Proposal for the ESA
M4 Mission Programme

ASTROGAM

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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:

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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

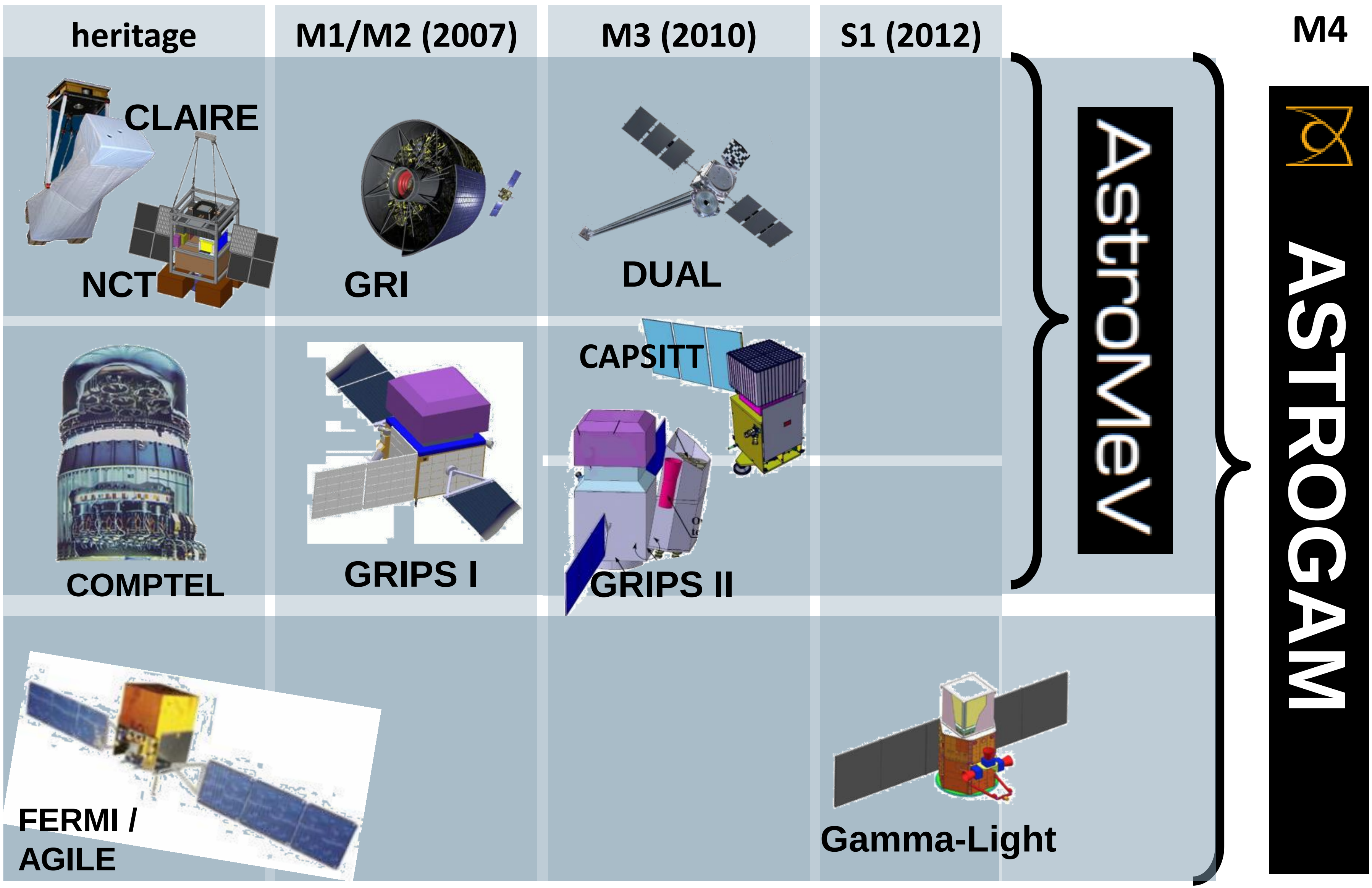
KTH

University of Tokyo

Ioffe Institute

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

ASTROGAM History & Heritage

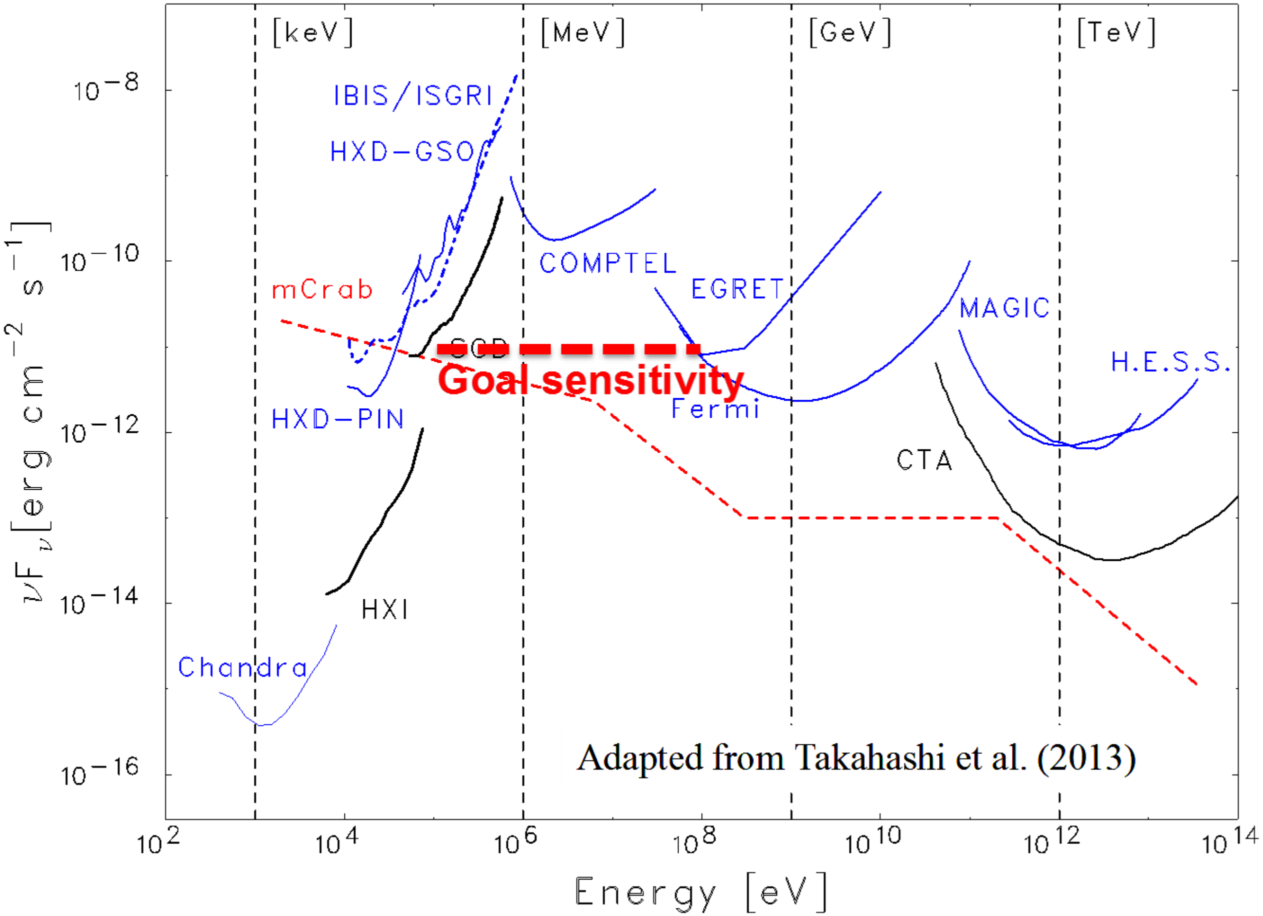


ASTROGAM Main requirements

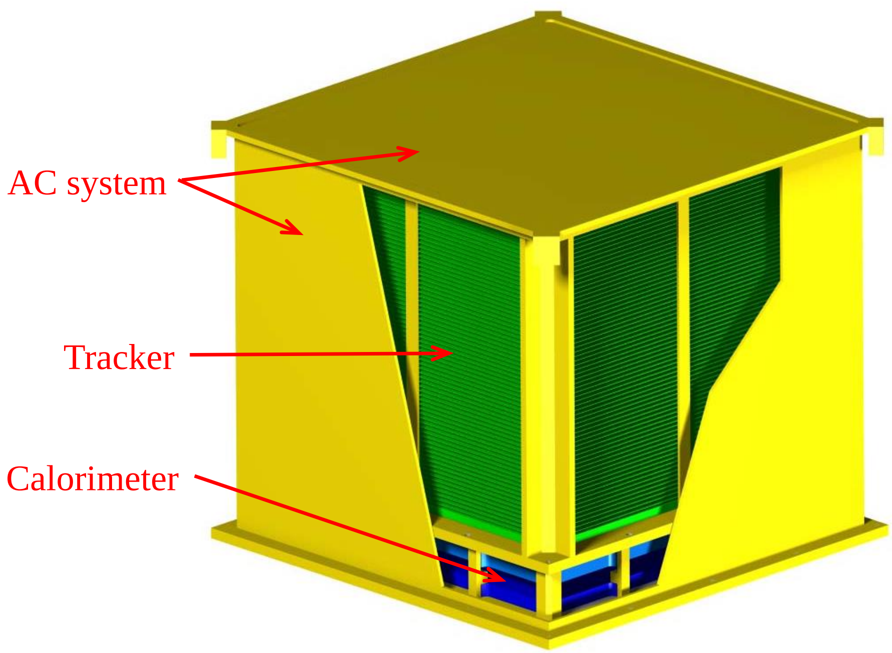
1. Cover a broad energy band (0.3 MeV – 3 GeV), focusing on the **mostly unexplored energy range 0.3 - 100 MeV** (continuum and line detection)

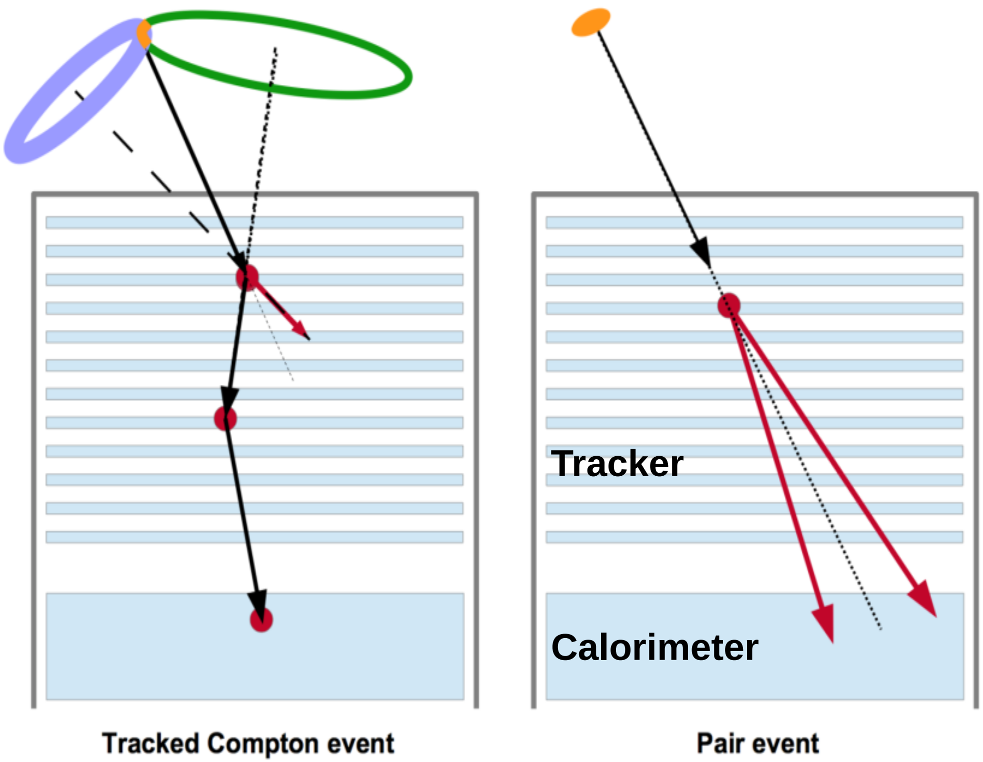
