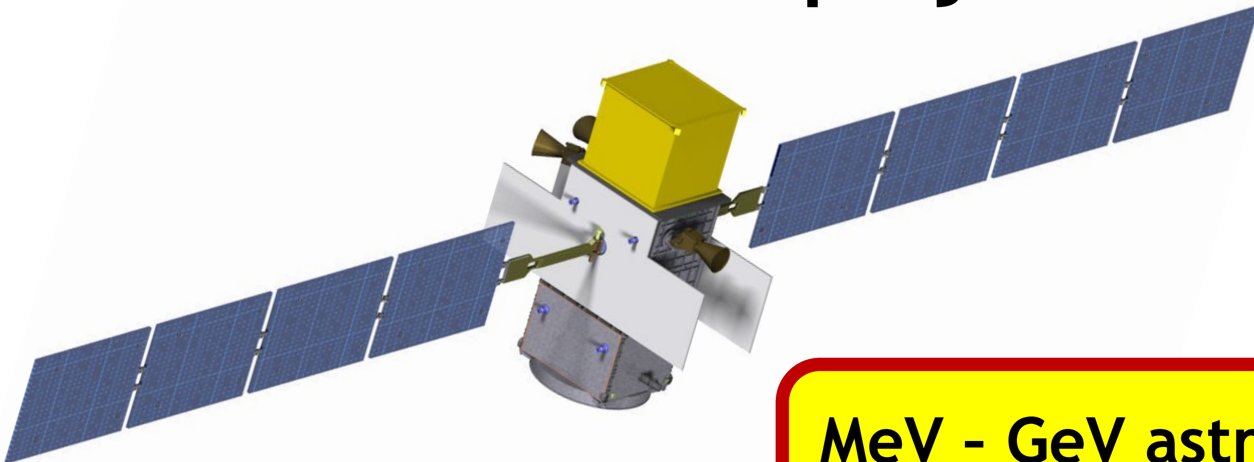
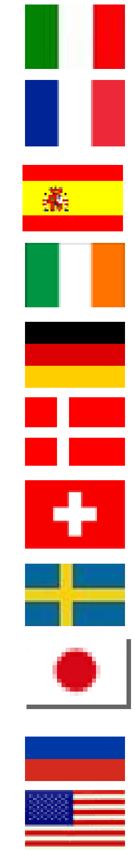
The next gamma-ray mission: the ASTROGAM project



MeV - GeV astrophysics
MeV - GeV community



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

- October 2014, ESA M4 Call, ESA briefing
- January 15, 2015: proposals' deadline
- April 10, 2015: Q&A's to the teams
- April 15, 2015: written answers
- April 20-21, 2015: ESA interview (SARP + SSC)
- May 11-12, 2015: SSC-M4 final recommendation

ESA constraints/recommendations for M4

- Payload mass: 300 kg
- Satellite mass: 800 kg
- Overall ESA cost: 450 Meuros

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- ESA Executive screening (technical & programmatic feasibility)
  - **First screening, 10 projects selected;**
  - Tecnical Report
- Science Assessment Review Panel (SARP)
  - Scientific Assessment
- Senior Science Committee for the M4 selection (SSC-M4)
  - **Final Recommendation**

- First screening: 10 proposals
  - Alfven+, ARIEL, **ASTROGAM**, EPIC, Galileo Galilei, **LOFT**, NITRO, Ravens, THOR, **XIPE**.
- Final decision for Phase A:
  - ARIEL: first dedicated mission to make IR spectroscopic obs. of hot exoplanets.
  - THOR: turbulent plasma physics, magnetosphere.
  - XIPE: unexplored domain of measuring high-sensitivity polarization in X-rays.

from reviews:

- From SARP: This proposal comes from a strong and experienced team in the MeV/GeV domain and enthusiastically presents a large variety of science topics…The main strength of the proposal is the ASTROGAM’s ability to study a very broad window in the high-energy spectrum that is not available to other missions…. ASTROGAM will do so with improved sensitivity, improved angular resolution and wide field of view that allows large visibility.

- From SARP: The mission provides a very significant improvement over previous missions, in the MeV band especially, and could be very strong. However, the proposal left many questions open and raised doubts on the mission itself and on how it will be coordinated to produce a coherent science program… The SARP’s evaluation changed positively with the answers to the written questions and aspects of the interview, providing many of the details the SARP would have expected to find in the proposal. Despite the remaining uncertainties and the impression of a not yet fully matured science case, ASTROGAM is an interesting mission proposal.

- From SSC-M4: The instrument is state of the art, combining large space heritage with new developments, in particular for LHC. The proposing team has substantial space experience gained in successful high-energy missions. It is difficult however to predict with confidence the science return from the observational capability of the mission, because of the inhomogeneous presentation of the science cases throughout the proposal.

