# ASTROGAM

**M. Tavani**
on behalf of the ASTROGAM
Collaboration


ASTROGAM

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)

- **the 1-100 MeV energy range**

- **mostly unexplored**

- **crucial energy range: transition from quasi-thermal (Comptonized) to non-thermal processes.**

- the 1-100 MeV energy range

- mostly u

- crucial e quasi-thermal al processes.

**A CRUCIAL NEW WINDOW !**
**THE MISSING LINK IN THE CHAIN OF KNOWLEDGE OF THE HIGH-ENERGY UNIVERSE**

# ESA guidelines for M4 Missions

- P/L mass: 300 kg
- Satellite mass: 800 kg
- Very high TRL (end of Definition Phase): > 5-6

- ESA budget 450 Meuros

- **P/L mass: 300 kg**
- **Satellite mass: 800 kg**

**can we do excellent science in the MeV-GeV range ?!?**

# ESA guidelines for M4 Missions

- P/L mass: 300 kg
- Satellite mass: 800 kg
- Very high TRL (end of Definition Phase): > 5-6

We approach the M4 Mission from ‘’ below’’

# ASTROGAM

- **Very high TRL on technologies for space based on Silicon detectors & analog readout, FEE (PAMELA, AGILE, Fermi, AMS).**
- **Unique skills on scientific management of space missions dedicated to the gamma-ray astrophysics (AGILE).**
- **Calorimeter heritage and new FEE developments.**

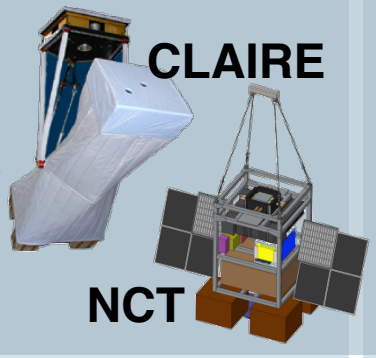
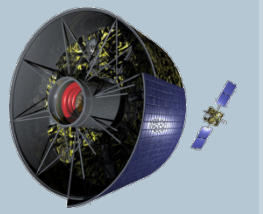
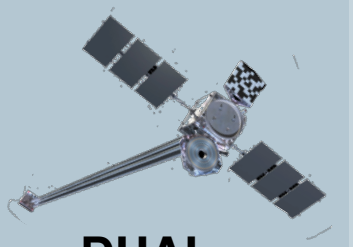
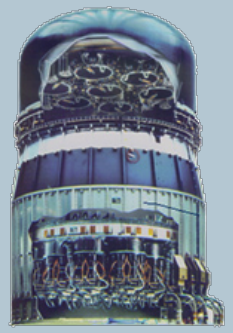
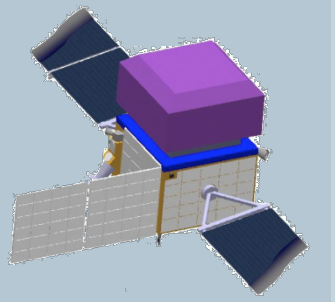
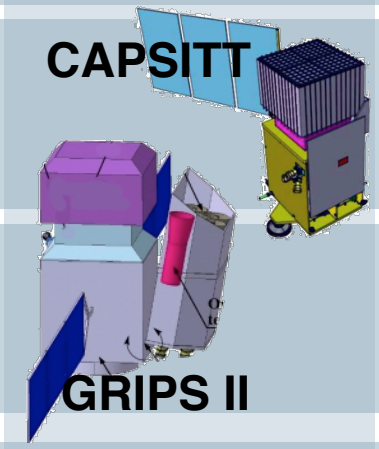
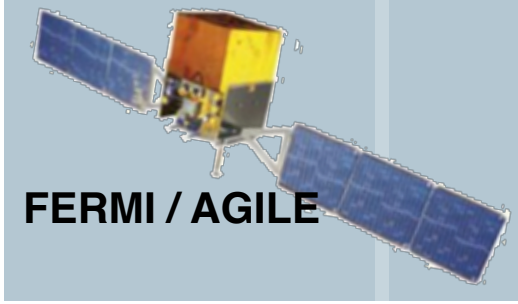
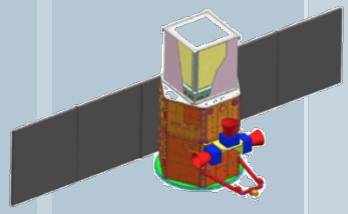
# ASTROGAM

- **Unique skills for the definition and development of Data Handling systems for high-energy astrophysics.**

- **Excellent knowledge of the background in near equatorial LEO orbits (BSAX, AGILE).**

- **Excellent and fast data reduction and alert system for gamma-ray data.**

# What is ASTROGAM ?

| heritage | M1/M2 (2007) | M3 (2011) | S1 (2012) | | M4 |
|---|---|---|---|---|---|
|  CLAIRE NCT |  GRI |  DUAL | | AstroMeV | AstroMeV & Gamma-Light |
|  COMPTEL |  GRIPS I |  CAPSITT GRIPS II | | | |
|  FERMI / AGILE | | |  Gamma-Light | | |

# ASTROGAM Collaboration organization

- Consortium members: 230 scientists from 18 countries
- Lead Proposer: Marco Tavani (INAF) – Co-Lead Proposer: Vincent Tatischeff (CSNSM)
- Executive board (representatives of key nations/labs):
  - INAF- Istituto di Astrofisica e Planetologia Spaziali, Rome, **Italy**: Andrea Argan
  - INFN Roma Tor Vergata, Rome, **Italy**: Aldo Morselli
  - INAF, Istituto di Astrofisica Spaziale e Fisica Cosmica, Milano, **Italy**: Sandro Mereghetti
  - IRAP, Toulouse, **France**: Peter von Ballmoos
  - Institut de Ciències de l'Espai, CSIC-IEEC, Bellaterra, Barcelona, **Spain**: Margarita Hernanz
  - University College Dublin, School of Physics, Belfield Dublin, **Ireland**: Lorraine Hanlon
  - MPI für Extraterrestrial Physics, Garching, **Germany**: Gottfried Kanbach
  - Johannes Gutenberg Universität Mainz, Institut für Physik, Mainz, **Germany**: Uwe Oberlack
  - DTU SPACE, Lyngby, **Denmark**: Carl Budtz-Jørgensen
  - University of Geneva, **Switzerland**: Roland Walter
  - KTH Royal Institute of Technology, Stockholm, **Sweden**: M.Pearce
  - The University of Tokyo, Department of Physics, Tokyo, **Japan**: Kazuhiro Nakazawa
  - Ioffe Physico-Technical Institute, St.Petersburg, **Russia**: Bykov Andrei
  - Clemson University, Clemson, SC, **USA**: Dieter Hartmann
  - **USA**: NASA GSFC, **USA**: J. McEnery

- Working group organization - coordinators:
  - ***Scientific instruments***: V. Tatischeff (Fr)
  - ***Simulations***: A. Zoglauer (USA), A. Bulgarelli (It)
  - ***Science case***: M. Tavani (It)
  - ***Mission profile***: P. von Ballmoos (Fr)
  - ***Management***: A. Argan (It)

| Institution | Country | Main participants |
|---|---|---|
| INAF | Italy | M. Tavani, A. Argan, M. Marisaldi, A. Bulgarelli, C. Labanti, S. Mereghetti |
| INFN | Italy | A. Morselli, V. Bonvicini, A. Vacchi, G. Barbiellini, F. Longo, P. Picozza, G. Zampa, N. Zampa, A. Rashevsky, G. Bertuccio |
| CSNSM | France | V. Tatischeff, J. Peyré, J. Kiener |
| APC | France | P. Laurent |
| CEA/Irfu | France | O. Limousin |
| IRAP | France | P. von Ballmoos |
| LUPM | France | F. Piron |
| IPNO | France | N. de Séréville |
| Univ. Mainz | Germany | U. Oberlack, M. Alfonsi, A. Brogna, C. Grignon, C. Hils, R. Othegraven, U. Schaefer |
| ICE (CSIC-IEEC) and IMB-CNM (CSIC) | Spain | M. Hernanz, M. Lozano |
| Univ. Geneva | Switzerland | R. Walter, X. Wu |
| Univ. Dublin | Ireland | L. Hanlon, S. McBreen |