2. Improve significantly the **angular resolution** (to reach ~ 0.15° at 1 GeV)

3. Enable **polarization** measurements for both steady and transient sources (GRB, blazars…)



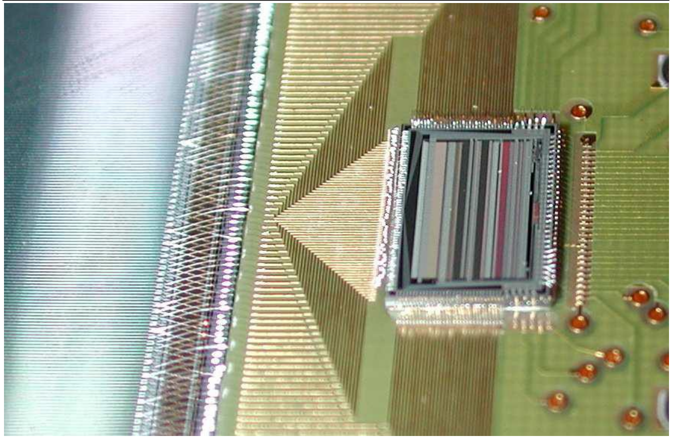
ASTROGAM Measurement principle





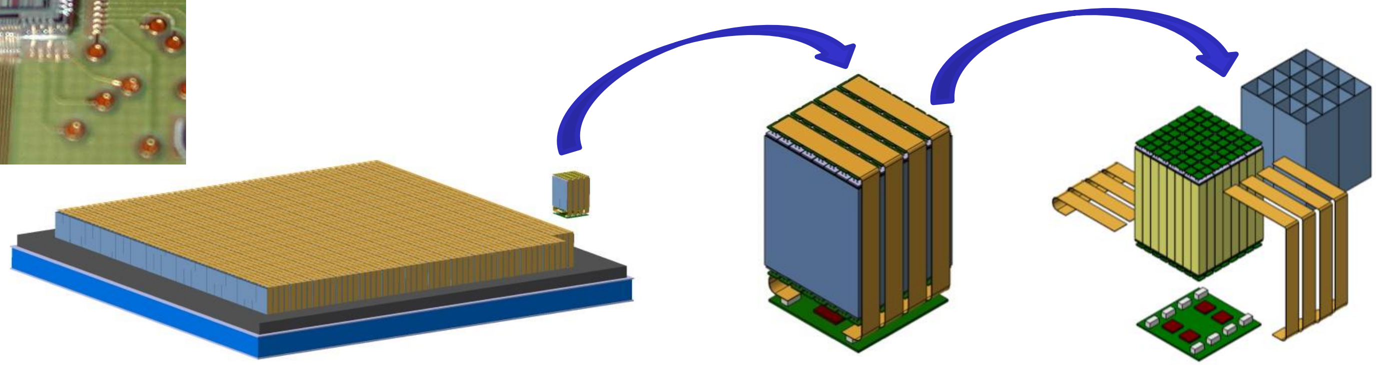
- **Tracker** – Double sided Si strip detectors (DSSDs) for fine 3-D position resolution
- **Calorimeter** – High-Z material for an efficient absorption of the scattered photon
  $\Rightarrow$ CsI(Tl) scintillation crystals readout by Si Drift Diodes for better energy resolution
- **Anticoincidence detector** to veto charged-particle induced background $\Rightarrow$ plastic scintillator

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
- 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

