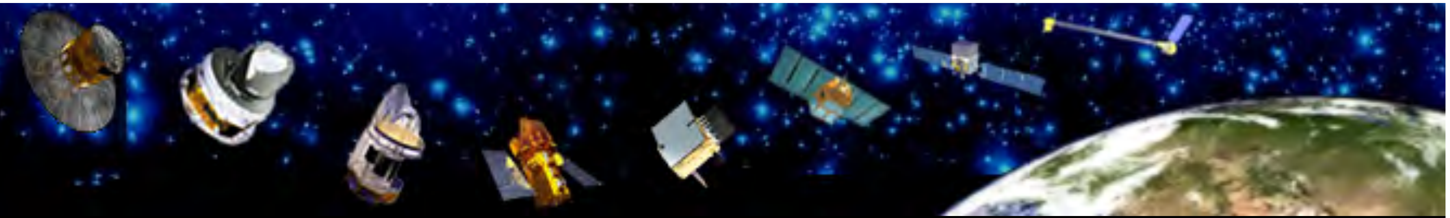
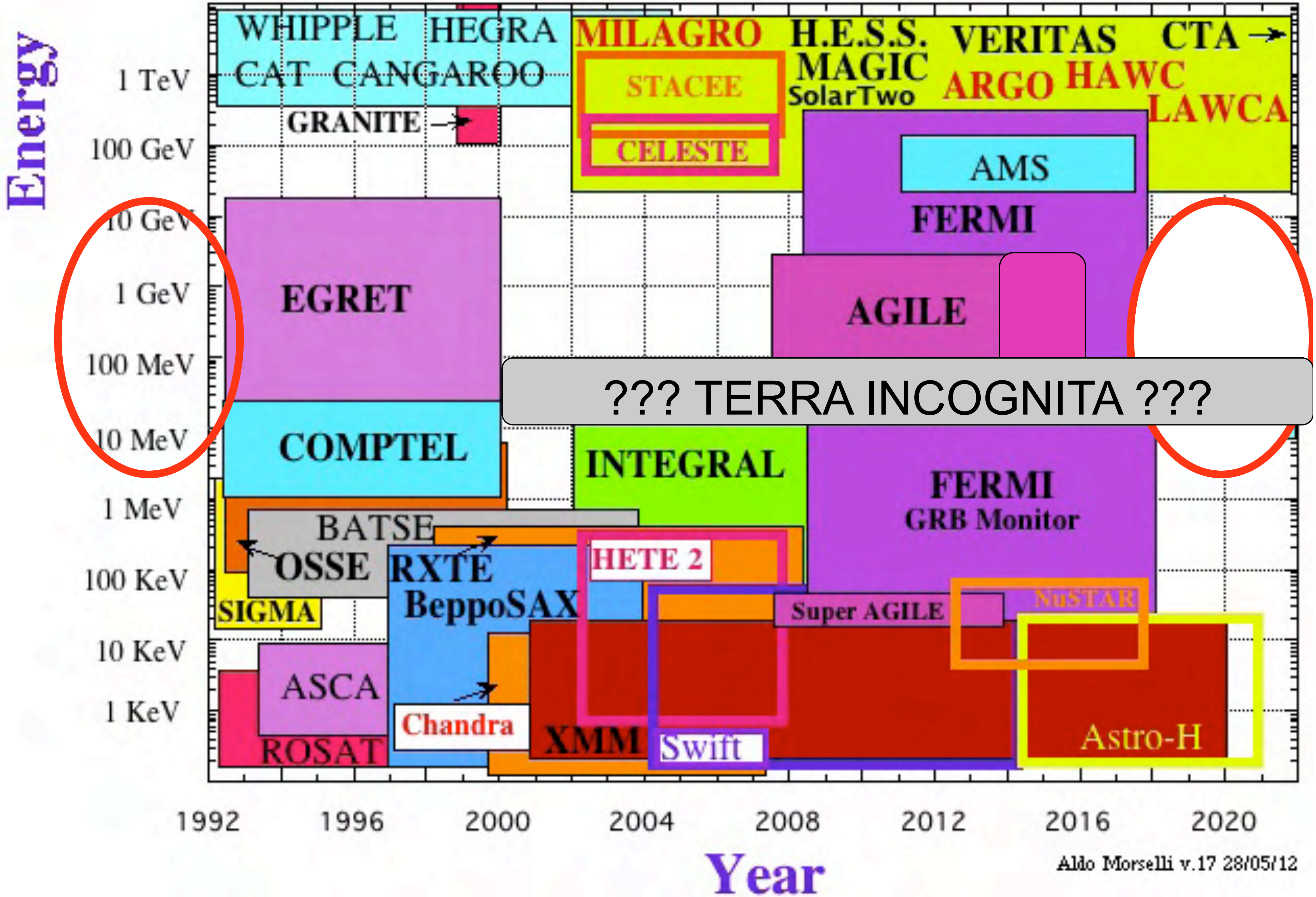


Dark matter signatures in a mostly unexplored gamma-ray energy window

Carlotta Pittori, ASDC & INFN
on behalf of the ASTROGAM Collaboration

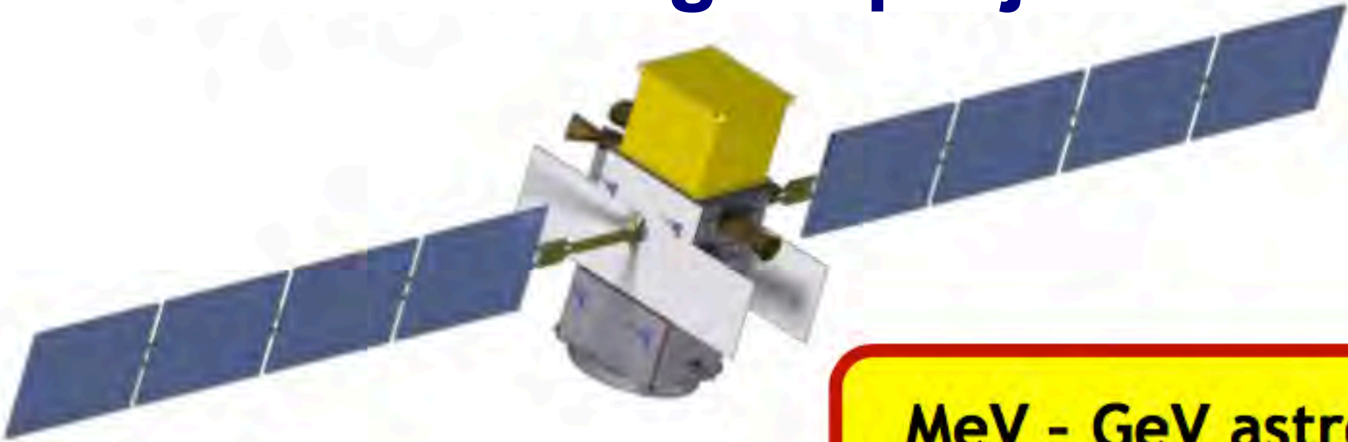
DSU2015 – Kyoto, Dec 15th



Energy
1 TeV
100 GeV
10 GeV
1 GeV
100 MeV
10 MeV
1 MeV
100 KeV
10 KeV
1 KeV
WHIPPLE
HEGRA
CAT
CANGAROO
GRANITE
MILAGRO
STACEE
CELESTE
H.E.S.S.
MAGIC
SolarTwo
VERITAS
ARGO
HAWC
CTA
LAWCA
AMS
FERMI
EGRET
AGILE
??? TERRA INCOGNITA ???
COMPTEL
INTEGRAL
FERMI
GRB Monitor
BATSE
OSSE
SIGMA
RXTE
BeppoSAX
HETE 2
Super AGILE
NuSTAR
ASCA
ROSAT
Chandra
XMM
Swift
Astro-H
1992
1996
2000
2004
2008
2012
2016
2020
Year
Aldo Morselli v.17 28/05/12

The next gamma-ray MeV-GeV mission:

the e-Astrogam project

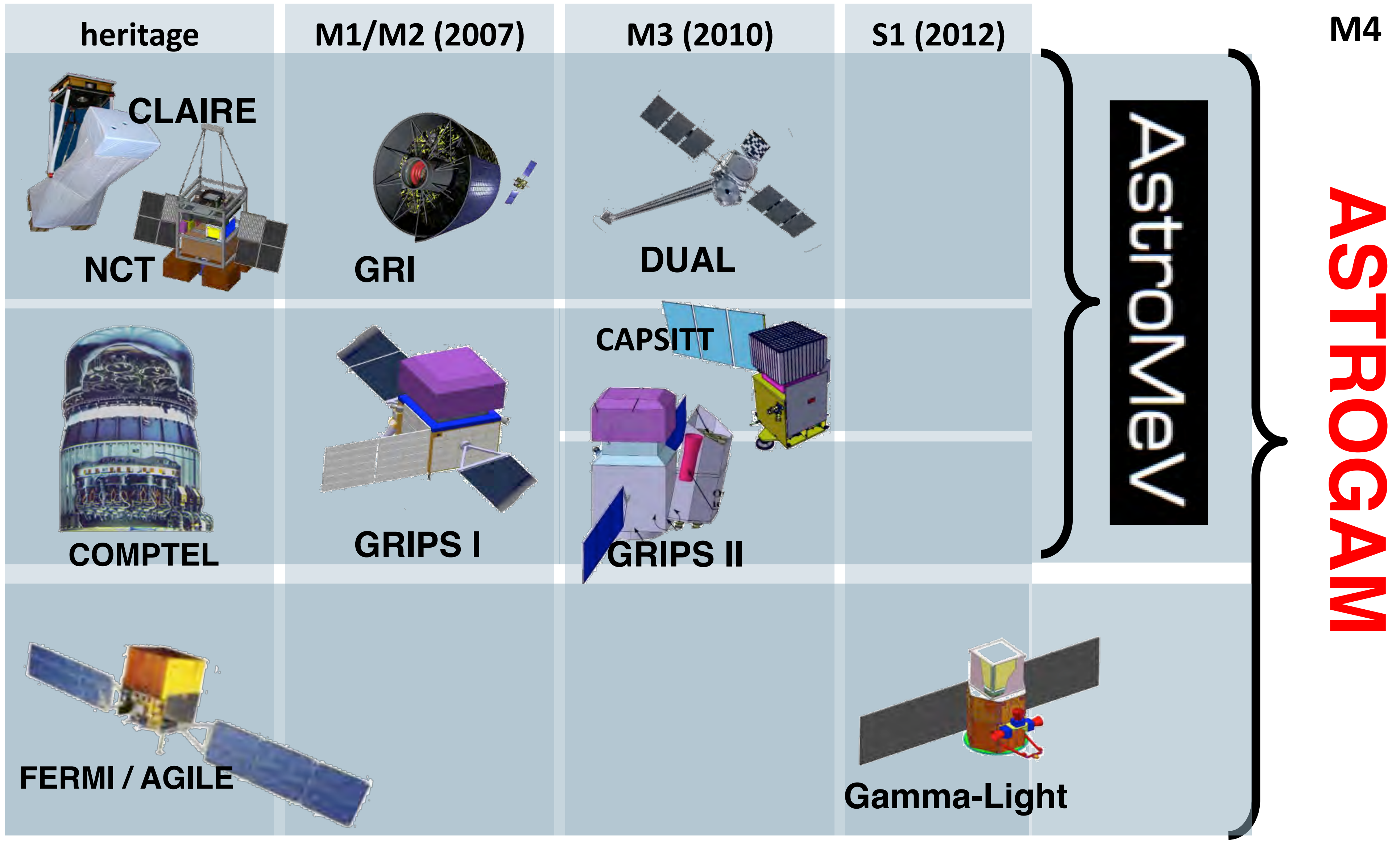


MeV - GeV astrophysics
MeV - GeV community

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.


Proposal for the ESA
M4 Mission Programme
ASTROGAM
Lead Proposer: M. Tavani
Co-Lead Proposer: V. Tatischeff
This proposal is the result of the merging of the ASTROMEV and GAMMA-LIGHT groups that submitted two separate LoIs.
The proposal is presented on behalf of the ASTROGAM Collaboration by:
M. Tavani (INAF and University of Rome Tor Vergata, Italy)
V. Tatischeff (CSNSM, France)
P. von Ballmoos (IRAP, France)
C. Budtz-Jorgensen (DTU Space, Lyngby, Denmark)
A. Bykov (Ioffe Institute, St. Petersburg, Russia)
L. Hanlon (University College Dublin, Ireland)
D. Hartmann (Clemson University, USA)
M. Hernanz (ICE/CSIC-IEEC, Barcelona, Spain)
J. Isern (ICE/CSIC-IEEC, Barcelona, Spain)
G. Kanbach (MPI, Garching, Germany)
P. Laurent (APC, France)
J. McEnery (NASA, USA)
S. Mereghetti (INAF-IASF, Milano, Italy)
A. Morselli (INFN, Italy)
K. Nakazawa (The University of Tokyo, Japan)
U. Oberlack (Univ. of Mainz, Germany)
R. Walter, (Univ. of Geneva, Switzerland)
A. Zdziarski (NCAC, Poland)
A. Zoglauer (UC Berkeley, USA)

ASTROGAM: a unified proposal from the entire gamma-ray community



ASTROGAM Collaboration

INAF, INFN, University of Rome 2

CSNSM, IRAP, APC, CEA, LUPM, IPNO

ICE (CSIC-IEEC), IMB-CNM (CSIC)

