Experiments on satellites : status and future perspectives in connection with Neutrinos experiments

Aldo Morselli

INFN Roma Tor Vergata

Dark Ghost **Brussels** 13-14 November 2018

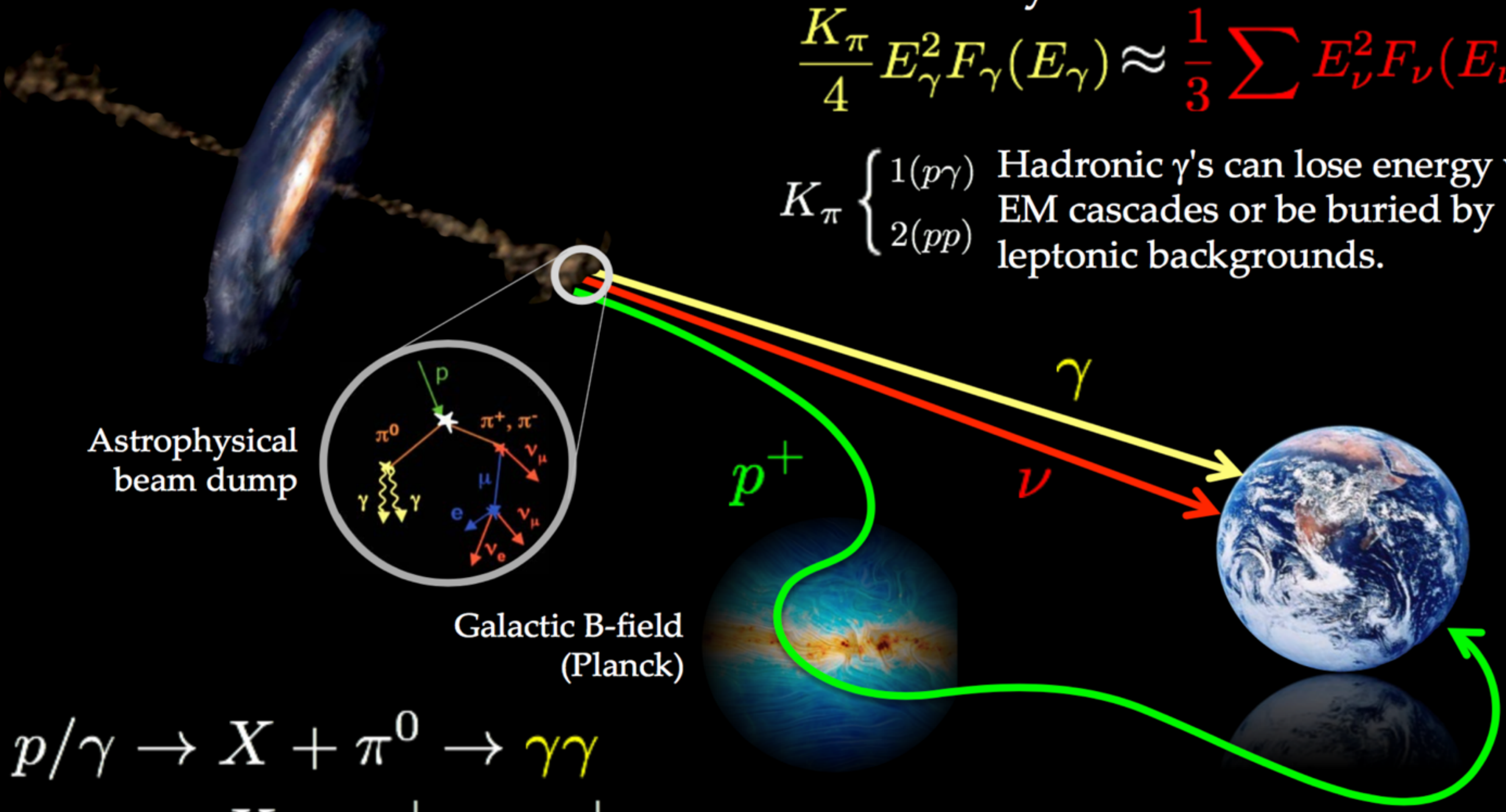
Neutrinos and Gamma Rays

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.

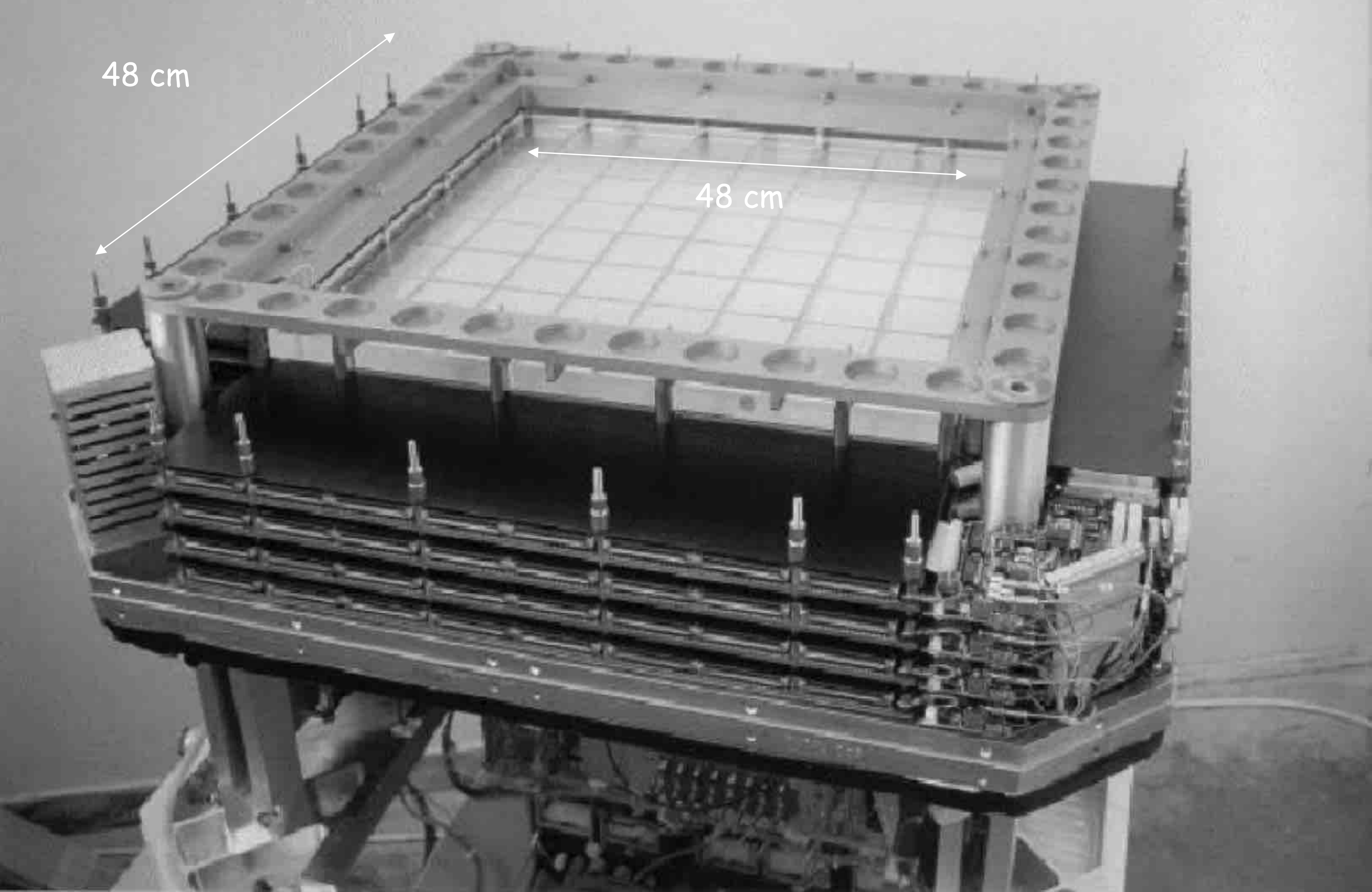


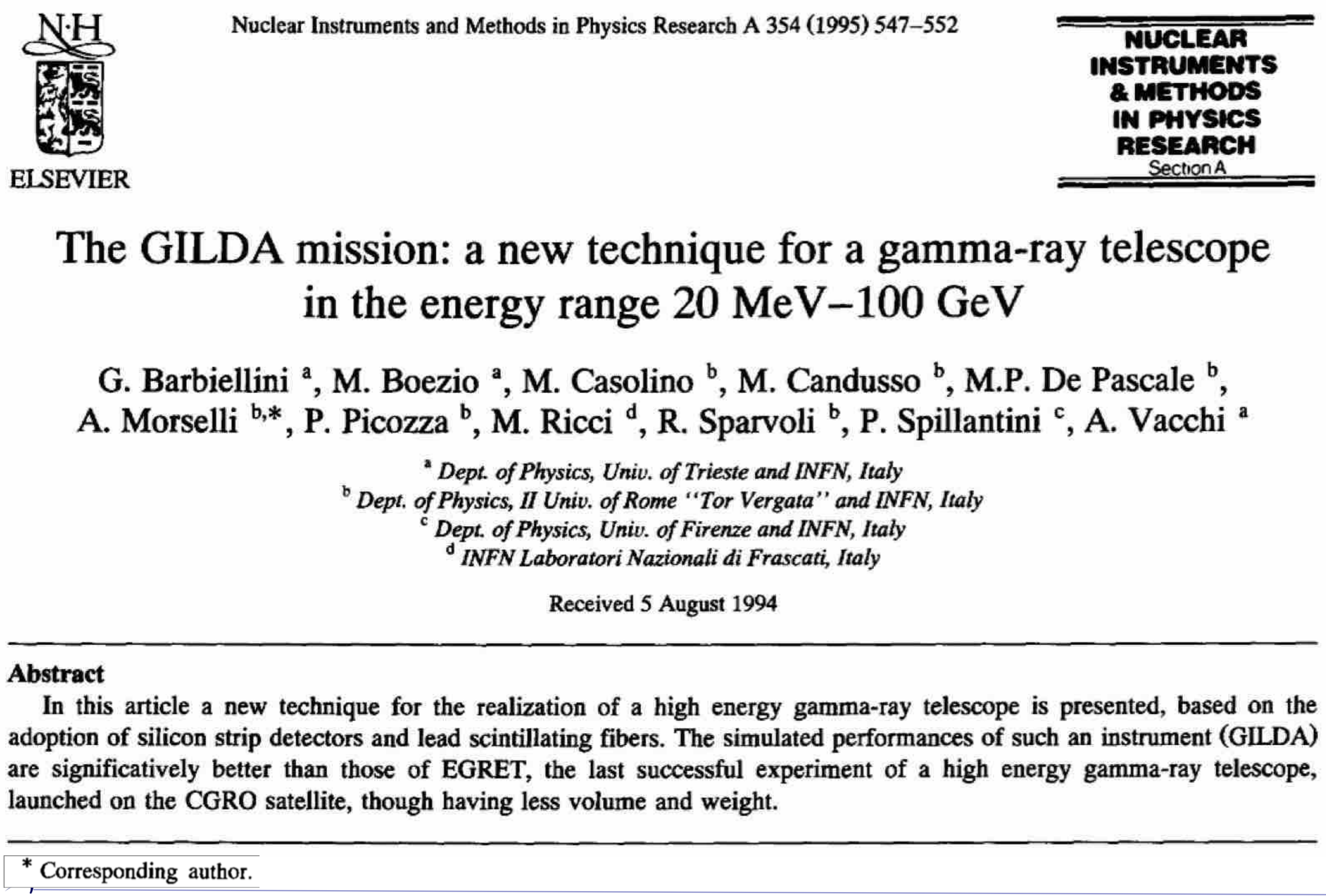
$$p + p/\gamma \rightarrow X + \pi^0 \rightarrow \gamma\gamma$$

$$\rightarrow X + \pi^+ \rightarrow \mu^+ + \nu_\mu$$

$$\mu^+ \rightarrow e^+ + \nu_e + \bar{\nu}_\mu$$ (oscillates to ~1:1:1)

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

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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.

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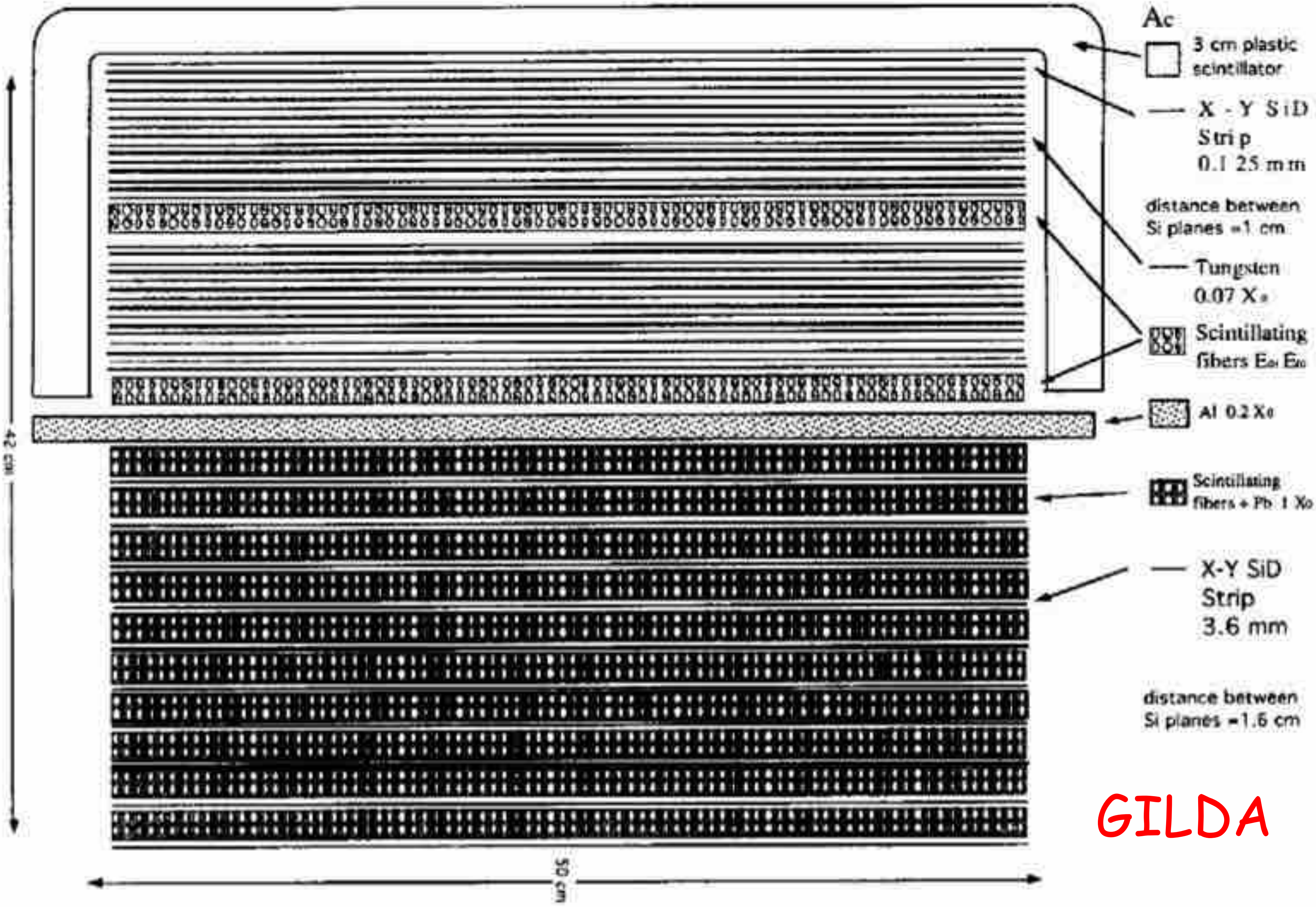
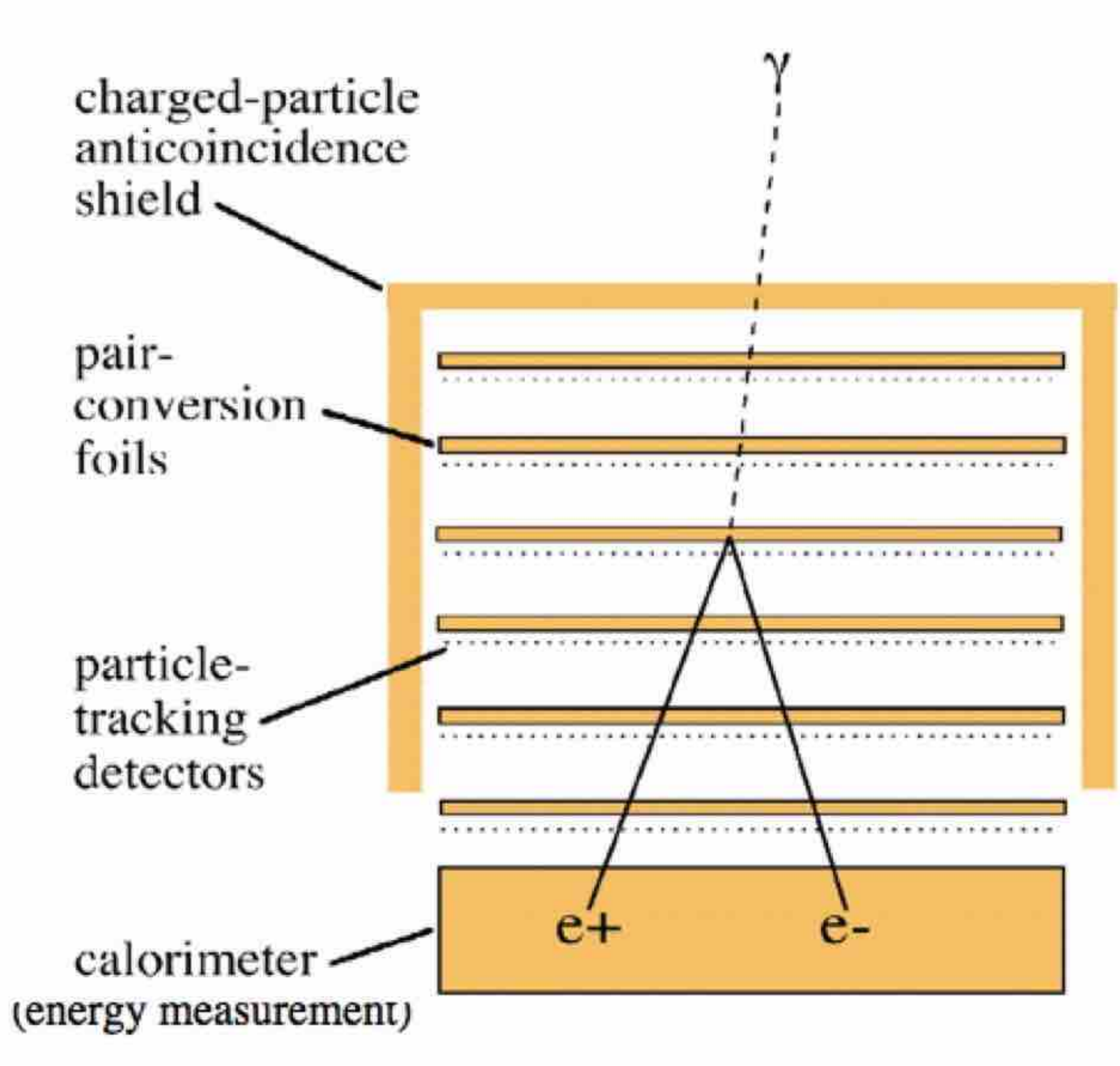
[*] Corresponding author.


Ac
3 cm plastic scintillator
X - Y SiD Strip 0.125 mm
distance between Si planes =1 cm
Tungsten 0.07 X_0
Scintillating fibers
Al 0.2 X_0
Scintillating fibers + Pb 1 X_0
X-Y SiD Strip 3.6 mm
distance between Si planes =1.6 cm
42 cm
50 cm

GILDA

Elements of a pair-conversion telescope

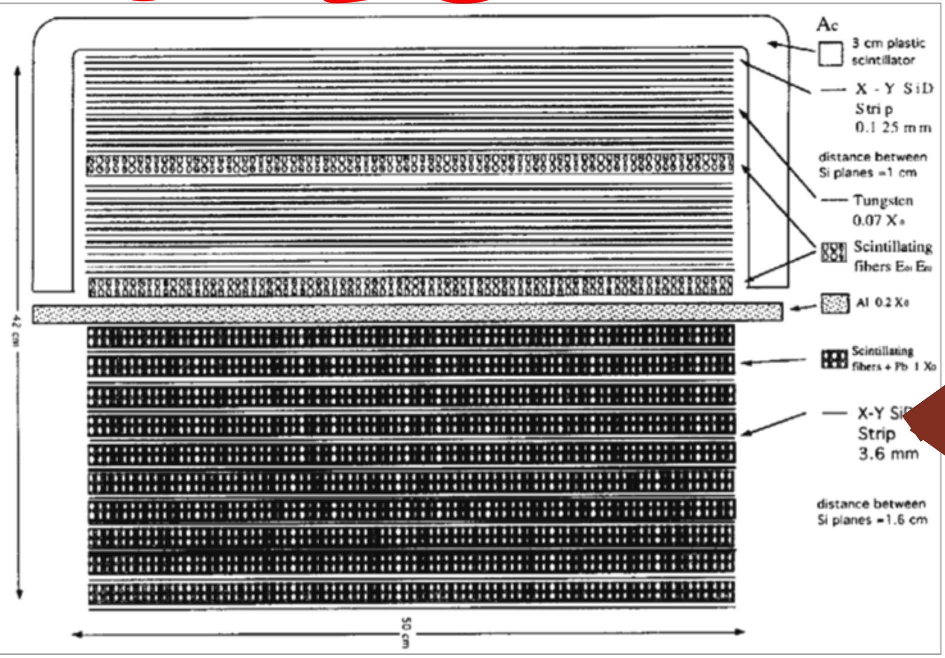


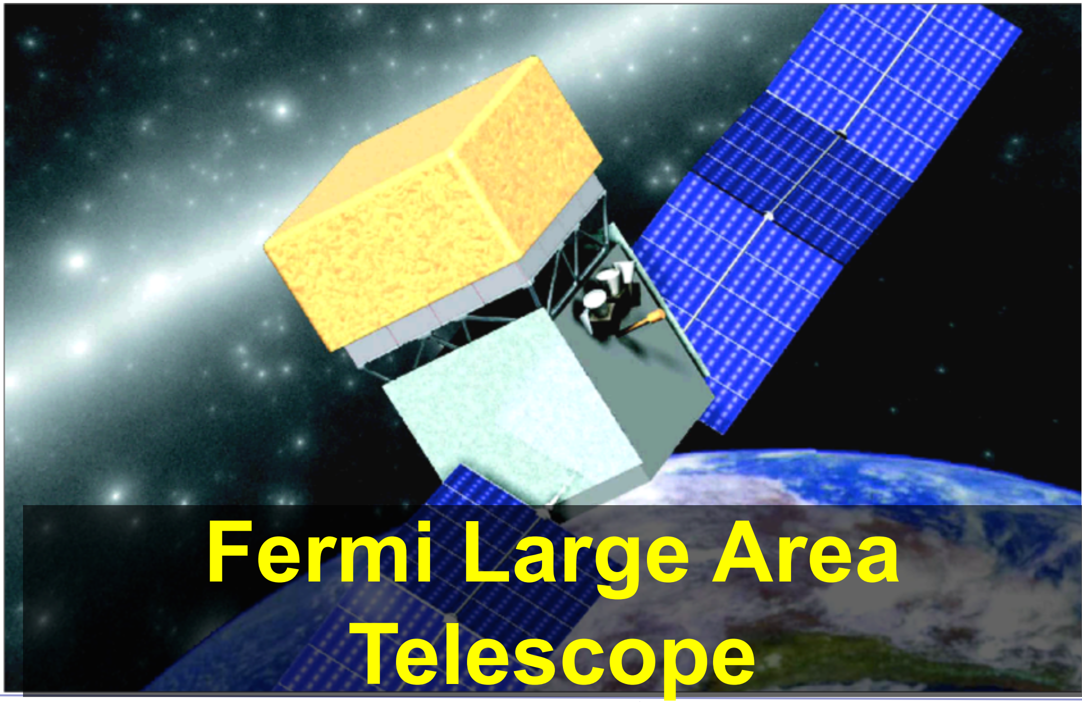
- photons materialize into matter-antimatter pairs:

  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

GILDA




Fermi Large Area Telescope

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

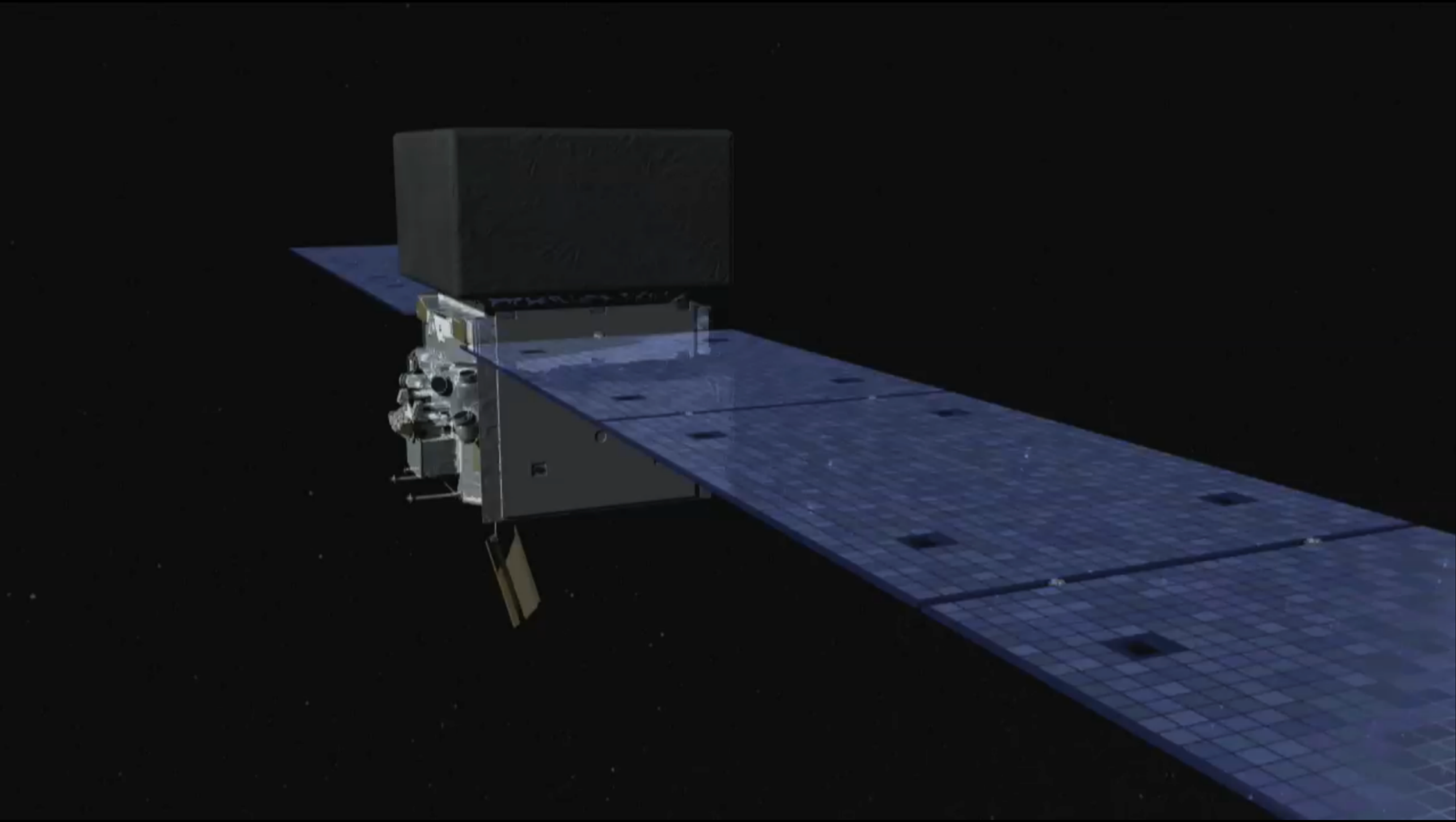
Happy 11th Birthday Agile !!

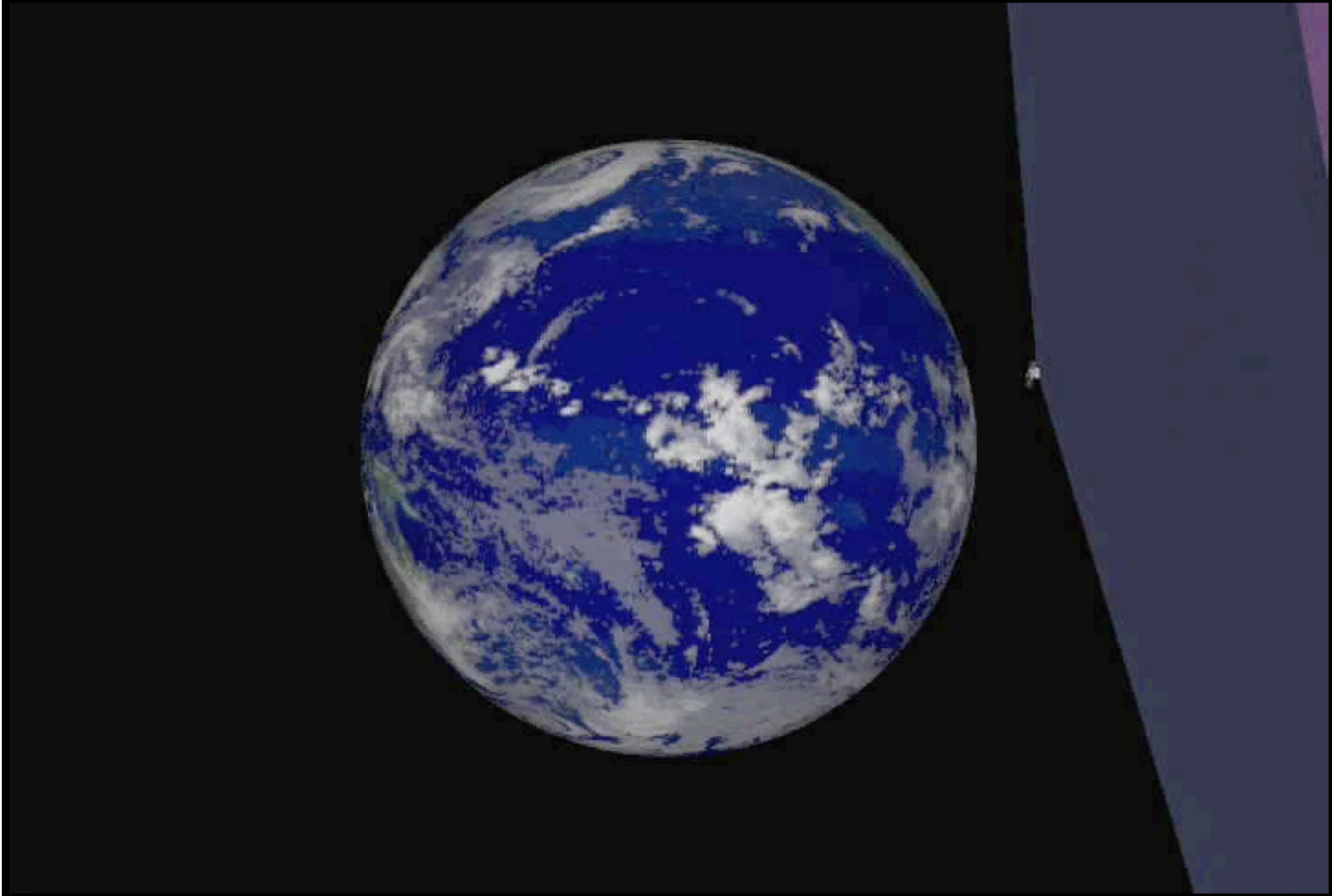
Fermi
Gamma-ray
Space Telescope

Happy 10th Birthday Fermi !!

