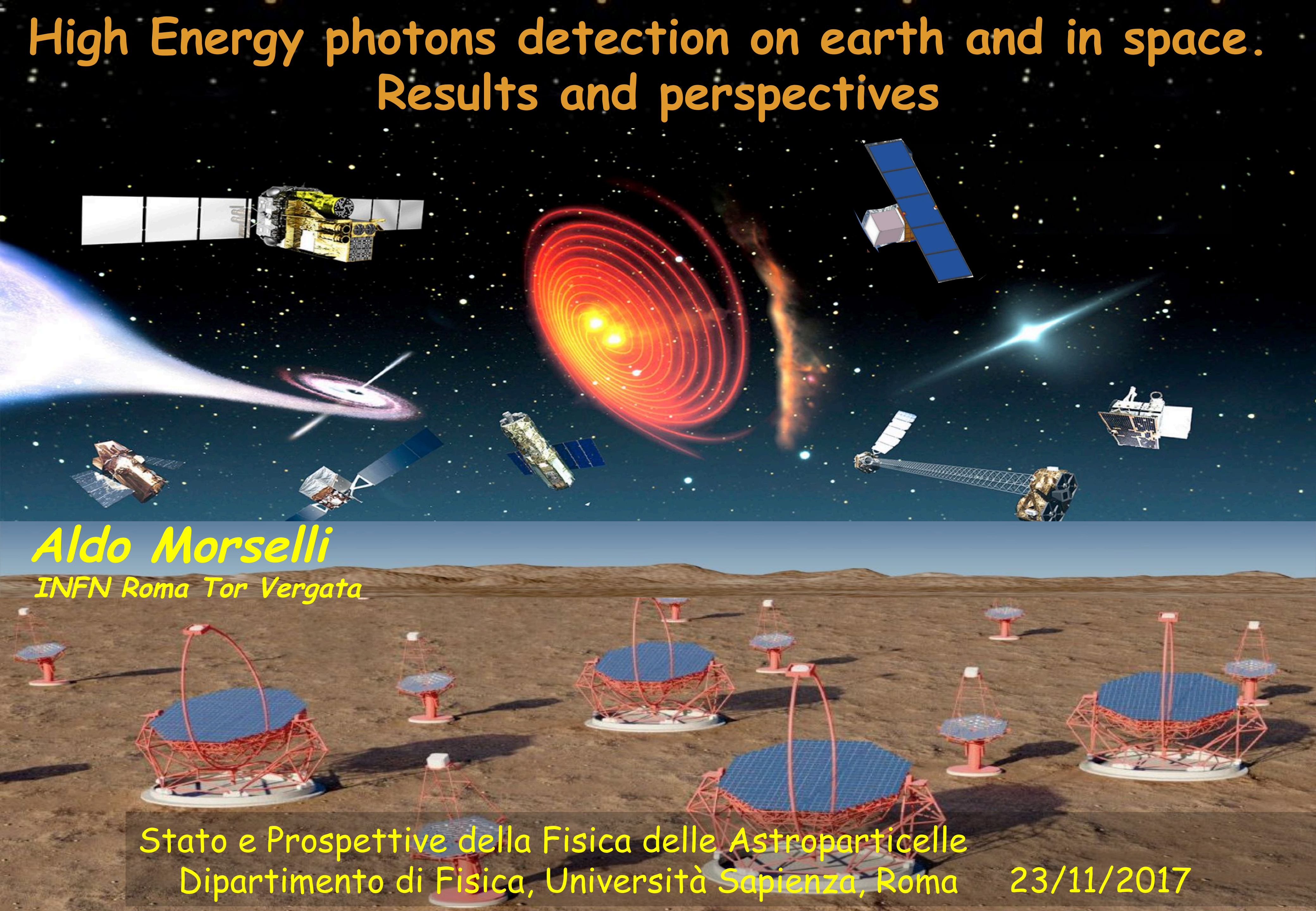


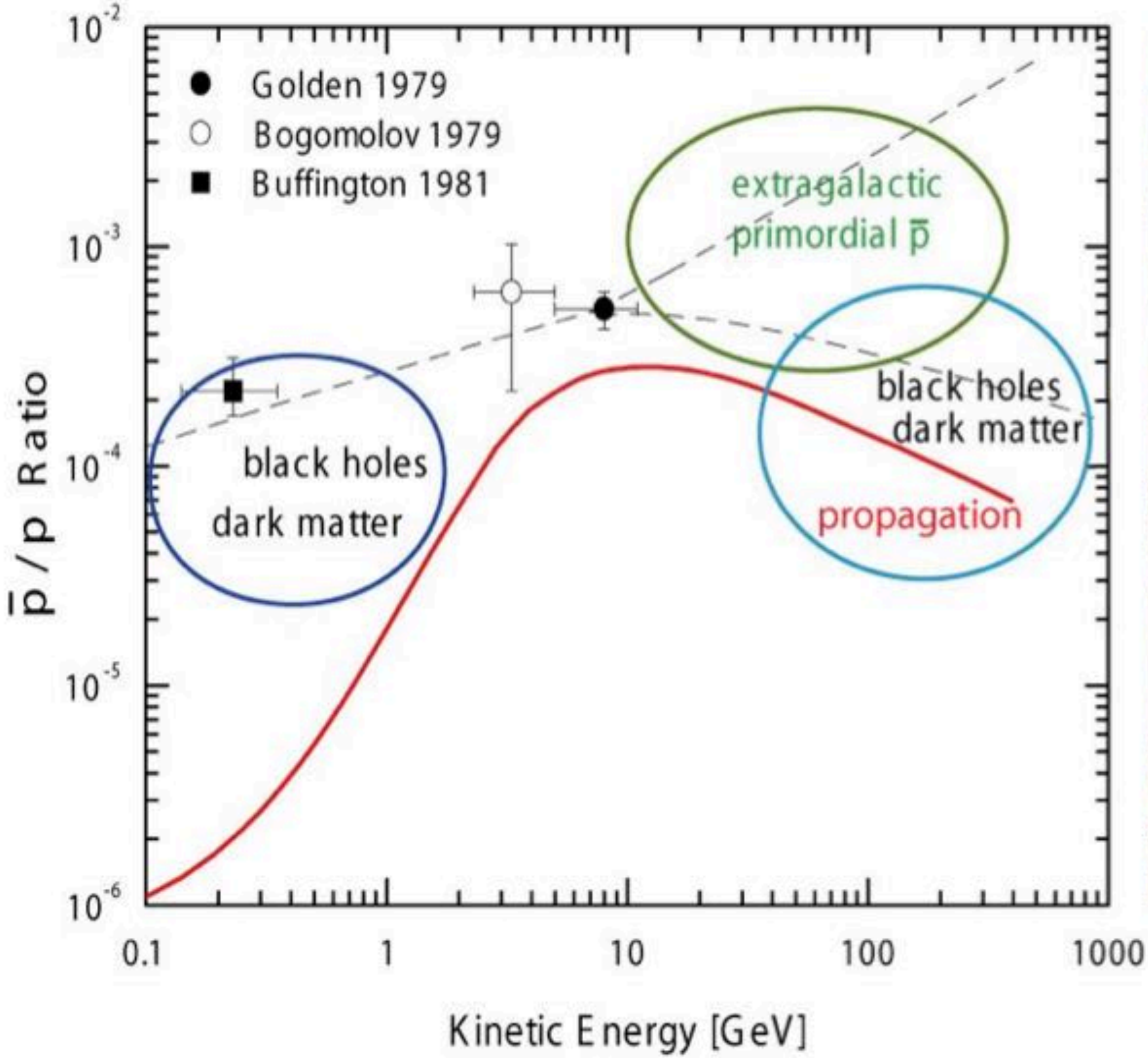
High Energy photons detection on earth and in space.
Results and perspectives
Aldo Morselli
INFN Roma Tor Vergata
Stato e Prospettive della Fisica delle Astroparticelle
Dipartimento di Fisica, Università Sapienza, Roma 23/11/2017

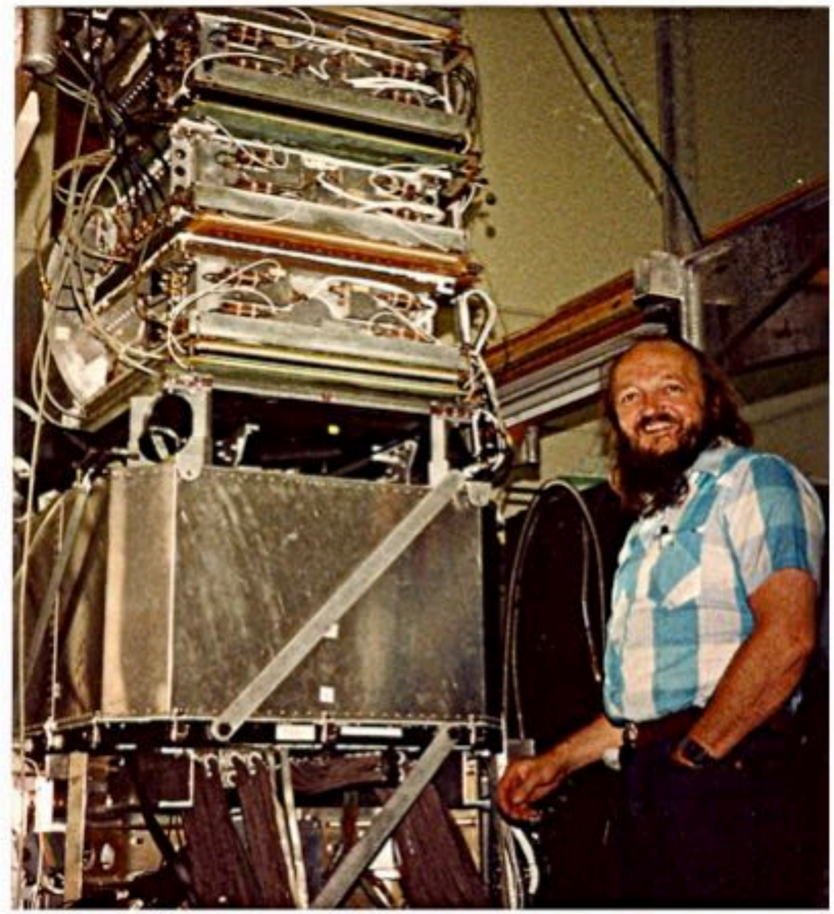
My involvements

- Agile and Fermi gamma rays instruments
- The new project e-AstroGam
- CTA

- In the past :
- Pamela cosmic ray experiment
- Several Cosmic ray balloons
- SilEye (Silicon Eye) Study of light flashes, Radiation Environment and Astronaut Brain Activity on board the International Space Station

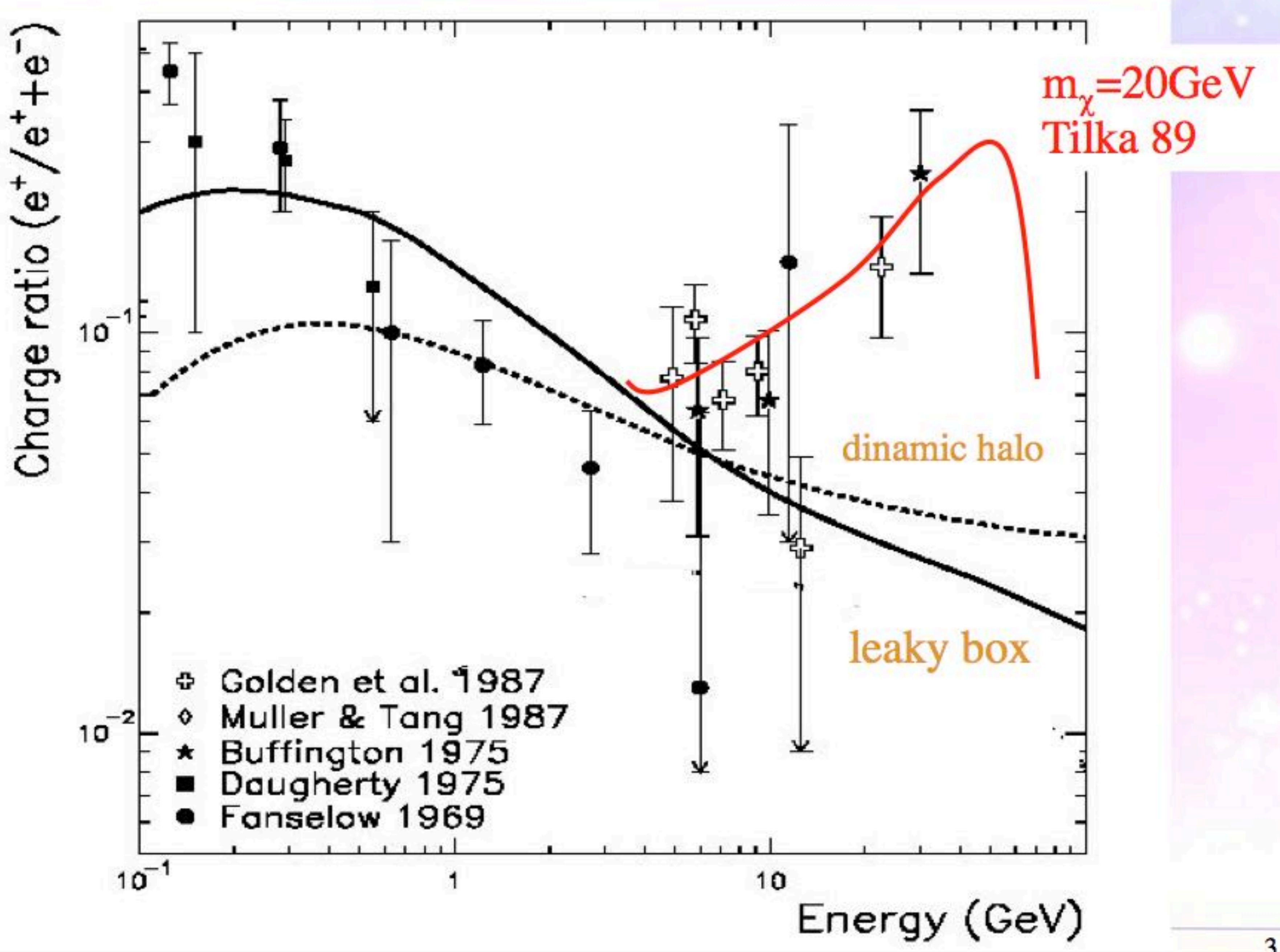
The first historical measurements of the p̄/p - ratio and various Ideas of theoretical Interpretations





Robert L. Golden

Balloon data : Positron fraction before 1990

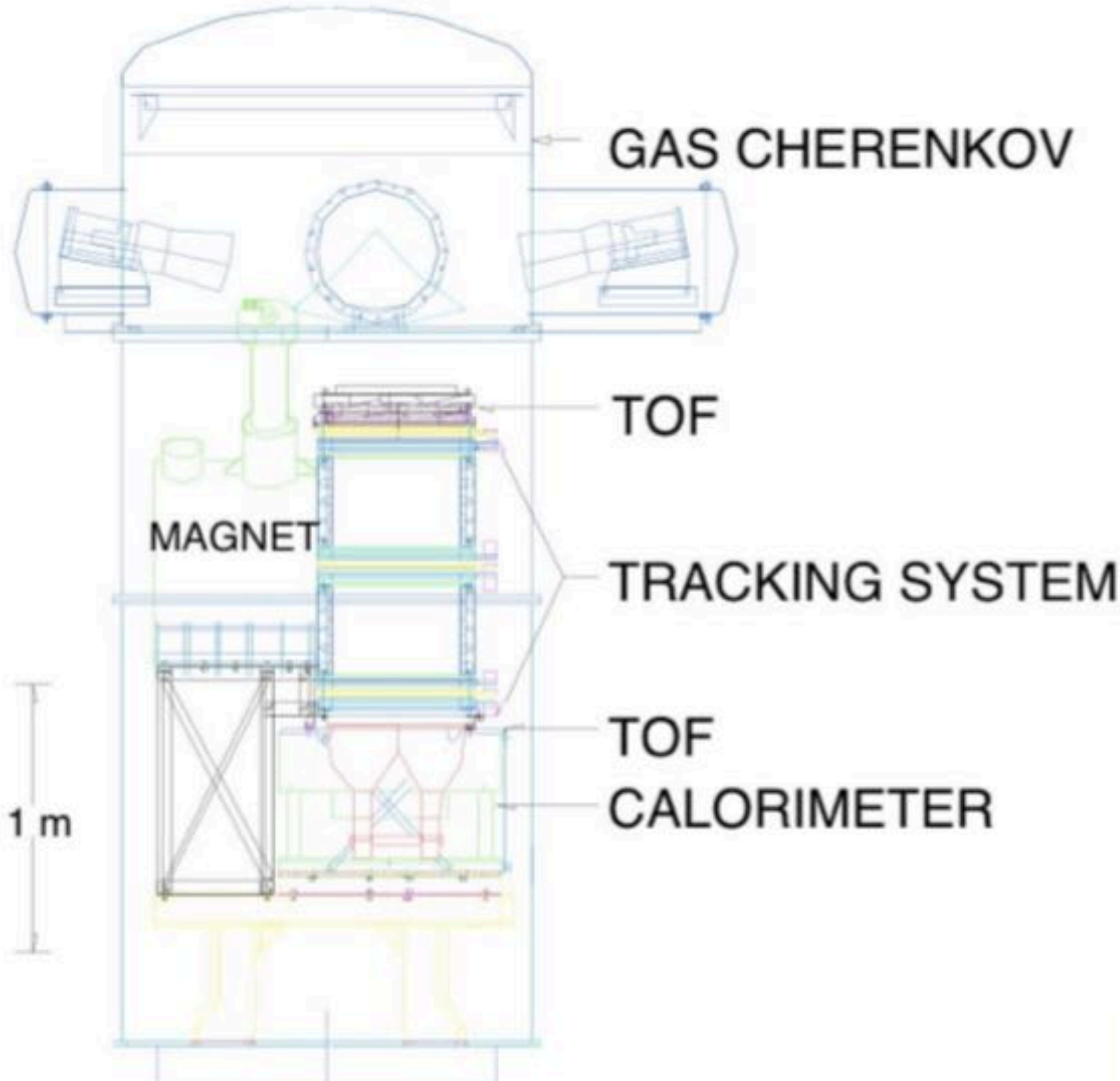


Neutralino WIMPs

Assume χ present in the Galactic halo

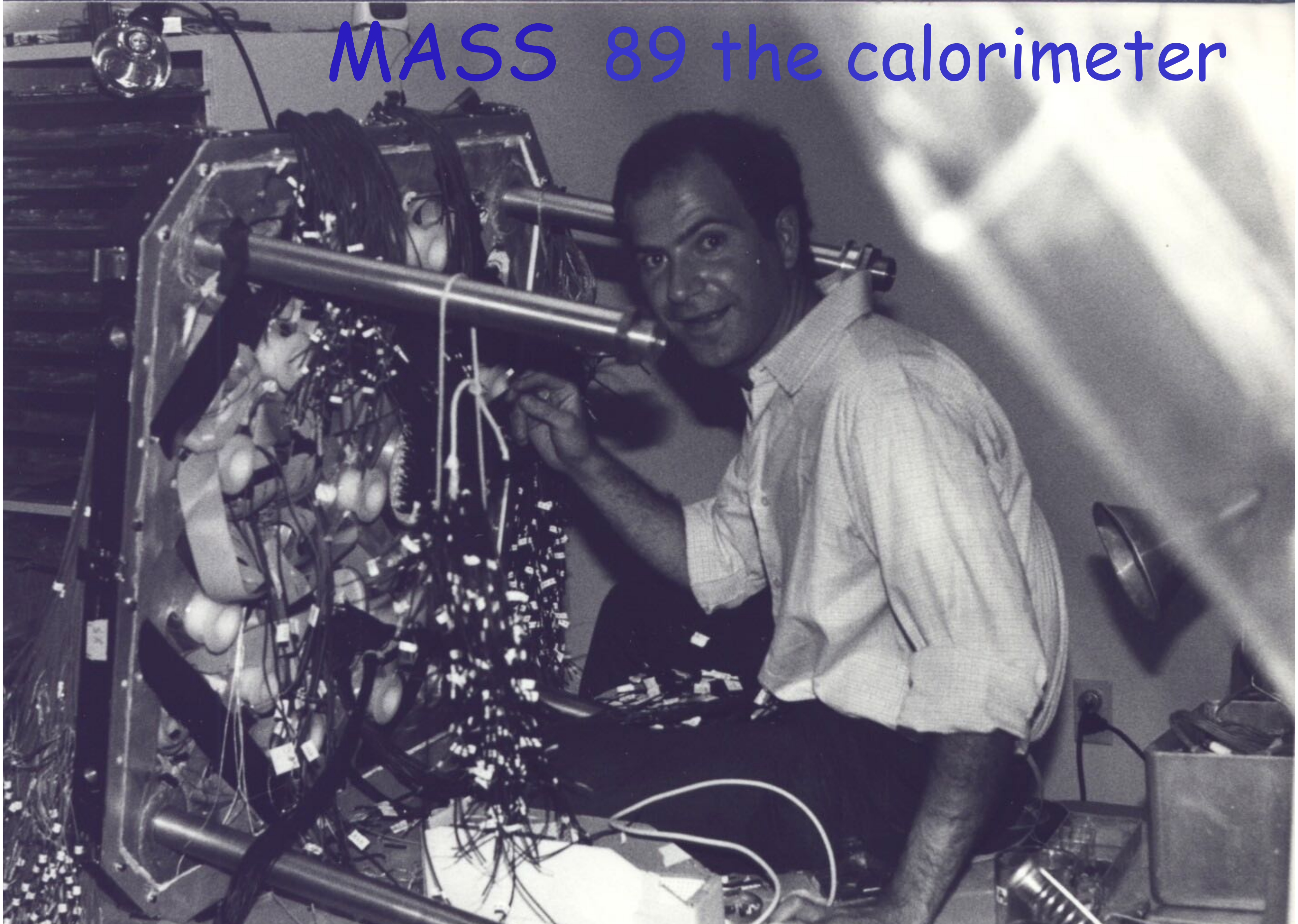
- χ is its own antiparticle **=>** can annihilate in galactic halo producing gamma-rays, antiprotons, positrons….
- Antimatter not produced in large quantities through standard processes (secondary production through p + p **-->** anti p + X)
- So, any extra contribution from exotic sources ($\chi\,\chi$ annihilation) is an interesting signature
- ie: $\chi\,\chi$ --> anti p + X
- Produced from (e. g.) $\chi\,\chi$ **-->** q / g / gauge boson / Higgs boson and subsequent decay and/ or hadronisation.

MASS Matter Antimatter Space Spectrometer




HOLD

MASS 89 the calorimeter



1989 POW WOW in Saskatchewan


MASS 89 flight

MASS 89 flight


MASS 89

PAMELA

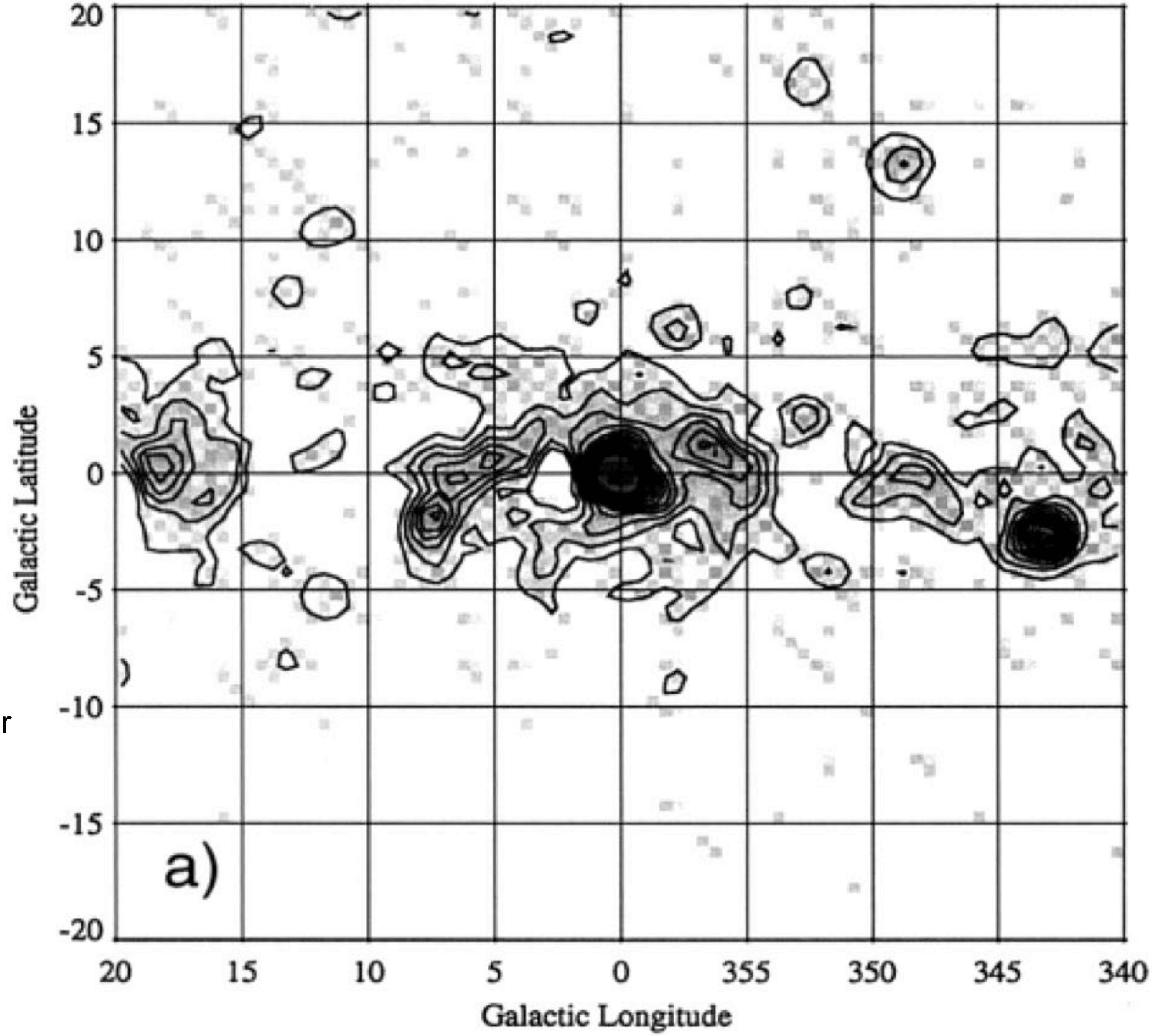
Payload for Antimatter Matter Exploration and Light Nuclei Astrophysics

see the talk of Manuela Vecchi

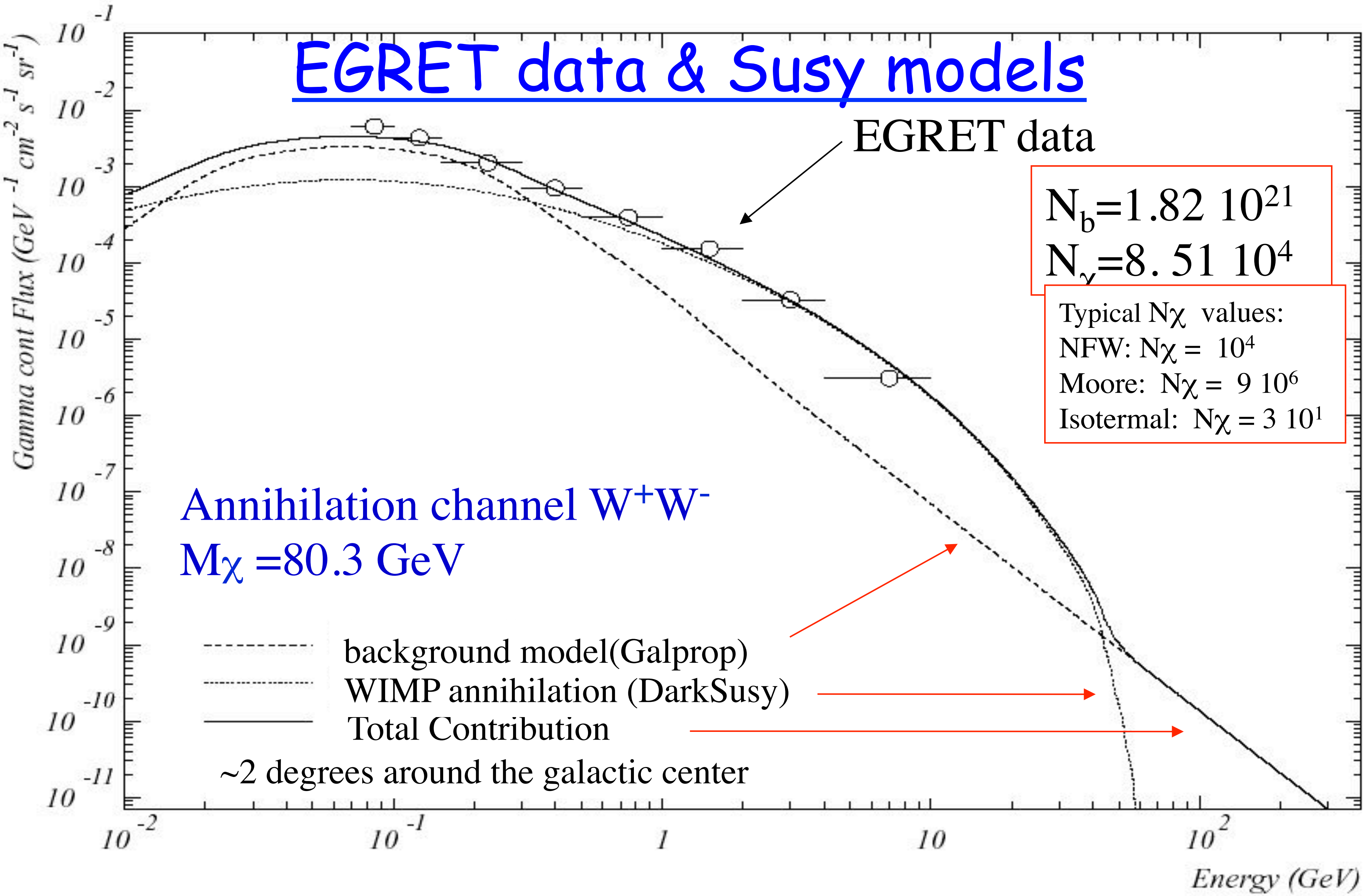
but there are also gamma-rays..