# ASTROGAM Consortium organization

INAF

INFN

Rome Tor Vergata University

IRAP

APC

IEEC

University College Dublin

MPI

Universität Mainz

DTU

University of Geneva

KTH

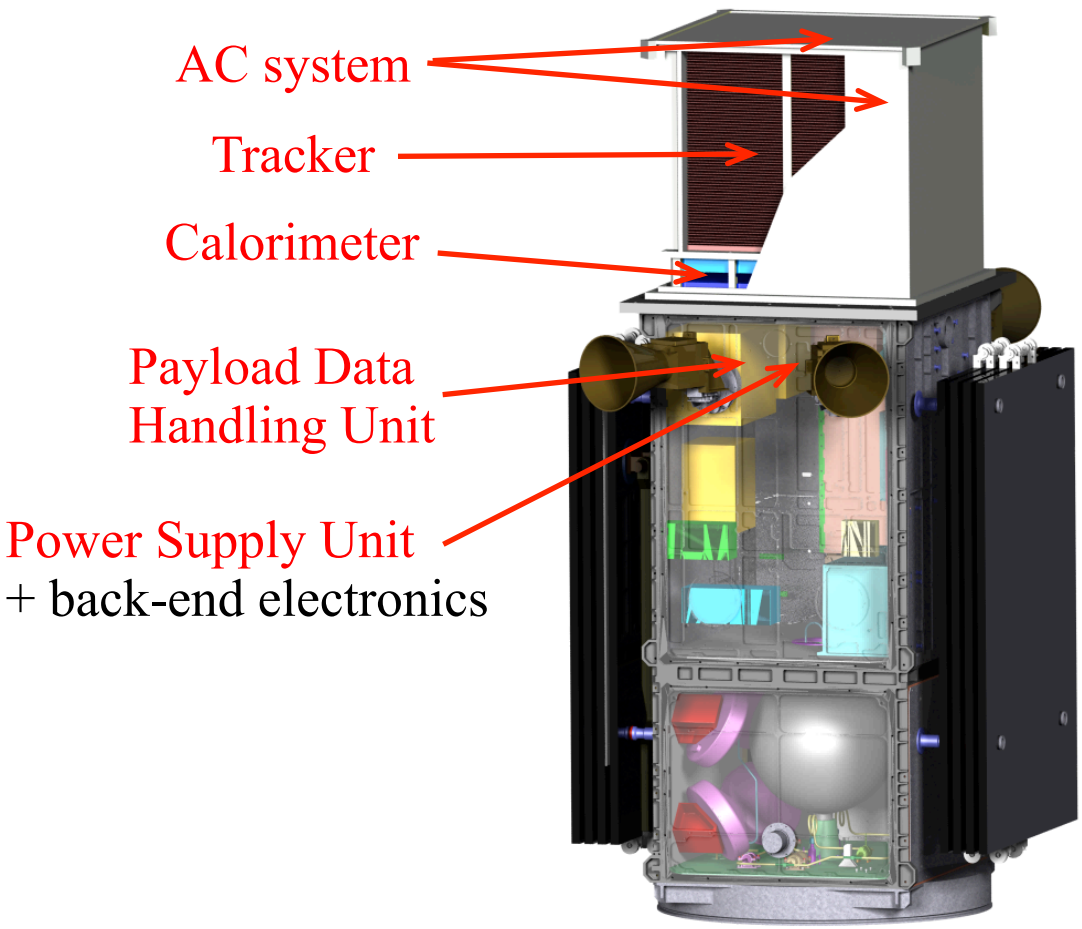
University of Tokyo

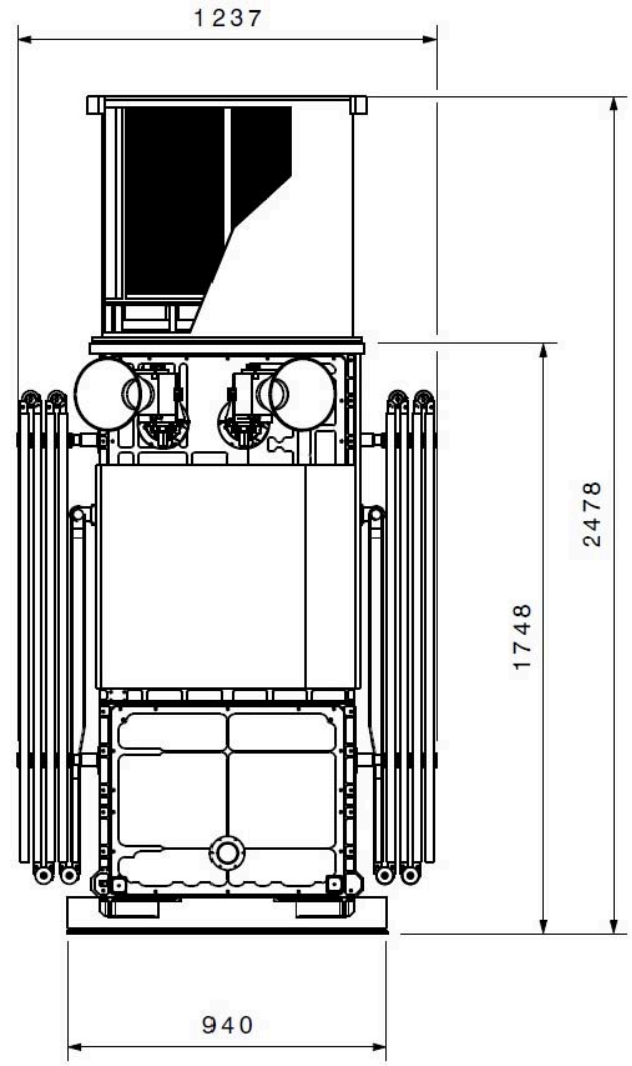
Ioffe Institute

Clemson University

# ASTROGAM Payload

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



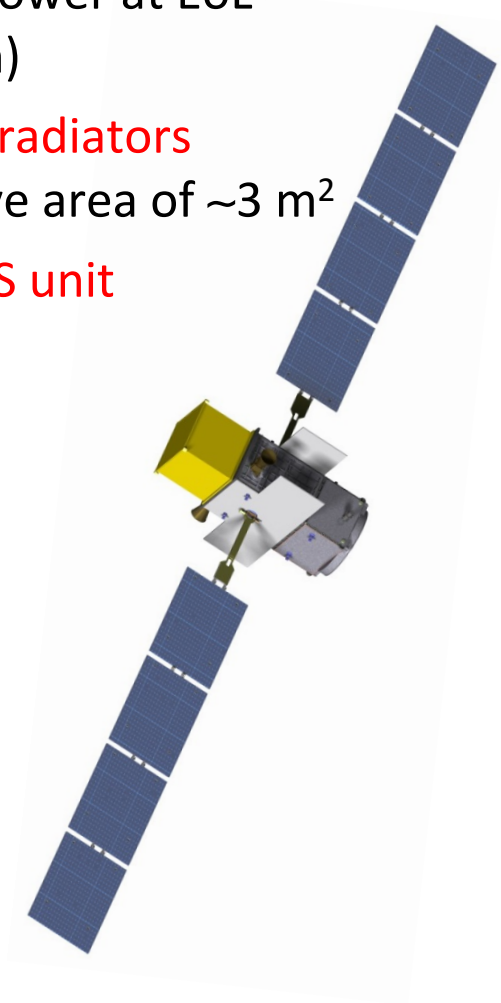



# ASTROGAM Spacecraft

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

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

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



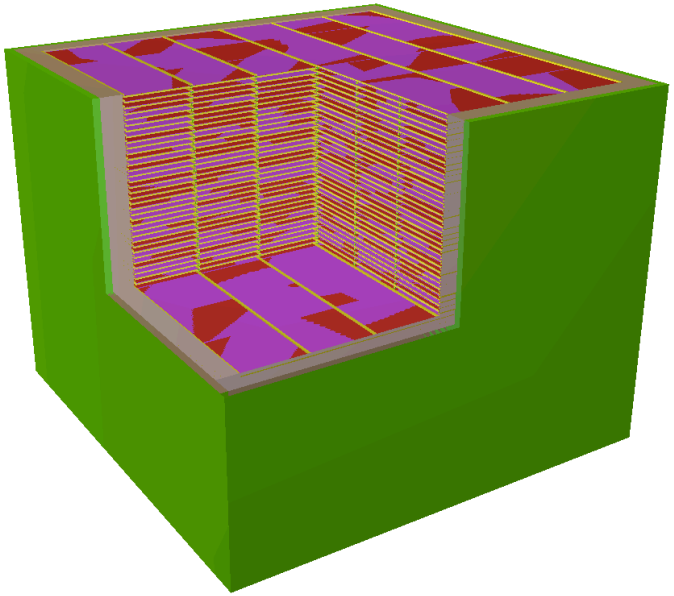
# ASTROGAM Silicon Tracker

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

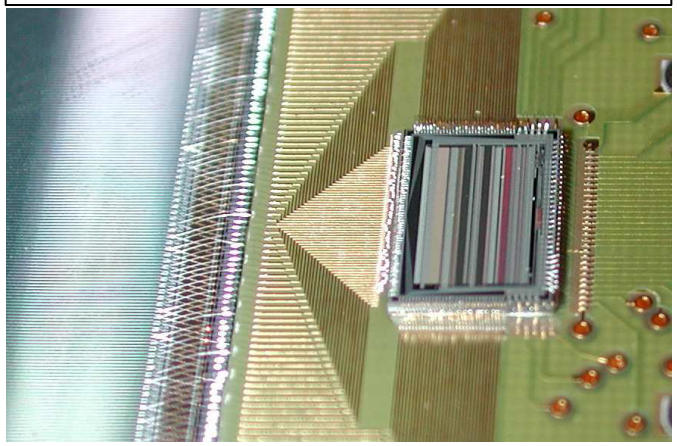
⇒ 322 560 electronic channels

- DSSD strips connected to ASICs (32 channels each) through a pitch adapter (DC coupling)
- 144 ASICs (IDeF-X HD) per layer (72 per DSSD side)

⇒ 10 080 ASICs total

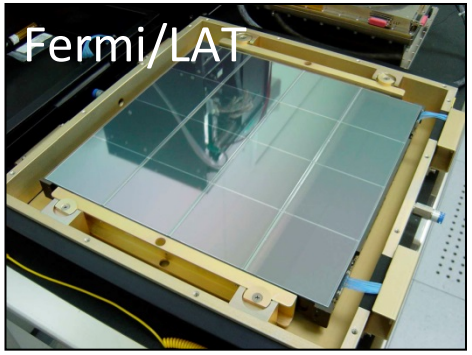


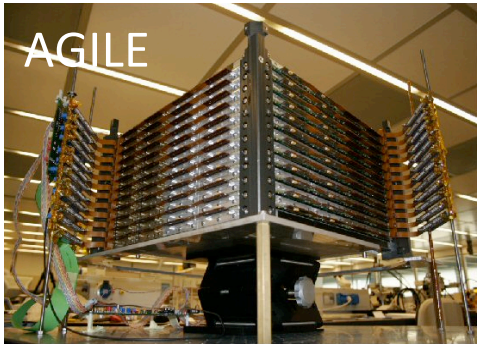

Detail of the detector-ASIC bonding in the AGILE Si Tracker

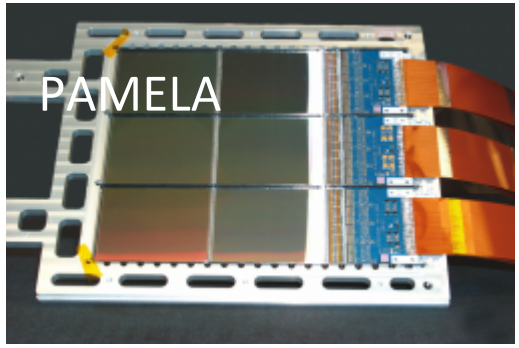


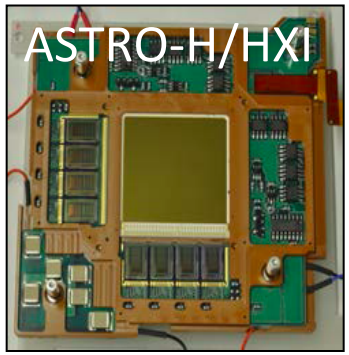
# ASTROGAM Tracker heritage - Technology challenges

- DSSDs are widely used in particle physics experiments, e.g. LHC/ATLAS+CMS
- Ladders of wire-bonded SSSDs in Fermi/LAT and AGILE, and of wire-bonded DSSDs in PAMELA and AMS-02 + ASTRO-H/HXI (do be launched in 2015)

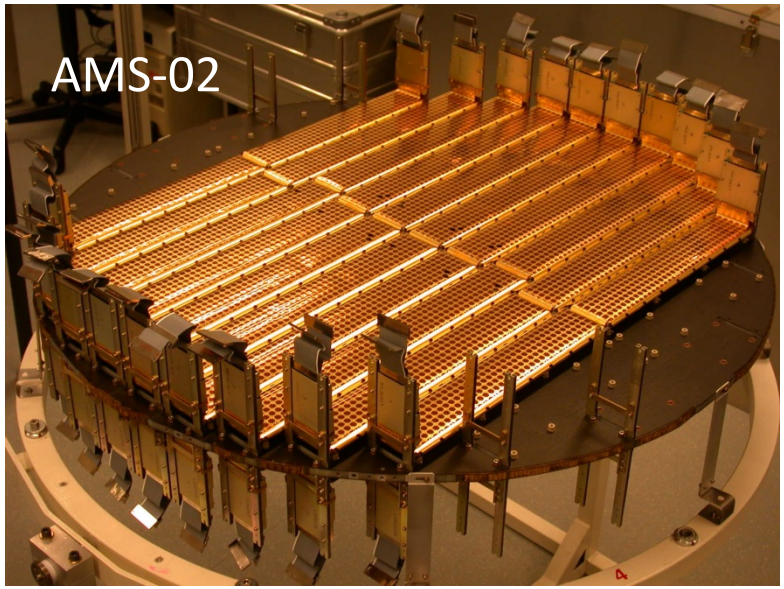


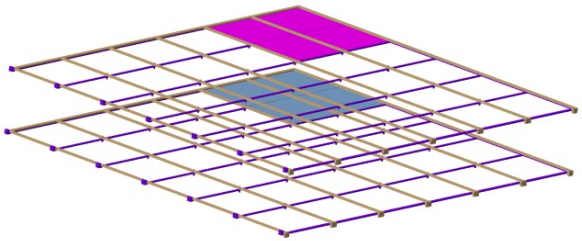




- **Main technology challenges**:
  - (i) Mechanical structure (no material between the Si layers) and 2-D bonding
  - (ii) Front-end electronics (noise not to exceed a few keV FWHM)
  - (iii) Thermal control (DSSDs & ASICs at $T \sim 0$ °C)