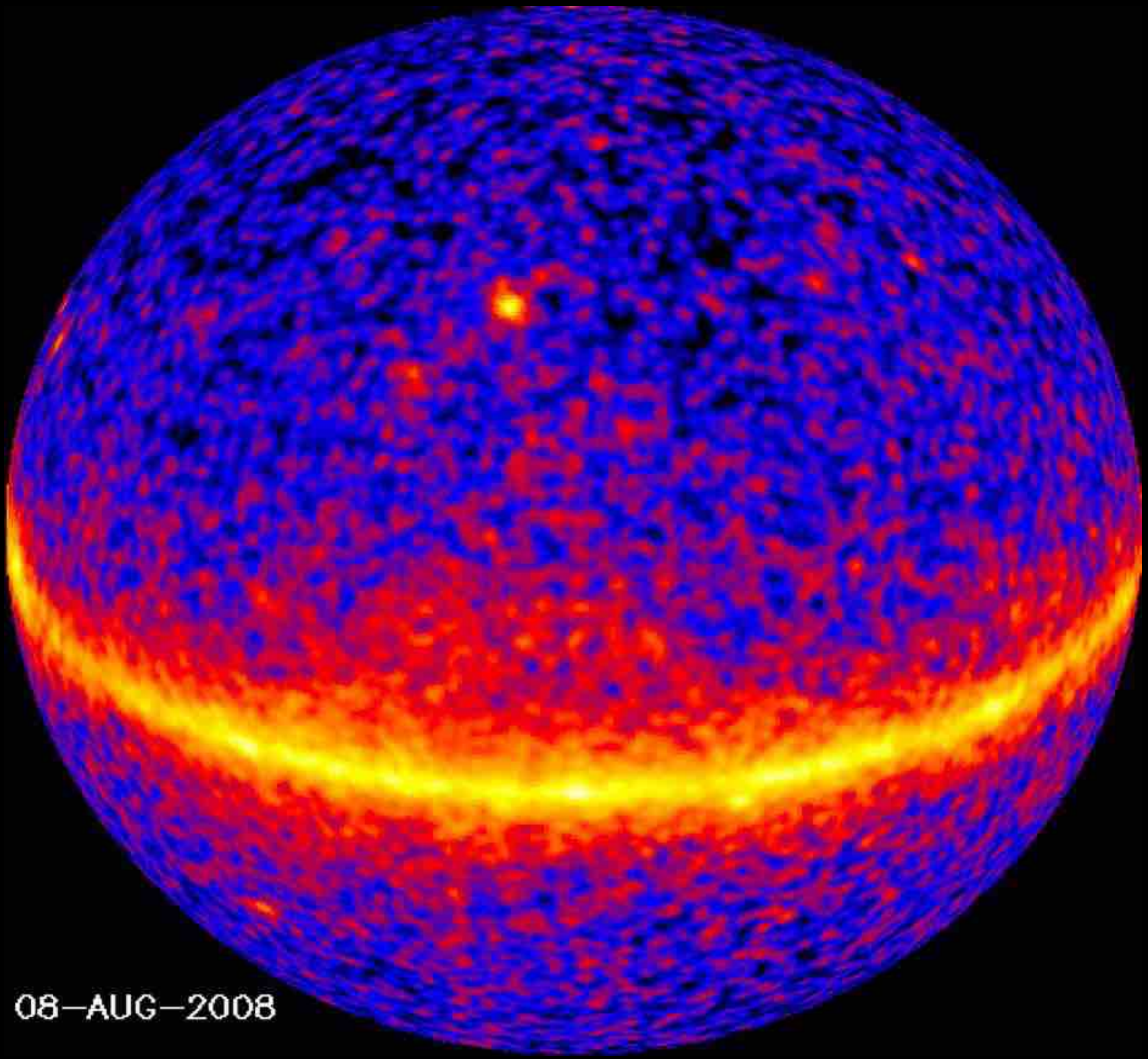
11 June 2008

Pisa 15 March 2018

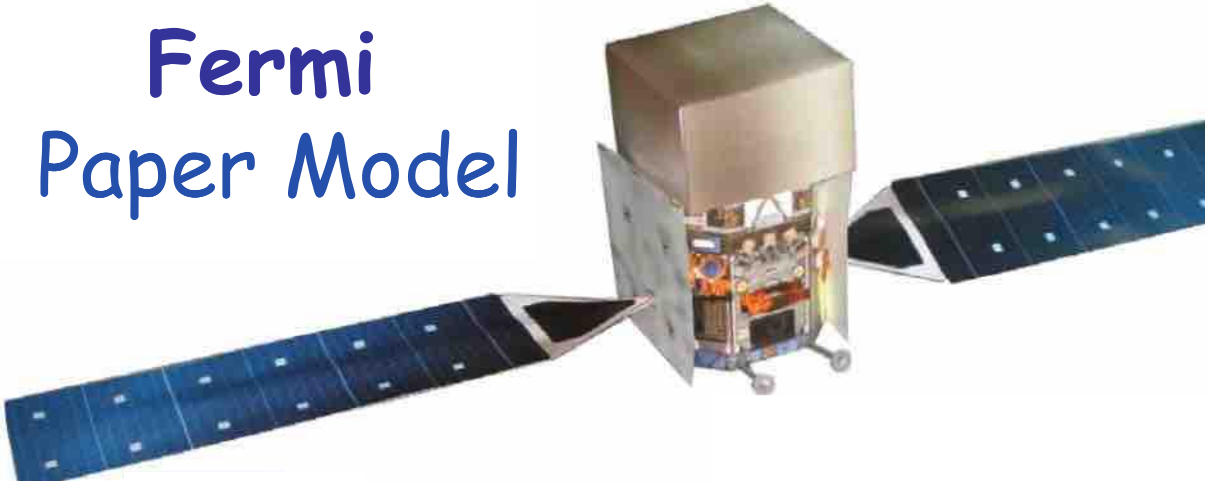


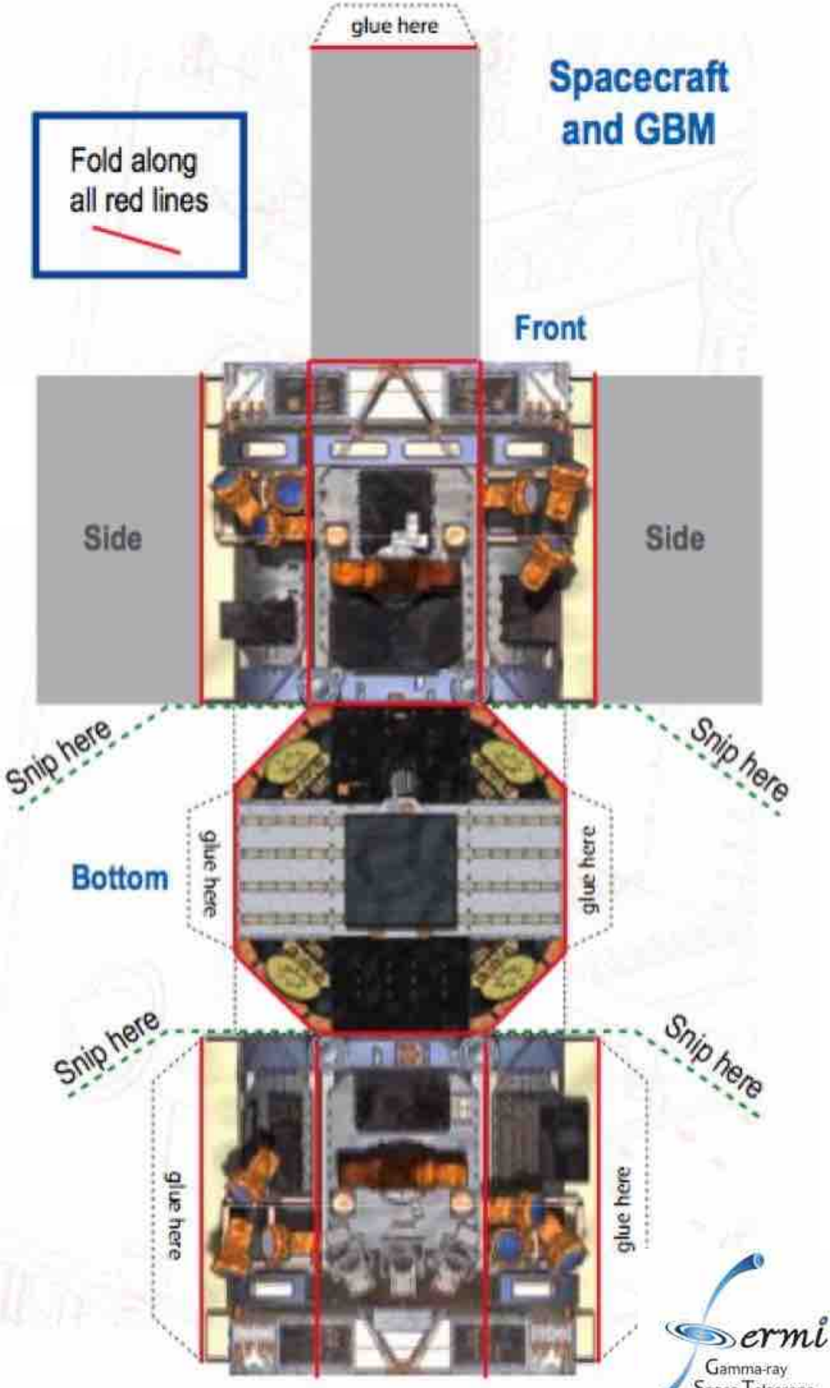


Daily Gamma-ray Sky



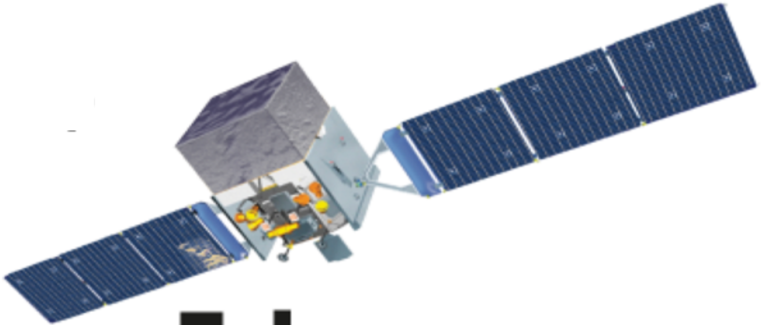
Fermi
Paper Model



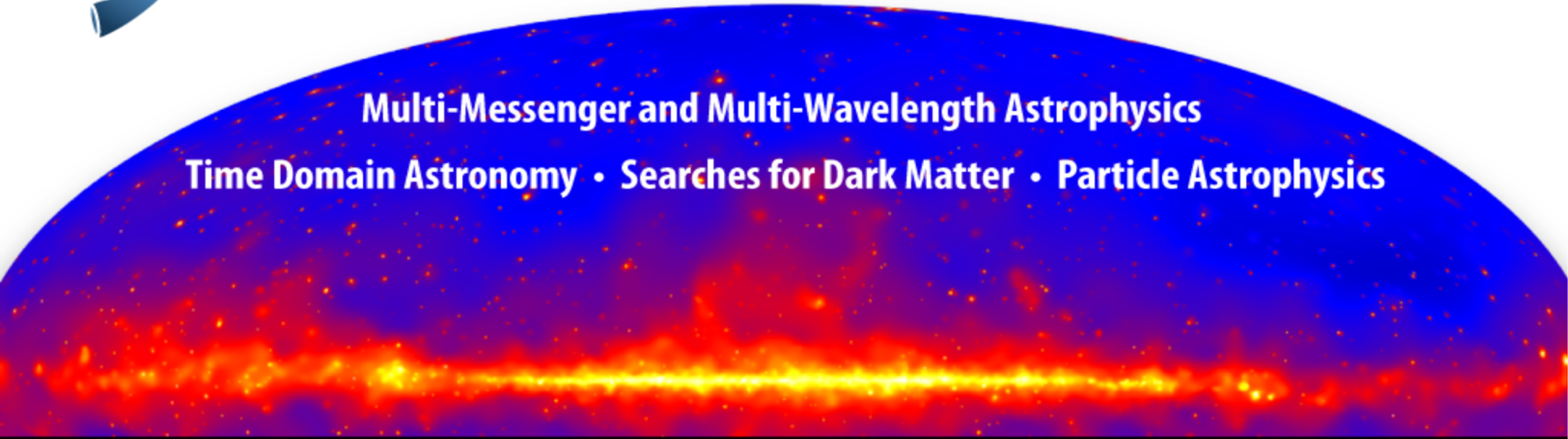


http://people.roma2.infn.it/~aldo/GLASTpaperModel.pdf

Fermi
Gamma-ray
Space Telescope

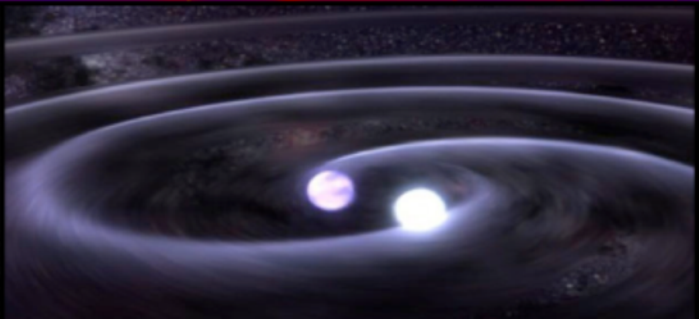


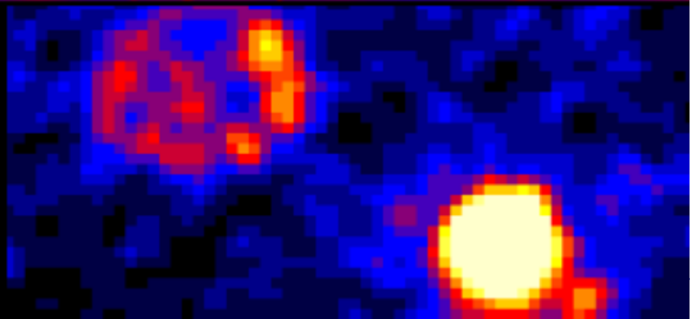
Fermi Gamma-Ray Space Telescope



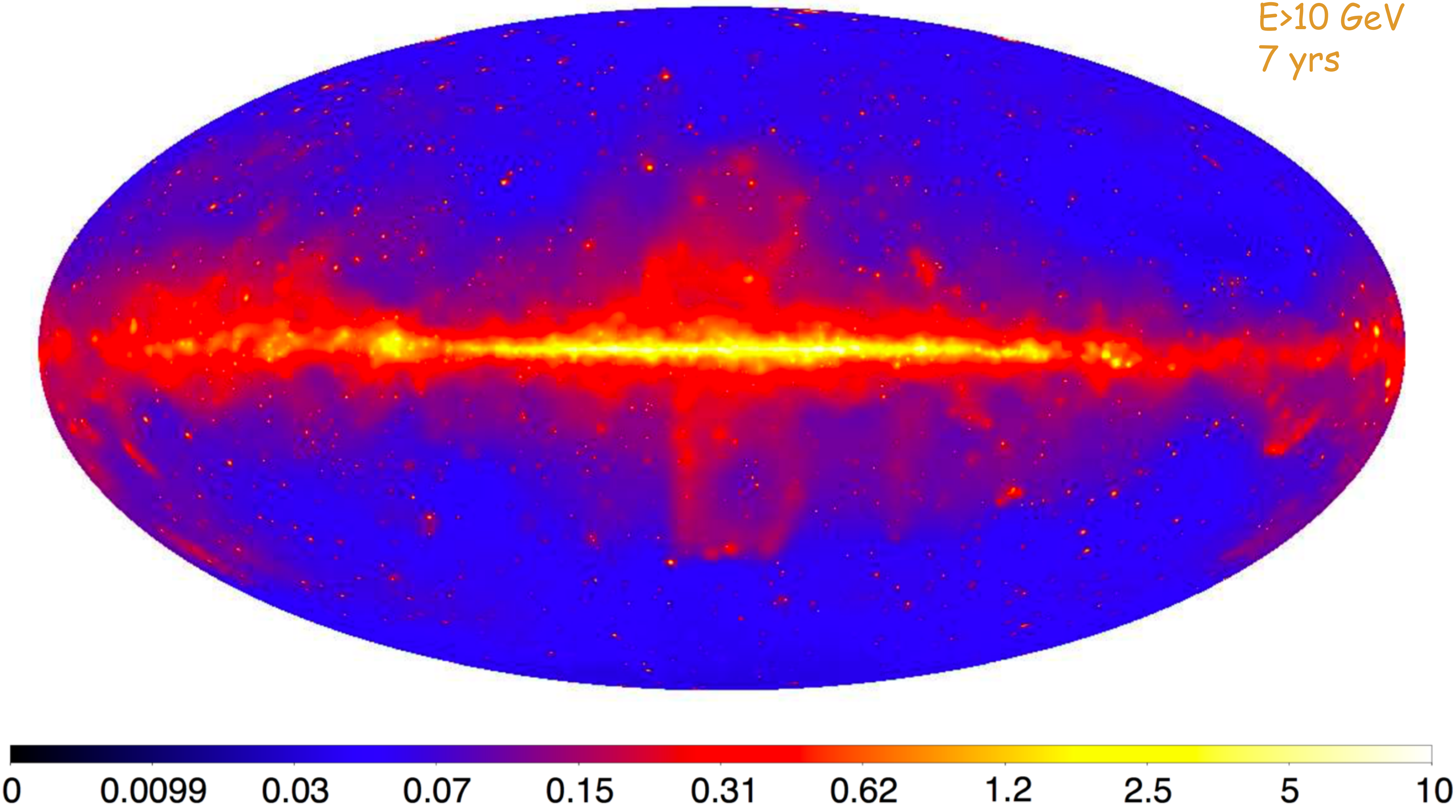
Multi-Messenger and Multi-Wavelength Astrophysics

Time Domain Astronomy • Searches for Dark Matter • Particle Astrophysics



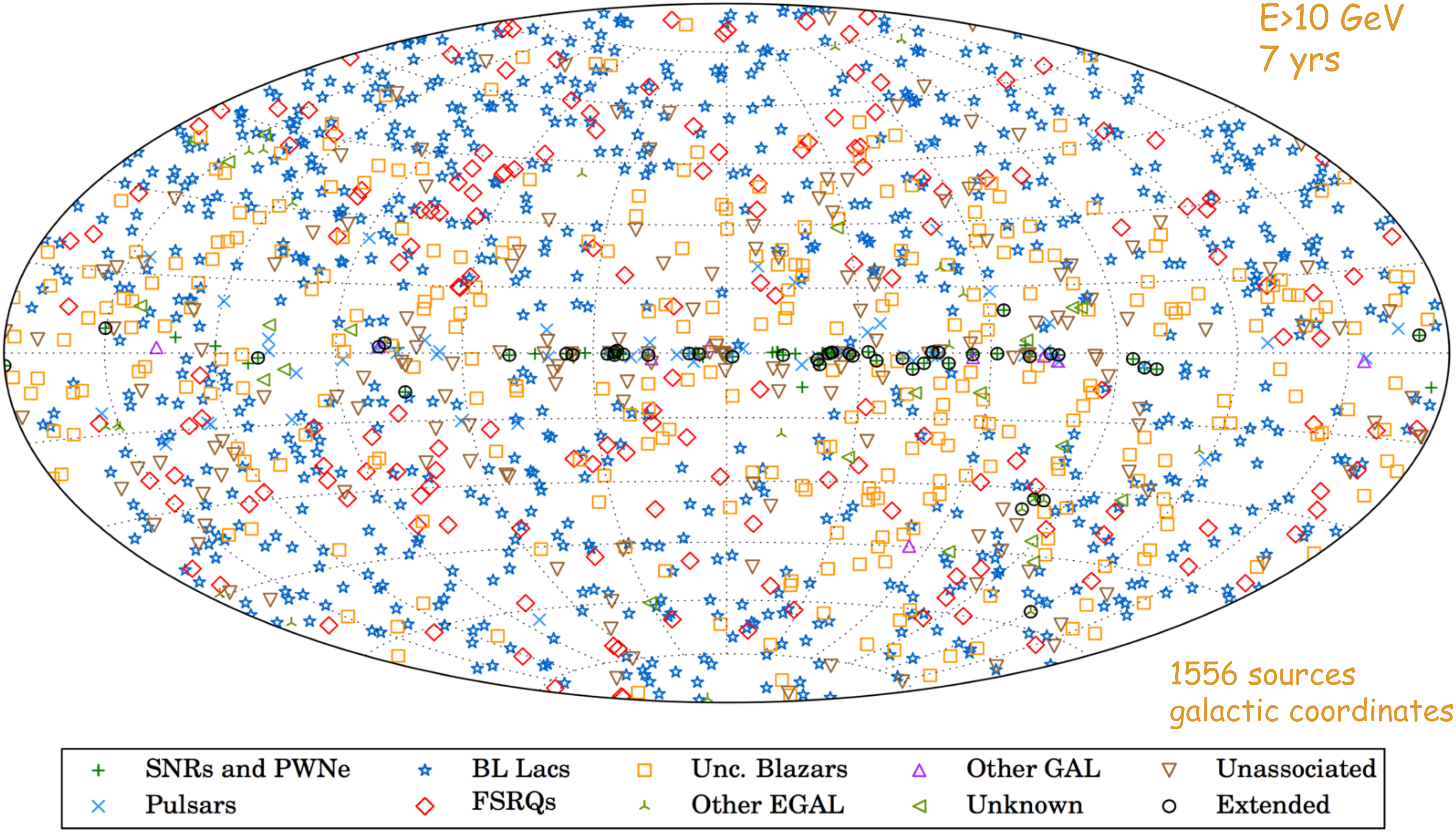


The sky in gamma-rays



M.Ackermann et al. [Fermi Coll.] 3FHL: The Third Catalog of Hard Fermi-LAT Sources ApJS, 2017 232:18 arXiv:1702.00664

The sky in gamma-rays

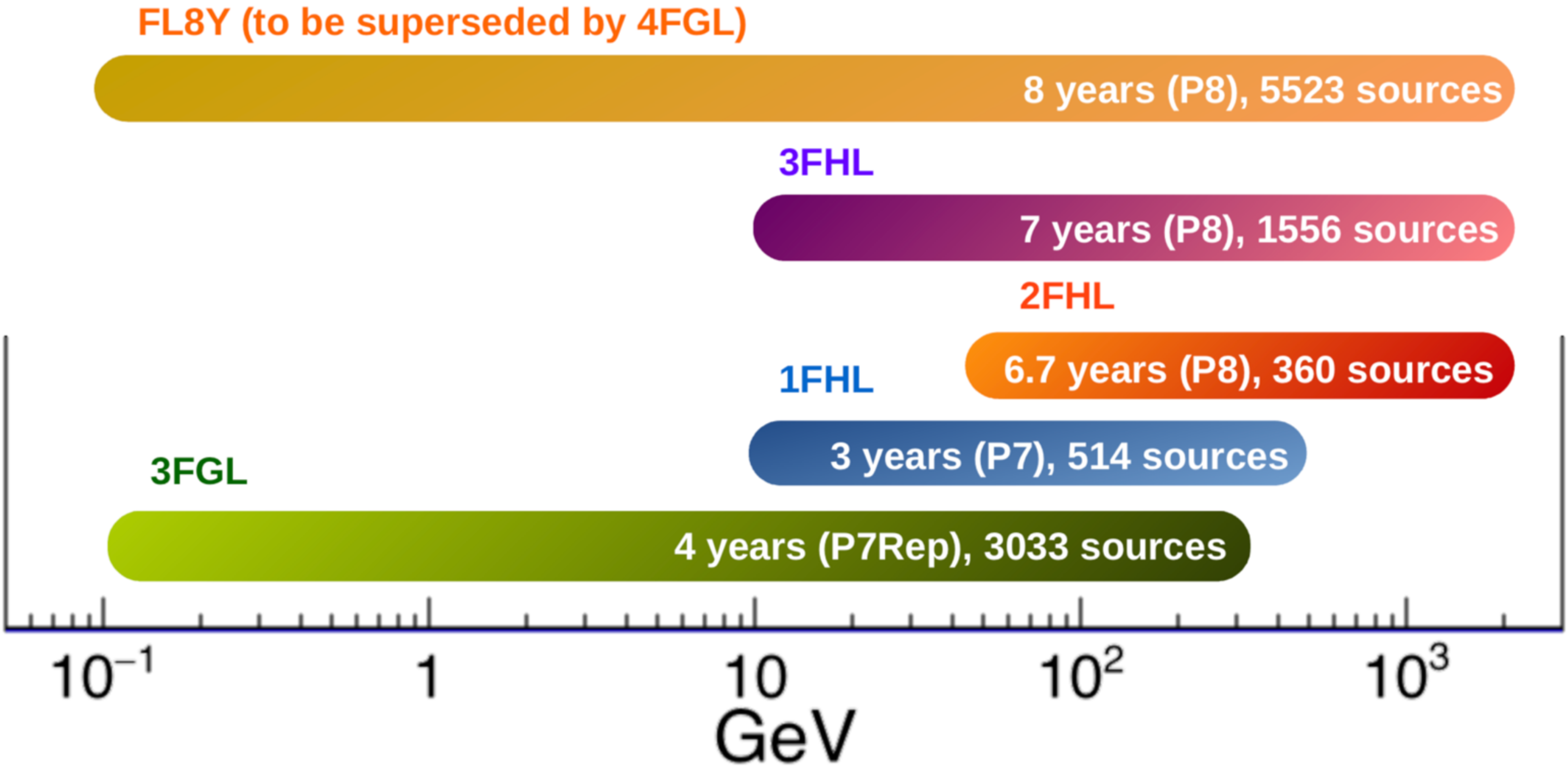


E>10 GeV
7 yrs

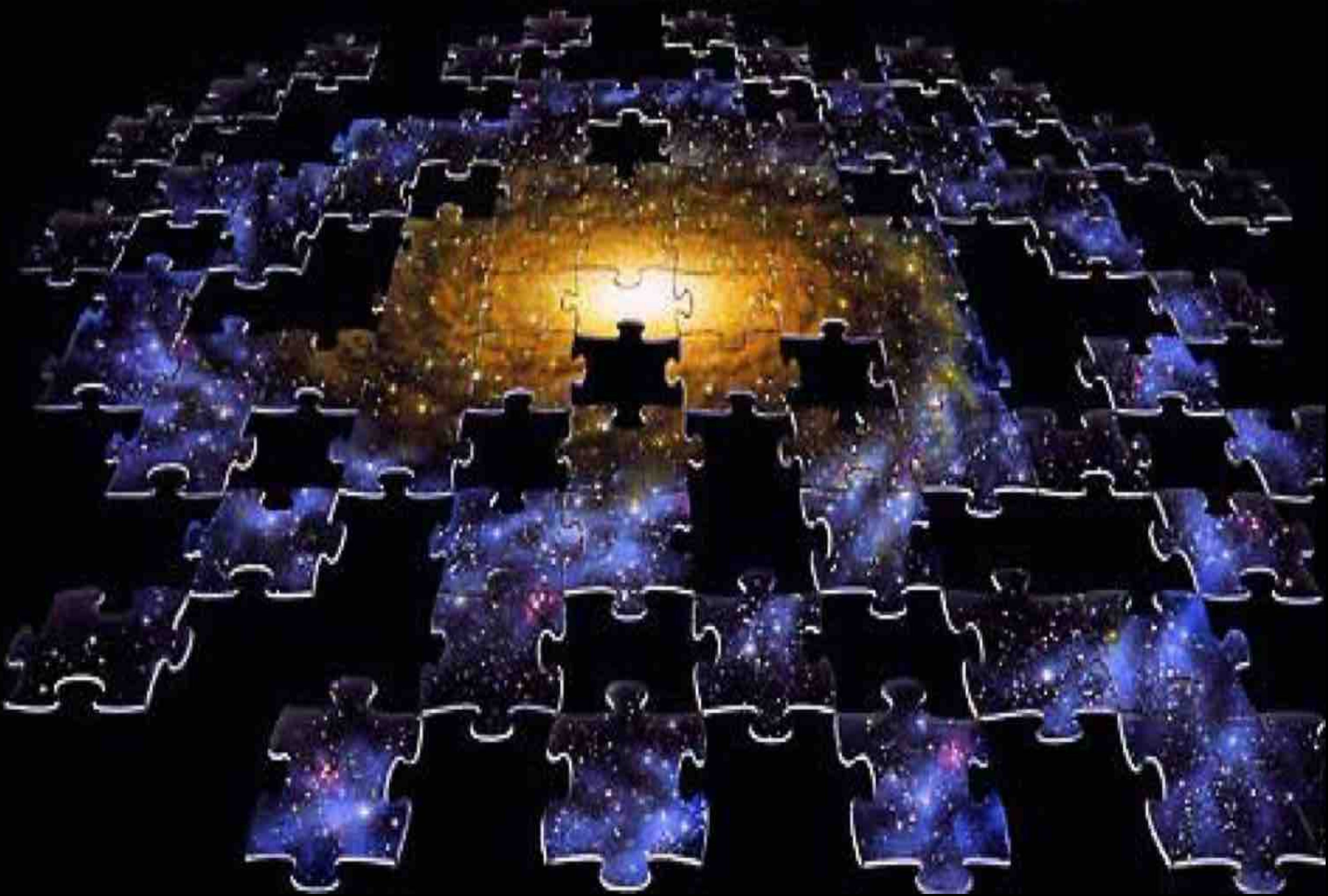
1556 sources
galactic coordinates

M.Ackermann et al. [Fermi Coll.] 3FHL: The Third Catalog of Hard Fermi-LAT Sources ApJS, 2017 232:18 arXiv:1702.00664

All-sky LAT Catalogs



Gamma- ν connection: Search for Dark Matter

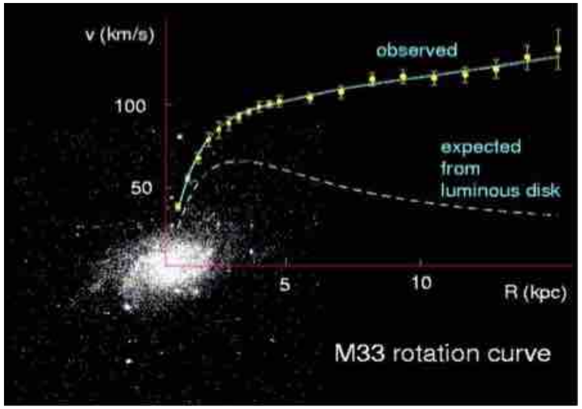


Dark Matter EVIDENCE

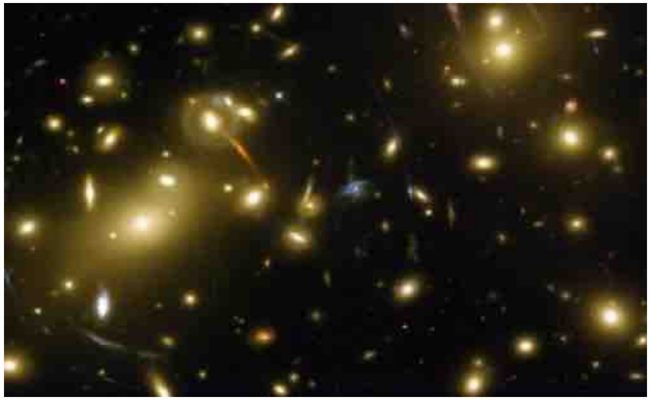
In 1933, the astronomer Zwicky realized that the mass of the luminous matter in the Coma cluster was much smaller than its total mass implied by the motion of cluster member galaxies.

Since then, even more evidence:

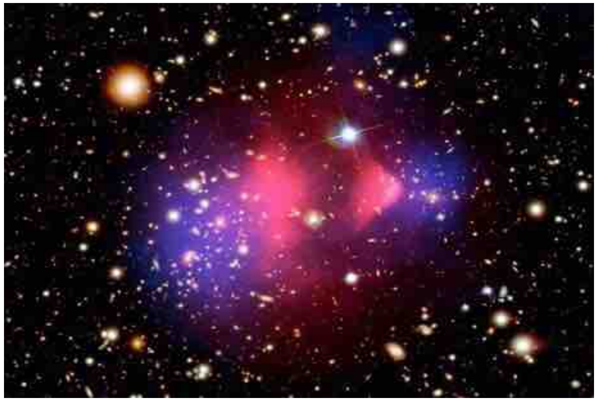
Rotation curves of galaxies



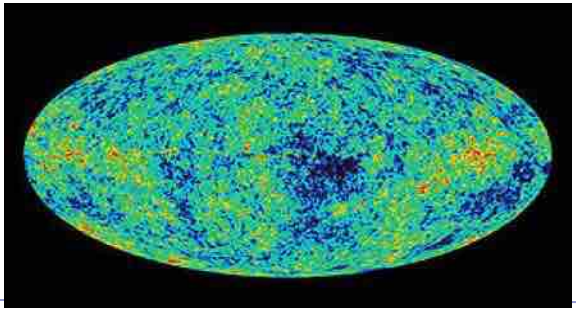
Gravitational lensing



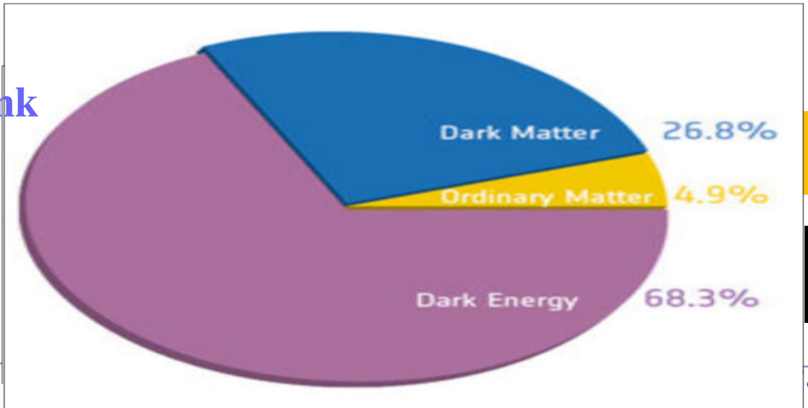
Bullet cluster



Structure formation as deduced from CMB



Data by Plank imply:



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

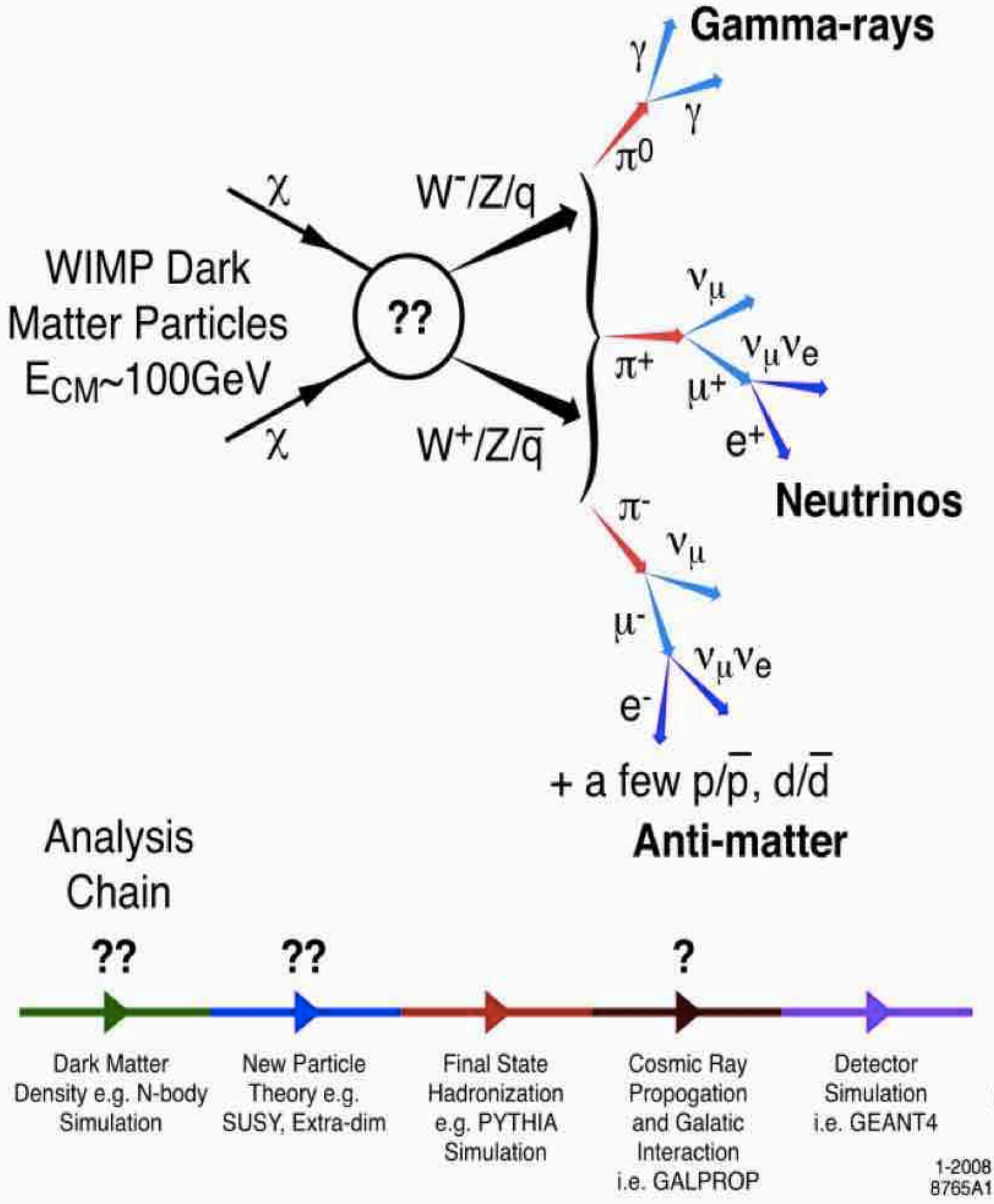
$\Omega_{M} \approx 4.9\%$

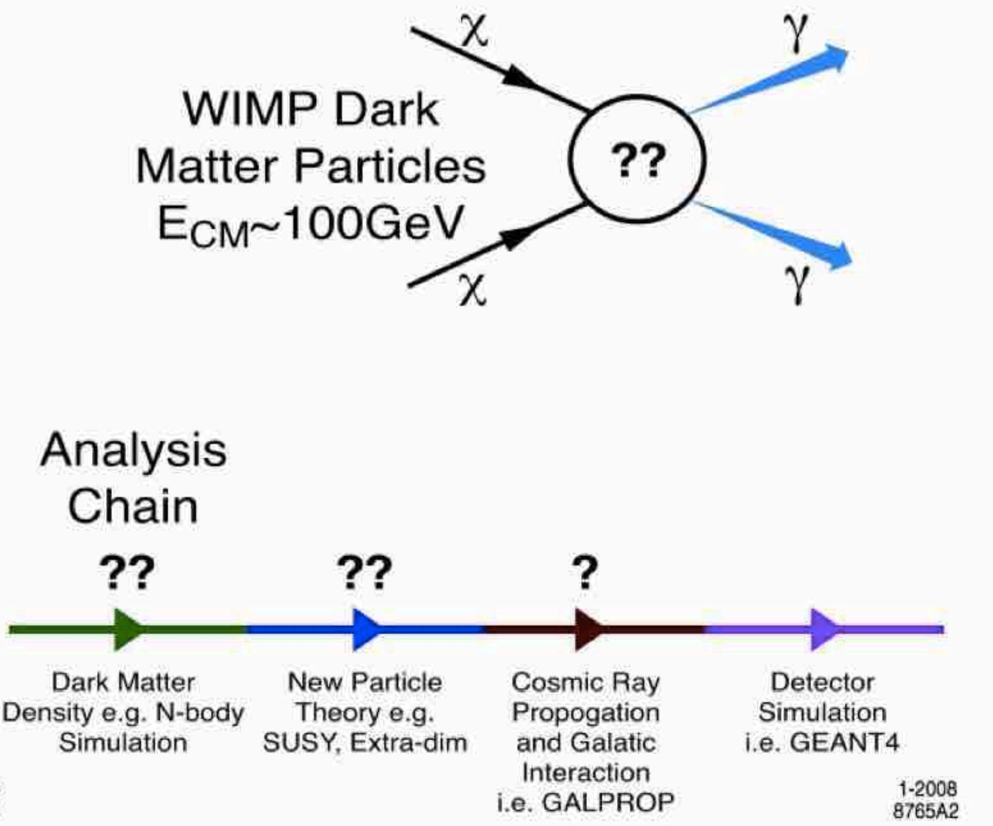
Neutralino WIMPs

Assume χ present in the Galactic halo

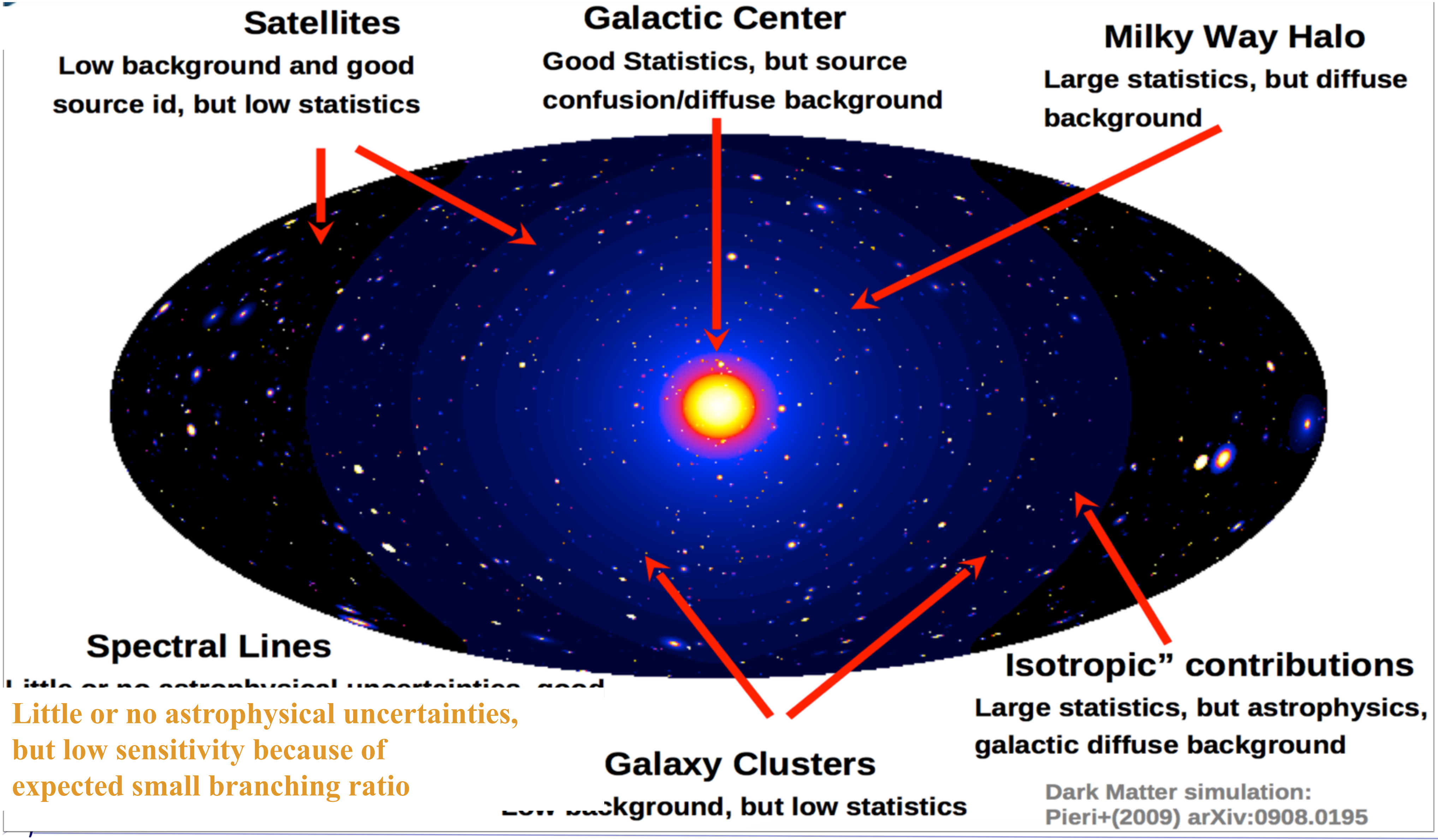
- χ is its own antiparticle **=>** can annihilate in galactic halo producing gamma-rays, antiprotons, positrons….
- Antimatter not produced in large quantities through standard processes (secondary production through p + p **-->** anti p + X)
- So, any extra contribution from exotic sources (χ χ annihilation)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

Annihilation channels





Dark Matter Search: Targets and Strategies



Satellites

Low background and good source id, but low statistics

Galactic Center

Good Statistics, but source confusion/diffuse background

Milky Way Halo

Large statistics, but diffuse background

Spectral Lines

Little or no astrophysical uncertainties, good

Little or no astrophysical uncertainties, but low sensitivity because of expected small branching ratio

Galaxy Clusters

Low background, but low statistics

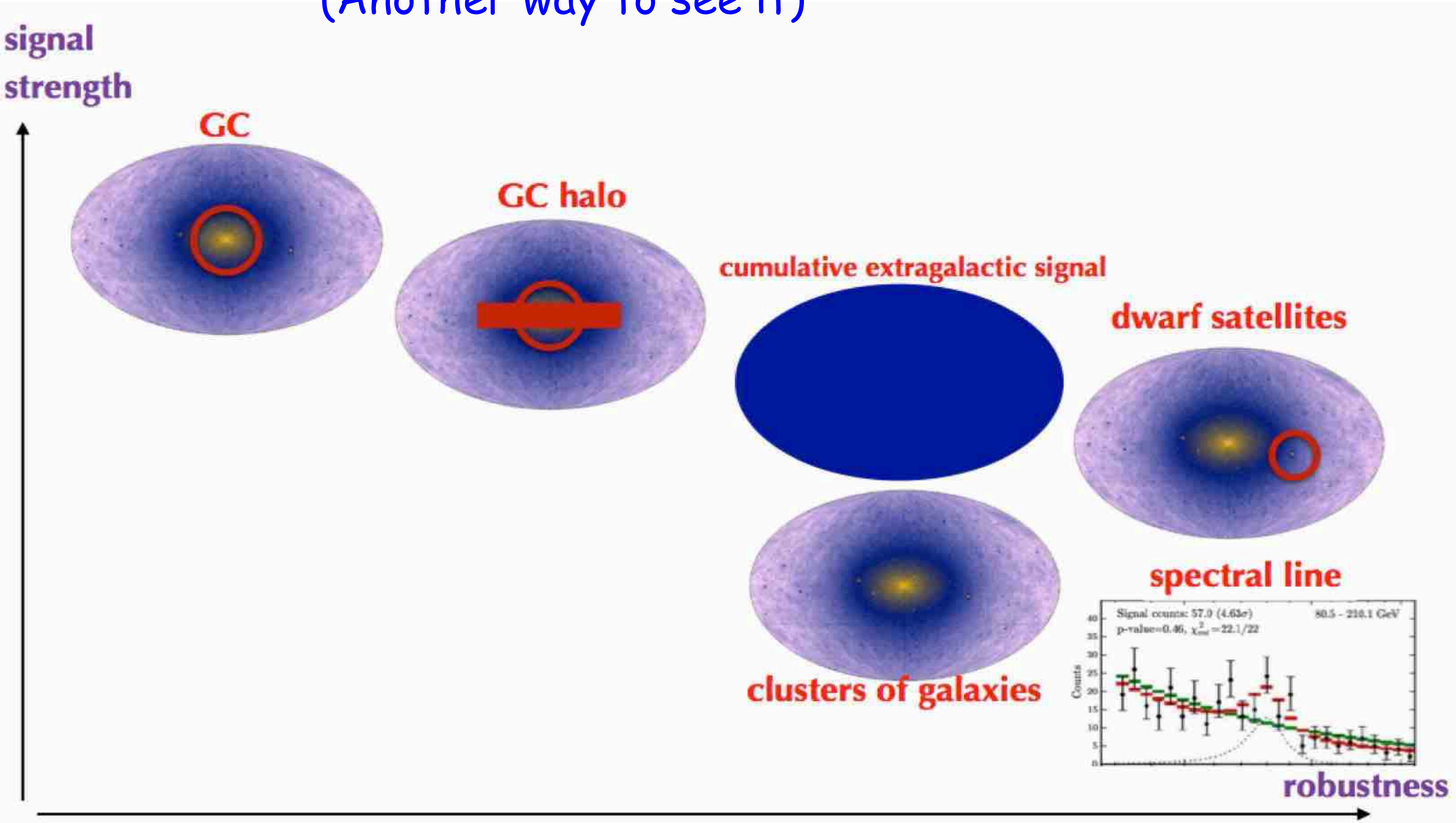
Isotropic" contributions

Large statistics, but astrophysics, galactic diffuse background

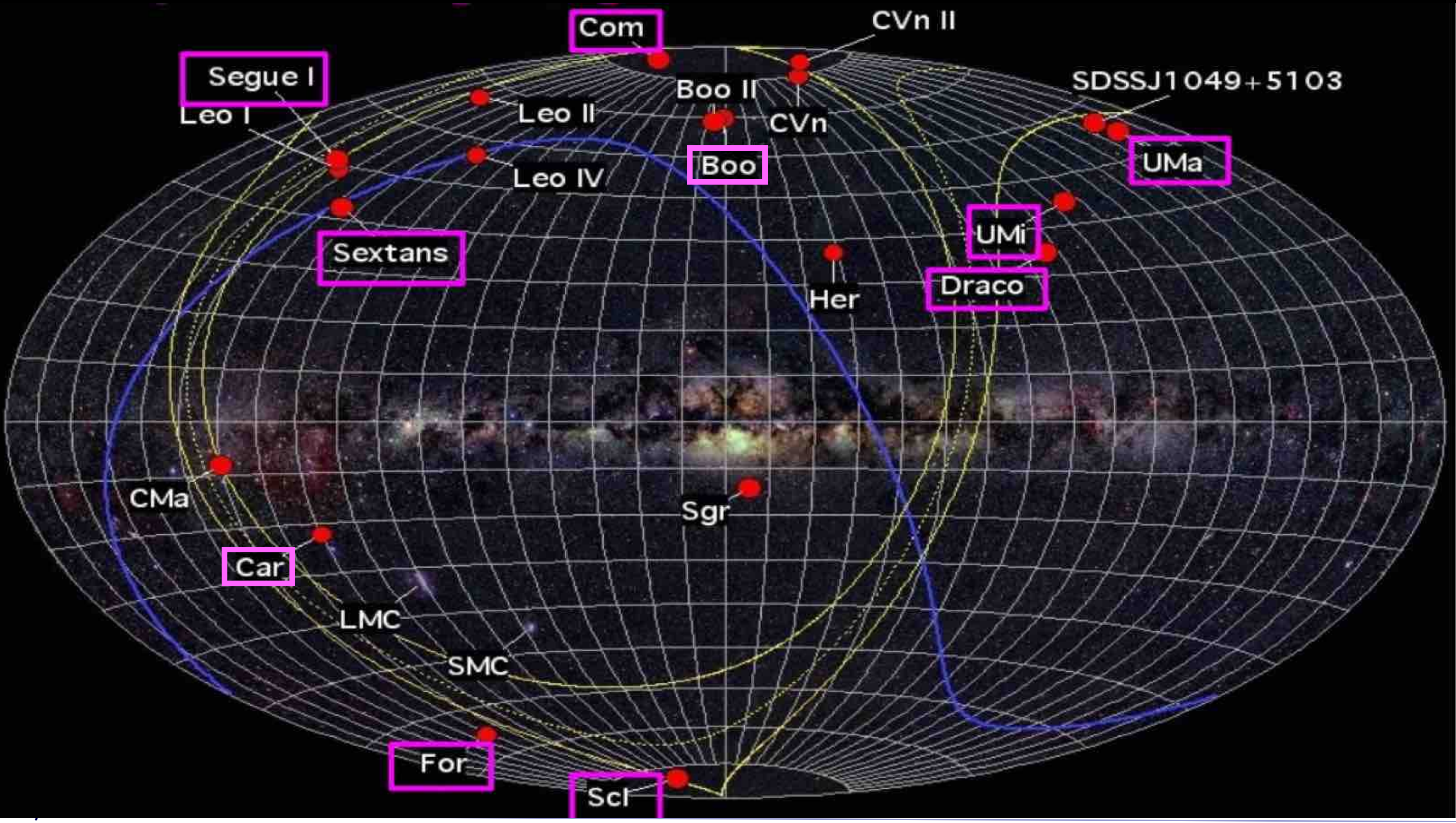
Dark Matter simulation:
Pieri+(2009) arXiv:0908.0195

Dark Matter Search: Targets and Strategies

(Another way to see it)



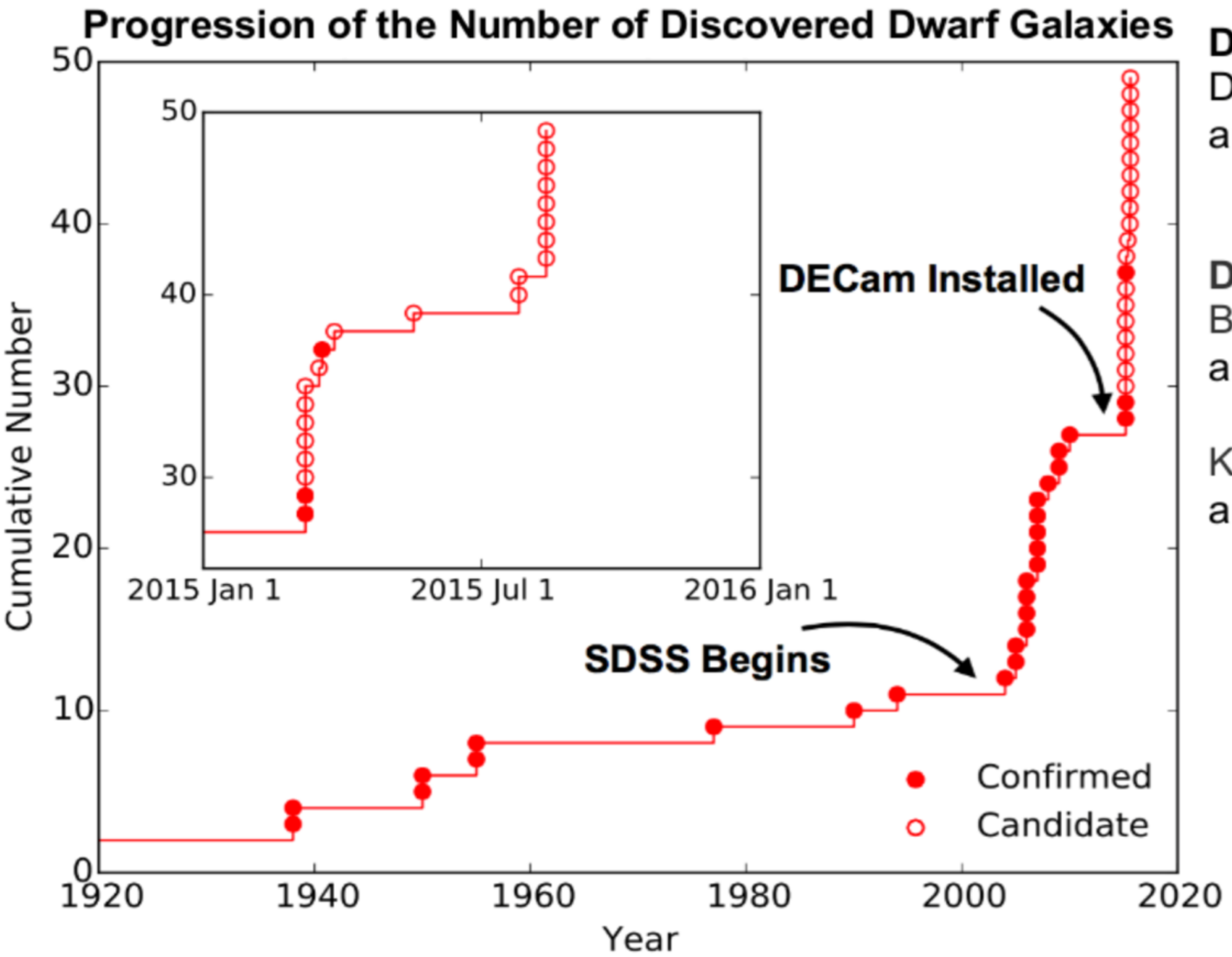
Dwarf spheroidal galaxies (dSph) : promising targets for DM detection



Dark Matter in the Milky Way (from simulations)

Springel et al. (Nature, 2005

Dwarf Spheroidal Galaxies: Growing number of known targets



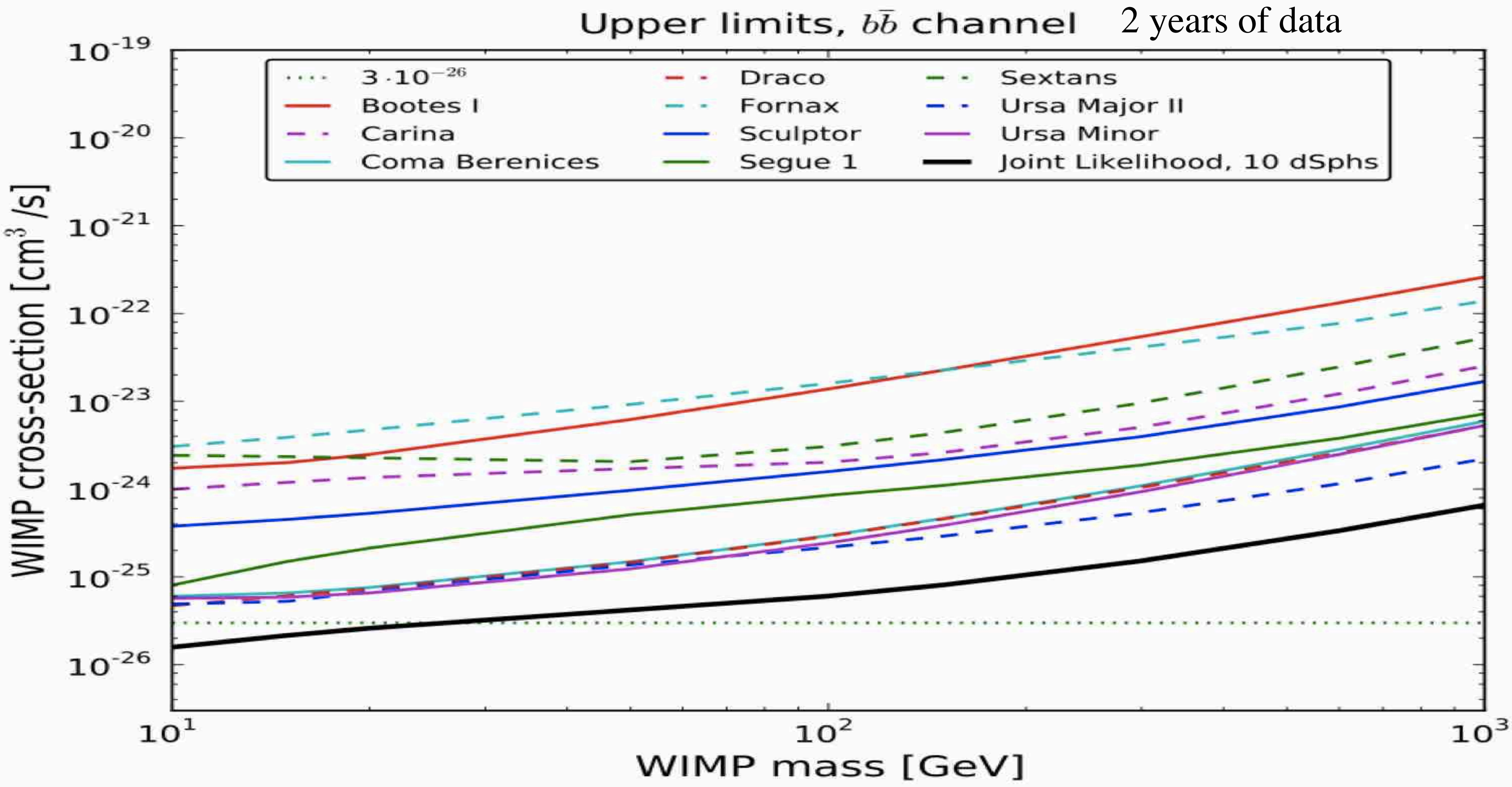
DES Year 2 Data:
Drlica-Wagner+,
arXiv:1508.03622