University College Dublin

MPI, Universität Mainz

DTU

University of Geneva

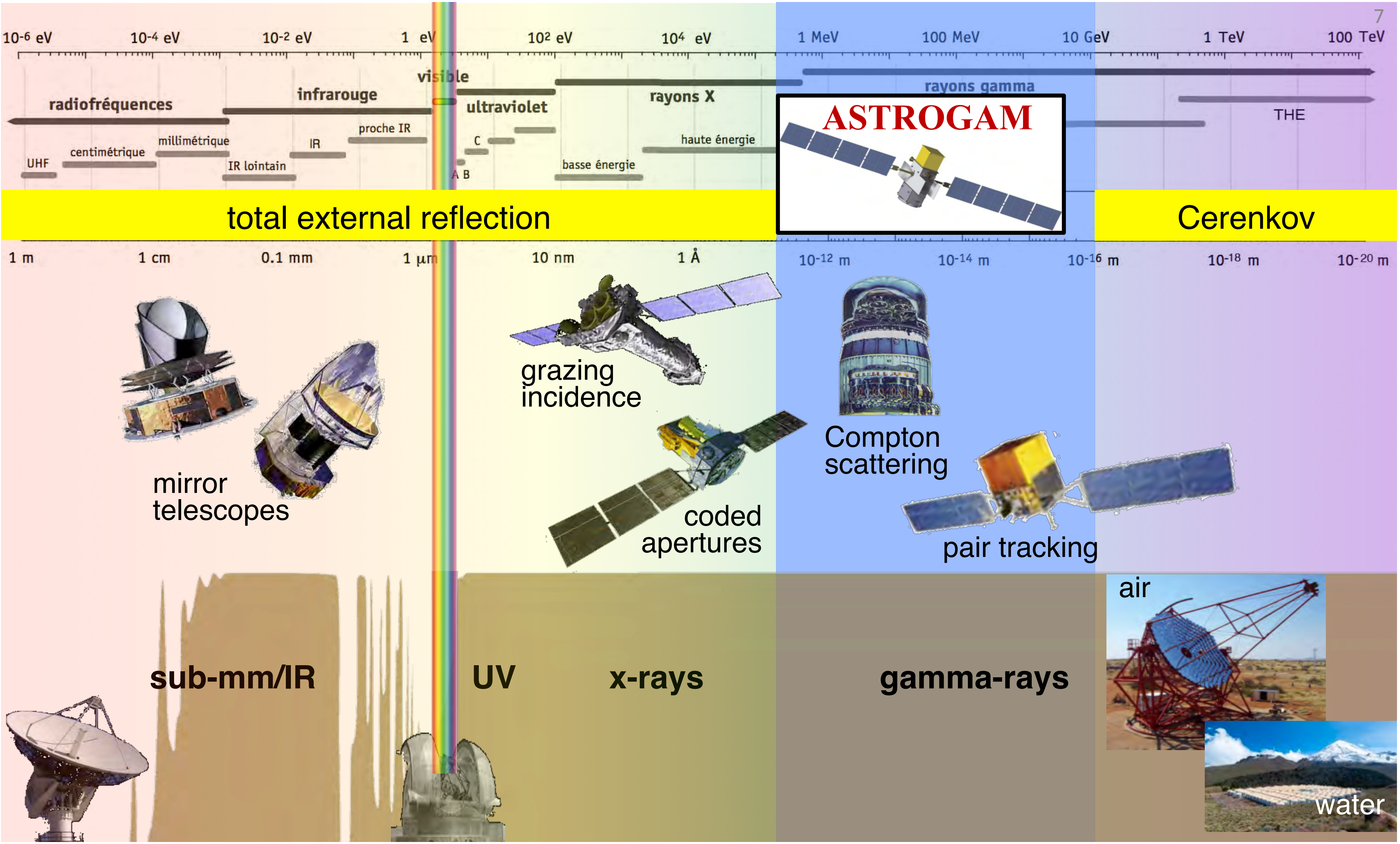
KTH

University of Tokyo

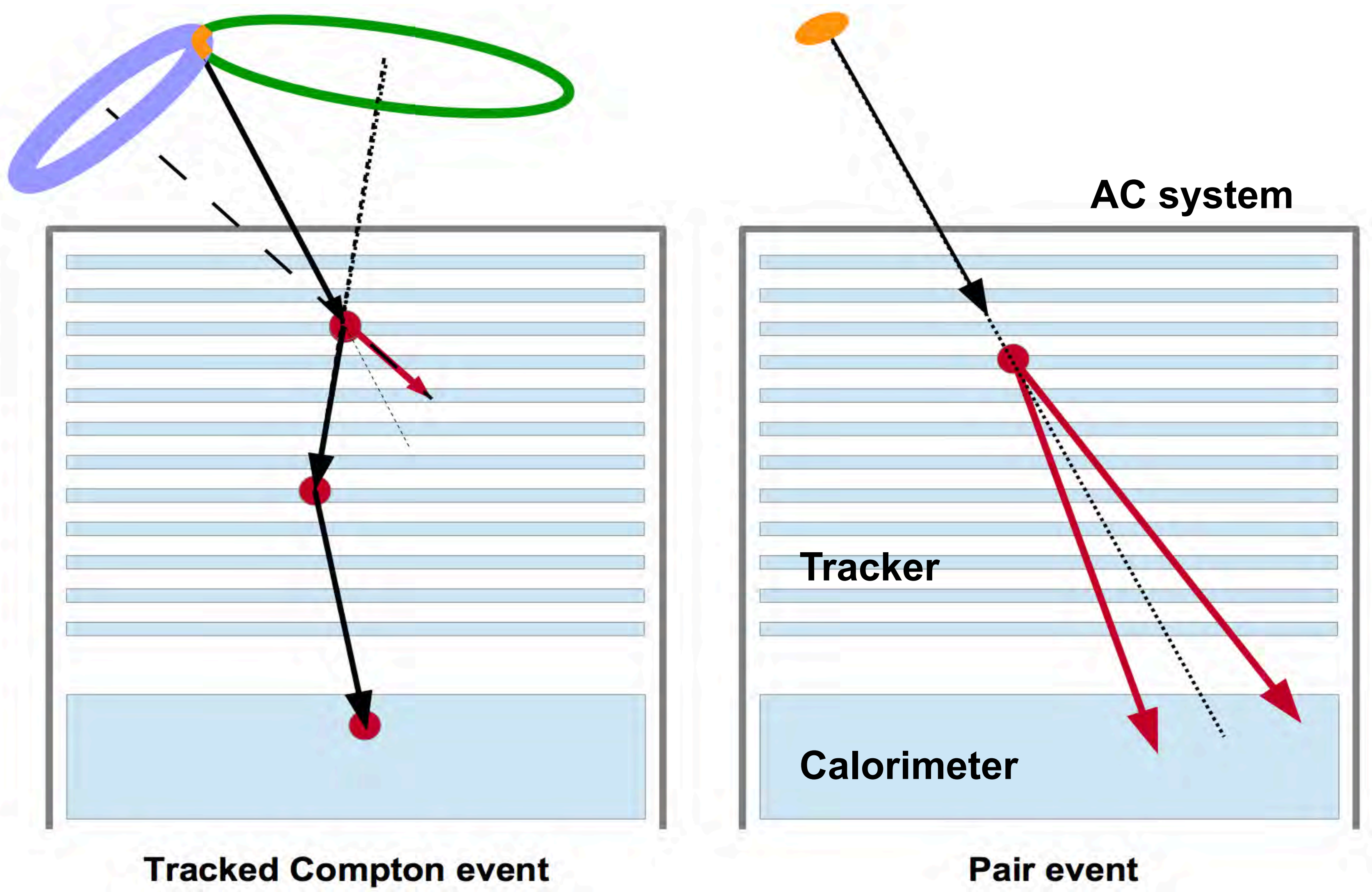
Ioffe Institute

NASA GSFC, NRL, Clemson Un., UC at Berkeley

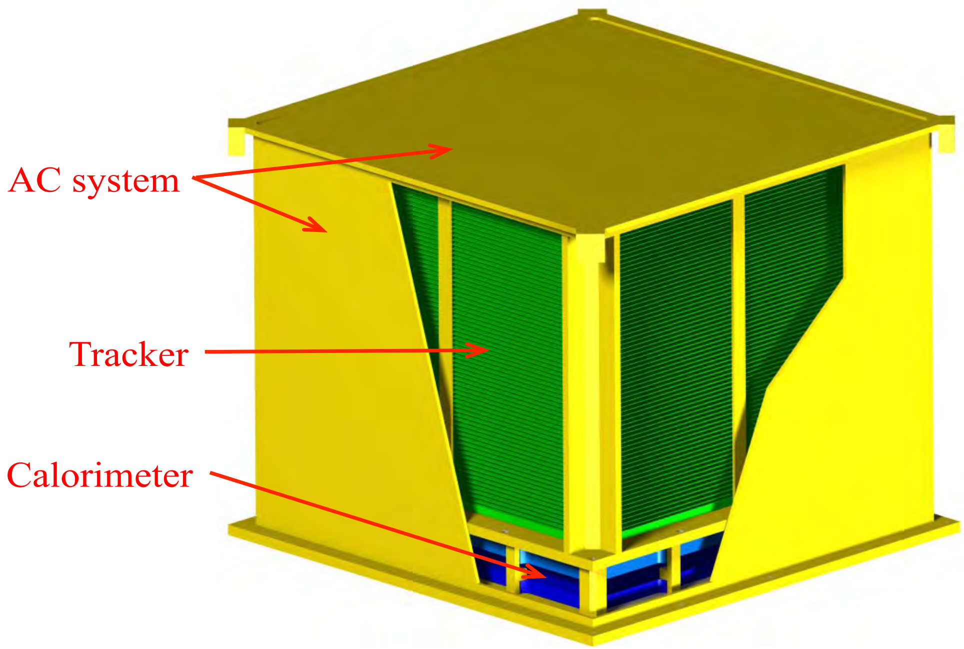
A single instrument for a complete coverage of the spaceborne gamma-ray domain

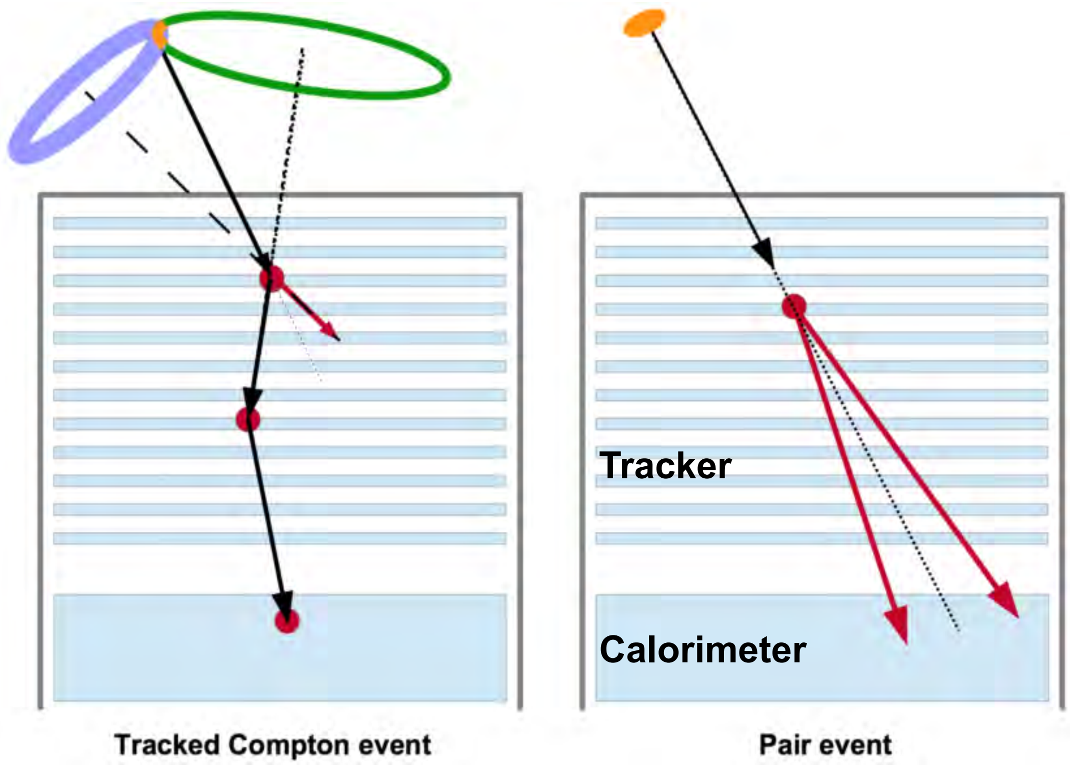


An instrument ingeniously combining two well-mastered detection techniques



ASTROGAM Measurement principle

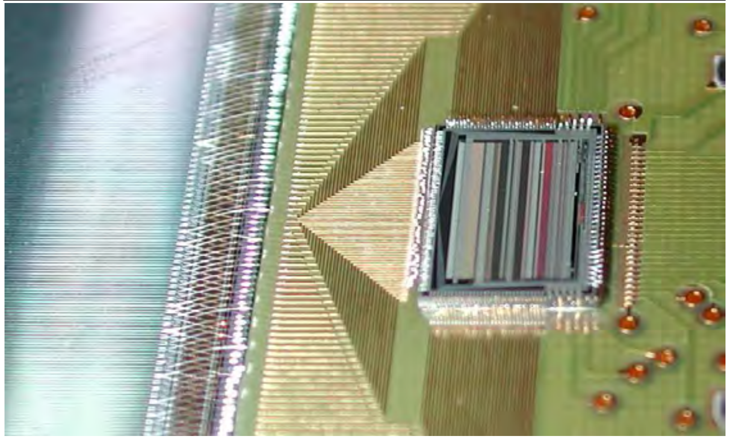




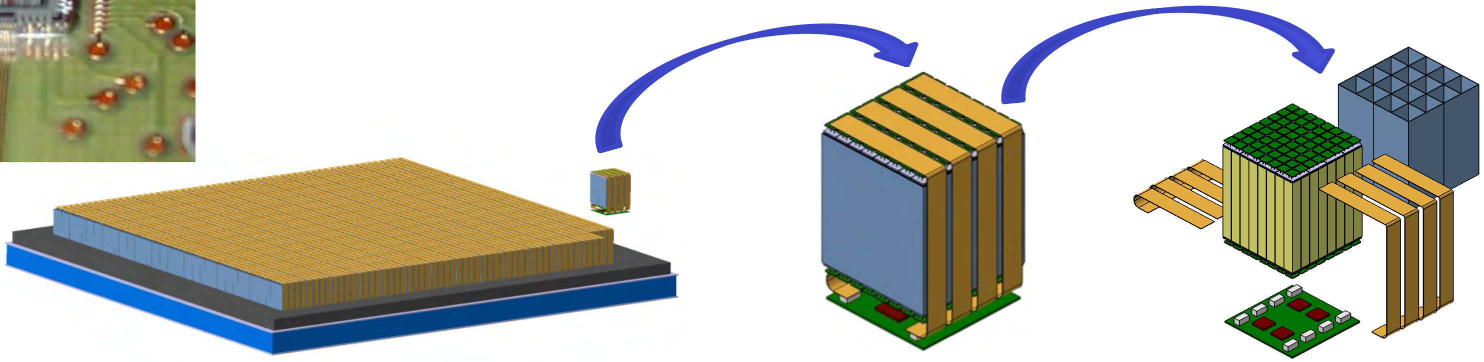
- **Tracker** – Double sided Si strip detectors (DSSDs) for fine 3-D position resolution **(No high-Z**)
- **Calorimeter** – High-Z material for an efficient absorption of the scattered photon ⇒ CsI(Tl) scintillation crystals readout by Si Drift Diodes for better energy resolution
- **Anticoincidence detector** to veto charged-particle induced background ⇒ plastic scintillator
- **Heritage**: AGILE, Fermi/LAT, AMS-02, INTEGRAL, LHC/ALICE…

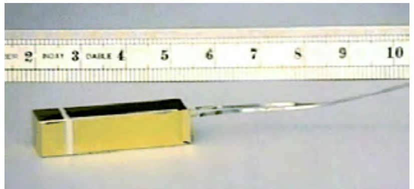
ASTROGAM Payload

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

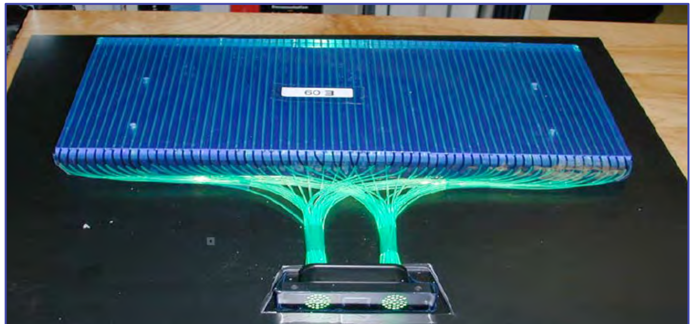


- **Tracker**: 70 layers of 6×6 DSSDs (= 2520) of 400 μm thickness and 240 μm pitch. **NO HEAVY CONVERTER**
- DSSDs bonded strip to strip to form 2-D ladders
- Light and stiff mechanical structure
- Ultra low-noise front end electronics