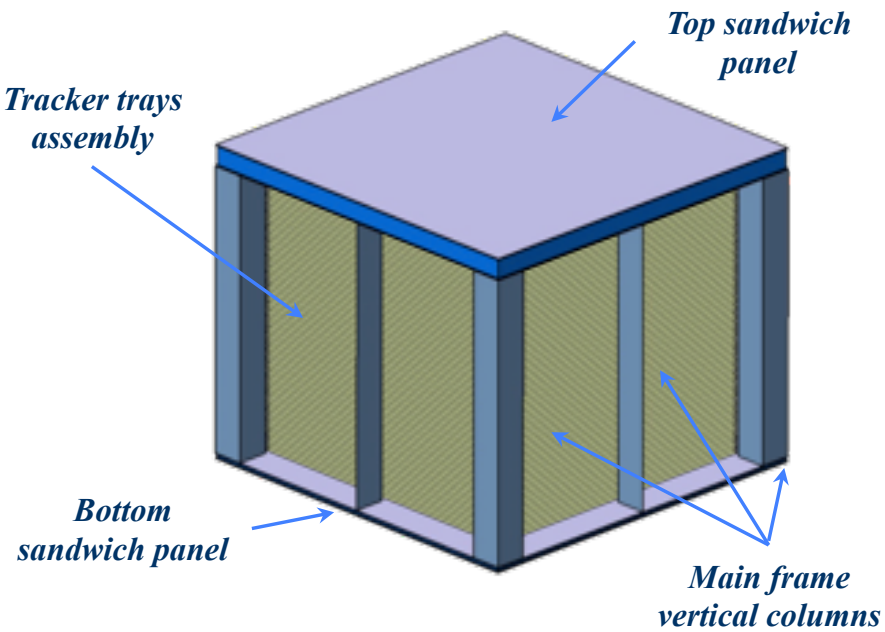


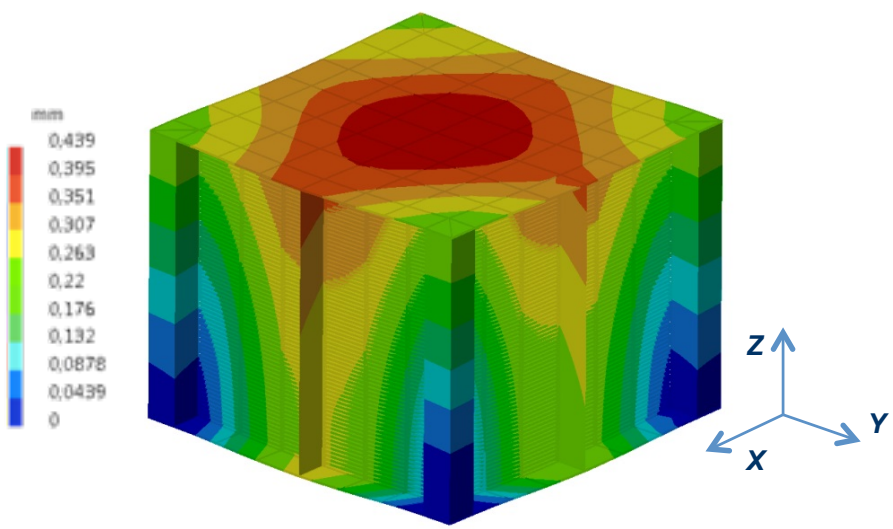
# ASTROGAM Tracker Mechanics

- Structure of a detection plane made of two frames sandwiching the Si detectors, with the support rods parallel to the DSSD strips to enable wire bonding



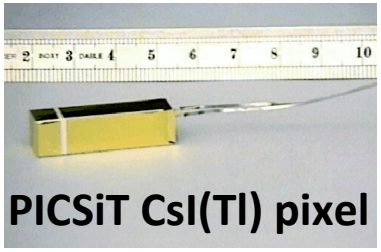
- Main structure composed of vertical fixing columns and two honeycomb panels above and below the instrument so to give it the required stiffness
- Detailed structural calculations including both static and modal analyses
  ⟹ maximum out plane displacement of 440 μm

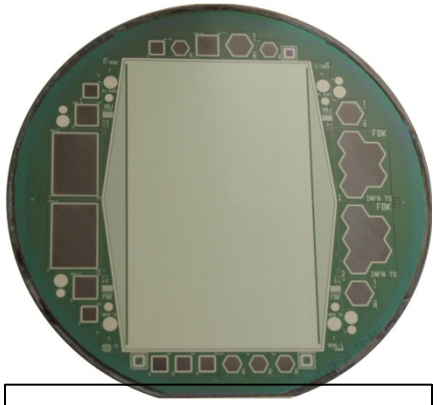


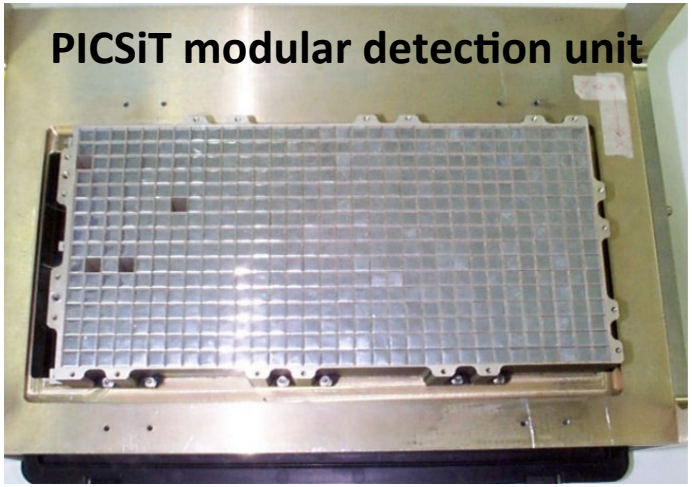



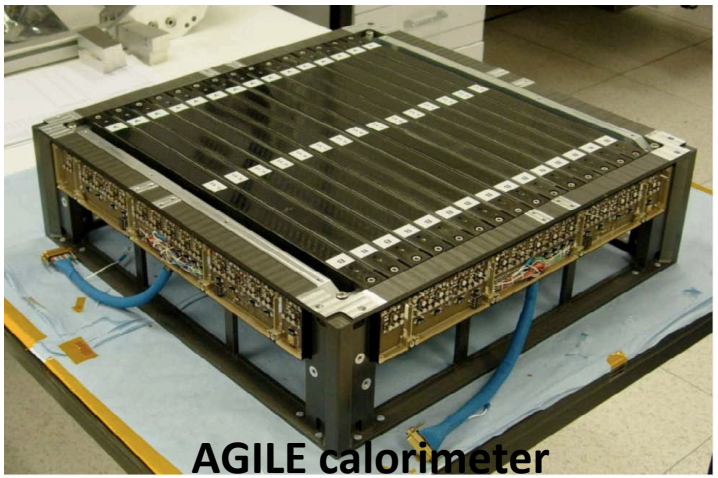
# ASTROGAM Calorimeter

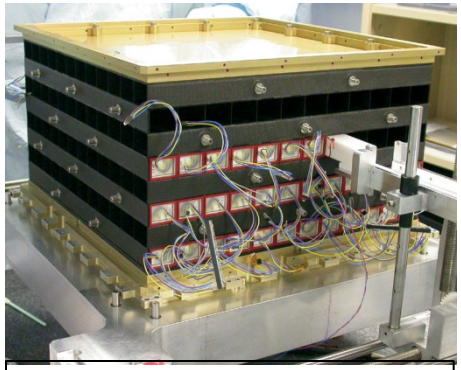
- Pixelated detector made of 12 544 CsI(Tl) scintillator bars of 5 cm length and 5×5 mm$^2$ cross section, glued at both ends to low-noise Silicon Drift Detectors (SDDs)
- Basic detector element formed by the coupling of 4 CsI(Tl) bars to 2 square arrays of 2×2 SDDs of 5 mm side
- Calorimeter formed by the assembly of 196 (14×14) individual modules, each comprising 16 basic detector elements (64 CsI(Tl) bars) held by a carbon-fiber structure
- **Heritage**: INTEGRAL/PICsIT, AGILE, Fermi/LAT, LHC/ALICE


PICSiT CsI(Tl) pixel


Samples of SDDs from FBK-SRS

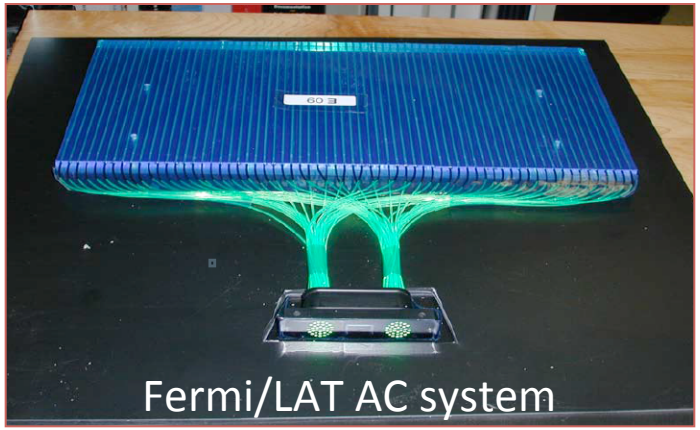

PICSiT modular detection unit

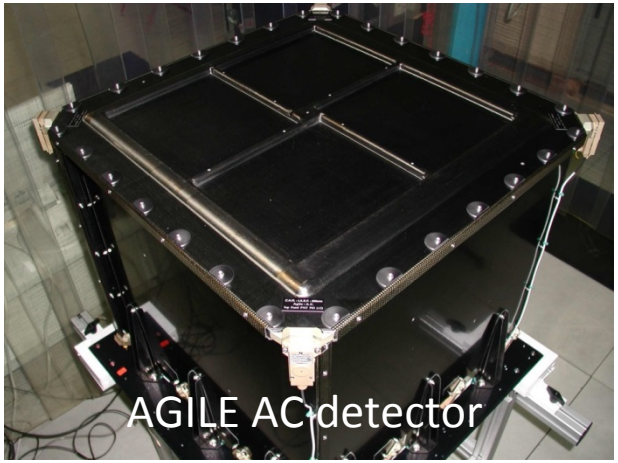

AGILE calorimeter

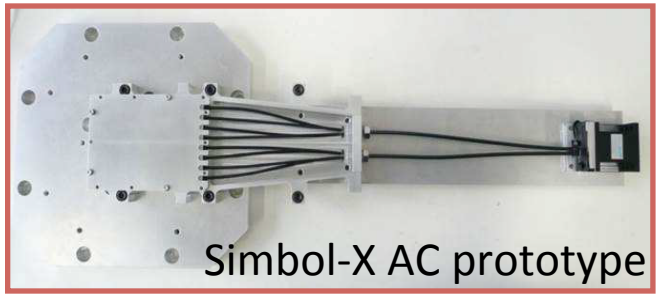

Fermi cal. module

# ASTROGAM Anticoincidence

- AC system formed with large 1 cm thick plastic BC408 panels covering 5 faces of the instrument. In each panel, clear optical fibers buried in trenches convey the scintillation light to Si photomultipliers (SiPMs) glued at the end of the fibers.
- With 72 fibers (70 cm long) for the top panel and 280 fibers (72 cm long) for the side panels, there are in total 352 SiPMs (= # of electronic channels)
- The SiPM signals are readout by 6 VATA64 ASICs of 64 channels each (space-qualified ASIC optimized for SiPM from Ideas©)
- **Heritage**: FERMI/LAT, AGILE, Simbol-X AC prototype

