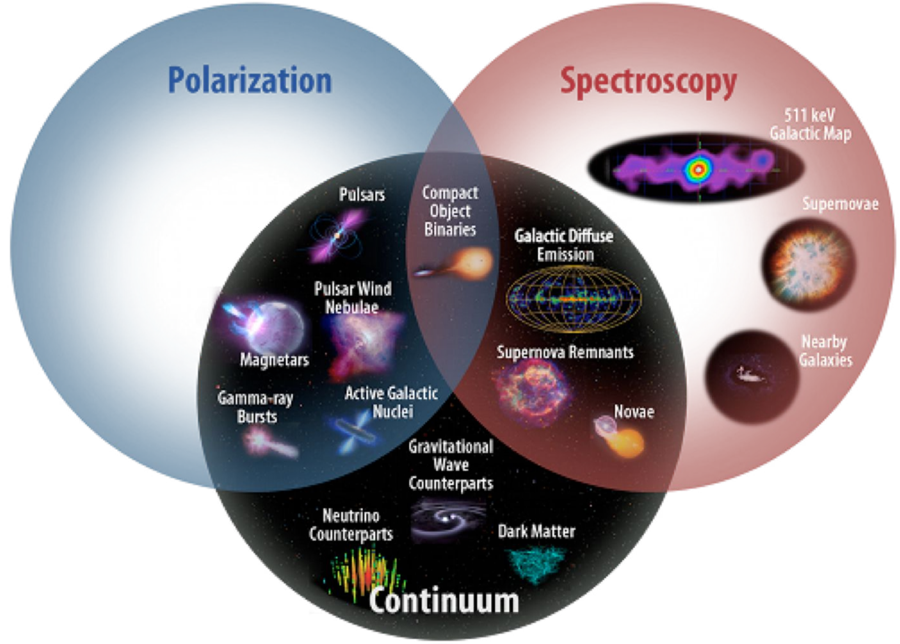


BL Lacs
Other/Unknown
Radio Lobes
Central Engine
>1000 sources expected with e-ASTROGAM
FSRQs
Blazars
Radio Galaxies
Sgr A*
Solar Flares
Supermassive Black Holes
Unidentified
Short
Solar System
Gamma-Ray Bursts
Terrestrial γ-Ray Flashes
Gamma-Ray Source Classes
Long
Satellite Galaxies
Core-collapse
Supernovae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

Our sister experiment: AMEGO (NASA)

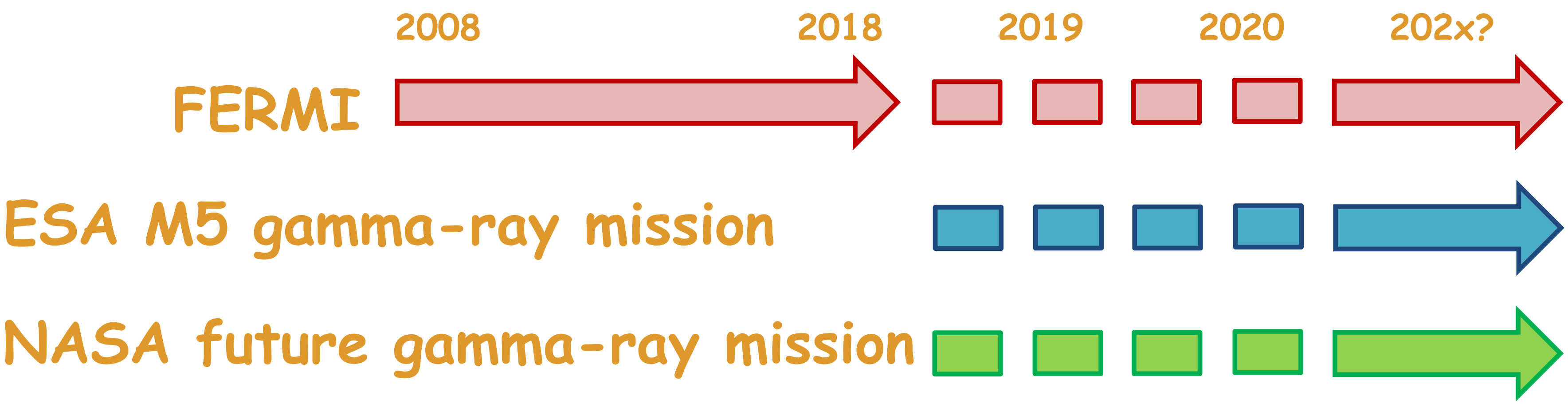
(two brands, one community)





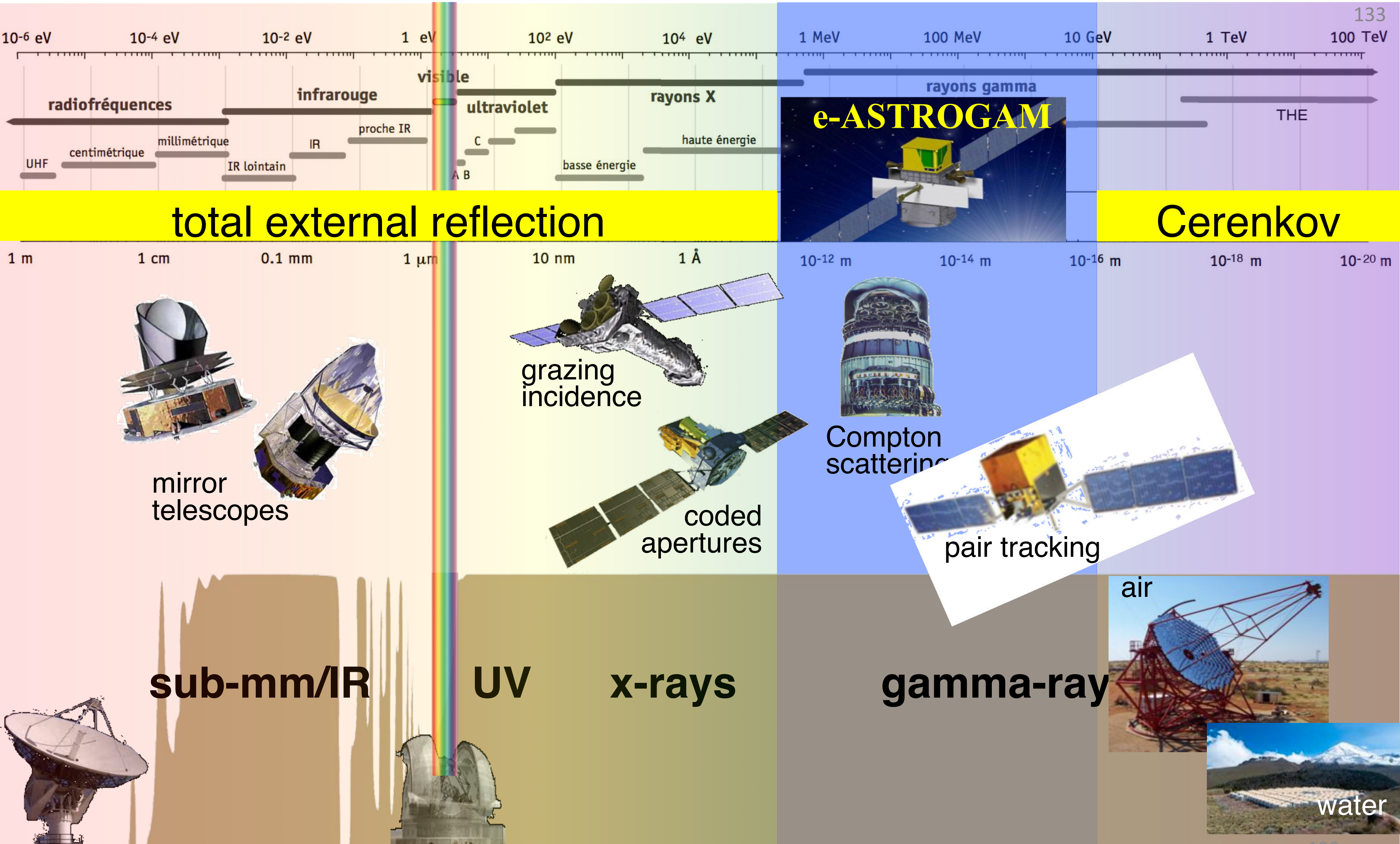
- ~20% smaller tracker
- CZT calorimeter layer
- In the decadal survey?