PICSiT CsI(Tl) pixel

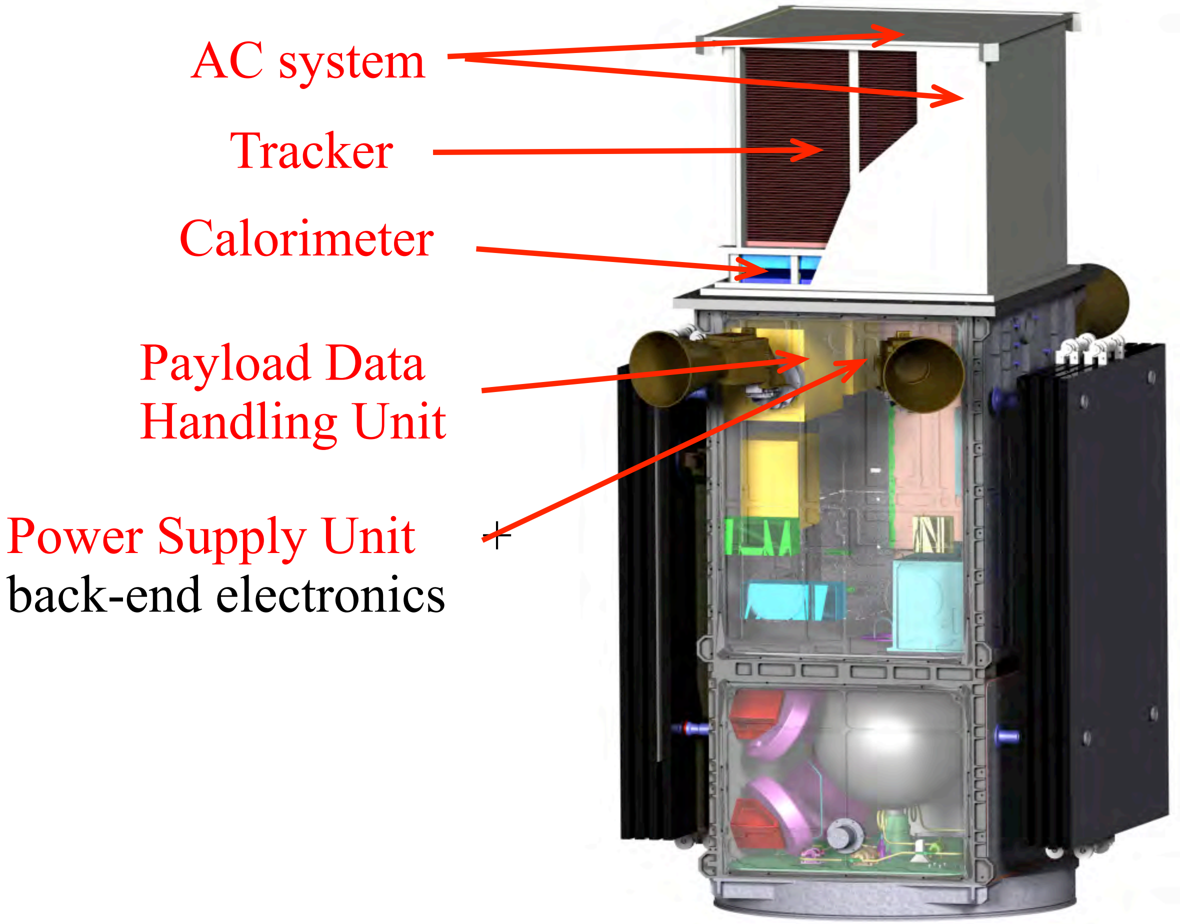


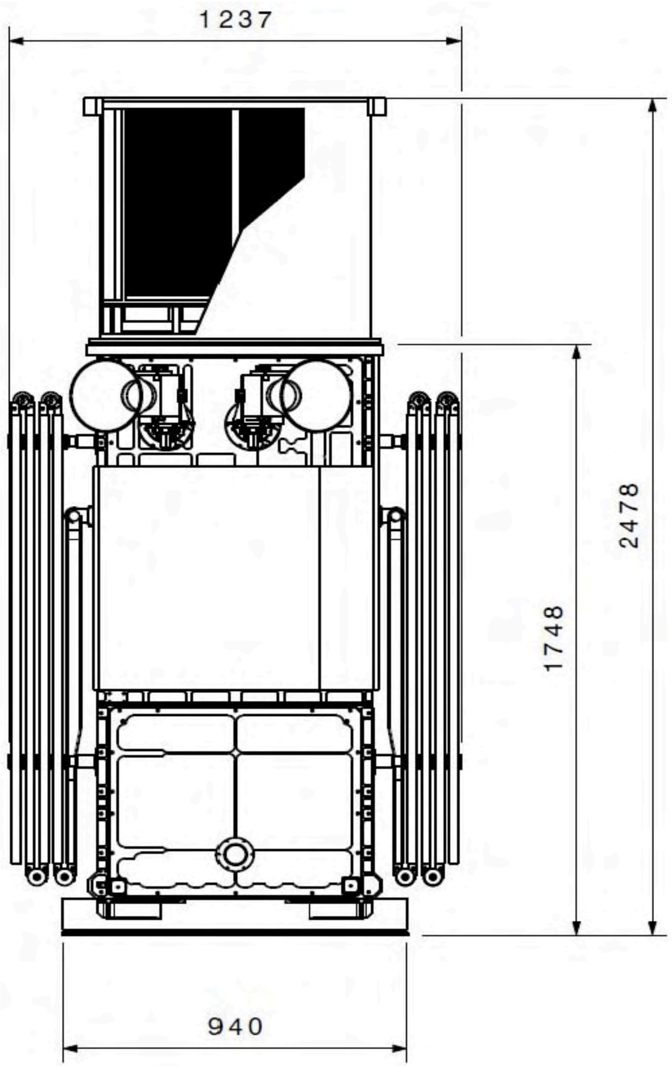
Fermi/LAT AC system

- **Calorimeter**: 12544 CsI(Tl) bars coupled at both ends to low-noise Silicon Drift Detectors
- **ACD**: segmented plastic scintillators coupled to SiPM by optical fibers
- **Heritage**: AGILE, Fermi/LAT, AMS-02, INTEGRAL, LHC/ALICE…

ASTROGAM Payload

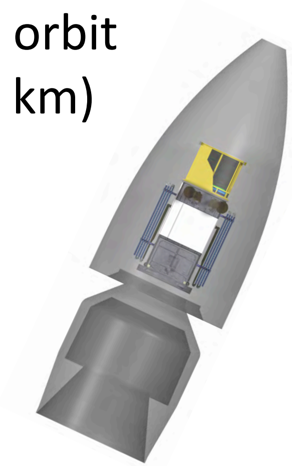
- ESA guidelines for the M4 Call interpreted at face value ⇒ ASTROGAM payload (single instrument) designed to be 300 kg

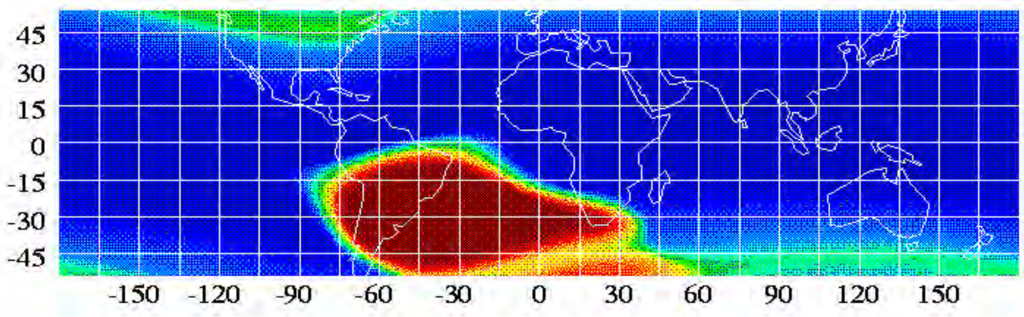




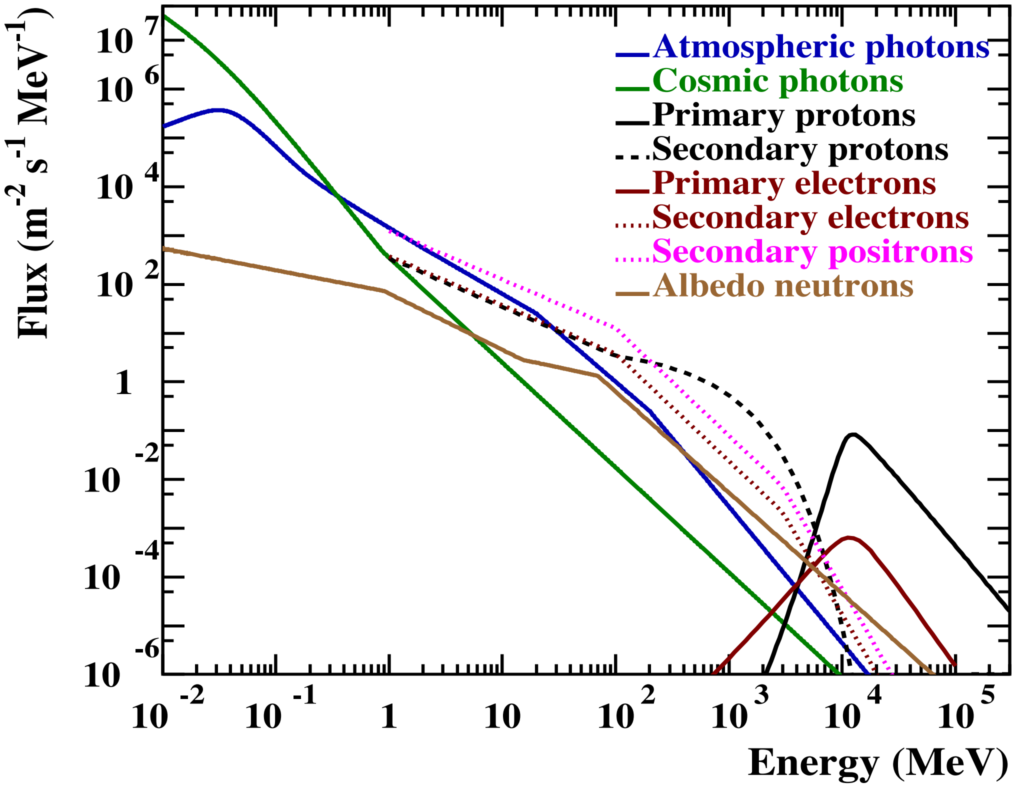
ASTROGAM Mission profile

- **Orbit** – Equatorial (inclination *i* < 2.5°, eccentricity *e* < 0.01) low-Earth orbit (altitude in the range 550 - 600 km)
- **Launcher** – standard VEGA
- **Satellite communication** – ESA ground station at Kourou + ASI Malindi station (Kenya)
- **Telemetry** – via X-band (available downlink of 10 Mbps), the average data acquisition rate being of 1.2 Mbps
- **Observation modes** – (i) zenith-pointing sky-scanning mode, (ii) nearly inertial pointing, and (iii) fast repointing to avoid the Earth in the field of view
- **In-orbit operation** – 3.5 years duration + provisions for a 2+ year extension (with 1 month of in-flight calibration)



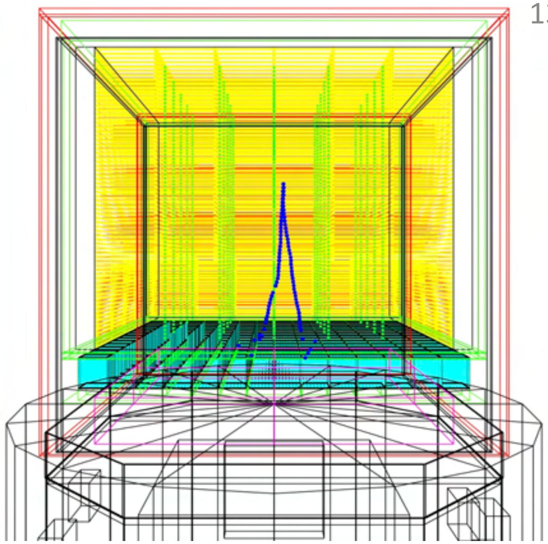


Background environment in an ELEO

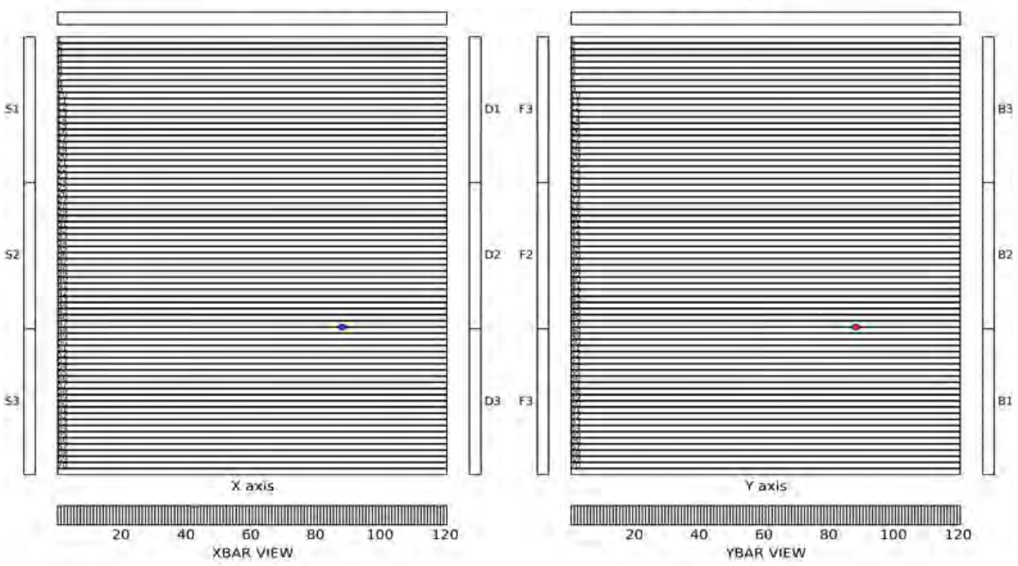


ASTROGAM Performance assessment

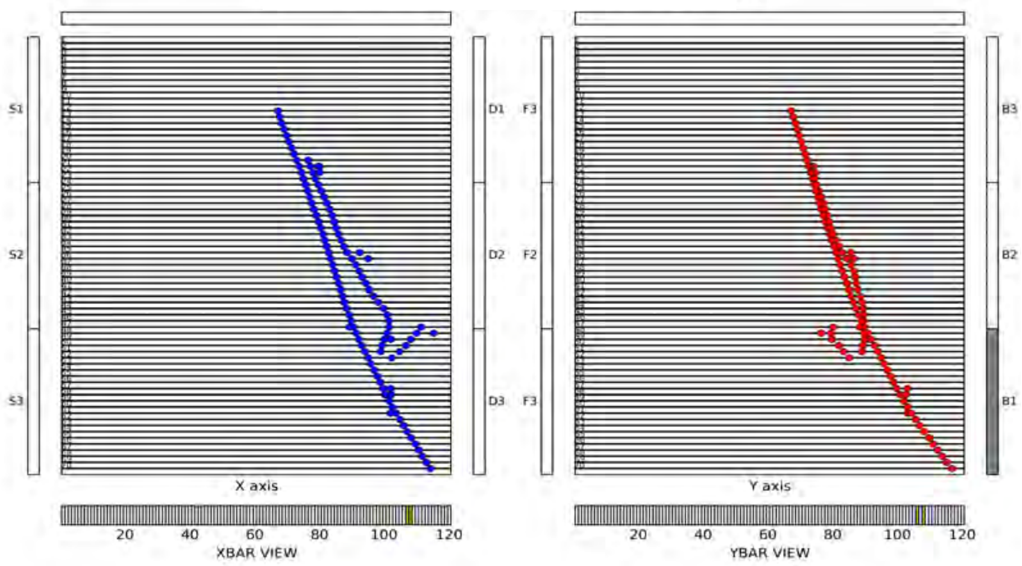
- ASTROGAM performance evaluated with **MEGAlib** and **Bogemms** (both based on Geant4) and a detailed mass model of the instrument
- Background environment in an equatorial (inclination *i* < 2.5°, eccentricity *e* < 0.01) low-Earth orbit (altitude 550 - 600 km) now well-known thanks to the **Beppo-SAX** and **AGILE** missions