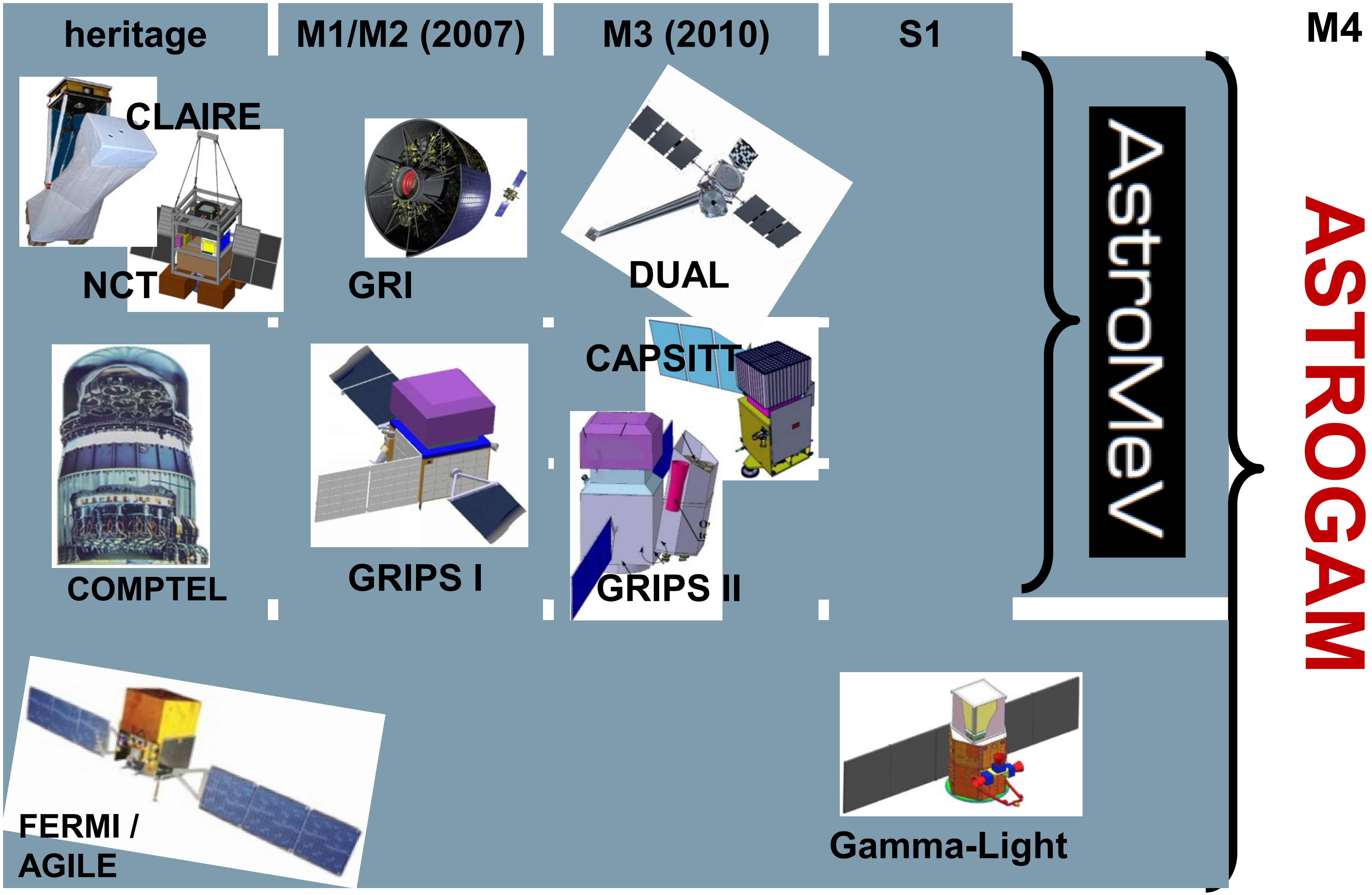
ASTROGAM

ASTROGAM

M. Tavani
V. Tatischeff, &
L. Hanlon, on behalf
of the ASTROGAM
Collaboration

ESA M4 Question & Answer Session,
ESTEC, Nordwijk, April 21, 2015

ASTROGAM History and heritage



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

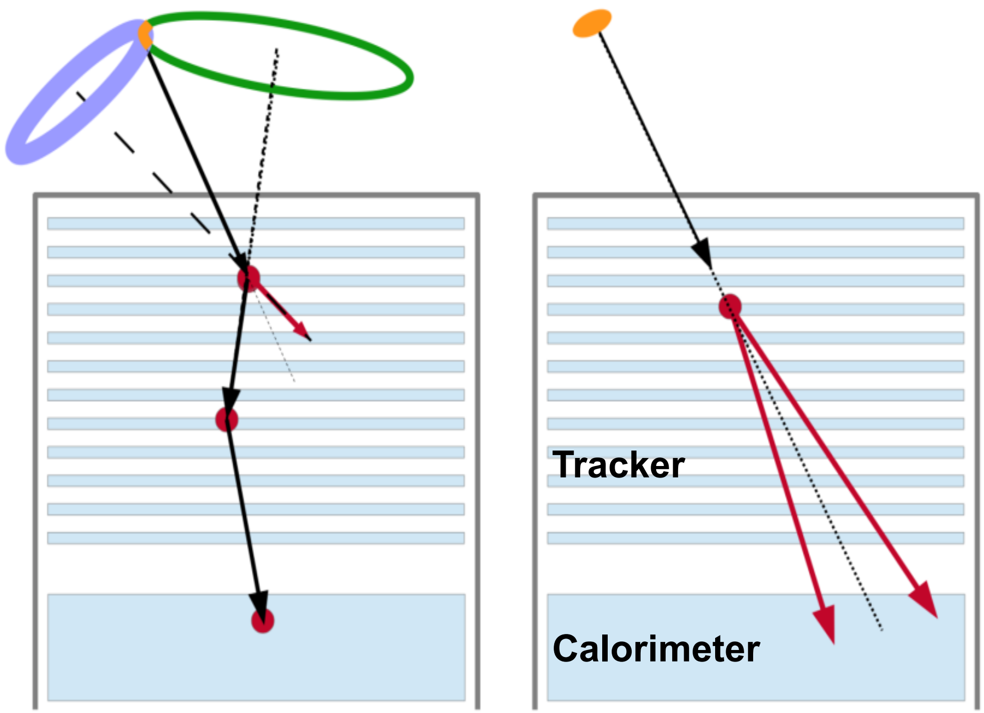
KTH

University of Tokyo

Ioffe Institute

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

MeV - GeV astrophysics



Tracked Compton event

Pair event

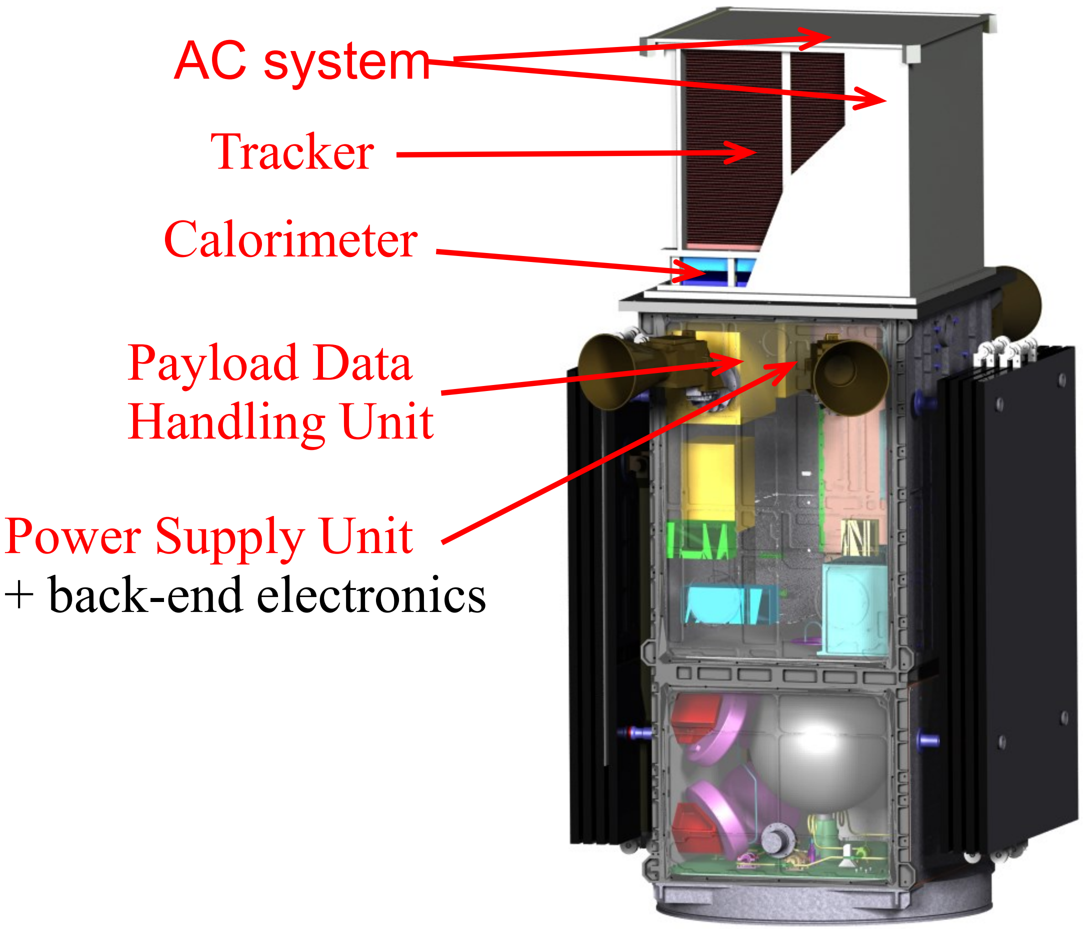
ASTROGAM

- A new window for Galactic, extragalactic & fundamental science.

- Broad band (0.3 MeV – 3 GeV), focused on the mostly unexplored energy range (0.3- 100 MeV). Continuum & line detection.

ASTROGAM Payload and satellite

- ESA guidelines for the M4 Call ⇒ ASTROGAM payload designed to be **300 kg** (total satellite mass 860 kg).



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

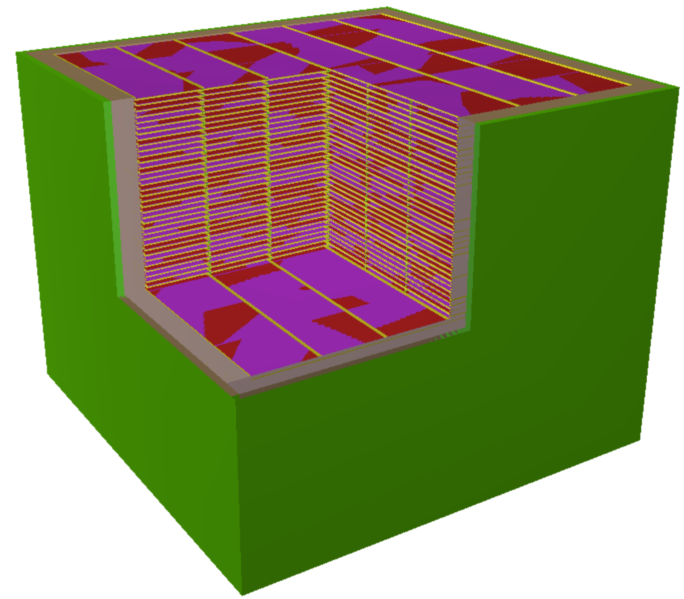
ASTROGAM Silicon Tracker

- 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

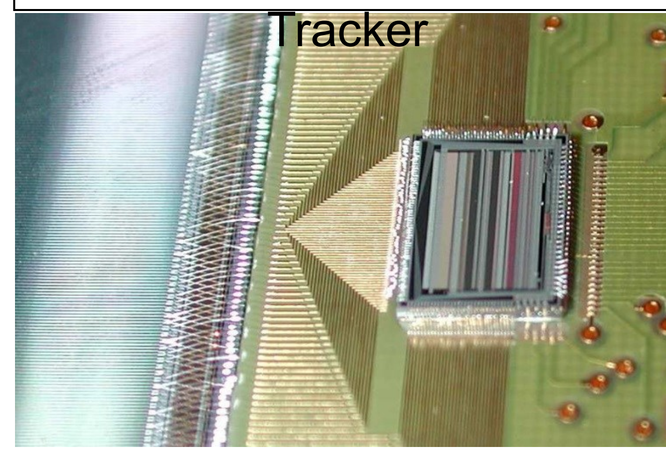
⇒ 322 560 electronic channels

- 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



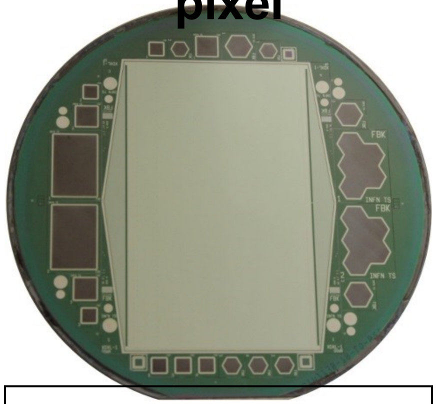
Detail of the detector-ASIC bonding in the AGILE Si Tracker

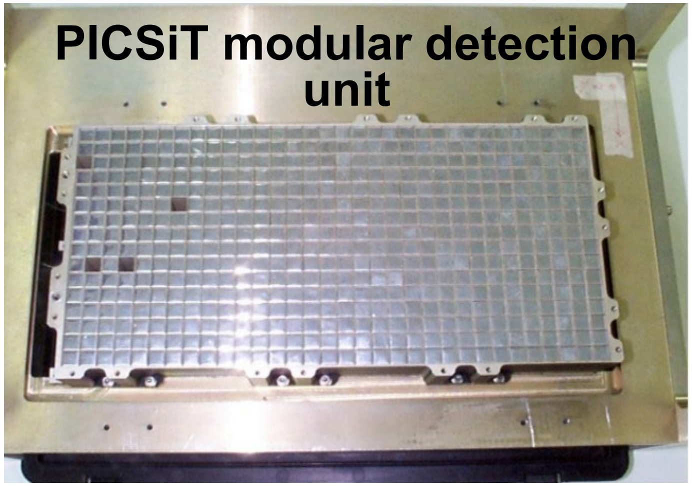


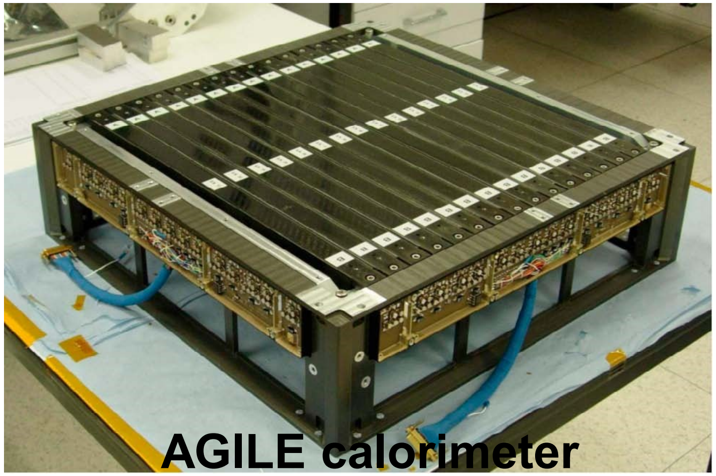
ASTROGAM Calorimeter

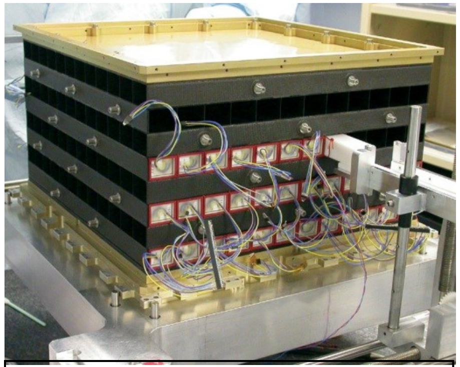
- Pixelated detector made of 12 544 CsI(Tl) scintillator bars of 5 cm length and 5×5 mm^2 cross section, glued at both ends to low-noise Silicon Drift Detectors (SDDs)
- Basic detector element formed by the coupling of 4 CsI(Tl) bars to 2 square arrays of 2×2 SDDs of 5 mm side
- Calorimeter formed by 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