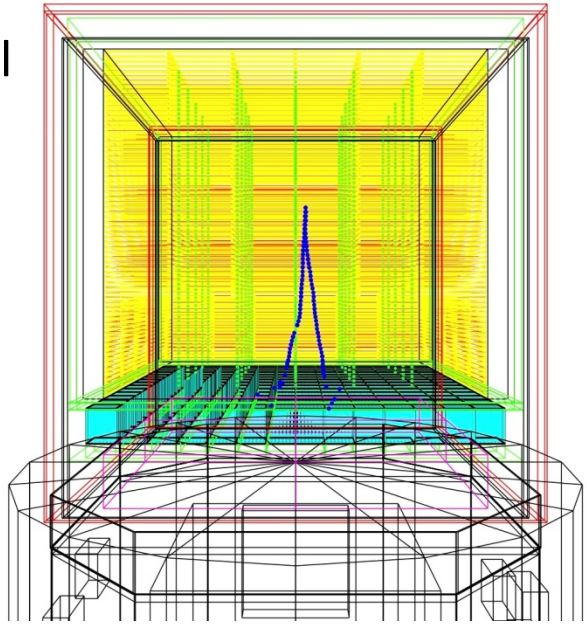

Fermi/LAT AC system

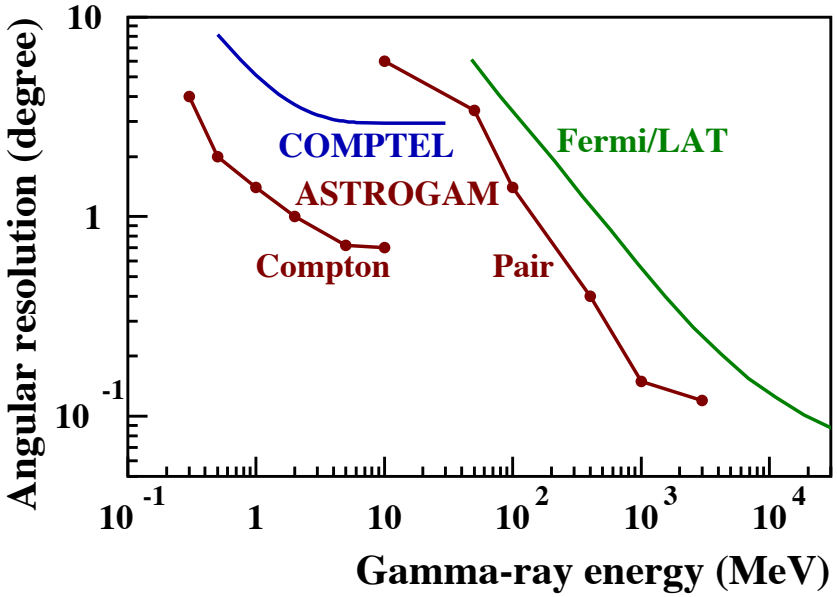

AGILE AC detector

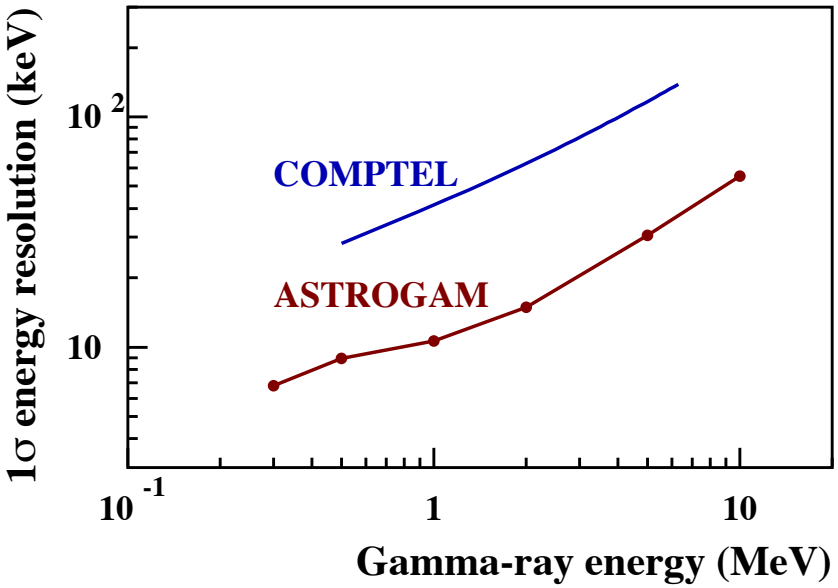

Simbol-X AC prototype

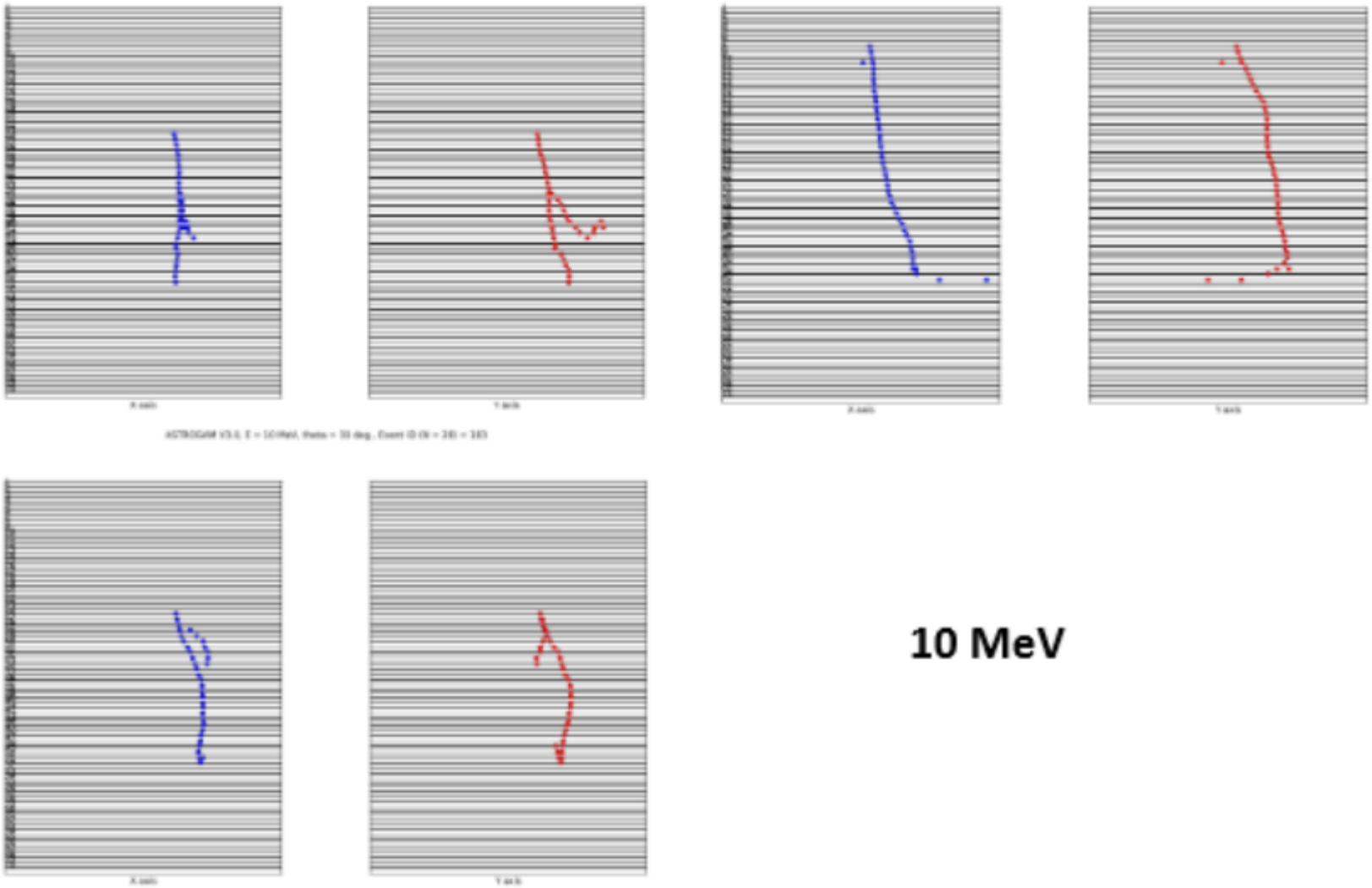
# ASTROGAM Performance assessment

- ASTROGAM scientific performance evaluated by numerical simulations using **MEGAlib** and **Bogemms** (both based on Geant4) and a detailed mass model of the instrument
- The background environment in an equatorial LEO is now well-known thanks to the Beppo-SAX and AGILE missions
- ASTROGAM angular resolution better than that of COMPTEL by a factor 4 at 5 MeV, and than that of Fermi/LAT by a factor of 3.5 at 1 GeV