E = 0.511 MeV, θ = 30°



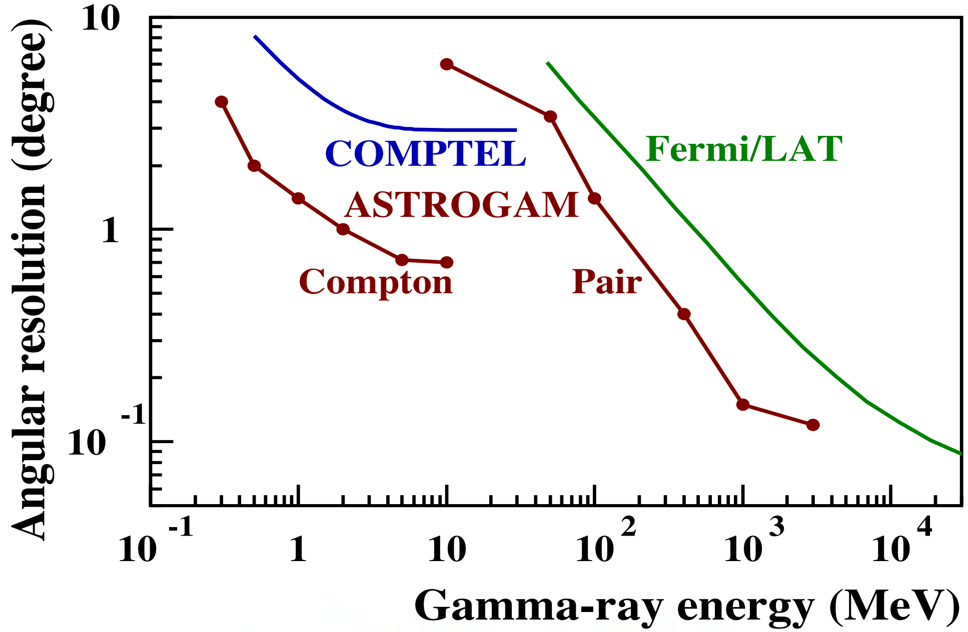
E = 50 MeV, θ = 30°

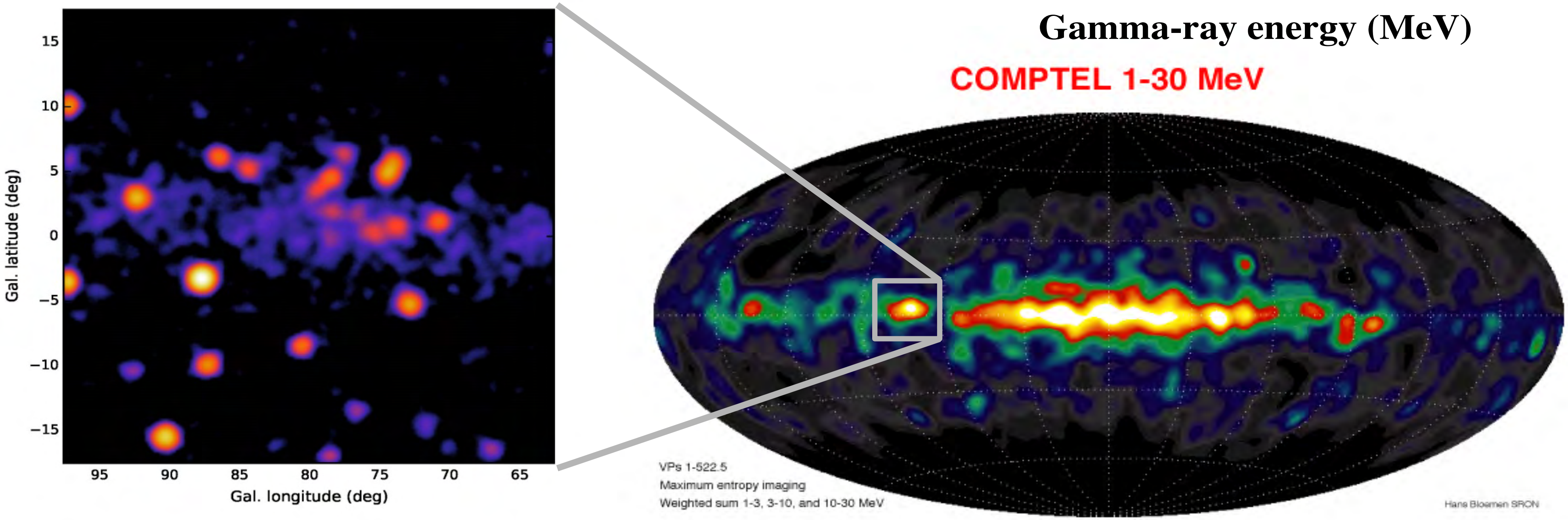


ASTROGAM Angular resolution

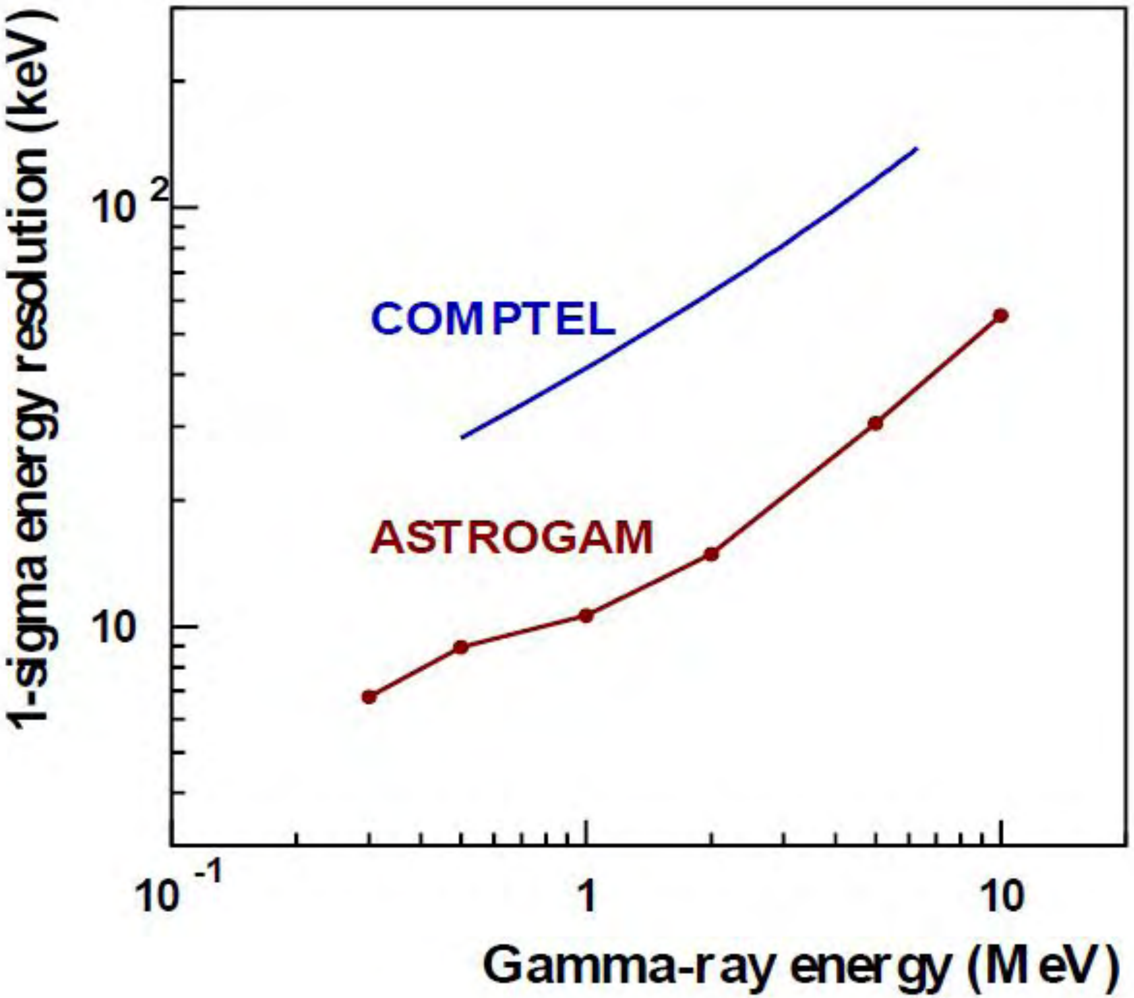
ASTROGAM imaging capability:
Cygnus region chosen as an illustrative example since source population and diffuse emission from this region is well known contrary to the GC

Simulation of the Cygnus region in the 1 – 3 MeV energy band using the ASTROGAM PSF, from an **extrapolation of the 3FGL source spectra to low energies**



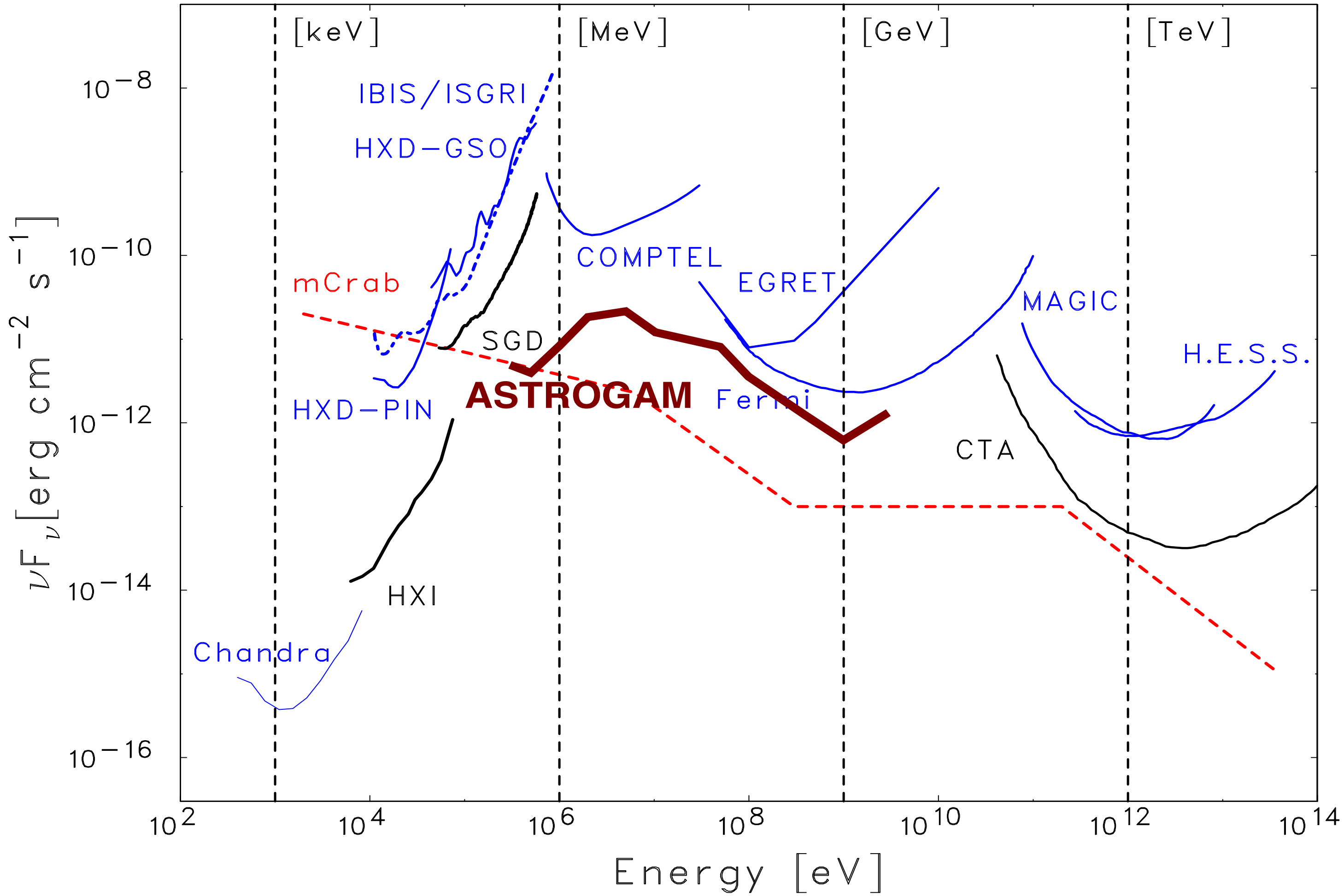


ASTROGAM Energy Resolution



Energy resolution up to 10 MeV (becomes 20-30% above 30 MeV)

ASTROGAM Sensitivity



Adapted from Takahashi et al. (2013)

- **ASTRO-H/SGD**: S(3σ) for 100 ks exposure of an isolated point source
- **COMPTEL and EGRET**: sensitivities accumulated during the whole duration of the CGRO mission (9 years)
- **Fermi/LAT**: 5σ sensitivity for a high Galactic latitude source and after 1 year observation in survey mode
- **ASTROGAM** – 3σ/5σ sensitivity for a 1-year effective exposure of a high Galactic latitude source

ASTROGAM Line Sensitivity

Gamma-ray line sensitivity:
ASTROGAM will gain a factor 10 - 30 in line sensitivity compared to INTEGRAL/SPI

E (keV)	FWHM (keV)	Origin	SPI sensitivity (ph cm^{-2} s^{-1})	ASTROGAM sens. (ph cm^{-2} s^{-1})
511	1.3	Narrow line component of the e+/e- annihilation radiation from the GC region	5.2×10^{-5}	8.0×10^{-6}
847	35	^{56}Co line from thermonuclear SN	2.3×10^{-4}	8.7×10^{-6}
1157	15	^{44}Ti line from core-collapse SN remnants	9.6×10^{-5}	8.4×10^{-6}
1275	20	^{22}Na line from classical novae of the ONe type	1.1×10^{-4}	1.1×10^{-5}
2223	20	Neutron capture line from accreting neutron stars	1.1×10^{-4}	1.2×10^{-5}

ASTROGAM Scientific motivation

- **Focused on the mostly unexplored energy range (0.5 - 100 MeV). Continuum & line detection.**
- **It combines, for the first time, Compton and pair production events with an extended energy range (0.3 MeV - 3 GeV), excellent PSF and optimal sensitivity (better than ~ 20 compared to COMPTEL), much improving AGILE and Fermi below 1 GeV.**
- **Access to completely new "science window" for Galactic, extragalactic & fundamental science.**

ASTROGAM Core science

- **Tracing the formation of heavy elements and propagation of cosmic rays to star forming regions**
- **Anti-matter in our Galaxy and beyond**
- **Galactic Center: central black hole, “*Fermi* bubbles”, dark matter studies**
- **Supermassive black holes, the extragalactic and cosmic gamma-ray backgrounds**
- **Jet formation, extreme accelerators, gamma-ray bursts**

ASTROGAM Science summary

Galactic Radioactivities

^{26}Al, ^{60}Fe, ^{44}Ti lines, star formation

Inner Galaxy and Antimatter

resolving the mystery of the GC, e+ sources

Compact Sources

binaries, μ-quasars, AGNs, polarization !

Gamma-Ray Bursts

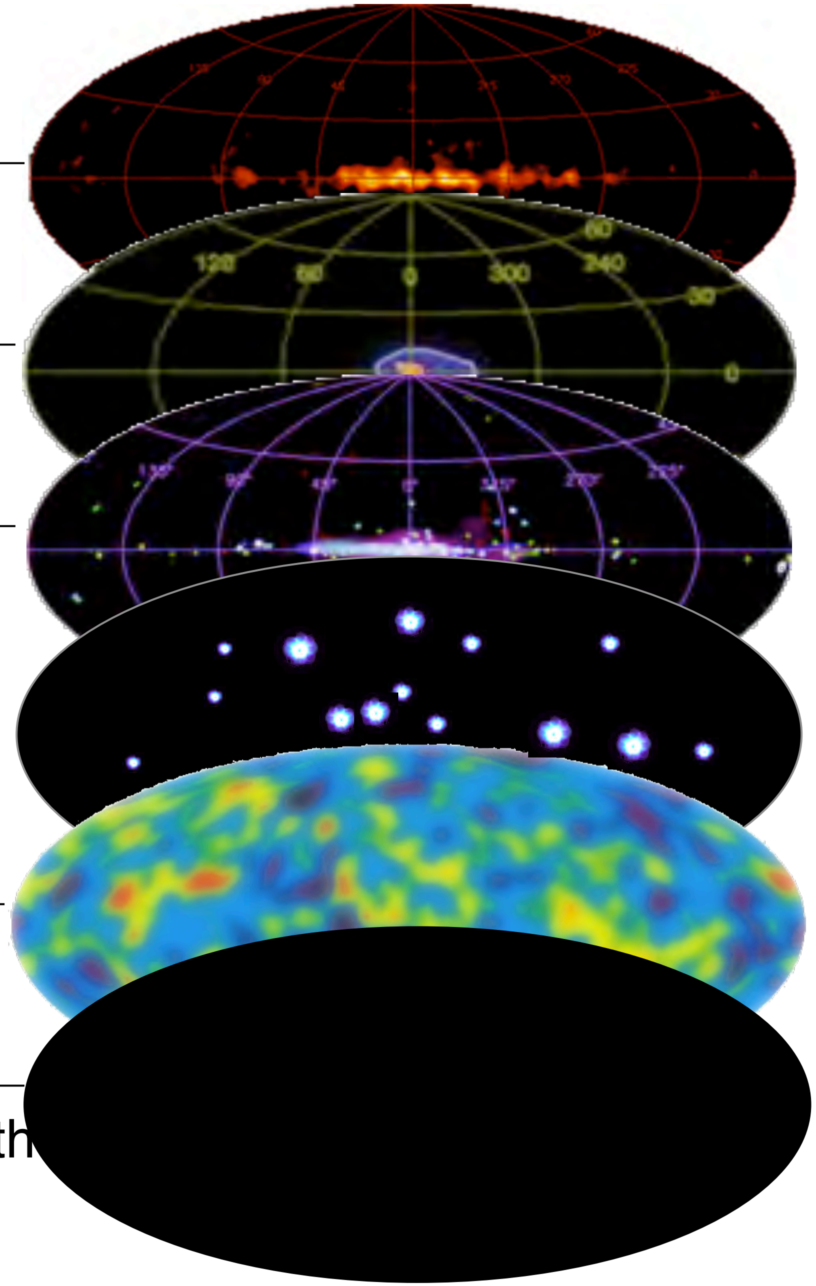
localization, spectroscopy, polarization !