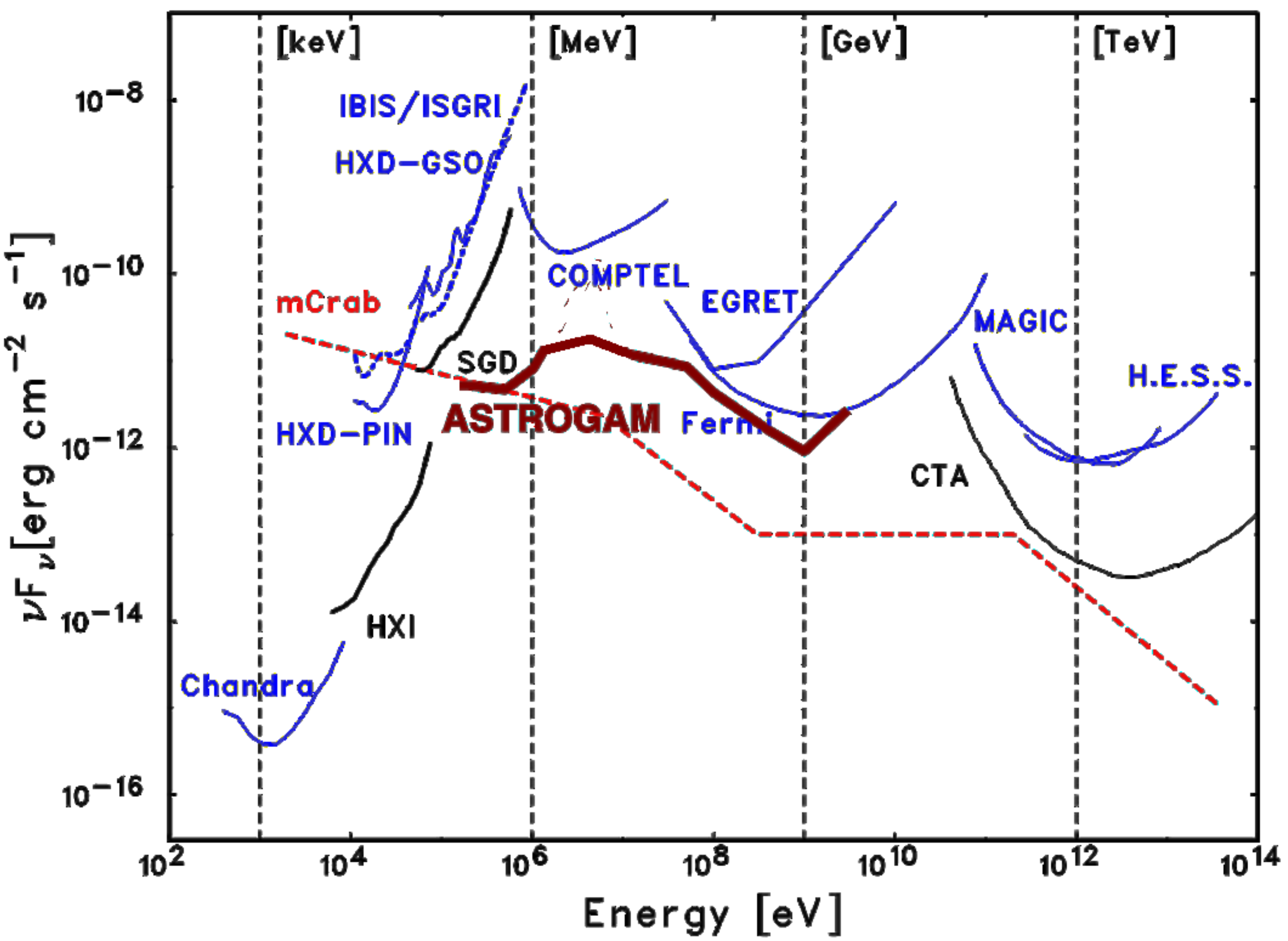

Samples of SDDs from FBK-SRS


PICSiT modular detection unit


AGILE calorimeter


Fermi cal. module

1-year (T_{eff}) pointing sensitivity

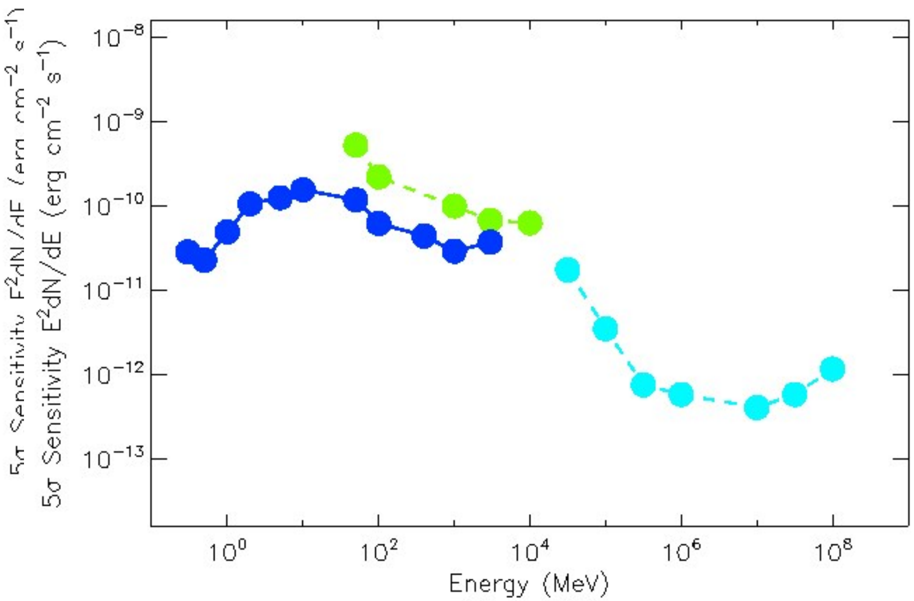


Adapted from Takahashi et al. (2013)

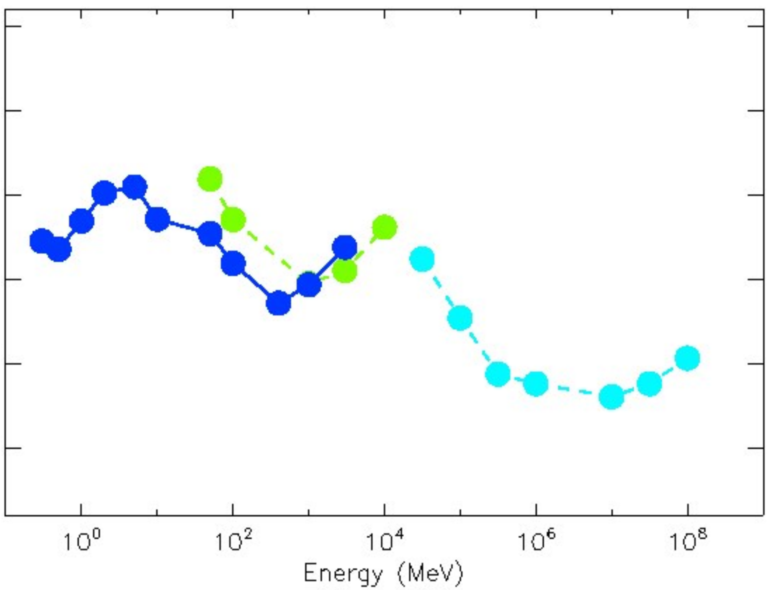
- **ASTRO-H/SGD** – 3σ sensitivity for 100 ks exposure of an isolated point source
- **COMPTEL** and **EGRET** – sensitivities accumulated during the whole duration of the CGRO mission (9 years)
- **Fermi/LAT** – 5σ sensitivity for a high Galactic latitude source and after 1 year observation in survey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

ASTROGAM

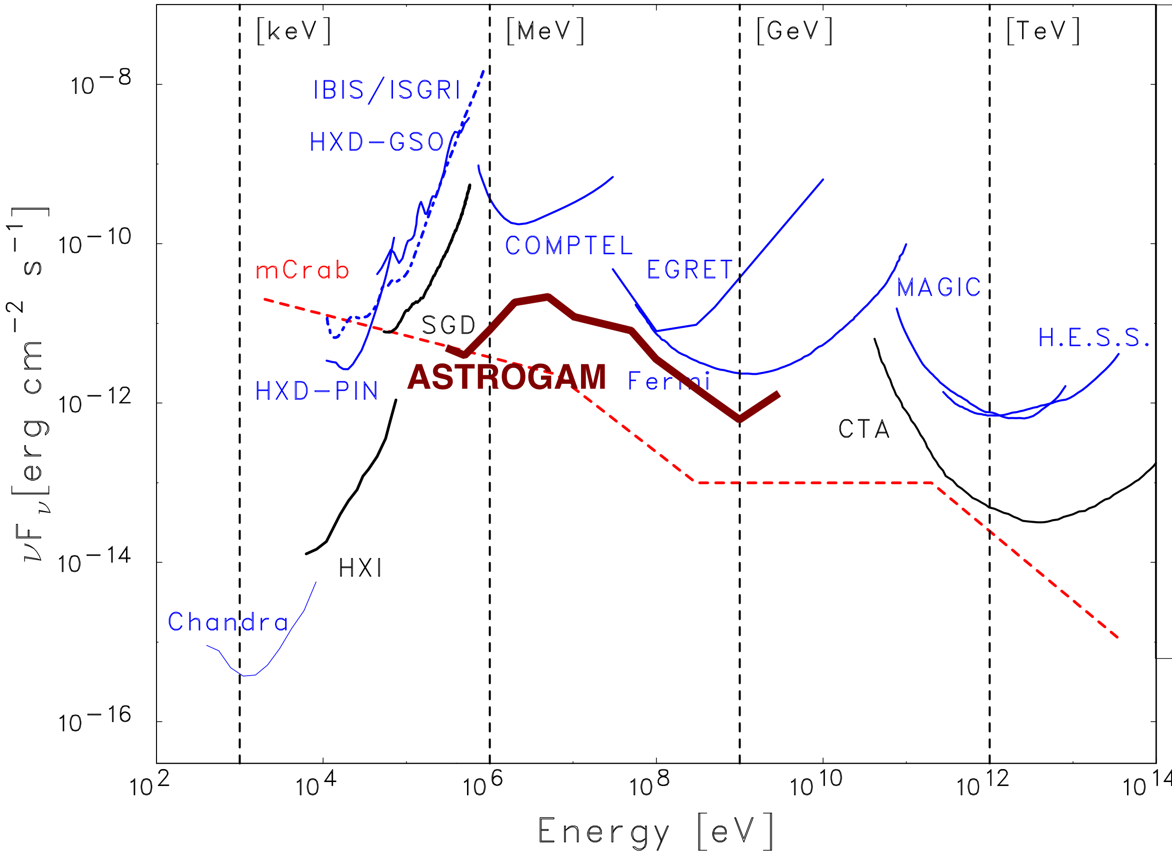
1-month, Galactic plane pointting



1-month, extragalactic pointing



ASTROGAM Sensitivity



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- **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

1. **ASTROGAM core science**
2. **source confusion**
3. **performance**
4. **source numbers**
5. **polarization**
6. **ASTROGAM as an Observatory**

1. ASTROGAM core science

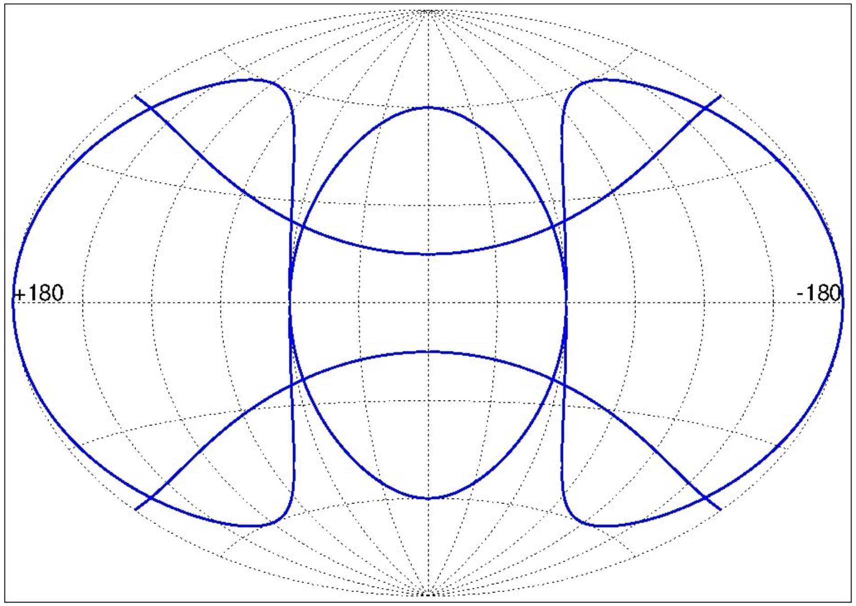
1. tracing the formation and propagation of heavy elements and cosmic rays to star forming regions
2. anti-matter in our Galaxy and beyond
3. Galactic Center: the central black hole, "*Fermi* bubbles", DM studies
4. supermassive black holes, the extragalactic and cosmic gamma-ray background
5. jet formation, extreme accelerators, GRBs