EGRET, E > 1GeV

Mayer-Hasselwander et al, 1998

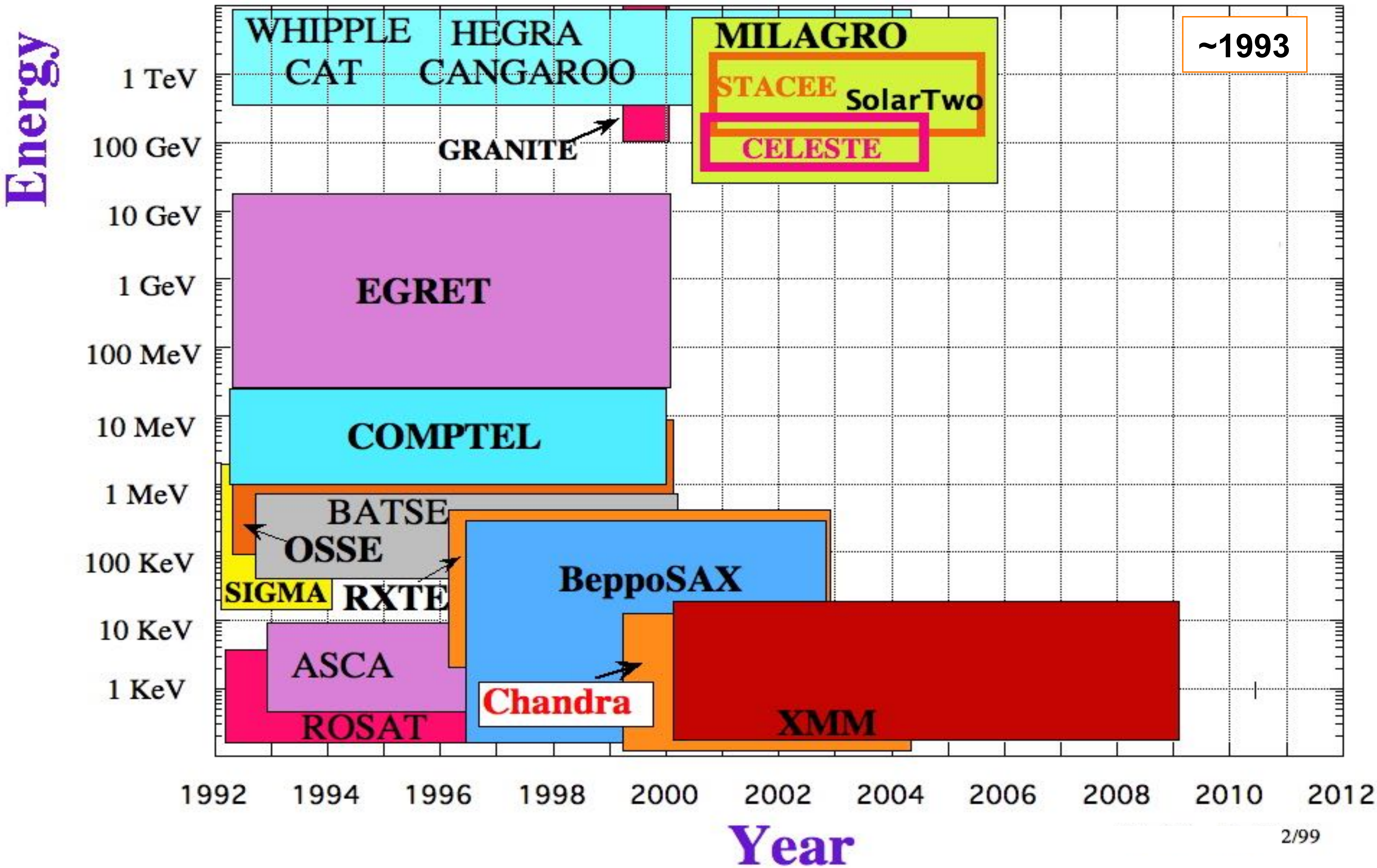


EGRET data & Susy models

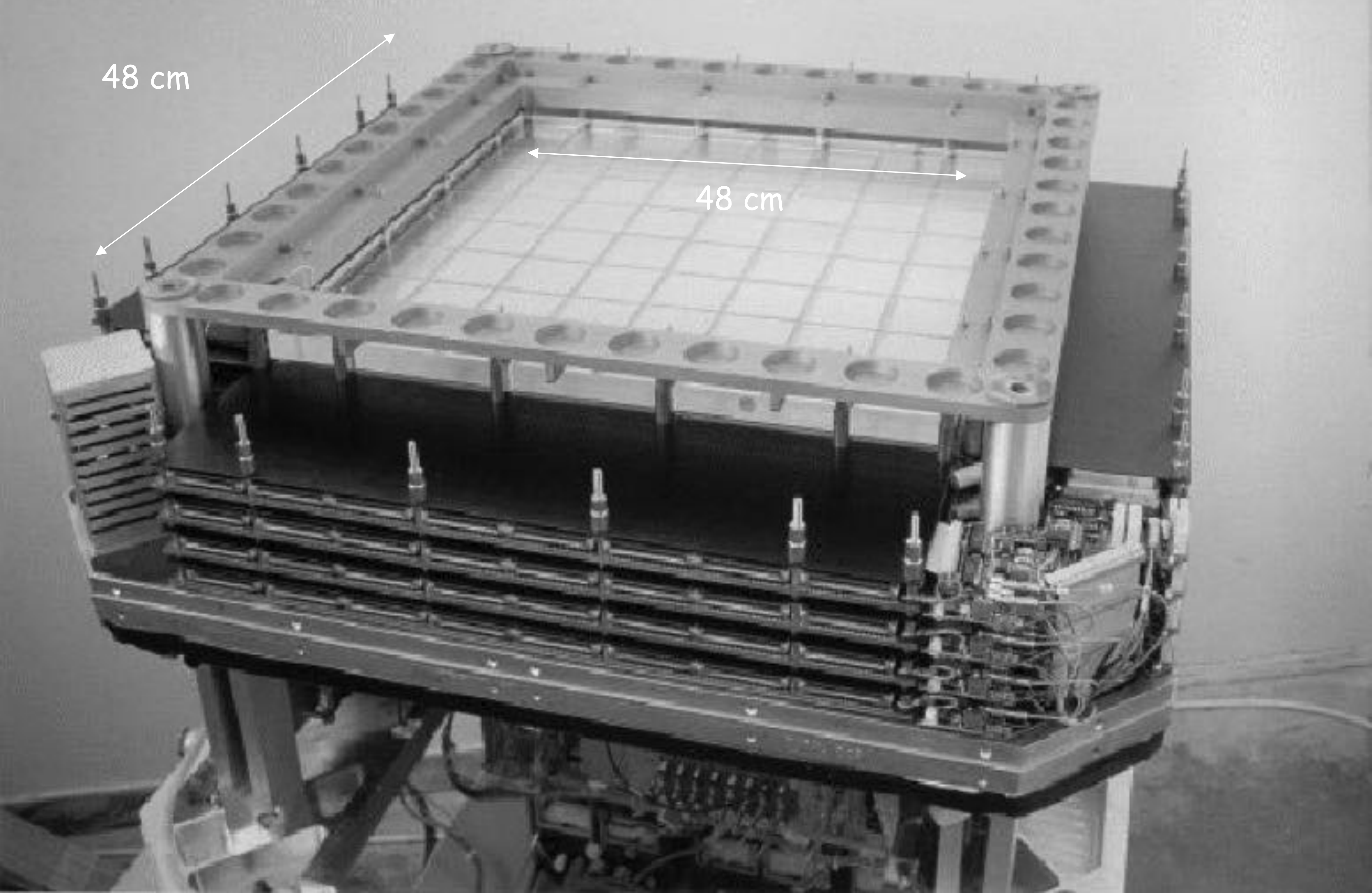


A.Morselli, A. Lionetto, A. Cesarini, F. Fucito, P. Ullio, Nucl. Phys. B 113B (2002) 213-220 [astro-ph/0211327]

High Energy Gamma Experiments 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]

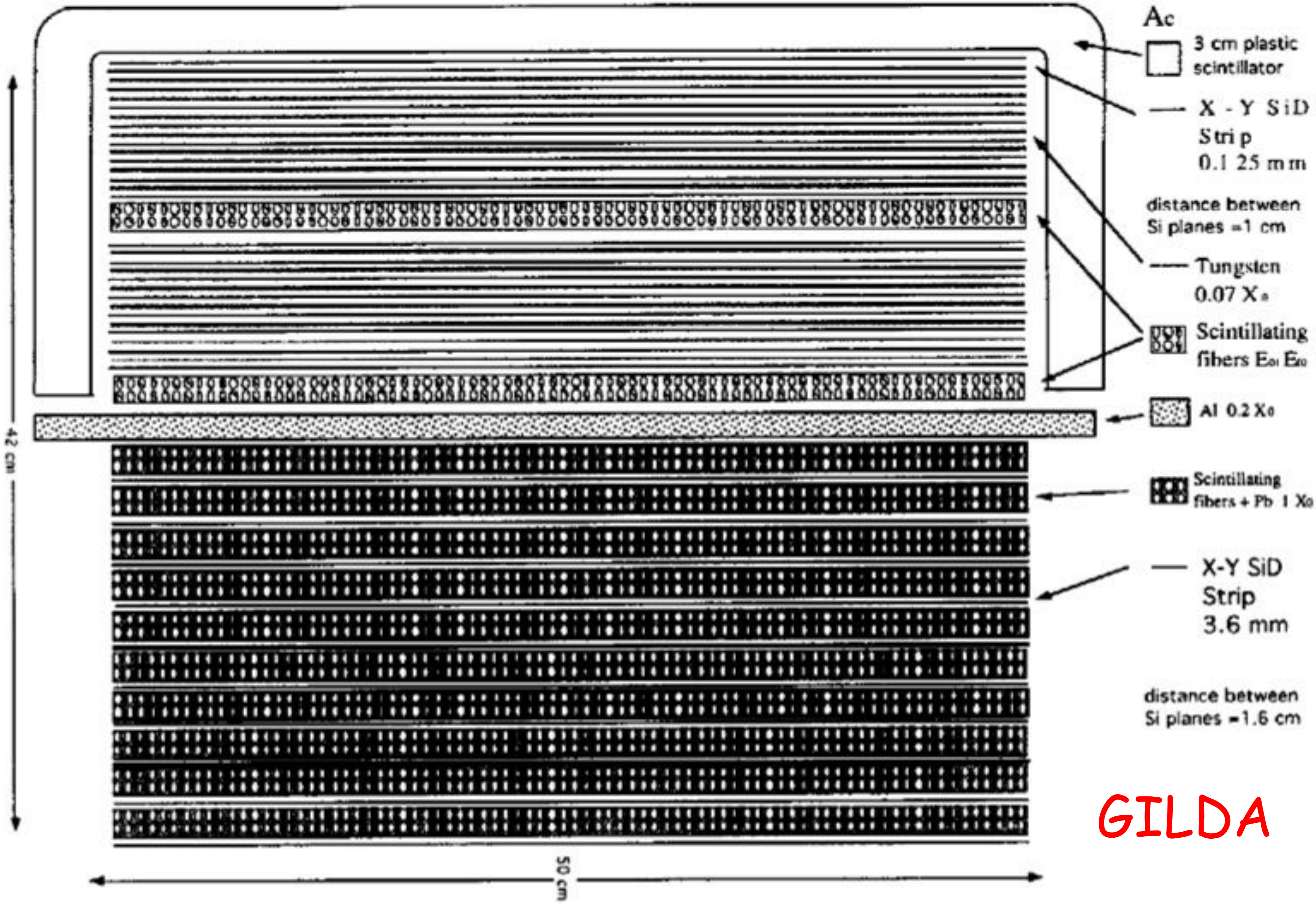
[a] *Dept. of Physics, Univ. of Trieste and INFN, Italy*
[b] *Dept. of Physics, II Univ. of Rome "Tor Vergata" and INFN, Italy*
[c] *Dept. of Physics, Univ. of Firenze and INFN, Italy*
[d] *INFN Laboratori Nazionali di Frascati, Italy*

Received 5 August 1994

Abstract

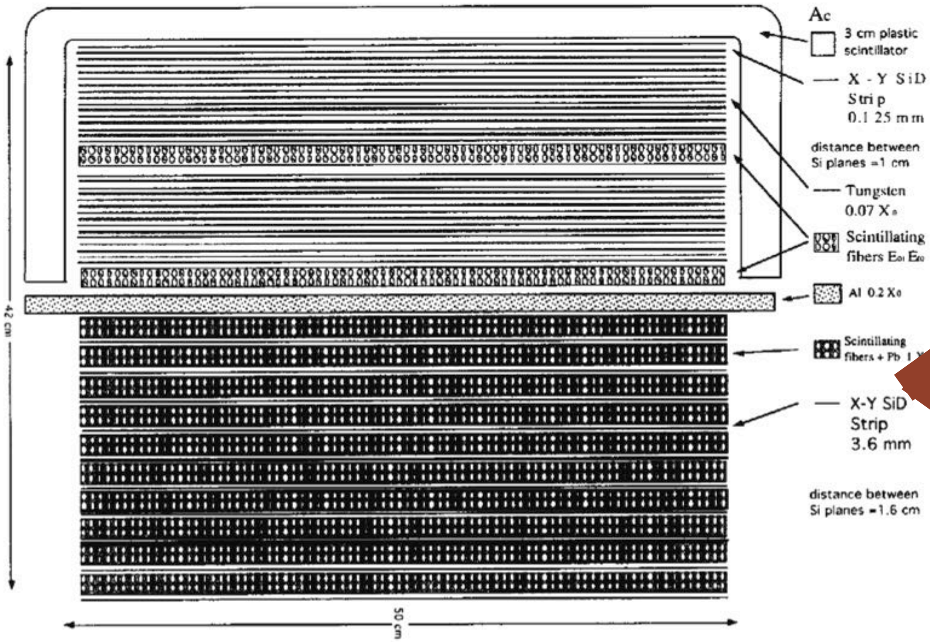
In this article a new technique for the realization of a high energy gamma-ray telescope is presented, based on the adoption of silicon strip detectors and lead scintillating fibers. The simulated performances of such an instrument (GILDA) are significatively better than those of EGRET, the last successful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

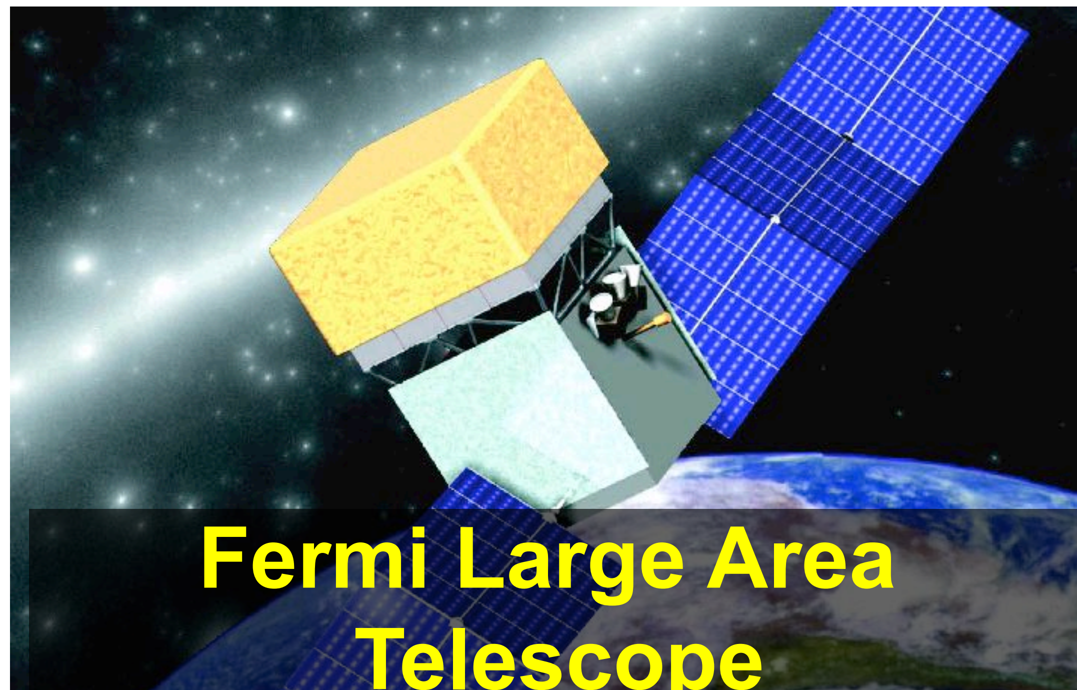
* Corresponding author.


Ac
3 cm plastic scintillator
X - Y SiD Strip 0.125 mm
distance between Si planes =1 cm
Tungsten 0.07 X₀
Scintillating fibers E₀₁ E₀₂
Al 0.2 X₀
Scintillating fibers + Pb 1 X₀
X-Y SiD Strip 3.6 mm
distance between Si planes =1.6 cm
42 cm
50 cm

GILDA

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 10th Birthday Agile !!

AGILE investigations of ICECUBE-160731

- **AGILE alert systems received automatically GCN/ AMON notice emitted by the ICECUBE Coll.**
- **No significant detection in the AGILE-GRID data was found around T0 at the ICECUBE coords.**
- **BUT … a gamma-ray excess above 100 MeV above 4 sigma was detected in the GRID data by the *AGILE QL* processing procedure a couple of days before, on a 48 hours integration between (T0 – 3; T0 – 1) days.**

The AGILE AGL J1418+0008 transient

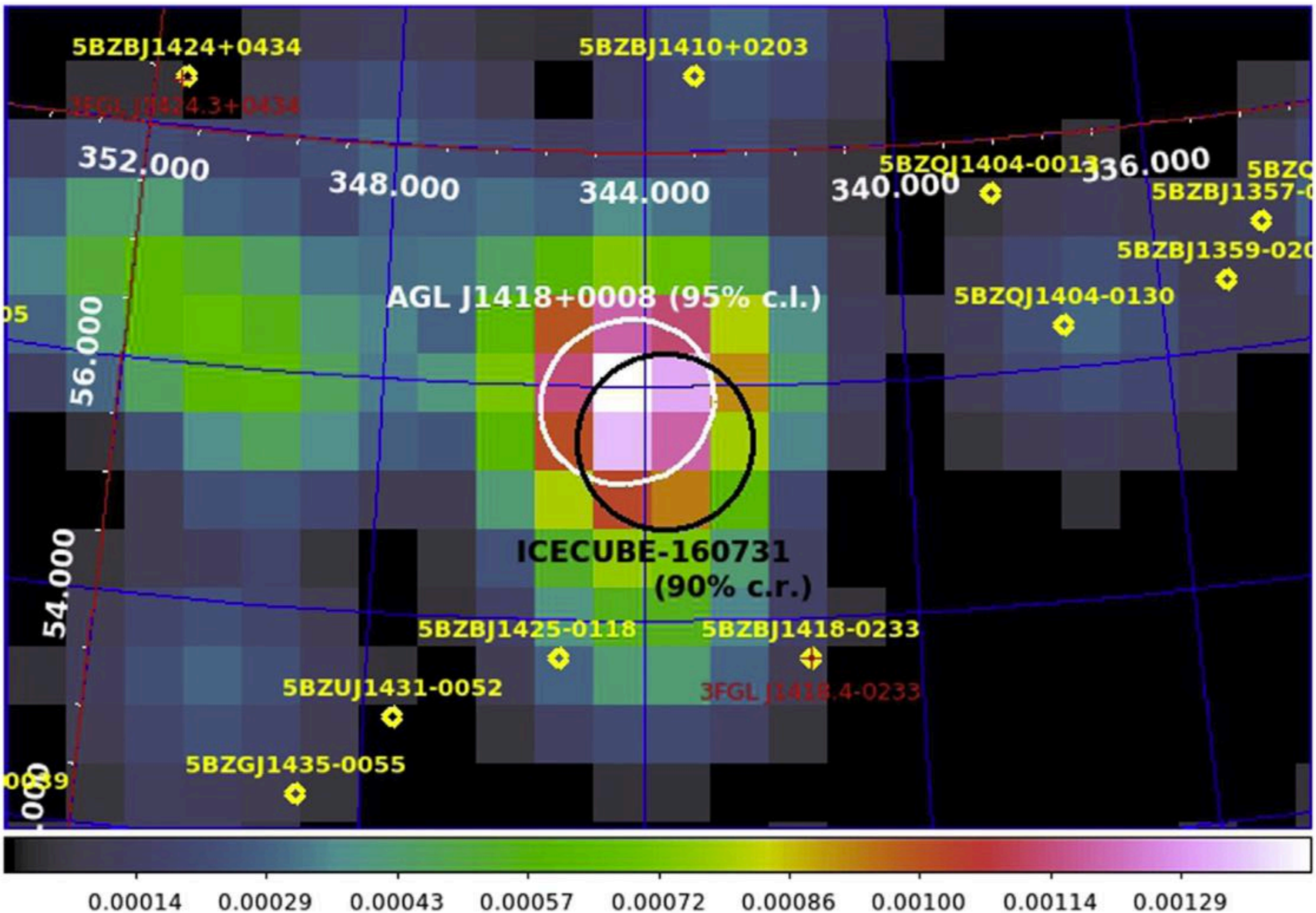
- Very brief episode (1 – 1.5 days).
- 4.1σ pre-trial significance on (T0 – 2; T0 - 1) days interval.
- Peak significance of 4.9σ on the 24 hours integration (T0 - 1.8; T0 - 0.8) days (peak flux (E>100 MeV)~3.5E-06 ph/cm2/s).
- Best-fit AGILE-GRID position:

l,b=(344.26, 55.86) [deg] +/- 0.8 [deg] (95% stat. c.l.)

➔ new AGILE transients: <u>AGL J1418+0008</u>

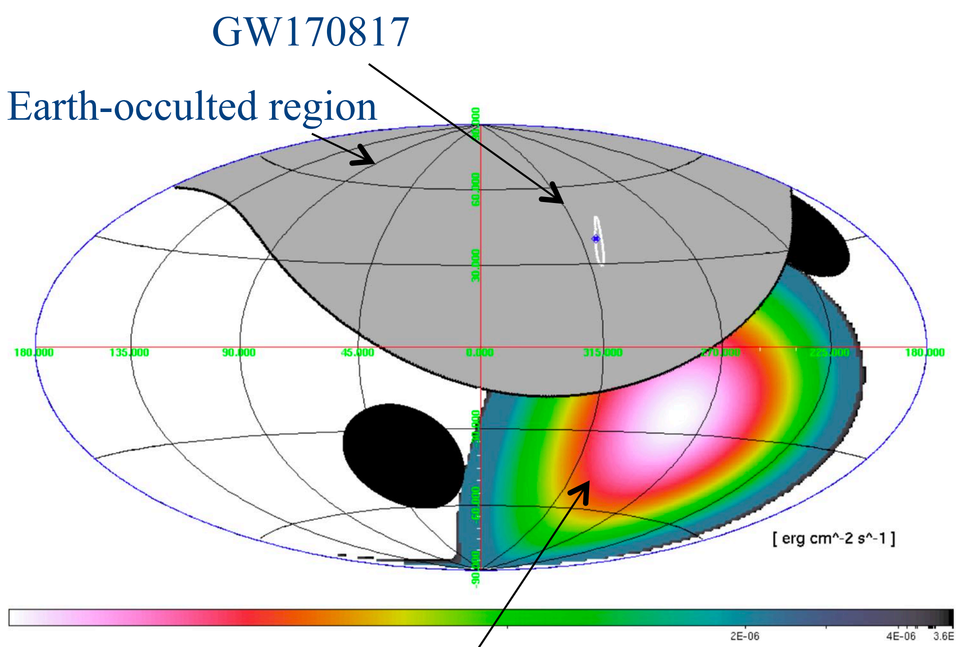
AGL J1418+008 possible gamma-ray precursor of the ICECUBE-160731 event (?)

The AGILE AGL J1418+0008 transient

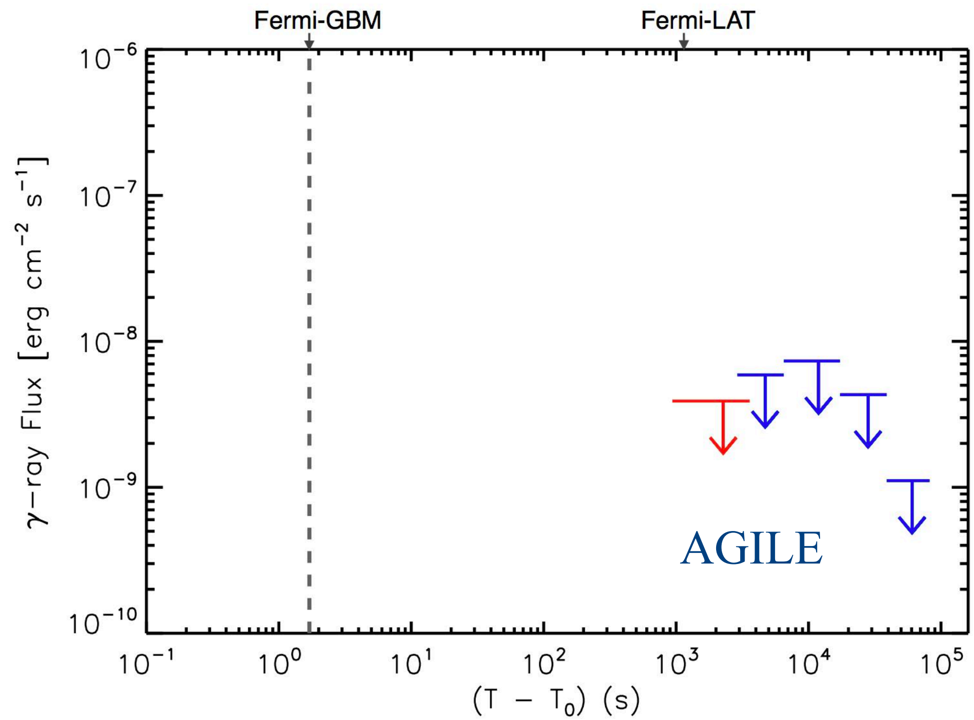


F. Lucarelli et al. Agile Coll. Apj, 2017, 846:121 [arXiv:1707.08599]

AGILE and GW170817



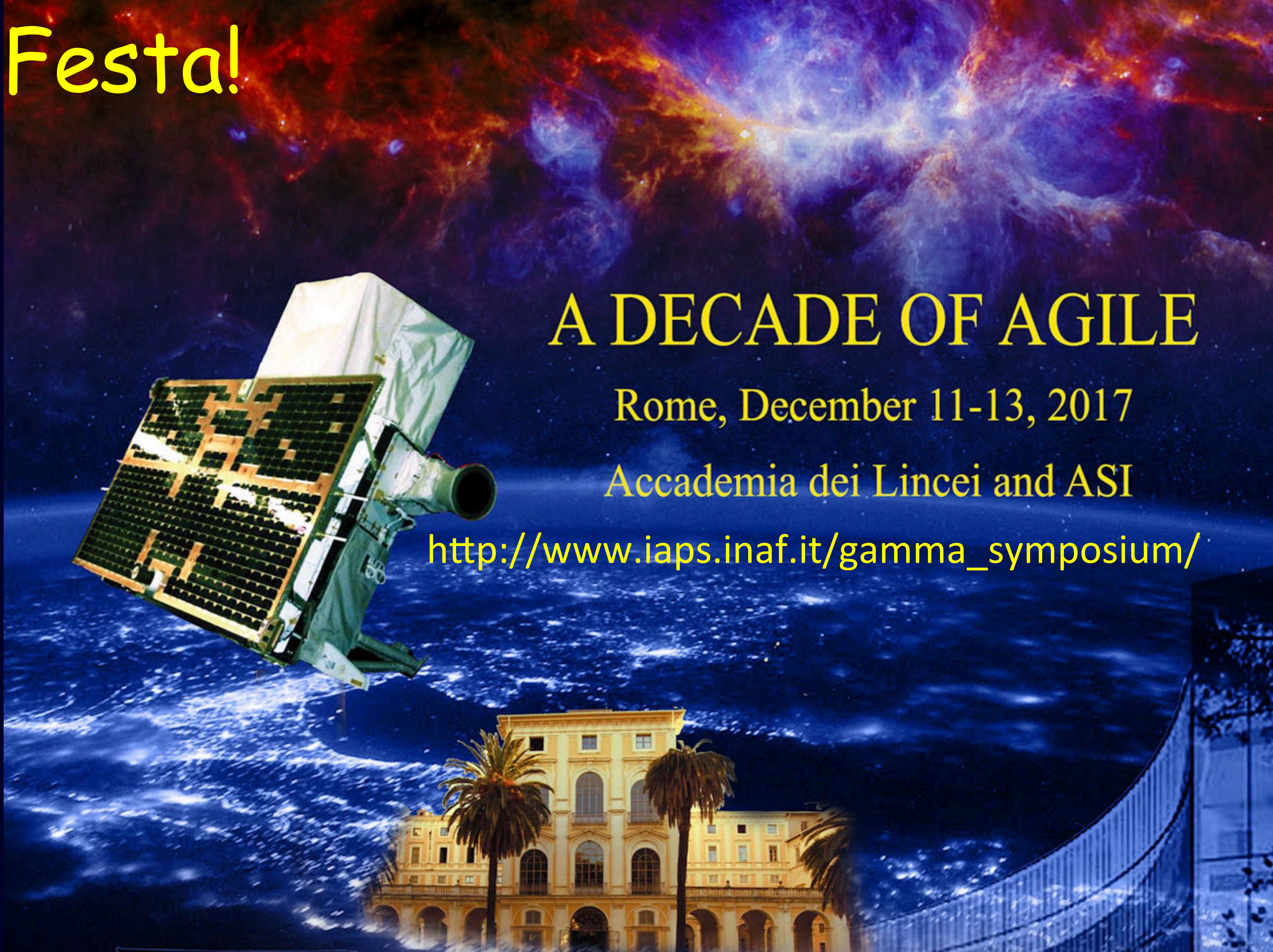
AGILE exposure at T_0



- At T_0 GW170817 was occulted by earth but AGILE instrument collected useful data before and after the GW/GRB event providing useful constraints on the precursor and delayed emission properties of the NS-NS coalescence event.
- Bright prospects for future events