DES Year 1 Data:
Bechtol+:
arXiv:1503.02584

Koposov+:
arXiv:1503.02079

Dwarf Spheroidal Galaxies combined analysis

2 years of data

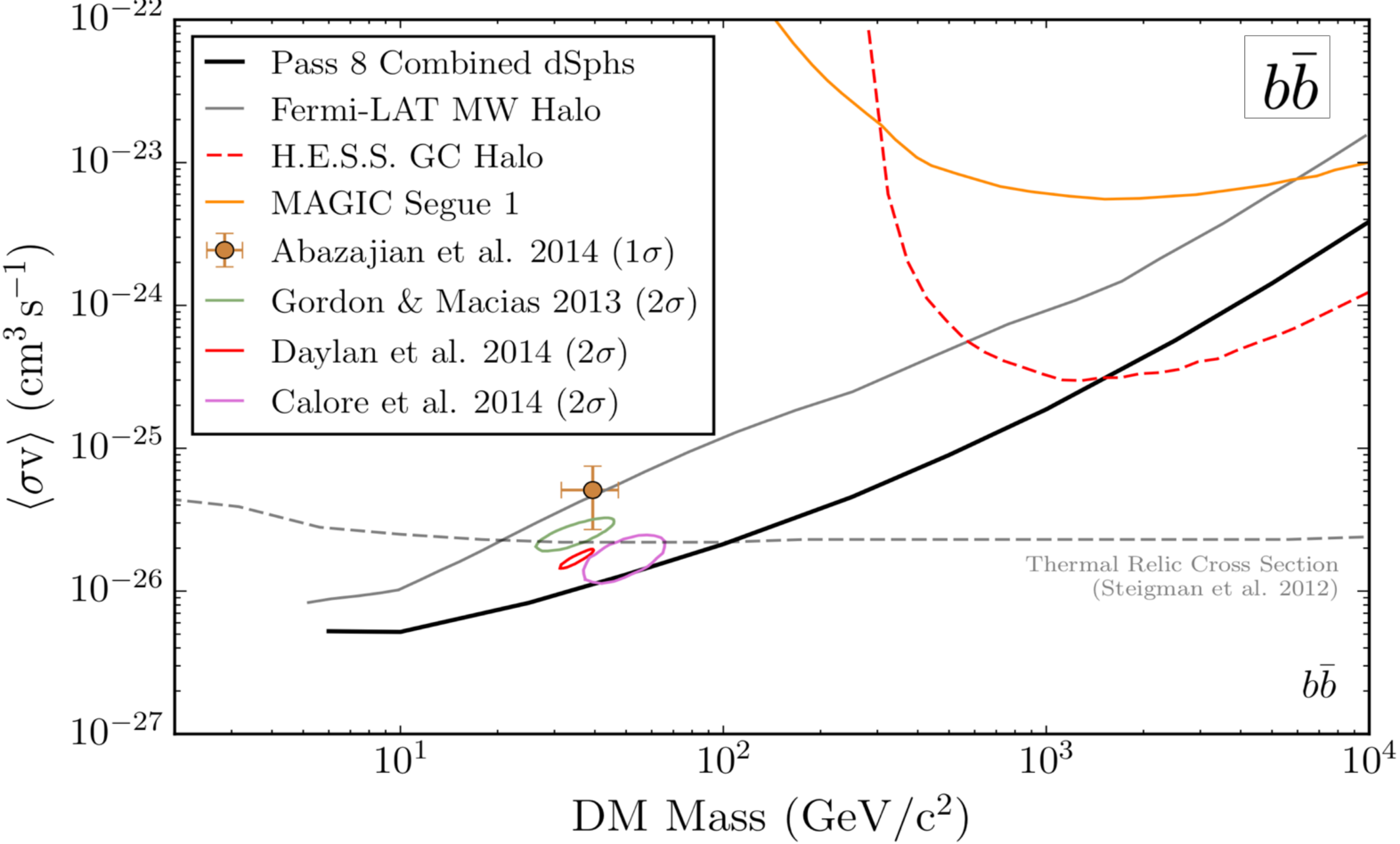


robust constraints including J-factor uncertainties from the stellar data statistical analysis

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

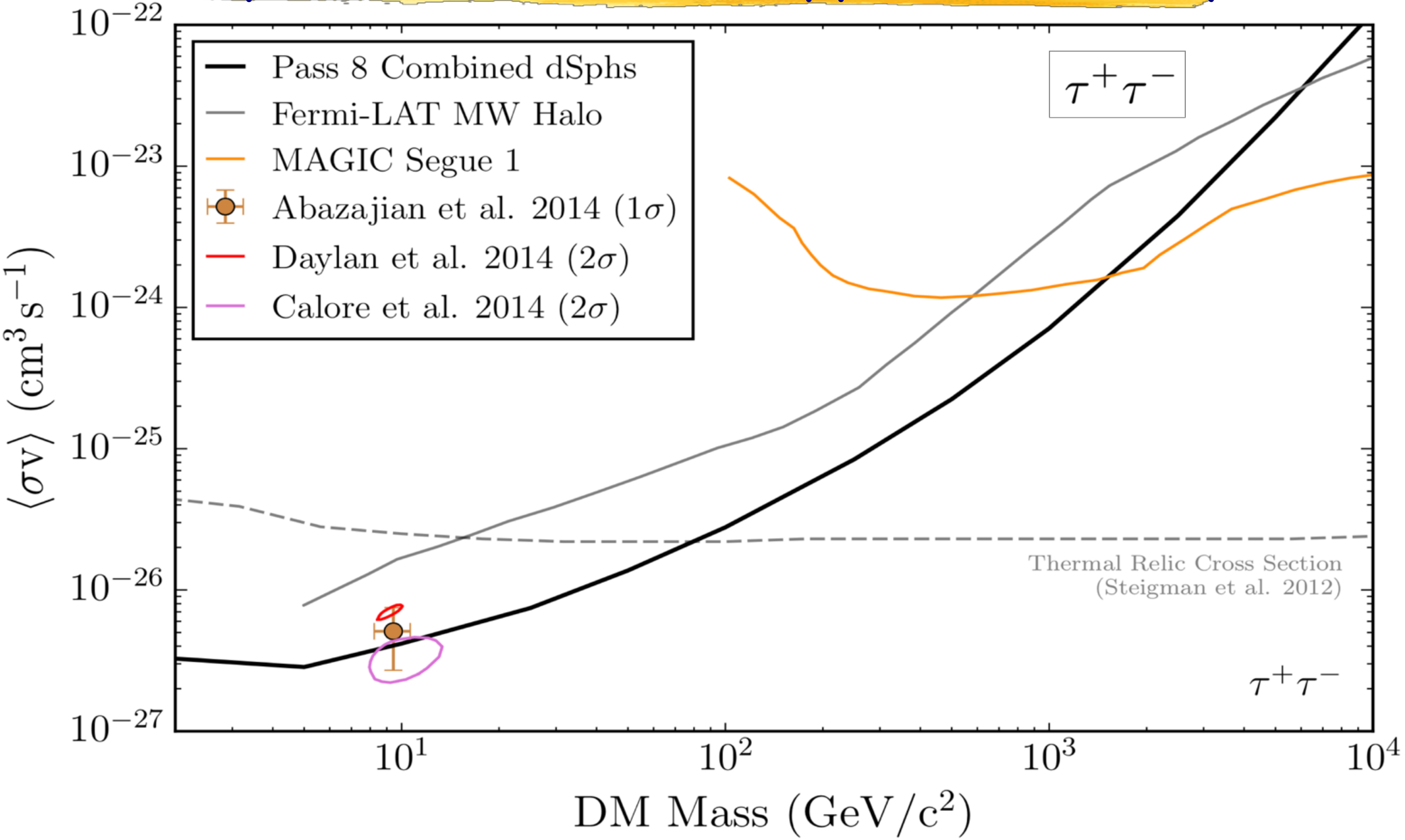
Fermi Lat Coll., PRL 107, 241302 (2011) [arXiv:1108.3546]

Dwarf Spheroidal Galaxies upper-limits (6 years)



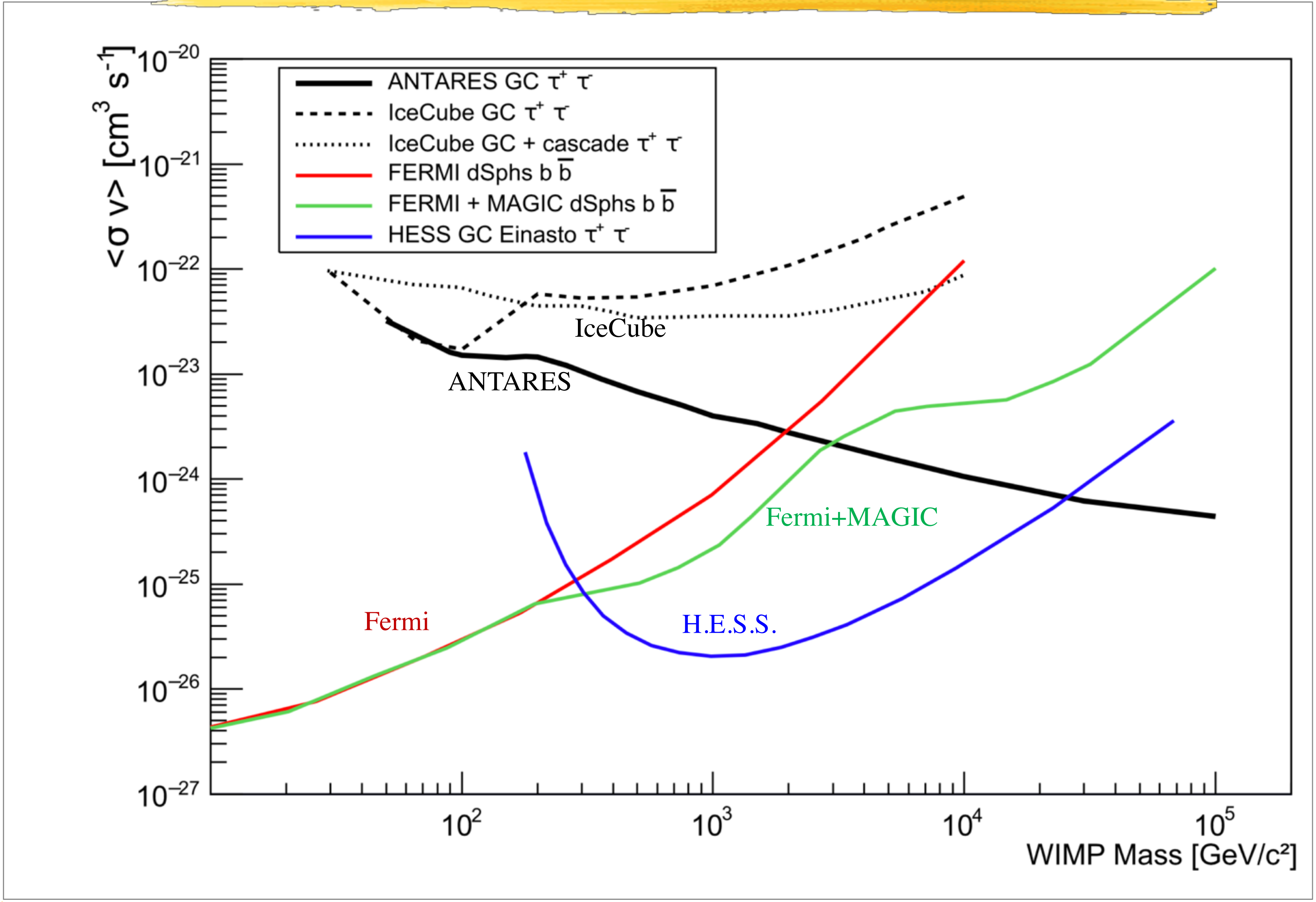
M.Ackermann et al., [Fermi Coll.] PRL 115, 231301 (2015) [arXiv:1503.02641]

Dwarf Spheroidal Galaxies upper-limits (6 years)



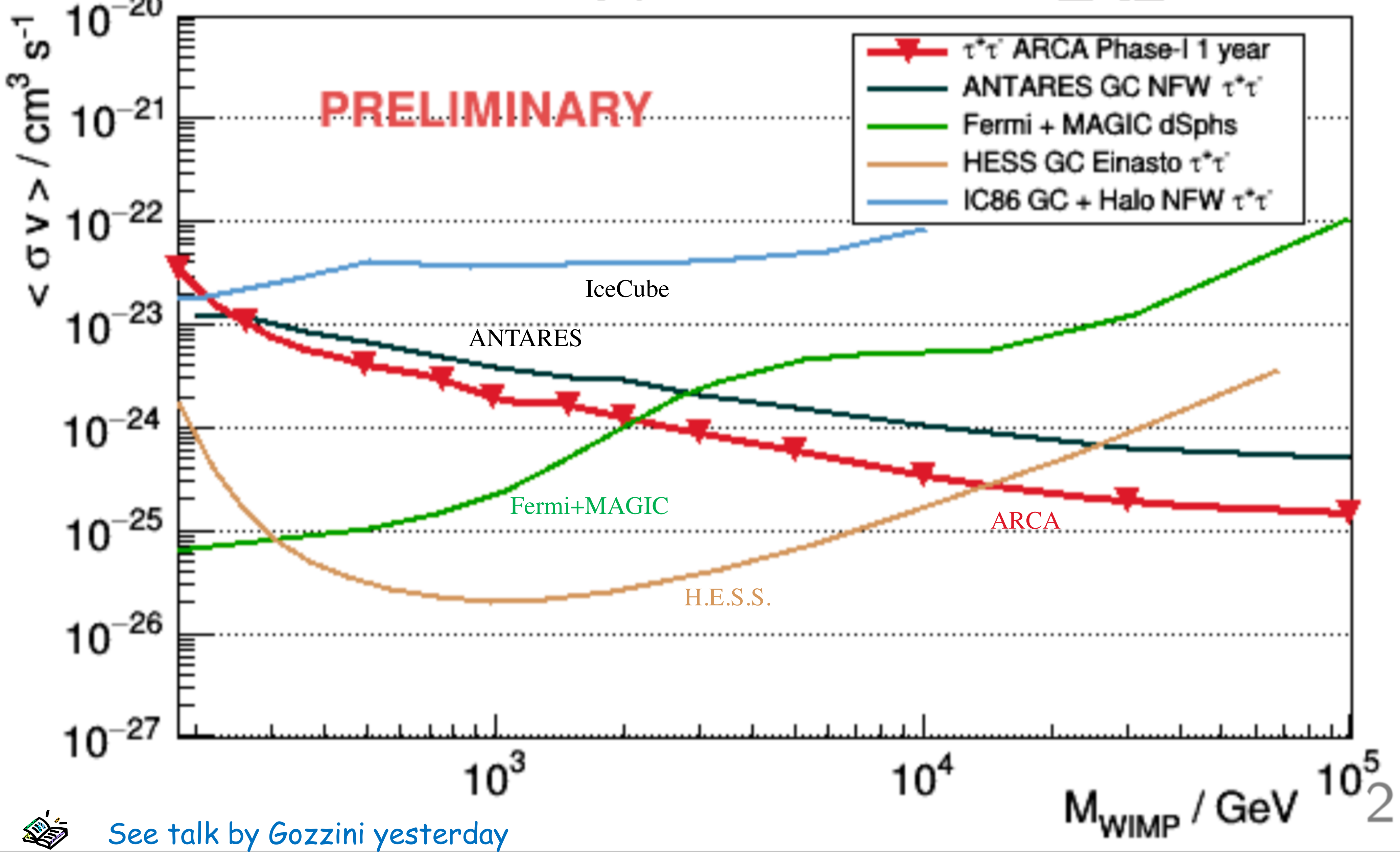
M.Ackermann et al., [Fermi Coll.] PRL 115, 231301 (2015) [arXiv:1503.02641]

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



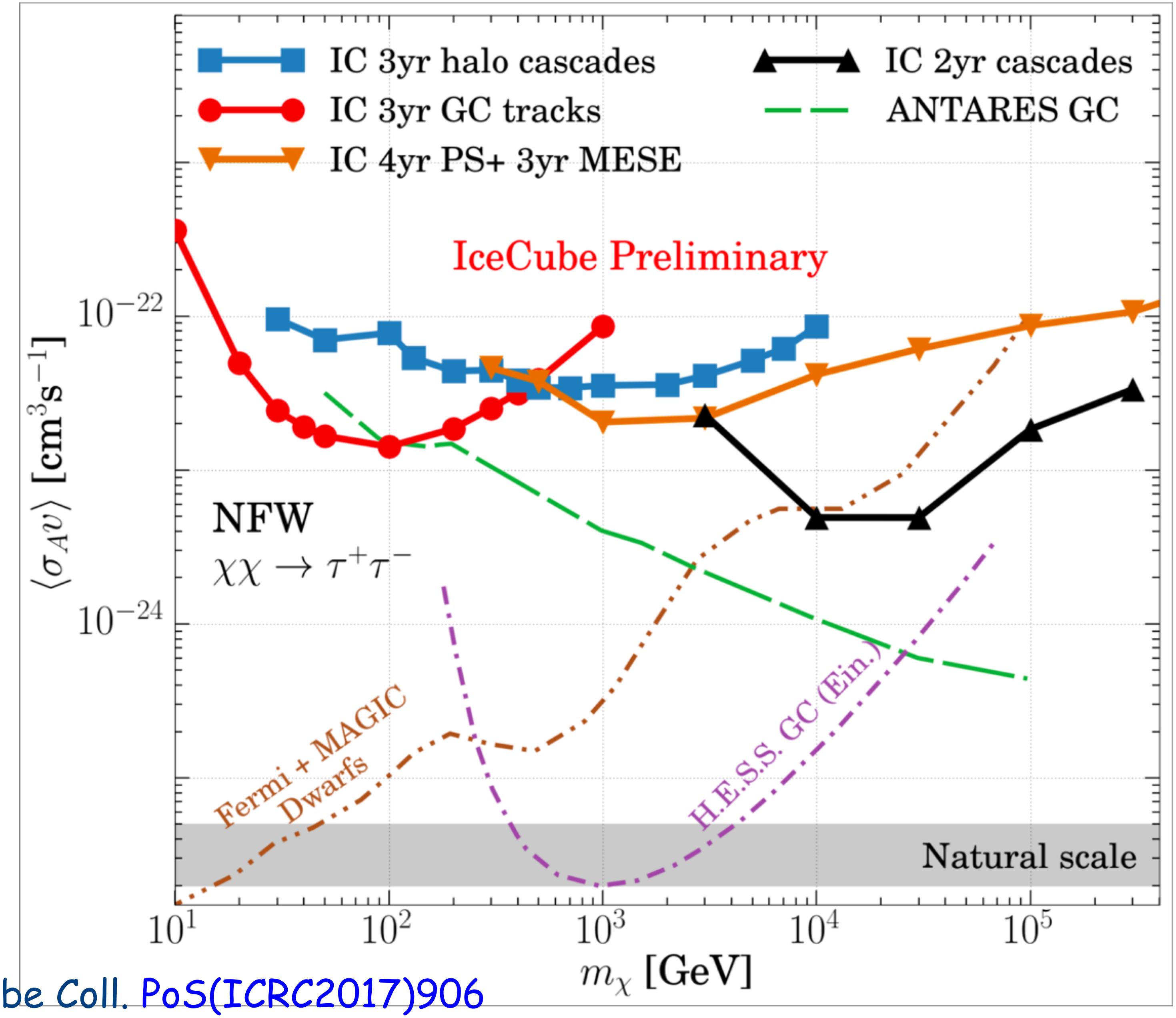
A. Albert, et al. ANTARES Coll. Physics Letters B 769 (2017) 249–254

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



See talk by Gozzini yesterday

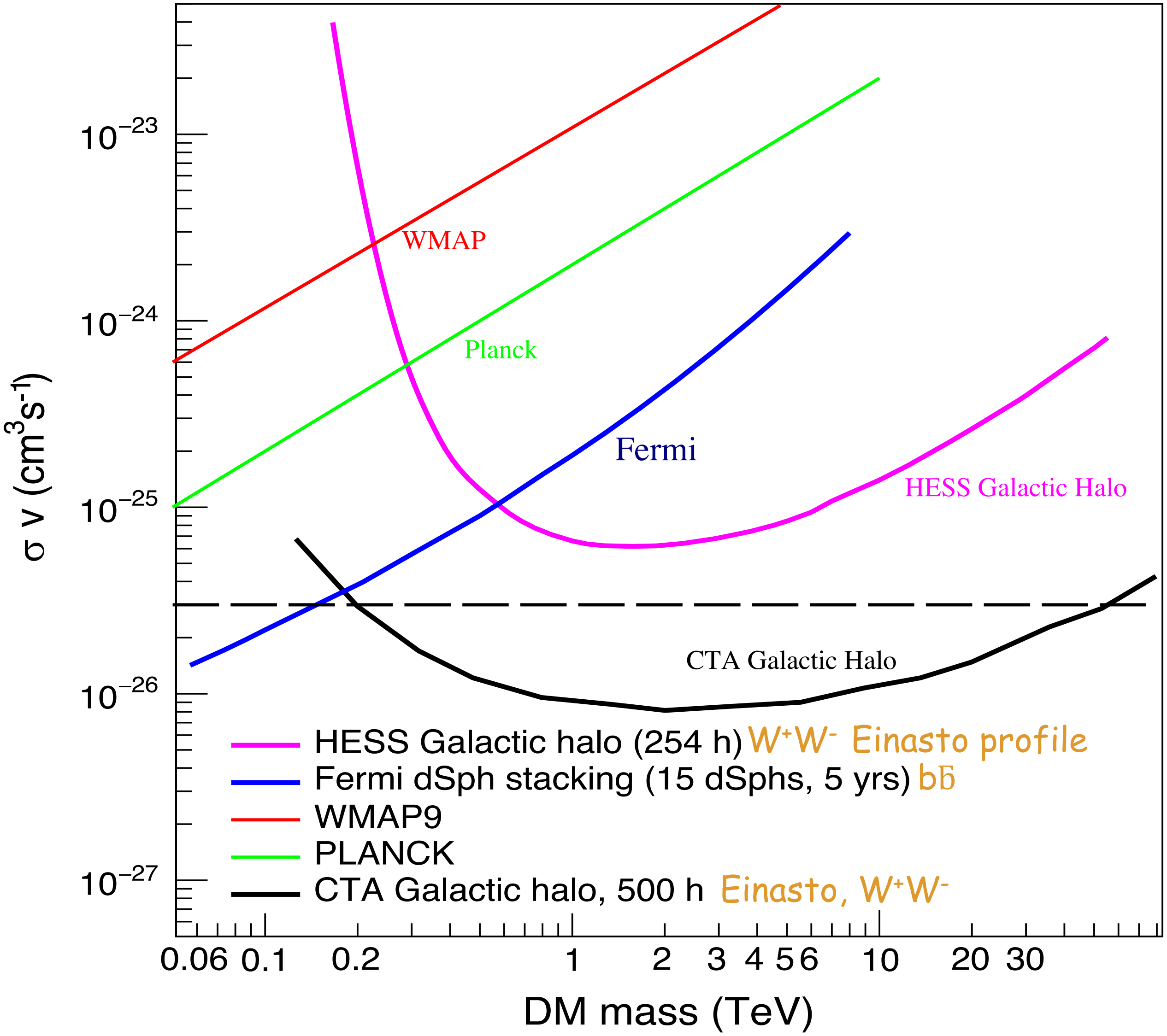
HESS, FERMI, Ice Cube, ANTARES Dark Matter upper-limits update



