Astrofisica Nucleare e Subnucleare

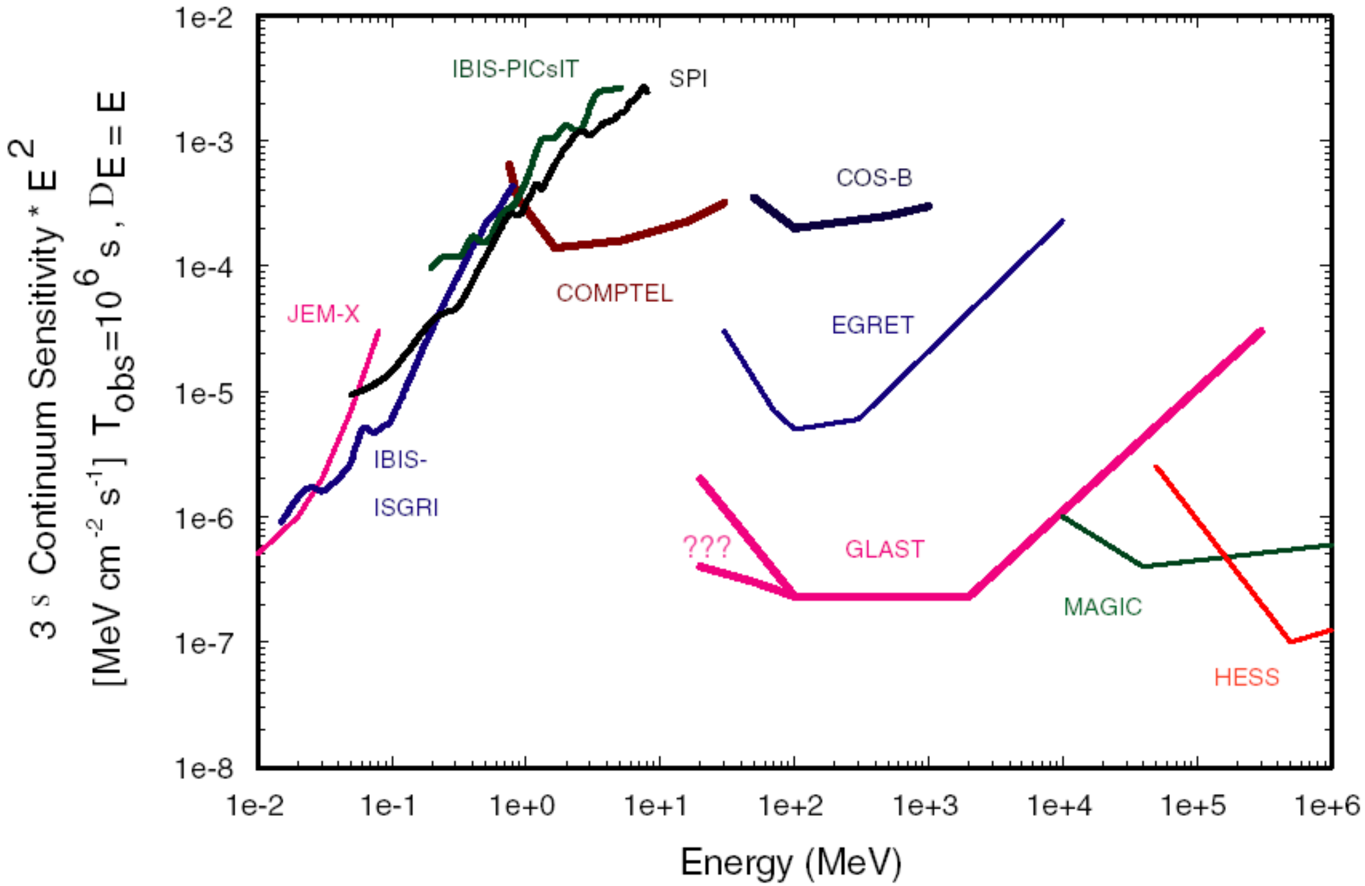
“MeV” Astrophysics - II

Exercise #4

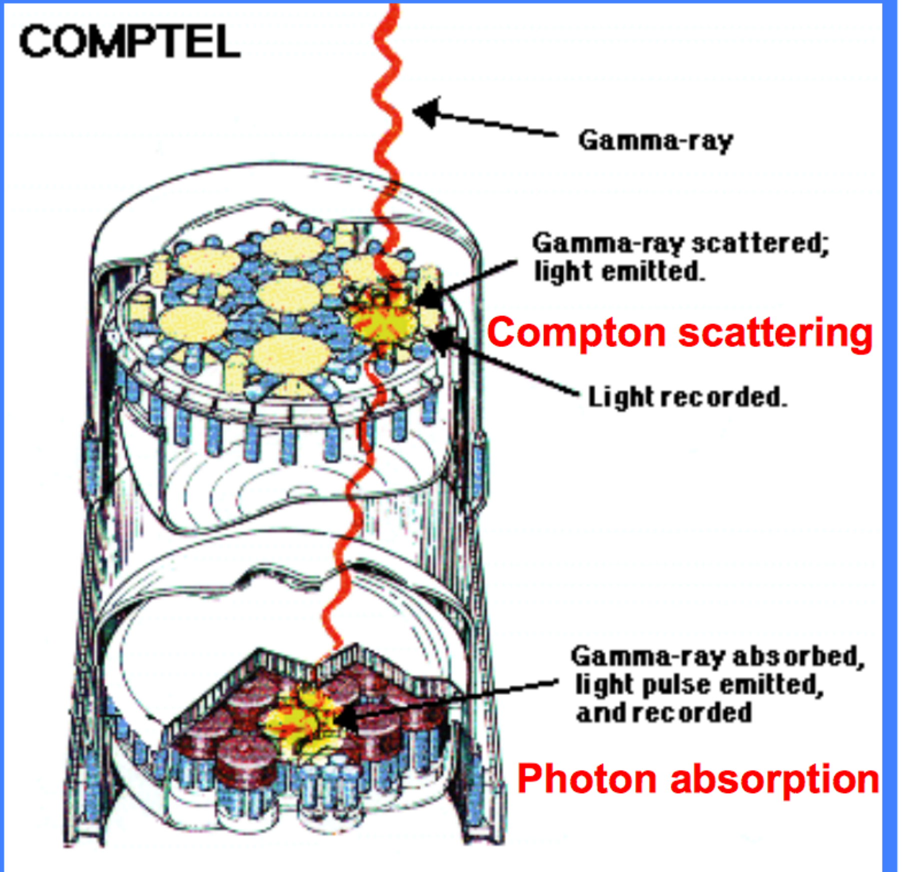
- Find information on the new MeV telescopes projects …
  - https://asd.gsfc.nasa.gov/conferences/future_gamma_obs/
  - https://asd.gsfc.nasa.gov/conferences/fgo2/
- Check the web sites of AMEGO and eASTROGAM