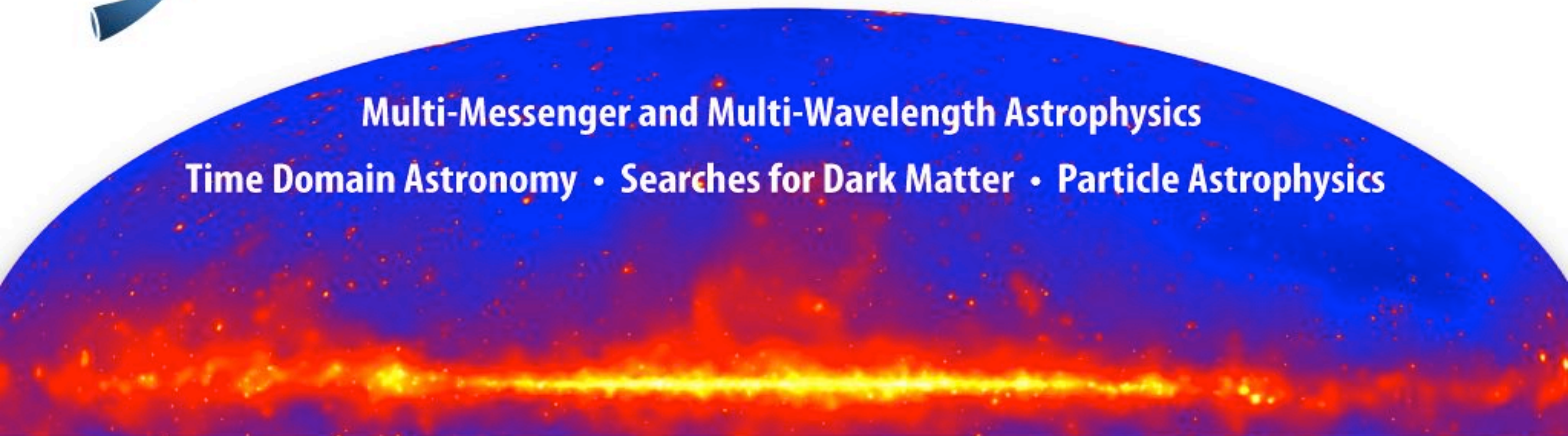
F. Verrecchia, et al, (AGILE Coll.) ApJL sub. arXiv:1409.0042v1

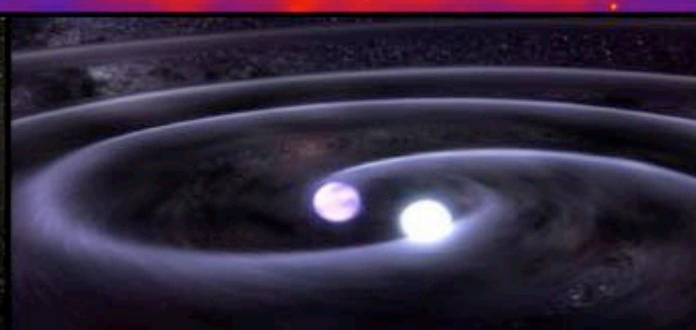
Festa!

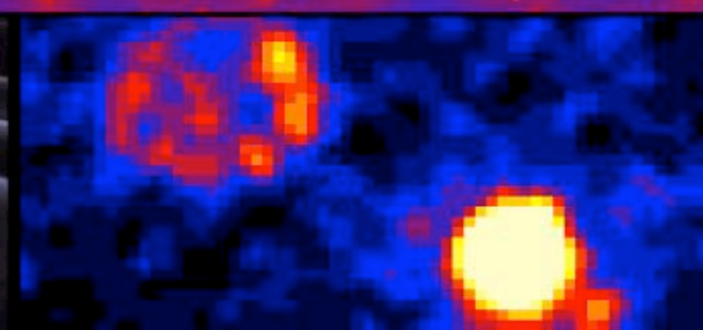

A DECADE OF AGILE
Rome, December 11-13, 2017
Accademia dei Lincei and ASI
http://www.iaps.inaf.it/gamma_symposium/

Fermi
Gamma-ray Space Telescope

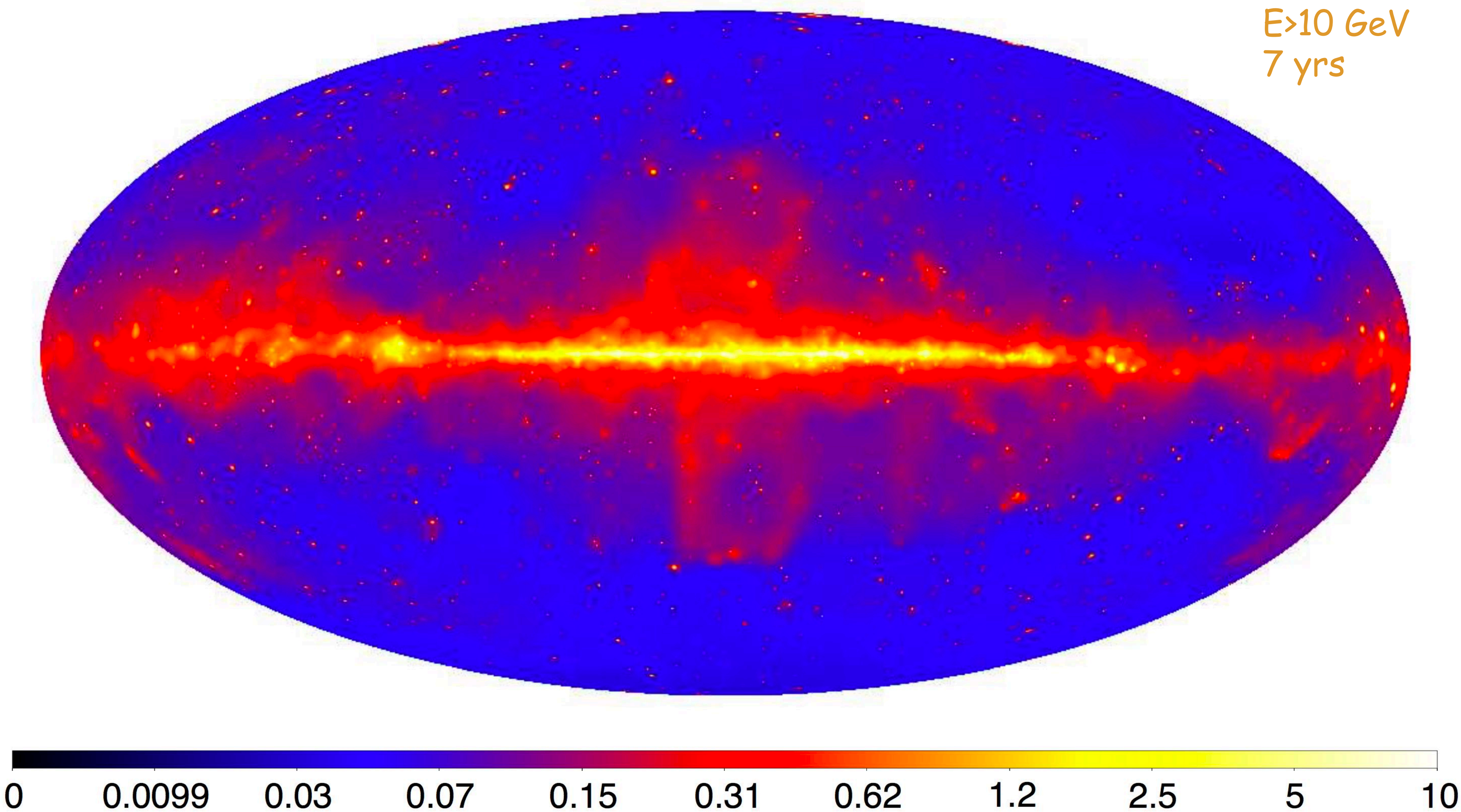
fermi Gamma-Ray Space Telescope





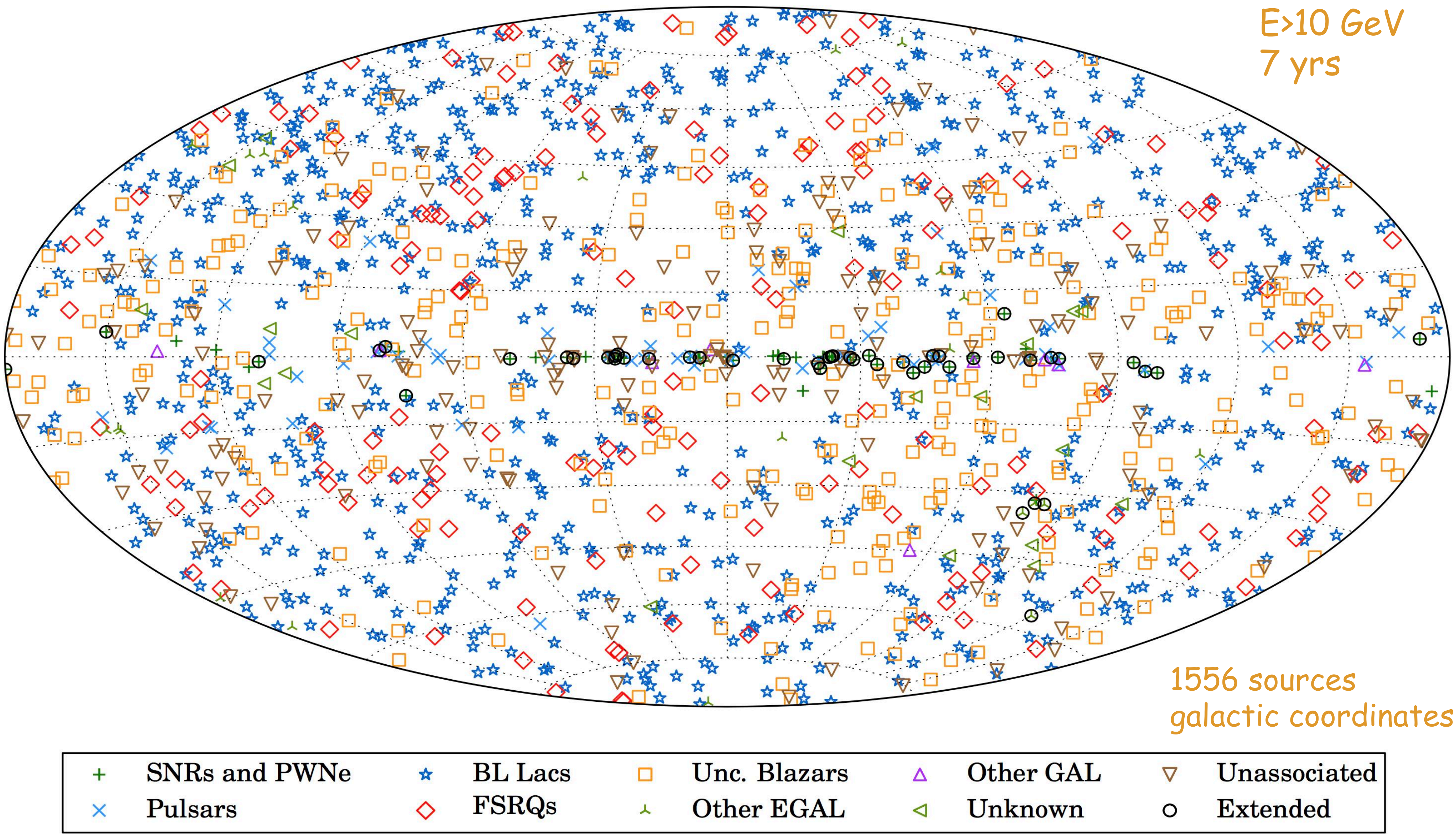


The sky in gamma-rays

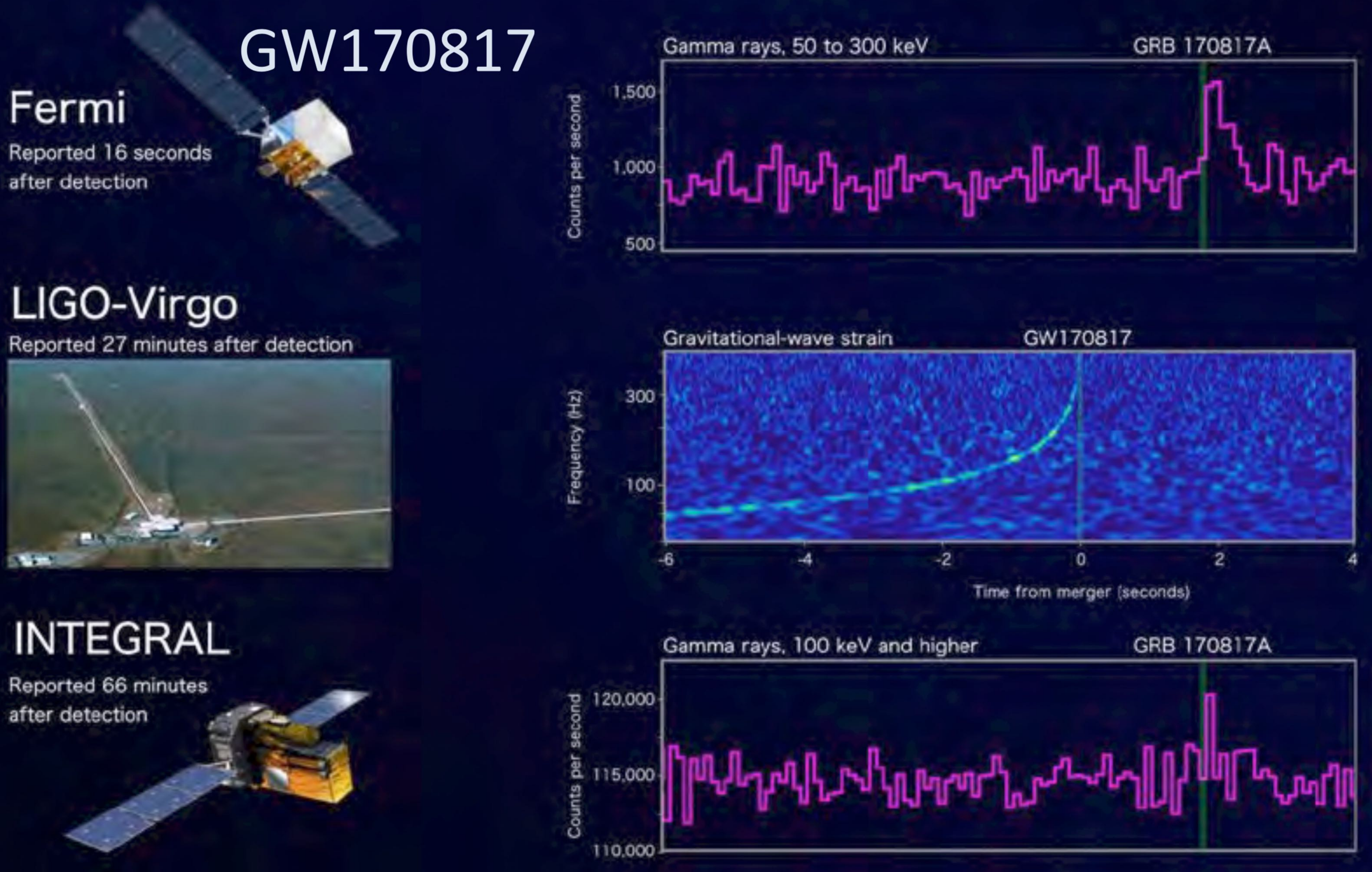


M.Ackermann et al. [Fermi Coll.] 3FHL: The Third Catalog of Hard Fermi-LAT Sources arXiv:1702.00664

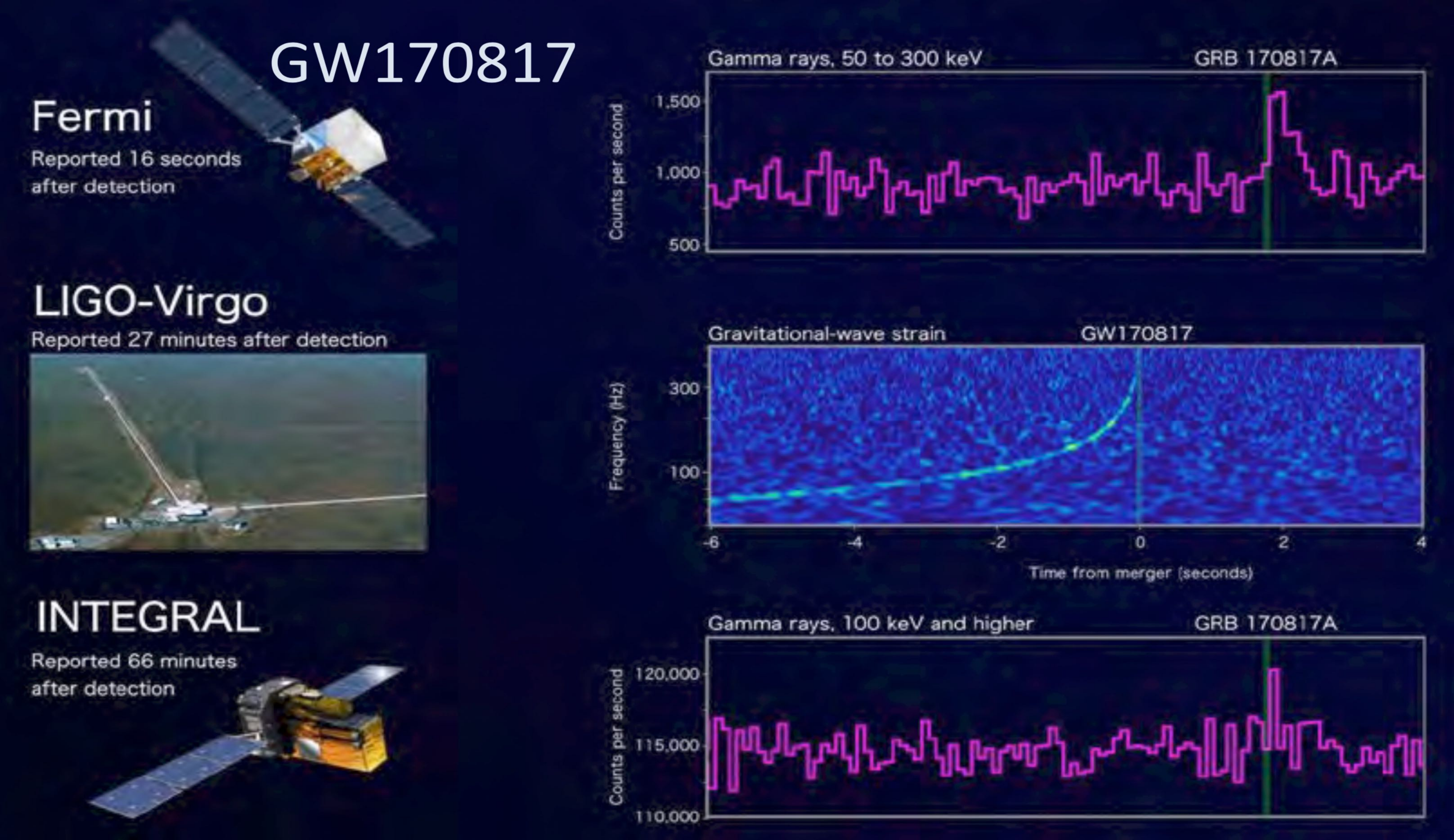
The sky in gamma-rays



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



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



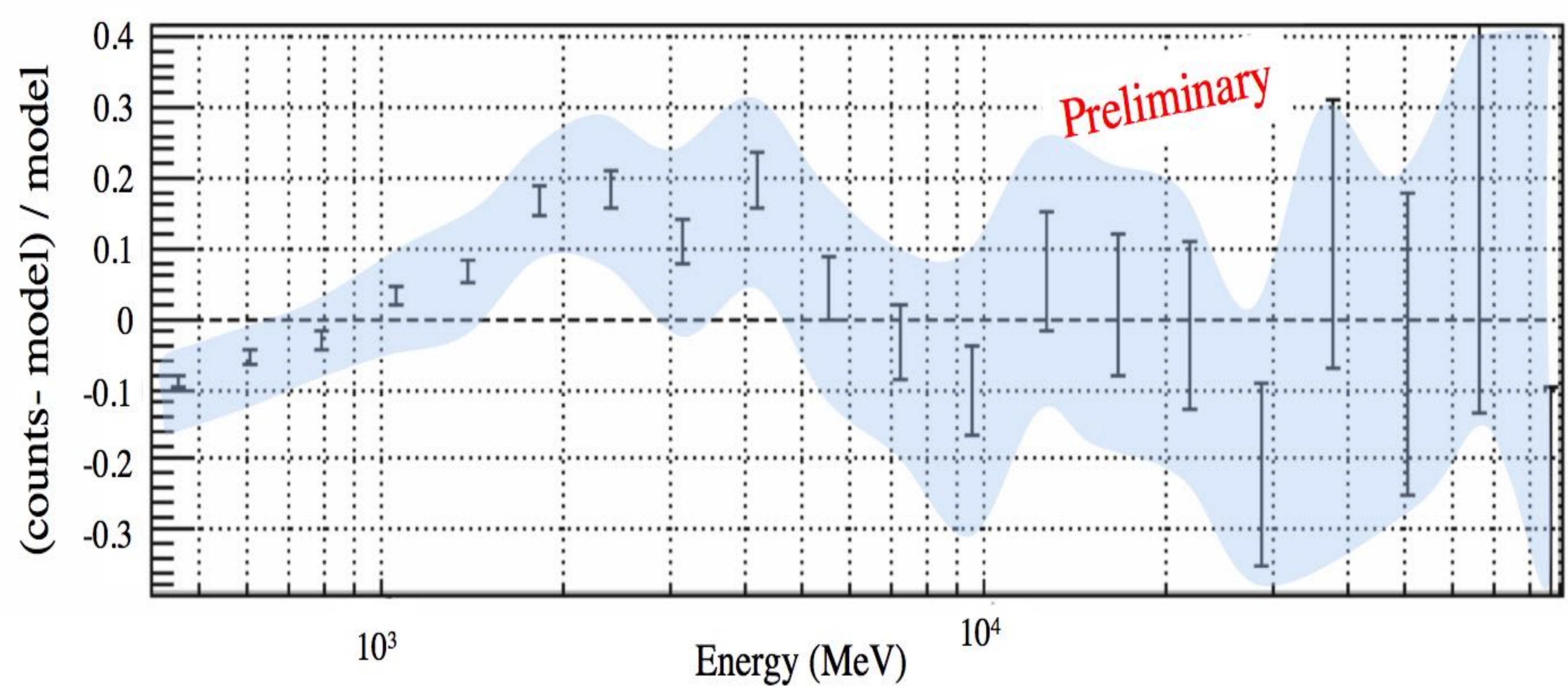
Onde gravitazionali, fotoni e neutrini   4 December 2017 ASI

http://www.asi.it/it/eventi/workshop/workshop-onde-gravitazionali-asi-4-dicembre

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



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)

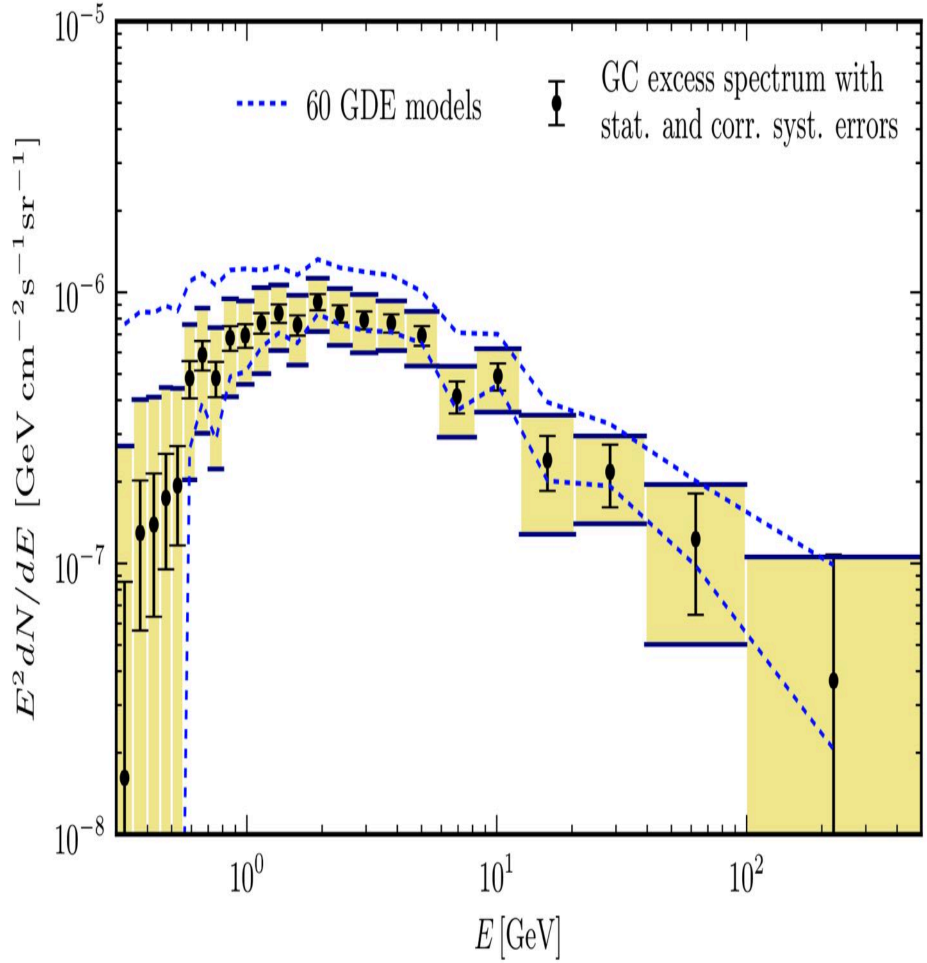
Dark Matter Annihilation in The Galactic Center As Seen by the Fermi Gamma Ray Space Telescope
Dan Hooper , Lisa Goodenough . (21 March 2011). 21 pp. **Phys.Lett. B697 (2011) 412-428**

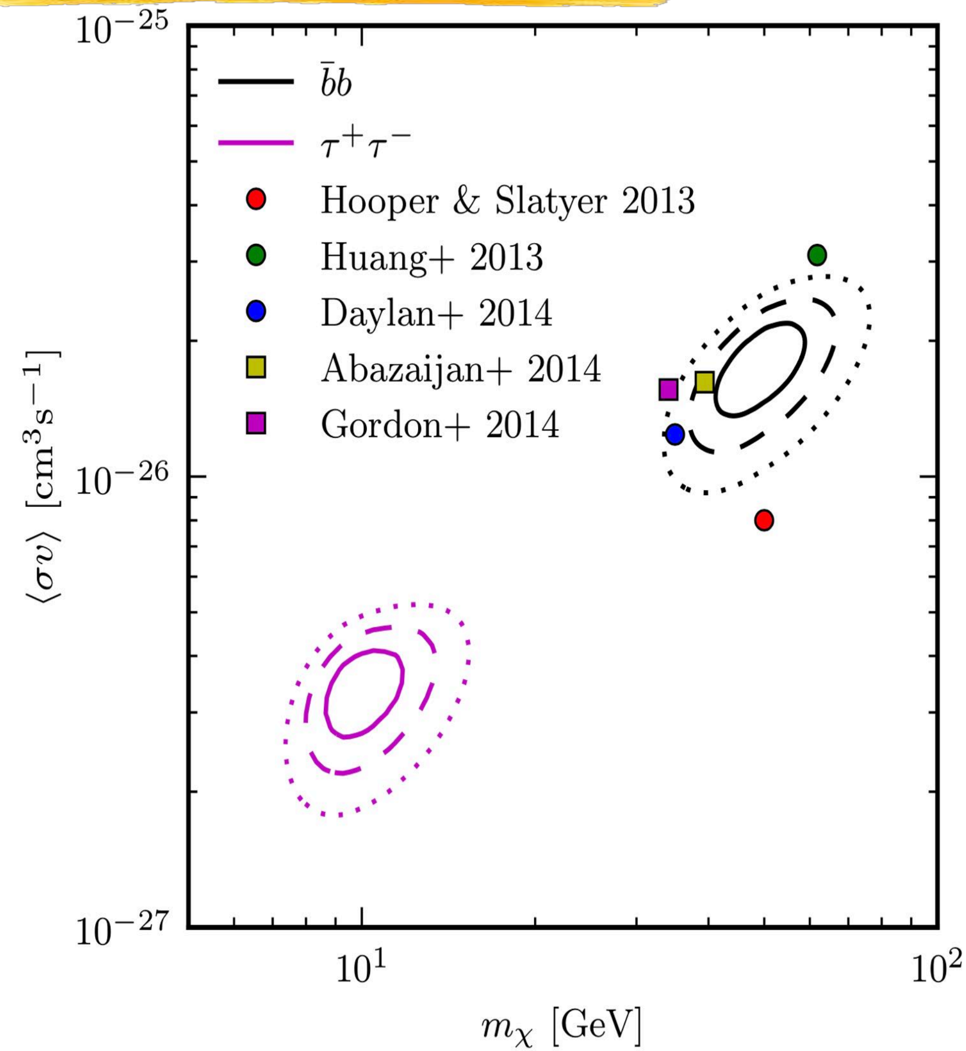
....