S.Flis for the Ice Cube Coll. PoS(ICRC2017)906

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%



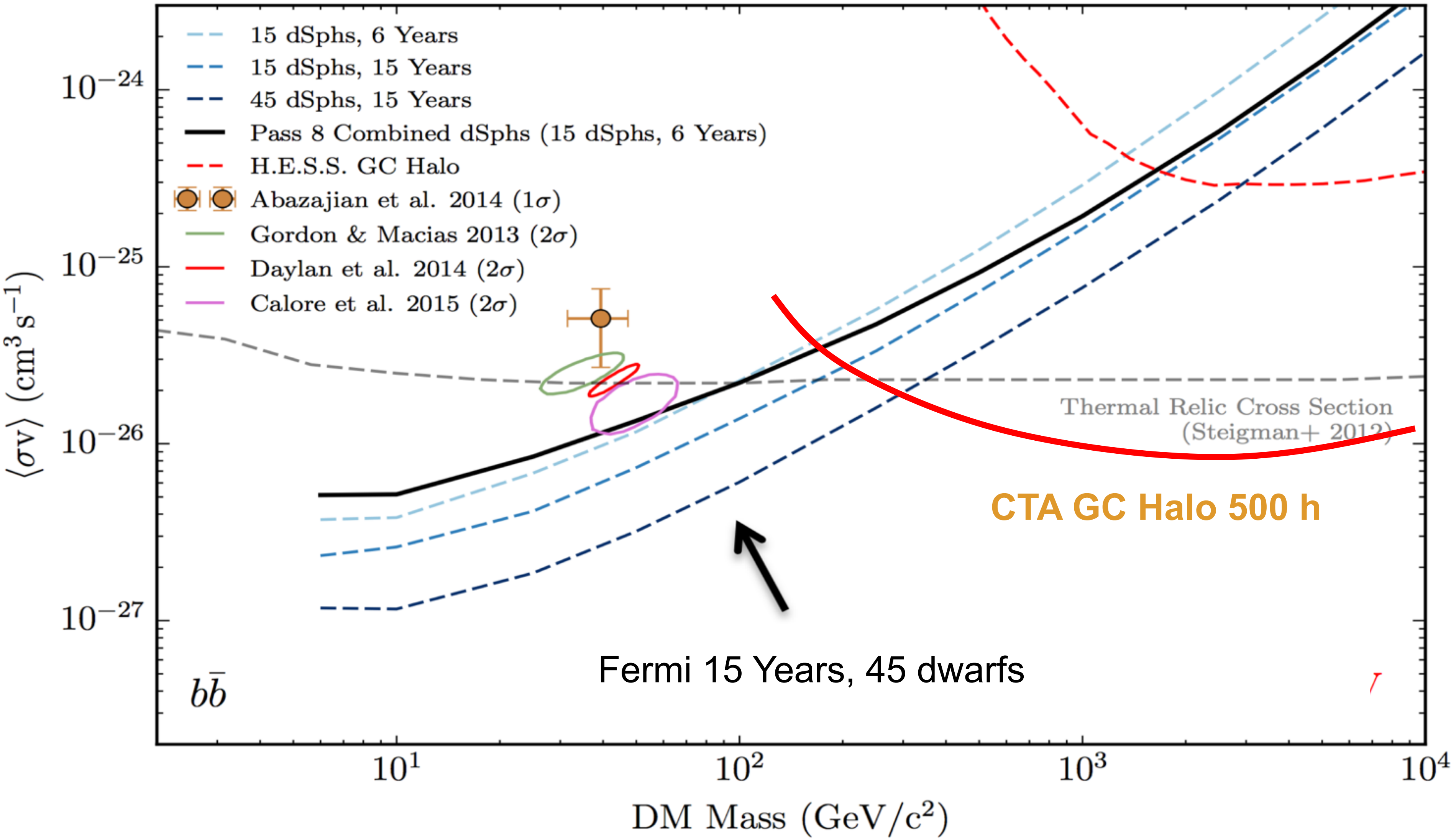
W^+W^- Einasto profile

$b\bar{b}$

Einasto, W^+W^-

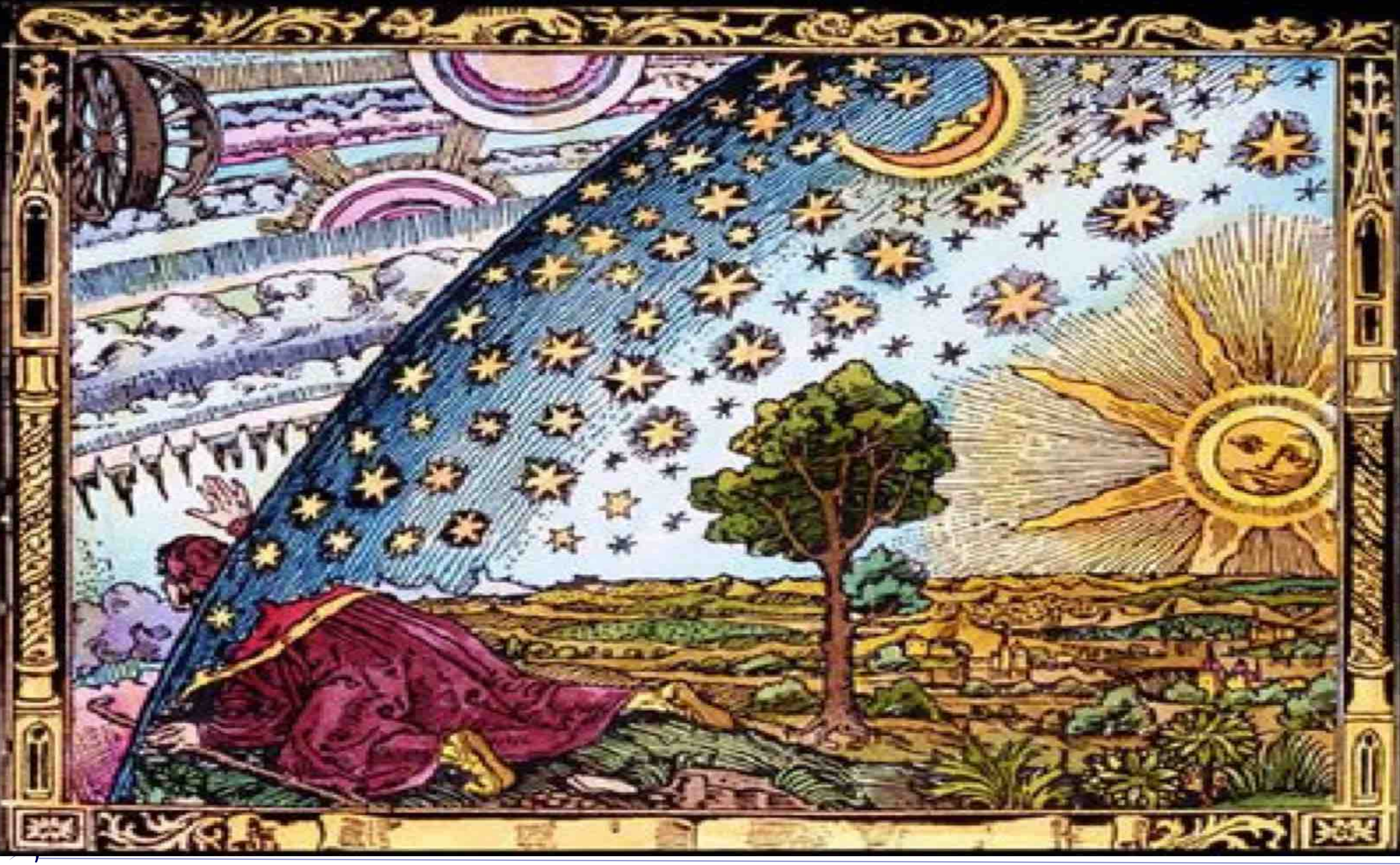
A.Morselli for the CTA Consortium PoS(ICRC2017)921 [arXiv:1709.01483]

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

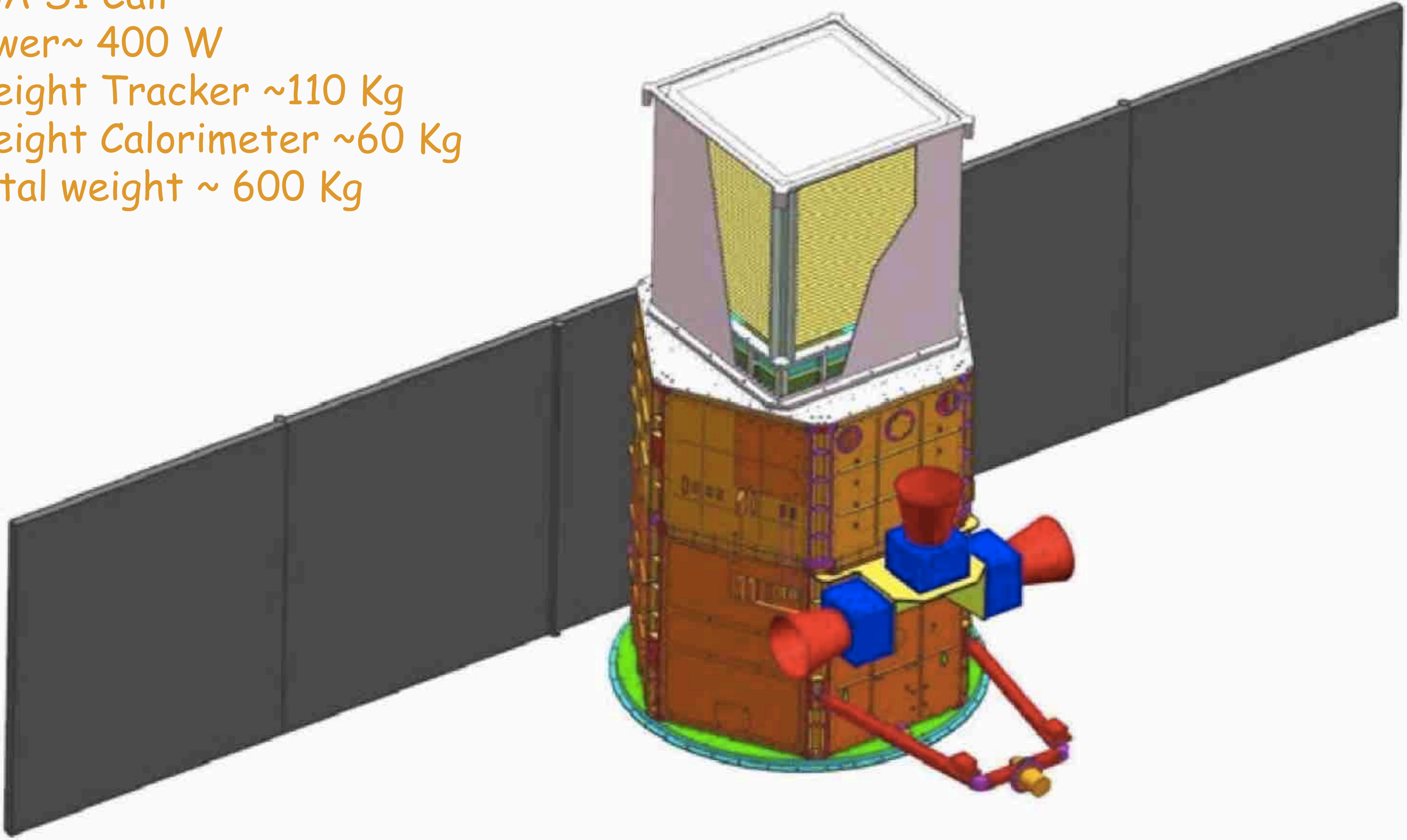
The Low Energy Frontier



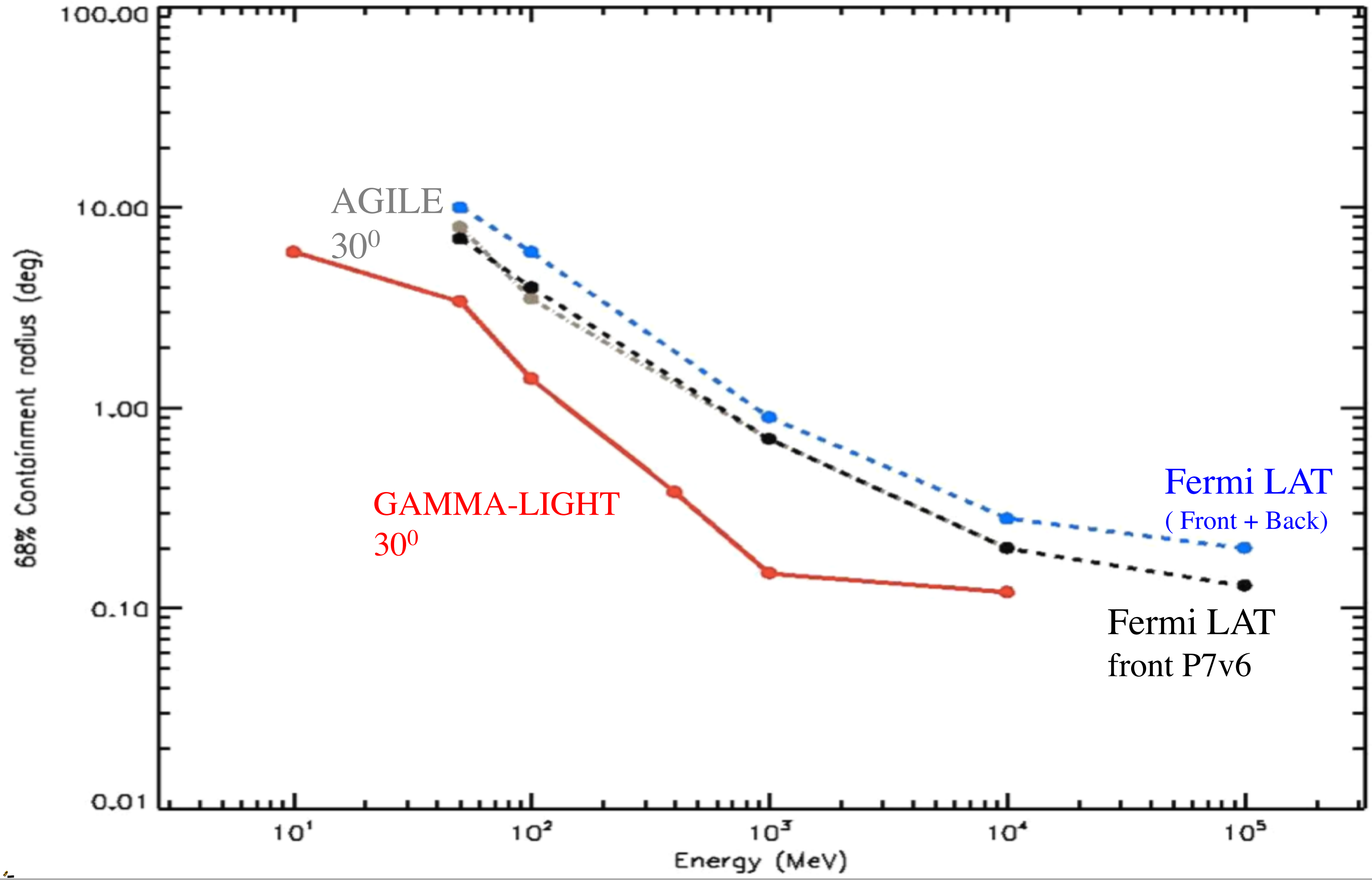
- 1-100 MeV unexplored domain for
  - Dark Matter searches
  - Galactic compact stars and nucleosynthesis
  - Cosmic rays
  - Relativistic jets, microquasars
  - Blazars
  - Gamma-Ray Bursts
  - Solar physics
- and…
  - Terrestrial Gamma-Ray Flashes

Gamma-light project

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

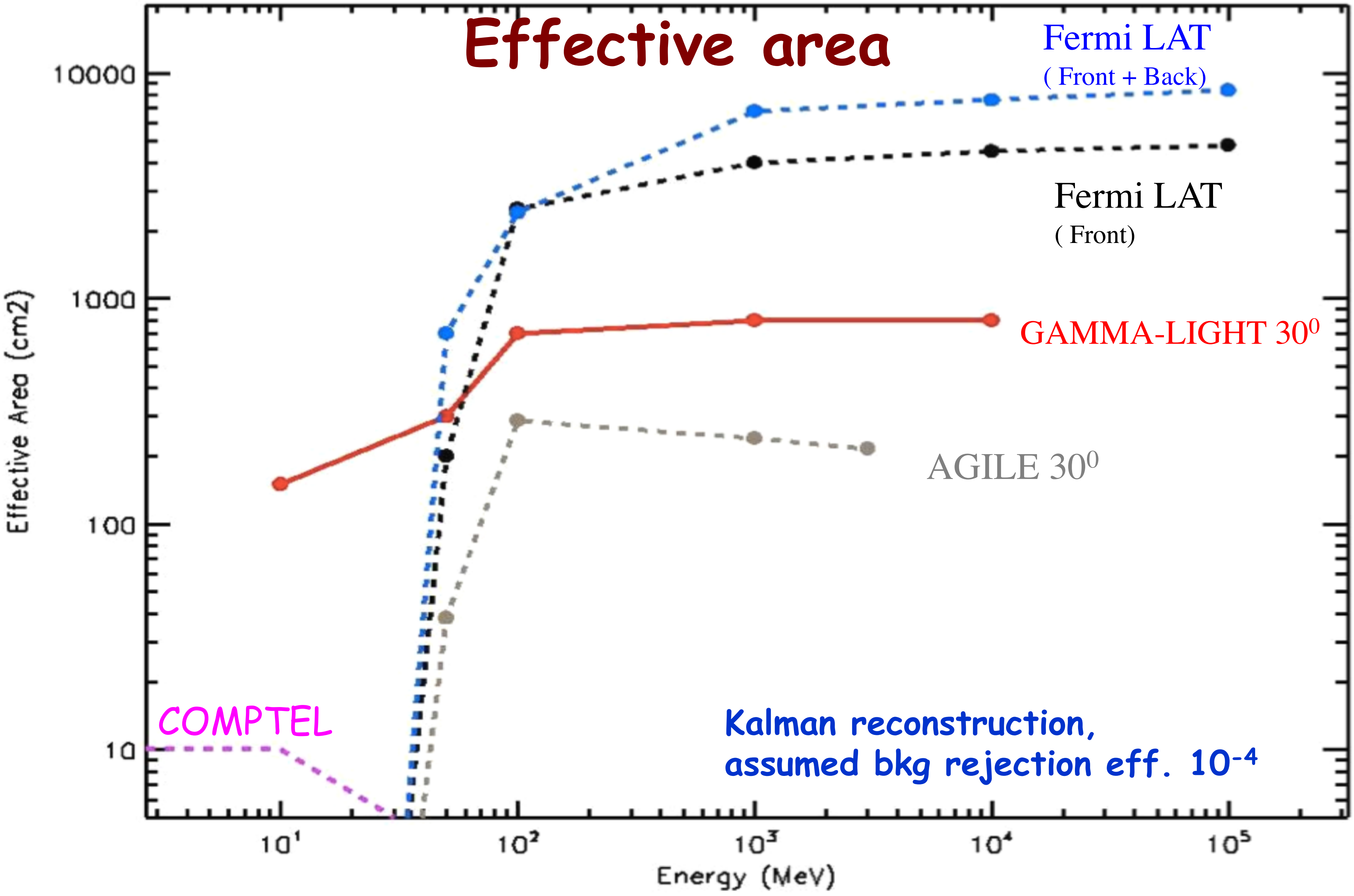


Gamma-Light Point Spread Function (angular resolution)