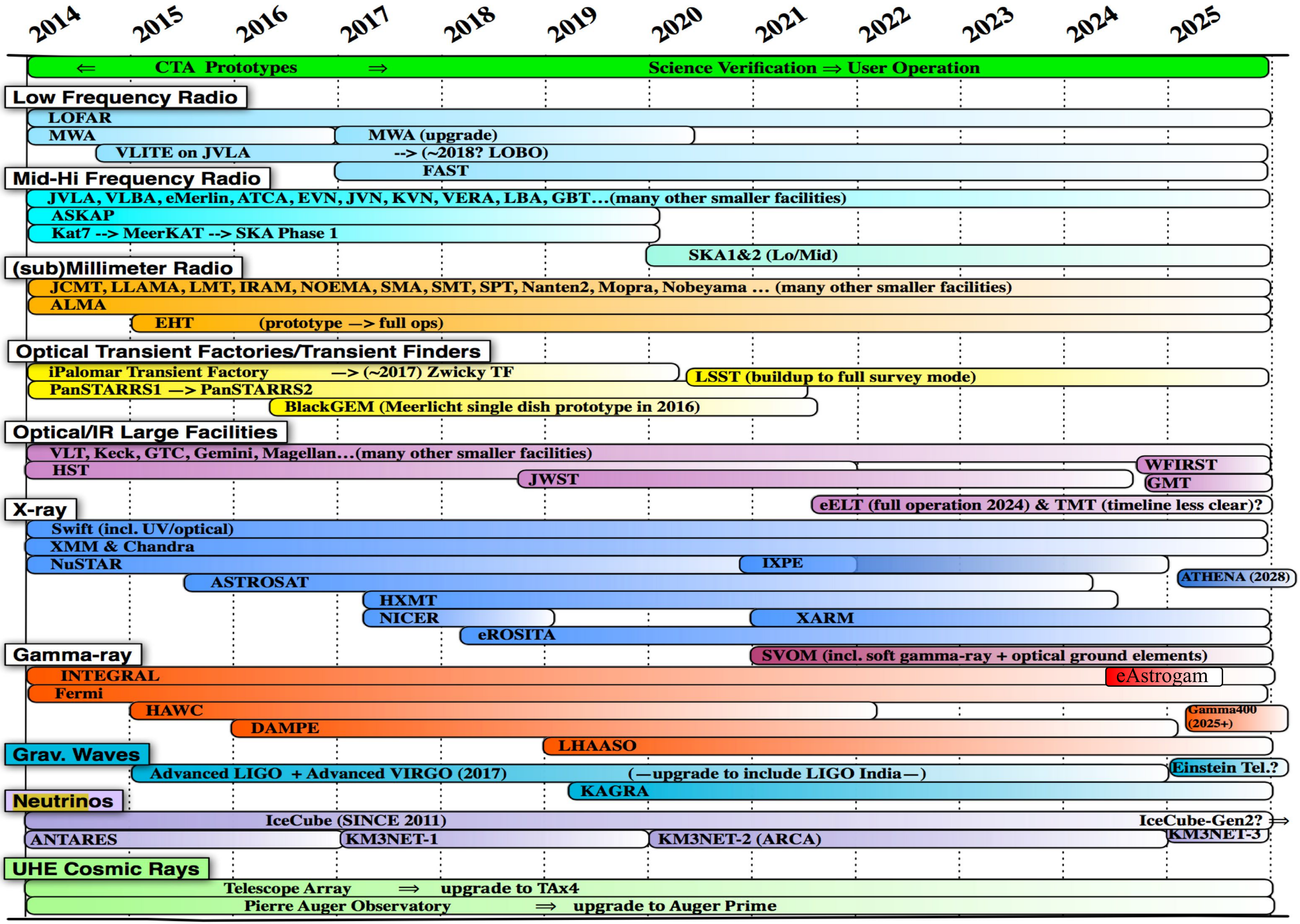
Space-based high energy gamma ray plan

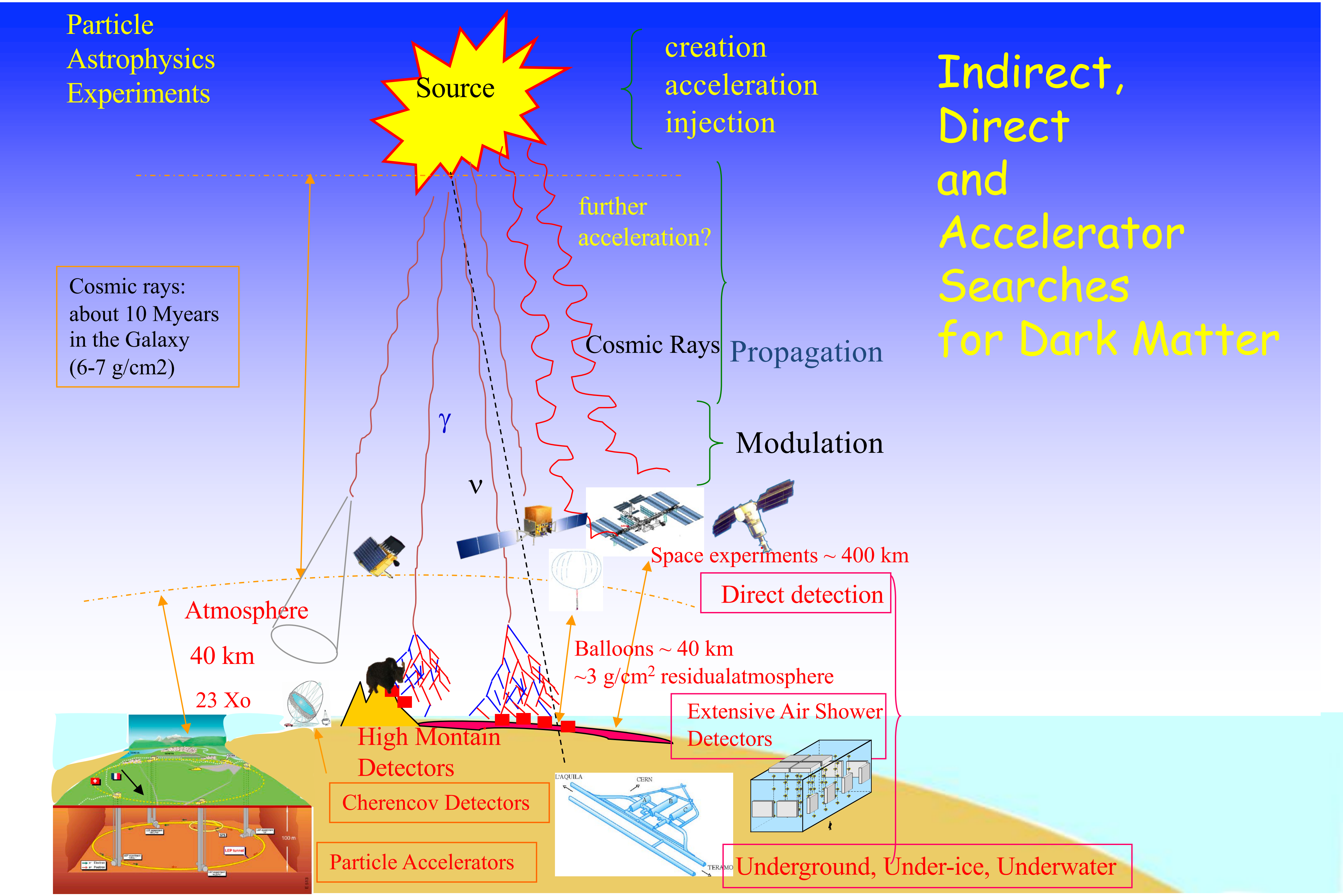


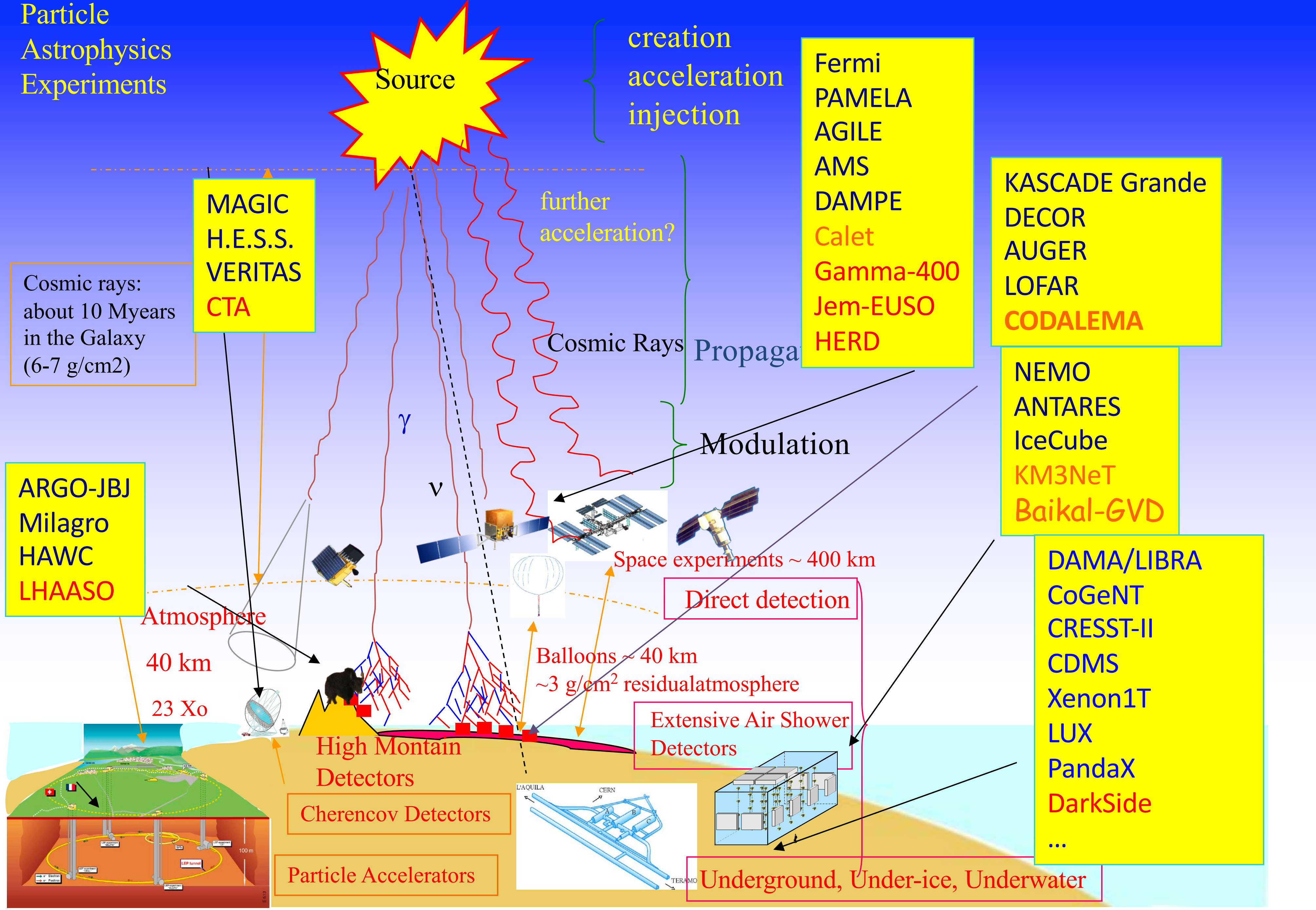
- M5 Phase A selection
  - 7 May 2018: ESA selects three new mission concepts for study:
    - A high-energy survey of the early Universe (Theseus), an infrared observatory to study the formation of stars, planets and galaxies (Spica) , and a Venus orbiter (EnVision) are to be considered for ESA's fifth 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 decadal review in 2019
  - 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)
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