Sensitivity

G. Kanbach et al. / New Astronomy Reviews 48 (2004) 275–280



Telescopi Compton



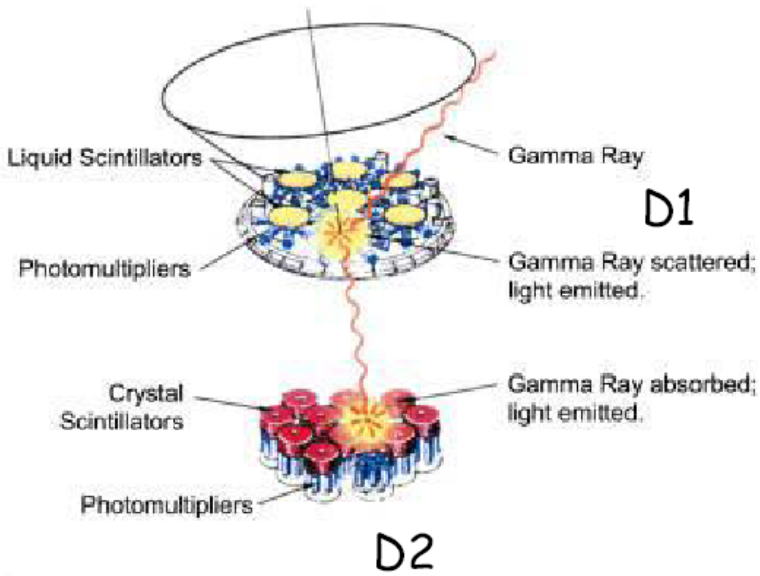
Two-level instruments:
1st level: the γ-ray Compton scatters off an electron in a **liquid scintillator**. The scattered photon enters into a **2nd level scintillator** (NaI) and is absorbed. Phototubes can determine the interaction points at the two layers and record the amount of energy deposited in each layer.

It is possible to reconstruct the angle of incidence the photon made wrt the original direction using the Compton scattering law, linking this angle and the energy of the scattered photon
(2nd level) and the scattering electron (1st level).

"Event circle" (ring on the sky), poor angular resolution (but multiple photons can help to reconstruct the position)

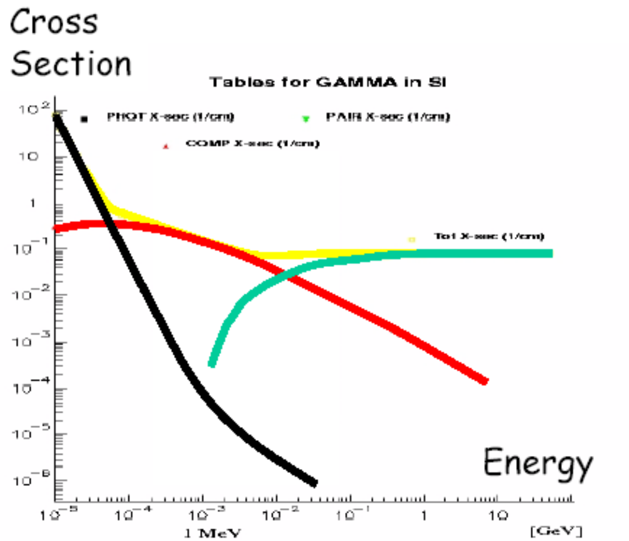
Compton Imaging

COMPTEL on CGRO



Compton Imaging

Detection of Gamma Radiation



Photoeffect(< 100 keV)

Photons effectively blocked and stopped

Telescopes:

Collimators
Coded Mask Systems

Compton Scattering (0.2-10 MeV)

Photon Crossection Minimum
Scattered photons with long range

Telescope:

Compton Camera Coincidence System

Pair Creation (> 10 MeV)

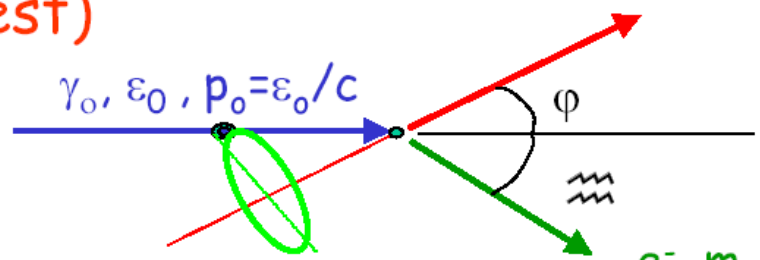
Photons completely converted to e^+e^-

Telescope:

Tracking chambers to visualize the pairs

Compton Imaging

Kinematics
(target at rest)



Energy: $\varepsilon_0 = \varepsilon_1 + T$

Momentum:

$\varepsilon_0 = \varepsilon_1 \cos\varphi + pc\cos\vartheta$ where $pc = \sqrt{T(T+2m_0c^2)}$