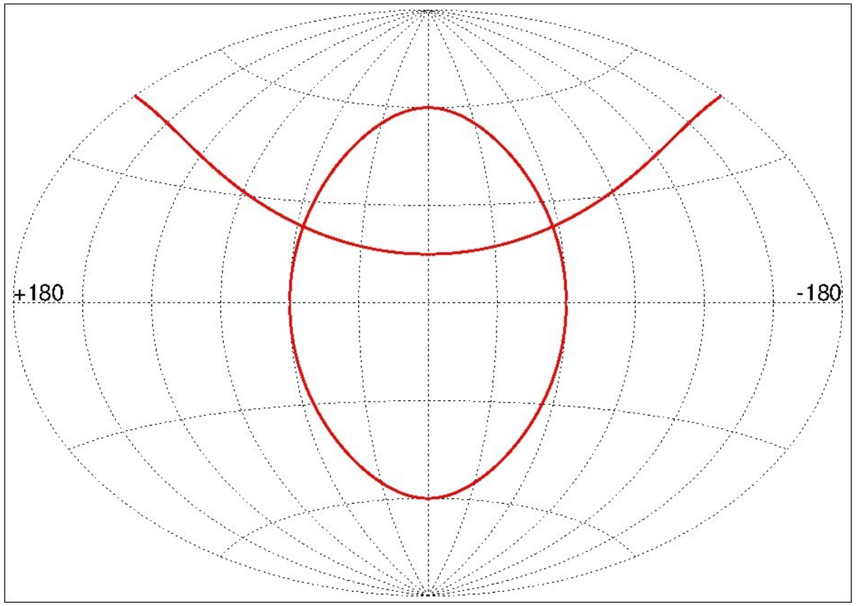
ASTROGAM Feasibility

- Implement key scientific objectives by
  - adequate exposure
  - PSF, data quality, bkg subtraction
  - broad spectral coverage

- Key Pointings
  - KP-1: inner Galaxy and Galactic Center
  - KP-2: deep extragalactic pointing
  - KP-3: fast reaction to transients

ASTROGAM Pointing strategy





Left panel: Covering the whole sky with 5 different pointings. Right panel: a strategy to implement key-projects 1 and 2. **About 40% of the sky will be exposed every 95 minutes.**

ASTROGAM Key pointings

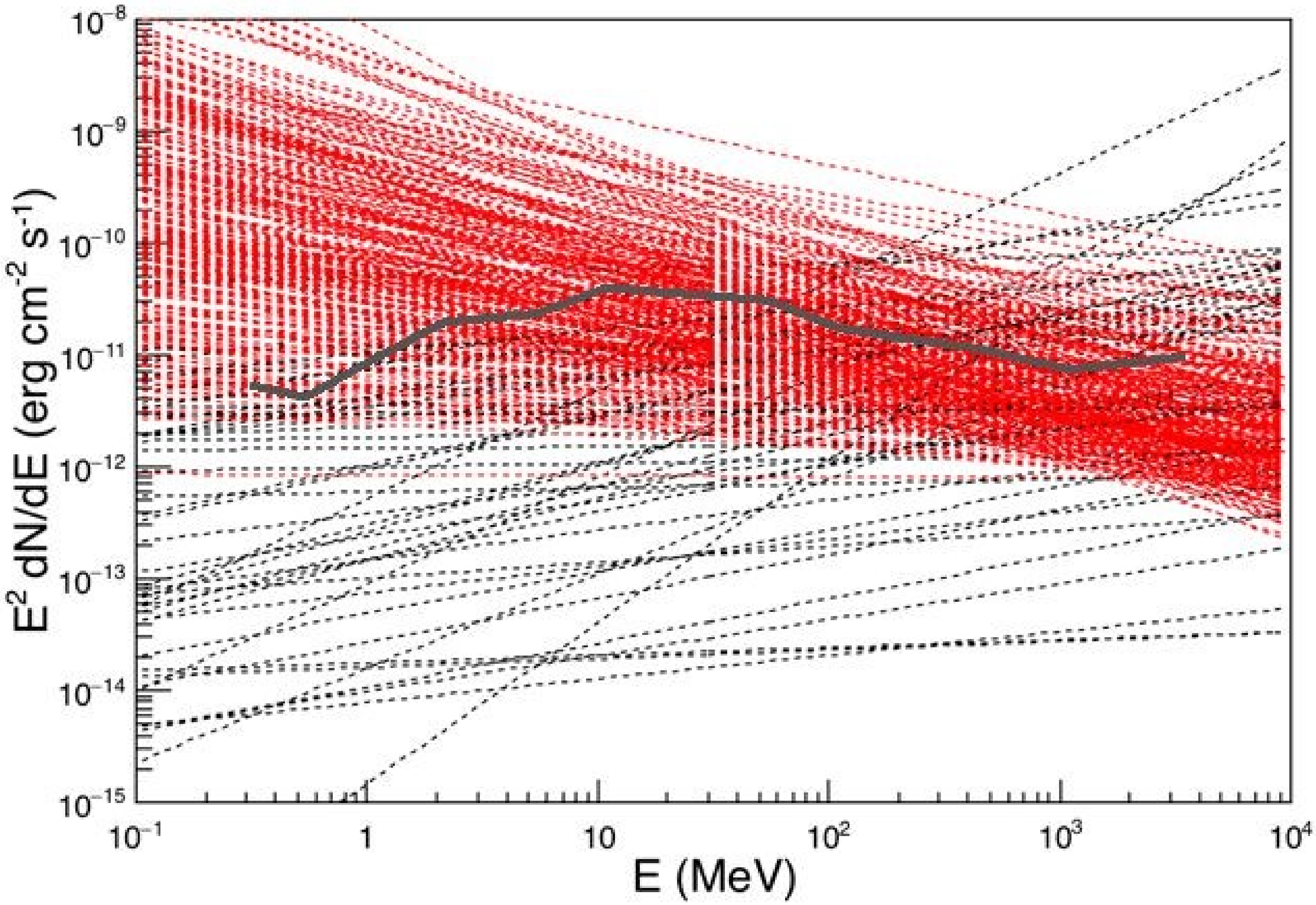
- **Key Pointing 1:**
  - Nucleosynthesis and star formation
  - Low-energy cosmic rays & star formation
  - The central Black Hole
  - Antimatter and source(s) of positrons
  - Compact objects
  - DM in GC
- **Key Pointing 2:**
  - Supermassive black holes, MeV blazars and other AGNs
  - EGB vs. CGB
  - DM in dwarf galaxies
- **Key Pointing 3: fast reaction to transients**

ASTROGAM Source numbers

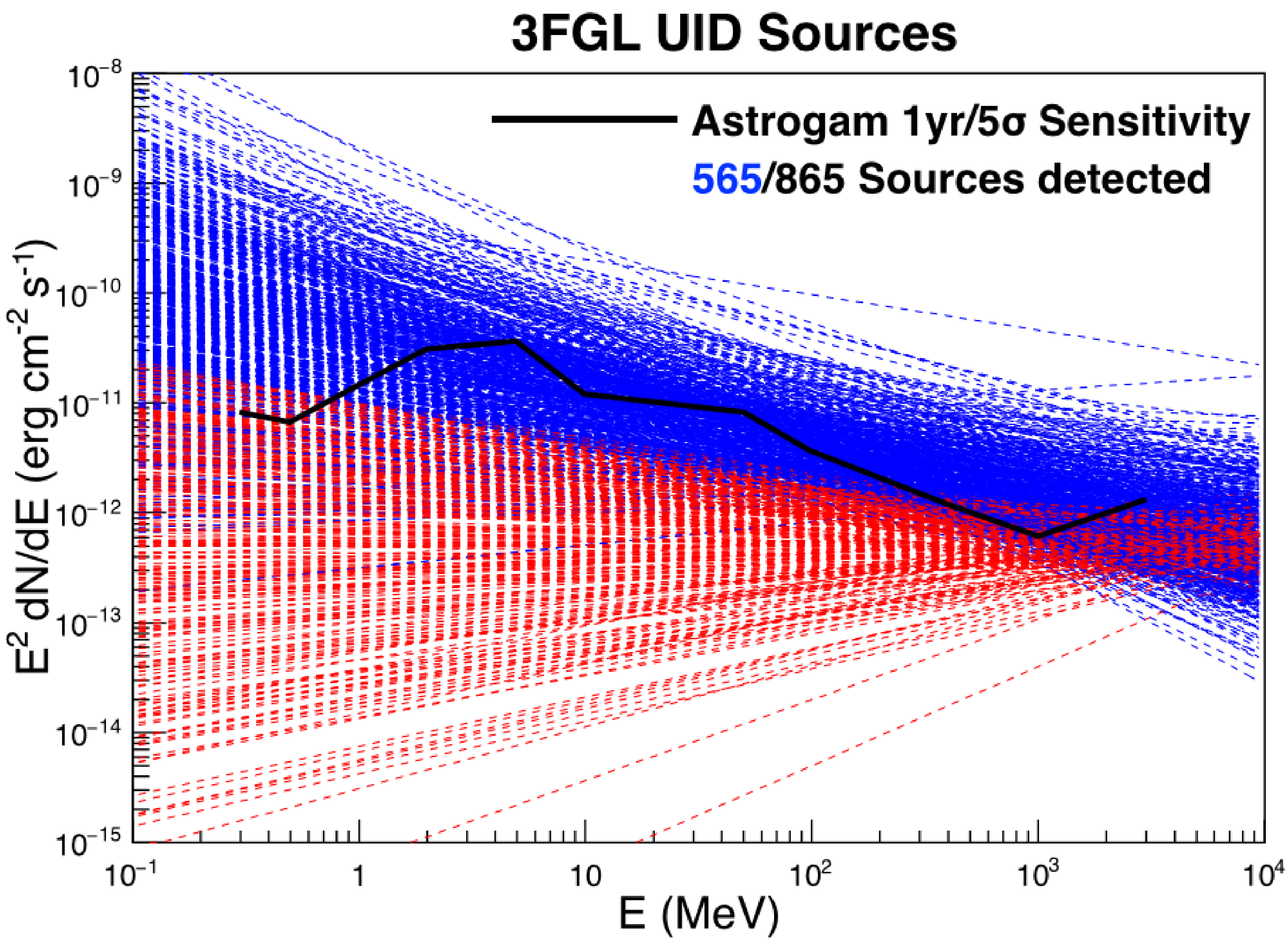
Type	3-yr lifetime	New sources
Total	**~ 860-1210**	**~ 600 (with GRBs)**
Galactic sources (< 30 MeV)	~ 50-100	~ 50
Galactic sources (> 30 MeV)	~ 200-300	~ 100
MeV-Blazars	~ 100	~ 100
GeV-Blazars	~ 300-400	~ 100
Other AGNs (<10 MeV)	~ 20-30	~ 10-20
Supernovae	~ 4-5	~ 4-5
Novae	~ 0-1	~ 0-1
GRBs	~ 200-300	

- **Sources and phenomena not accessible by Fermi-LAT and X-ray detectors**
  - **Galactic sources:**
    - accreting with MeV tails
    - pulsars with 1-10 MeV cutoffs
    - microquasars going from thermal to non-thermal, jet launching, hadronic vs. leptonic
    - Nuclear lines
  - **AGNs**
    - MeV blazars (high-z blazars)
    - Tidal disruptions in supermassive BHs at their peak energy
    - Radio galaxies in the MeV range
  - **Extragalactic MeV background**
  - **GRBs**
    - Polarization and broad band spectroscopy

Spectral extrapolation of 3FGL sources in the inner Galaxy (+/- 40°in long.) & ASTROGAM 1-yr Gal. sensitivity