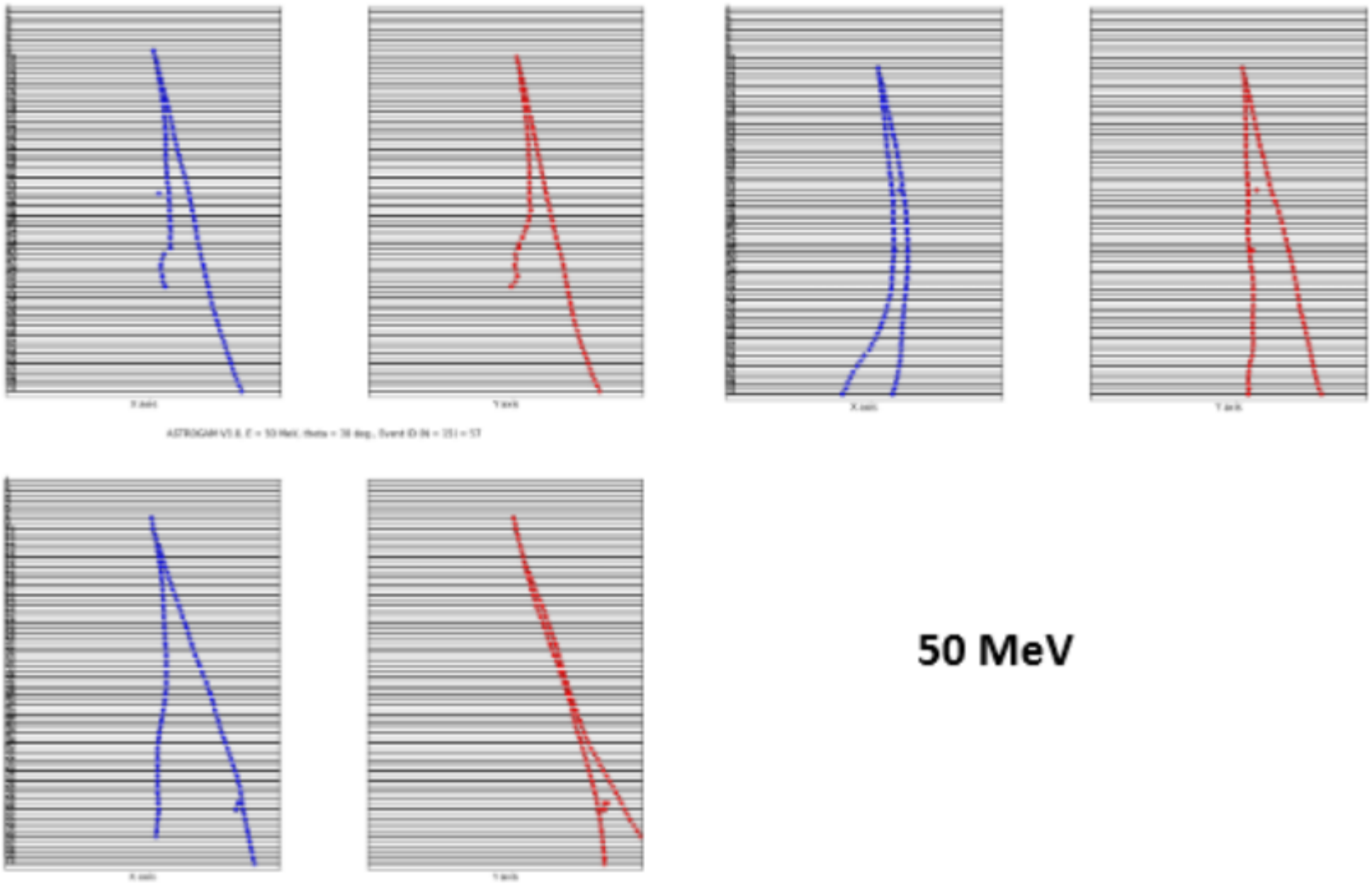




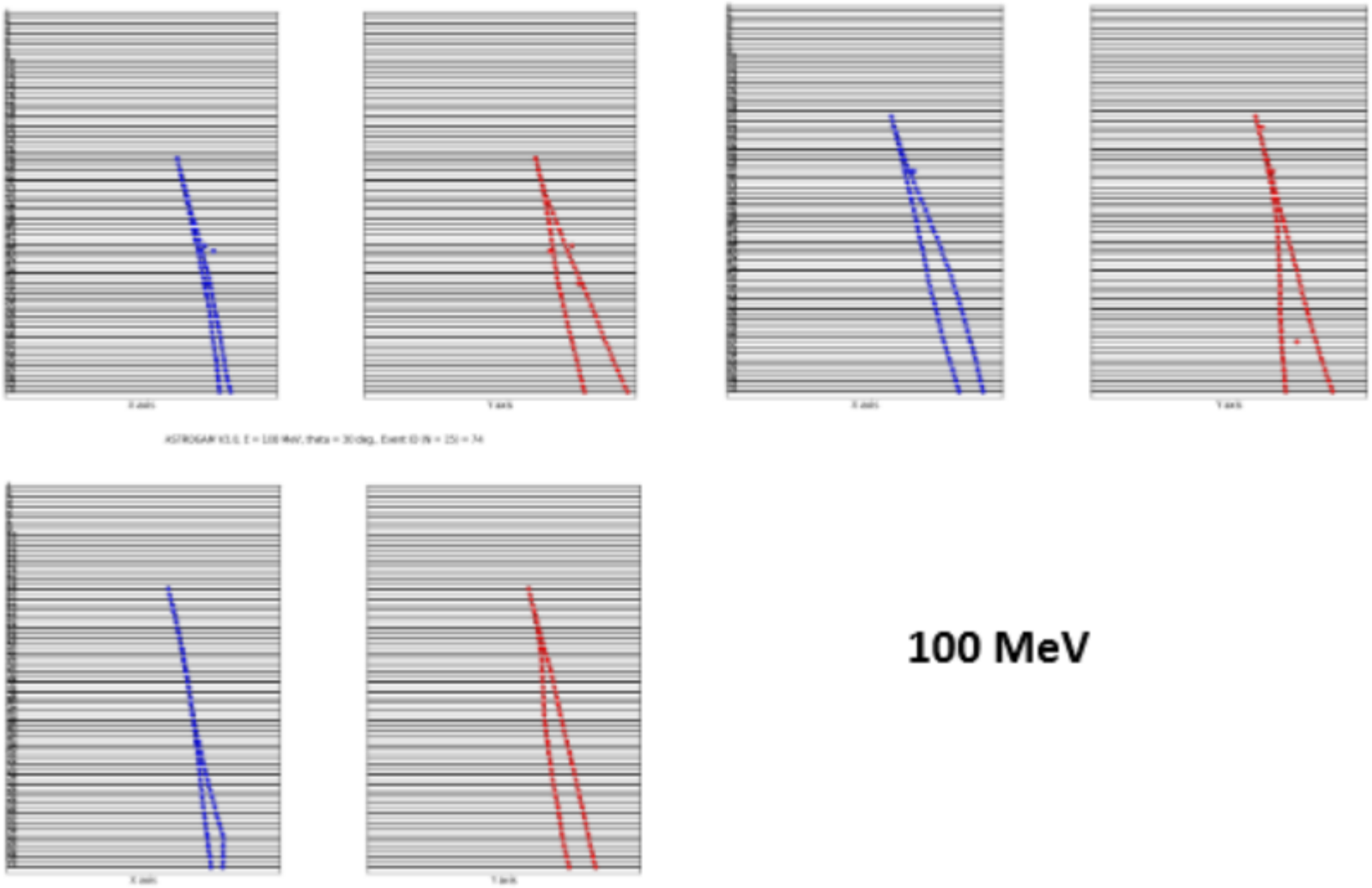




X axis
Y axis
X axis
Y axis
ASTROGAM V3.0, E = 10 MeV, theta = 30 deg., Event ID (X = 2ID + 1ID)
X axis
Y axis