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

Effective area

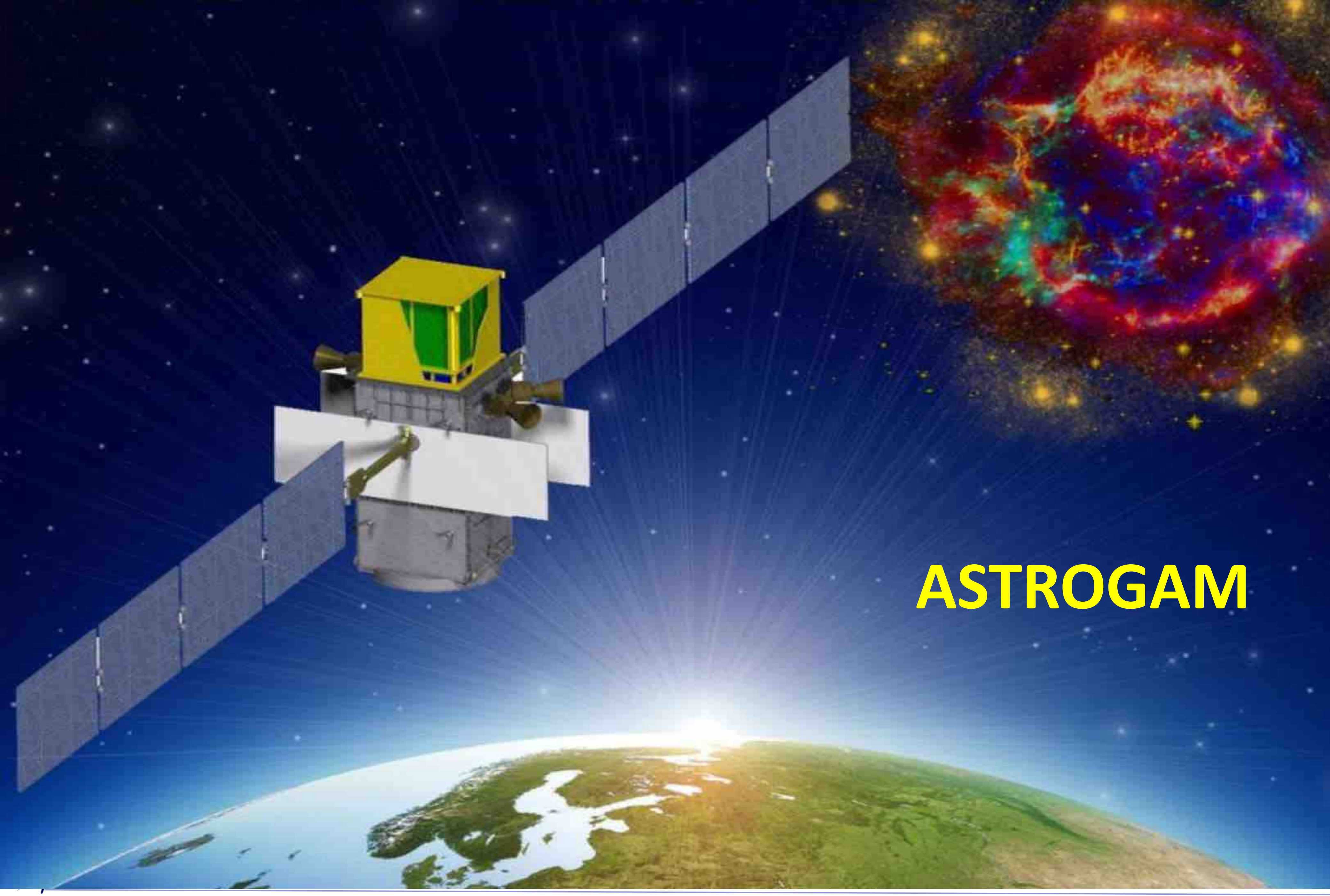


Kalman reconstruction,
assumed bkg rejection eff. 10^{-4}

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

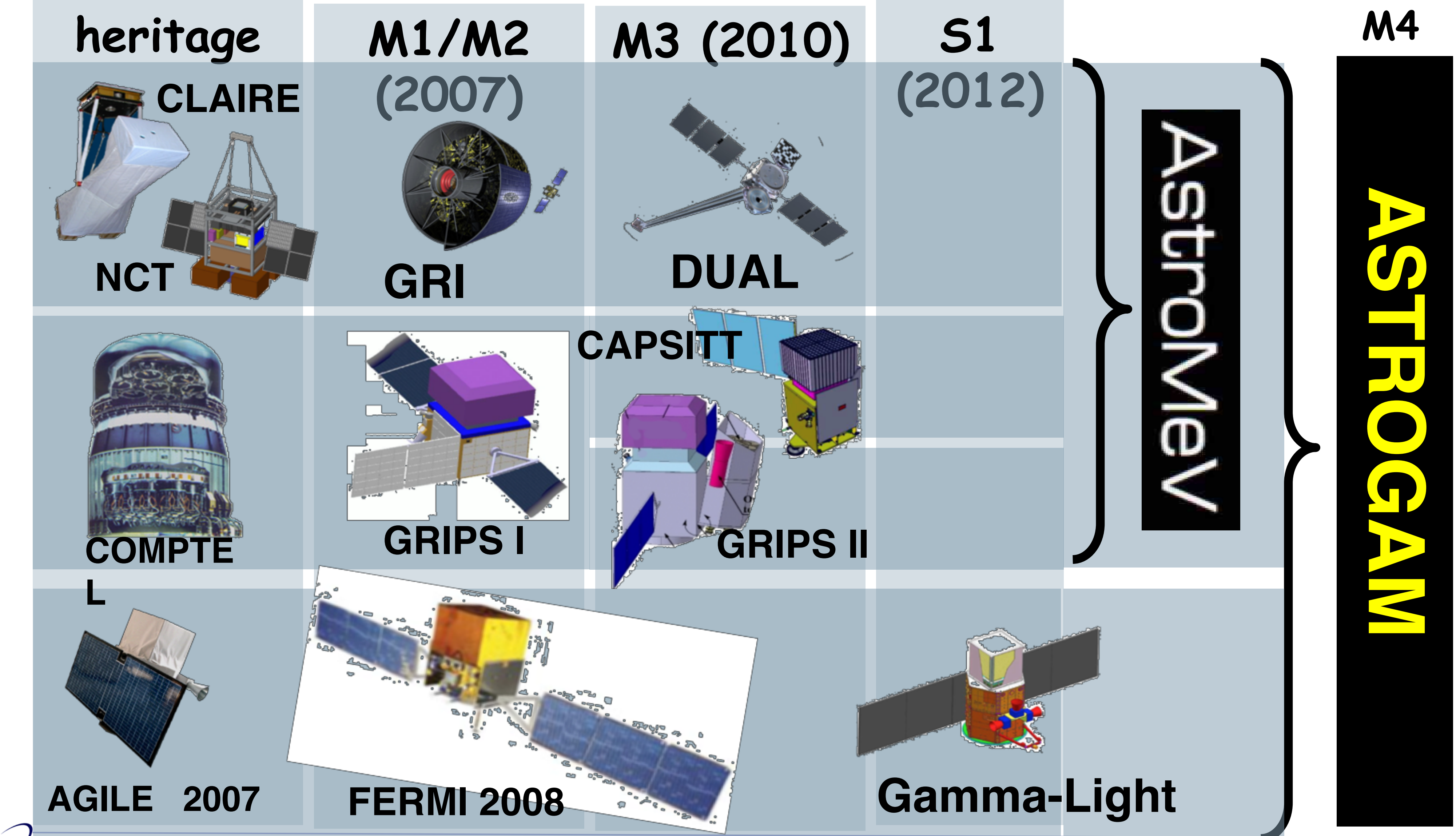
ESA M-4 Call

- **quite different from previous Medium-sized Mission Calls (Solar Orbiter, EUCLID, PLATO);**
- **total ESA budget: 450 Meuro.**
- **guidelines for an ‘‘ESA-only’’ mission:**
  - **Payload mass: 300 kg;**
  - **total spacecraft mass: 800 kg.**



ASTROGAM

ASTROGAM a unified proposal from the entire gamma-ray community



heritage

M1/M2 (2007)

M3 (2010)

S1 (2012)

M4

CLAIRE

NCT

GRI

DUAL

CAPSITT

COMPTEL

GRIPS I

GRIPS II

AGILE 2007

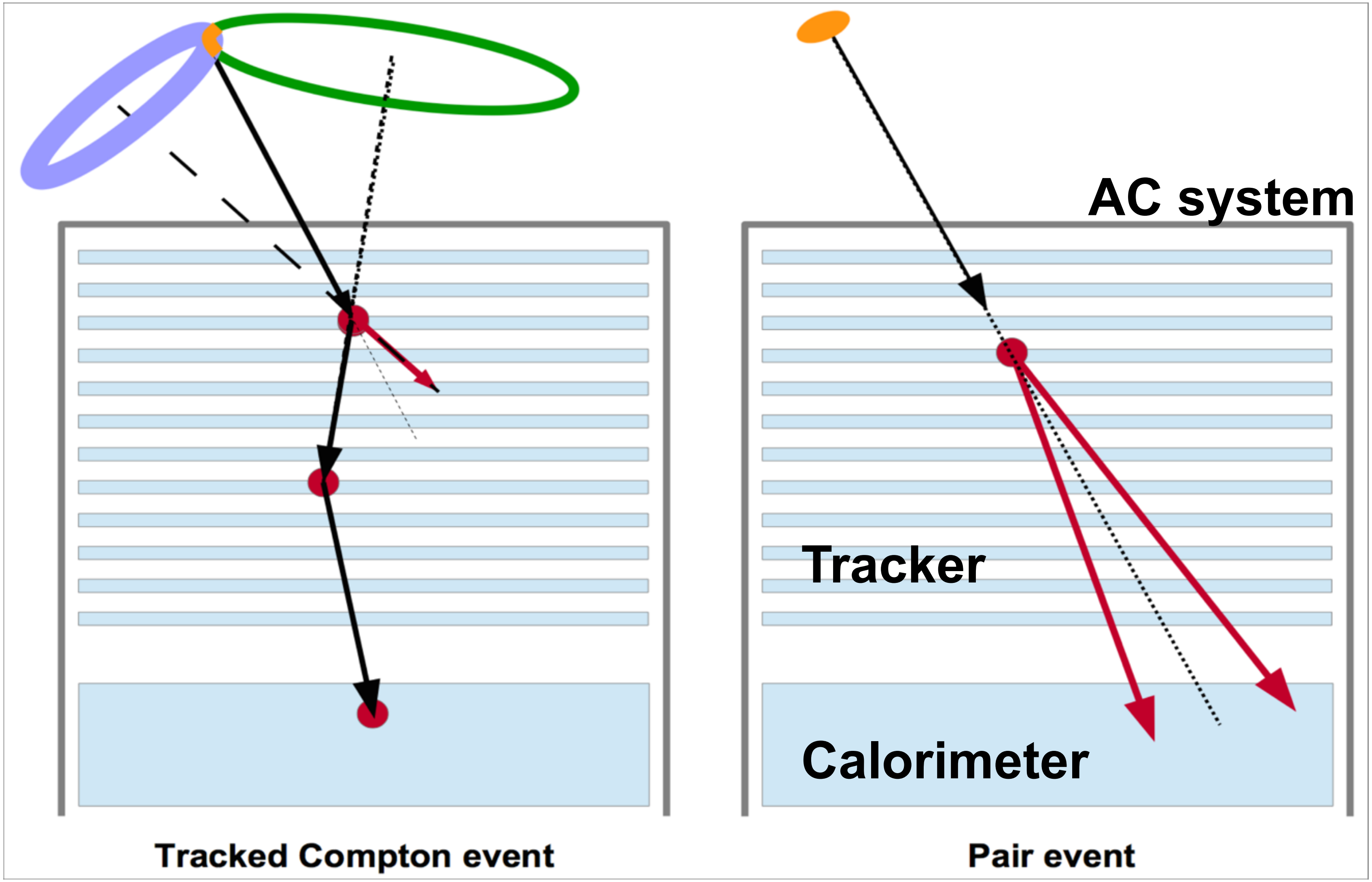
FERMI 2008

Gamma-Light

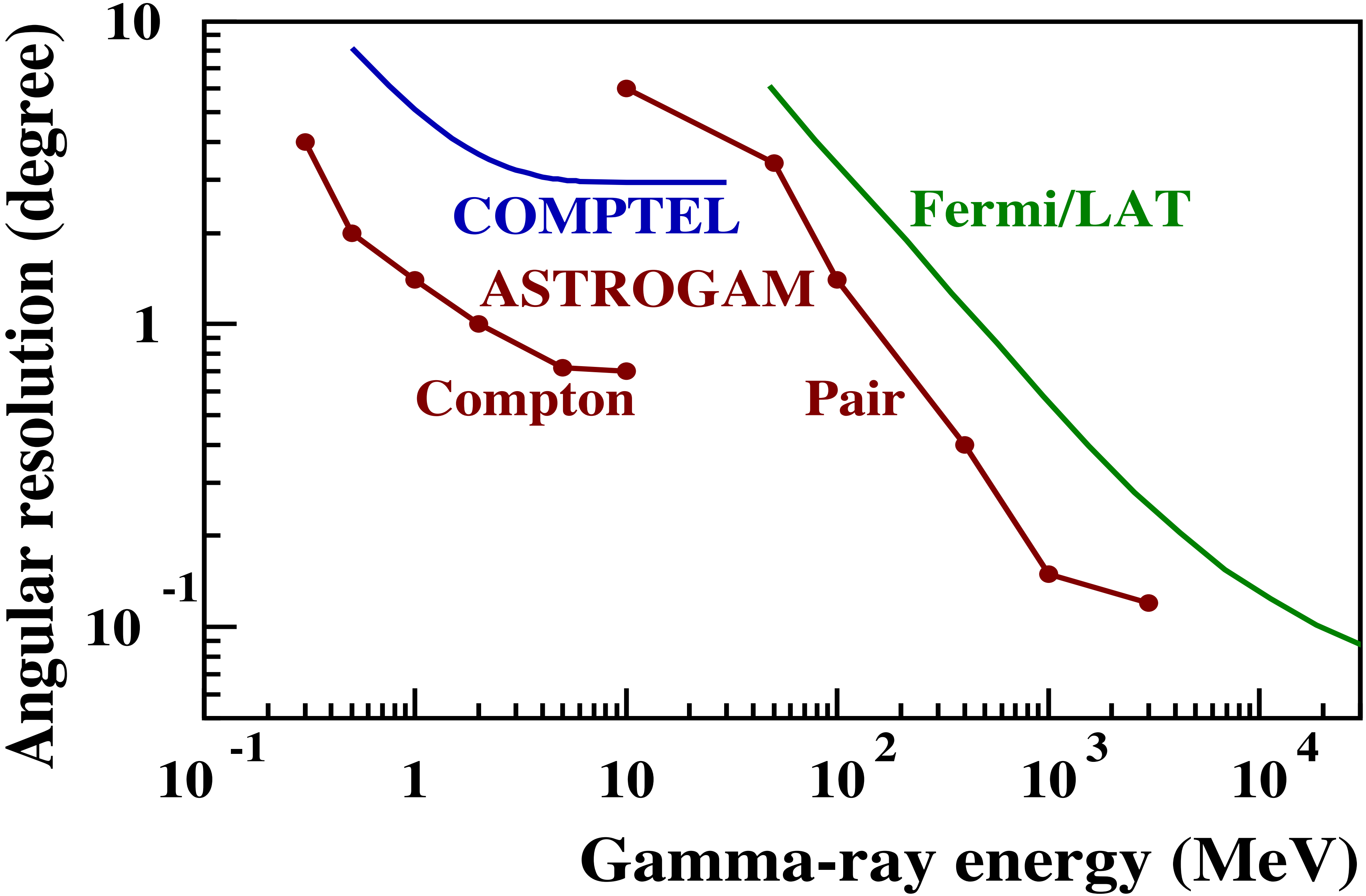
AstroMeV

ASTROGAM

An instrument that combine two detection techniques

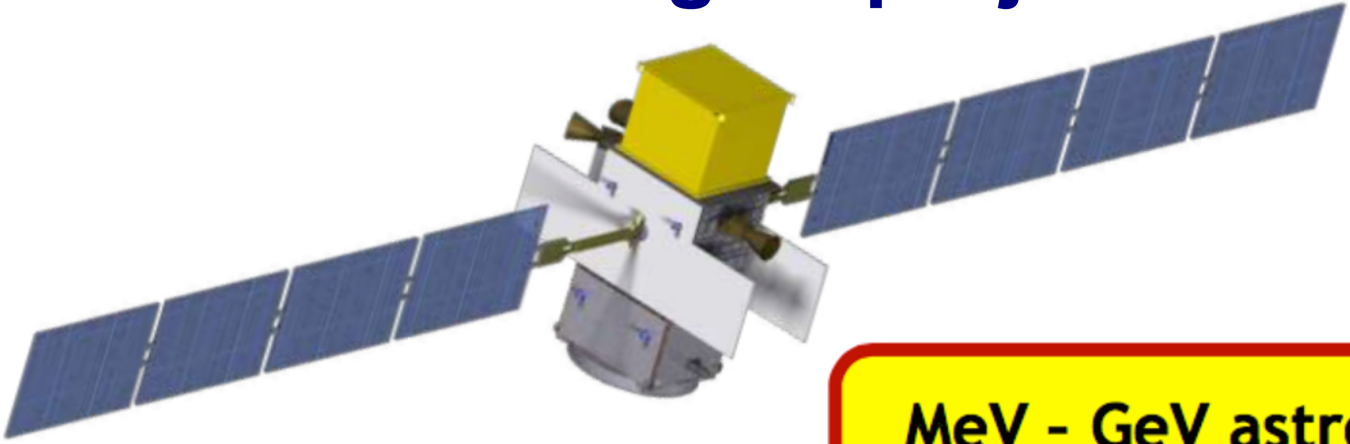


ASTROGAM Angular Resolution



The next gamma-ray MeV-GeV mission:

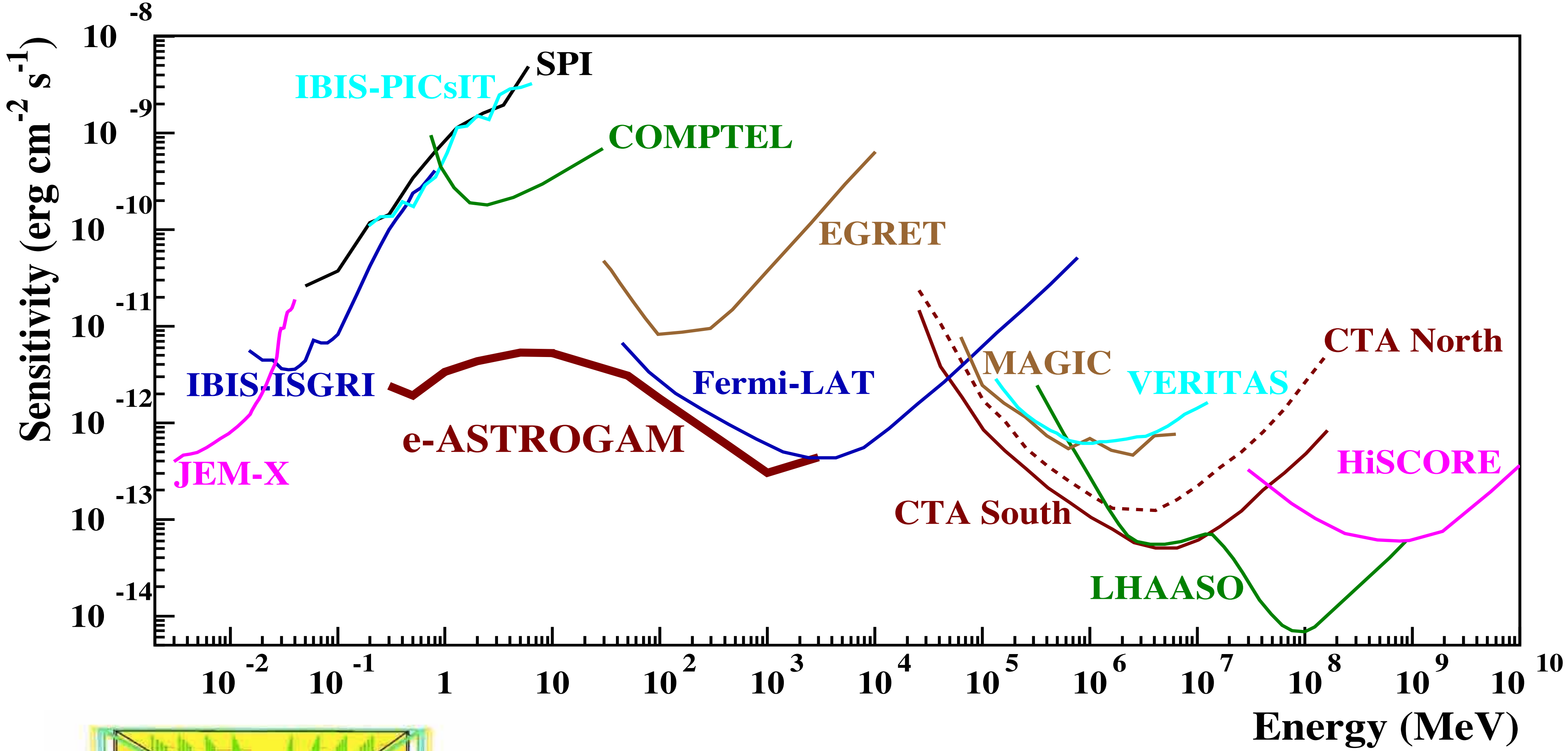
the e-Astrogam project

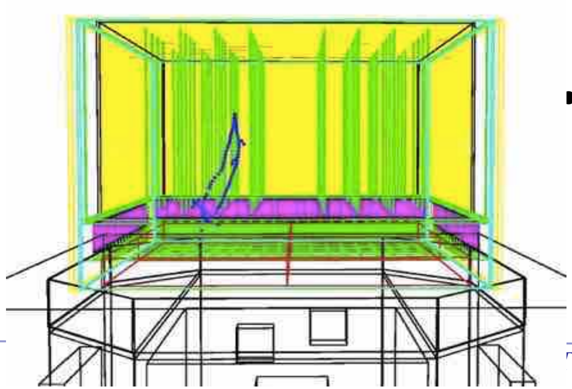


MeV - GeV astrophysics
MeV - GeV community

Proposed for the ESA M4 call; currently under study for enhancement and reconfiguration for the ESA M5 call. ASTROGAM is **focused on gamma-ray astrophysics in the range 0.3-100 MeV** with excellent capability also at GeV energies.

e-ASTROGAM Performance assessment

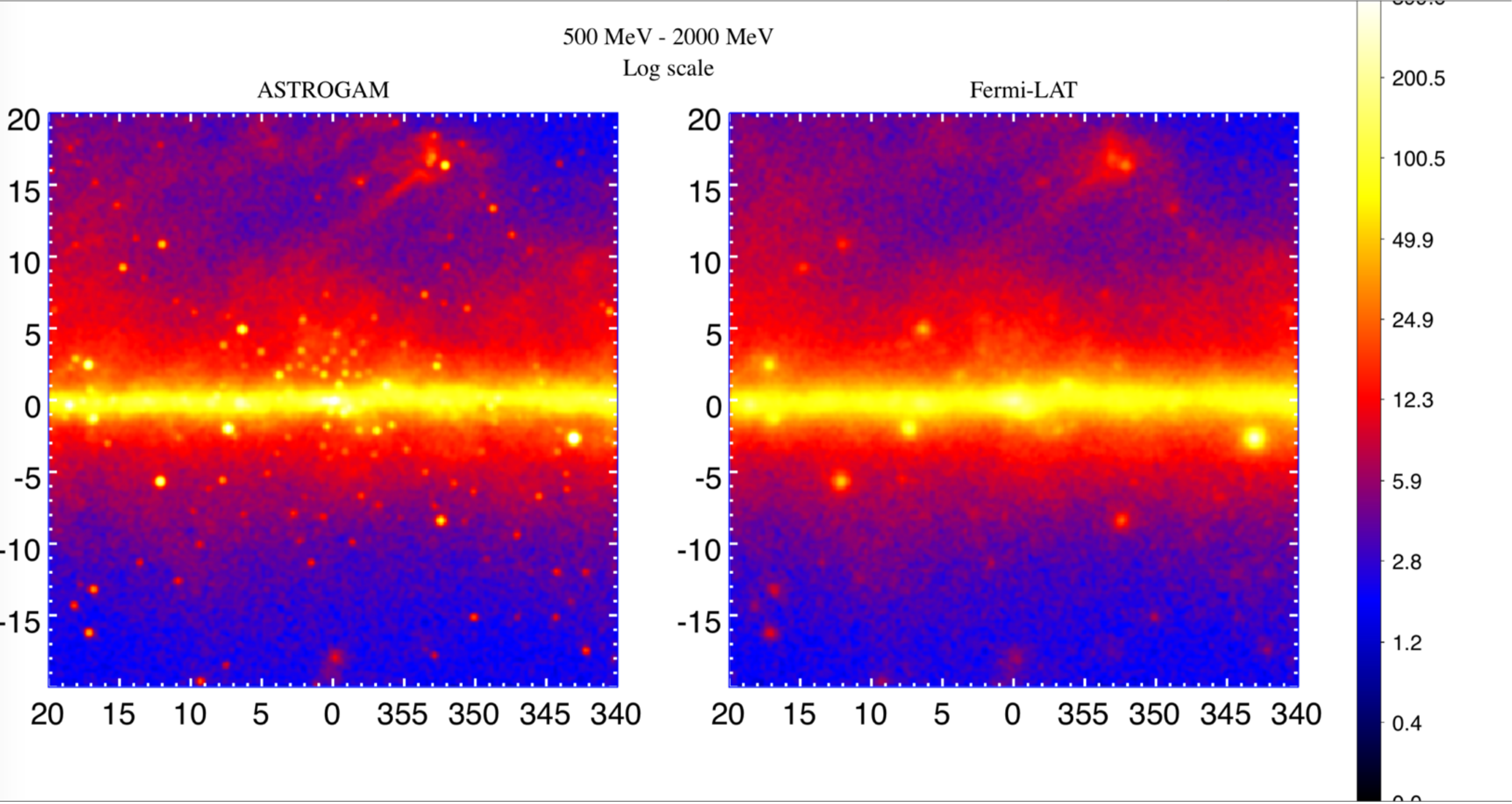




- e-ASTROGAM performance evaluated with **MEGAlib** and – both tools based on Geant4 – and a detailed numerical mass model of the gamma-ray instrument
  - e-Astrogam: arXiv:1611.02232