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 residualatmosphere
Extensive Air Shower
Detectors
High Montain
Detectors
Cherencov Detectors
Particle Accelerators
L'AQUILA
CERN
TERAMO
Underground, Under-ice, Underwater


Particle
Astrophysics
Experiments
Source
creation
acceleration
injection
Fermi
PAMELA
AGILE
AMS
DAMPE
Calet
Gamma-400
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
Propaga
NEMO
ANTARES
IceCube
KM3NeT
Baikal-GVD
γ
Modulation
ν
ARGO-JBJ
Milagro
HAWC
LHAASO
Space experiments ~ 400 km
DAMA/LIBRA
CoGeNT
CRESST-II
CDMS
Xenon1T
LUX
PandaX
DarkSide
…
Direct detection
Atmosphere
40 km
Balloons ~ 40 km
~3 g/cm² residualatmosphere
23 Xo
Extensive Air Shower
Detectors
High Montain
Detectors
Cherencov Detectors
Particle Accelerators
L'AQUILA
CERN
TERAMO
Underground, Under-ice, Underwater

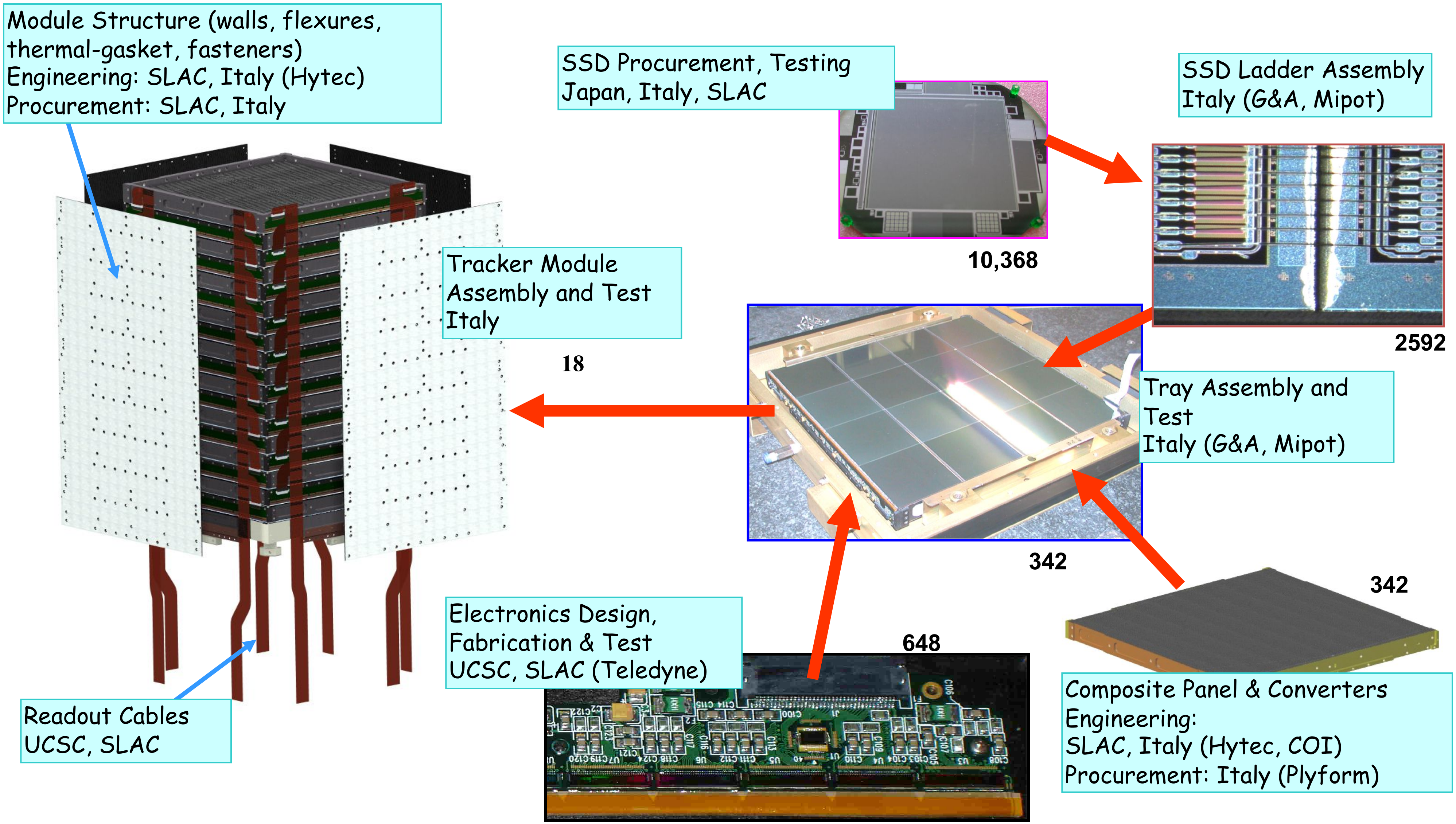

Through most of history, the cosmos has been
viewed as eternally tranquil

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

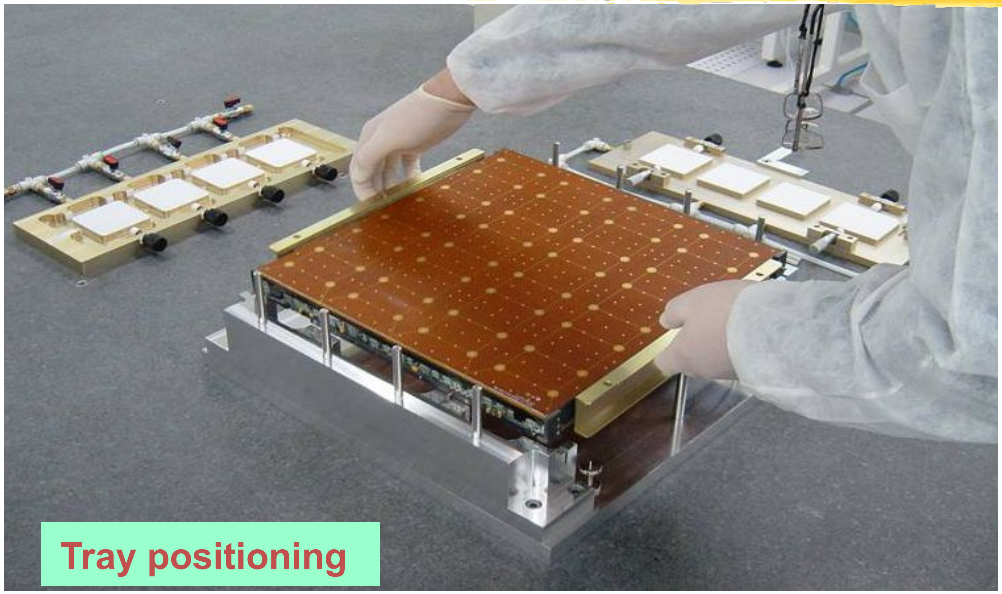

The future?
Thank you !