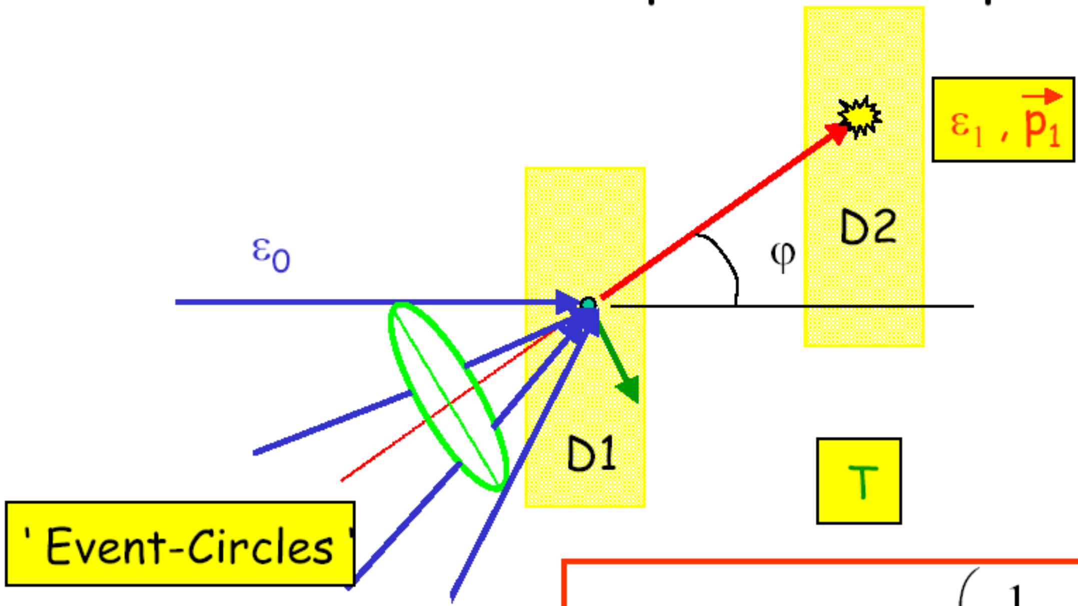
$\varepsilon_1 \sin\varphi = pc\sin\vartheta$

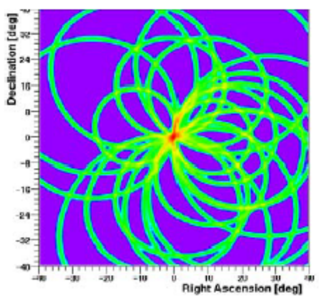
Compton Equation:

$$\cos\varphi = 1 - m_0c^2\left(\frac{1}{\varepsilon_1} - \frac{1}{\varepsilon_0}\right)$$

Compton Imaging

The ,classical' Compton telescope

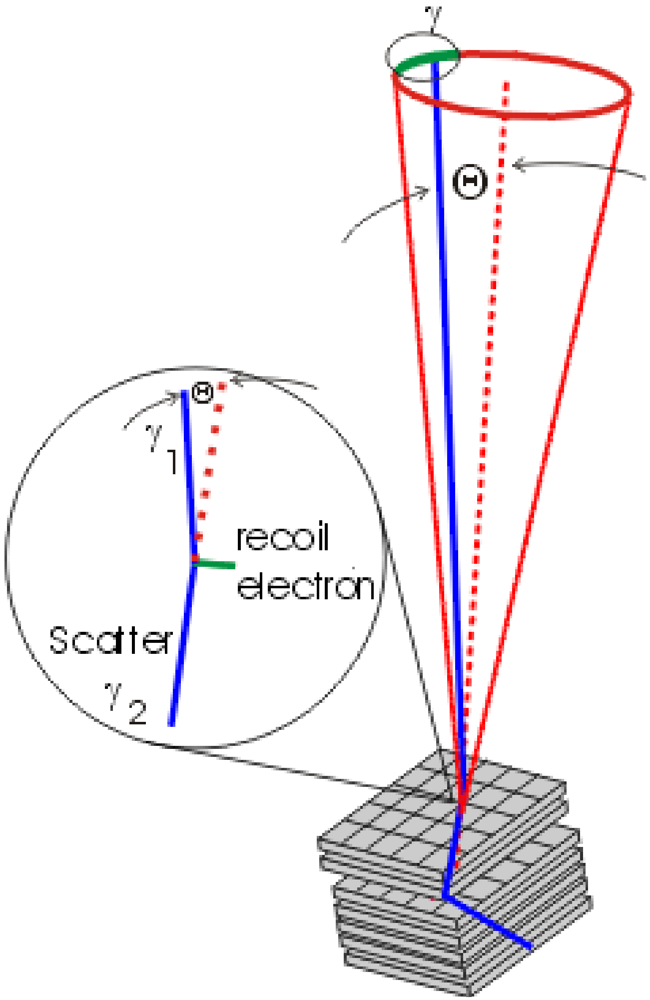


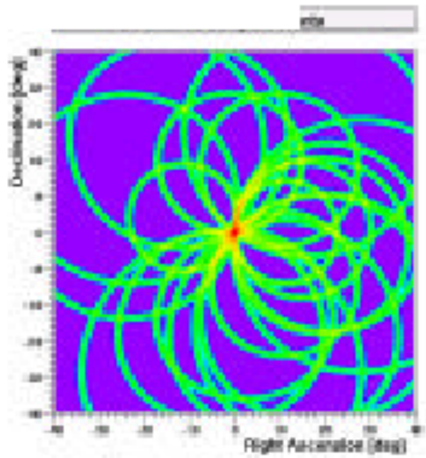


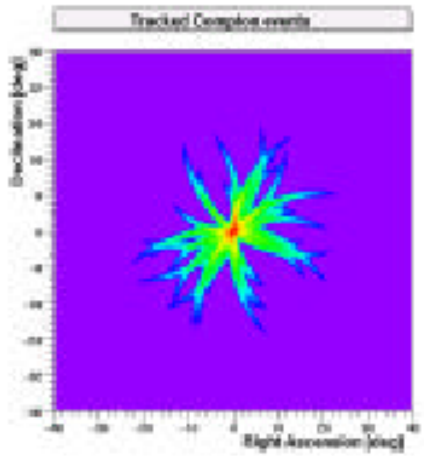
$$\cos\varphi = 1 - m_0 c^2 \left(\frac{1}{\varepsilon_1} - \frac{1}{\varepsilon_0} \right)$$