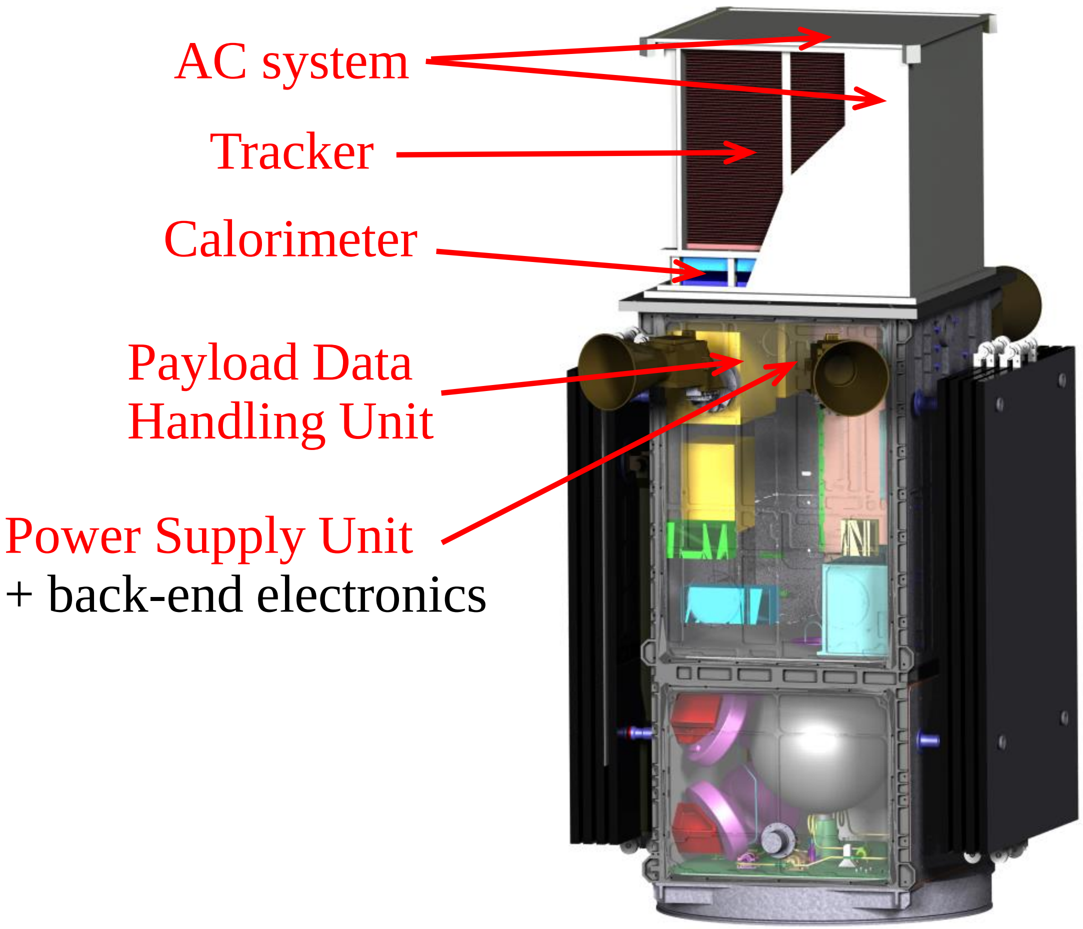


- **Calorimeter**: 12544 CsI(Tl) bars coupled at both ends to low-noise Silicon Drift Detectors
- **ACD**: segmented plastic scintillators coupled to SiPM by optical fibers
- **Heritage**: AGILE, Fermi/LAT, AMS-02, INTEGRAL, LHC/ALICE…

Fermi/LAT AC system

ASTROGAM Satellite

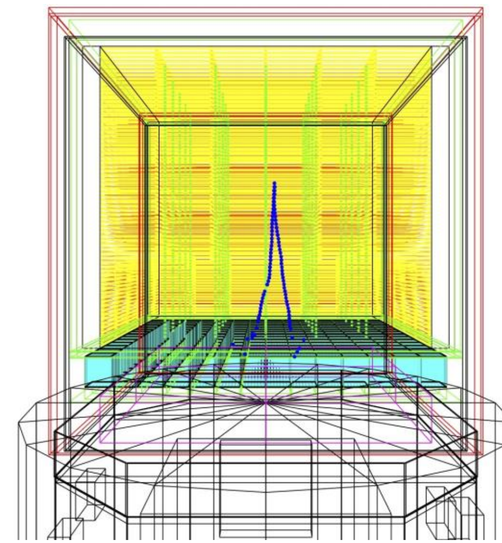
- ESA guidelines for the M4 Call ⇒ ASTROGAM payload designed to be 300 kg, satellite dry mass of 860 kg (with margins)



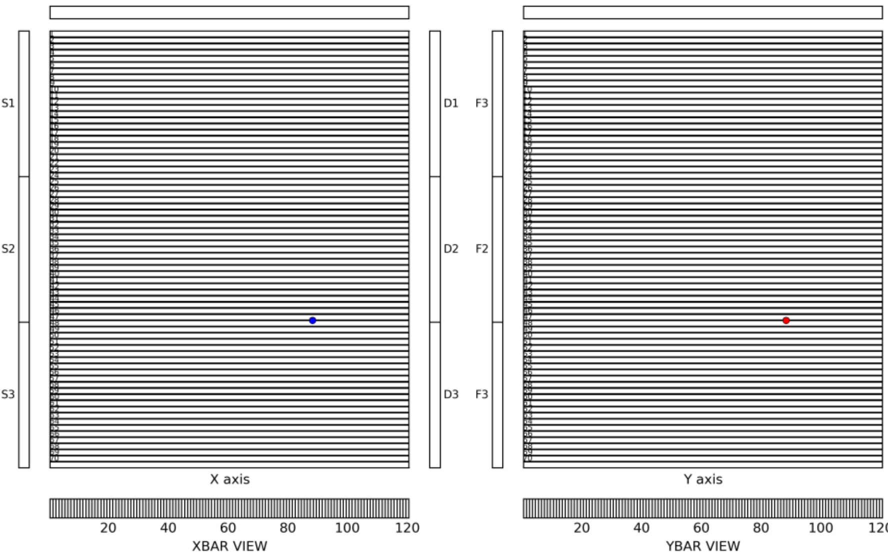
- Steerable solar panels
- Microsecond timing through a GPS unit
- Possibility of fast communication to the ground through TDRSS

ASTROGAM Performance assessment

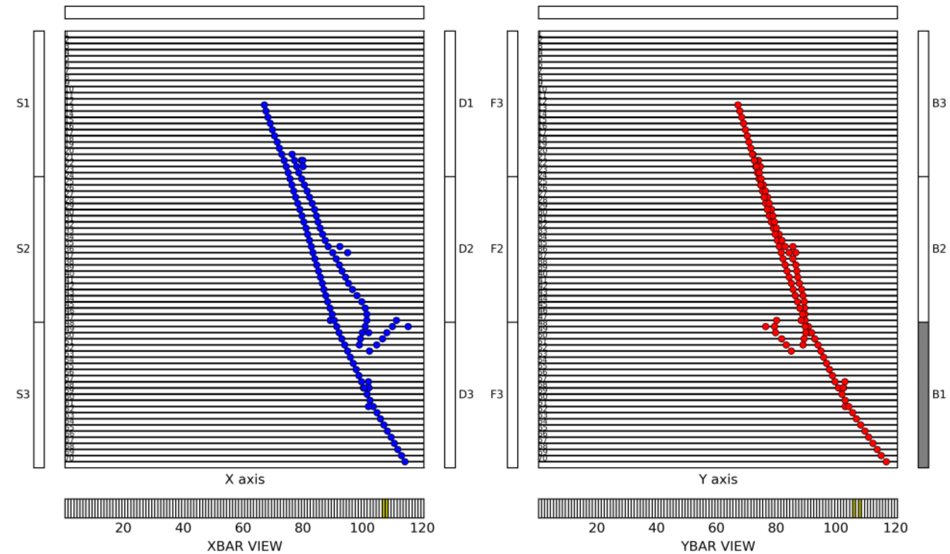
- ASTROGAM performance evaluated with **MEGAlib** and **Bogemms** (both based on Geant4) and a detailed mass model of the instrument
- Background environment in an equatorial (inclination $i < 2.5°$, eccentricity $e < 0.01$) low-Earth orbit (altitude 550 - 600 km) now well-known thanks to the **Beppo-SAX**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