Cosmic gamma-ray background

MeV background

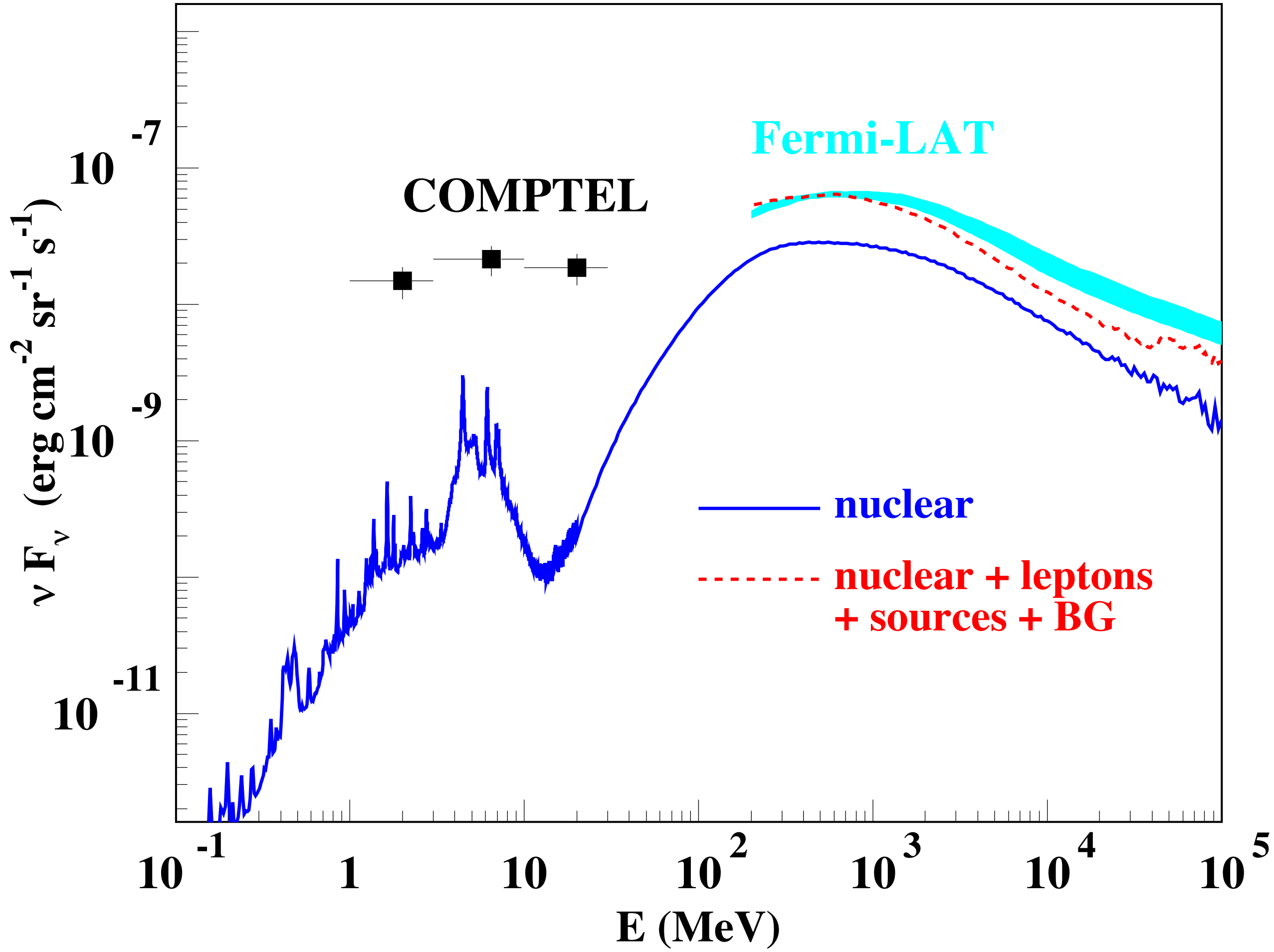
Dark Matter & Fundamental Physics

DM signatures, fundamental physics, linked with
Athena, GWs, TeV, neutrino astronomy



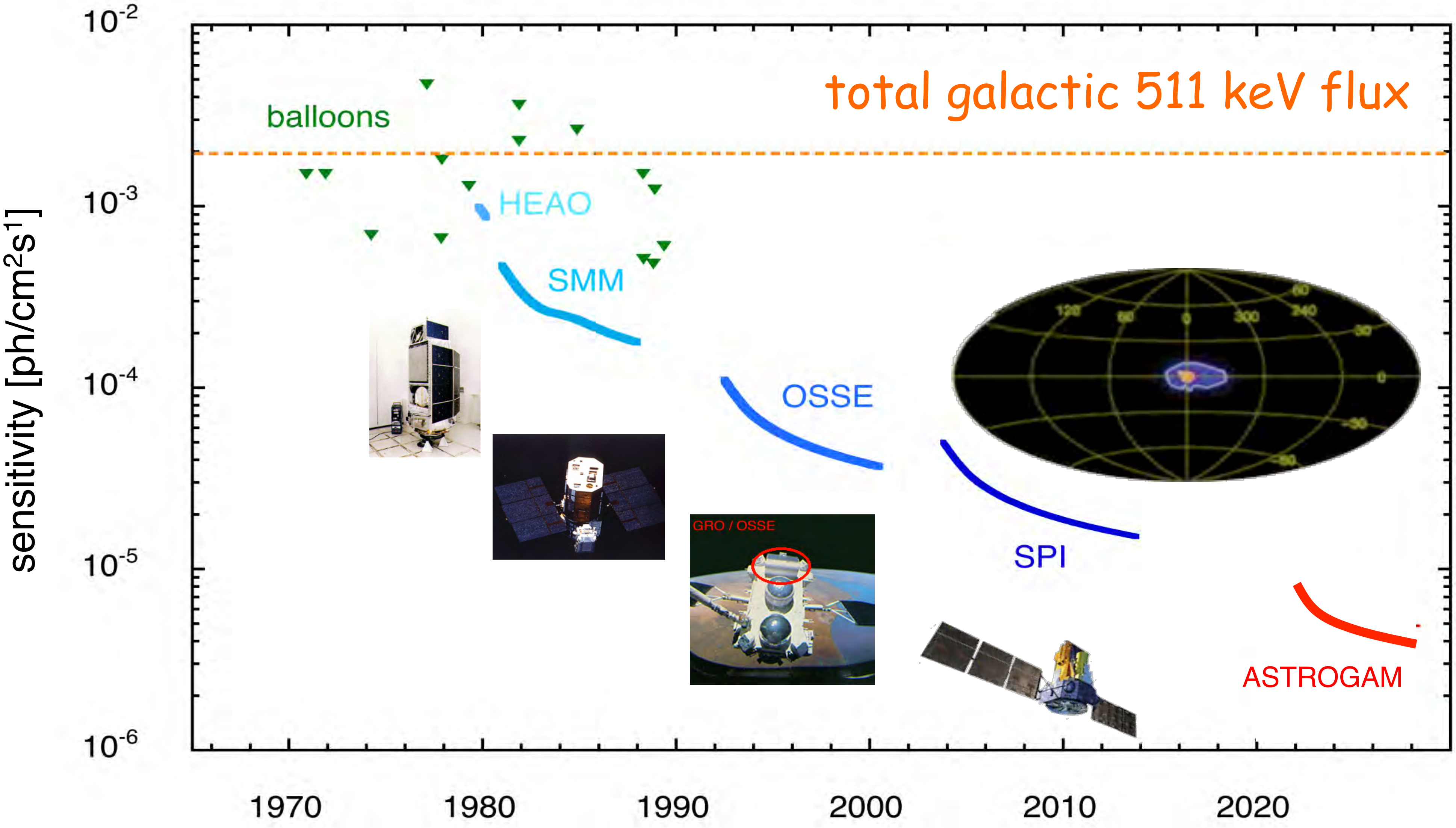
What's special about the medium-energy gamma-ray domain?

- Nuclear spectroscopy (independent of T° and ionization state)
- Thermal/non thermal transition (variety of cosmic accelerators)
- Positron annihilation
- Dark matter



Predicted gamma-ray emission from the inner Galaxy due to nuclear interactions of CRs containing a low-energy component adjusted to reproduce the observed mean CR ionization rate

ASTROGAM Positron annihilation



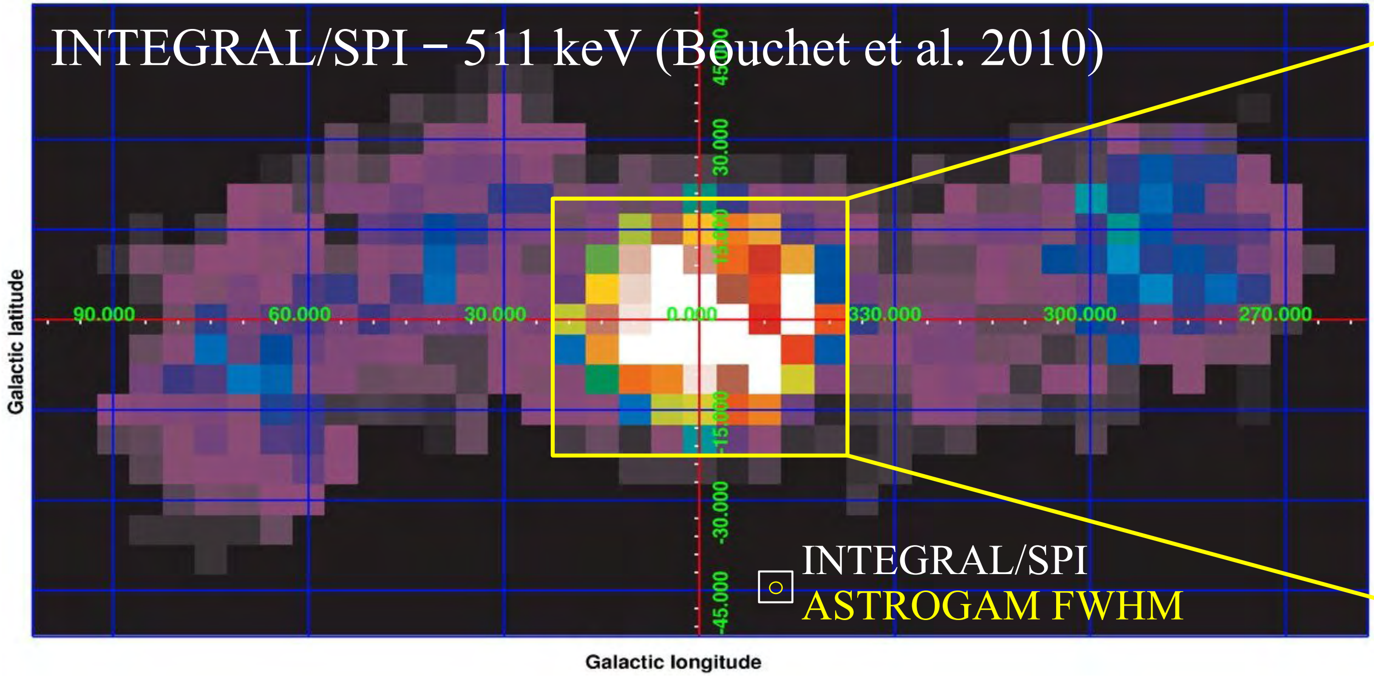
Despite the fact that electron-positron annihilation is the brightest gamma-ray line in the sky the source of the Galaxy's bulge positrons remains a mystery!

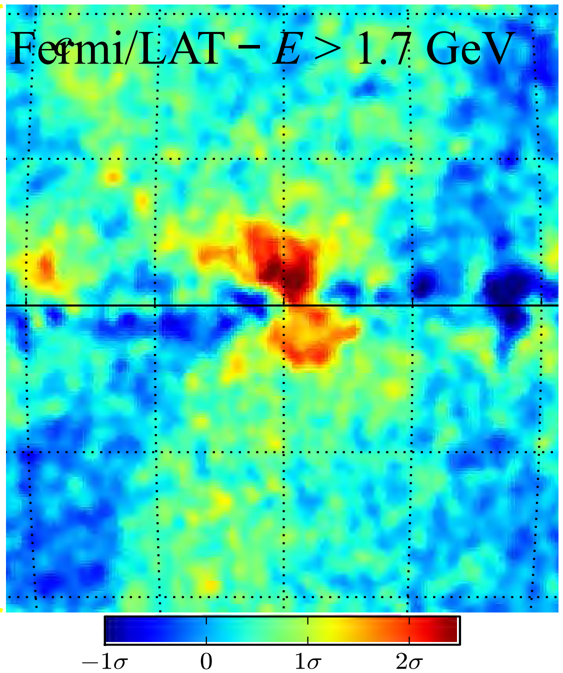
ASTROGAM Antimatter in the Galactic bulge

- The 511 keV emission from the Galactic center is still a mystery after more than 40 yr of observations (Johnson et al. 1972)
- The **bulge emission** can be explained by the injection of 10^{58} - 10^{60} positrons in the Galactic center some millions years ago

⇒ Supermassive black hole activity? Related to the Fermi bubbles?