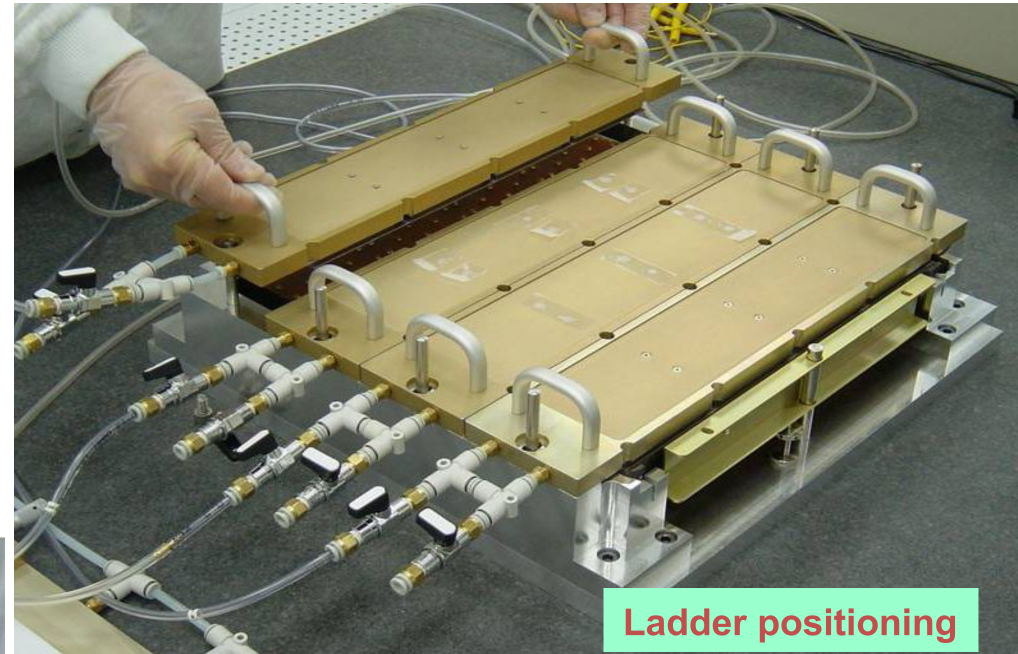

11 June 2008

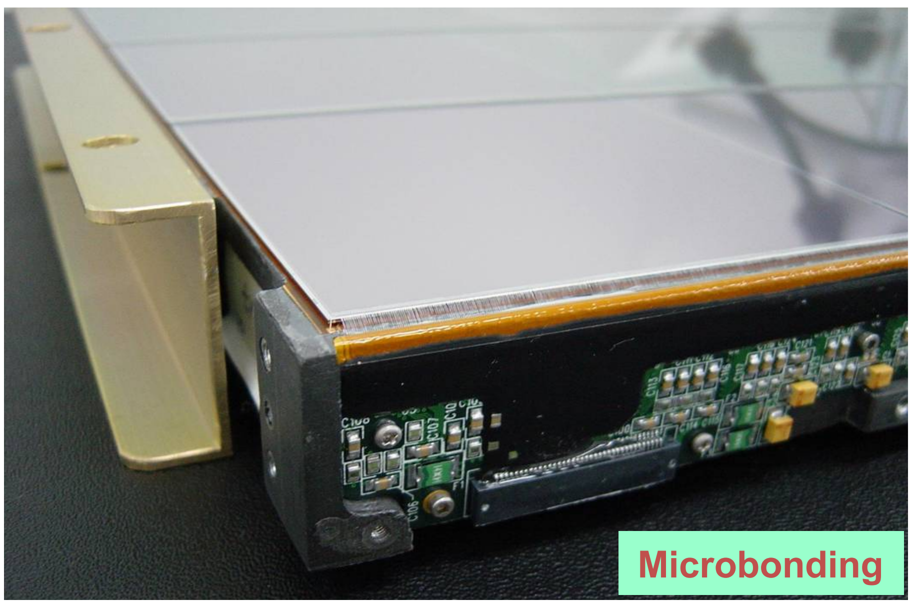
Tracker Production Overview



Tray assembly in G&A

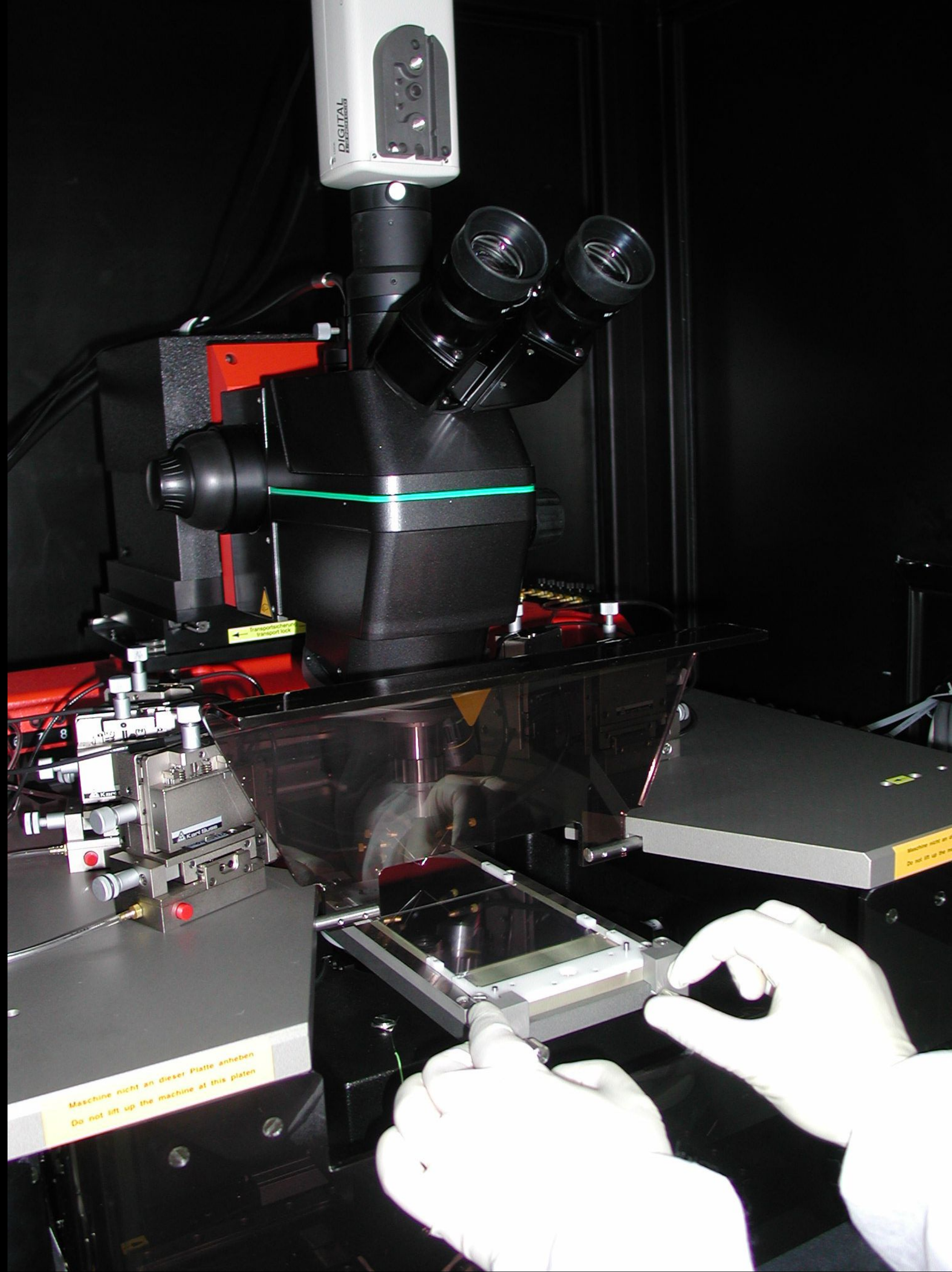


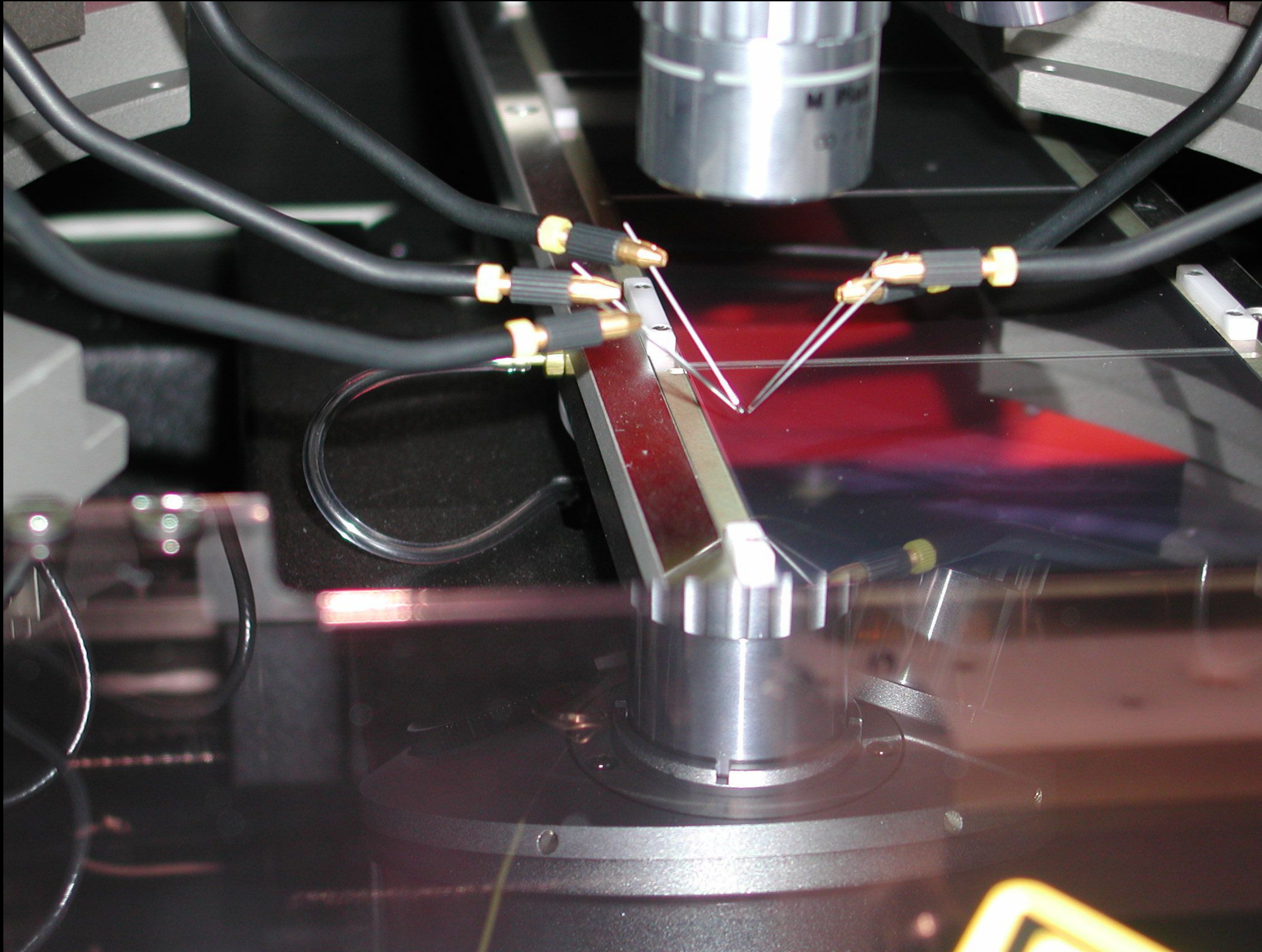




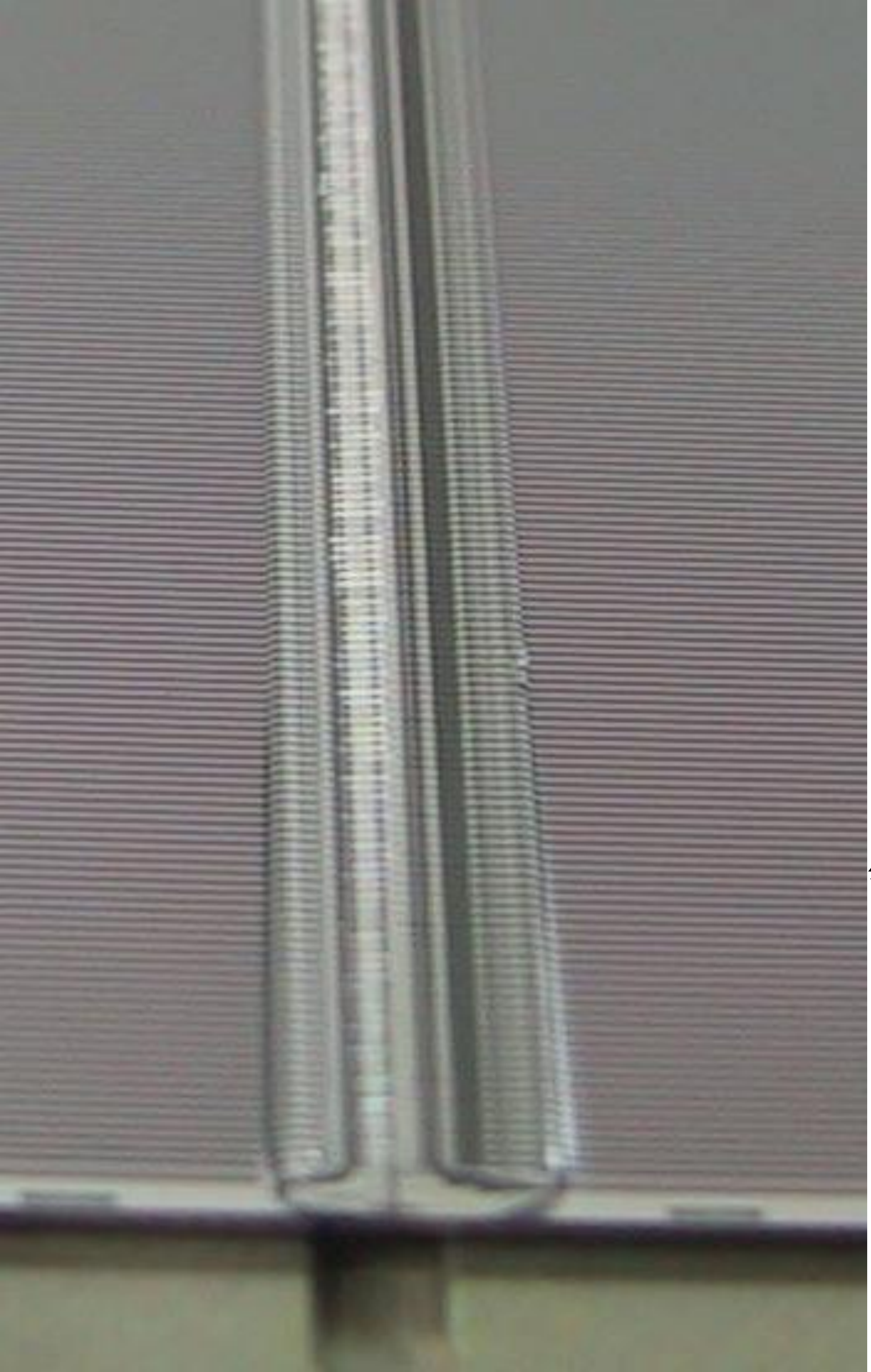
- 160 bare panels produced
- 100 tested and qualified for integration with ladders
- completed trays for 3.3 towers
- 6 assembly chain ready
- Max assembly rate : 3 trays/day/shift


EMERGENCY STOP