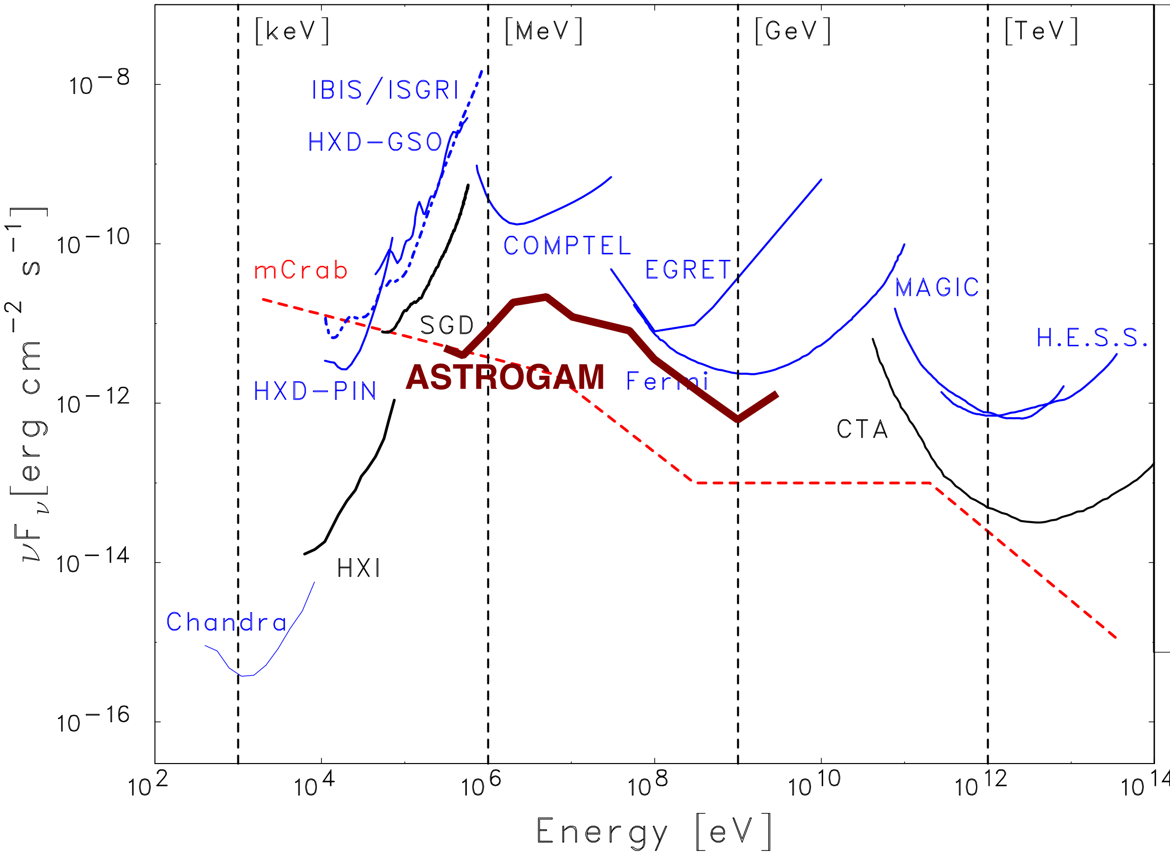
$E = 0.511$ MeV, $\theta = 30°$



$E = 50$ MeV, $\theta = 30°$



ASTROGAM Sensitivity



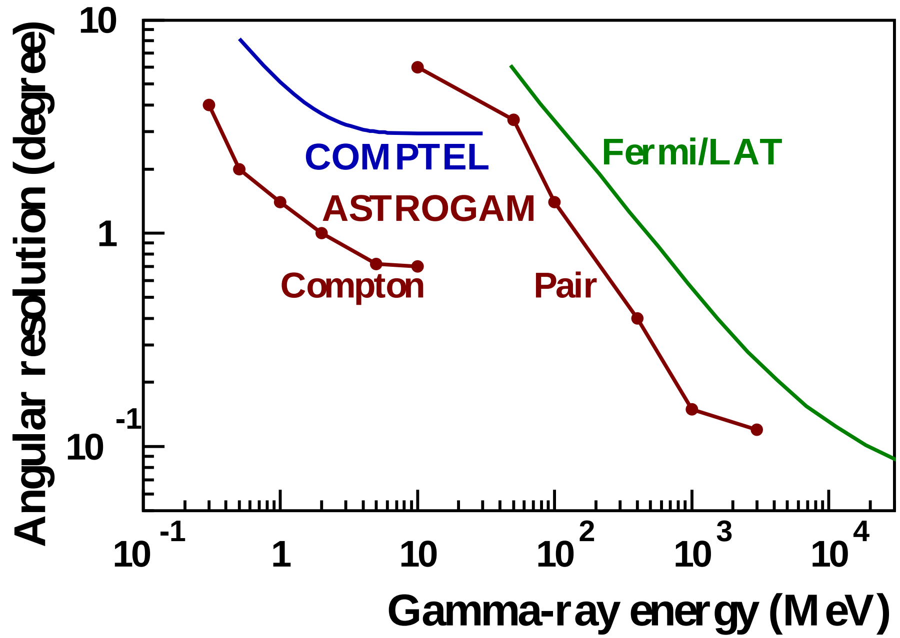
Adapted from Takahashi et al. (2013)

- **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

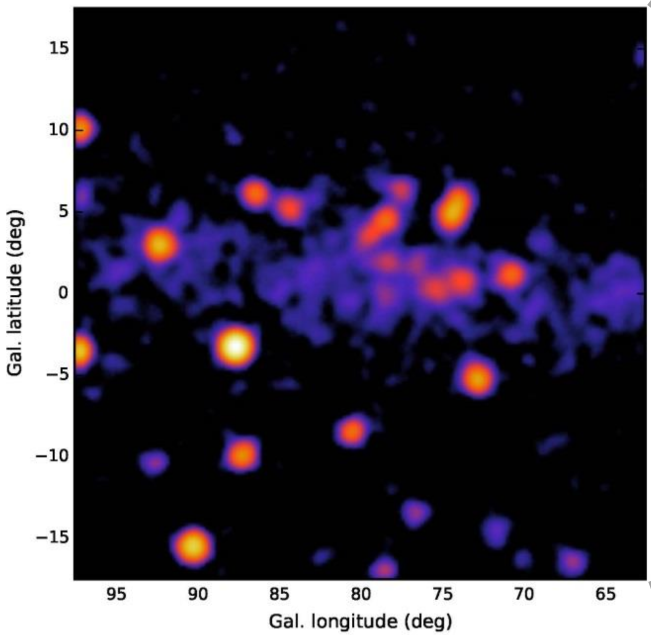
ASTROGAM will gain a factor 10−30 in line sensitivity compared to INTEGRAL/SPI

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 ´ 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}

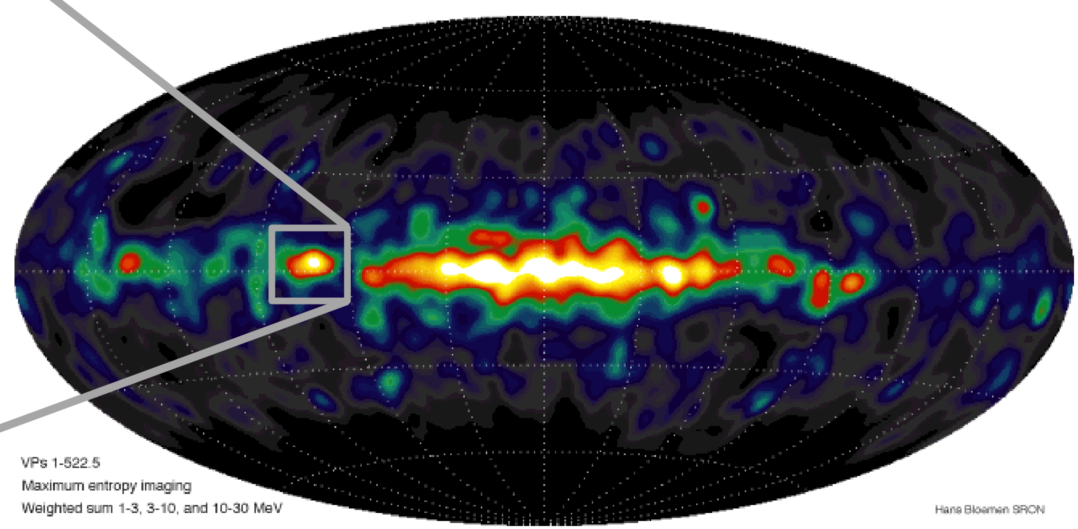
ASTROGAM Angular resolution



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



COMPTEL 1-30 MeV



ASTROGAM Core science

1. **Tracing the formation of heavy elements and propagation of cosmic rays to star forming regions**

2. **Anti-matter in our Galaxy and beyond**

3. **Galactic Center: central black hole, "*Fermi* bubbles", dark matter studies**

4. **Supermassive black holes, the extragalactic and cosmic gamma-ray backgrounds**