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





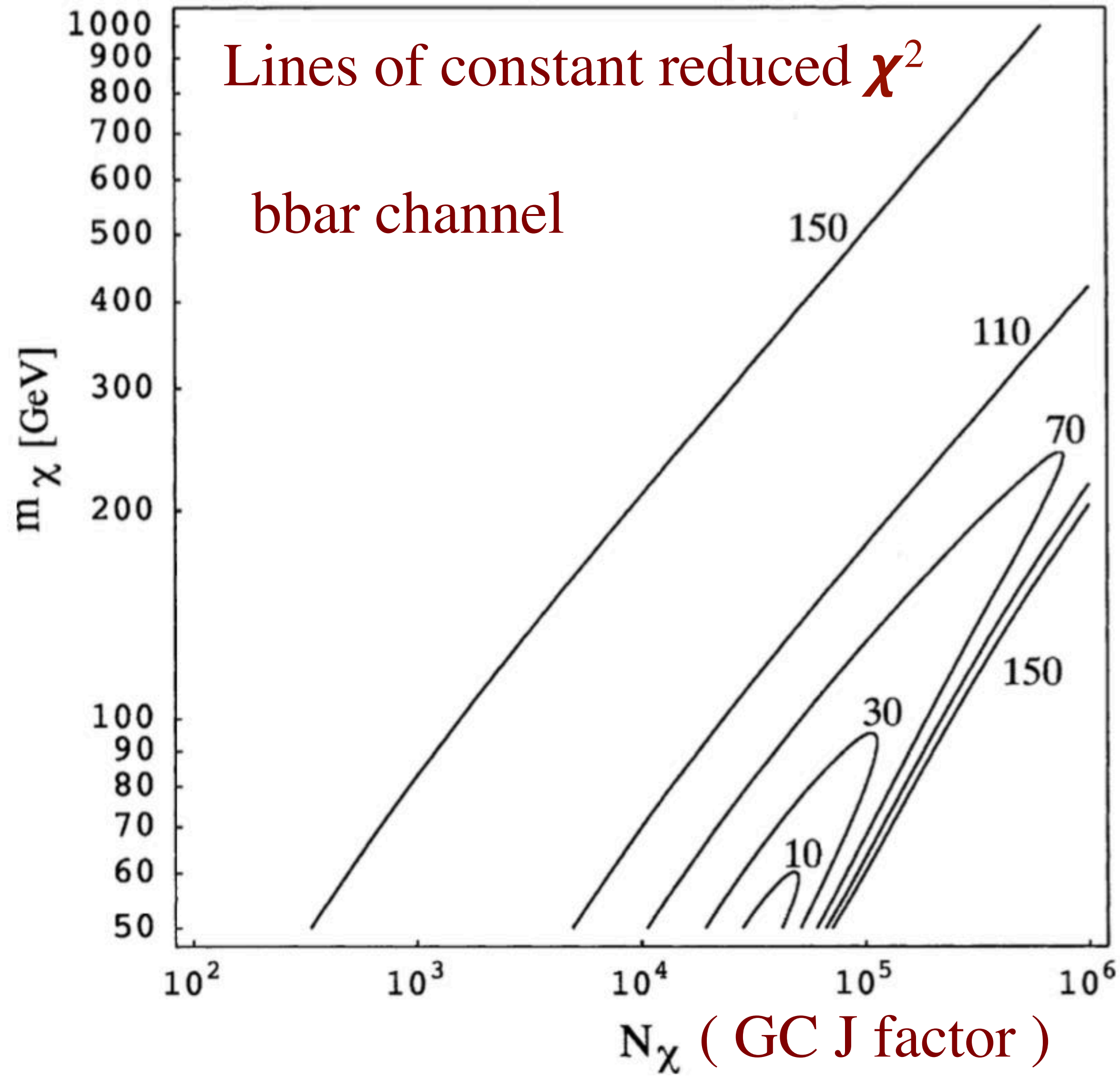
A lot of activity outside the Fermi collaboration with claims of evidence for dark matter in the Galactic Center

i.e. Calore et al, arXiv:1409.0042v1

Lines of constant reduced χ^2 corresponding to best fits of the EGRET GC excess

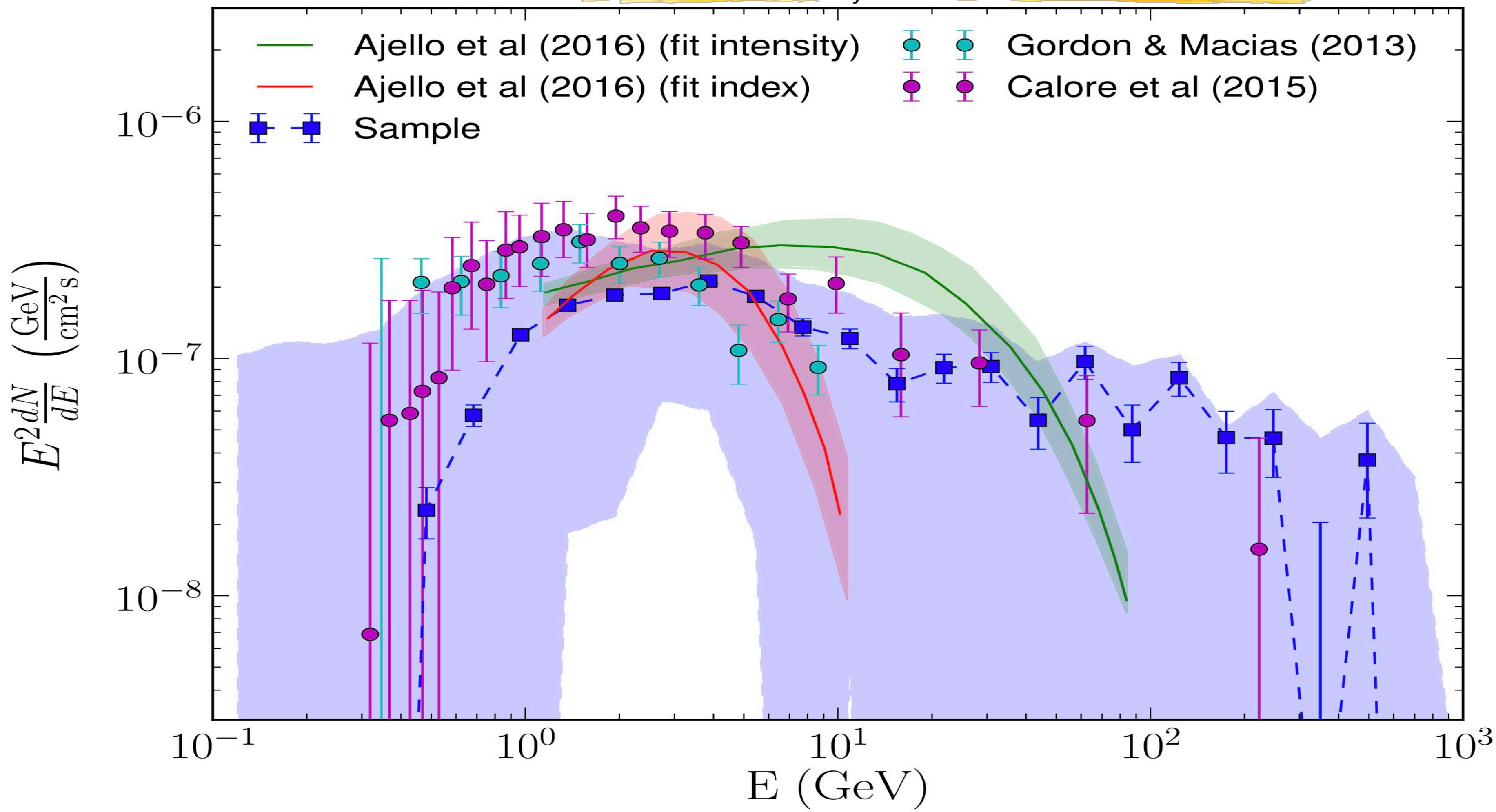
Very similar to the mass range found with the EGRET data in 2004 !

mass ~ 50- 80 GeV



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

The GeV excess (Pass8 analysis)



following uncertainties have relatively small effect on the excess spectrum

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

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

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

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

The GeV excess : Other explanations exist

• past activity of the Galactic center

(e.g. Petrovic et al., arXiv:1405.7928, Carlson & Profumo arXiv:1405.7685)

• Series of Leptonic Cosmic-Ray Outbursts

Cholis et al. arXiv:1506.05119

• Stellar population of the X-bulge and the nuclear bulge

Macias et al. arXiv:1611.06644

• Molecular Clouds in the disk

De Boer et al. arXiv:1610.08926, arXiv:1707.08653 **(see Wim De Boer's talk)**

• 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

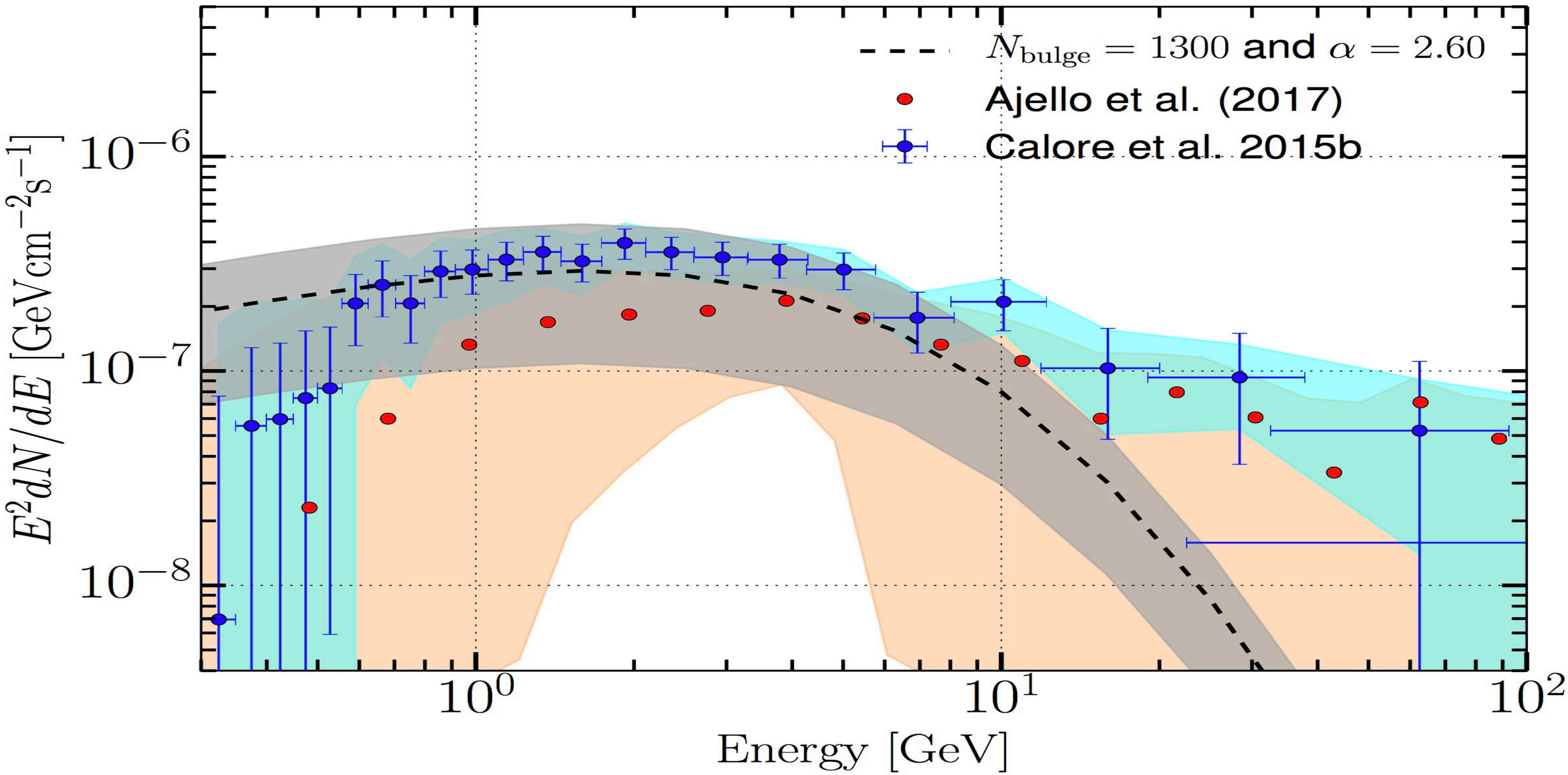
M.Ajello et al. [Fermi-LAT Coll.] Phys. Rev. D 95, 082007 (2017) [arXiv:1704.07195]

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

....

How to discriminate between different hypothesis ?

Population of pulsars in the Galactic bulge and the GeV excess



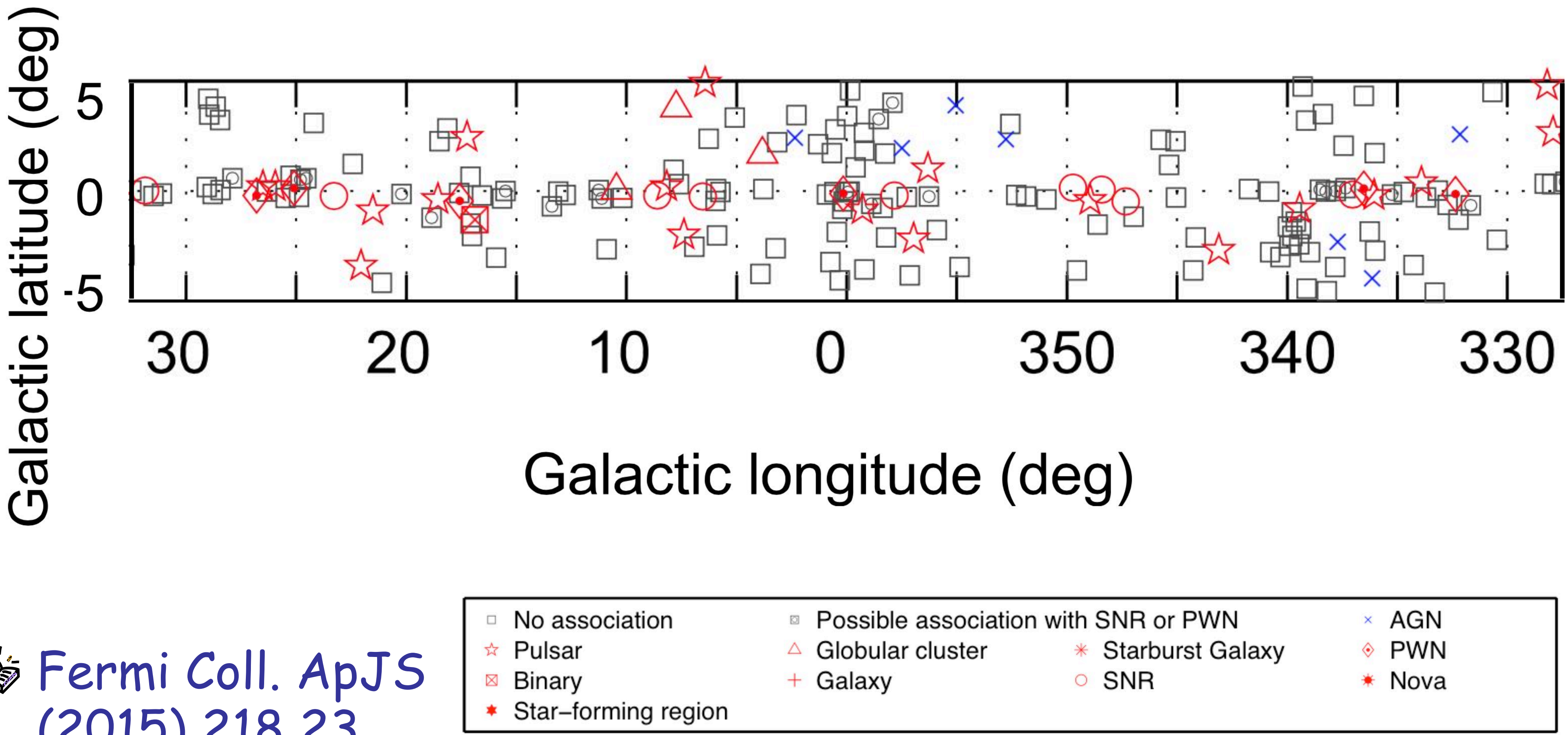
the Galactic bulge must include 800-3600 pulsars (most of them unresolved) in order to explain the GC excess

M.Ajello et al. [Fermi-LAT Coll.] Apj sub. [arXiv:1705.00009v2]

The Fermi LAT 3FGL Inner Galactic Region

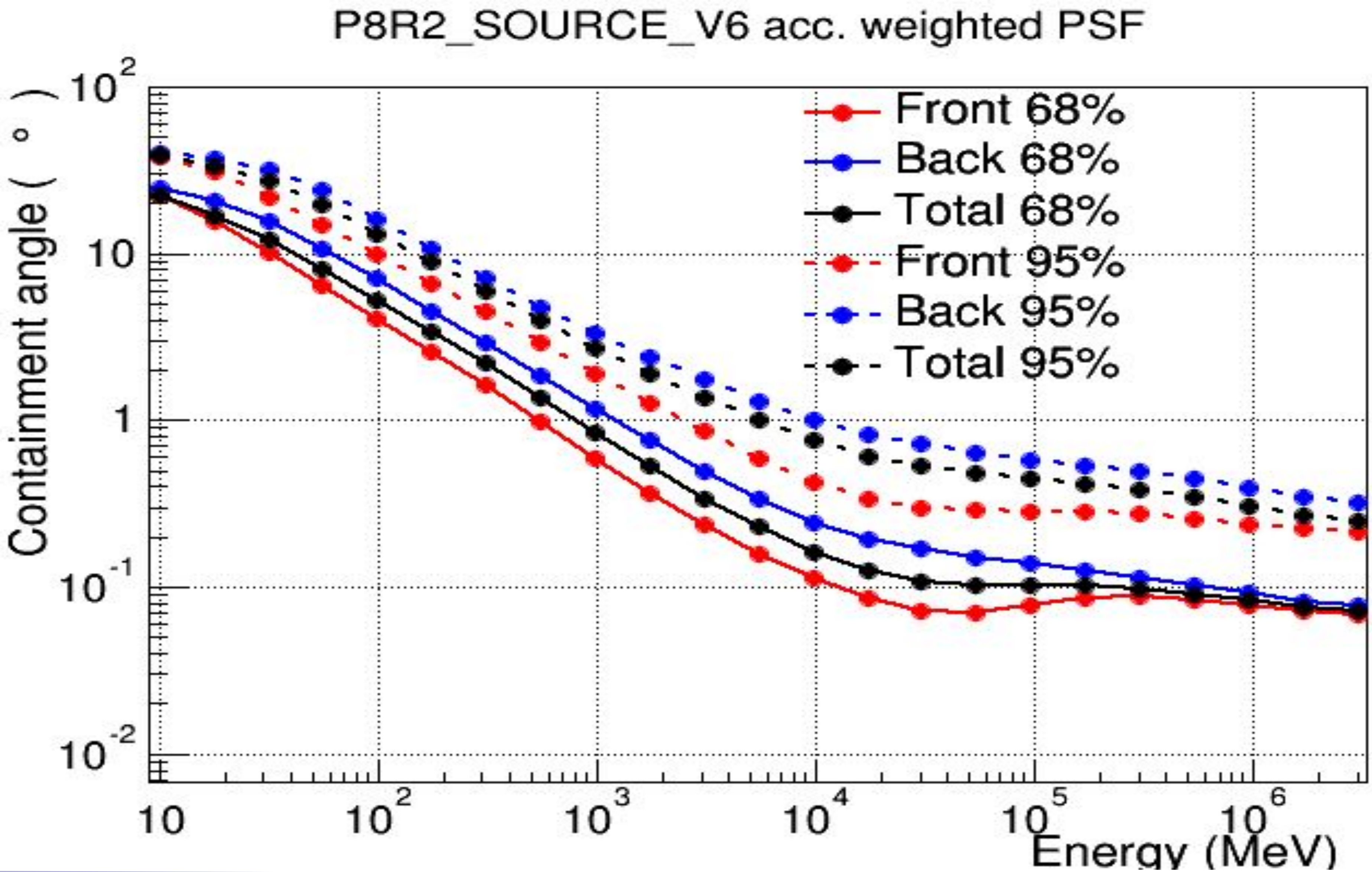
August 4, 2008, to July 31, 2010

100 MeV to 300 GeV energy range



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

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



How to discriminate between different hypothesis ?

eROSITA

Modeling of the Fermi bubbles
Look for correlated features near the Galactic center

HESS, MAGIC, CTA

Fermi bubbles near the GC are much brighter
Possible to see with Cherenkov telescopes?

Radio observations, MeerKAT, SKA

Search for individual pulsars in the halo around the GC

Radio surveys, Planck

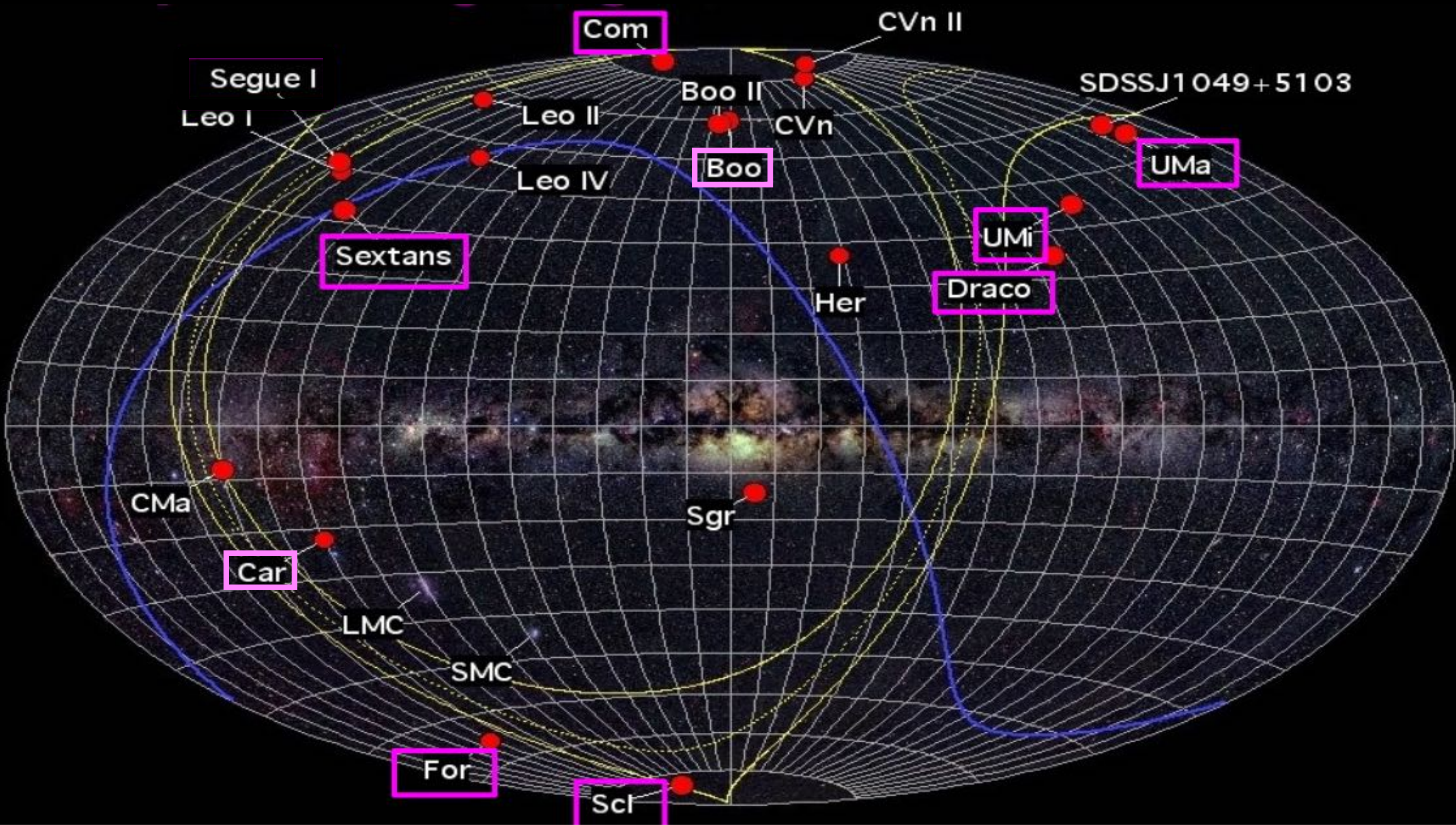
Look for correlated synchrotron emission near the GC

More Fermi LAT analysis

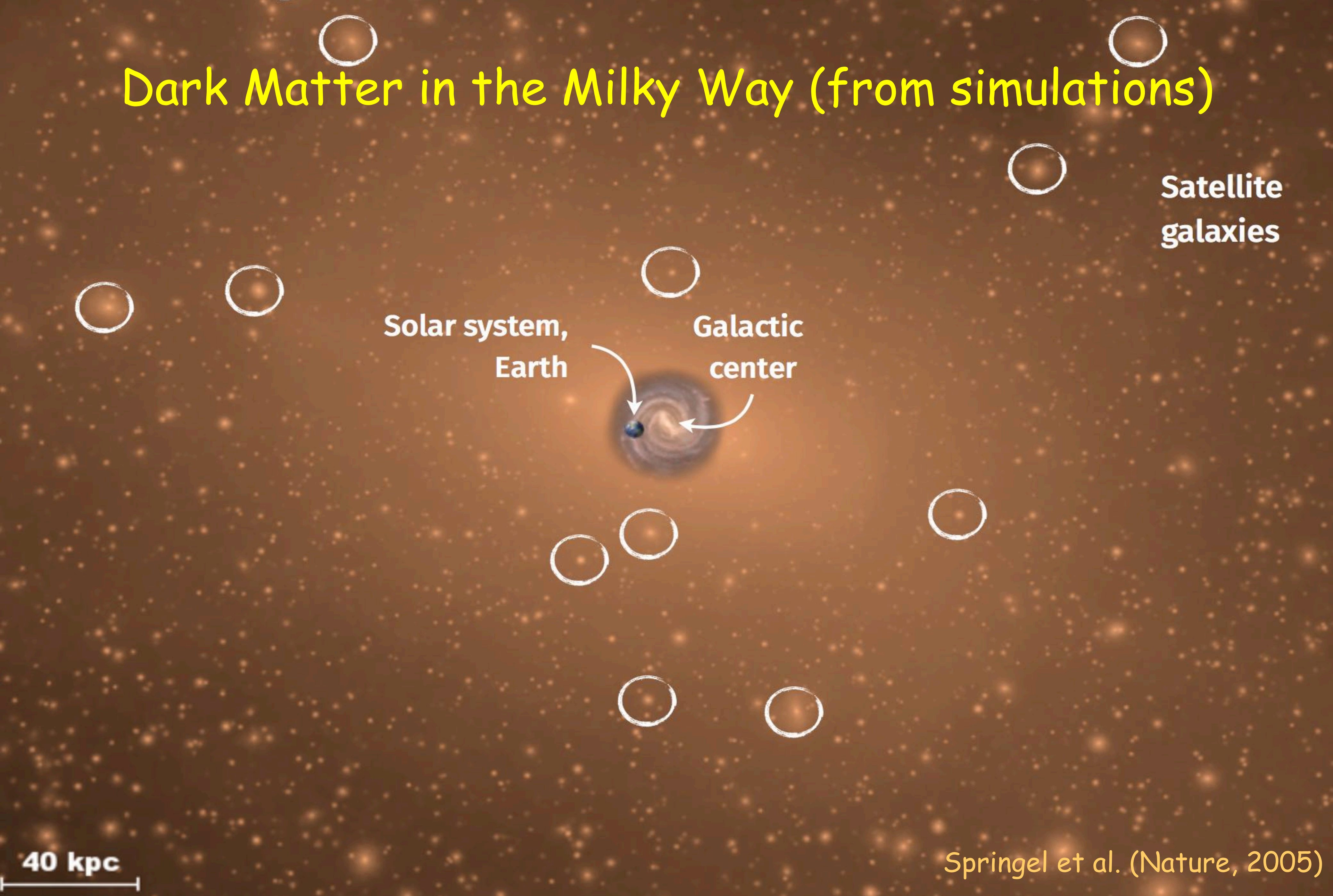
Diffuse emission modeling
Analysis of point sources near the GC