- ASTROGAM will produce much better maps of the 511 keV radiation



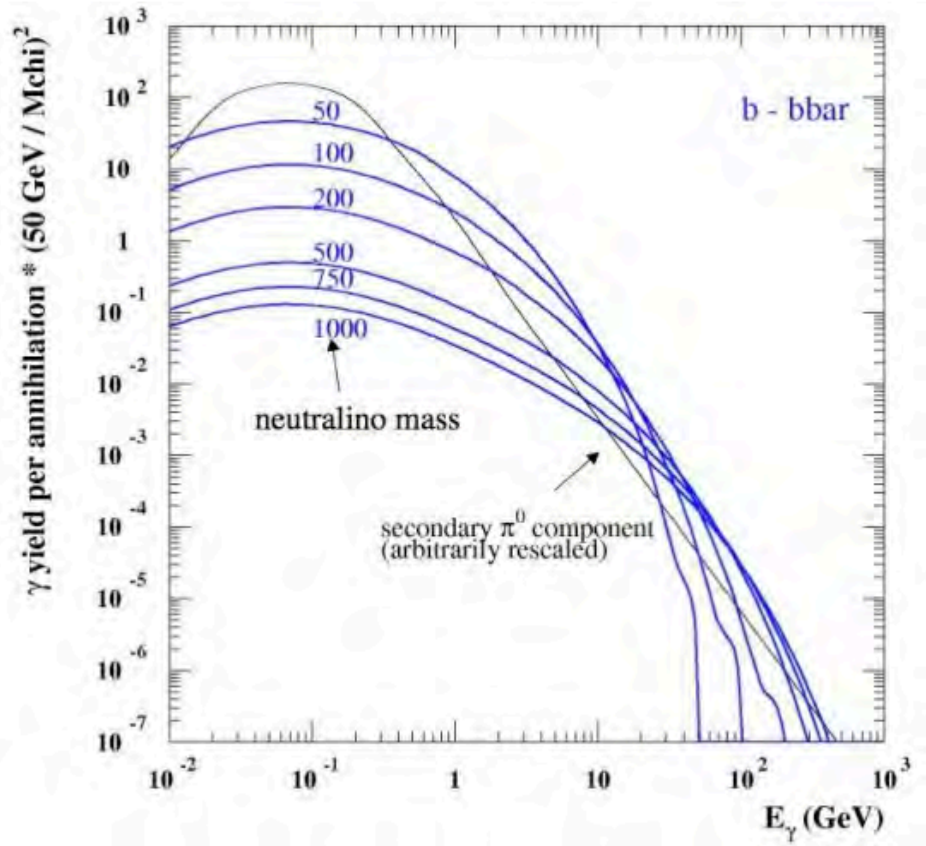


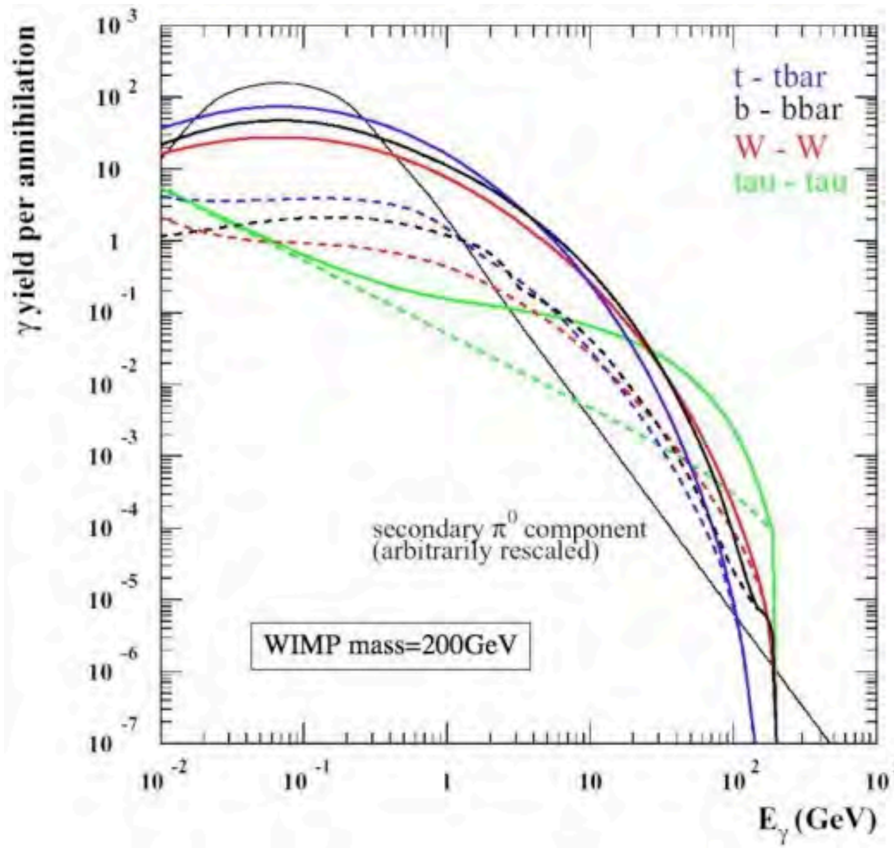
ASTROGAM Dark Matter studies

- **Dark Matter explored in an unique way**
  - **Galactic Center**
  - **Dwarf spheroids**

- **DM mass range unachievable by other means, unique**

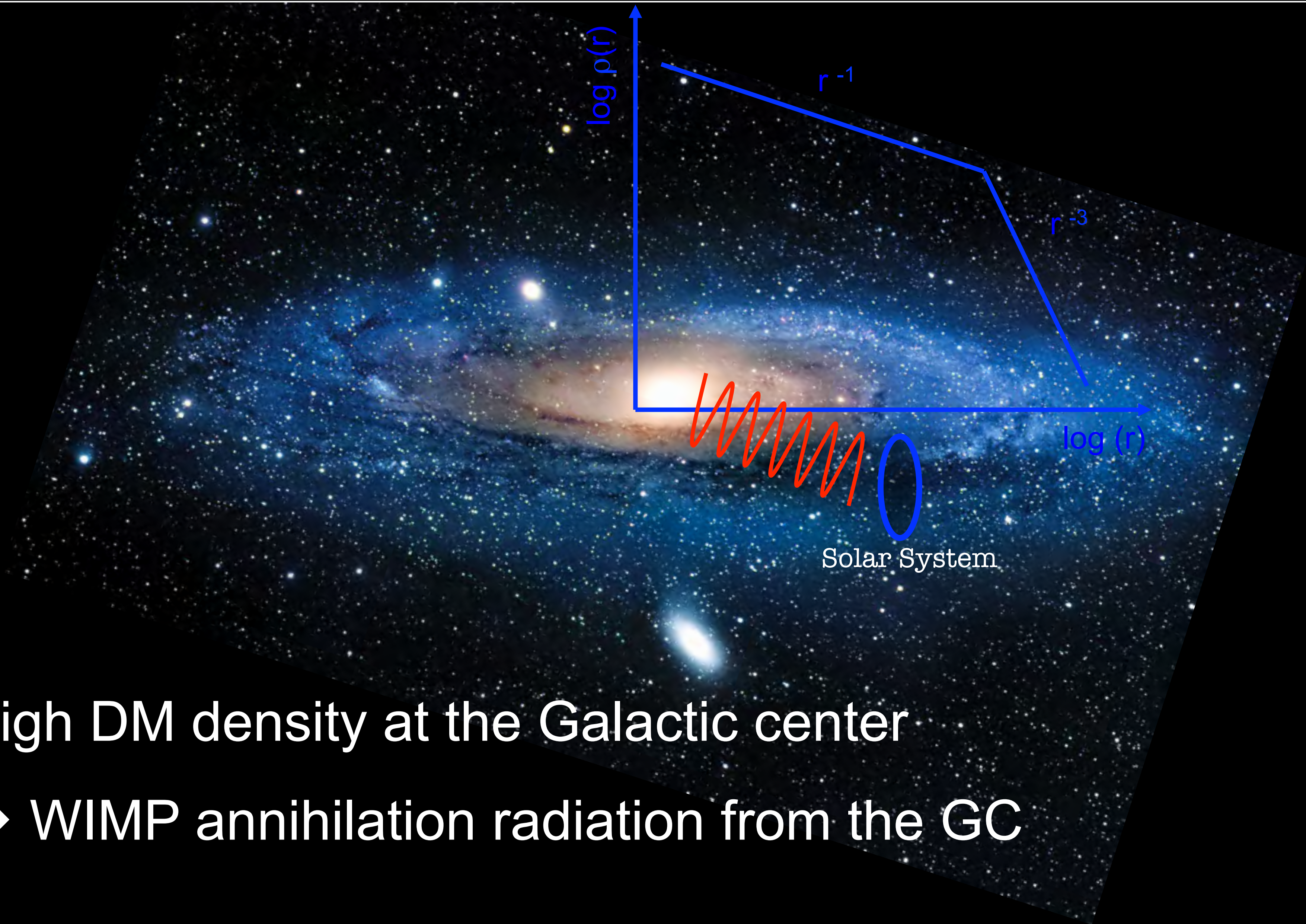
ASTROGAM Dark Matter studies





The bulk of the emission even for high WIMP masses is in the energy range 5 - 100 MeV. Decaying DM can also produce a detectable line in the ASTROGAM energy range that might be detectable out of the continuum

ASTROGAM Dark Matter in the Galactic Center



High DM density at the Galactic center

→ WIMP annihilation radiation from the GC

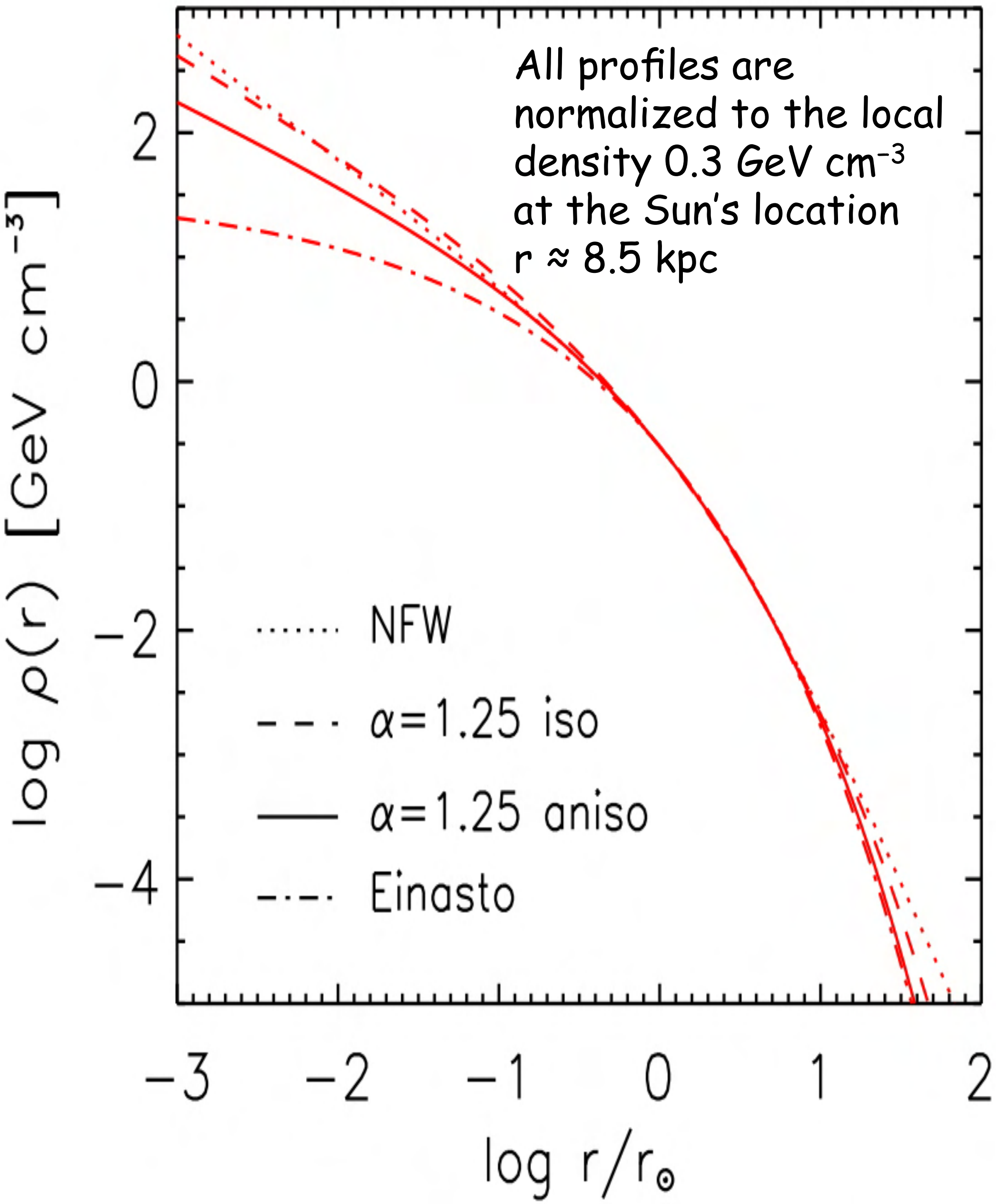
Slide adapted from A. Morselli

Milky Way Dark Matter Density Profiles:

$$\rho(r) = \rho_\odot \left[\frac{r_\odot}{r}\right]^\gamma \left[\frac{1 + (r_\odot/r_s)^\alpha}{1 + (r/r_s)^\alpha}\right]^{(\beta-\gamma)/\alpha}$$

Halo model	α	β	γ	r_s in kpc
Cored isothermal	2	2	0	5
Navarro, Frenk, White	1	3	1	20
Moore	1	3	1.16	30

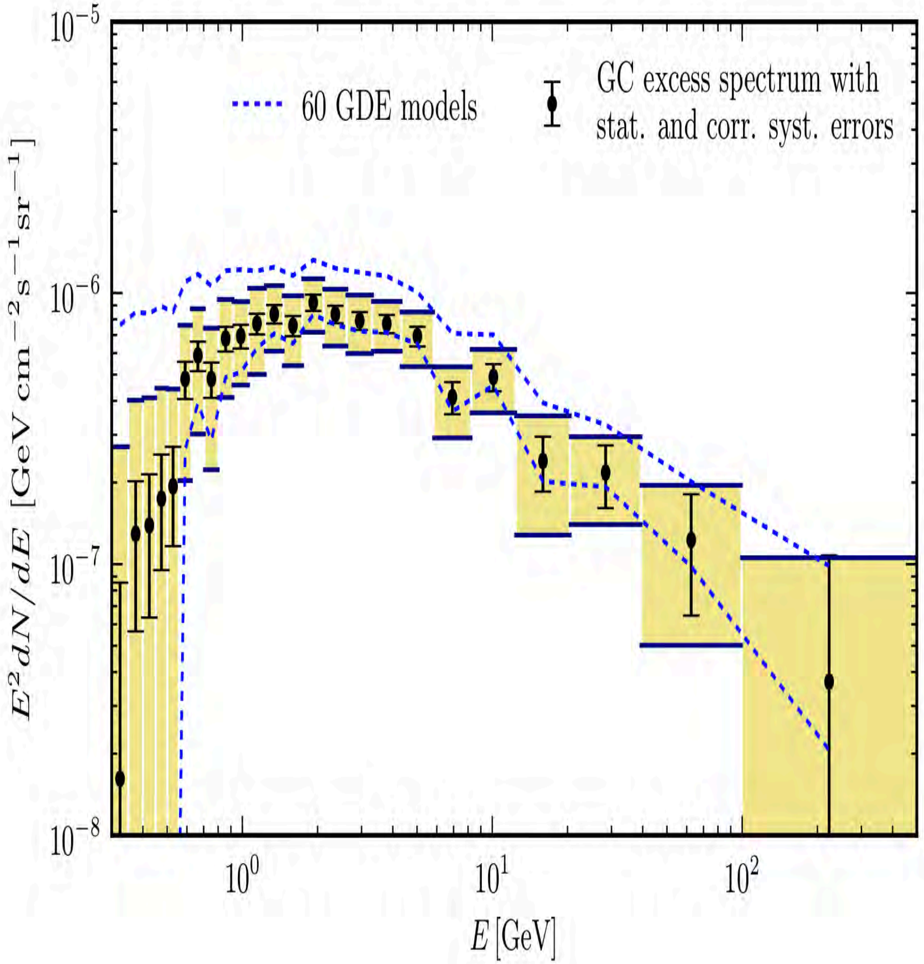
Einasto | $\alpha = 0.17$ $r_s = 20\,\mathrm{kpc}$ $\rho_s = 0.06\,\mathrm{GeV/cm^3}$