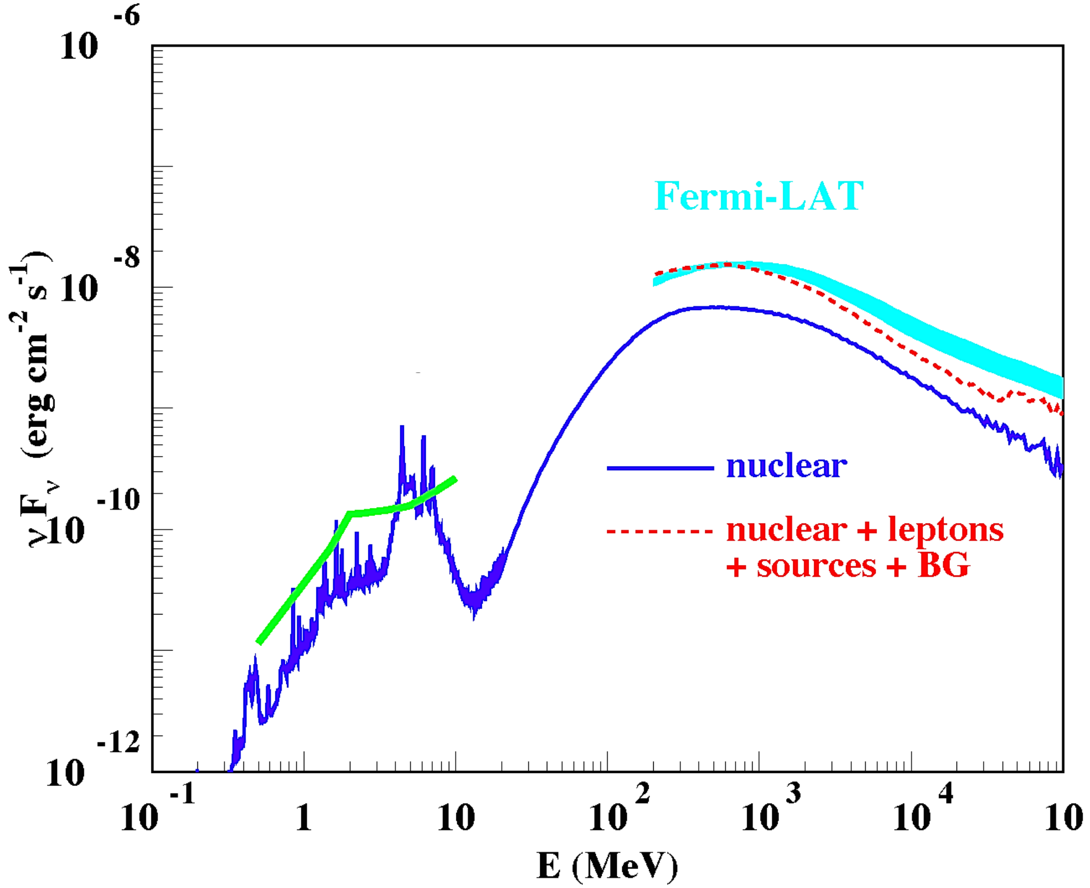
5. **Jet formation, extreme accelerators, gamma-ray bursts**

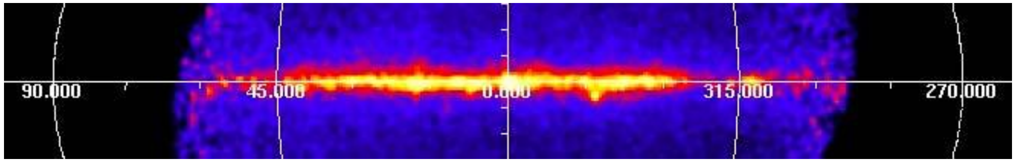
ASTROGAM Low-energy cosmic rays

- Measurements of high ionization rates of H_2 in diffuse clouds (H_3^+ observations) point to a distinct component of LECRs in the ISM

- LECRs play a key role in the chemistry and dynamics of the ISM, and for star formation (e.g., M17 and RCW 131).

- A unique probe of LECRs in the ISM by detecting nuclear excitation γ-ray lines in the 3 – 8 MeV band (with 4.4 and 6.1 MeV lines from ^{12}C and ^{16}O) from the central radian of the Galaxy.



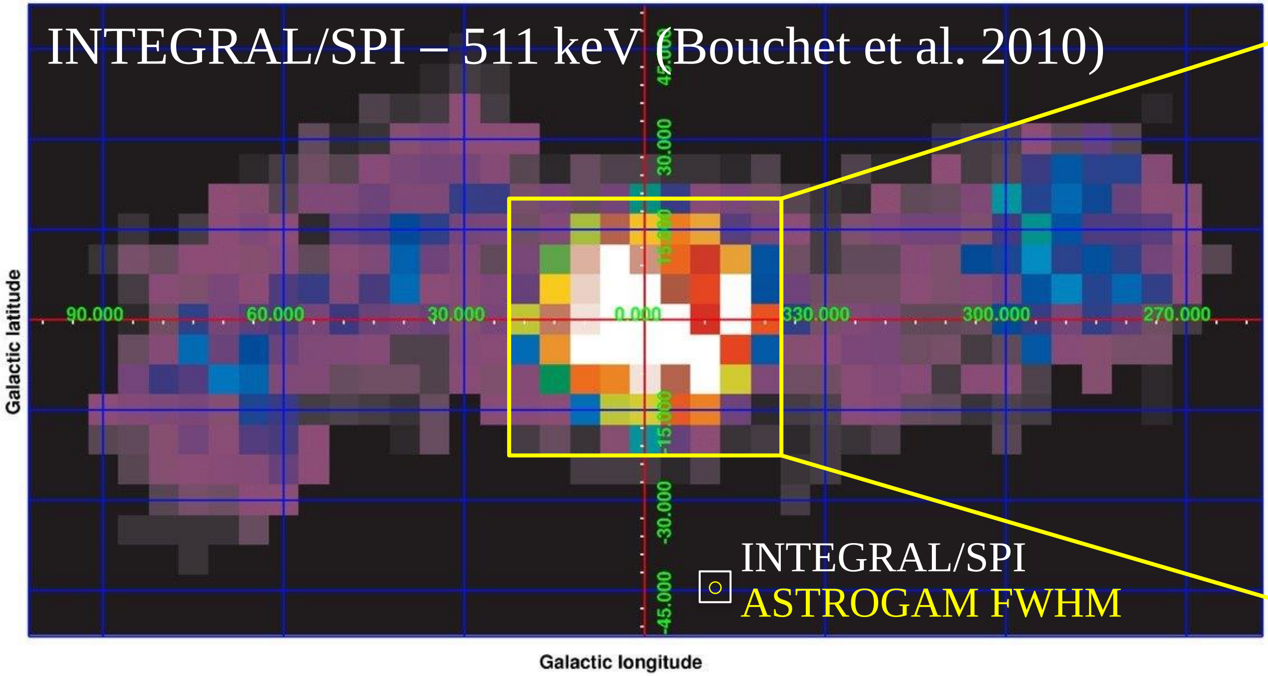


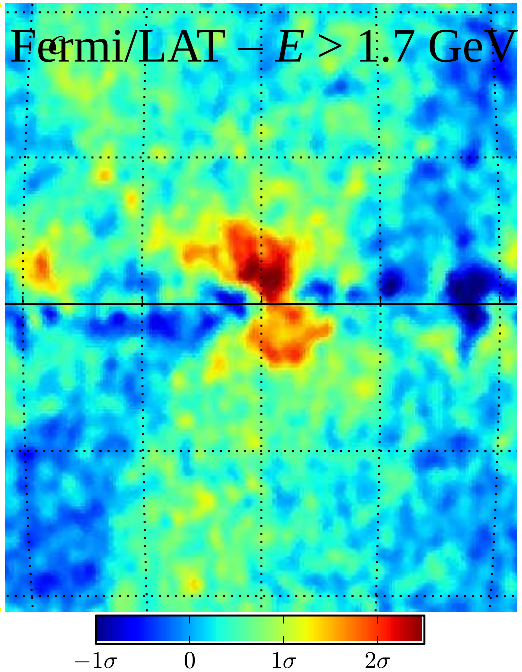
ASTROGAM Antimatter in the Galactic bulge

- 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

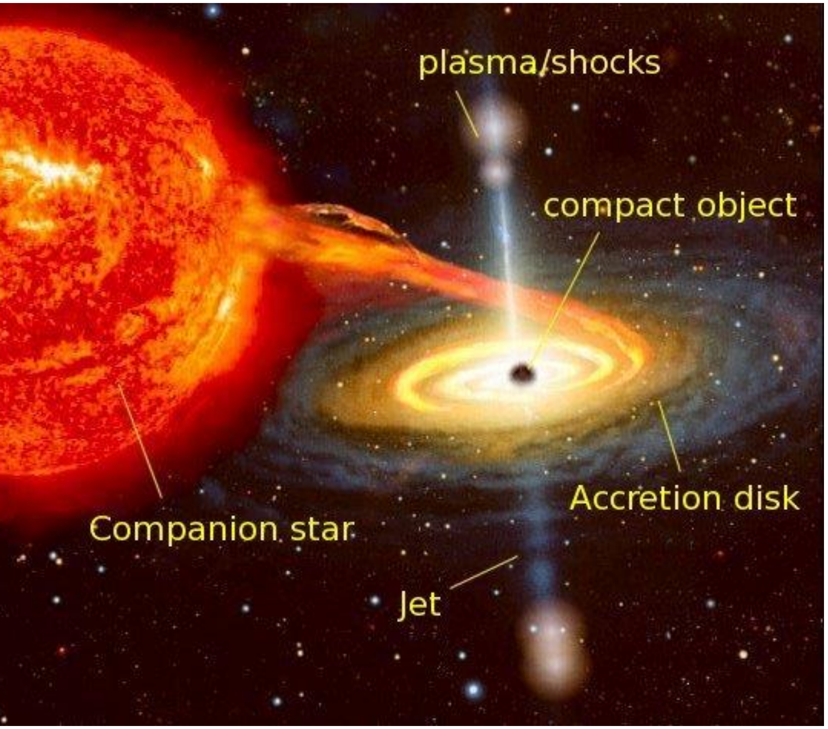
⇒ Supermassive black hole activity? Related to the Fermi bubbles?