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

Classical Dwarf spheroidal galaxies: promising targets for DM detection

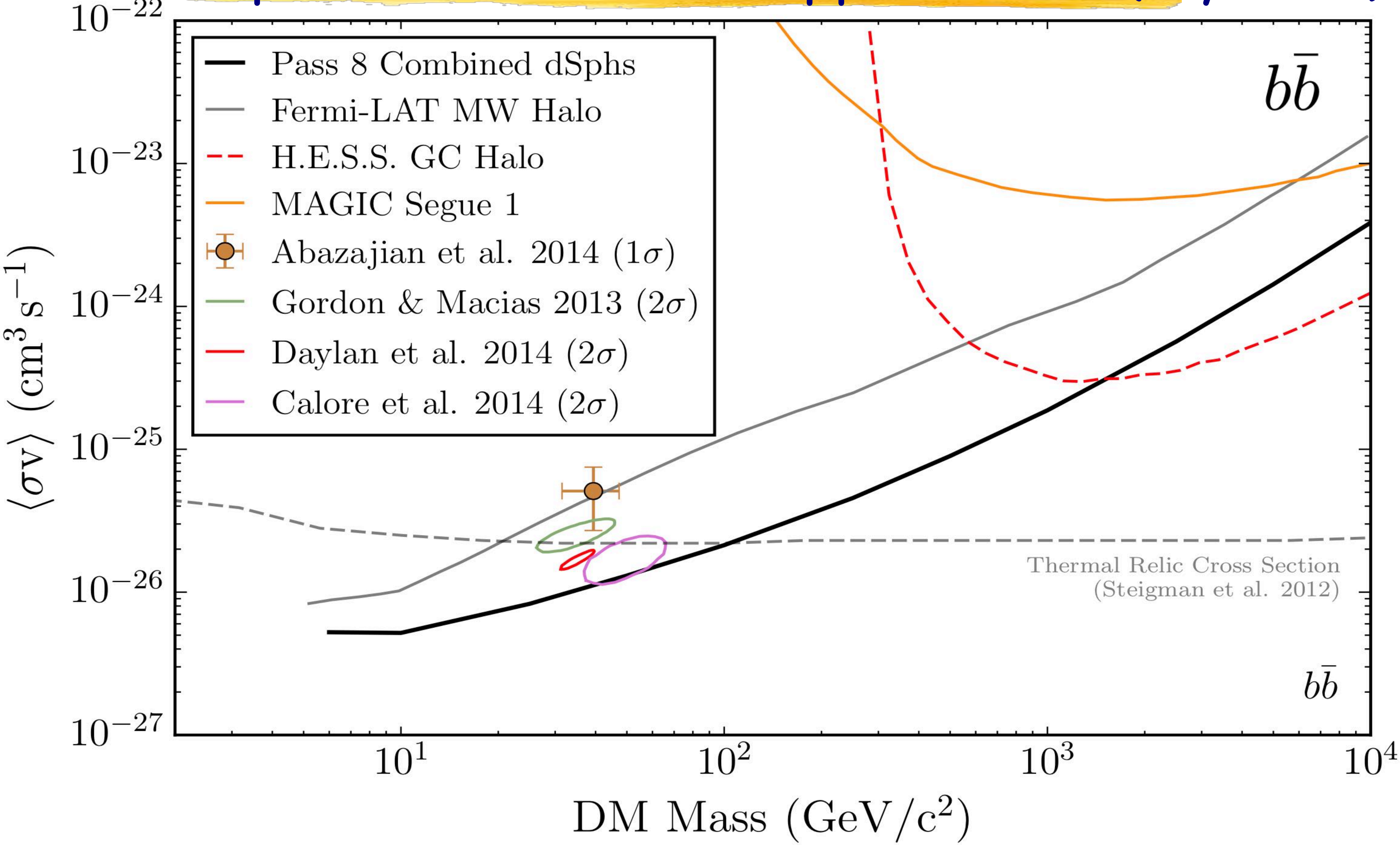


Dark Matter in the Milky Way (from simulations)



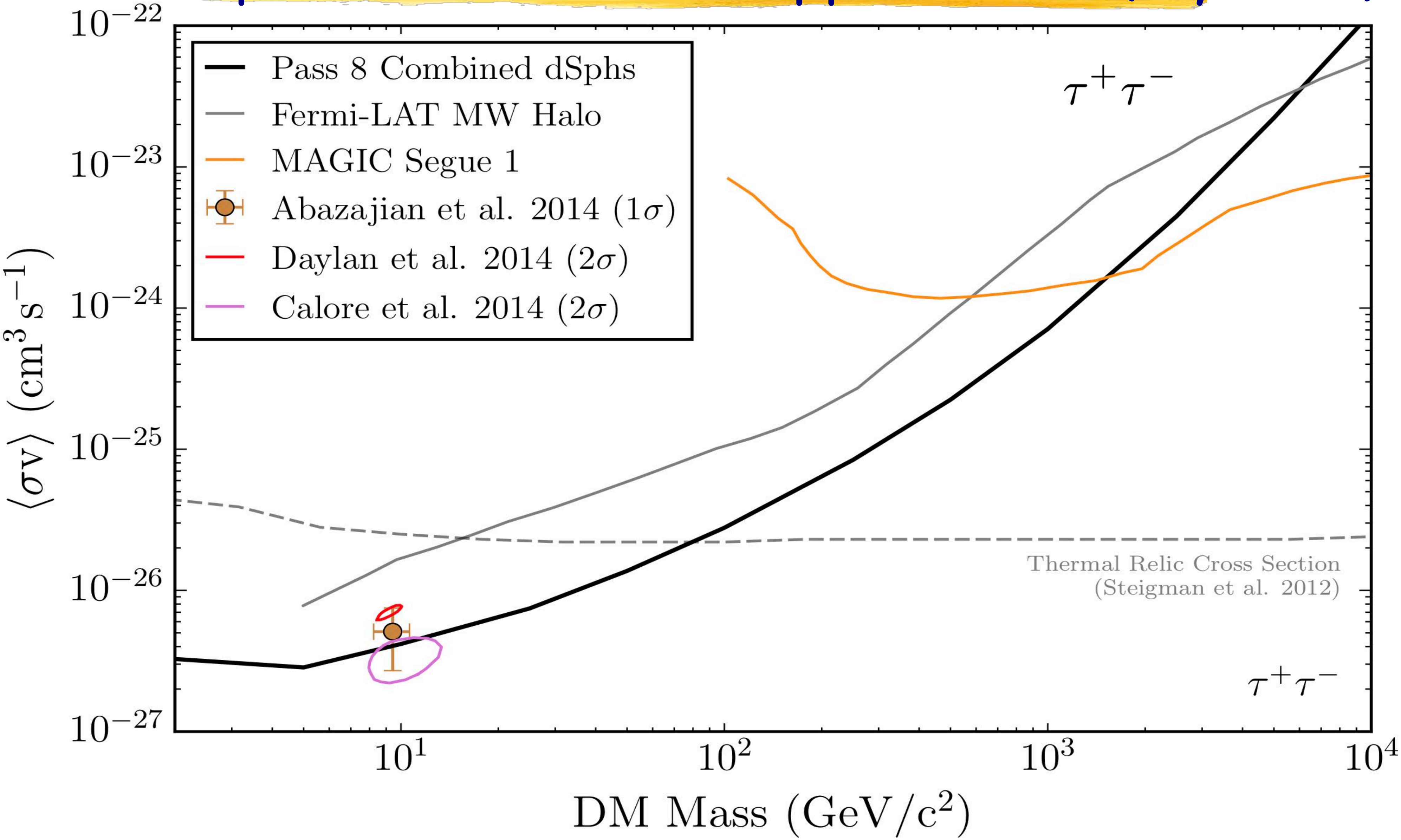
Springel et al. (Nature, 2005)

Dwarf Spheroidal Galaxies upper-limits (6 years)



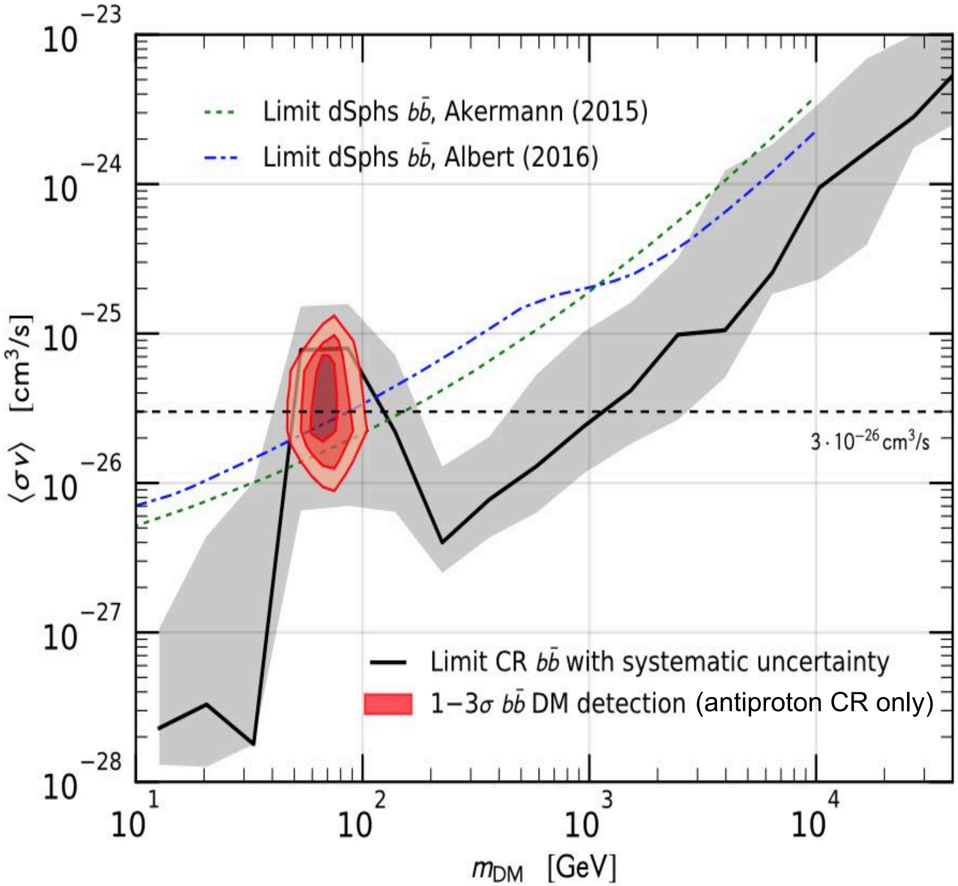
M.Ackermann et al., [Fermi Coll.] PRL 115, 231301 (2015) [arXiv:1503.02641]

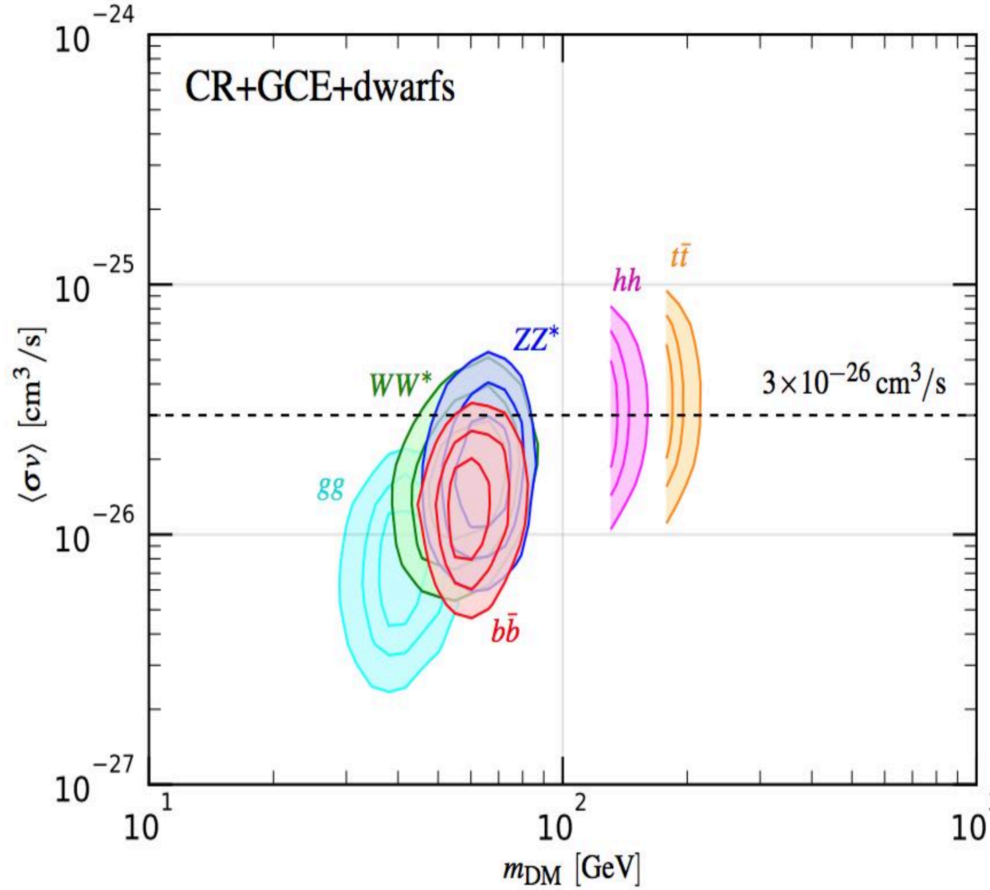
Dwarf Spheroidal Galaxies upper-limits (6 years)



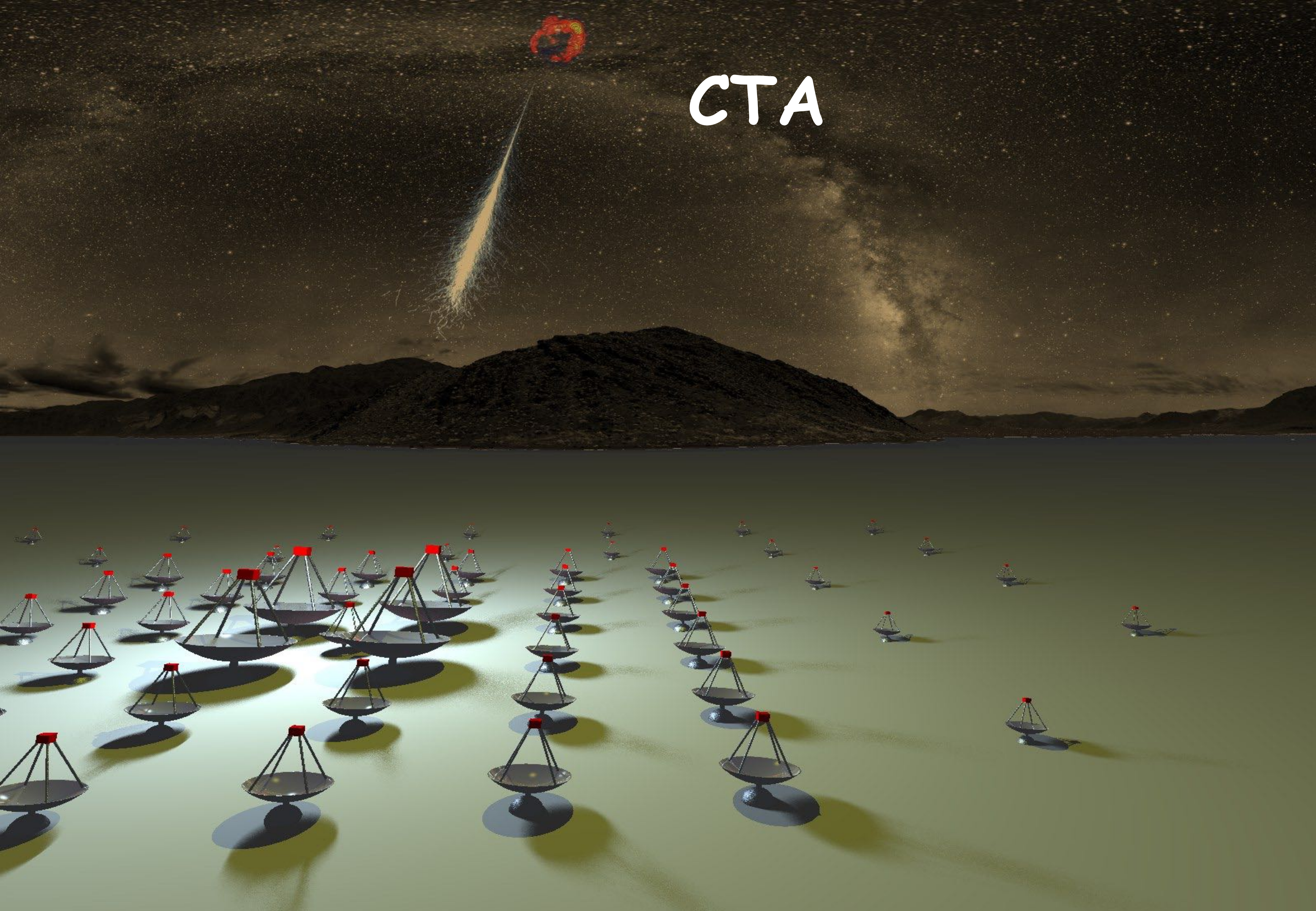
M.Ackermann et al., [Fermi Coll.] PRL 115, 231301 (2015) [arXiv:1503.02641]

AMS Antiprotons, Fermi Galactic Center and Fermi dwarf galaxies combined analysis





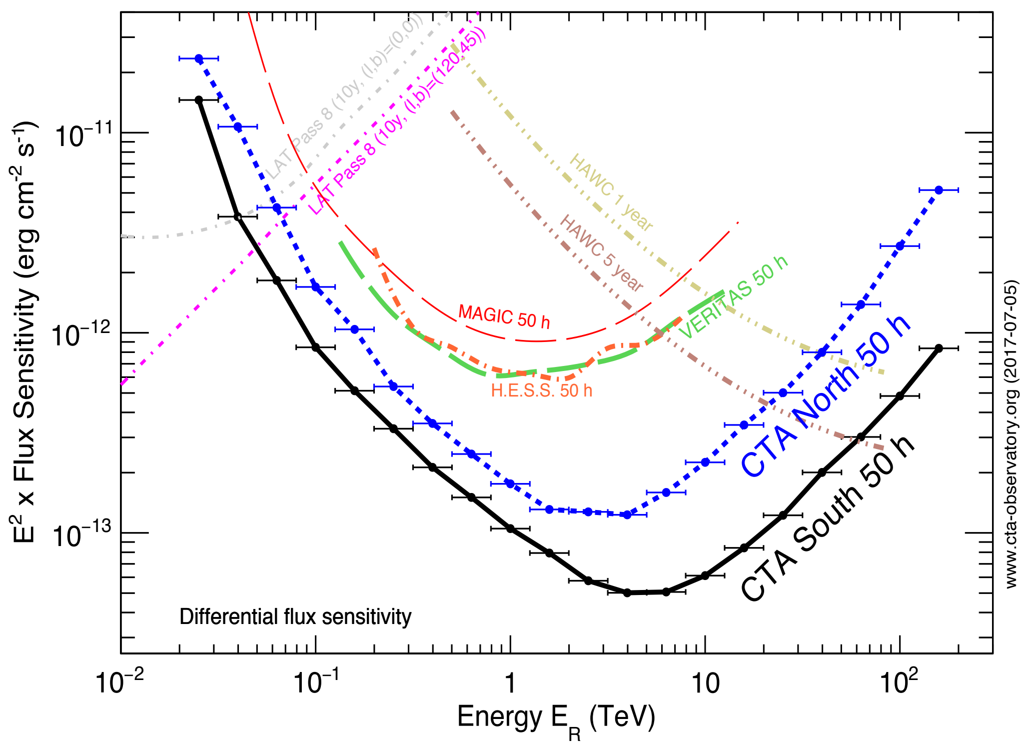
A.Cuoco et al., arXiv:1711.06460

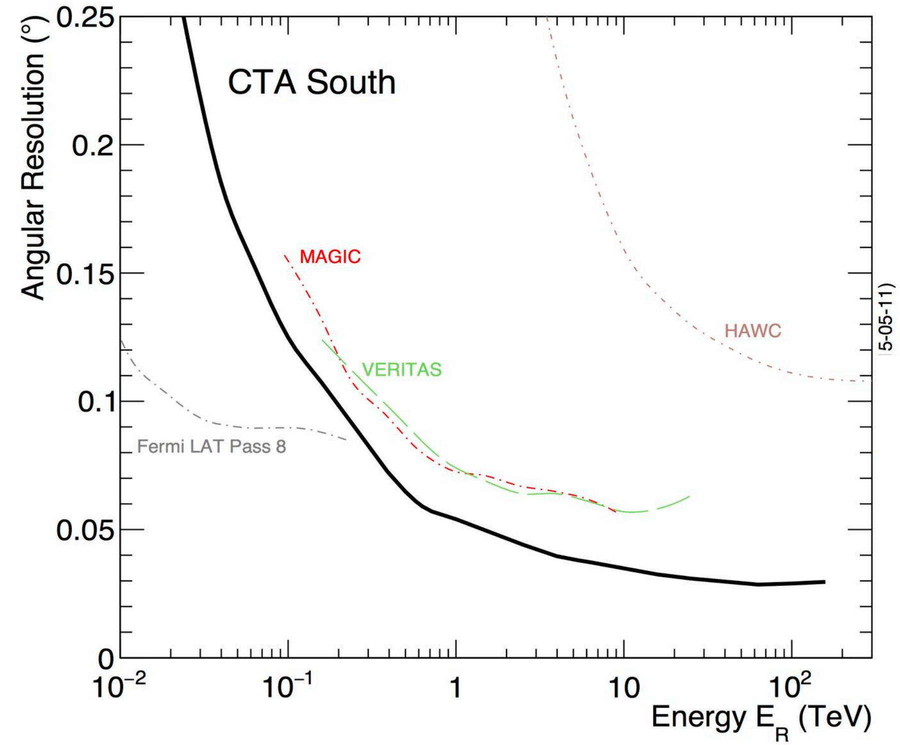

CTA

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





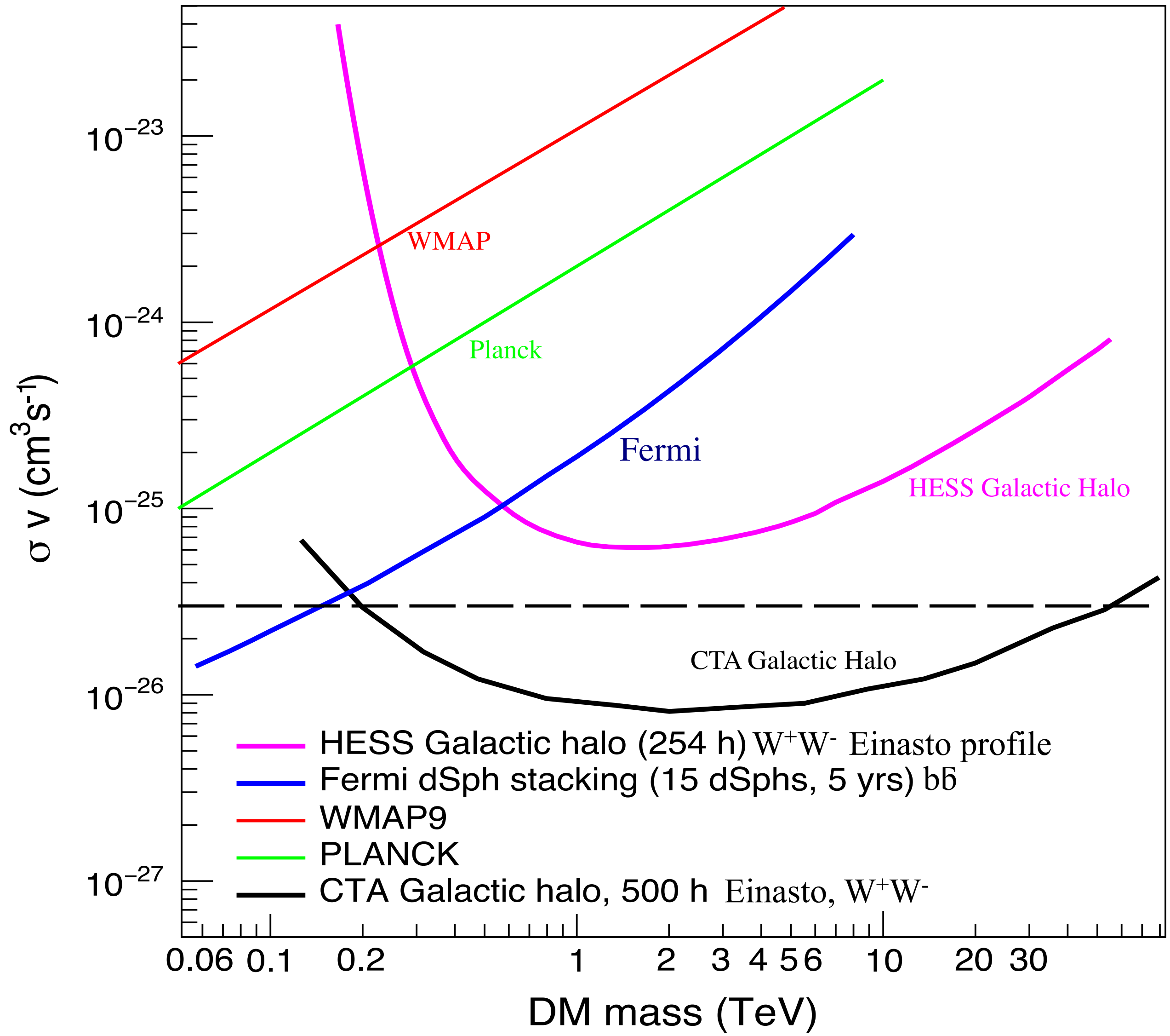
Science with the Cherenkov Telescope Array arXiv:1709.07997 211 pages

CTA, HESS, FERMI, PLANK DM upper-limits

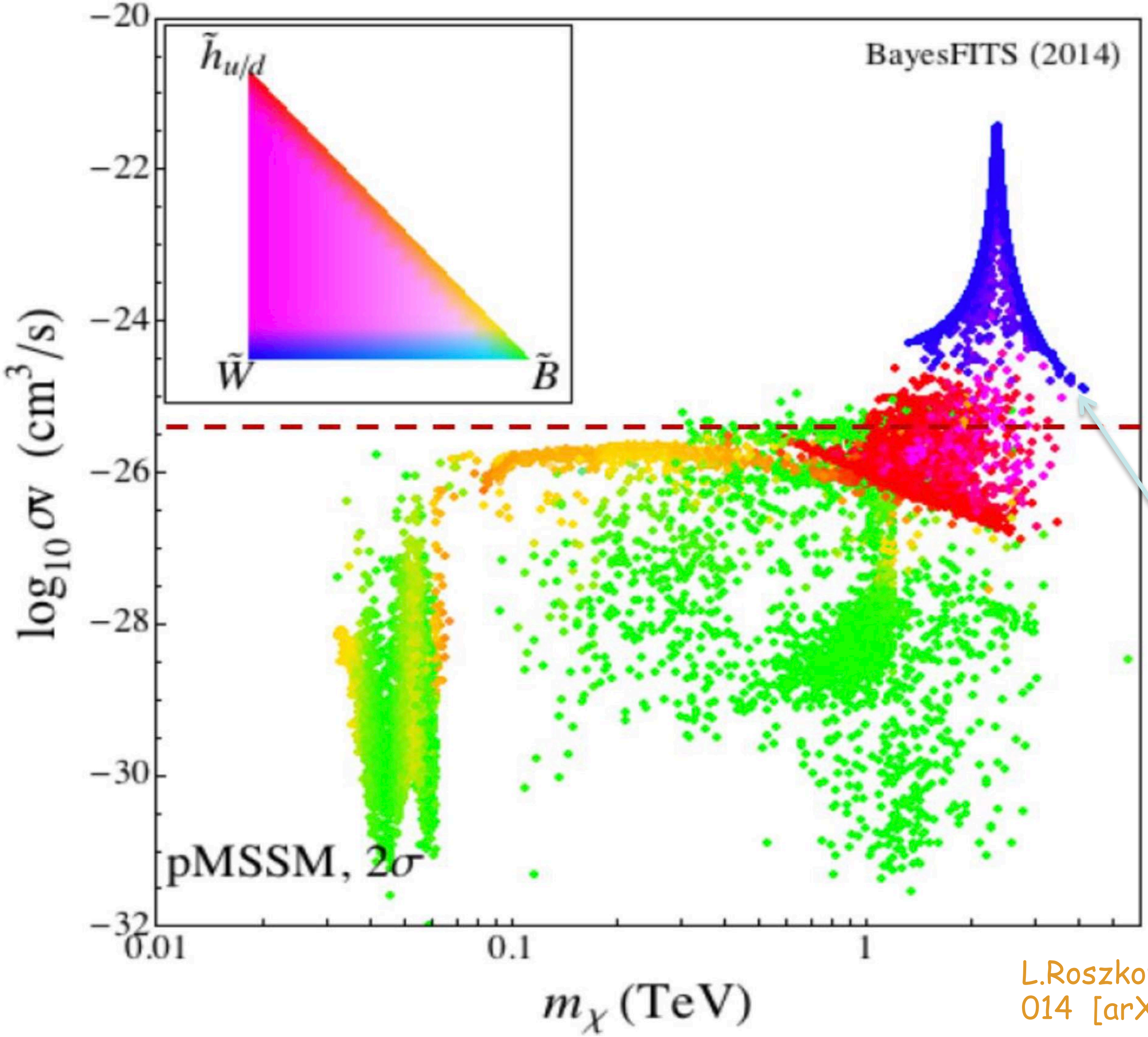
Together Fermi and CTA will probe most of the space of WIMP models with thermal relic annihilation cross section