ASTROGAM Source number estimate

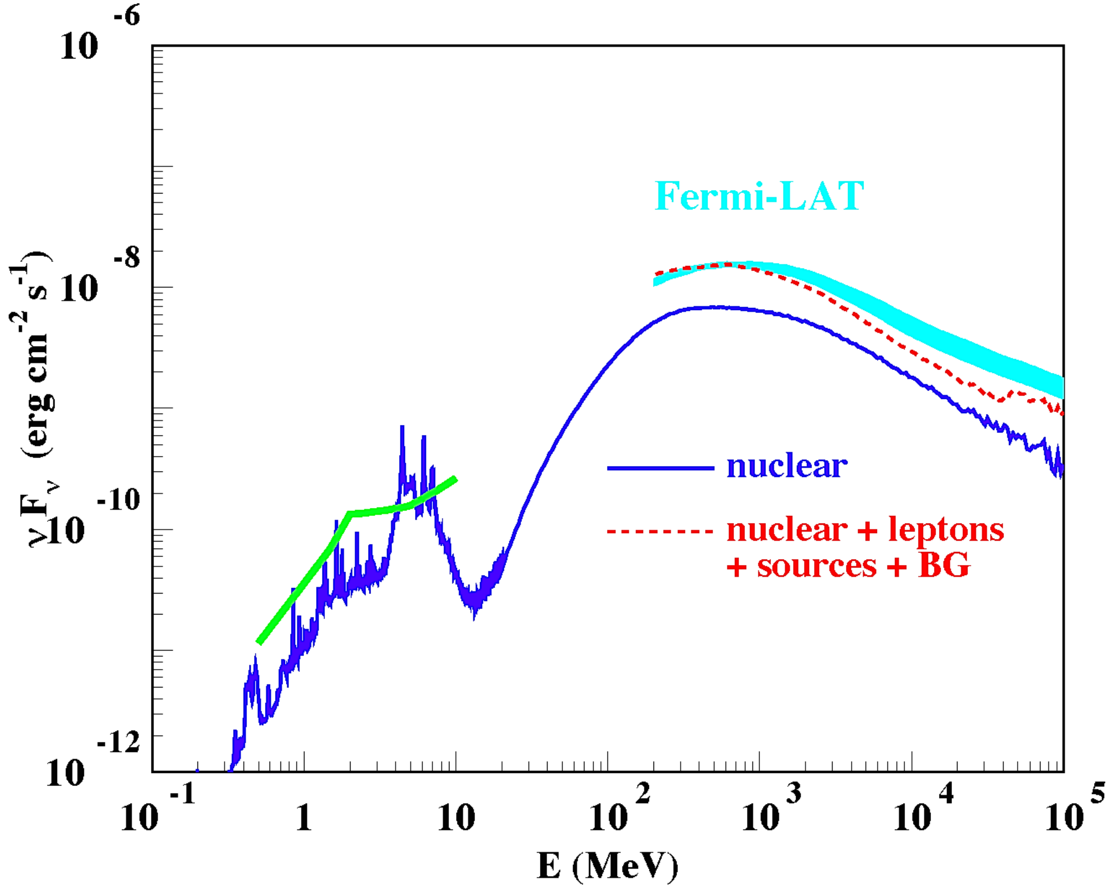


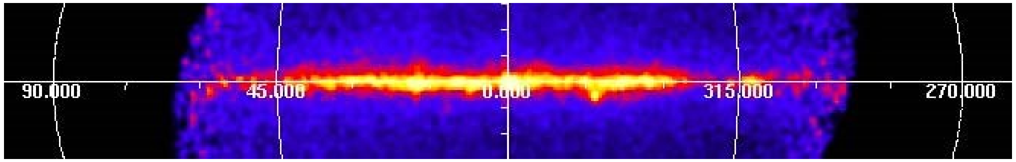
ASTROGAM Low-energy cosmic rays

- 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.



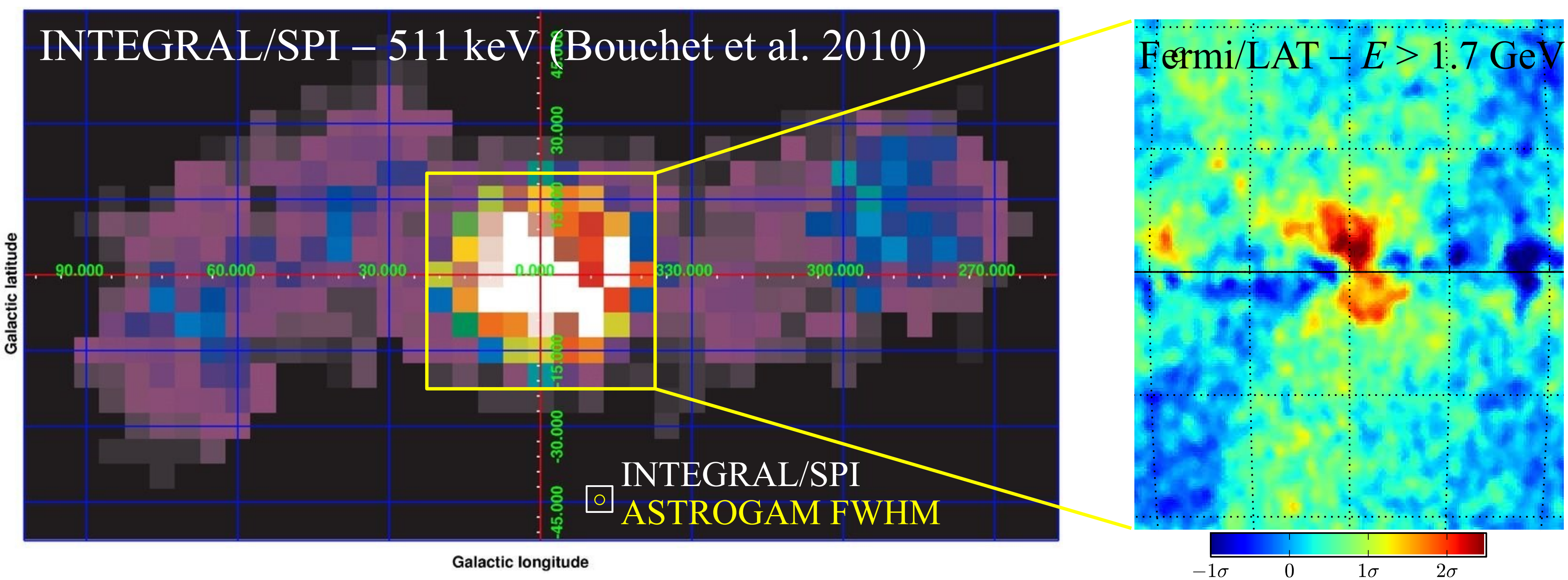


ASTROGAM Antimatter in the Galactic bulge

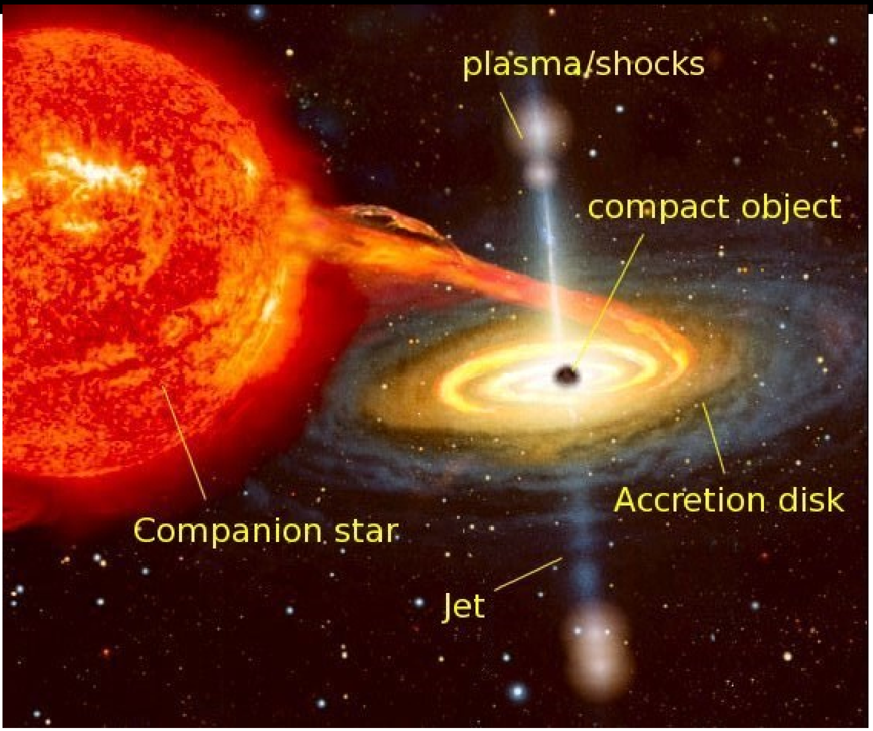
- The 511 keV emission from the Galactic center is still a mystery after more than 40 yr of observations, **rate of 10^{43} s^{-1}** .
- The **bulge emission** can be explained by the injection of 10^{58} - 10^{60} positrons in the Galactic center some millions years ago