Galactic Center Region 0.5-2 GeV

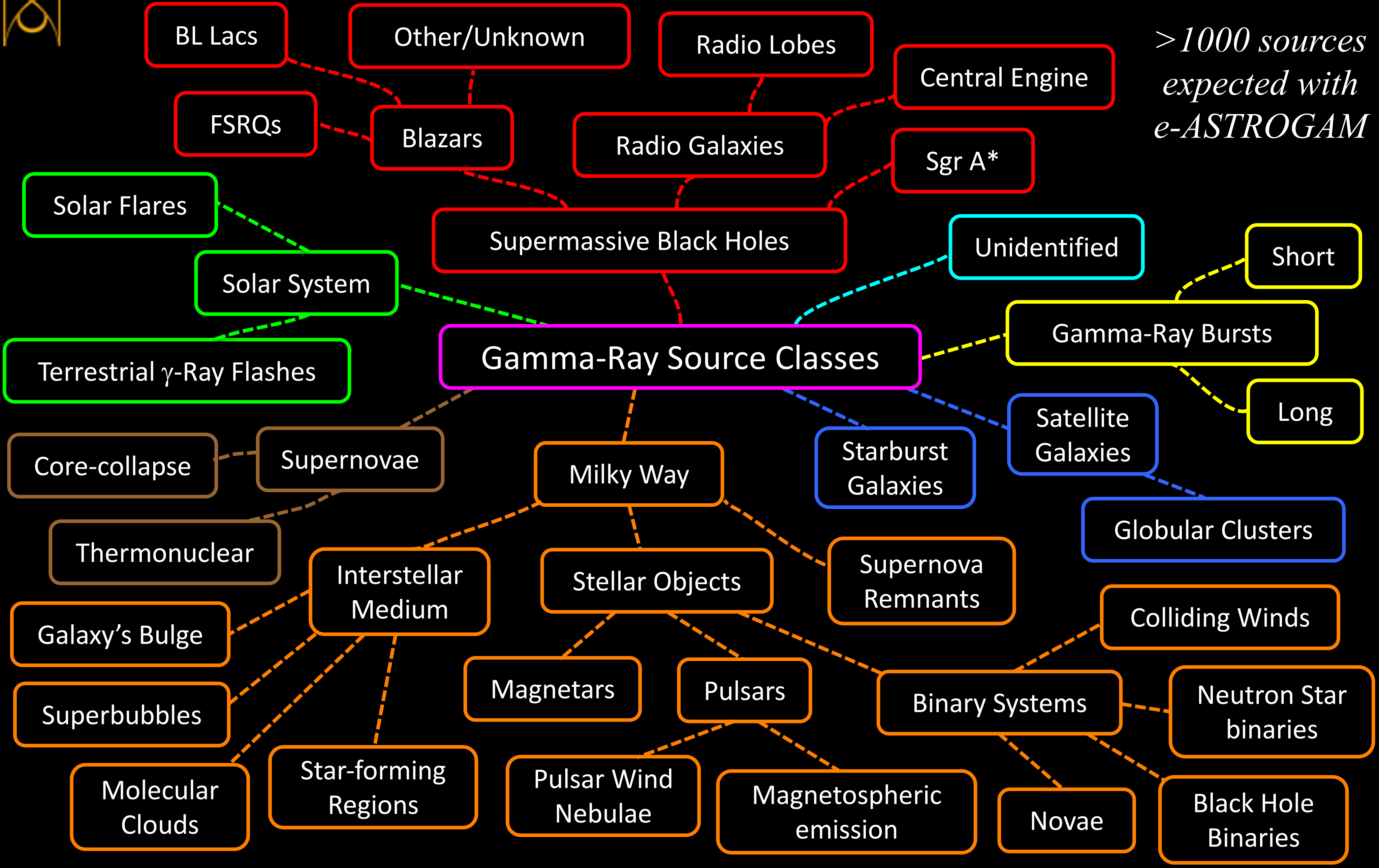
Fermi PSF Pass7 rep v15 source



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

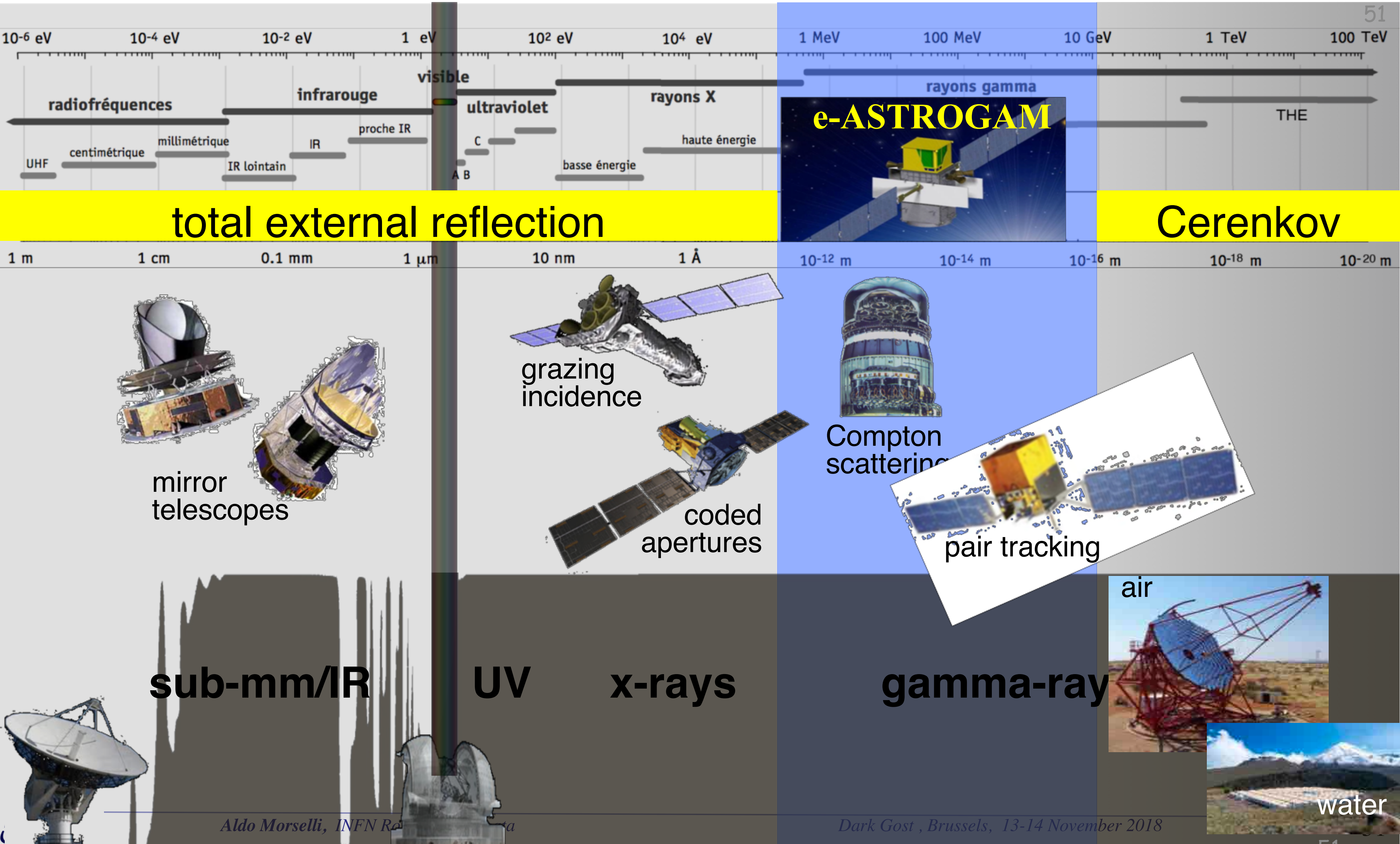


Gamma-Ray Source Classes

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

>1000 sources expected with e-ASTROGAM

An instrument to complete the coverage of the electromagnetic spectrum



total external reflection

Cerenkov

mirror telescopes

grazing incidence

coded apertures

Compton scattering

pair tracking

air

water

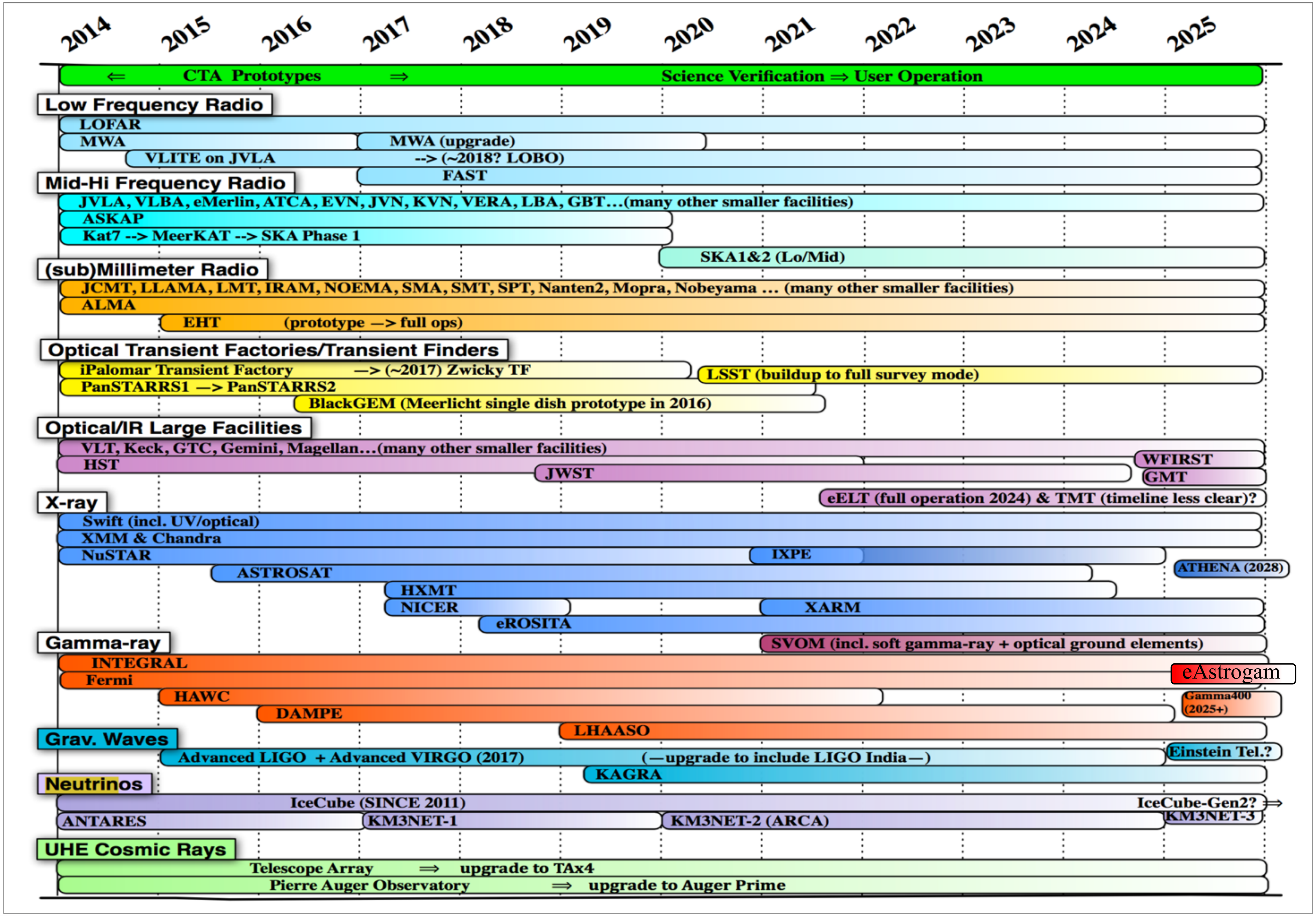
sub-mm/IR

UV

x-rays

gamma-ray

multi-wavelength/multi-messenger facilities over the next decade


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

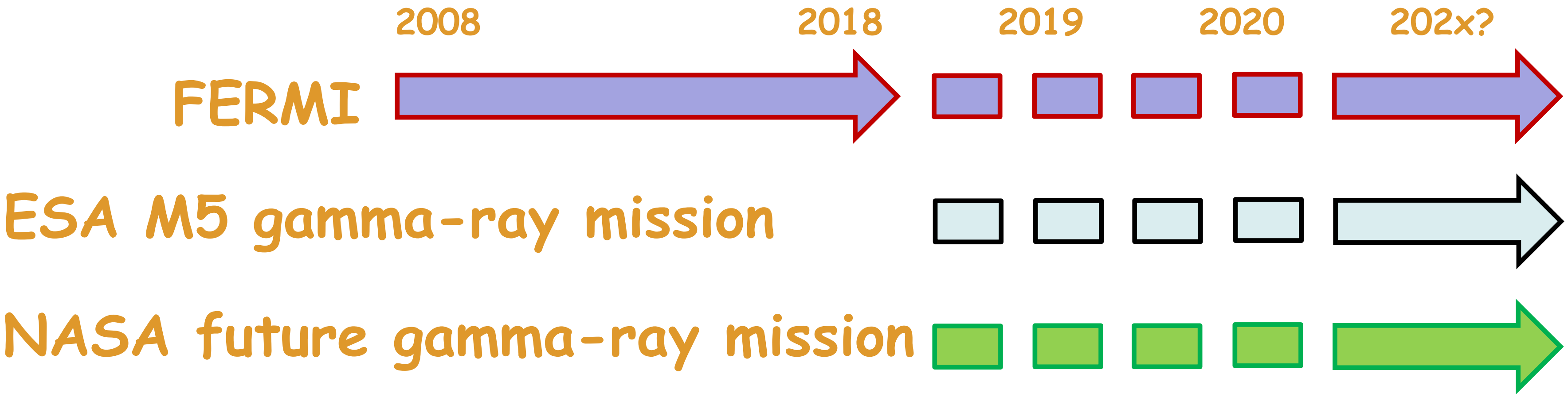
Neutrinos

- 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

Space-based high energy gamma ray plan



2008 2018 2019 2020 202x?

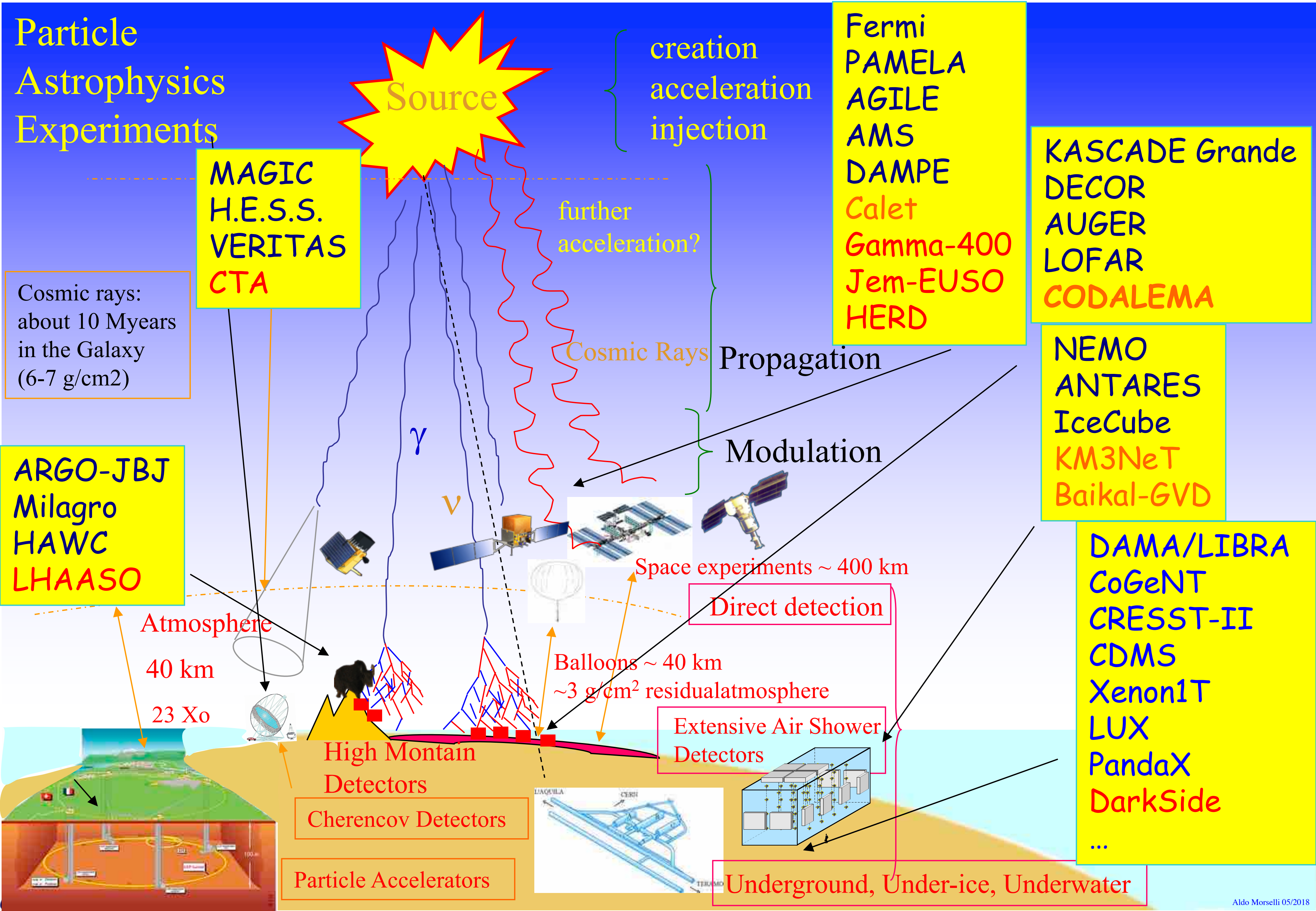
FERMI

ESA M5 gamma-ray mission

NASA future gamma-ray mission

- 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

Particle Astrophysics Experiments



Source

creation
acceleration
injection

further acceleration?

Cosmic Rays

Propagation

Modulation

γ

ν

Cosmic rays:
about 10 Myears
in the Galaxy
(6-7 g/cm2)

MAGIC
H.E.S.S.
VERITAS
CTA

Fermi
PAMELA
AGILE
AMS
DAMPE
Calet
Gamma-400
Jem-EUSO
HERD

KASCADE Grande
DECOR
AUGER
LOFAR
CODALEMA

NEMO
ANTARES
IceCube
KM3NeT
Baikal-GVD

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/cm^2 residualatmosphere

Extensive Air Shower Detectors

High Montain Detectors

Cherencov Detectors

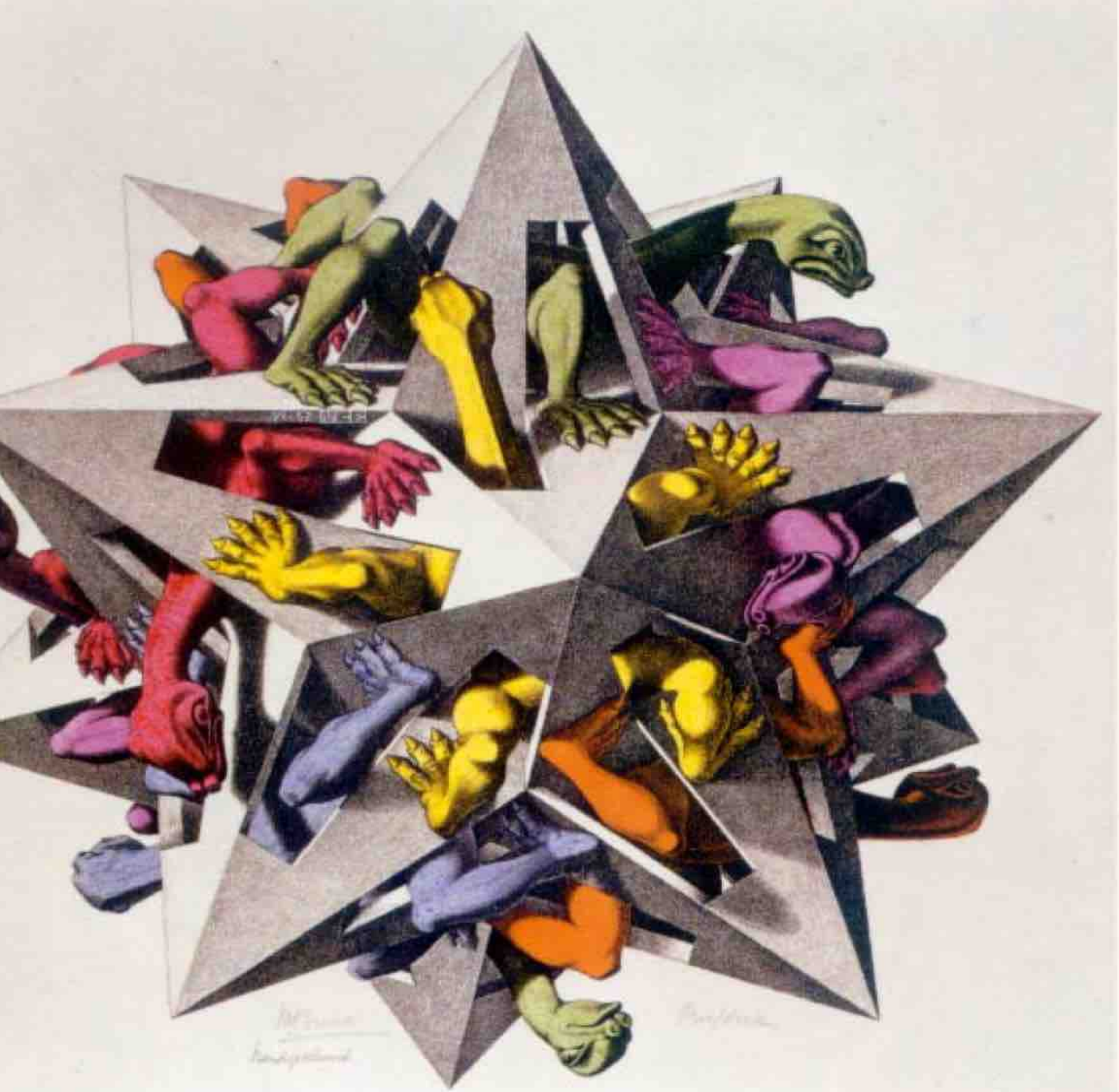
Particle Accelerators

Underground, Under-ice, Underwater

Aldo Morselli 05/2018

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 !