The expectation for CTA 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%



A.Morselli for the CTA Consortium PoS(ICRC2017)921 [arXiv:1709.01483] note:the “thermal” cross section is only a reference value. The real cross section can be higher or lower

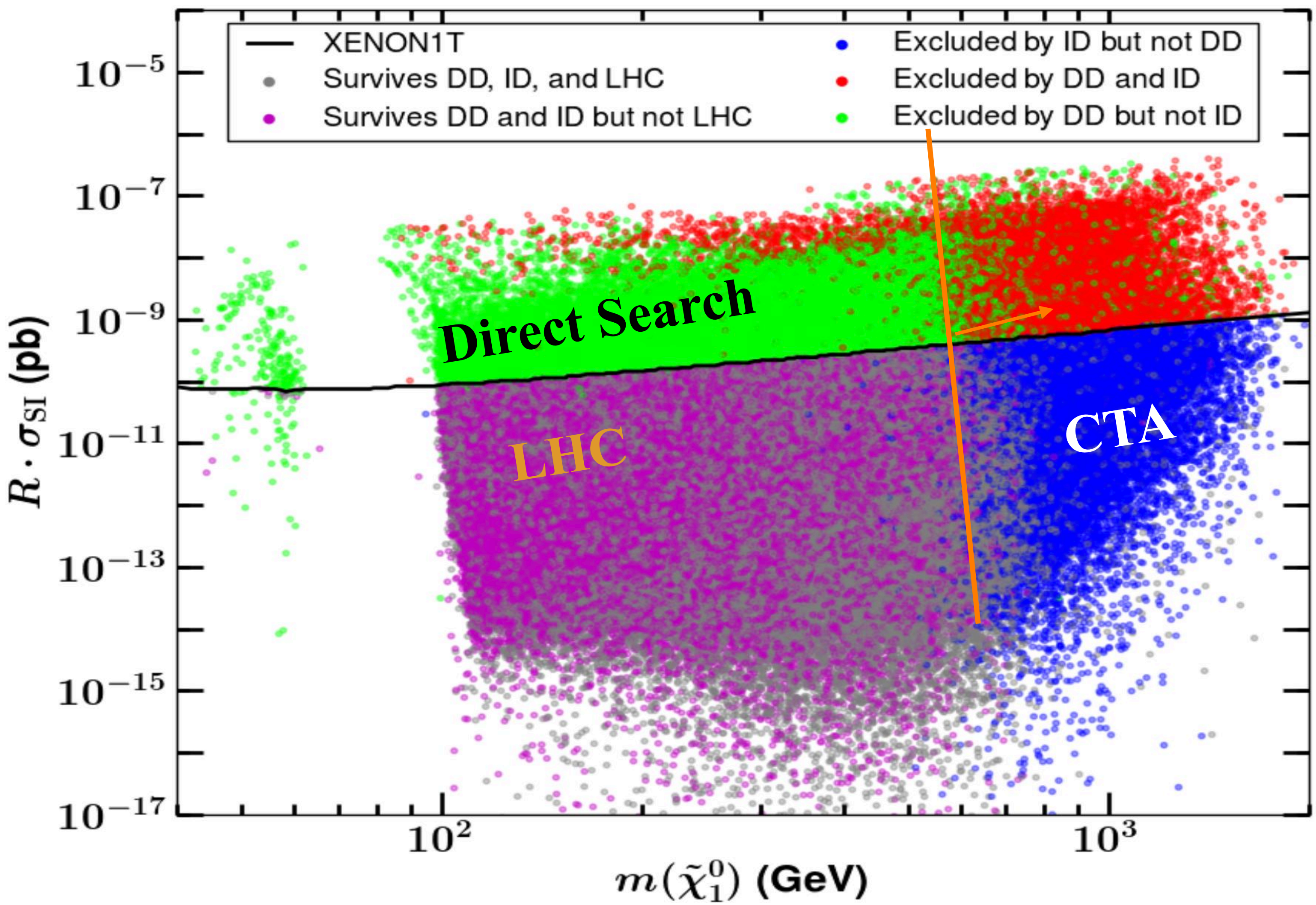


Example: Annihilation cross-section points from a 19 dimensional pMSSM fit

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

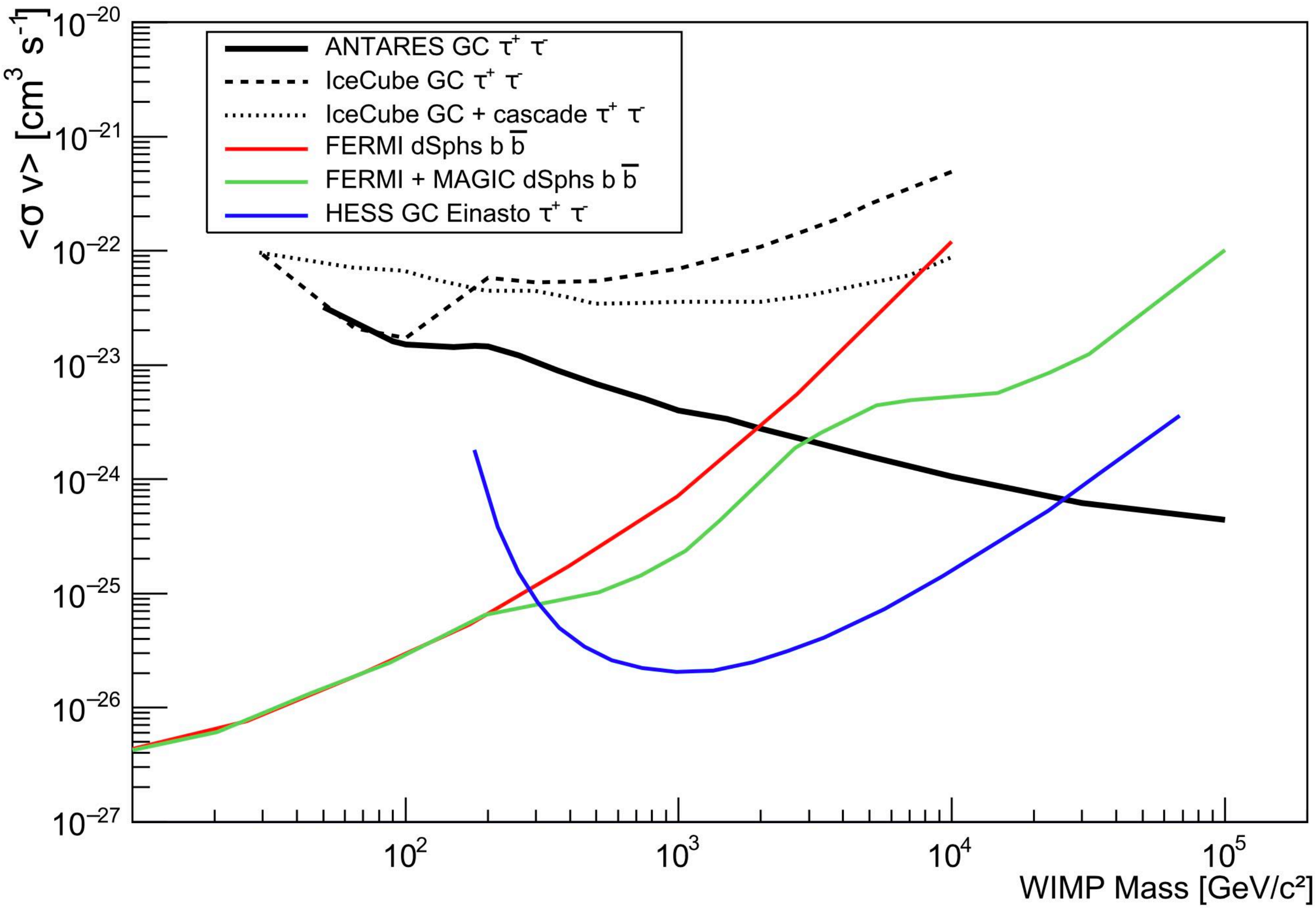
L.Roszkowski et al., JHEP 1502 (2015) 014 [arXiv:1411.5214]

Complementarity and Searches for Dark Matter in the pMSSM



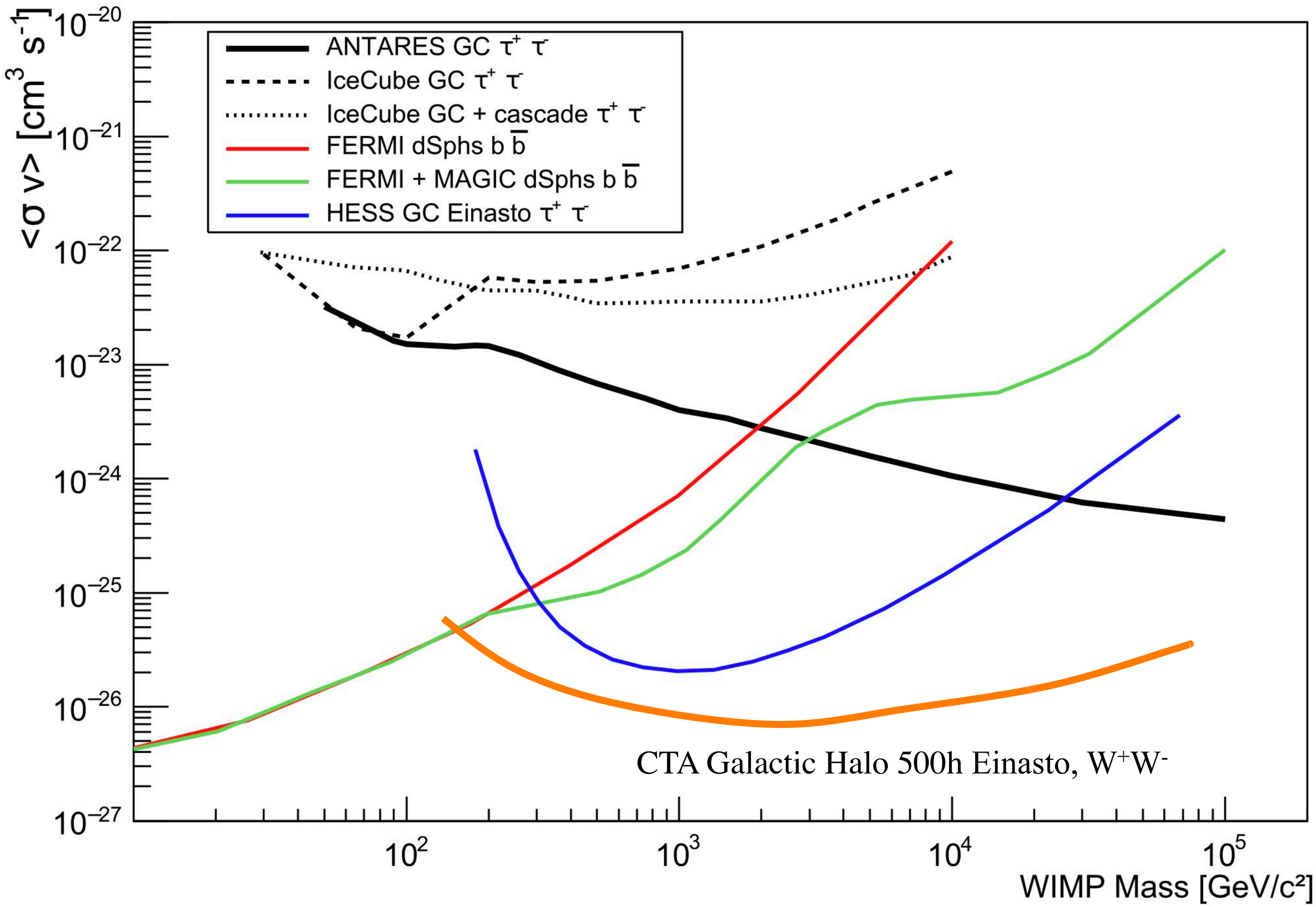
Cahill-Rowley et al. arXiv:1305.6921

HESS, FERMI, Ice Cube, ANTARES Dark Matter upper-limits

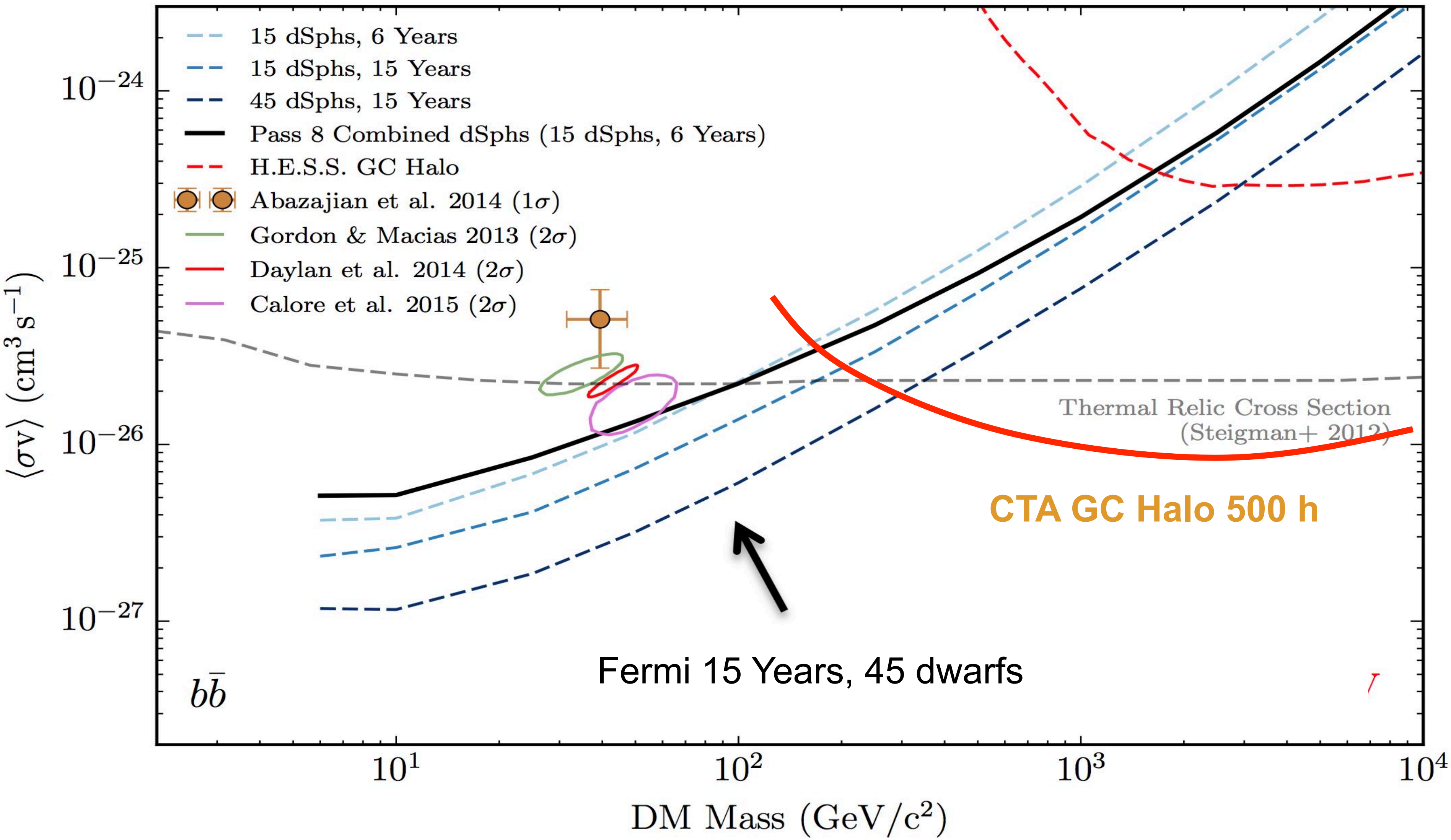


A. Albert, et al. ANTARES Coll. Physics Letters B 769 (2017) 249–254

HESS, FERMI, Ice Cube, ANTARES Dark Matter upper-limits



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 Consortium Meeting, La Palma Nov.2017

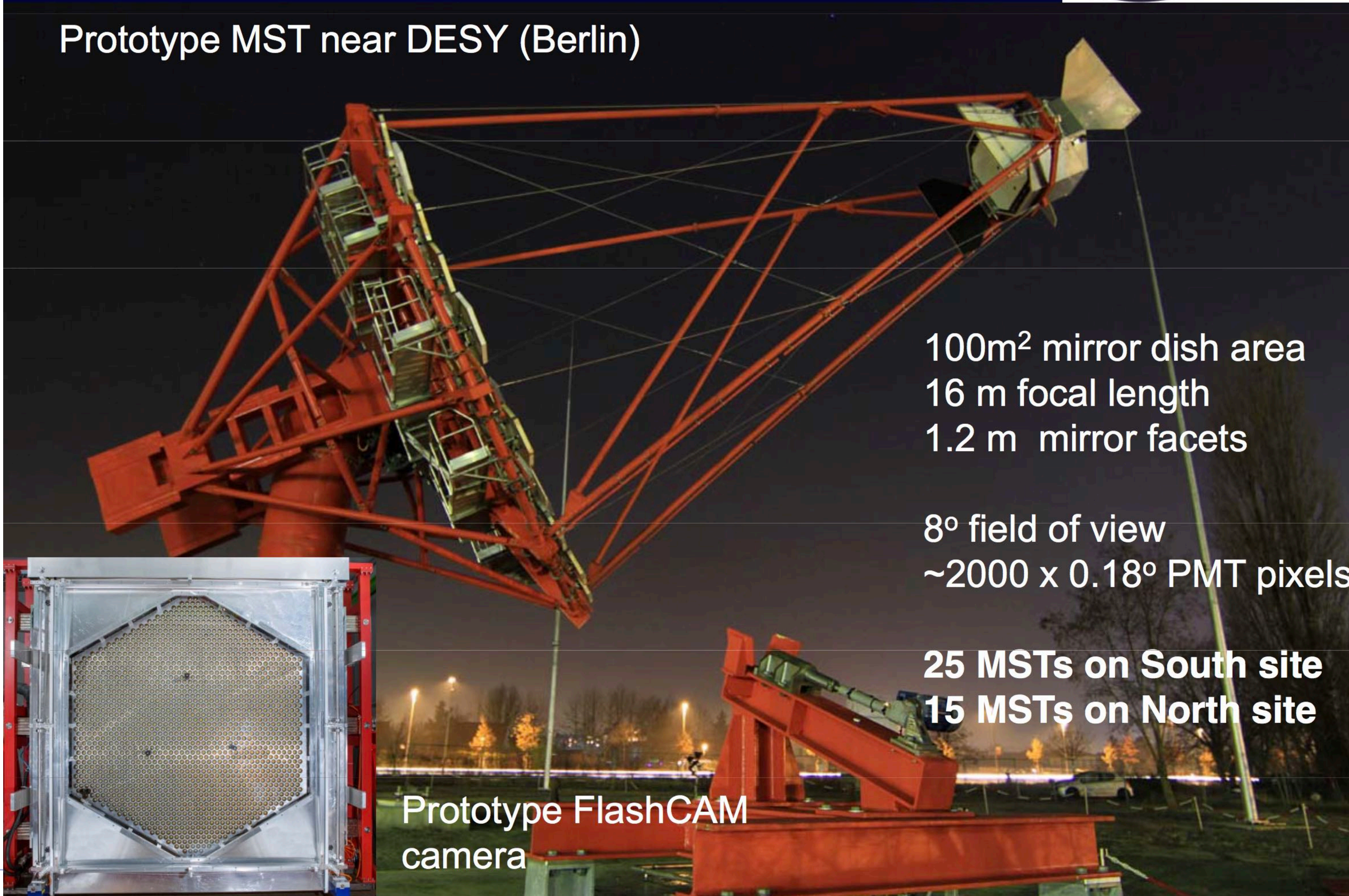

CTA 1st LST contruction

We are building CTA-LSTs in North

- CTA LST-1 will have the first light in the early summer 2018
- LST2-4 will be constructed in FY2018-FY2019.
- We start the engineering run with LST1 in 2018 and the early operation with the array of LST1-4 in 2019/2020 in La Palma, Spain
- The construction of LST5-8 is planned in 2020-2024 at Paranal, Chile

Medium Telescope (MST)

Prototype MST near DESY (Berlin)



100m^2 mirror dish area
16 m focal length
1.2 m mirror facets

8^o field of view
~2000 x 0.18^o PMT pixels

25 MSTs on South site
15 MSTs on North site

Prototype FlashCAM camera

Medium 2-mirror Telescope

cherenkov telescope array

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 (SSTs)

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

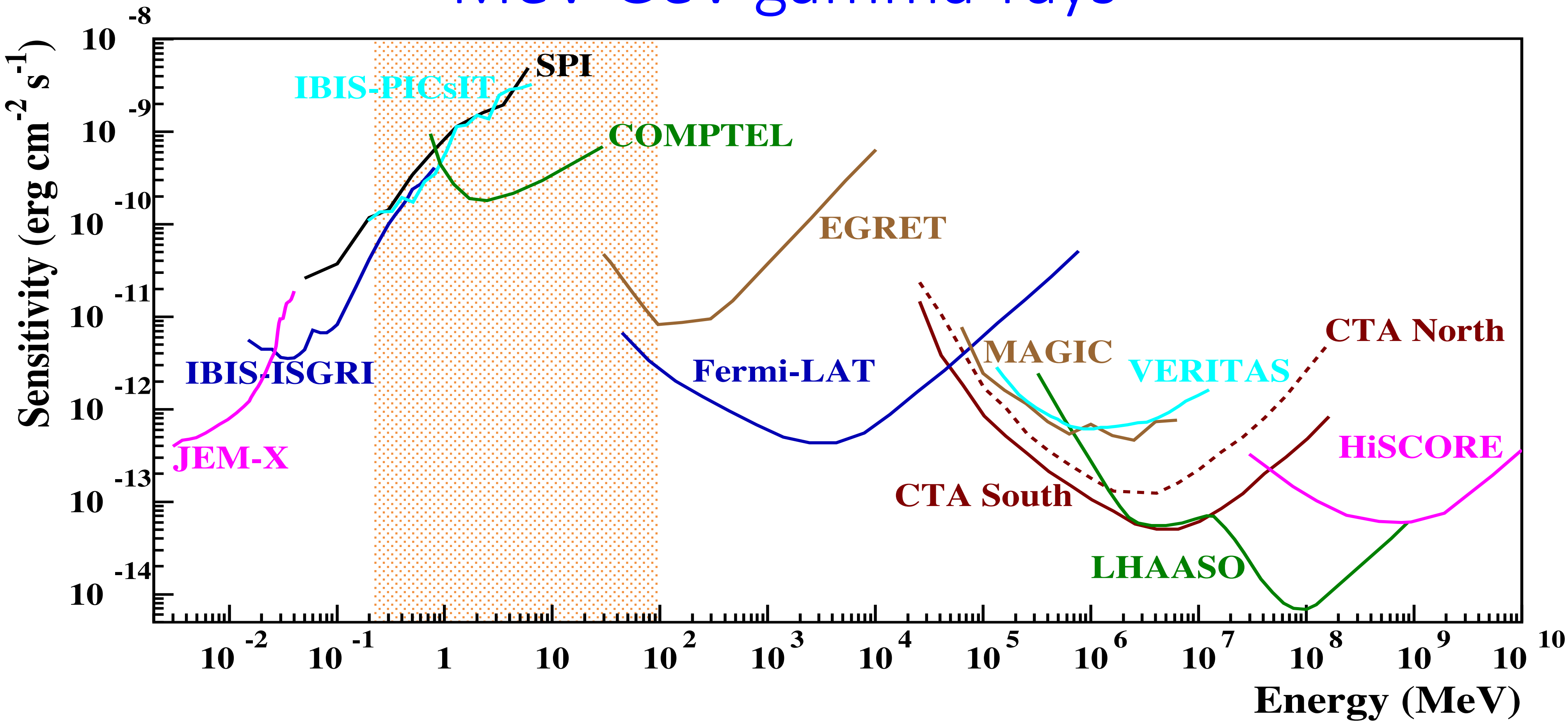
SST-1M
Krakow, Poland

SST-2M ASTRI
Mt. Etna, Italy

SST-2M GCT
Meudon, France

The Low Energy Frontier

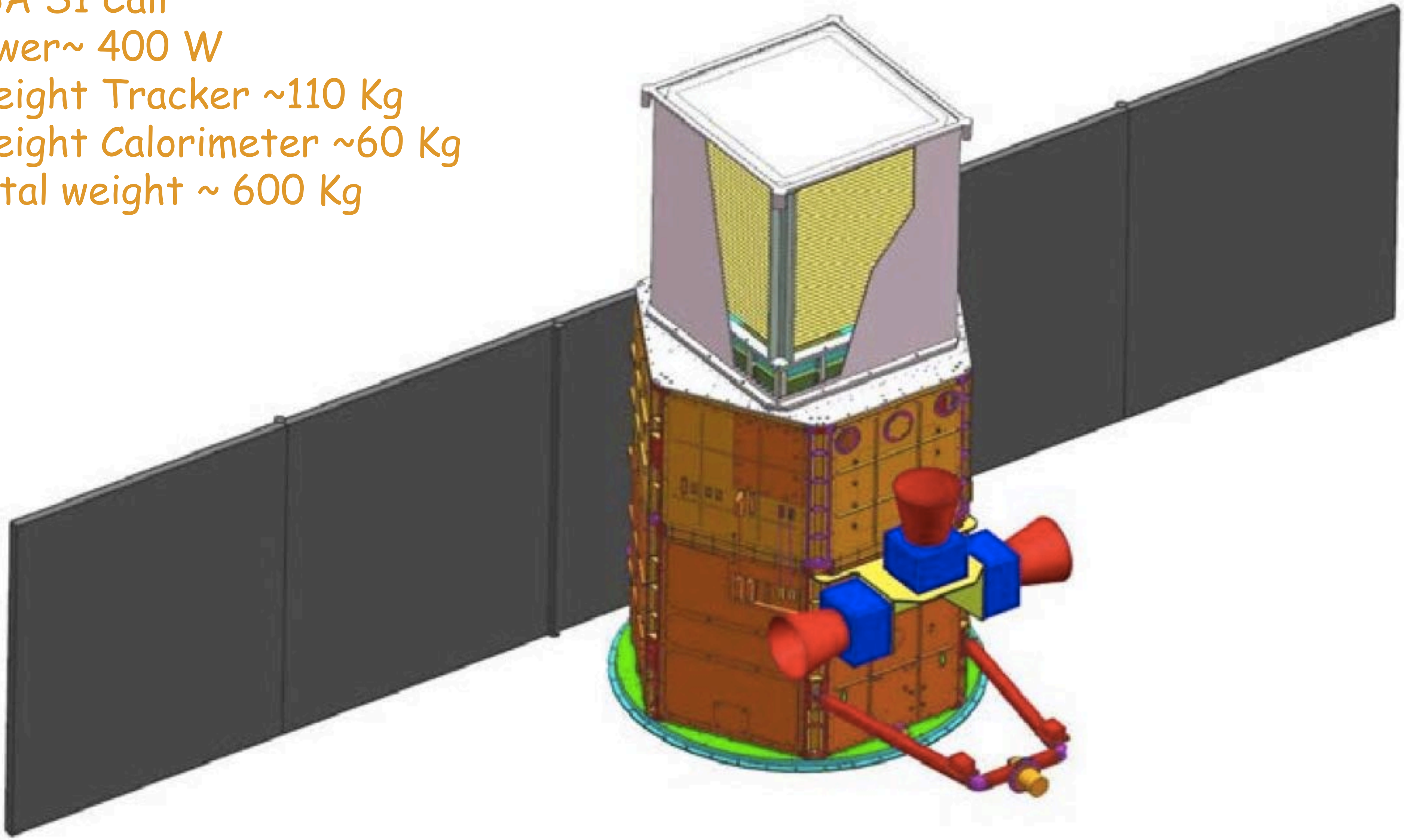
MeV-GeV gamma-rays



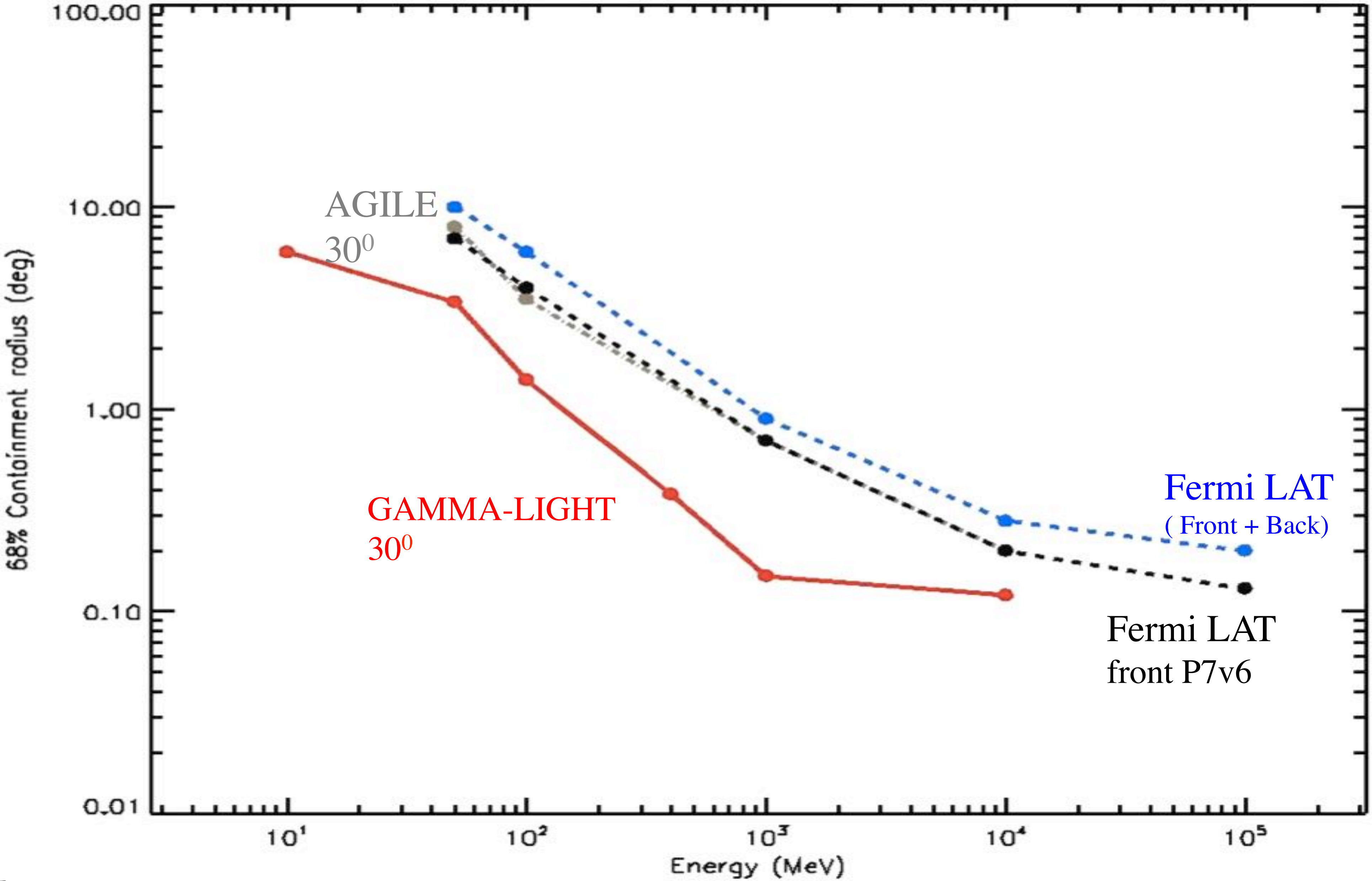
- Worst covered part of the electromagnetic spectrum in 0.1-100 MeV
- Many objects have their peak emissivity in this range (GRBs, blazars, pulsars...)
- The MeV range is the domain of nuclear gamma-ray lines (supernovae, nucleosynthesis and Galactic chemical evolution)