Maschine nicht an dieser Platte anheben
Do not lift up the machine at this platen



Encapsulation

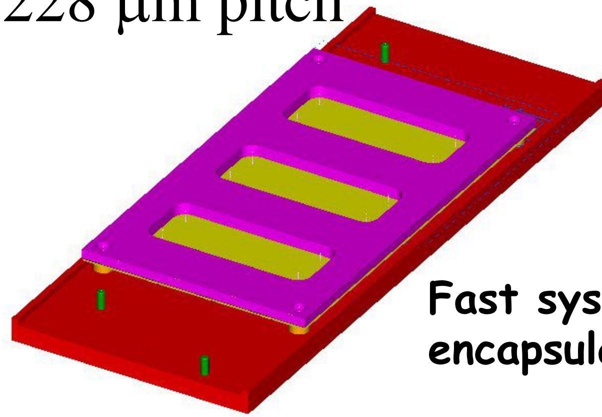


Dam & Fill encapsulation

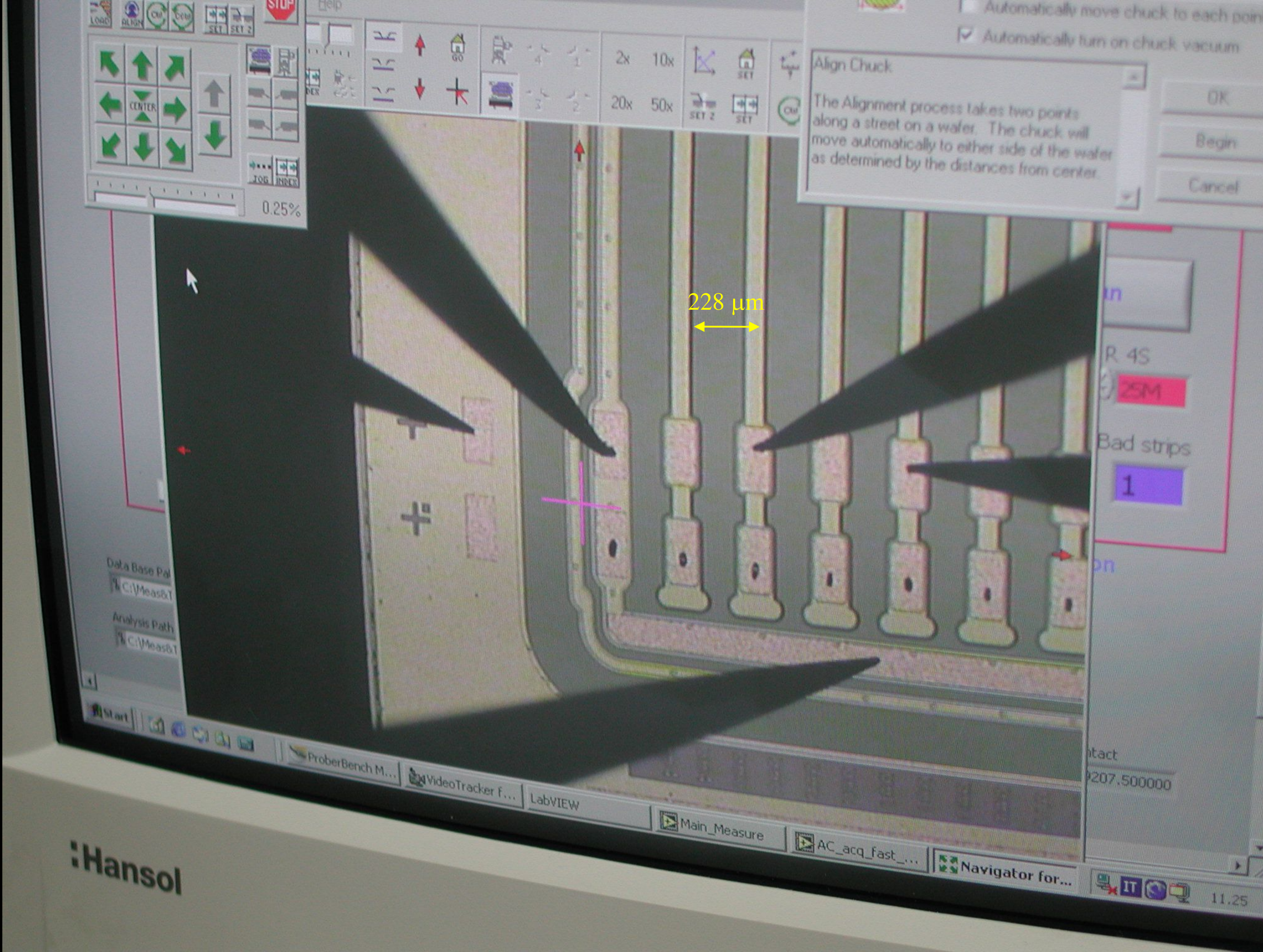
Dam Nusil 1142
Fill Nusil 15-2500

Requirements:
1. **Height <0.5mm**
2. **Lateral overflow <0.05mm**
3. **Coverage of all the bondings and pads**

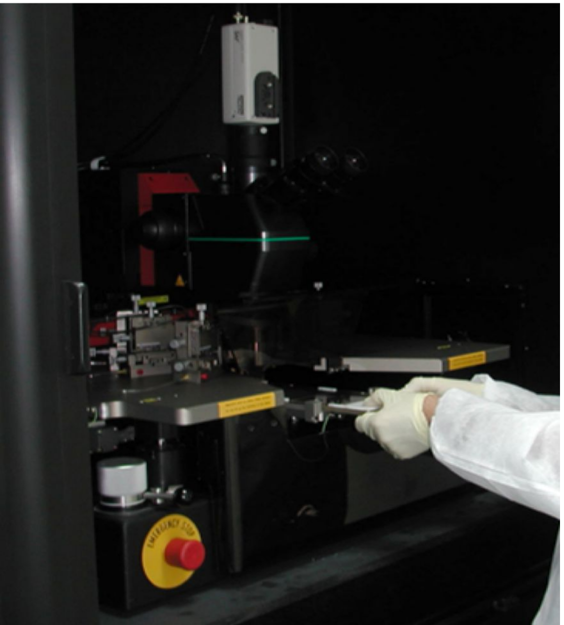
228 μm pitch



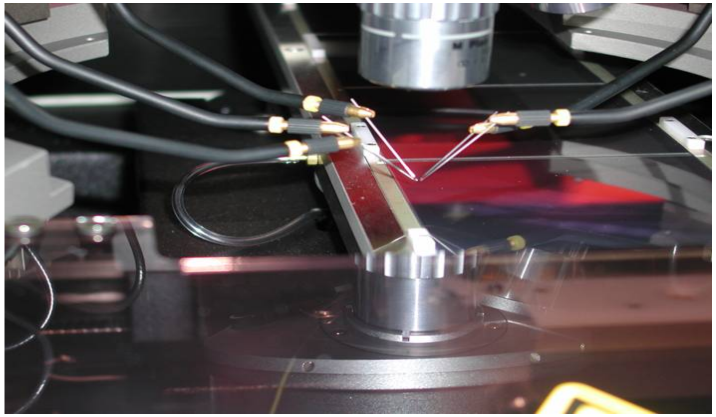
Fast system to check encapsulation height