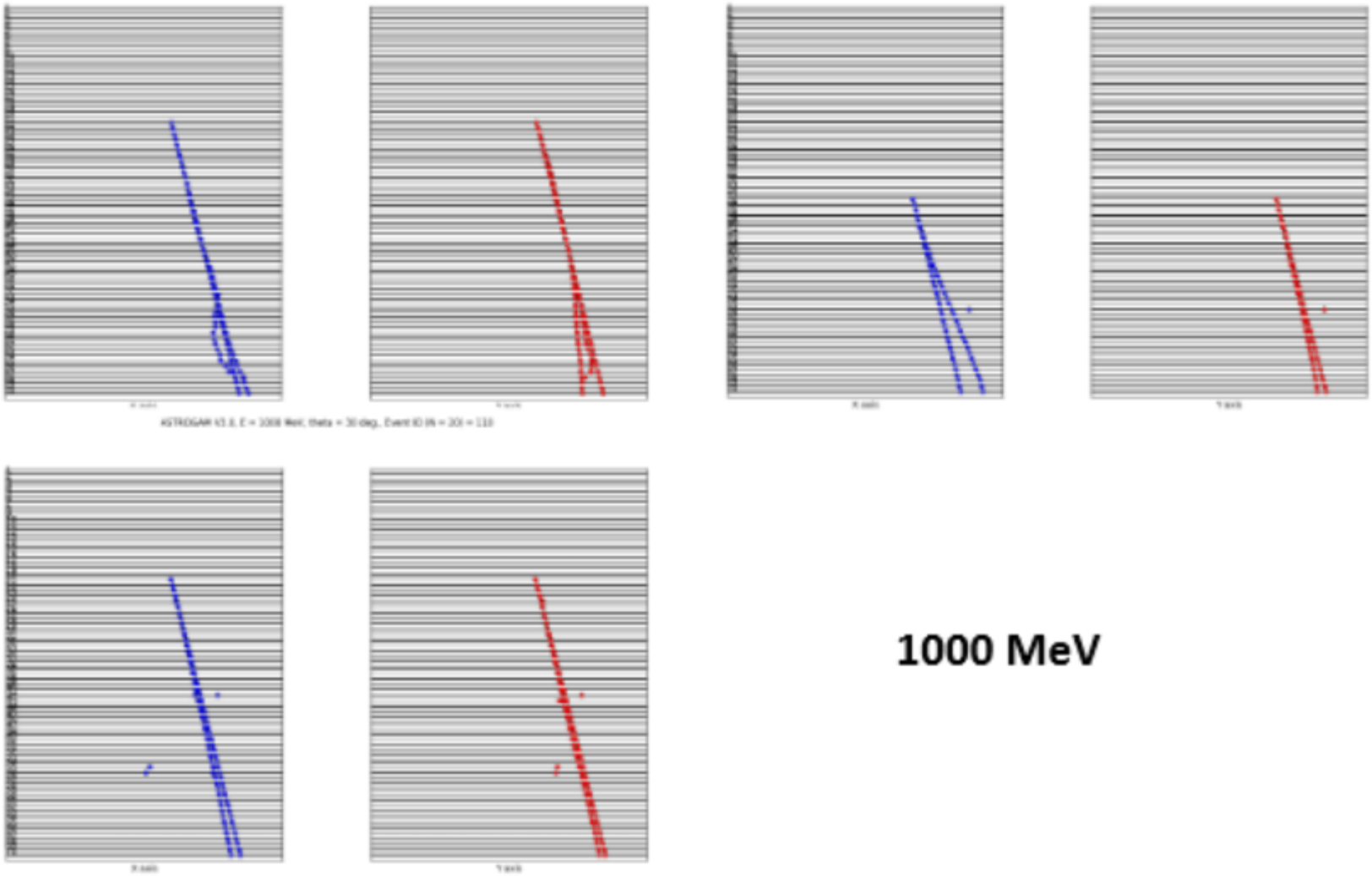
**10 MeV**



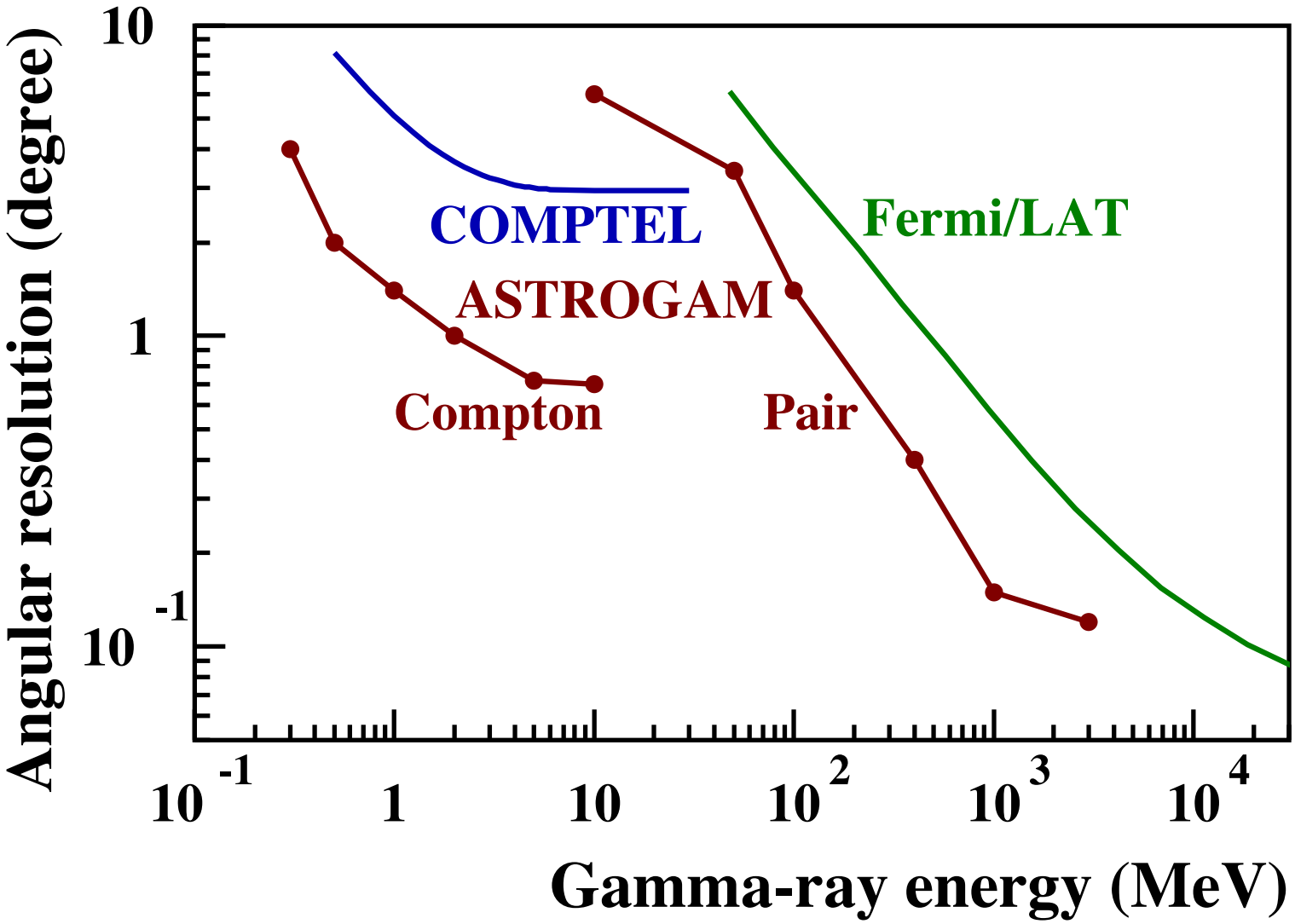

**50 MeV**


X axis
Y axis
X axis
Y axis
ASTROGAM K1.0, E = 100 MeV, theta = 30 deg., Event ID (N = 25) = 74
X axis
Y axis

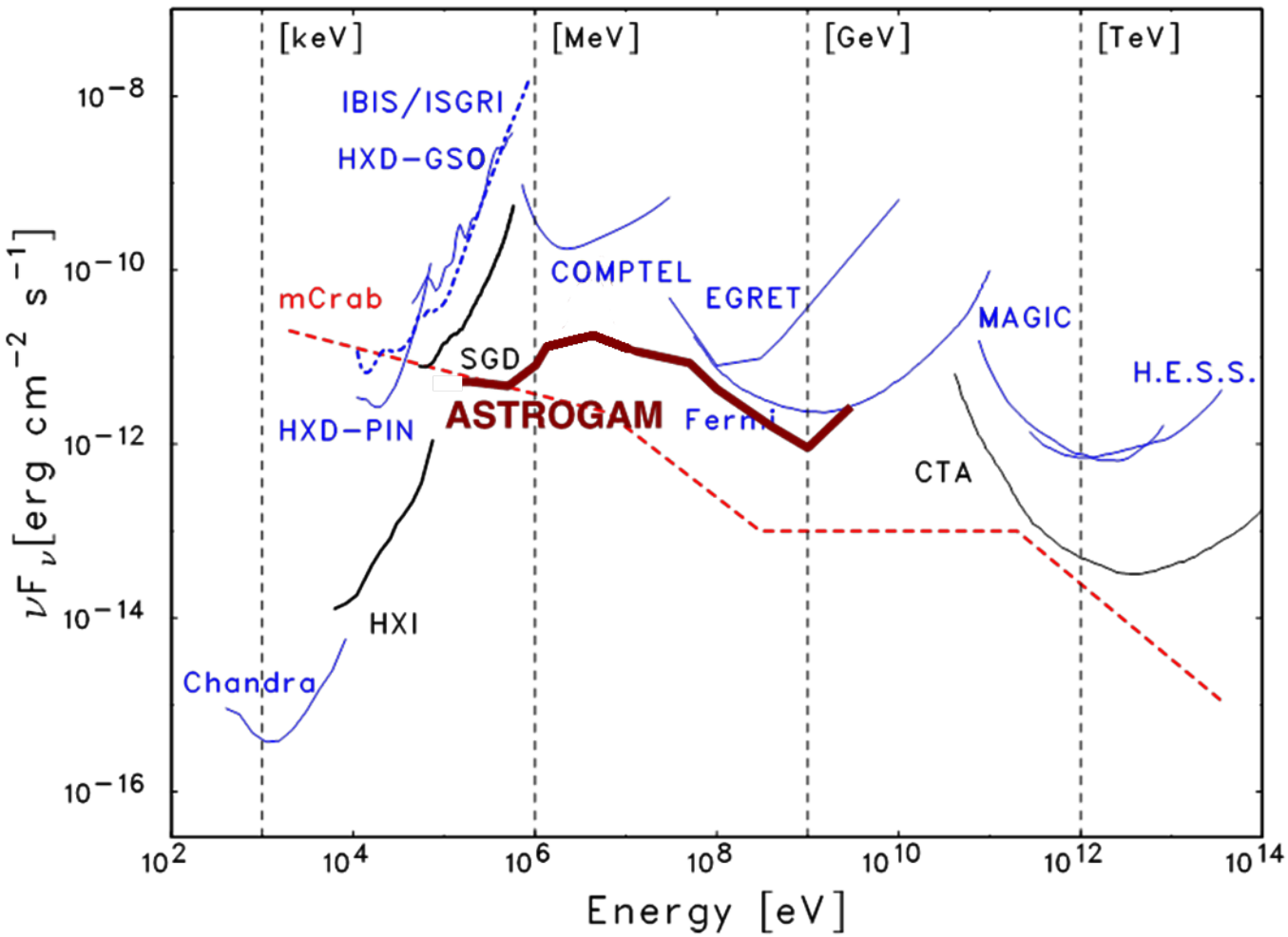
**100 MeV**


X axis
Y axis
ASTROGAM v3.3, E = 1000 MeV, theta = 30 deg, Event ID (N = 20) = (1)

**1000 MeV**


Angular resolution (degree)
10
1
10^-1
COMPTEL
ASTROGAM
Fermi/LAT
Compton
Pair
10^-1
1
10
10^2
10^3
10^4
Gamma-ray energy (MeV)

# ASTROGAM 3.5 yr survey sensitivity

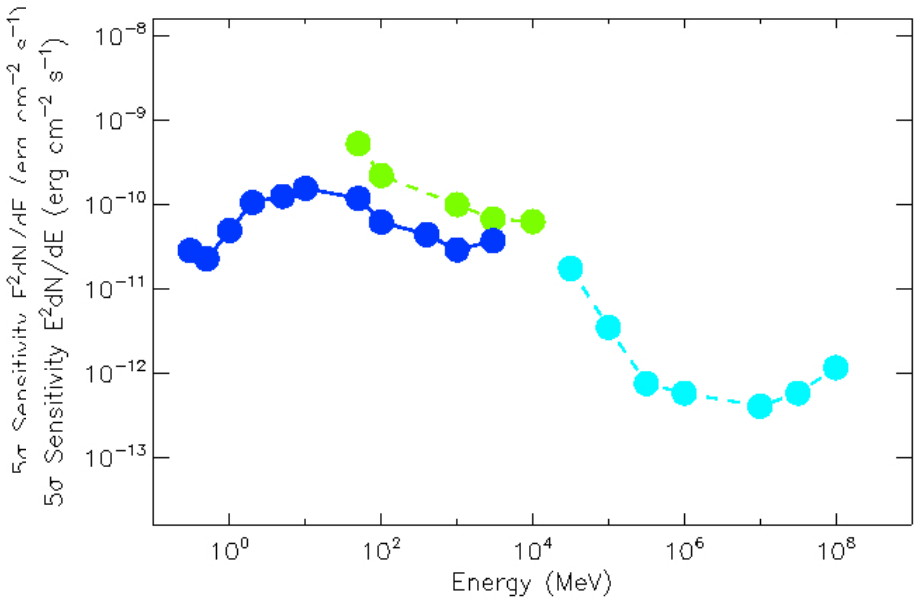



*Adapted from Takahashi et al. (2013)*

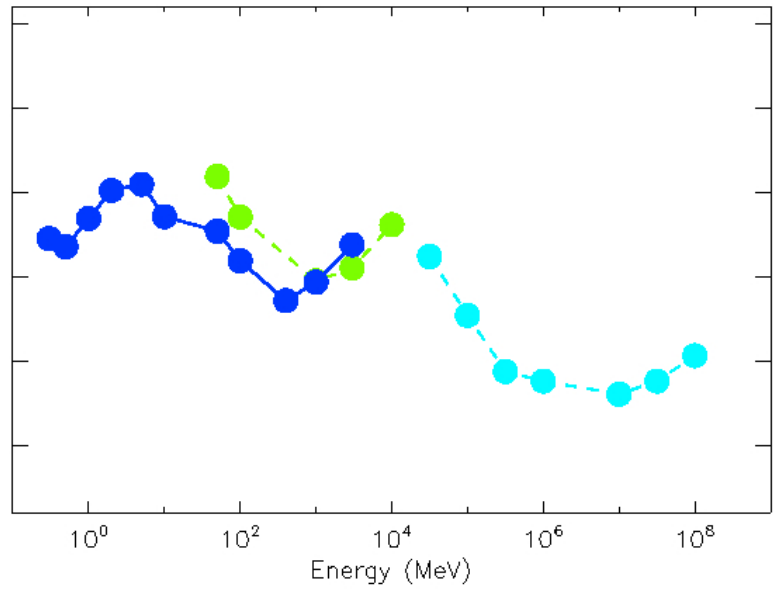
- **ASTRO-H/SGD** − 3σ sensitivity for 100 ks exposure of an isolated point source
- **COMPTEL** and **EGRET** − sensitivities accumulated during the whole duration of the CGRO mission (9 years)
- **Fermi/LAT** − 5σ sensitivity for a high Galactic latitude source and after 1 year observation in survey mode
- **ASTROGAM** − 5σ sensitivity for a high Galactic latitude source after 3.5 years in survey mode