Gamma-light project

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

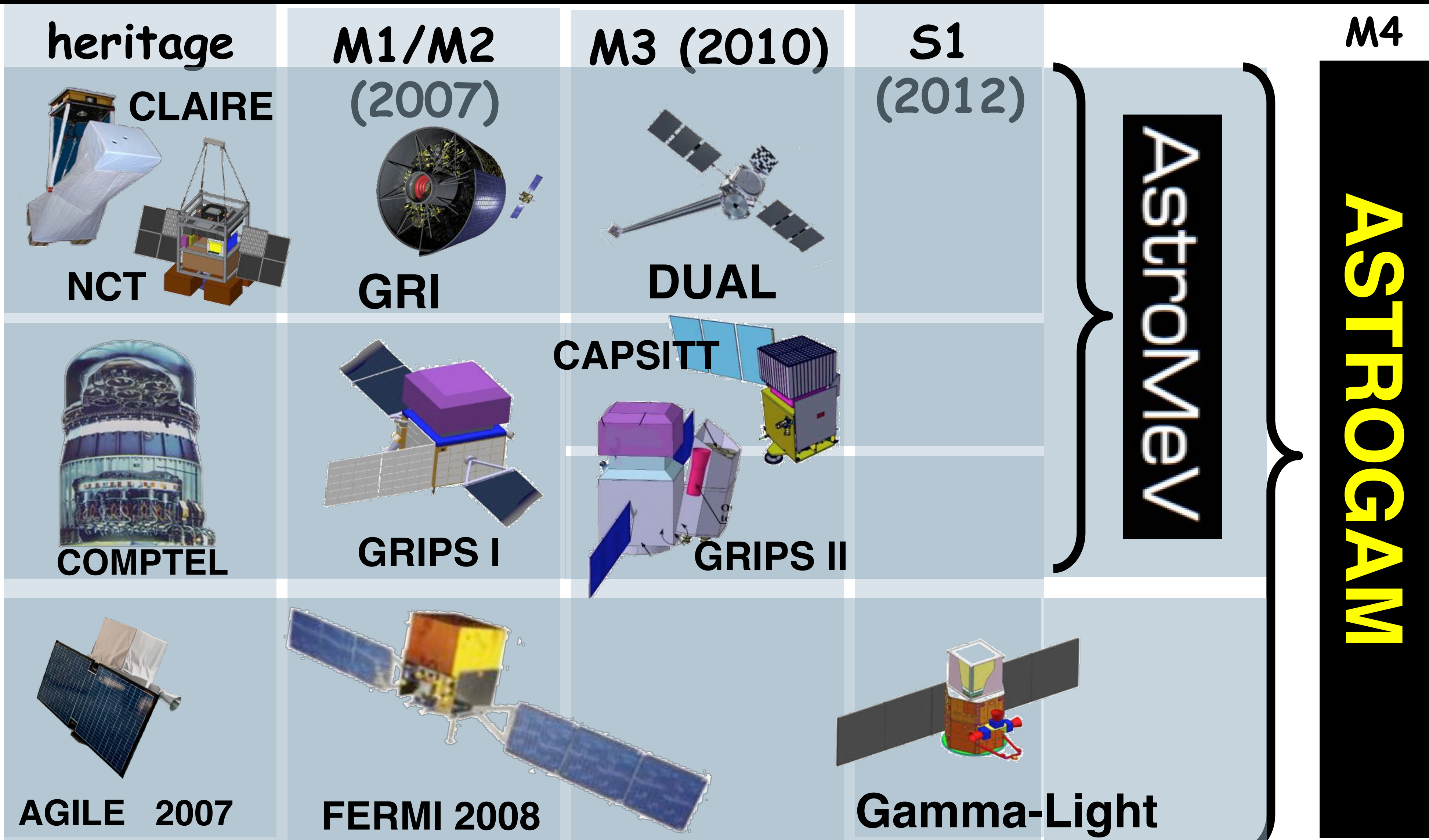


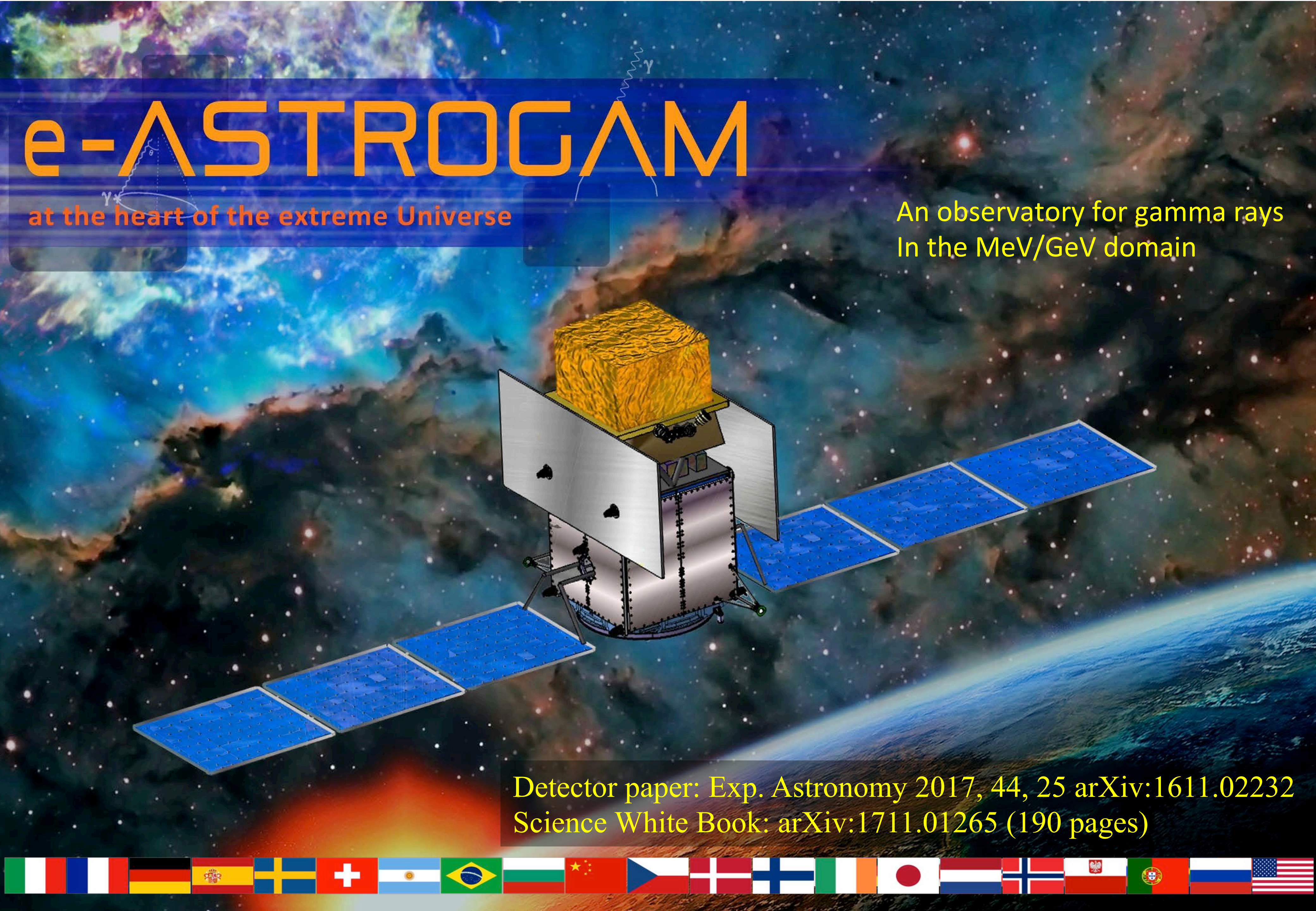
Gamma-Light Point Spread Function (angular resolution)



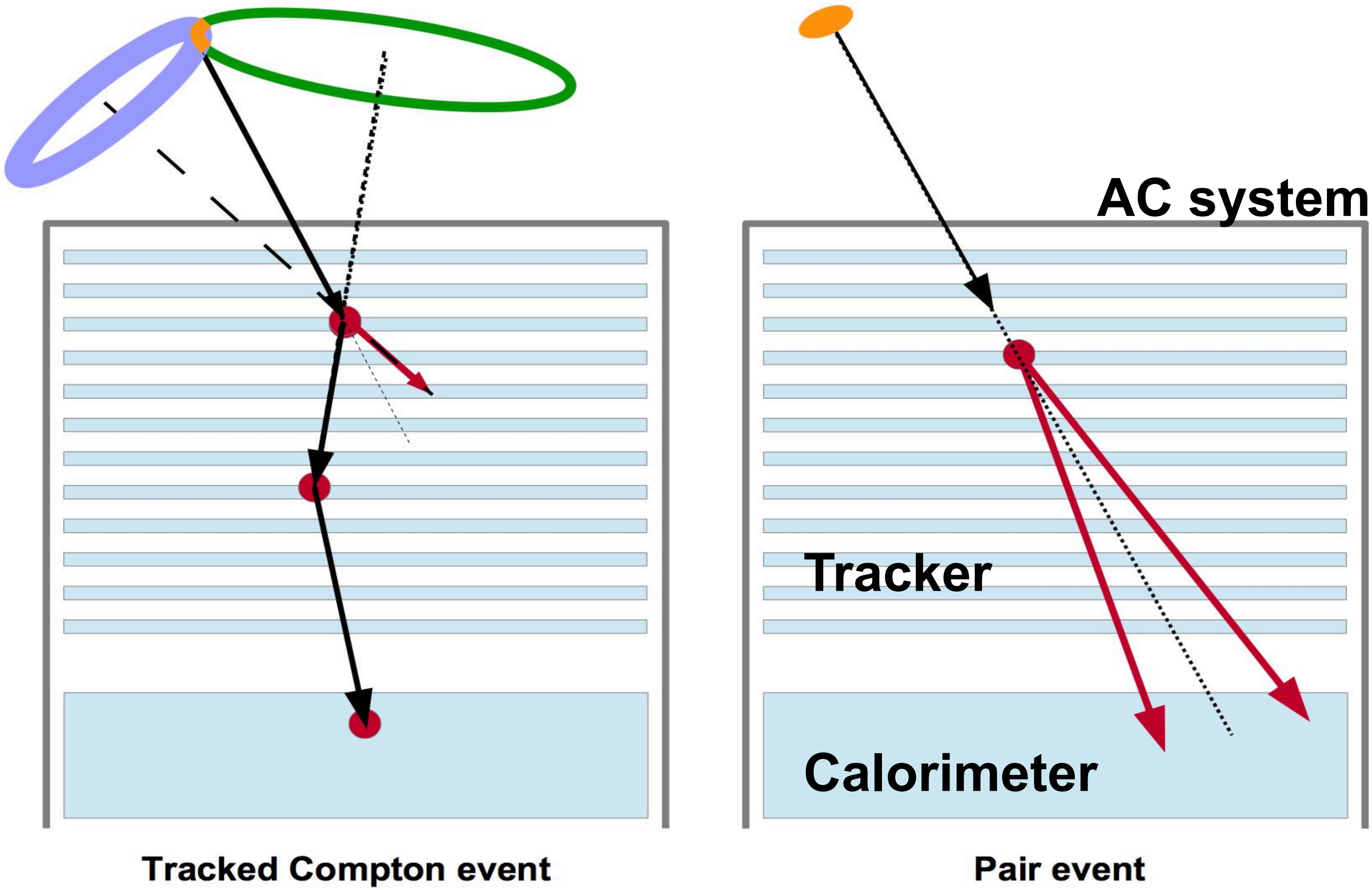
A.Morselli et al. , Nuclear Physics B Proc. Supp. 239–240 (2013) 193-198 [arXiv:1406.1071]

ASTROGAM a unified proposal from the entire gamma-ray community

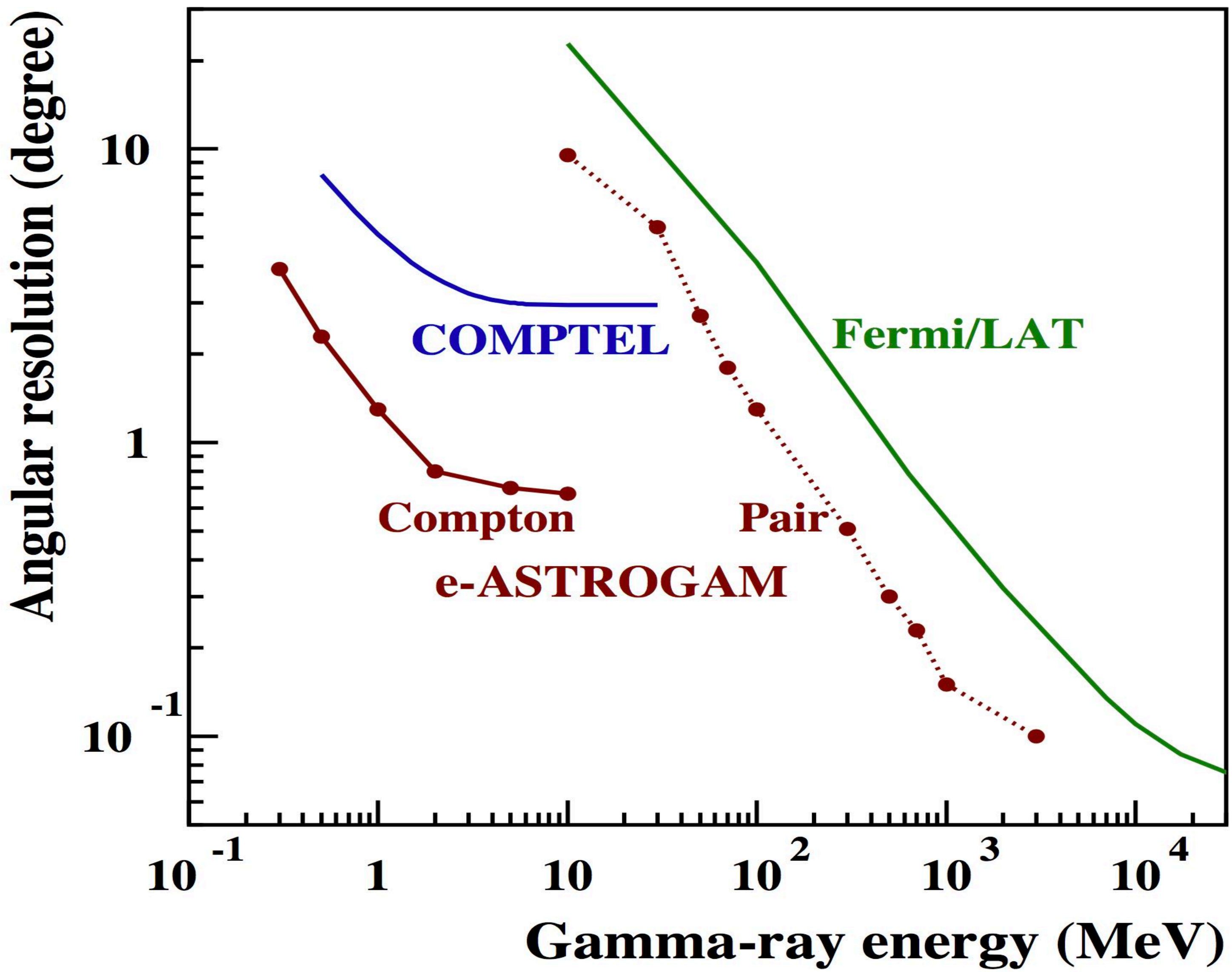



e-ASTROGAM
at the heart of the extreme Universe
An observatory for gamma rays
In the MeV/GeV domain
Detector paper: Exp. Astronomy 2017, 44, 25 arXiv:1611.02232
Science White Book: arXiv:1711.01265 (190 pages)

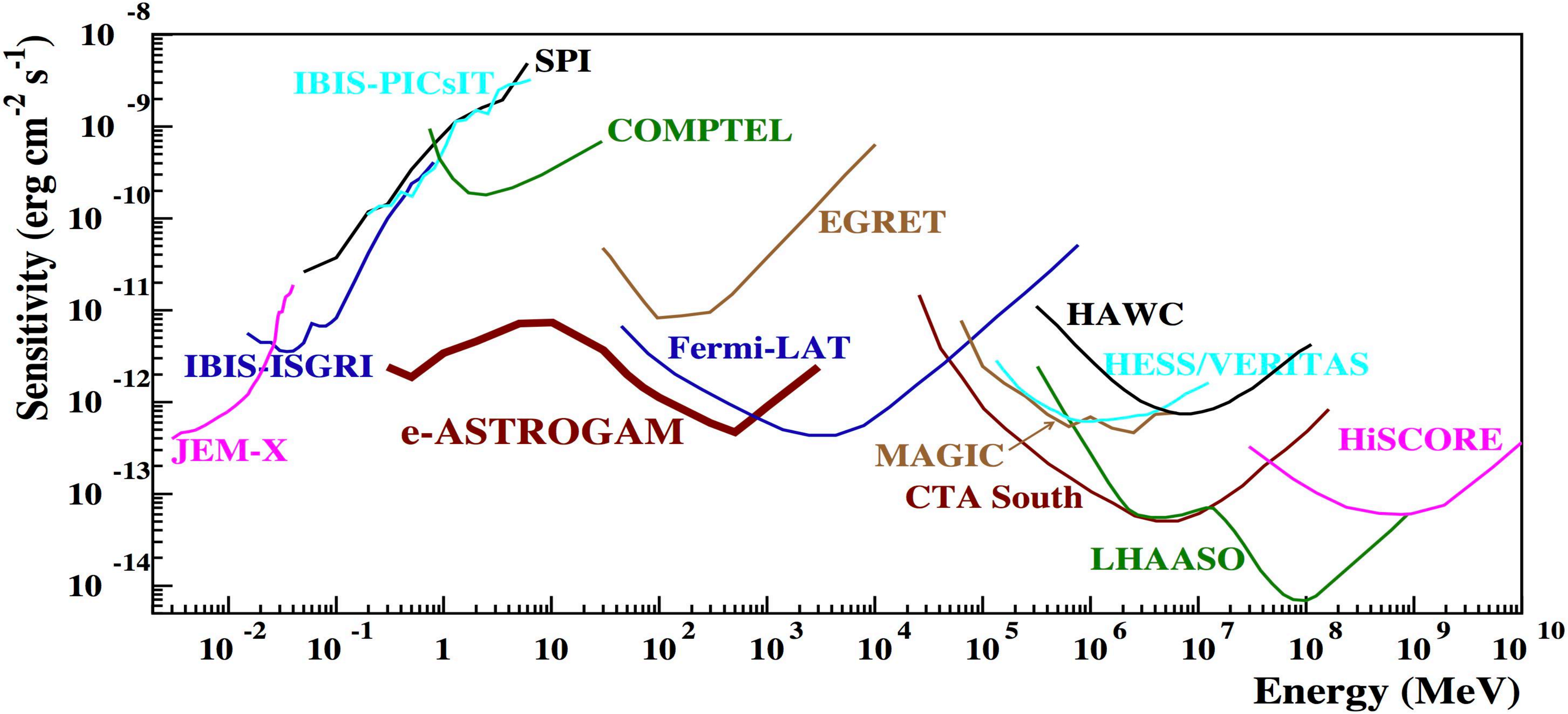
An instrument that combine two detection techniques

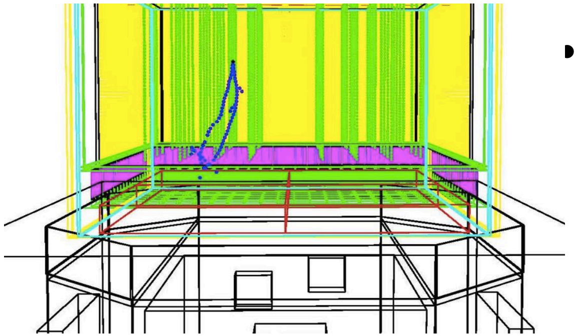


e-ASTROGAM Angular Resolution



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

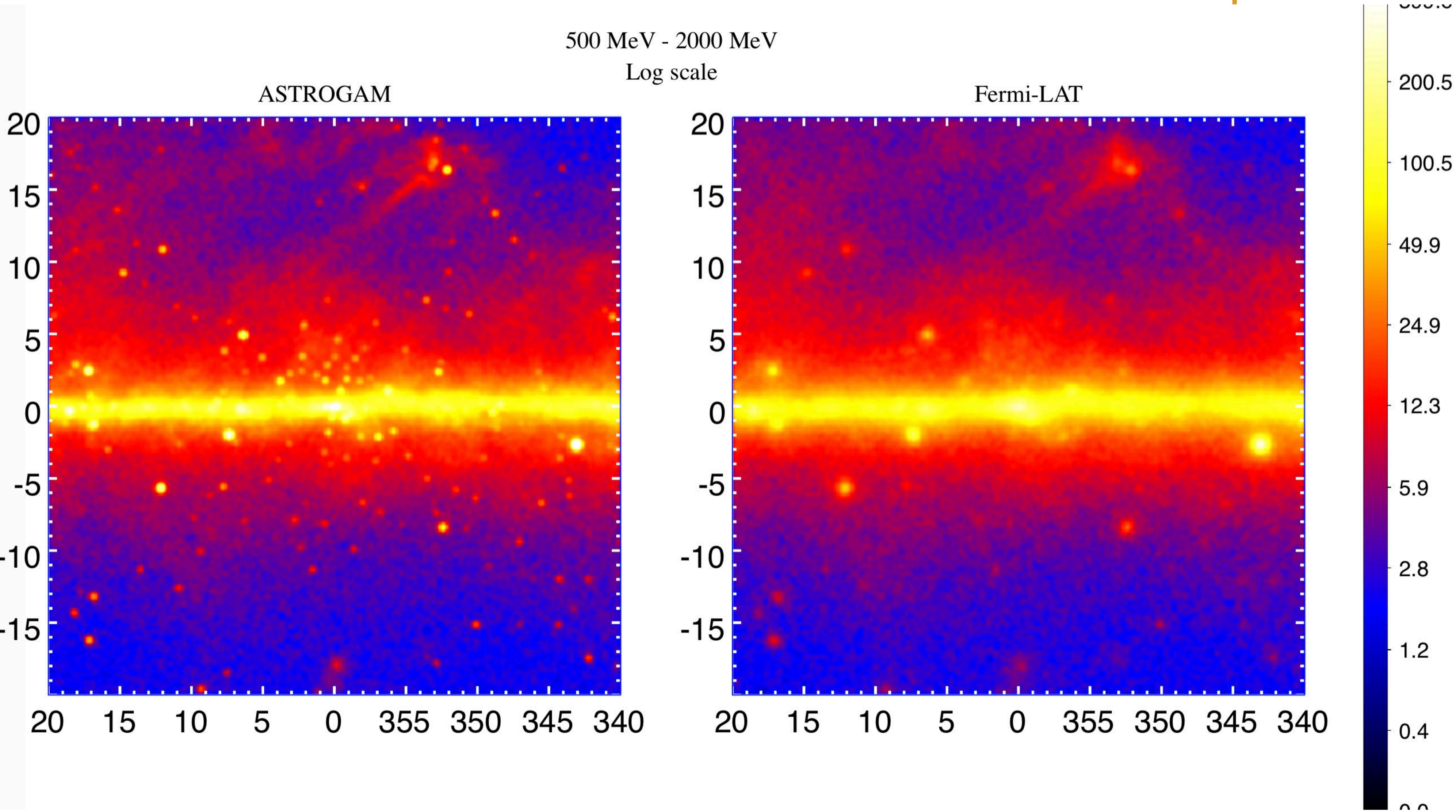
e-Astrogam: arXiv:1711.01265

ESA Medium-size M5 mission opportunity

- Call for a Medium-size mission opportunity in ESA's Science Programme (M5)
  - Statement of Interest deadline: 25 September 2015
  - Release of Call for M5 mission: 29 April 2016
  - Letter of Intent submission deadline: 6 June 2016
    - Briefing meeting (ESTEC): 24 June 2016
  - Proposal submission deadline: 5 October 2016
  - Letters of Endorsement deadline: 8 February 2017
  - Selection of missions for study: June 2017
  - End of 2017: Selection up to three proposals for the study phase (A)
    - Space agencies funds start running
  - M5 selection: June 2019
    - Mission selection review in ~ April 2019
    - Technology Readiness Level (TRL) 5/6 must be reached
  - M5 adoption: June 2021
    - Mission adoption review in ~ April 2021
  - Launch: 2029/2030 (mission dependent)