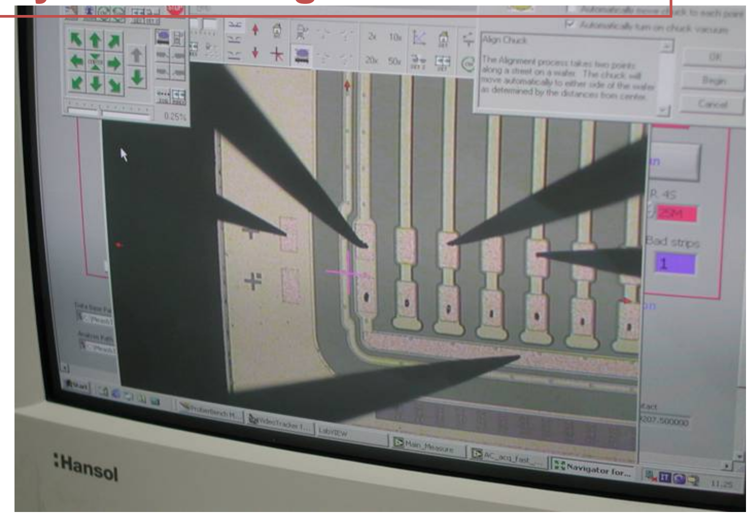

228 µm
Automatically move chuck to each point
Automatically turn on chuck vacuum
Align Chuck
The Alignment process takes two points along a street on a wafer. The chuck will move automatically to either side of the wafer as determined by the distances from center.
OK
Begin
Cancel
2x
10x
20x
50x
0.25%
Bad strips
1
Data Base Pat
Analysis Path
ProberBench M...
VideoTracker f...
LabVIEW
Main_Measure
AC_acq_fast_...
Navigator for...
207.500000
Hansol

Ladders testing



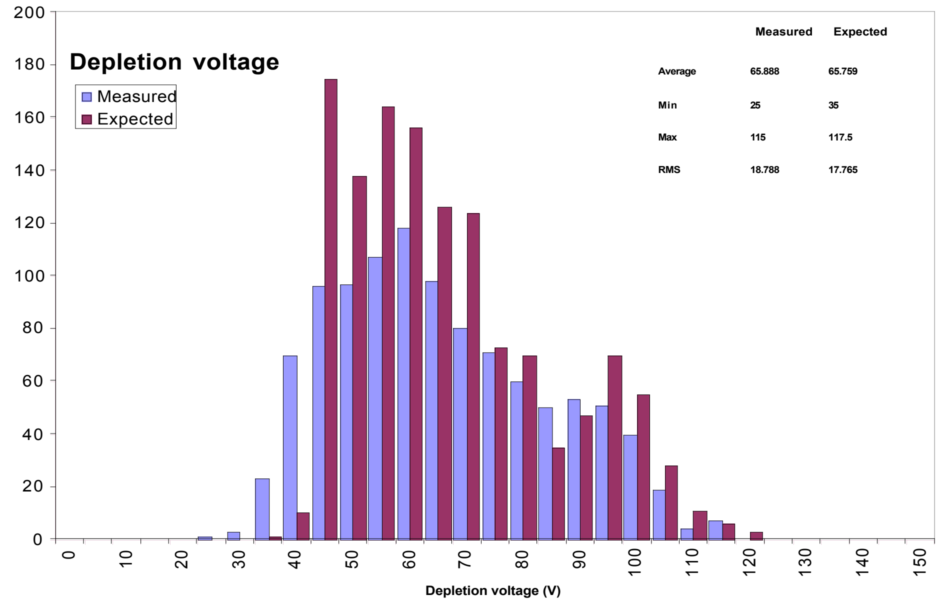
Ladders probe station: 5 probes are used to measure body and single strip I, C to check sanity of each single channel



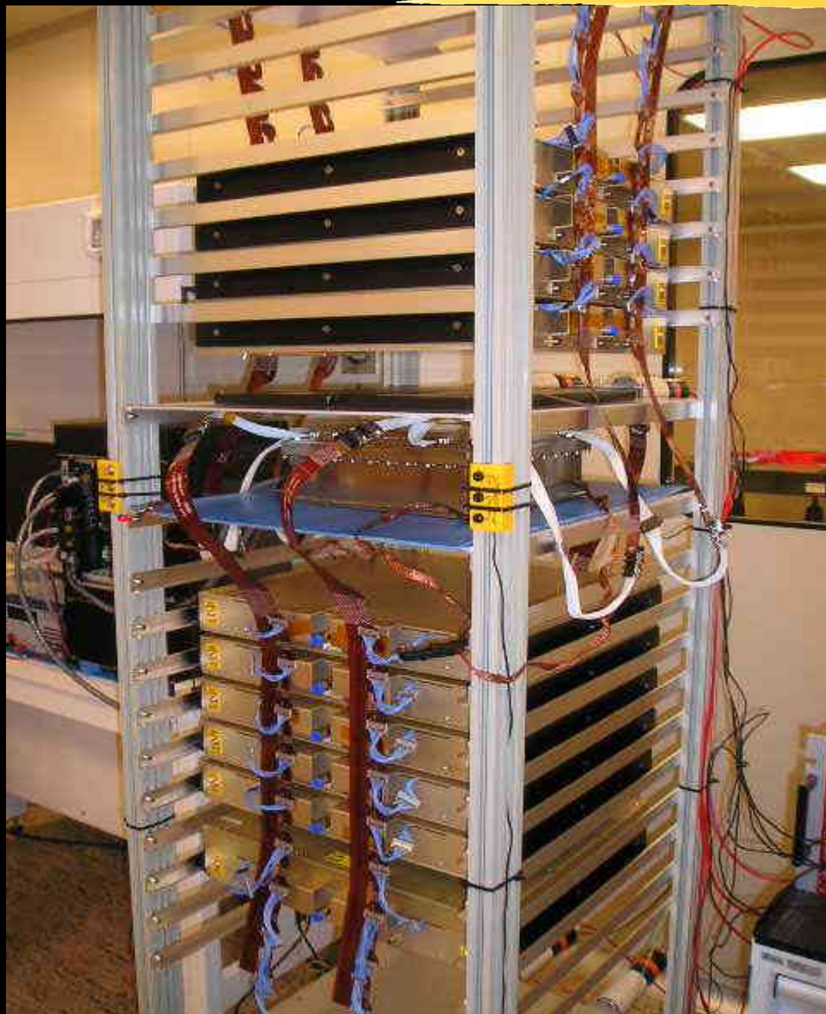


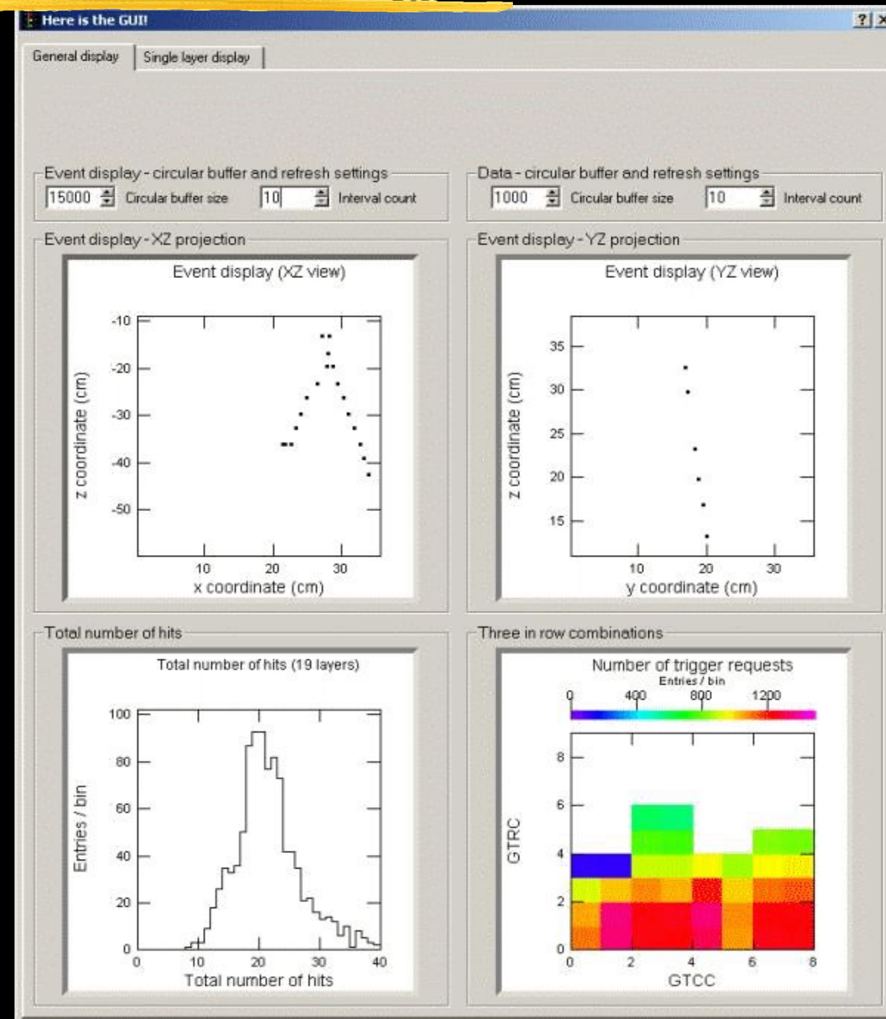
Flight ladders production status:

- Completed and tested (INFN BA/RM2/PG) 1900
- Under construction 800
- rejected ~ 1%
- 0.016% bad chans caused by bonding or probing
- 2μm RMS alignment spread
- All results in good agreement with what expected from SSDs



Tray test at INFN





Stack of trays:

- functional tests/CR burn-in for a whole tower in parallel
- external trigger capability
- 4 stacks operating in parallel at INFN (Pi/Pg/Rm2/Ba)

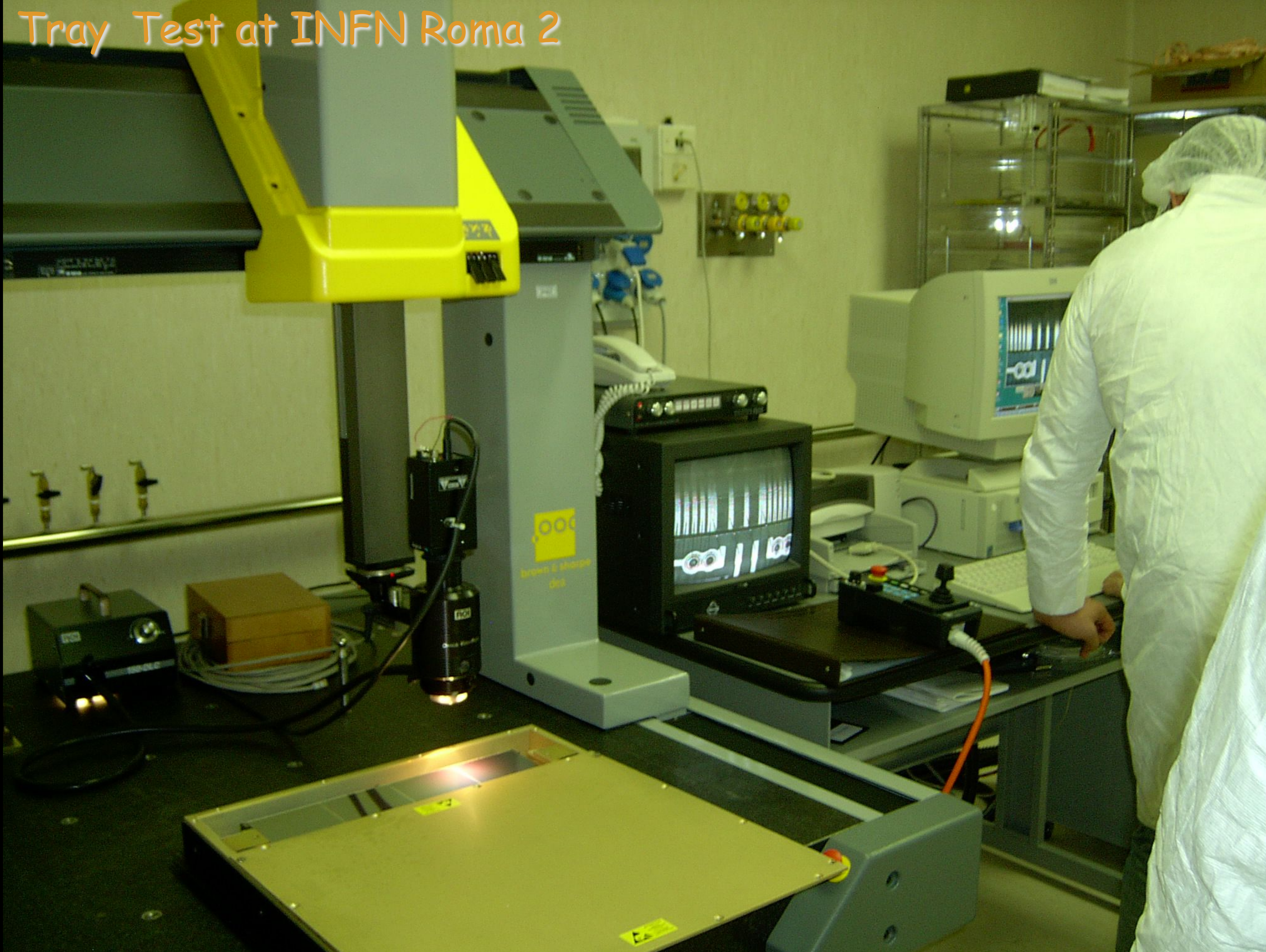
Tray Test at INFN Roma 2

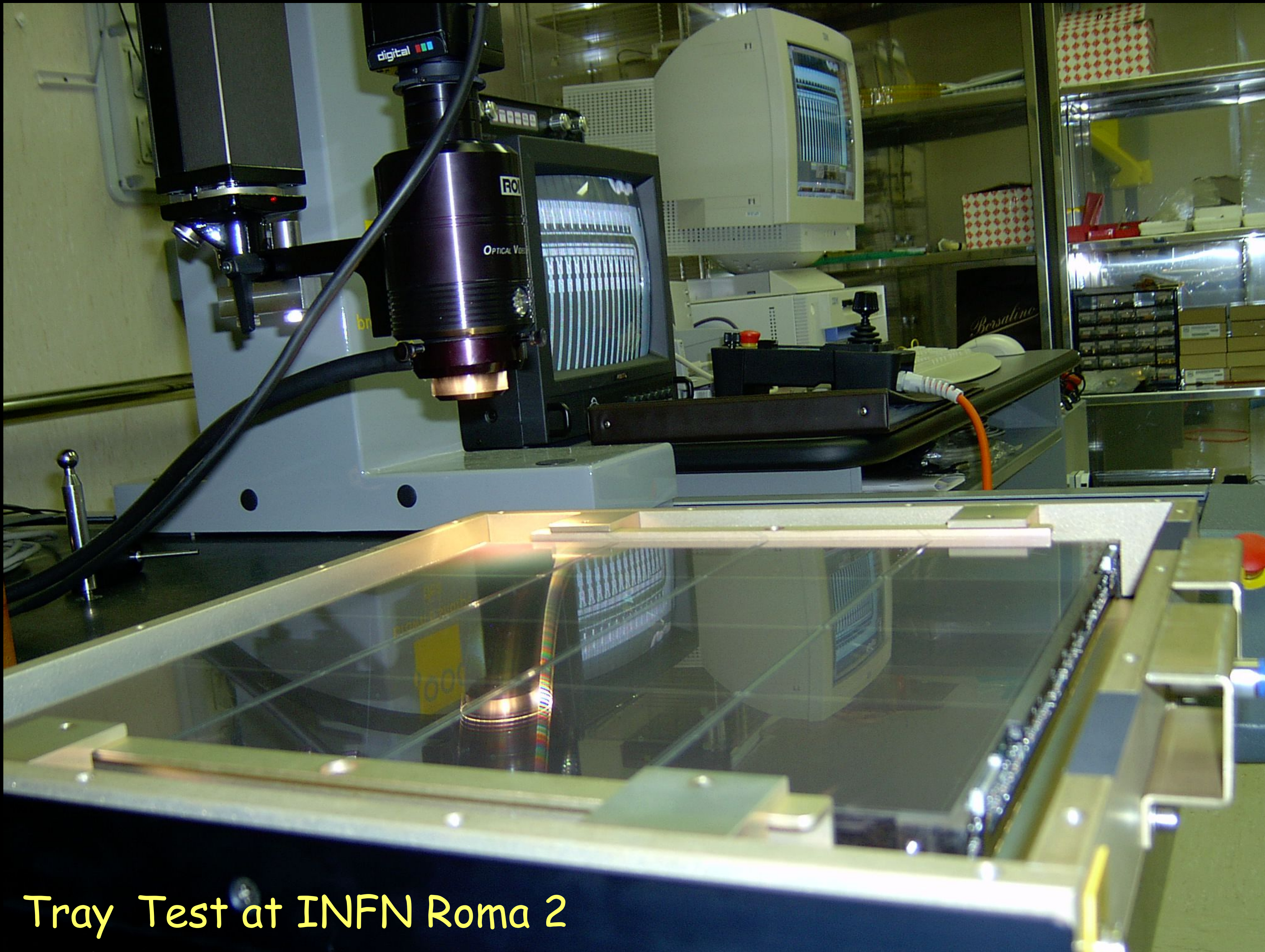

LAMINAR FLOW
ASALAIR 1200
LAMINAR FLOW
1200 FLV
PROIBITO
FUMARE
VIETATO
L'ACCESSO
a chi non è
autorizzato