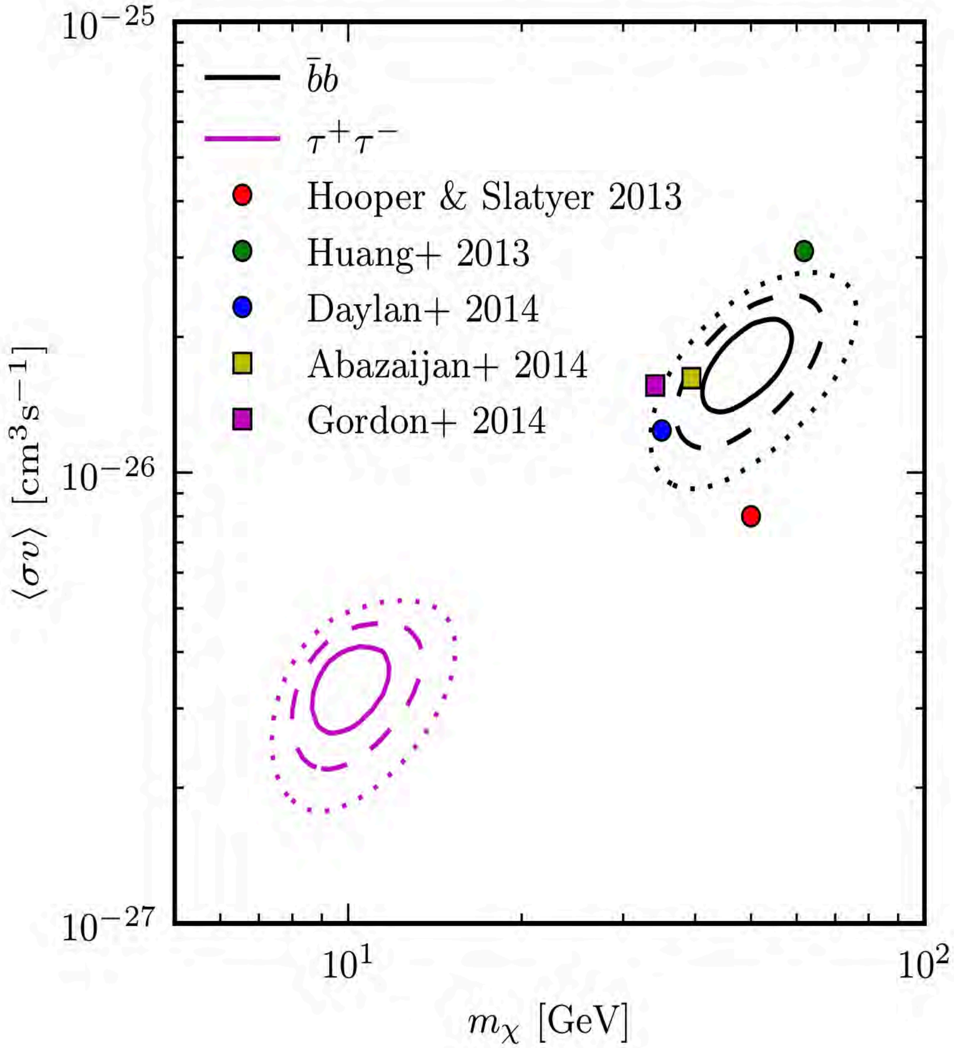


A.Lapi, A.Paggi, A.Cavaliere, A.Lionetto, A.Morselli, V.Vitale. A&A 510, A90 (2010) [arXiv:0912.1766]

Slide adapted from A. Morselli

The GeV excess from the GC





Claims of evidence for dark matter in the Galactic Center in Fermi data (outside the Fermi Collaboration): i.e. Calore et al., JCAP 2015 and arXiv:1409.0042v1

Gamma-ray excess from the GC?

Possible explanations:

- signal from WIMP dark matter annihilation
- gamma-ray emission from a population of millisecond pulsars,
- emission from cosmic rays injected (burst-like events or continuously) at the GC

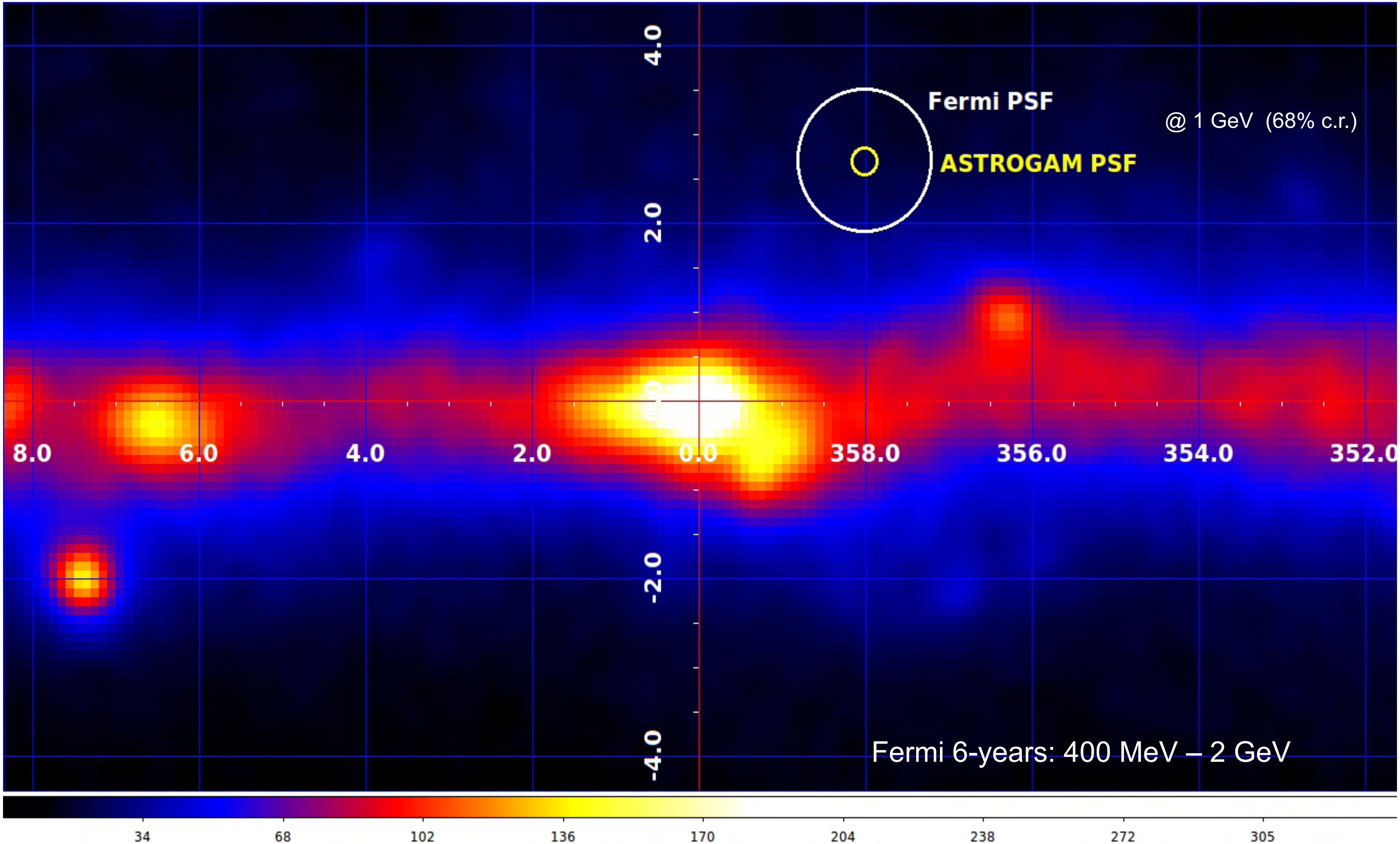
Large uncertainties: very crowded region, extremely difficult subtraction of the Galactic diffuse emission and contribution of unresolved sources.

ASTROGAM will provide:

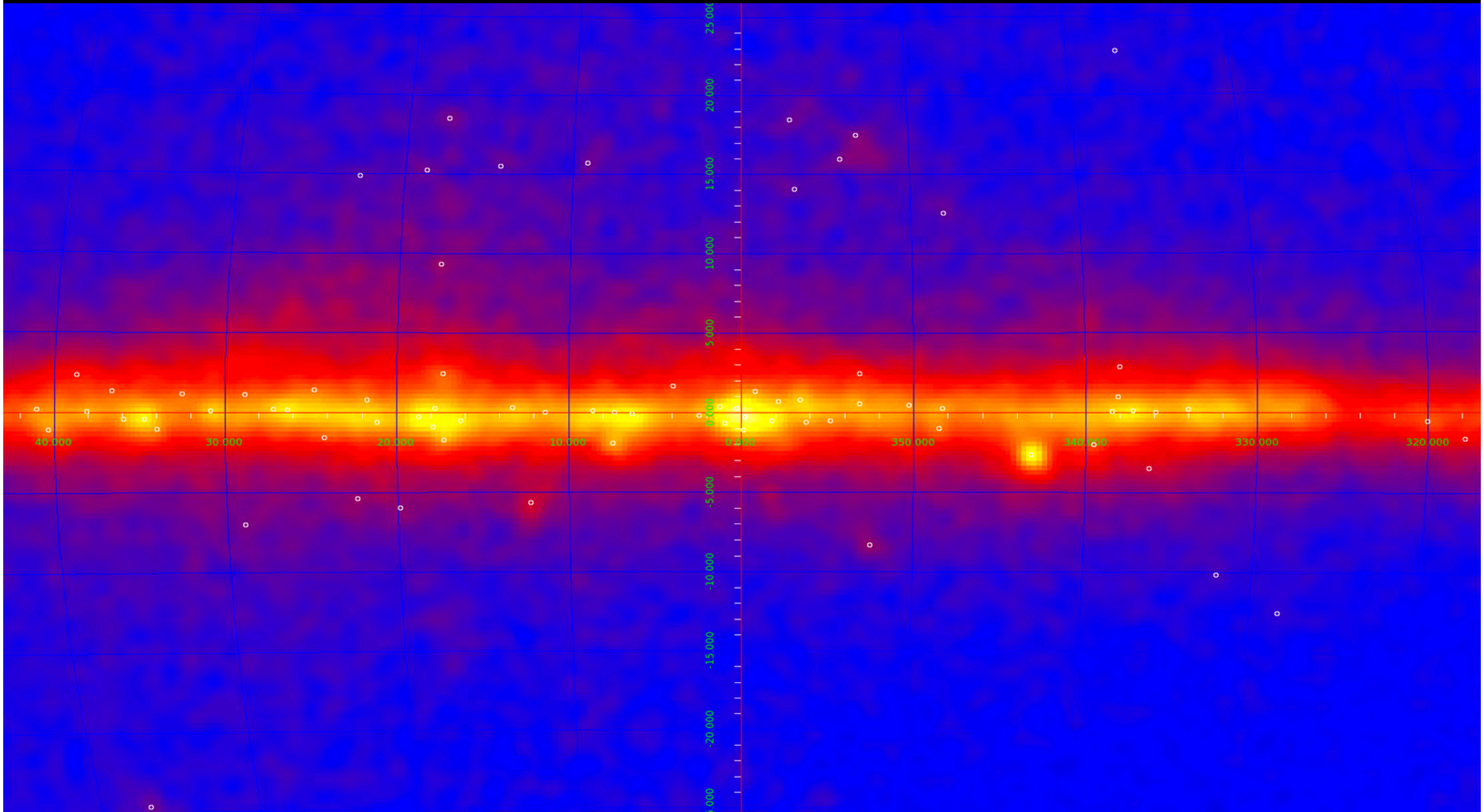
- precise source identification above a few hundreds MeV
- a much improved analysis (factor of 10 in resolving power) of the diffuse gamma-ray background

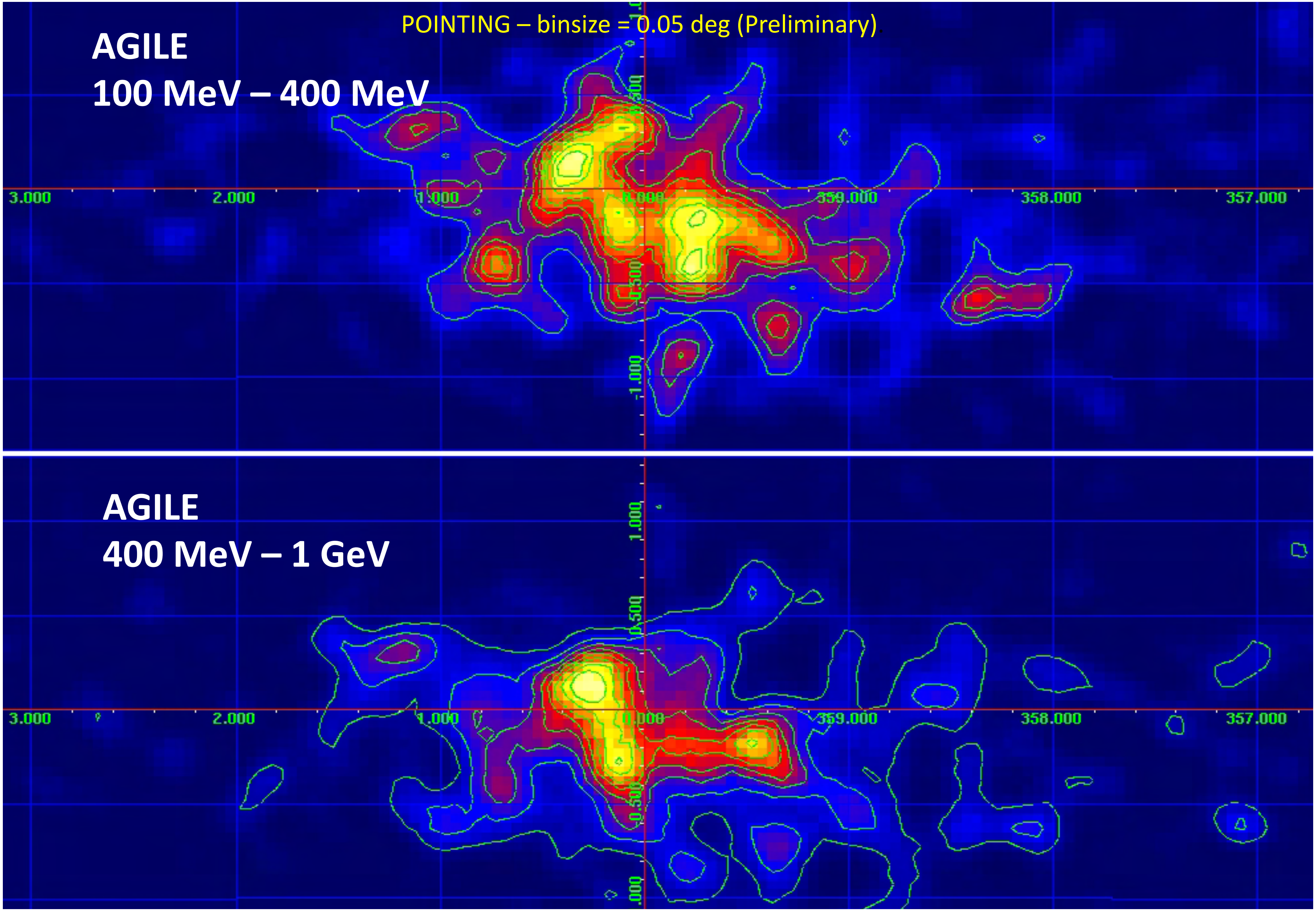
→ **It will be possible to distinguish between astrophysical sources and a signal that follows a Dark Matter halo distribution**

Gamma-ray excess from the GC?