July 2002

Compton Imaging







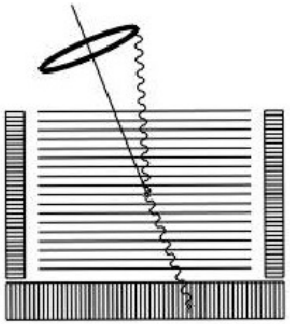
Compton Imaging

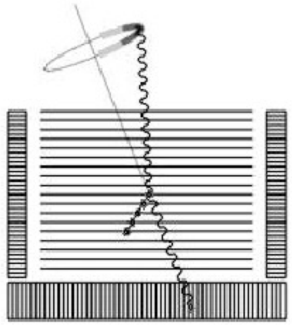
Coincidence Detector Schematics

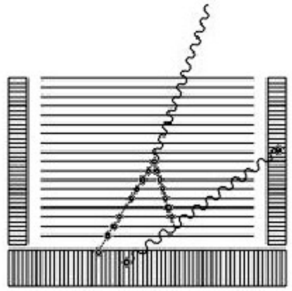
Classical Compton Event Circles (no electron tracking)

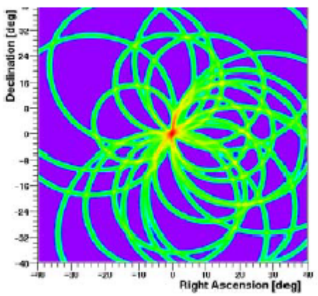
Reduced Compton circles of events with electron track

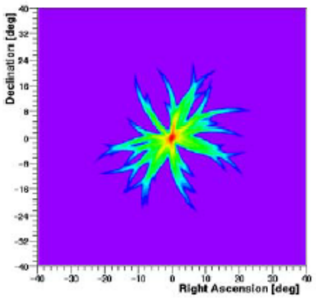
Direct imaging of pair-creation events

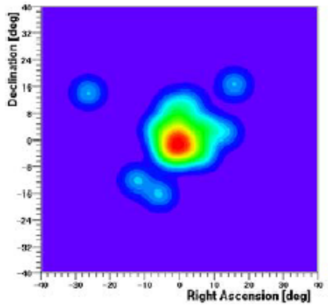










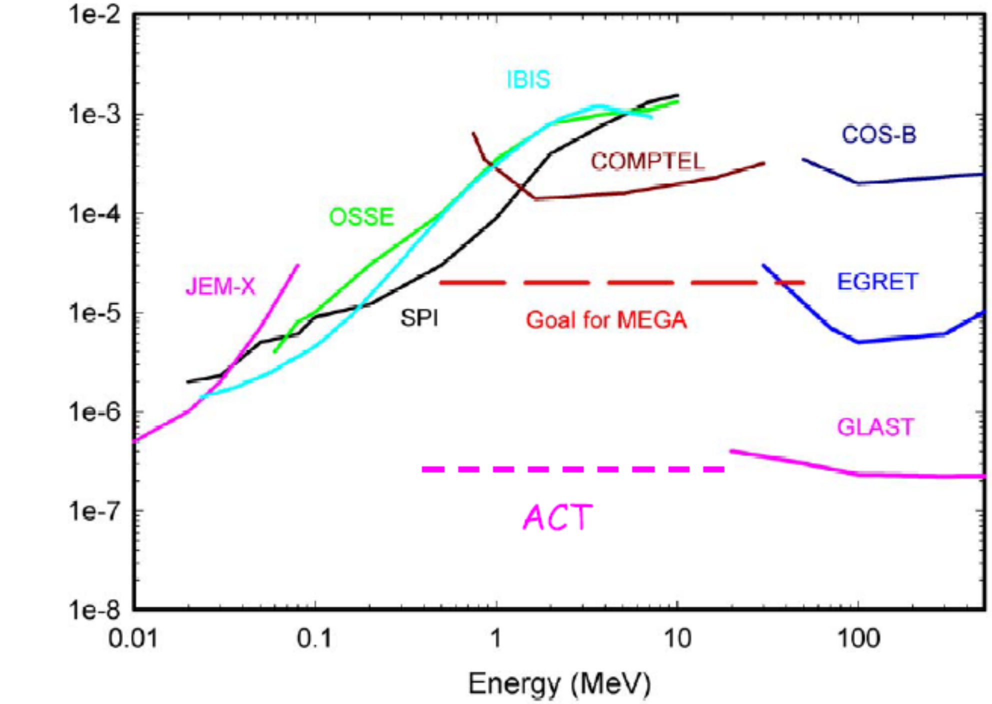


Compton Imaging

Sensitivities

Generations of γ-ray Missions:

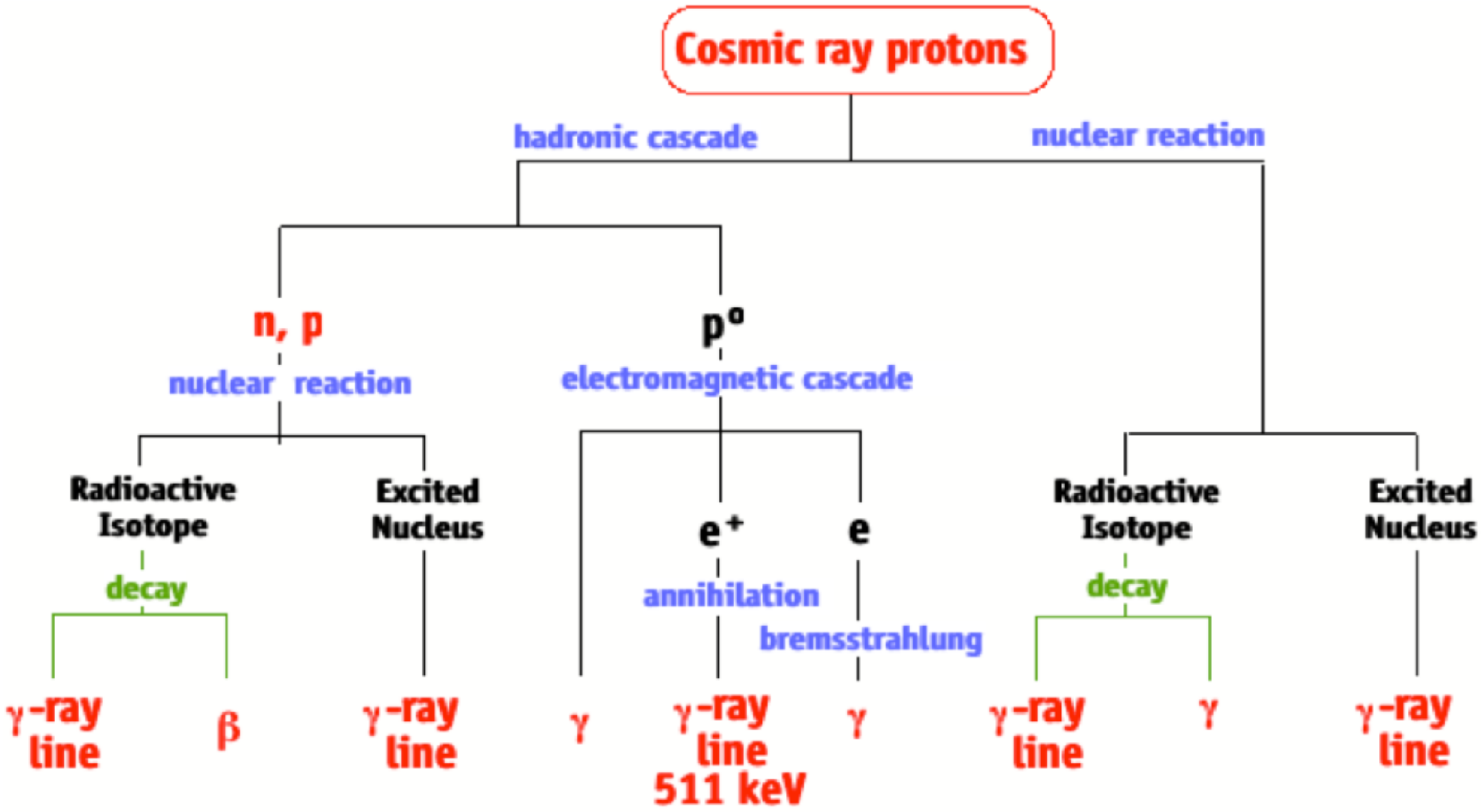
1. COMPTEL ⇔ COS-B
2. MEGA (~2006) ⇔ EGRET
3. Advanc[d] Compton ⇔ GLAST
   (ACT,~2012) (~2006)