# ASTROGAM

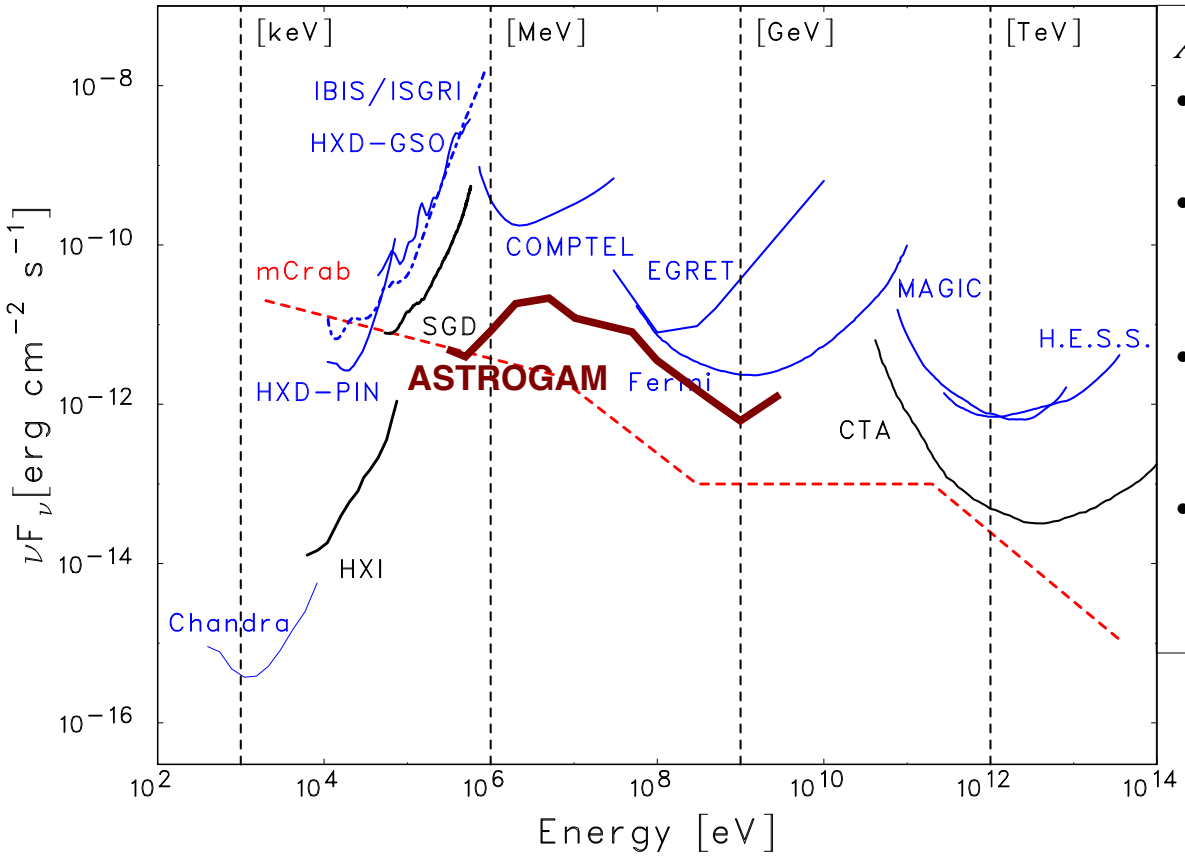
1-month, Galactic plane pointing




1-month, extragalactic pointing



# 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 will gain a factor 10−30 in line sensitivity compared to INTEGRAL/SPI

| E (keV) | FWHM (keV) | Gamma-ray line origin | SPI sensitivity (ph cm$^{-2}$ s$^{-1}$) | ASTROGAM (ph cm$^{-2}$ s$^{-1}$) |
|---|---|---|---|---|
| 847 | 35 | $^{56}$Co line from thermonuclear SN | $2.3 \times 10^{-4}$ | $8.7 \times 10^{-6}$ |
| 1157 | 15 | $^{44}$Ti line from core-collapse SN remnants | $9.6 \times 10^{-5}$ | $8.4 \times 10^{-6}$ |
| 1275 | 20 | $^{22}$Na line from classical novae of the ONe type | $1.1 \times 10^{-4}$ | $1.1 \times 10^{-5}$ |
| 2223 | 20 | Neutron capture line from accreting neutron stars | $1.1 \times 10^{-4}$ | $1.2 \times 10^{-5}$ |

# ASTROGAM Scientific objectives

- **Theme-1: Matter and antimatter in our Galaxy and beyond**
- **Theme-2: Accelerators in the nearby & distant Universe**
- **Theme-3: Fundamental Physics and new messengers**

# ASTROGAM Scientific objectives

## Theme-1: Matter and antimatter in our Galaxy and beyond

- *How is nuclear enrichment in our Galaxy related to SN activity and star formation? What is the physics of thermonuclear and core-collapse supernovae?*
- *What is the cosmic-ray density in our Galaxy? Are supernova remnants responsible for cosmic-ray acceleration up to PeV energies?*
- *How is the central black hole in the Galactic Center powering the surrounding regions? What is the source of the puzzling antimatter in the Galactic Center?*

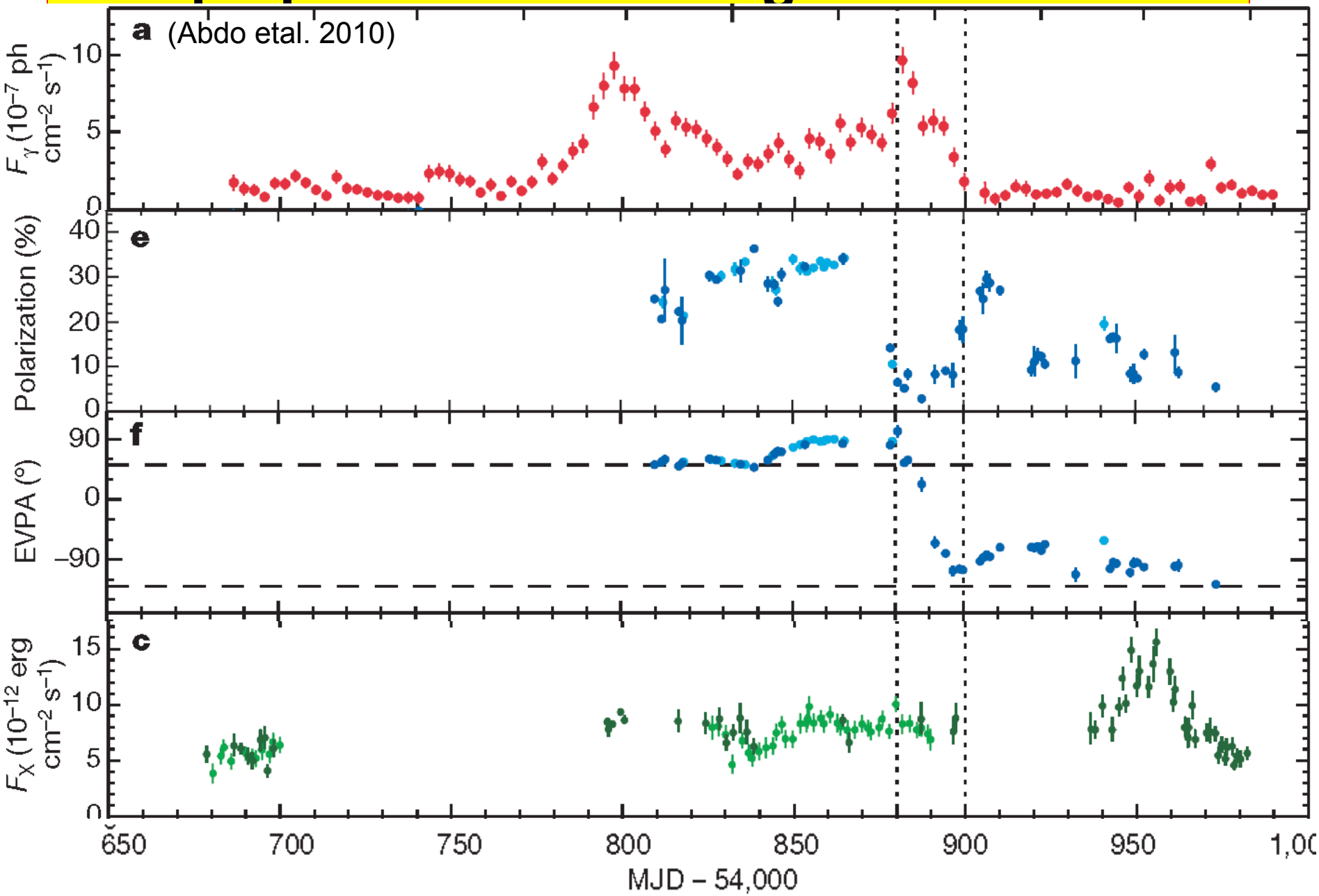
## Theme-2: Accelerators in the nearby & distant Universe

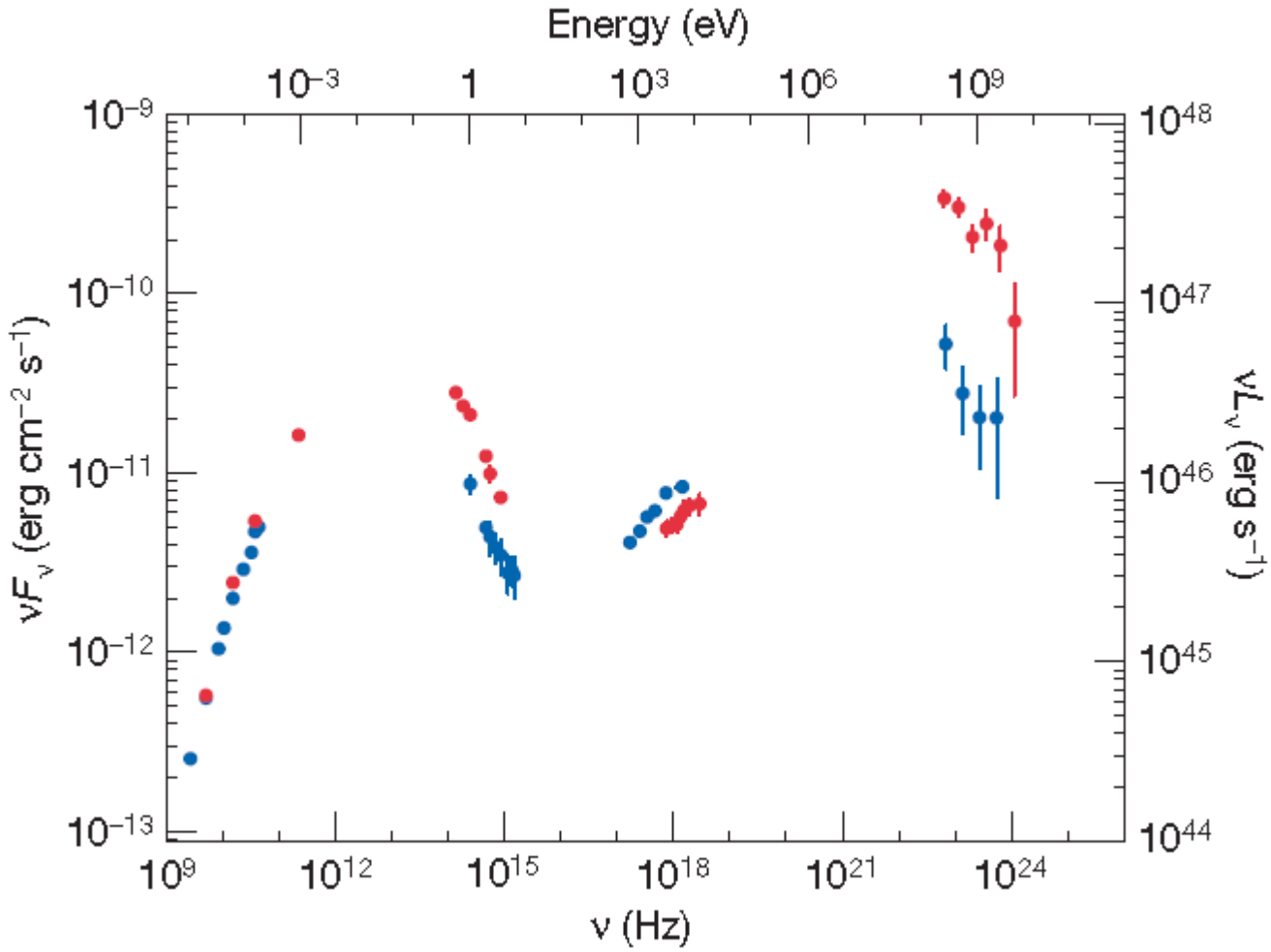
- *How are relativistic jets launched? How does the disk/jet transition occur?*
- *Is magnetic field reconnection at work in high-energy sources?*
- *How is the MeV extragalactic background produced? Where do ultra-high-energy cosmic rays (UHECRs) originate?*
- *What is the physics of acceleration and transient nuclear spectroscopy in solar flares?*
- *How are Terrestrial Gamma Ray Flashes (TGFs) generated? What is their impact on the Earth environment and connection with global climate?*