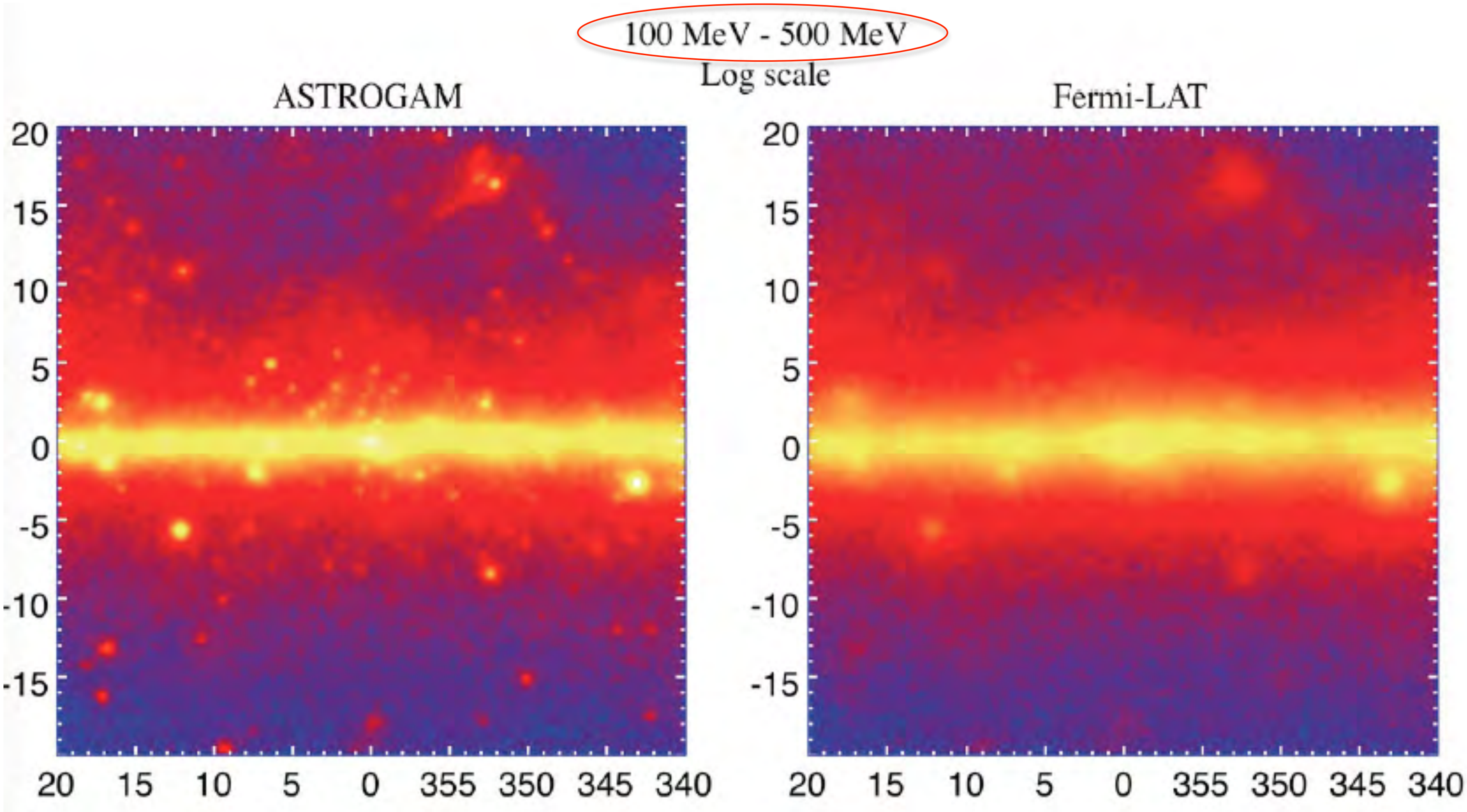
The inner Galaxy seen by AGILE (E > 100 MeV)
(work in progress)





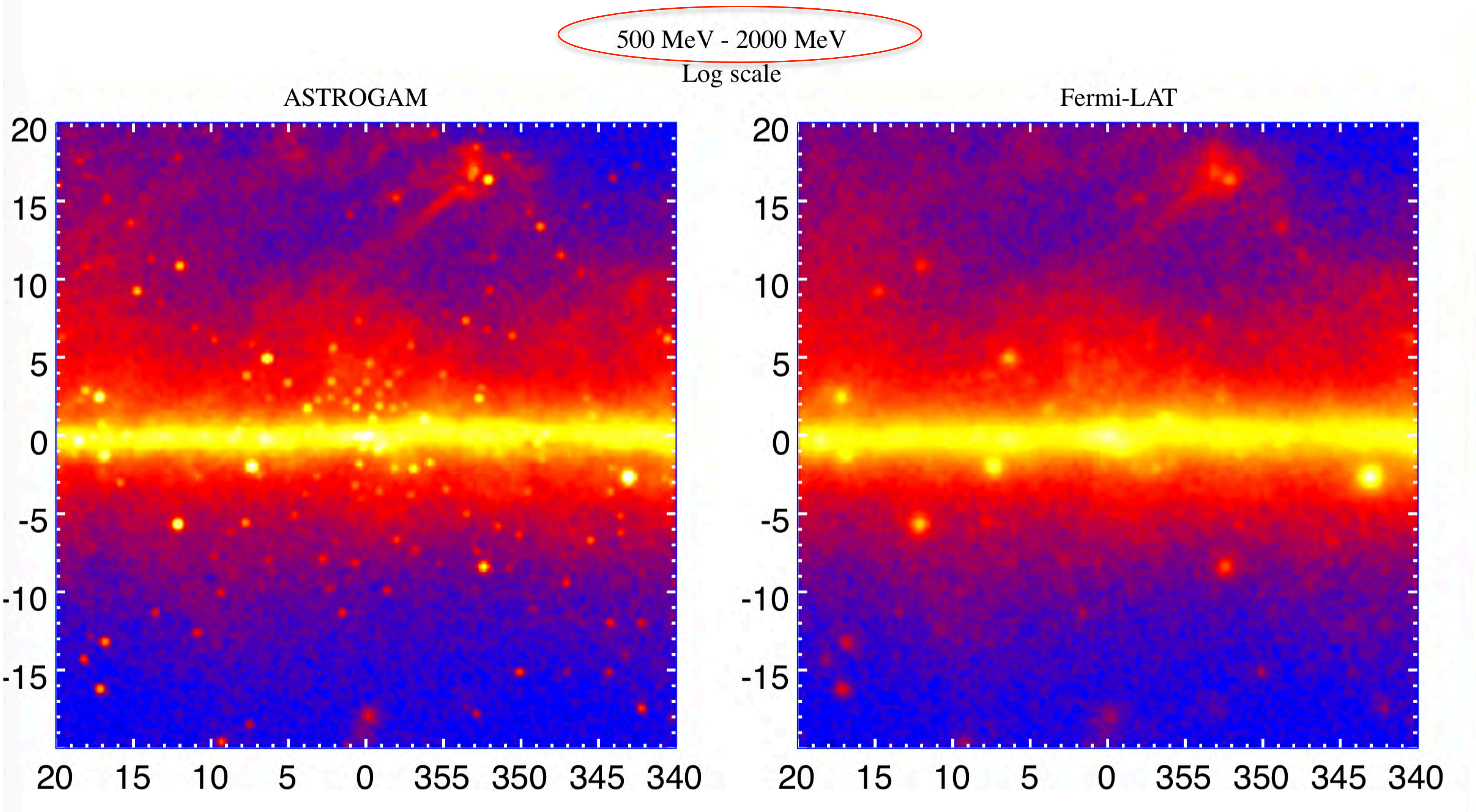
POINTING – binsize = 0.05 deg (Preliminary)
AGILE
100 MeV – 400 MeV
3.000
2.000
1.000
0.000
359.000
358.000
357.000
0.500
-0.500
-1.000
AGILE
400 MeV – 1 GeV
1.000
0.500
3.000
2.000
1.000
0.000
359.000
358.000
357.000
-0.500

Galactic Center Region
ASTROGAM simulated data



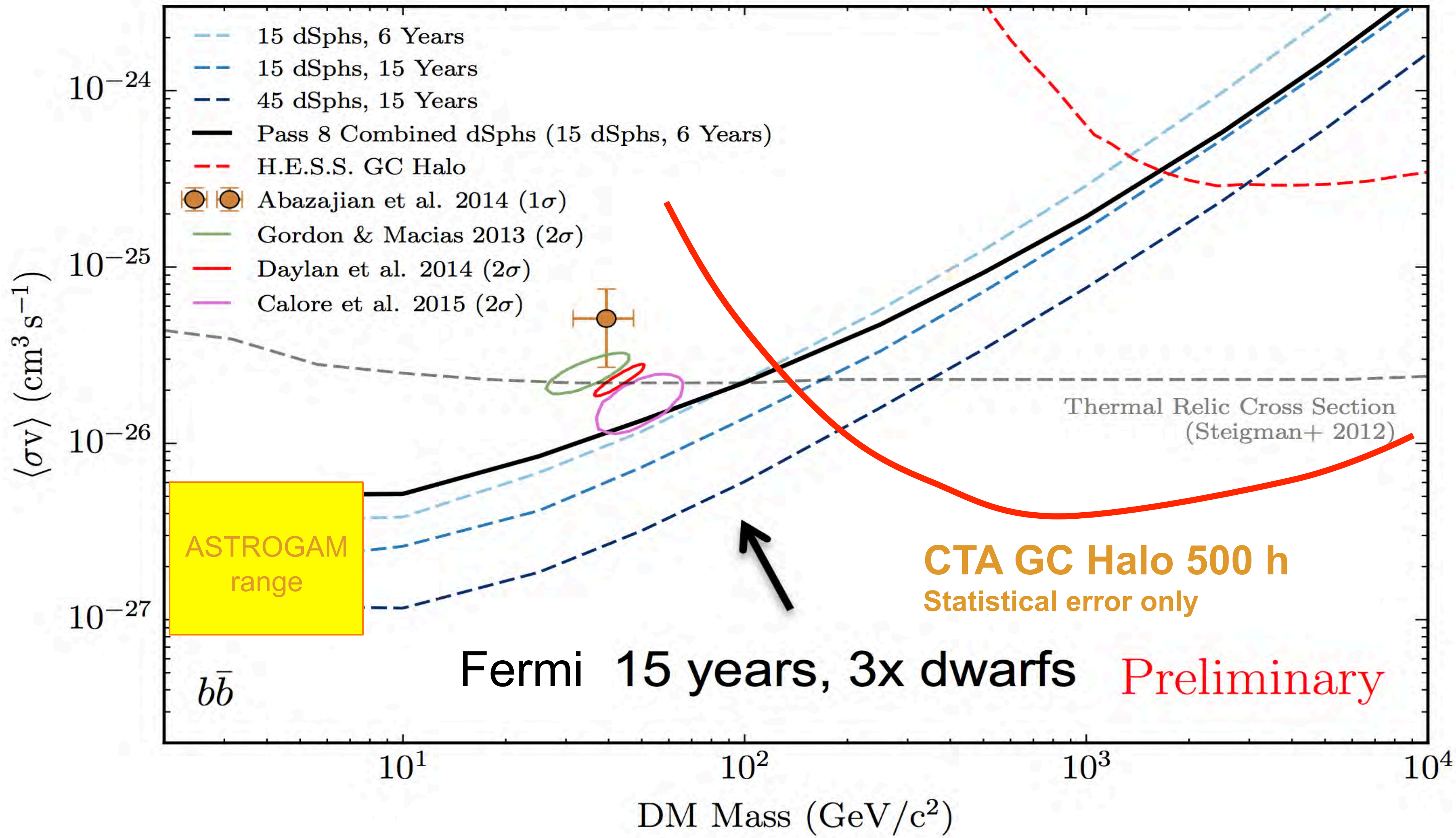
Left: ASTROGAM simulated sky map of the GC using the 3FGL catalogue for a 1.5-year integration. Right: Fermi-LAT (pass 7) data for a 6-year exposure (Gomez-Vargas and Morselli)

Galactic Center Region
ASTROGAM simulated data



Left: ASTROGAM simulated sky map of the GC using the 3FGL catalogue for a 1.5-year integration. Right: Fermi-LAT (pass 7) data for a 6-year exposure (Gomez-Vargas and Morselli)

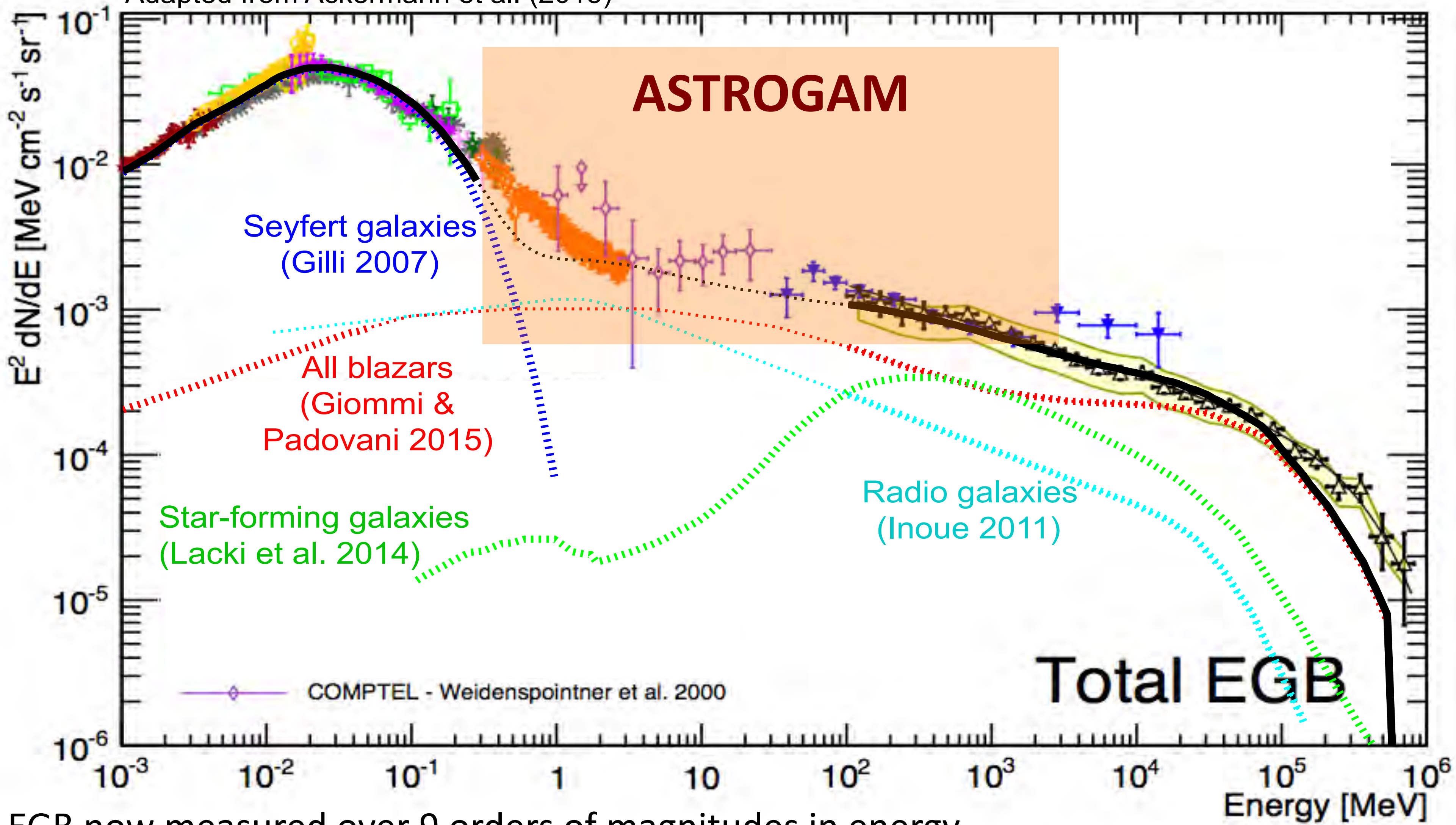
Together with Fermi and CTA, **ASTROGAM** will probe most of the space of WIMP models with thermal relic annihilation cross section



See Morselli Talk on Thursday

ASTROGAM Extragalactic gamma-ray background

Adapted from Ackermann et al. (2015)



- EGB now measured over 9 orders of magnitudes in energy
- Largest uncertainties in the 1 MeV - 100 MeV range
- Origin of the EGB in the 0.3 - 100 MeV range?? **Dark matter contribution?**

Conclusions

- e-ASTROGAM will change our view of the nearby and distant Universe!
- Next chance: ESA M5
- Open to discussion and collaboration