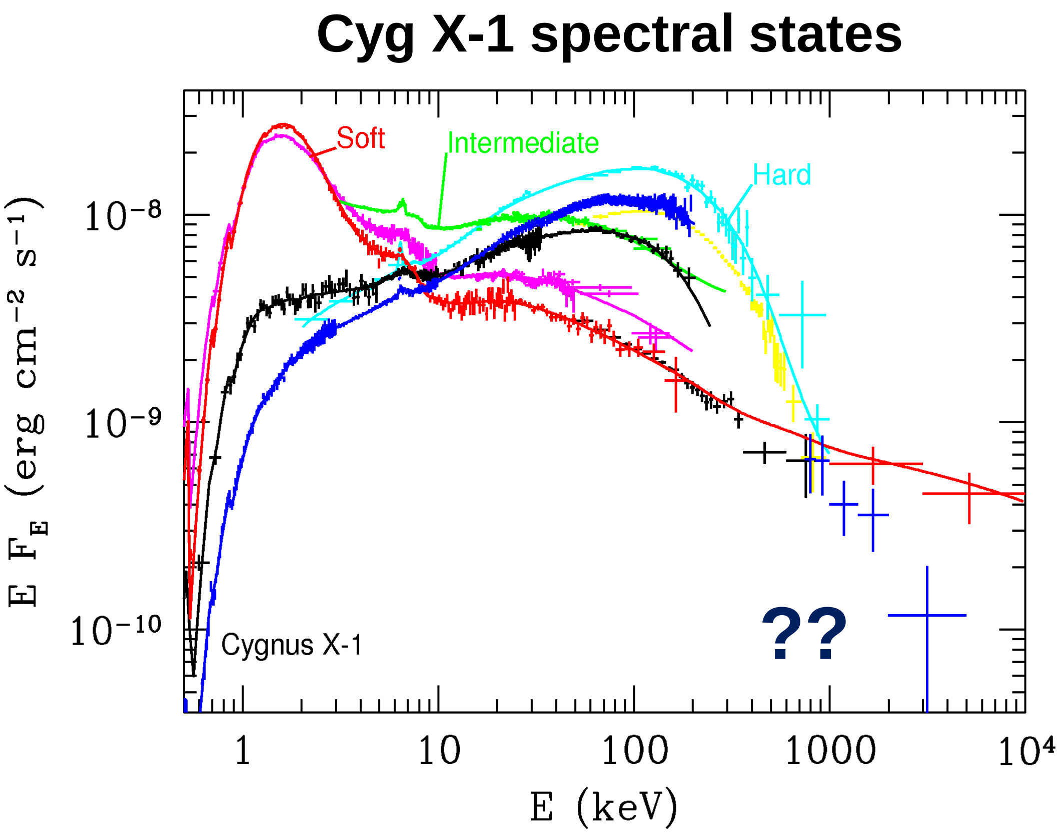
- ASTROGAM will produce much better maps of the 511 keV radiation





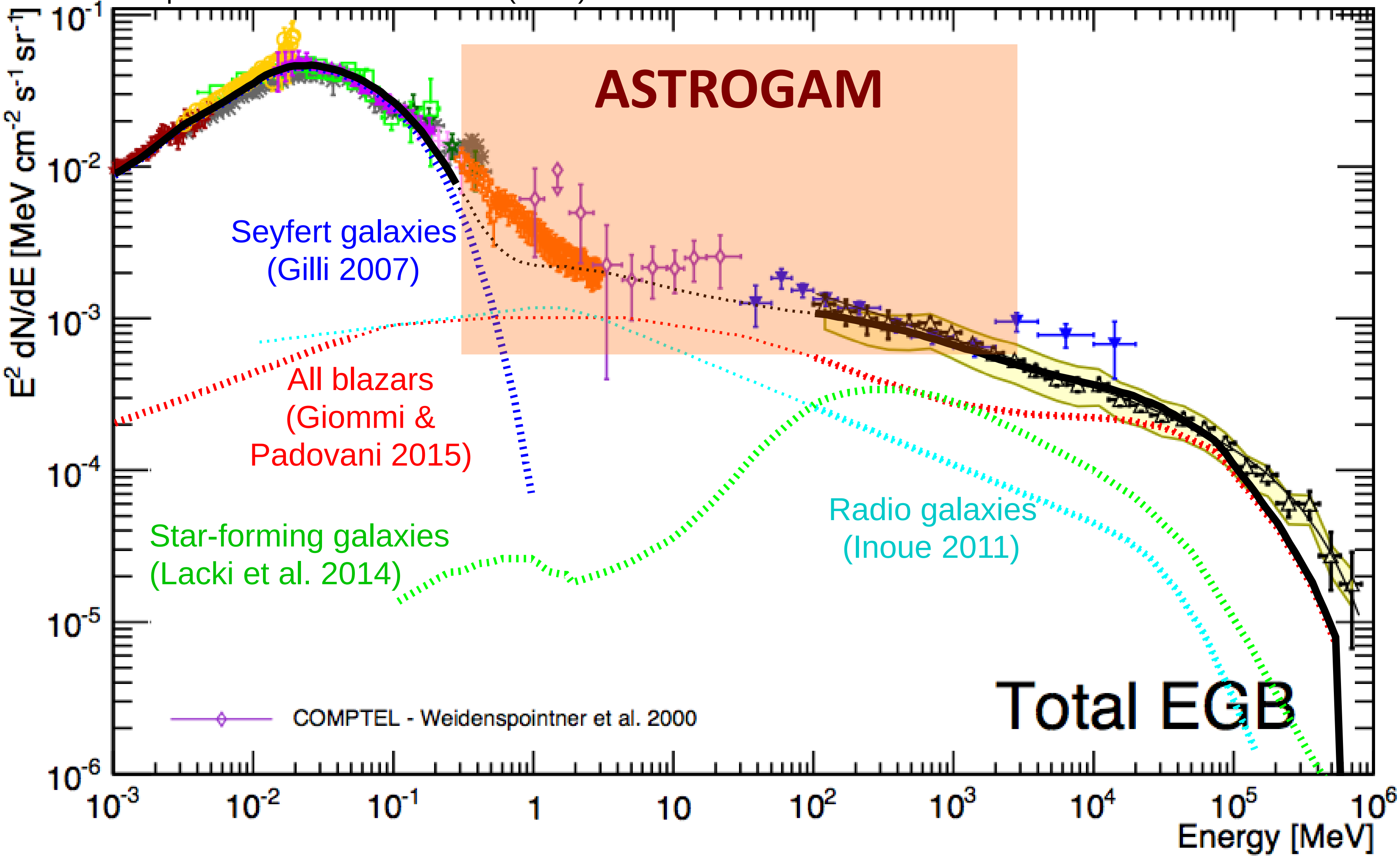
Microquasars





- **Transition from thermal to non-thermal**
- **Jet launching !**
- **Leptonic vs. hadronic**