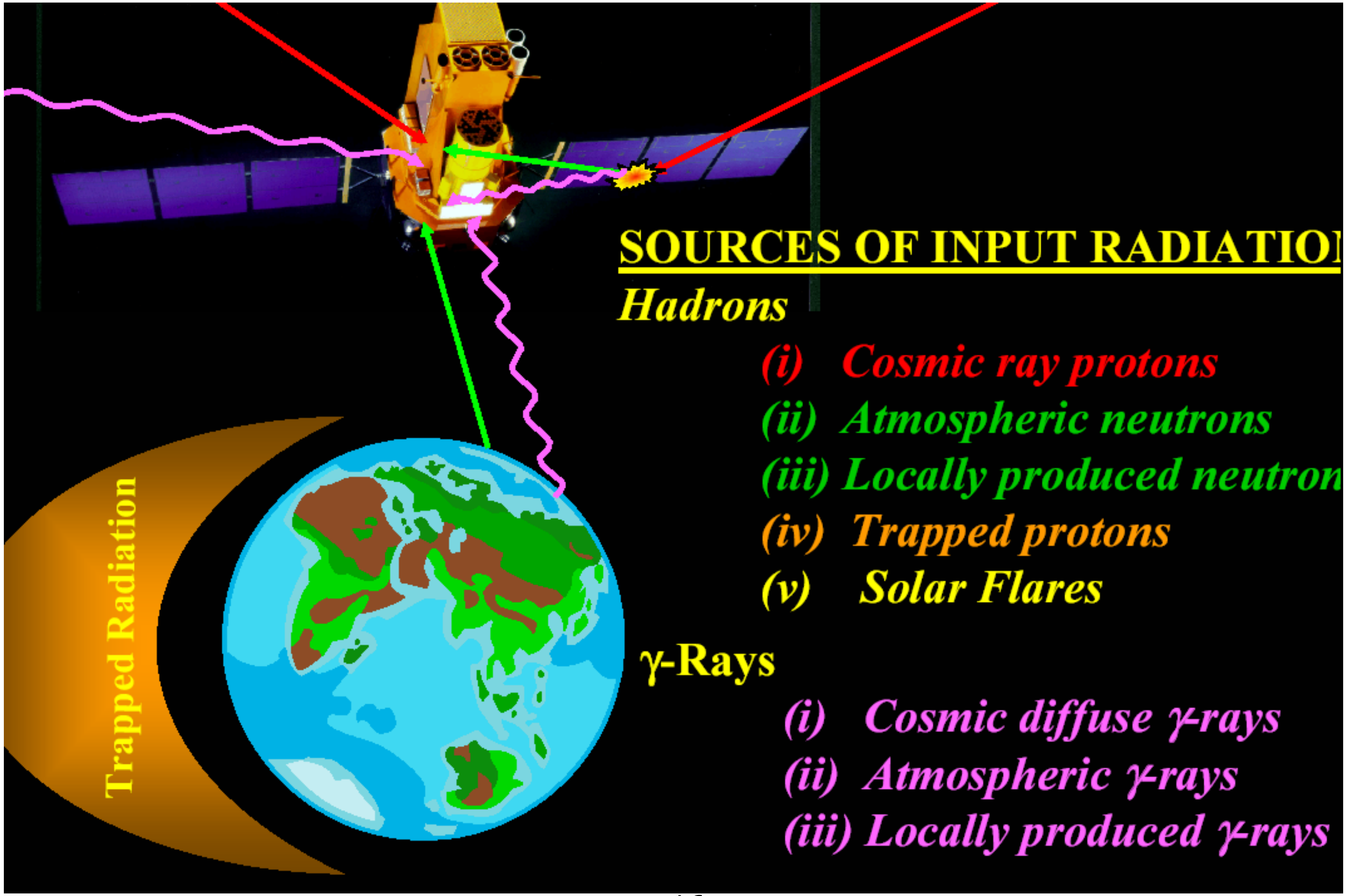
Il background- 1

- Il **fondo** di un telescopio X e gamma consiste dei segnali misurati dal rivelatore NON dovuti alla sorgente osservata
- Parametro fondamentale nel calcolo della sensibilità
- Difficilmente calcolabile con precisione PRIMA della operatività in orbita del telescopio:
  - Simulazioni MC
  - Valutazioni geometriche
  - Environment dello spacecraft
  - Orbita
  - Attività solare
  - Geometria dello strumento e del telescopio