Tray Test at INFN Roma 2

Tray Test at
INFN Roma 2

Tray Test at INFN Roma 2



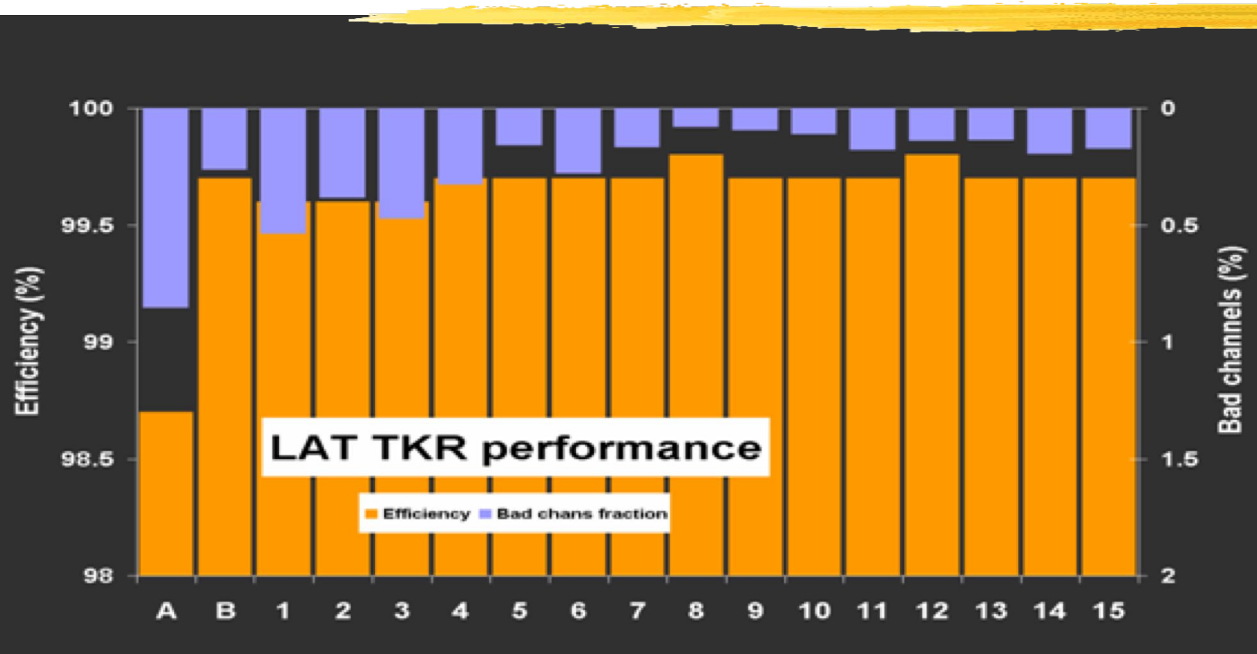


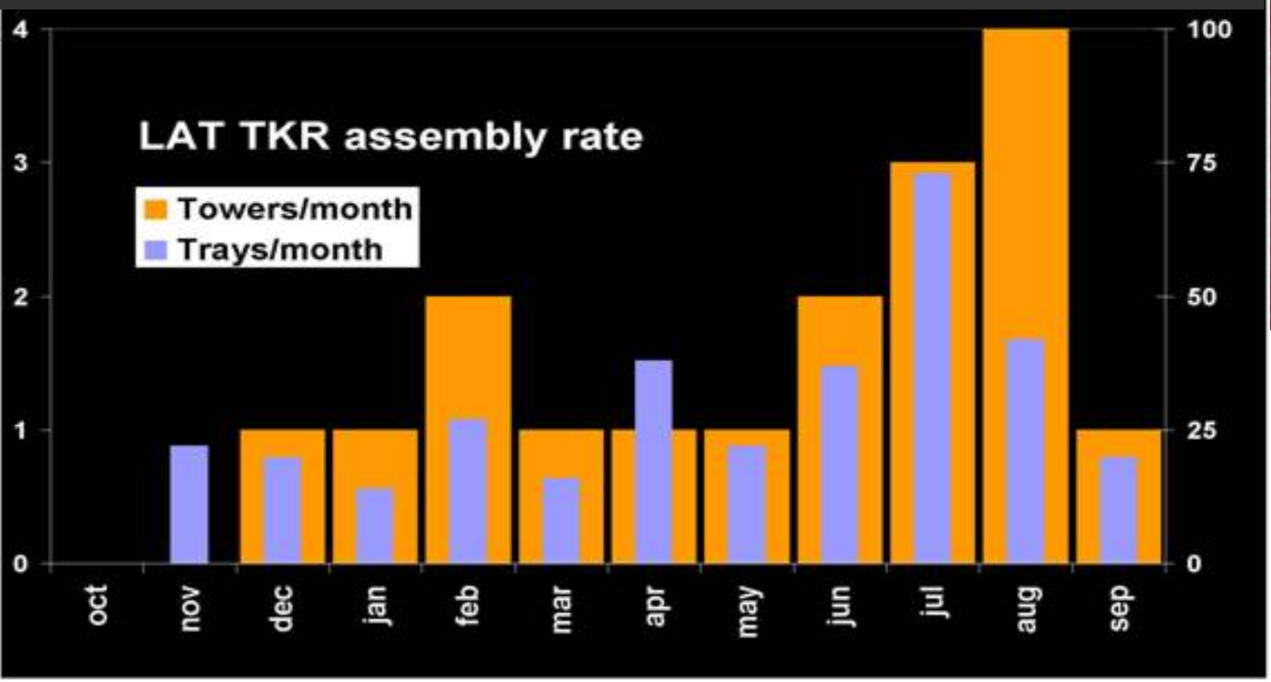
Tray Test at INFN Roma 2

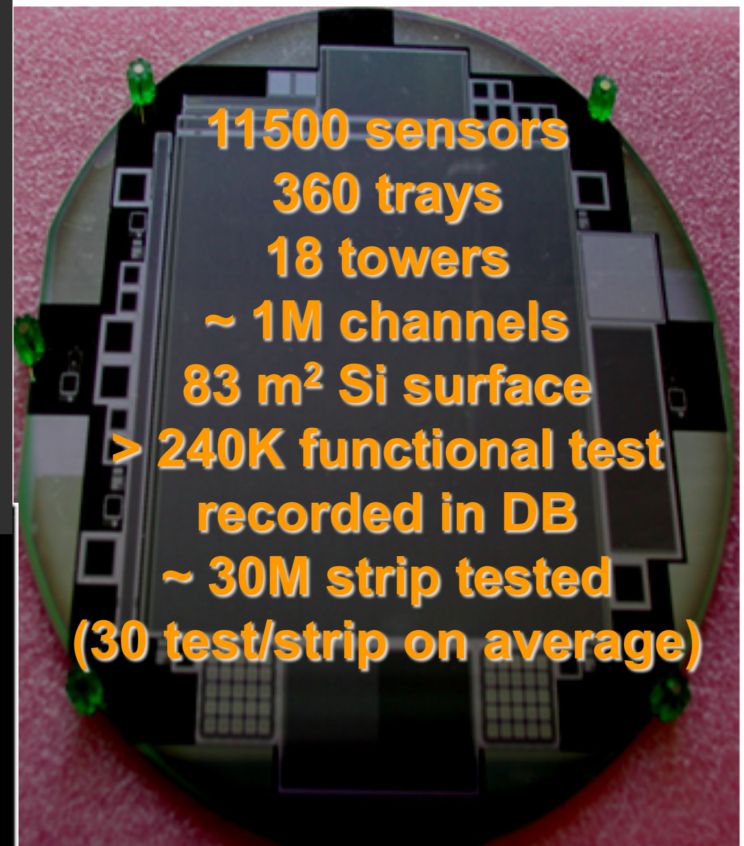

40 CHANNEL
VOLTAGE SYSTEM
Mod. SY 127
-0.00
017


INFN

The LAT Tracker numbers



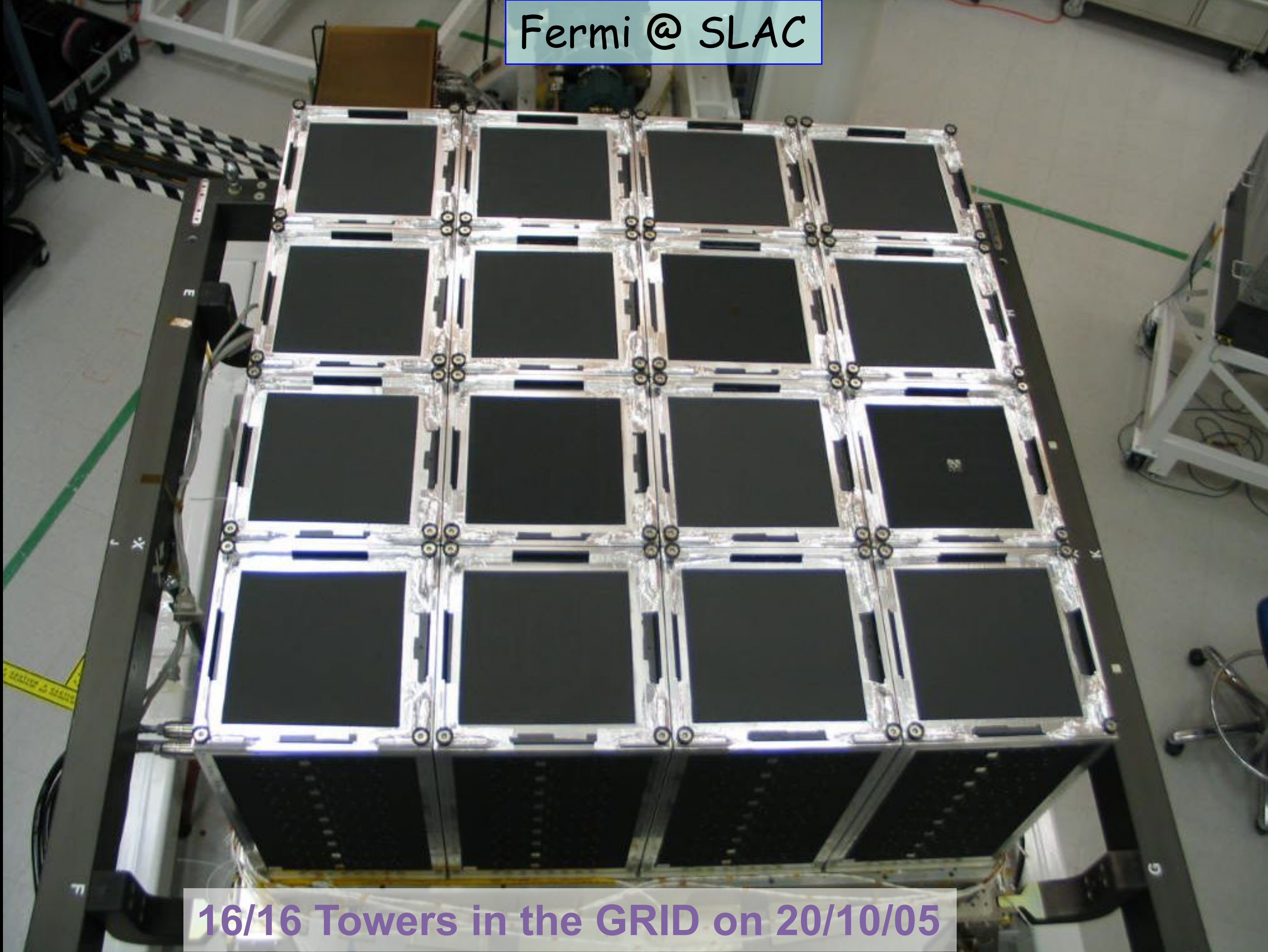




GLAST @ SLAC

12/16 Towers in the GRID on 7/10/05

Fermi @ SLAC



16/16 Towers in the GRID on 20/10/05