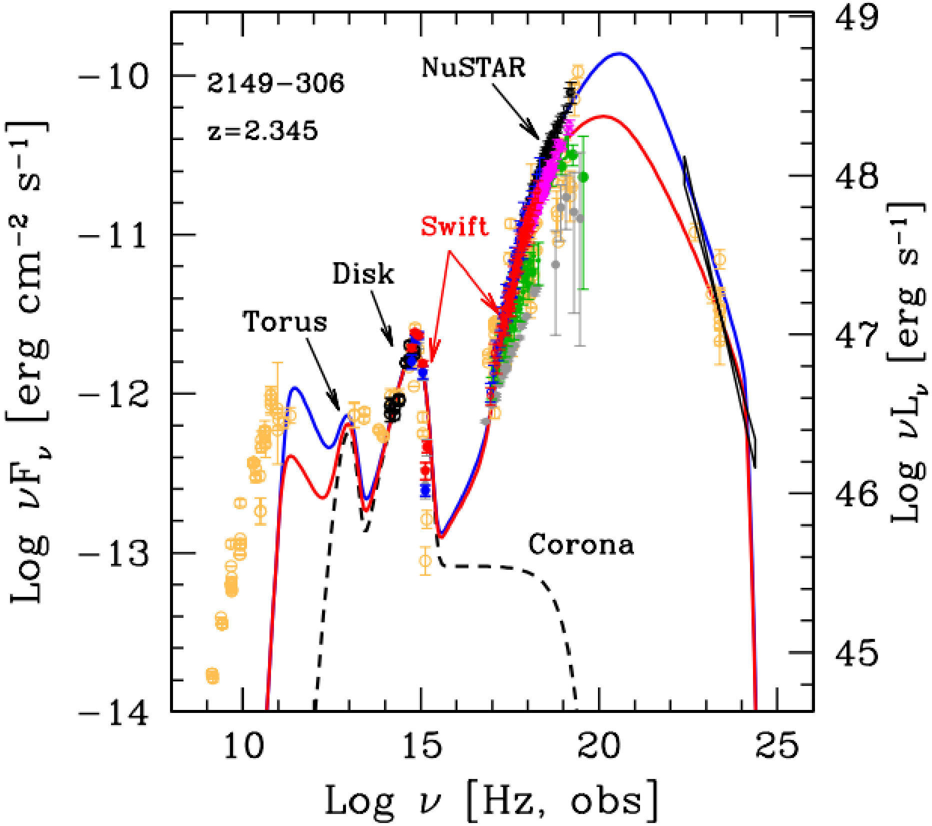
Adapted from Ackermann et al. (2015)



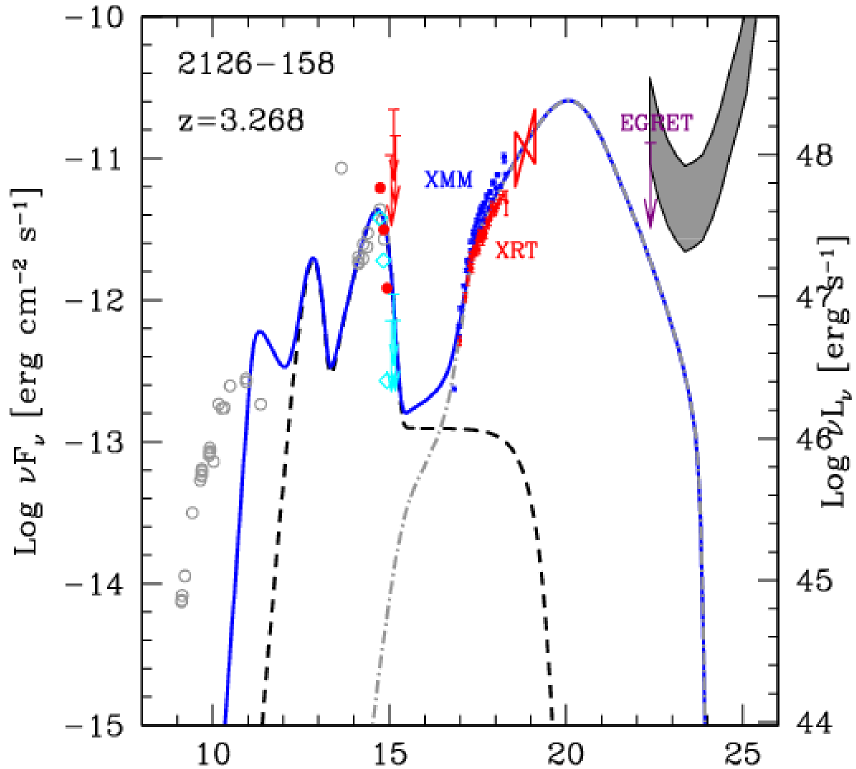
- Origin of the EGB in the 0.3 - 100 MeV range? **Dark matter contribution?**

MeV-blazars detectable by ASTROGAM

PKS 2149-306 (z = 2.345)



PKS 2126-158 (z = 3.268)

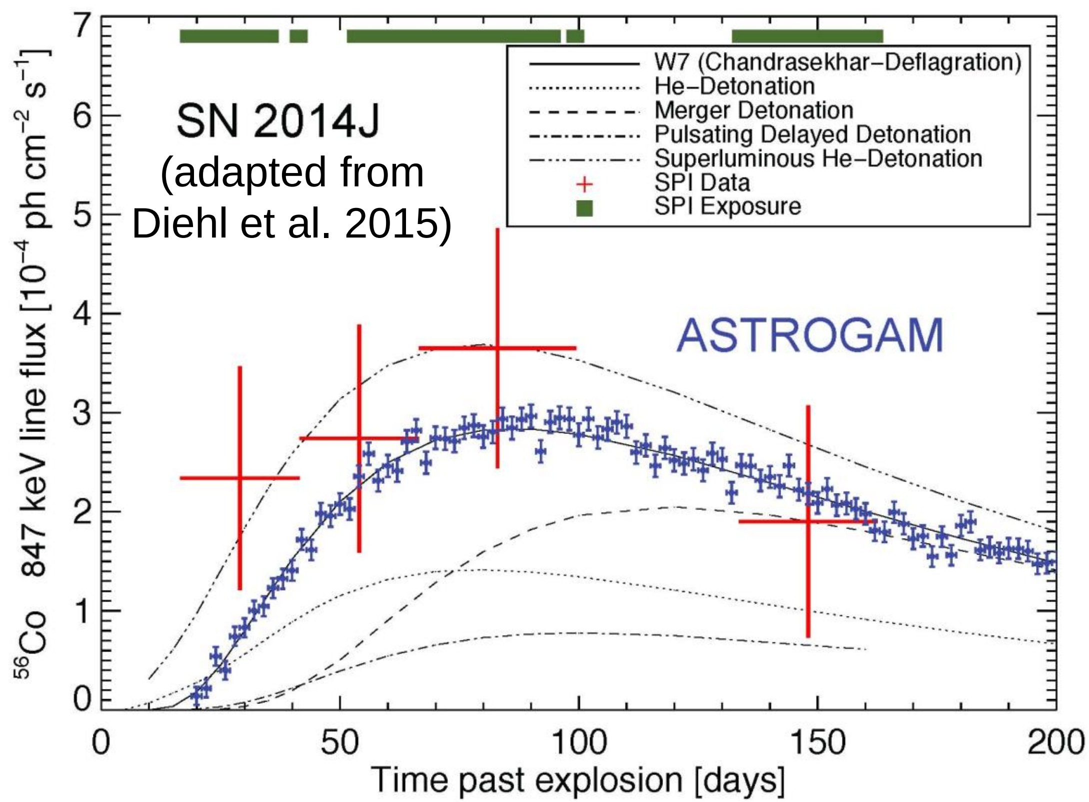


ASTROGAM Thermonuclear supernovae

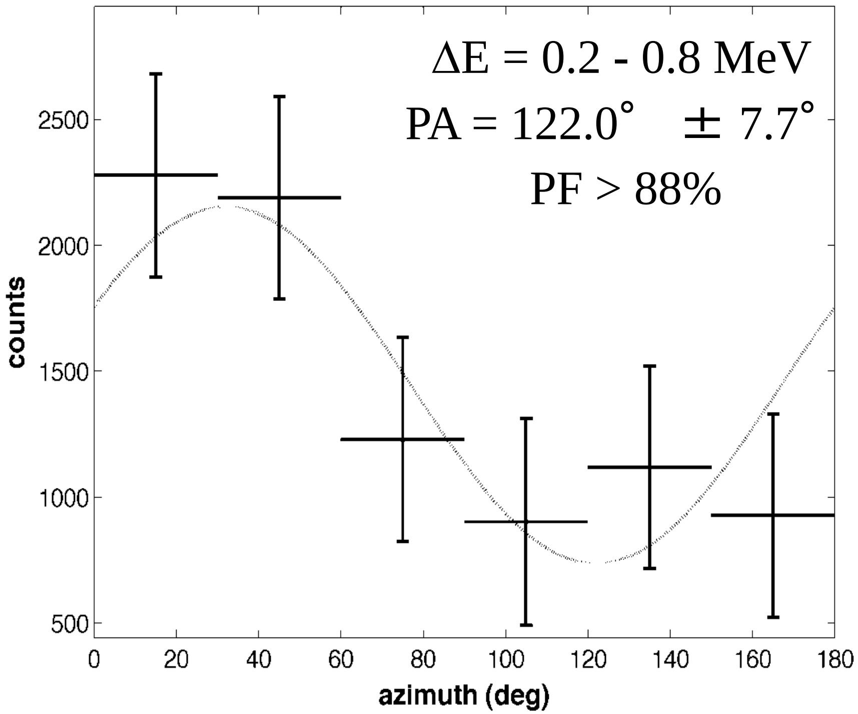
- Type Ia SNe are key tools for modern cosmology, yet we do not understand their progenitor systems, as well as the initiation and propagation of the thermonuclear burning