Cosmic Ray interactions and γ-ray background

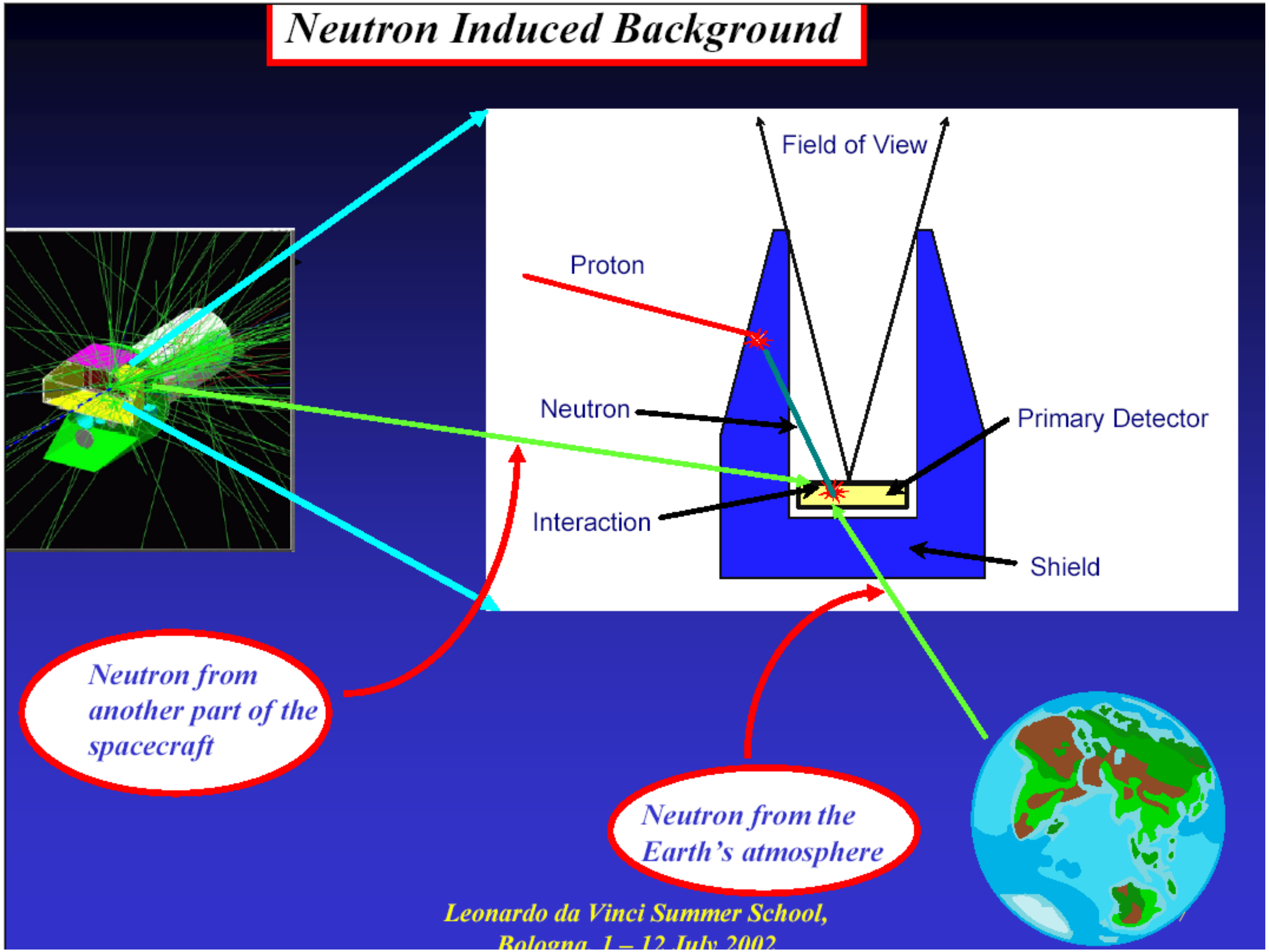


Background



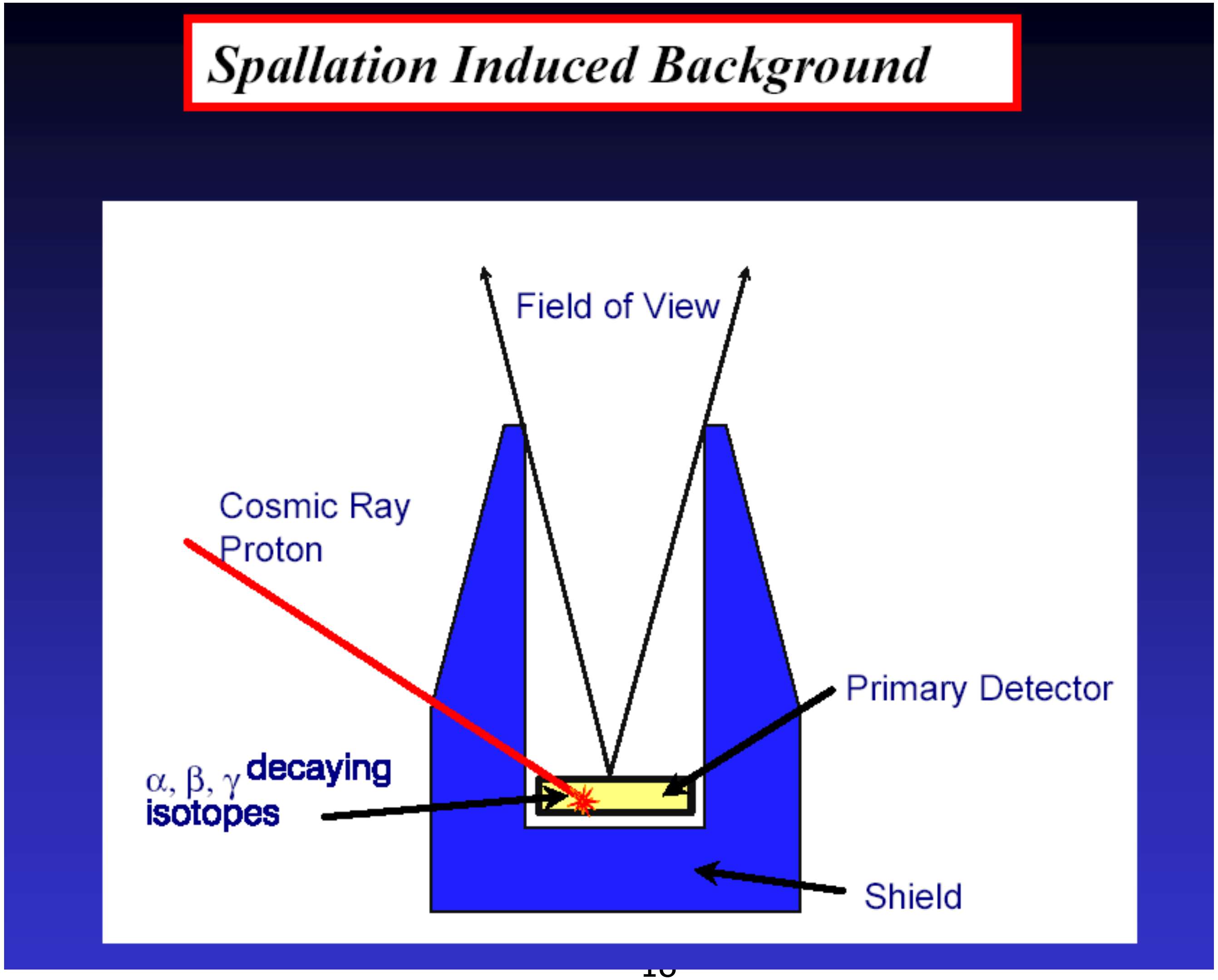
Trapped Radiation
SOURCES OF INPUT RADIATIO
Hadrons
(i) Cosmic ray protons
(ii) Atmospheric neutrons
(iii) Locally produced neutron
(iv) Trapped protons
(v) Solar Flares
γ-Rays
(i) Cosmic diffuse γ-rays
(ii) Atmospheric γ-rays
(iii) Locally produced γ-rays

Background

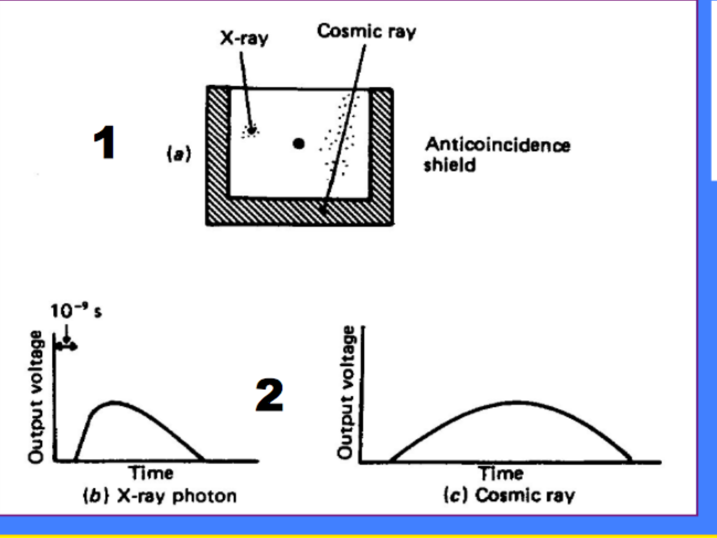


Neutron Induced Background
Field of View
Proton
Neutron
Primary Detector
Interaction
Shield
Neutron from another part of the spacecraft
Neutron from the Earth's atmosphere
Leonardo da Vinci Summer School,
Bologna, 1 – 12 July 2002