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

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

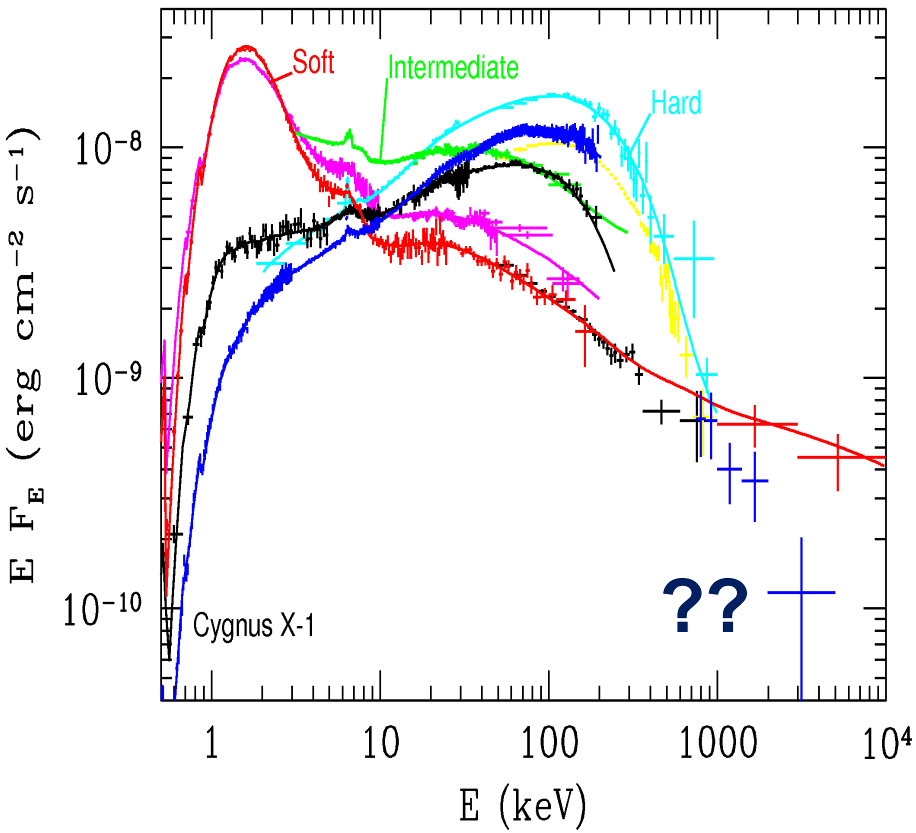


ASTROGAM Microquasars



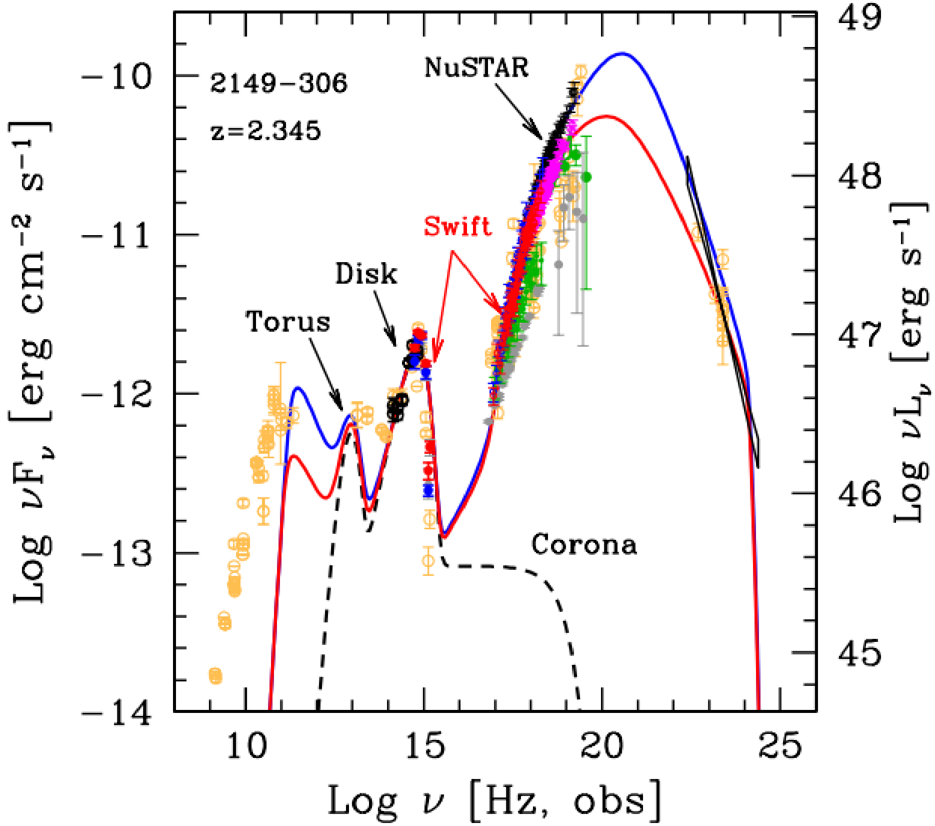
- **transition from thermal to non-thermal**
- **Jet launching !**
- **leptonic vs. hadronic**

Cyg X-1 spectral states

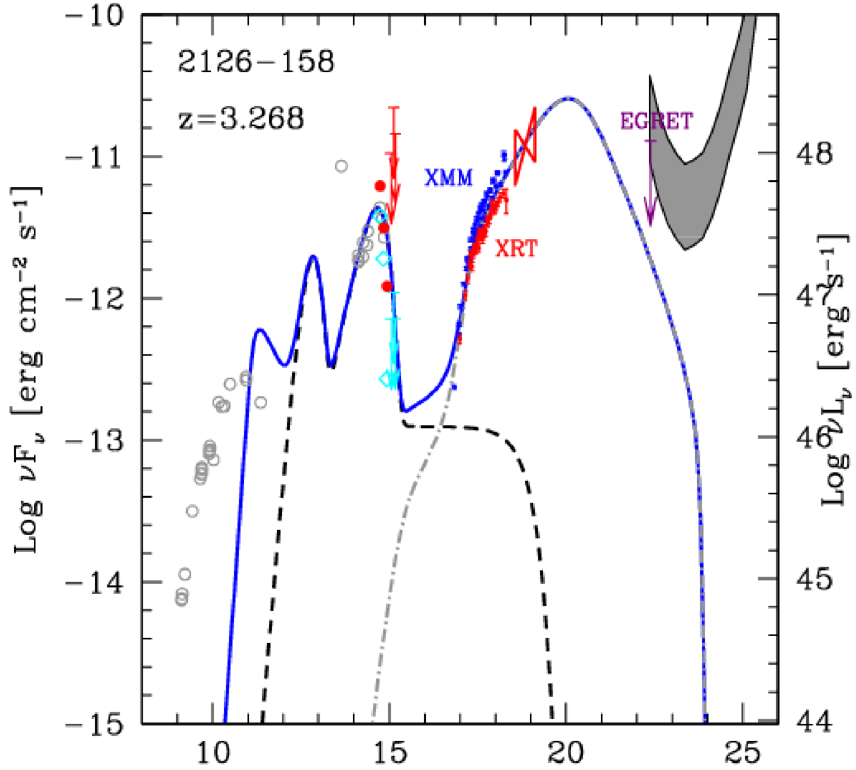


MeV-blazars detectable by ASTROGAM

2149-306 (z = 2.345)

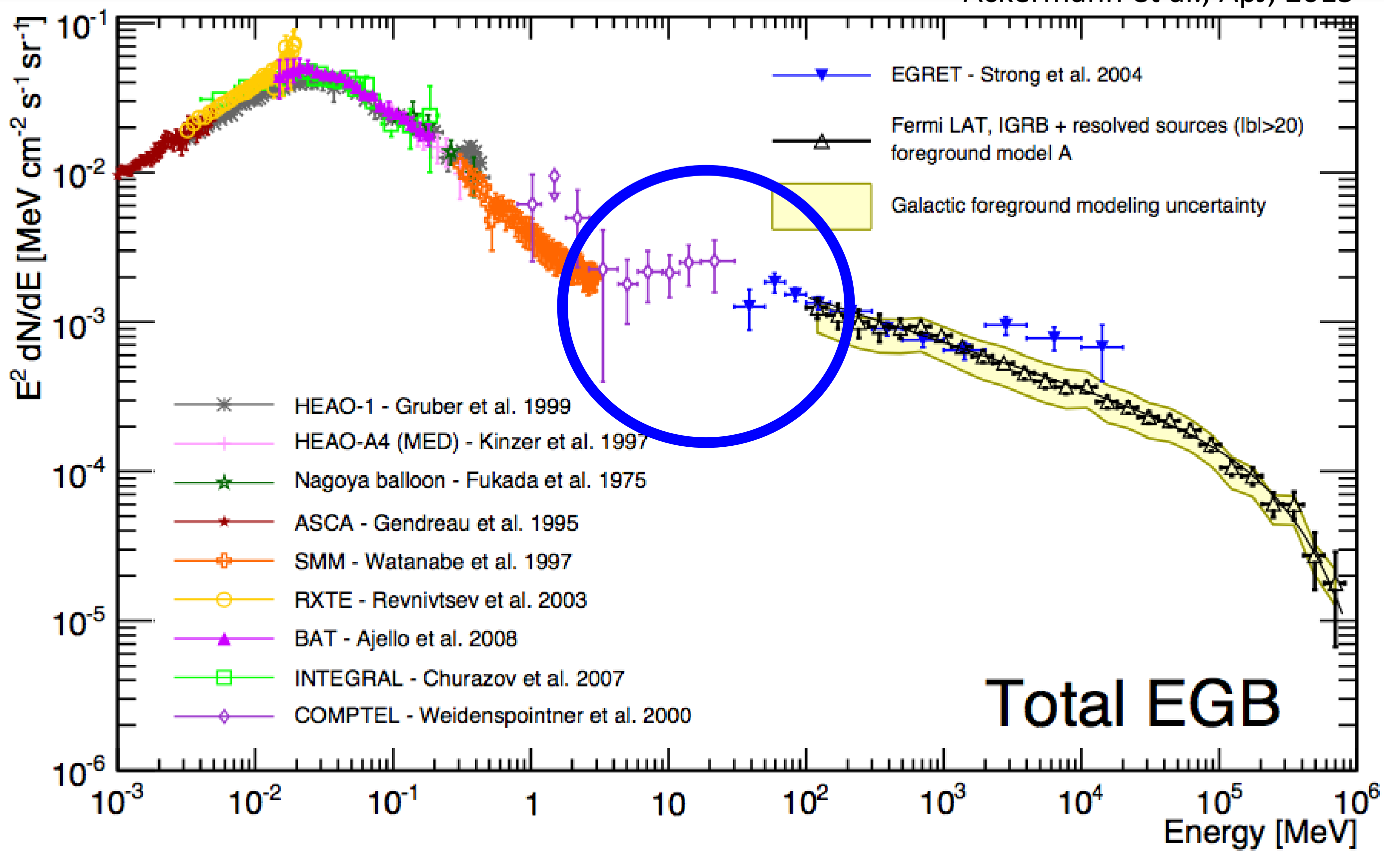


2126-158 (z = 3.268)



The extragalactic gamma-ray background (EGB)

Ackermann et al., ApJ, 2015

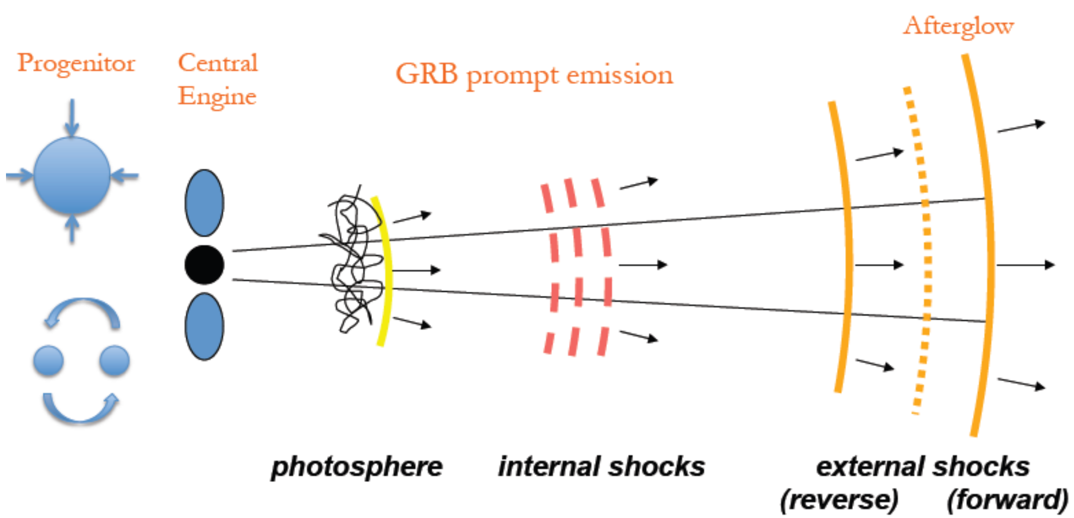


- Extragalactic X-ray and gamma-ray background now **measured over 9 orders of magnitude in energy**.
- **Largest uncertainties in the 1 MeV - 100 MeV range.**

ASTROGAM Gamma-ray Bursts (GRBs)

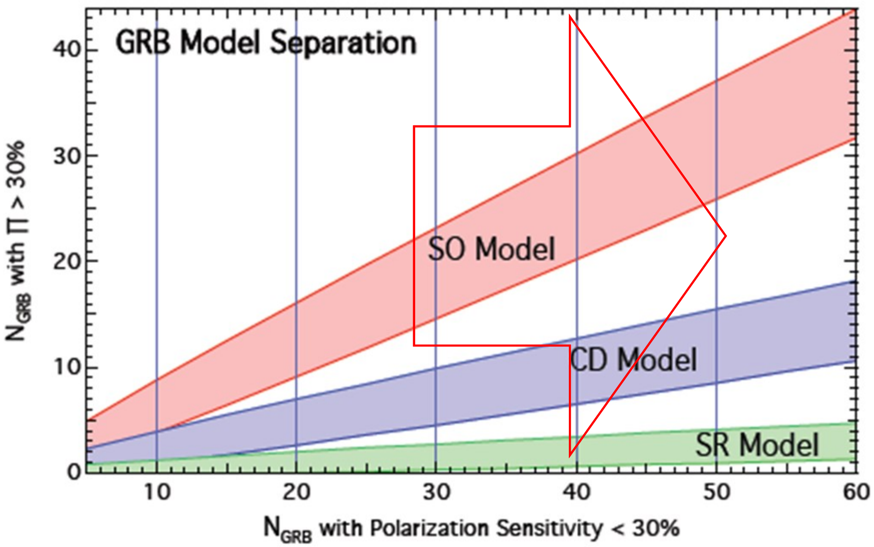
- ASTROGAM will be a capable GRB instrument, **detecting ~ 120 yr^{-1}**.
- **1-3 combined short GRB/aLIGO GW events expected.**
- Synergy with ground and space instruments (e.g., SVOM, 4-250 keV).