- INTEGRAL results for the nearby (D = 3.3 Mpc) supernova SN 2014J show the potential of γ-ray spectroscopy to study the explosion process of SNIa

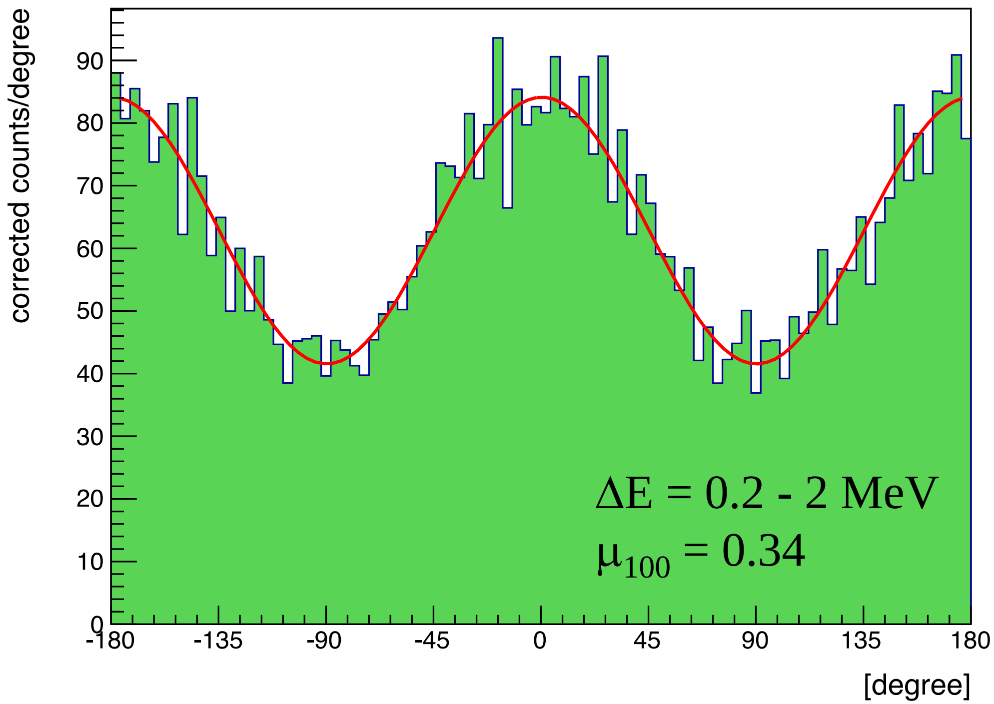
- ASTROGAM should detect 4 - 5 SNIa in 3 yr up to a distance of about 20 Mpc



ASTROGAM Polarization



***INTEGRAL/IBIS** polarigramme for the **Crab** emission in the off-pulse and bridge intervals (Forot et al. 2008)*

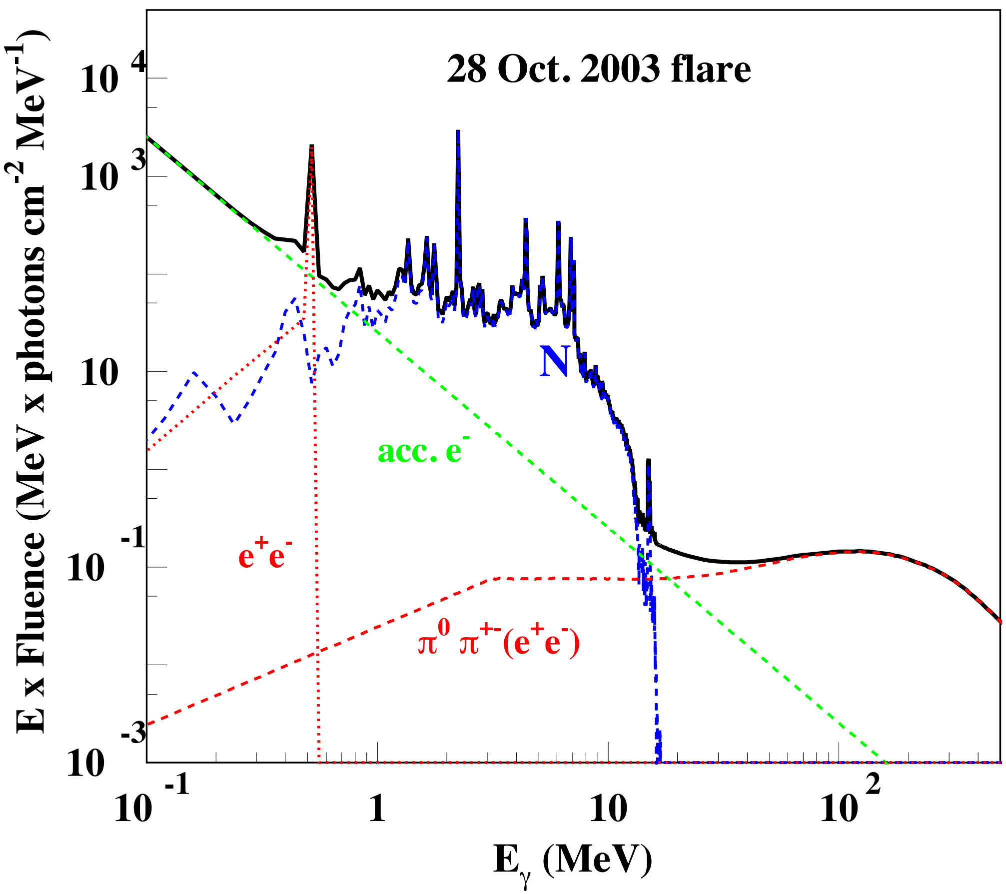


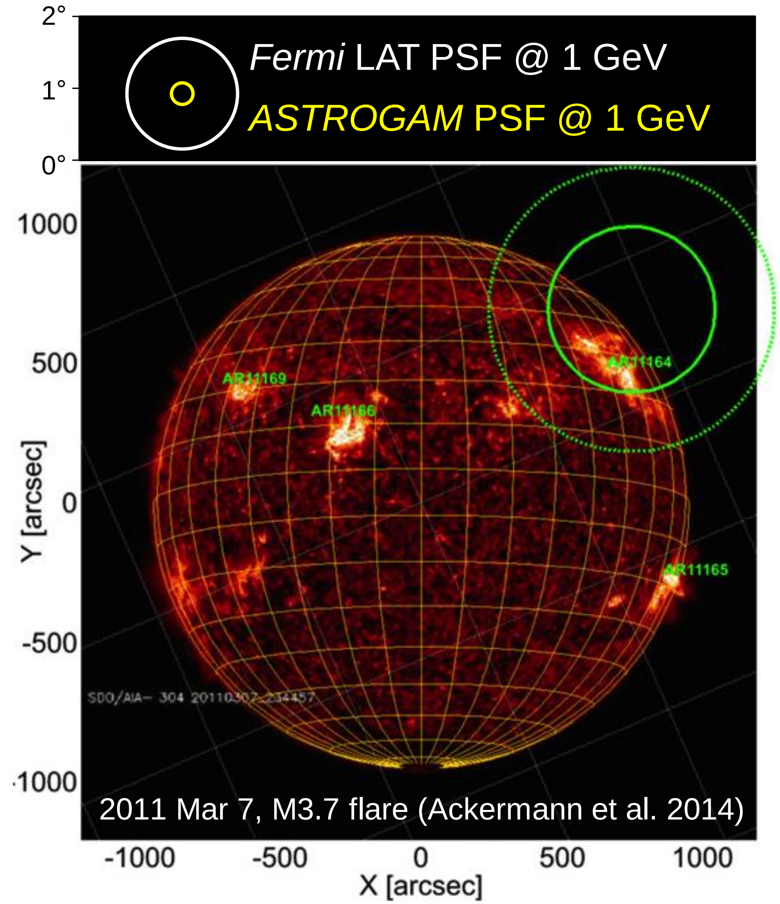
***ASTROGAM** polarization response for a 100% polarized, **10 mCrab-like** source observed on axis for 10^6 s*

- ASTROGAM will enable the study of the polarimetric properties of many pulsars and black hole binaries in the Galaxy, and detect the polarization of several dozen AGNs and GRBs

ASTROGAM Solar flares and TGFs

- ASTROGAM's broadband coverage and polarization sensitivity will add new information on the physics of solar flares and terrestrial gamma-ray flashes
- ASTROGAM's sensitivity and angular resolution will also be crucial to study the origin of the temporally extended γ-ray emission in long-duration flares





Conclusions

- **ASTROGAM will change our view of the nearby and distant Universe !**