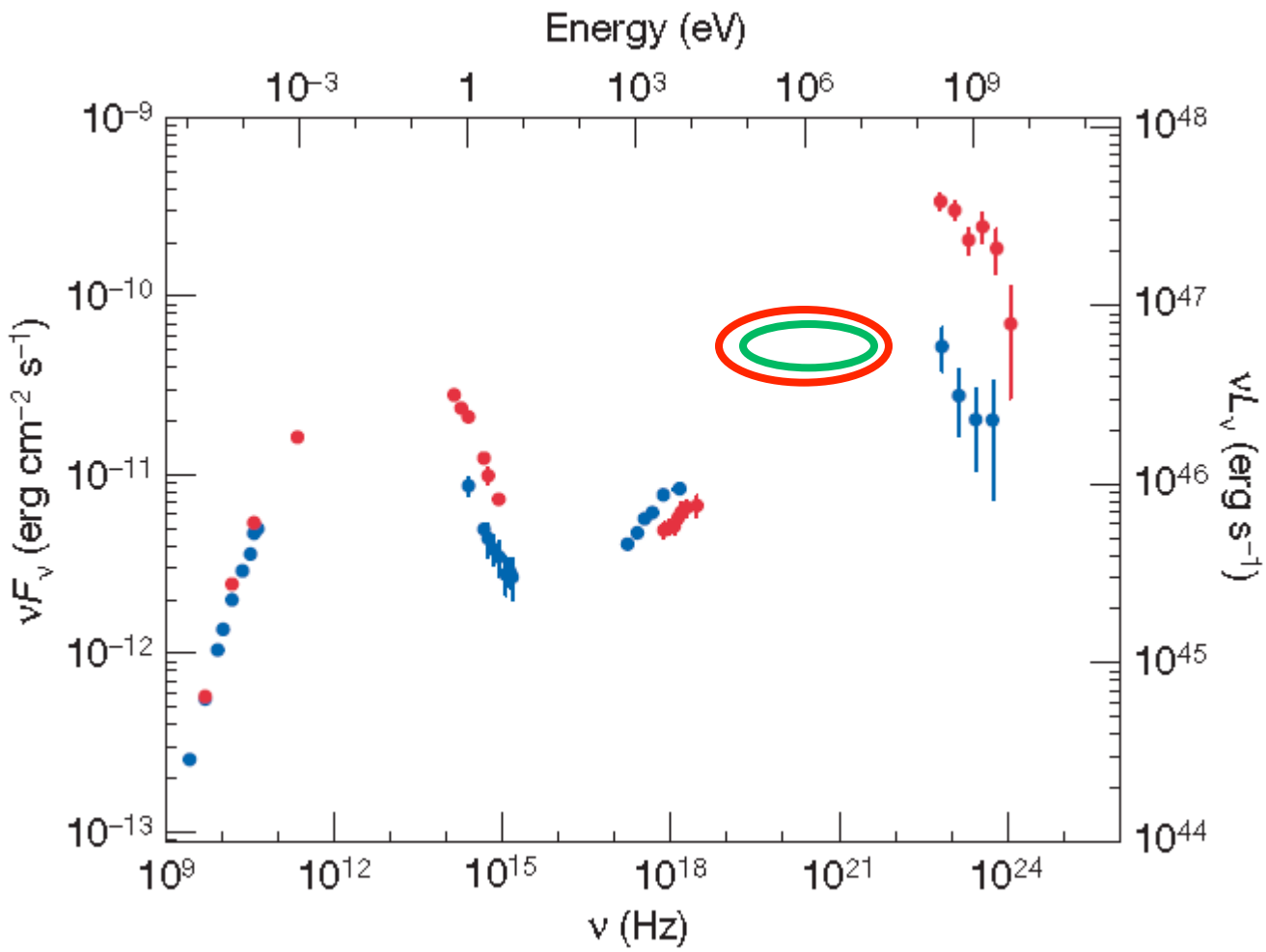
## Theme-3: Fundamental Physics and new messengers

- *What is the nature of Dark Matter?*
- *Are MeV-GeV sources related to the emission of gravitational waves and neutrinos? What is the connection of gamma-ray bursts (GRBs) to gravitational collapse?*

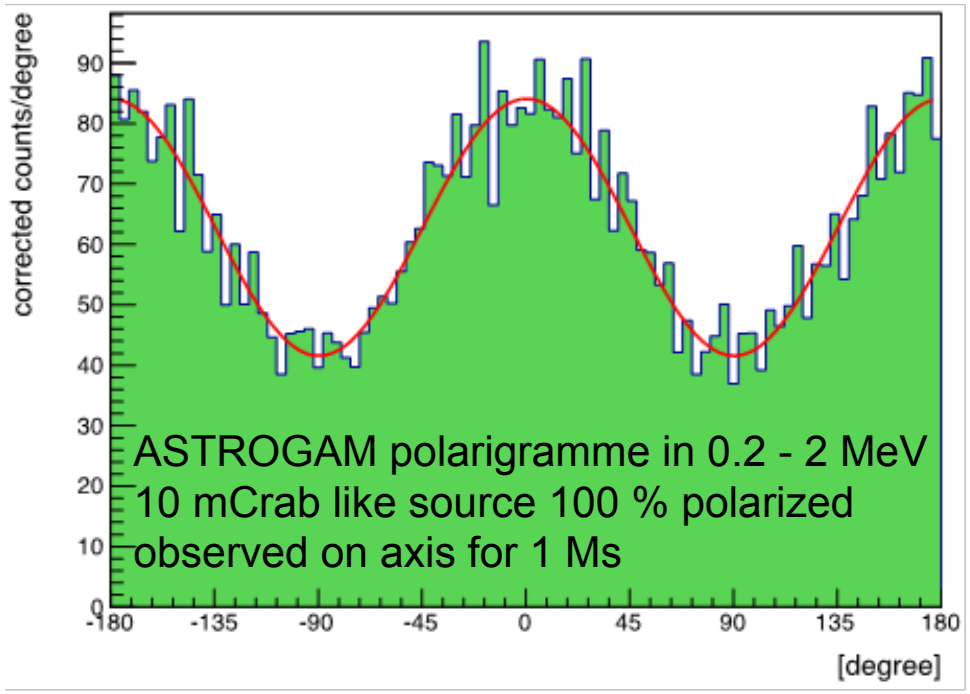
# opt. polarization swings in 3C 279 !

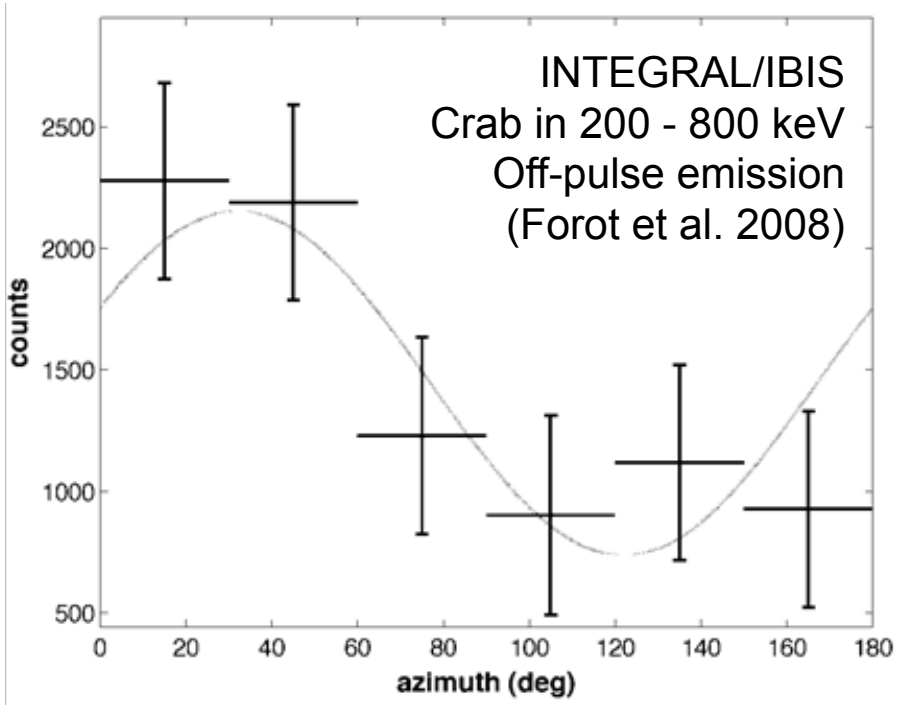



Energy (eV)
10−3
1
103
106
109
10−9
10−10
10−11
10−12
10−13
νFν (erg cm−2 s−1)
1048
1047
1046
1045
1044
νLν (erg s−1)
109
1012
1015
1018
1021
1024
ν (Hz)


Energy (eV)
10−3
1
103
106
109
10−9
10−10
10−11
10−12
10−13
νFν (erg cm−2 s−1)
1048
1047
1046
1045
1044
νLν (erg s−1)
109
1012
1015
1018
1021
1024
ν (Hz)

# ASTROGAM Polarization



- **ASTROGAM website:**
  **http://astrogam.iaps.inaf.it**

- **2nd ASTROGAM Workshop**
  **Paris, 26-26 March, 2015**