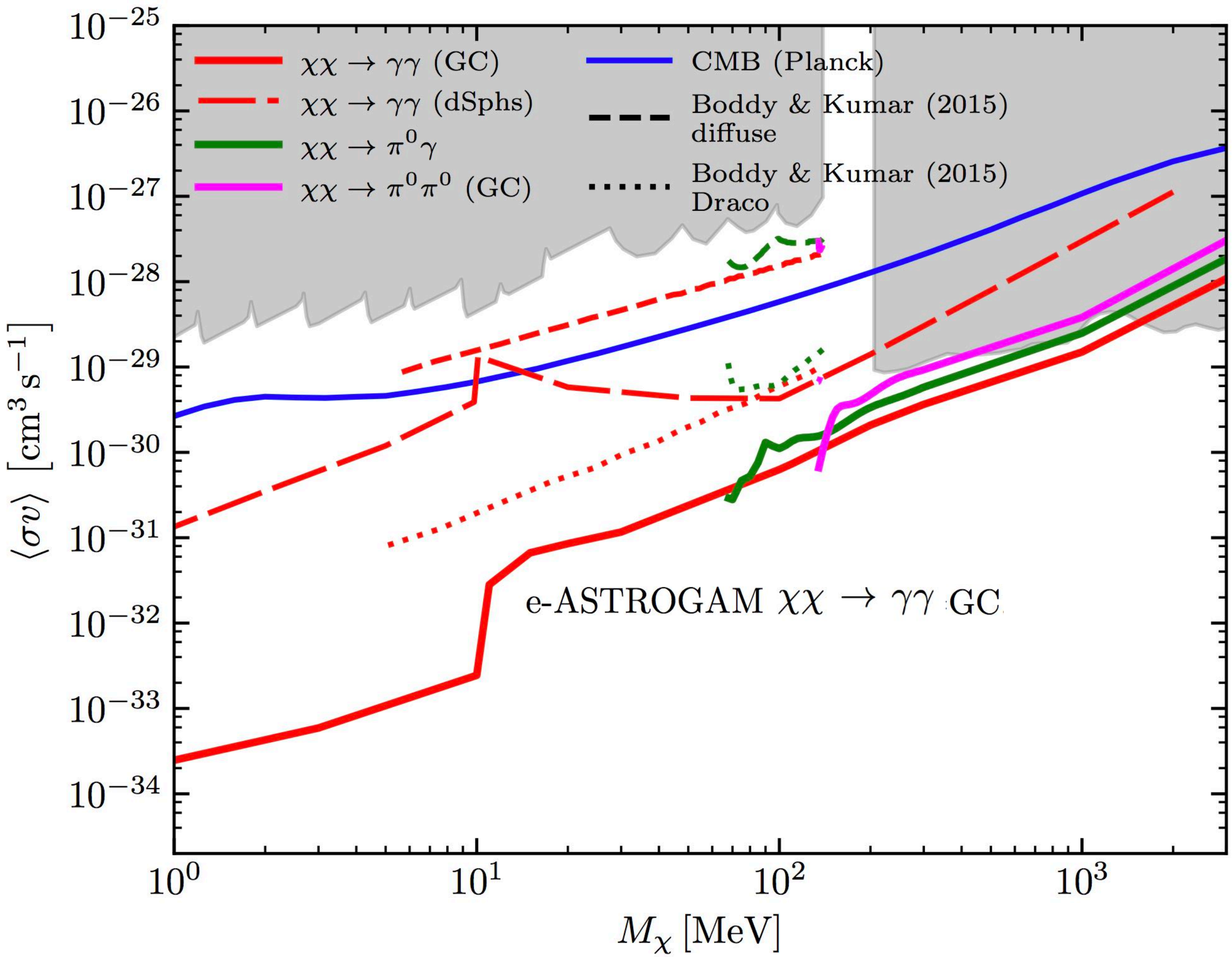
Galactic Center Region 0.5-2 GeV

Fermi PSF Pass7 rep v15 source



Morselli, Gomez Vargas, preliminary

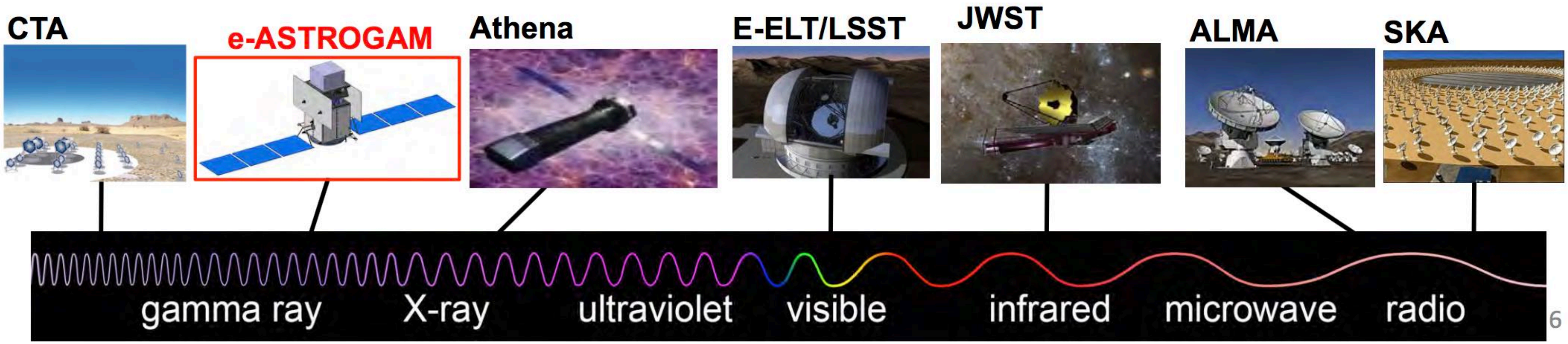
DM limits with e-ASTROGAM in the MeV region

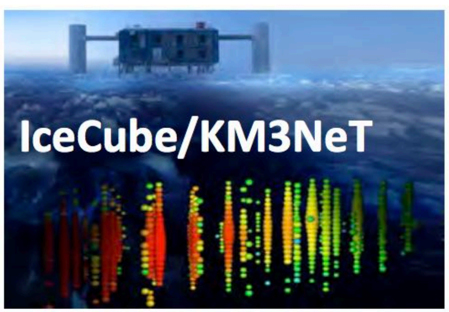


e-ASTROGAM White Book arXiv:1711.01265

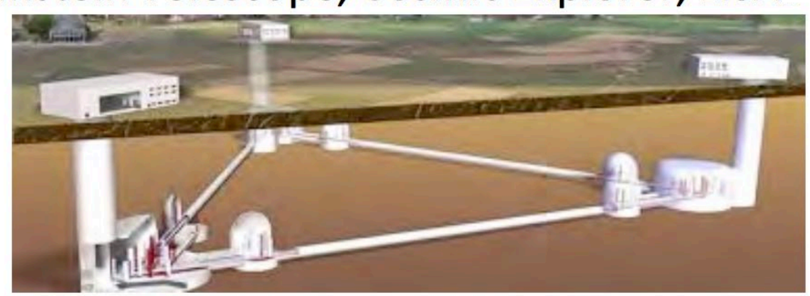
A unique Observatory integrated with future astrophysics

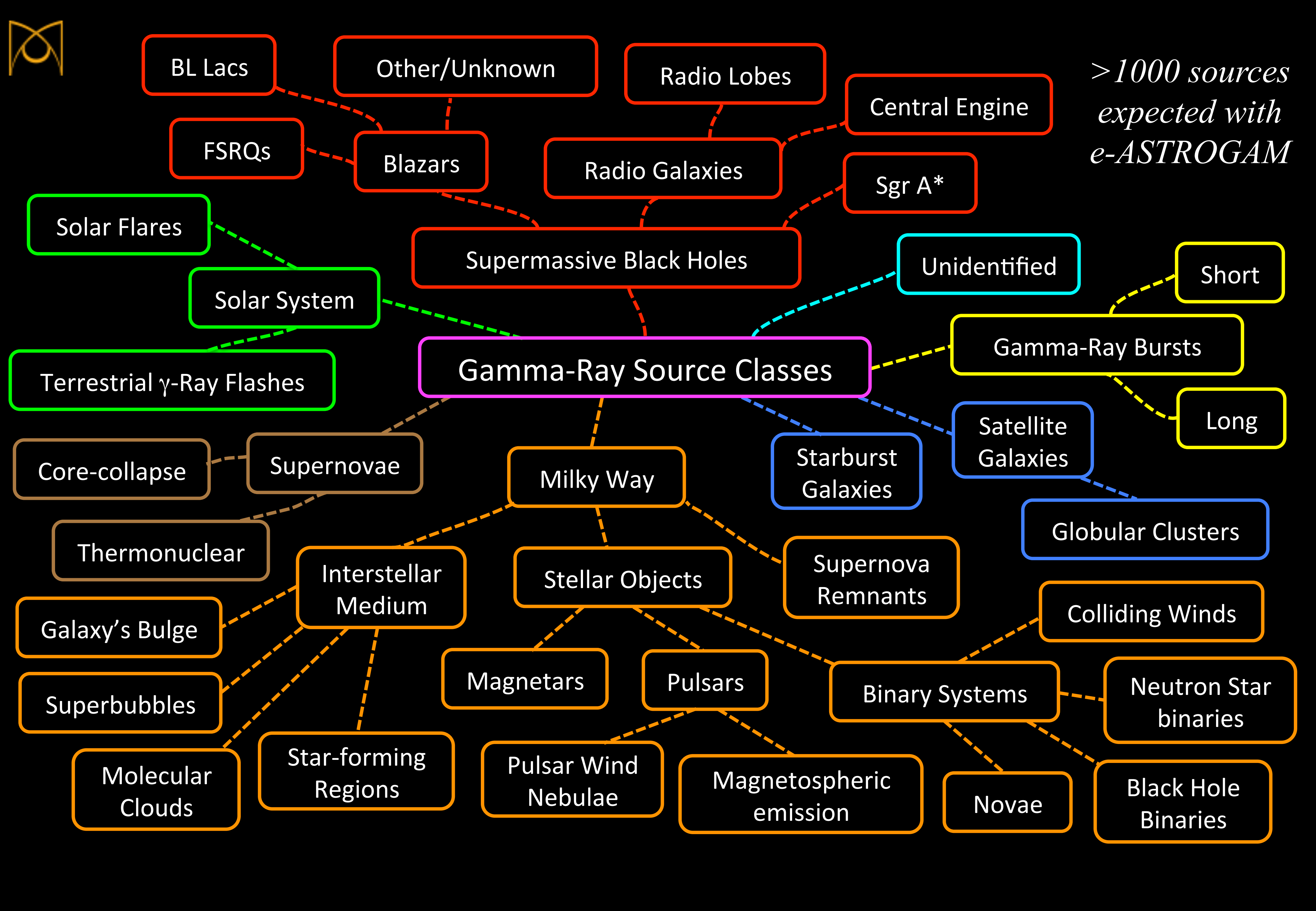
- Multi-messenger, multi-wavelength, well suited for transient phenomena





Einstein Telescope, Cosmic Explorer, LISA



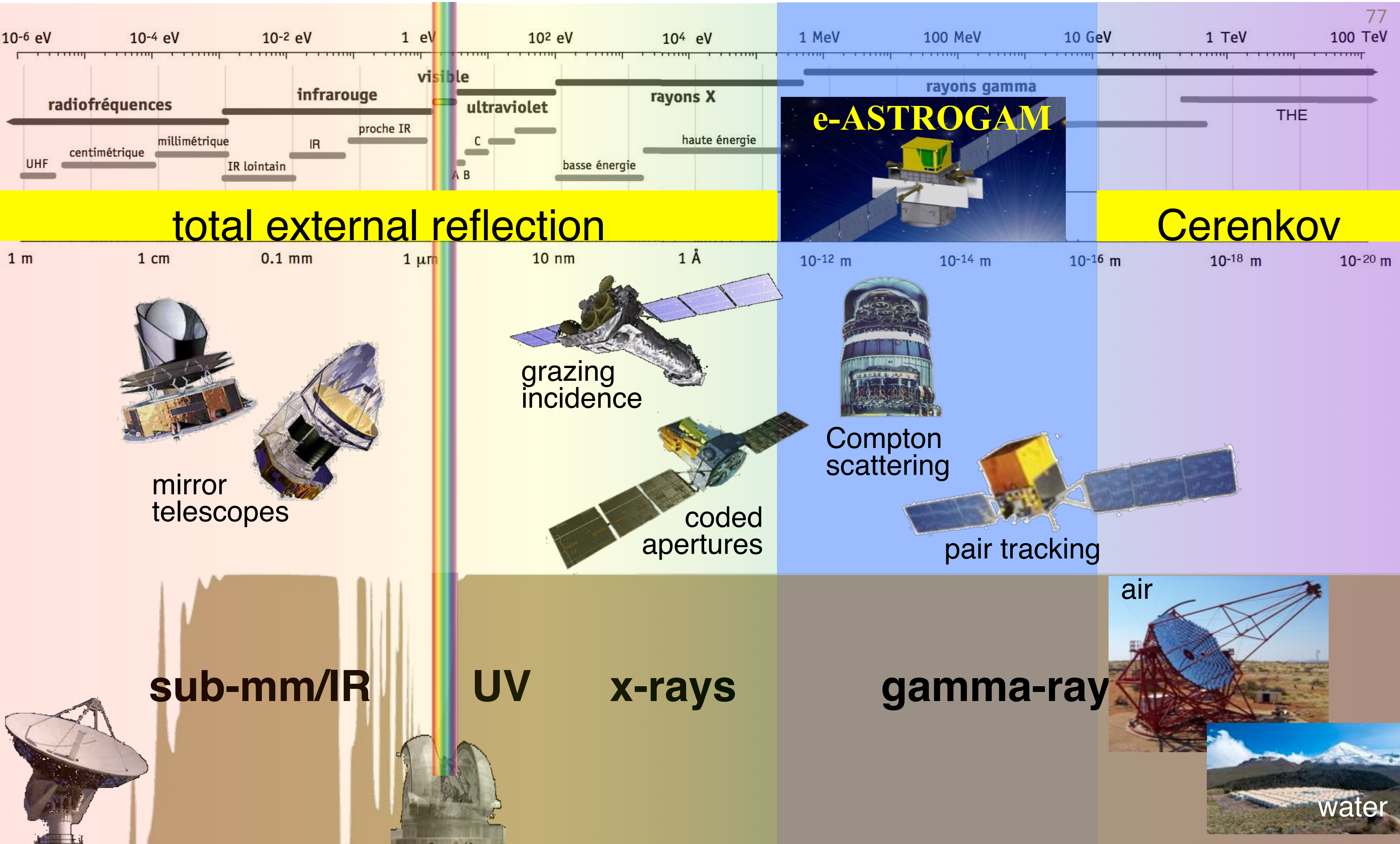


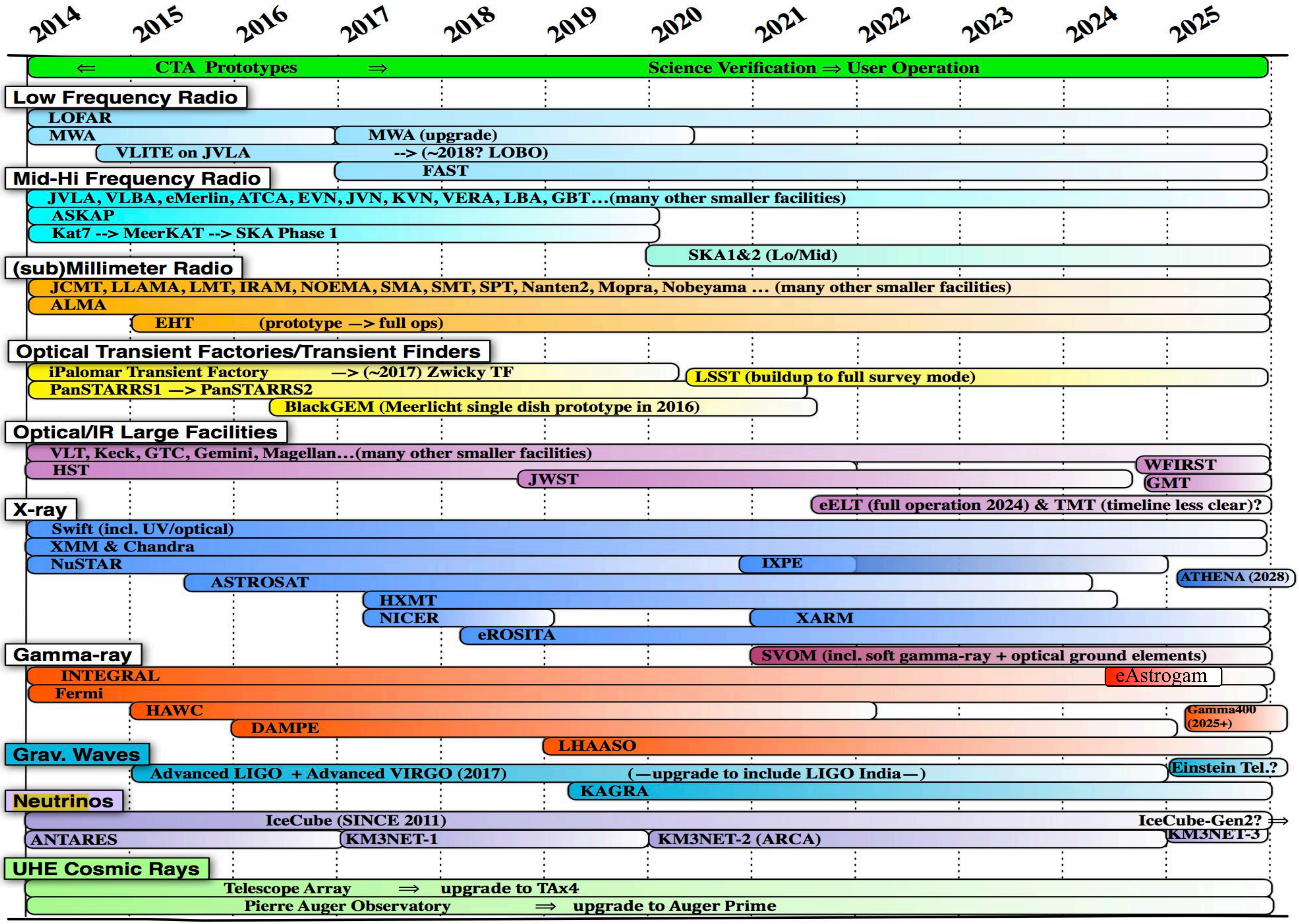
BL Lacs
Other/Unknown
Radio Lobes
Central Engine
>1000 sources expected with e-ASTROGAM
FSRQs
Blazars
Radio Galaxies
Sgr A*
Solar Flares
Supermassive Black Holes
Unidentified
Short
Solar System
Gamma-Ray Bursts
Terrestrial γ-Ray Flashes
Gamma-Ray Source Classes
Long
Satellite Galaxies
Core-collapse
Supernovae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

Why eAstrogam is important for IceCube and KM3Net

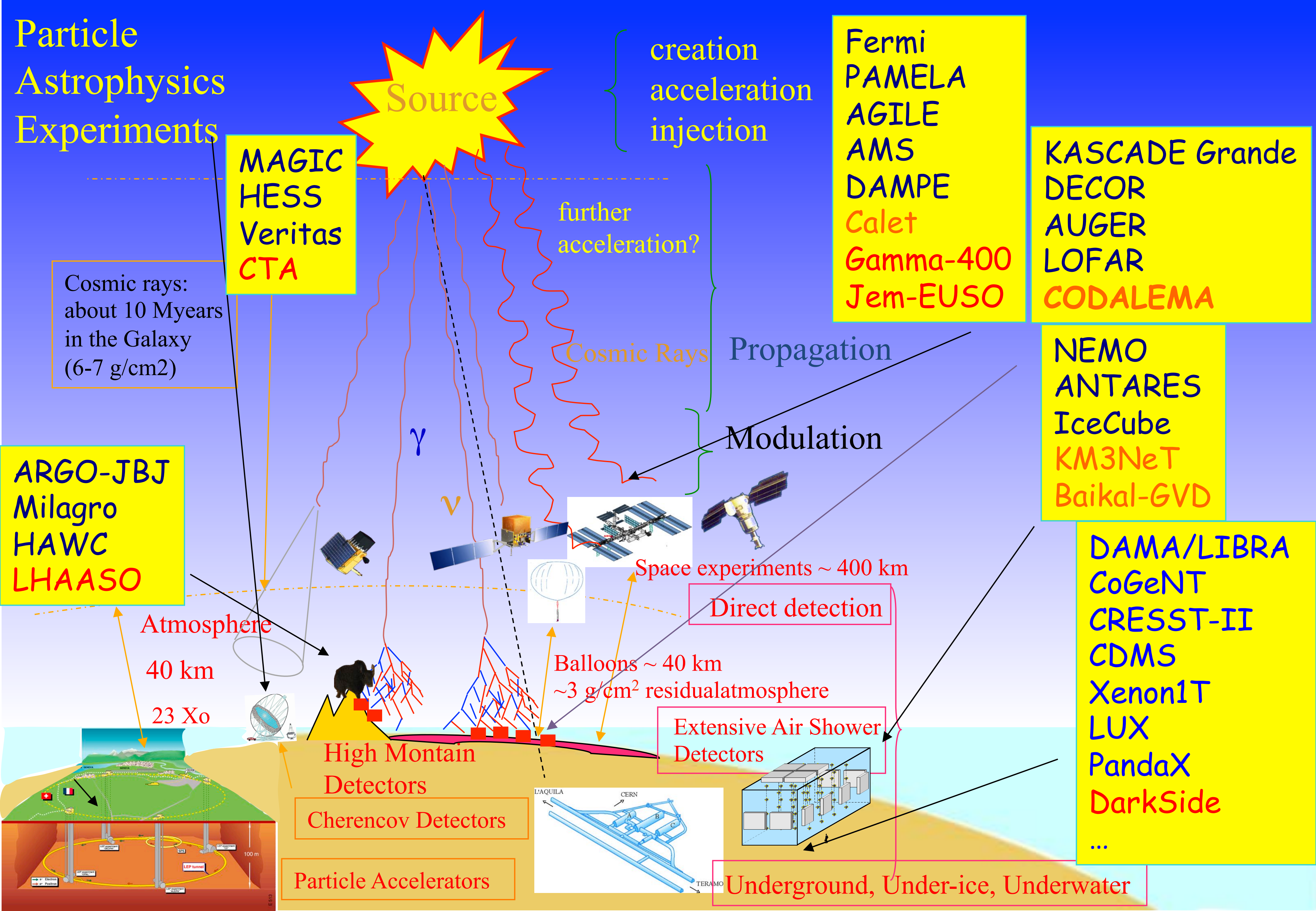
- Wide FoV (> 2.5 sr at 10 MeV) in survey mode.
- Sources of astrophysical neutrinos detected by IceCube may be opaque to 1–100 GeV gamma-rays but bright in the MeV domains (expecially if the neutrino flux originates from photo-hadronic processes)
- eAstrogam can select the best blazar candidates for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

An instrument to complete the coverage of the electromagnetic spectrum



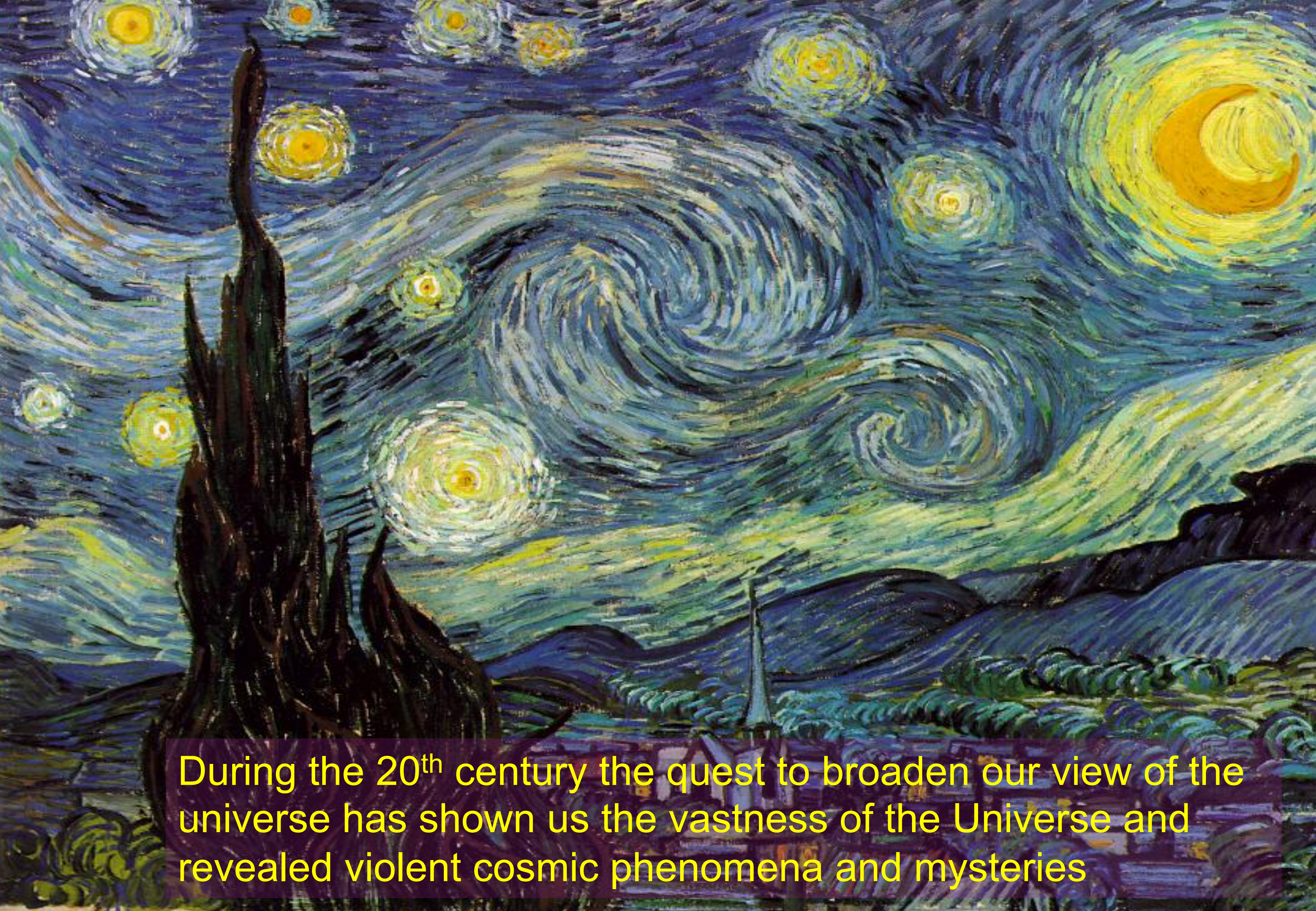


2014
2015
2016
2017
2018
2019
2020
2021
2022
2023
2024
2025
⇐ CTA Prototypes ⇒
Science Verification ⇒ User Operation
Low Frequency Radio
LOFAR
MWA
MWA (upgrade)
VLITE on JVLA
--> (~2018? LOBO)
FAST
Mid-Hi Frequency Radio
JVLA, VLBA, eMerlin, ATCA, EVN, JVN, KVN, VERA, LBA, GBT…(many other smaller facilities)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

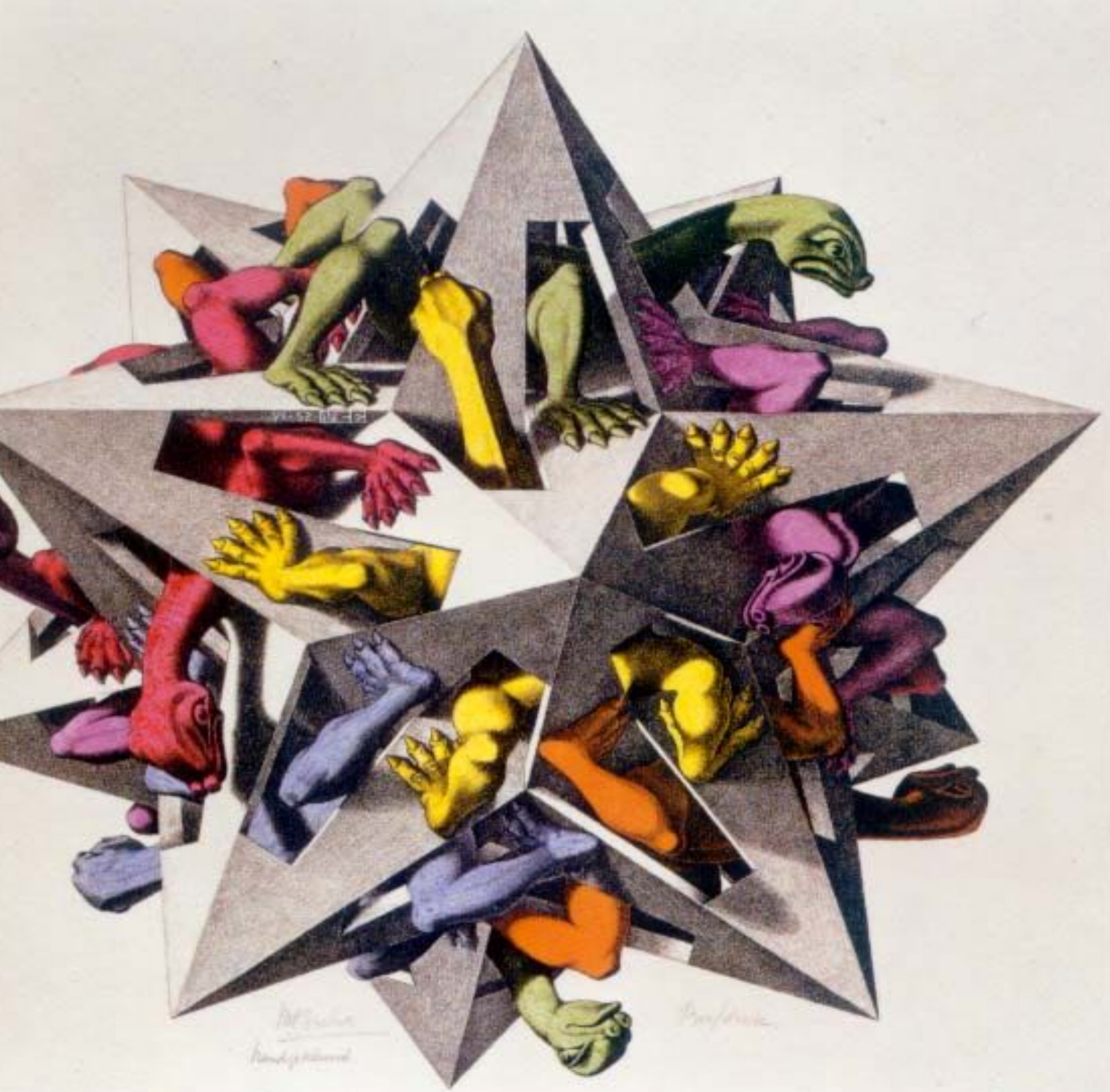


Particle Astrophysics Experiments
Source
creation
acceleration
injection
Fermi
PAMELA
AGILE
AMS
DAMPE
Calet
Gamma-400
Jem-EUSO
KASCADE Grande
DECOR
AUGER
LOFAR
CODALEMA
MAGIC
HESS
Veritas
CTA
further acceleration?
Cosmic rays: about 10 Myears in the Galaxy (6-7 g/cm2)
Cosmic Rays
Propagation
NEMO
ANTARES
IceCube
KM3NeT
Baikal-GVD
Modulation
γ
ν
ARGO-JBJ
Milagro
HAWC
LHAASO
DAMA/LIBRA
CoGeNT
CRESST-II
CDMS
Xenon1T
LUX
PandaX
DarkSide
...
Space experiments ~ 400 km
Direct detection
Atmosphere
40 km
23 Xo
Balloons ~ 40 km
~3 g/cm2 residualatmosphere
Extensive Air Shower Detectors
High Montain Detectors
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 !