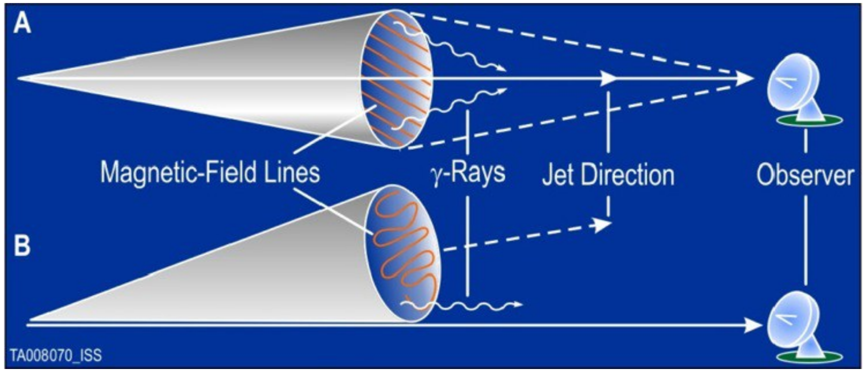
- Major open questions:
  - MeV – GeV connection
  - Jet composition
  - Radiation mechanism
  - Geometric configuration



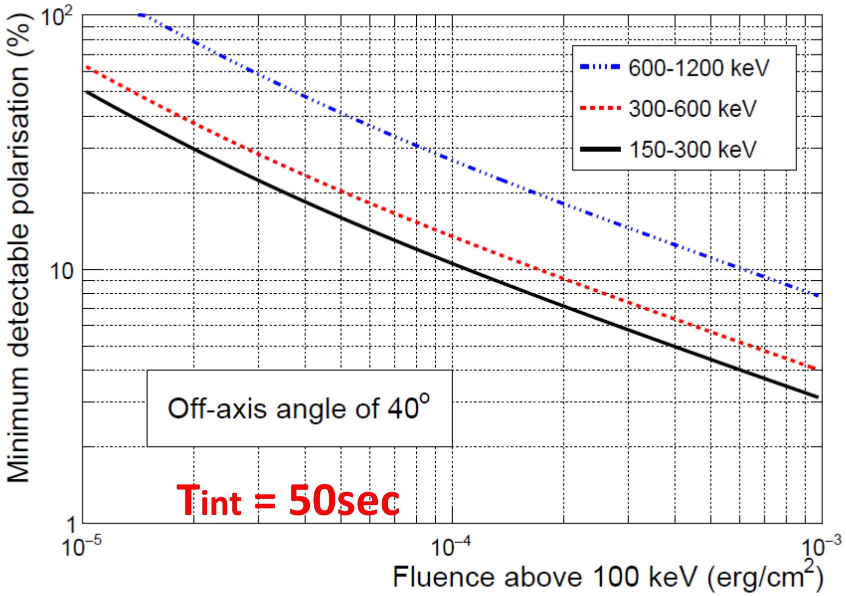
ASTROGAM Polarization - GRBs

- ASTROGAM's bright GRB sample (**>30 bursts in 3 years**), combining polarization + broadband spectroscopy for the first time, opens a new window to answer these key questions…



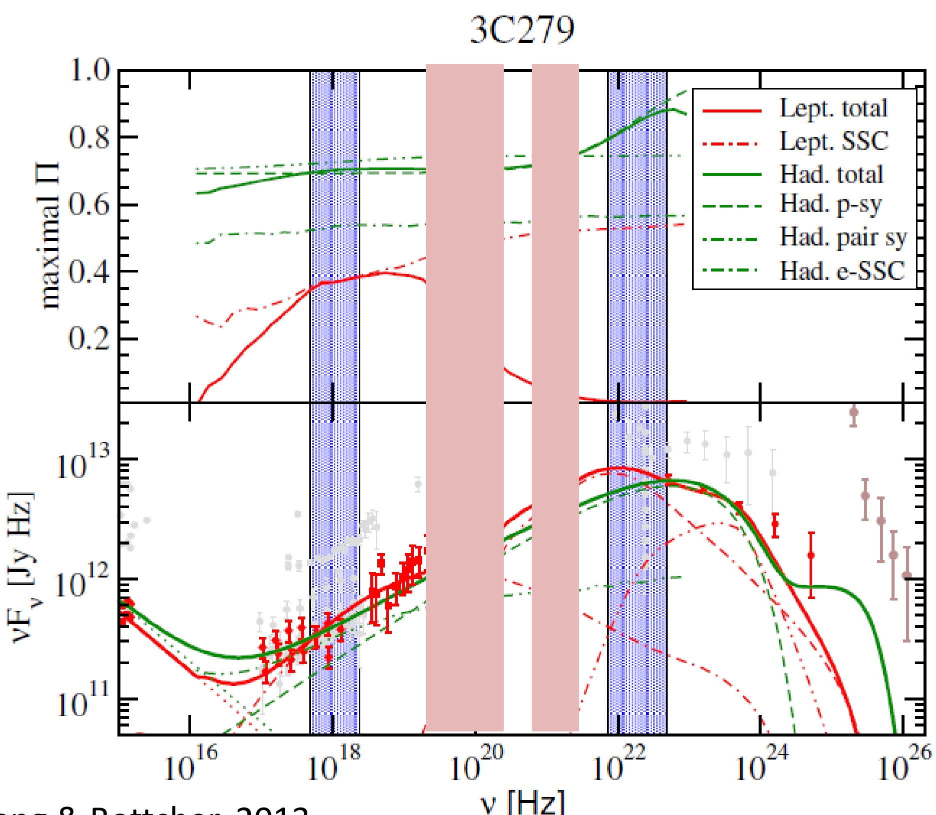


GRB polarization vs energy @ cosmological distances constrains Lorentz- and CPT-invariance violation in the photon sector.



ASTROGAM Polarization - Blazars

- Mechanism producing high energy (X-ray through γ-ray) emission in blazars remains under debate.
- Leptonic and hadronic models can both reproduce observed SEDs.
- Polarization can distinguish between them.

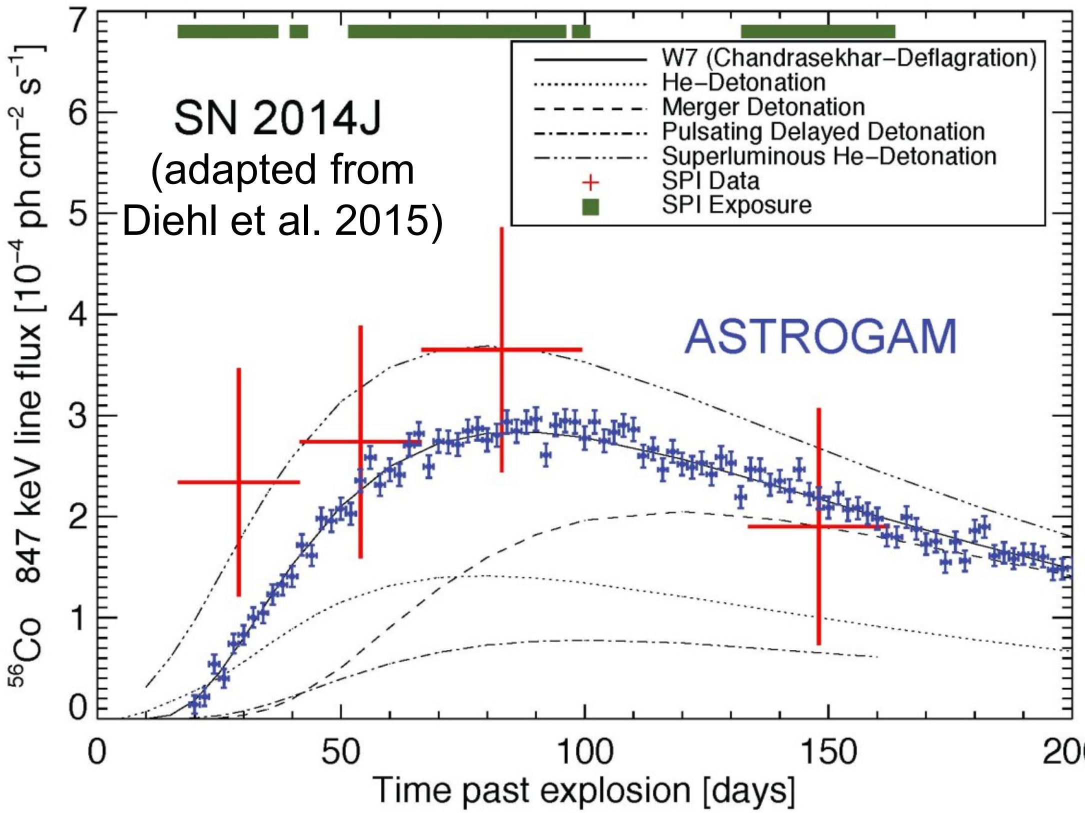


Zhang & Bottcher, 2013

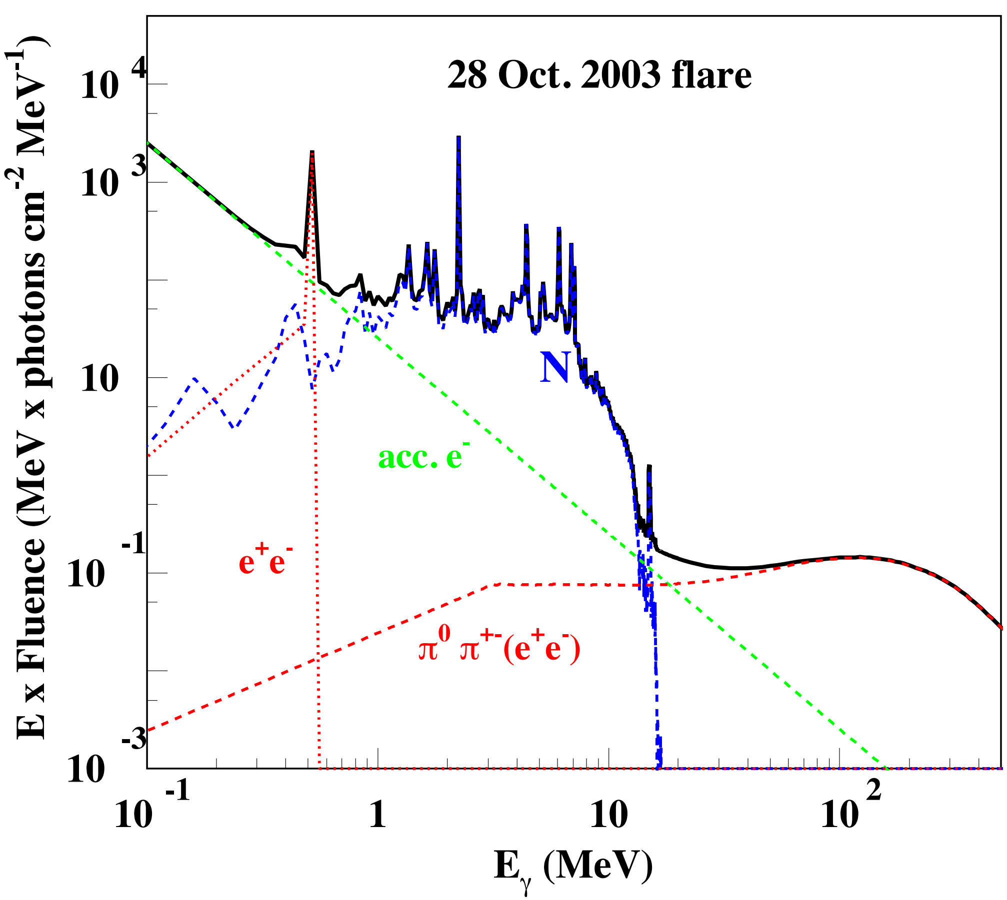
- $MDP_{3\sigma}$ of 1.1% for 1 Crab (0.2-2 MeV) in 1 Ms.
- $MDP_{3\sigma}$: 50% for 1 Crab (10-30 MeV) in 1 Ms.
- Blazar flares can reach fluxes of a few Crab, lasting ~days.
- High polarization => hadrons accelerated in rel. jets.
- Source of UHECRs.

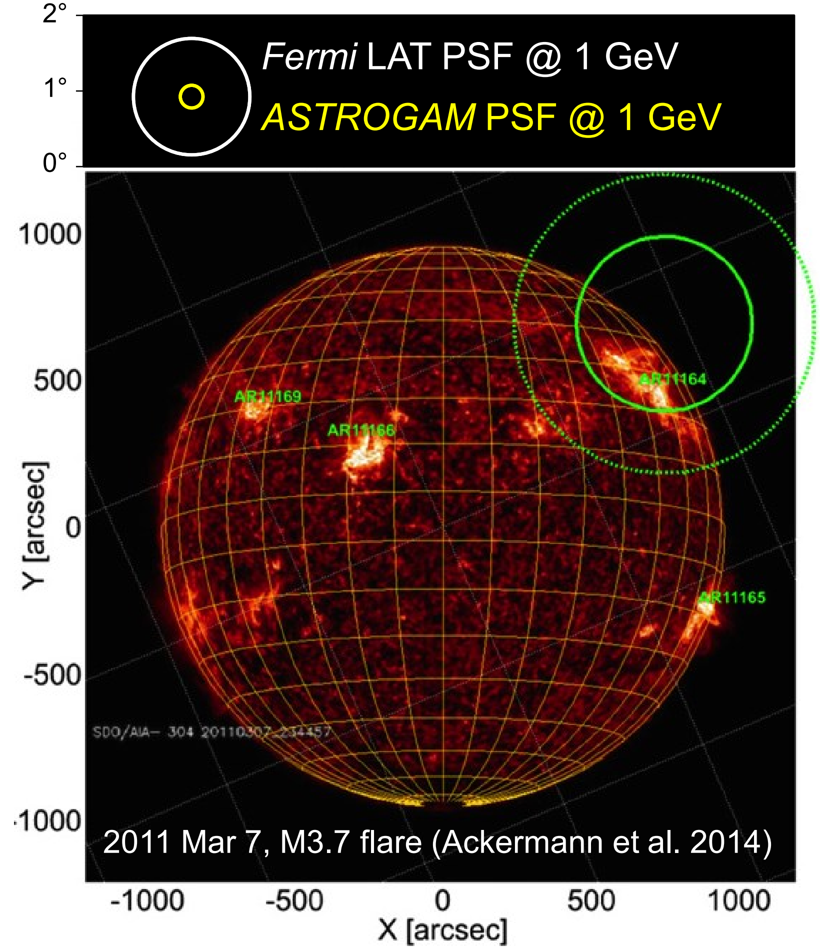
ASTROGAM Thermonuclear supernovae

- 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 gamma-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 will disentangle the various radiation components from fast ions and electrons in solar flares through broadband spectroscopic observations.
- ASTROGAM's sensitivity and angular resolution will be crucial to study the origin of the temporally extended γ-ray emission in long-duration flares.





2011 Mar 7, M3.7 flare (Ackermann et al. 2014)

Observatory

- an Observatory open to the community
  - Program based on Key Pointings
  - ToO observations performed with fast reaction
- most open & fast use of the data
  - Quicklook results, fast alerts for transient sources
  - Standard products in friendly format
- a very large community involved (from radio to TeV)

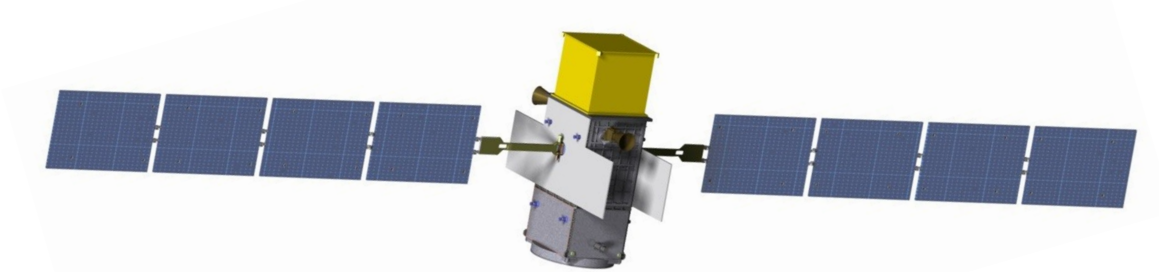
- **Multifrequency**
  - **Radio (SKA, ALMA, VLA)**
  - **Optical telescopes (e.g., LSST)**
  - **X-rays (Athena)**
  - **TeV (CTA, HAWK).**

- **Multimessenger**
  - **gravitational waves**
  - **neutrinos**

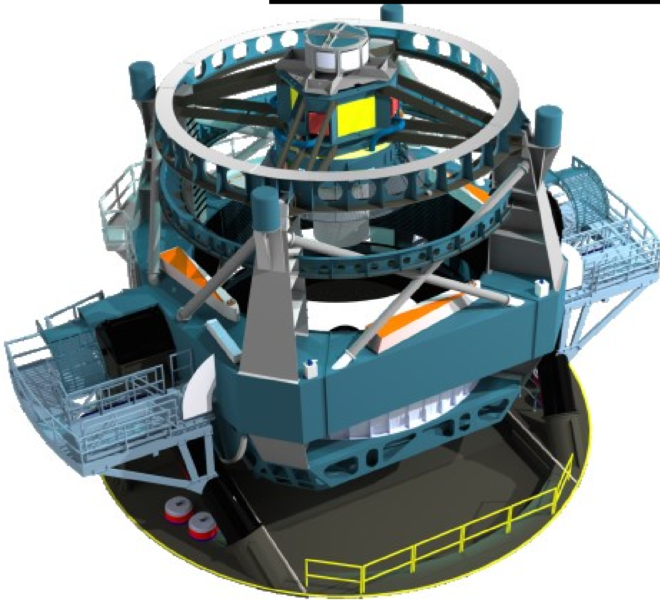
- **Very large communities and potential users in Europe, and across the world.**

ASTROGAM

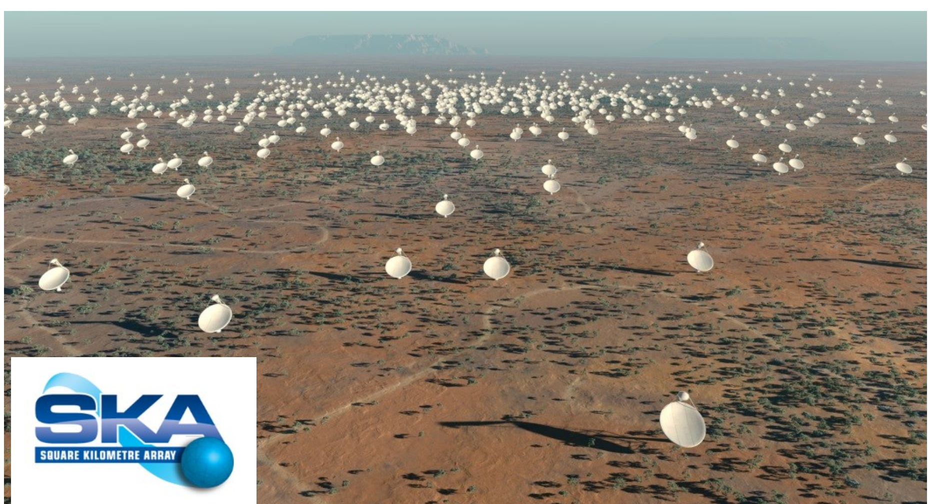
Time domain astronomy

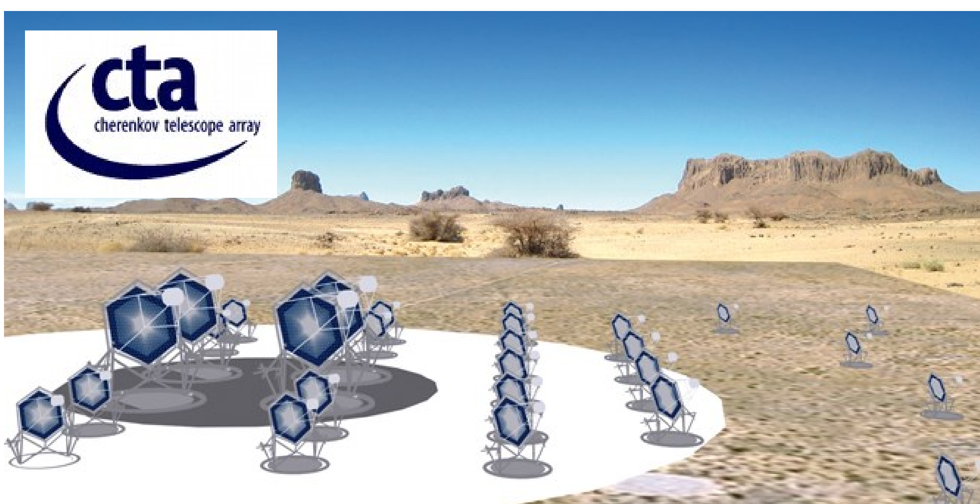


Large Synoptic Survey Telescope



- A wide-field γ-ray observatory operating at the same time as facilities like LSST and SKA will give a more coherent picture of the transient sky.
- CTA science related to variable sources will need a coverage of the γ-ray sky at lower energies to trigger Target-of-Opportunity observations.





ASTROGAM

- **For what will ASTROGAM be remembered ?**
  - **Origin of the elements & CR feedback in star formation**
  - **Central region of the Galaxy, the BH activity, origin of antimatter**
  - **Resolving the mystery of the extragalactic gamma-ray background in the MeV range**
  - **DM searches in regimes not accessible by current accelerators or other indirect searches**

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

The future…

- Community should focus and «coalesce» into future projects
- enhanced-ASTROGAM: a possibility
  - How ?
  - Technology development, prototypes, balloon
  - Killer science
- Next chance: ESA M5
- Open to discussion and collaboration