Background


Spallation Induced Background
Field of View
Cosmic Ray
Proton
Primary Detector
α, β, γ decaying
isotopes
Shield

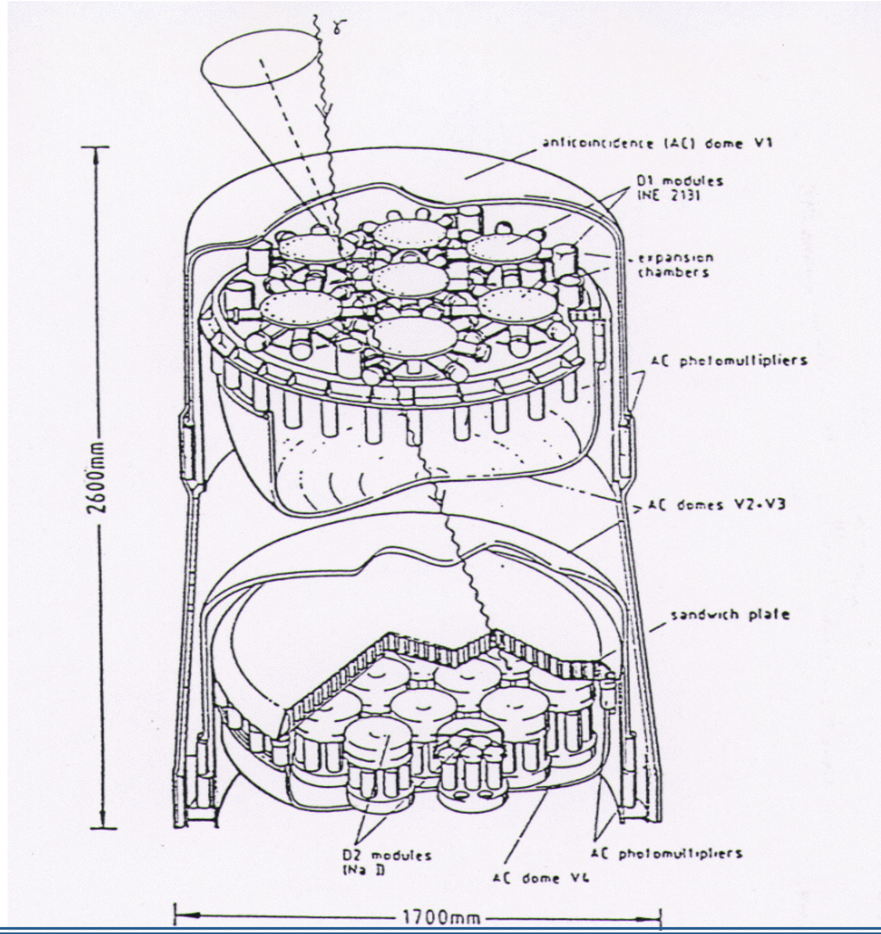
Tecniche di schermaggio



From M.S. Longair, "High Energy Astrophysics" (Vol. 1)

1. Anti-coincidence detectors: any event triggering both the counter and the scintillating material can be safely rejected as cosmic ray (CR)
2. Rise-time or pulse-shape discrimination: a fast particle (CR) or electron produces a tail of ionization and, consequently, results in a broad pulse, whereas an X-ray photon produces a sharper pulse.
3. Technique using a phoswich detector: the detector consists of alternate layers of material having different responses as scintillator detectors for photons and CR. While the first material is sensitive to photons, the following is not. A photon produces only a pulse, while a CR results in a double pulse in a certain time interval.

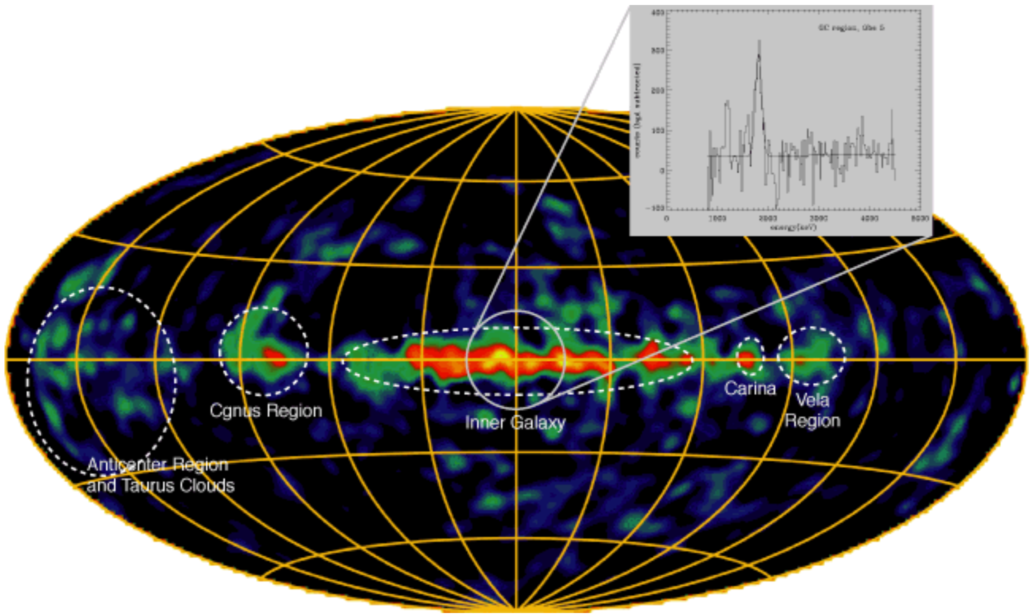
The Compton Gamma Ray Observatory



COMPTEL

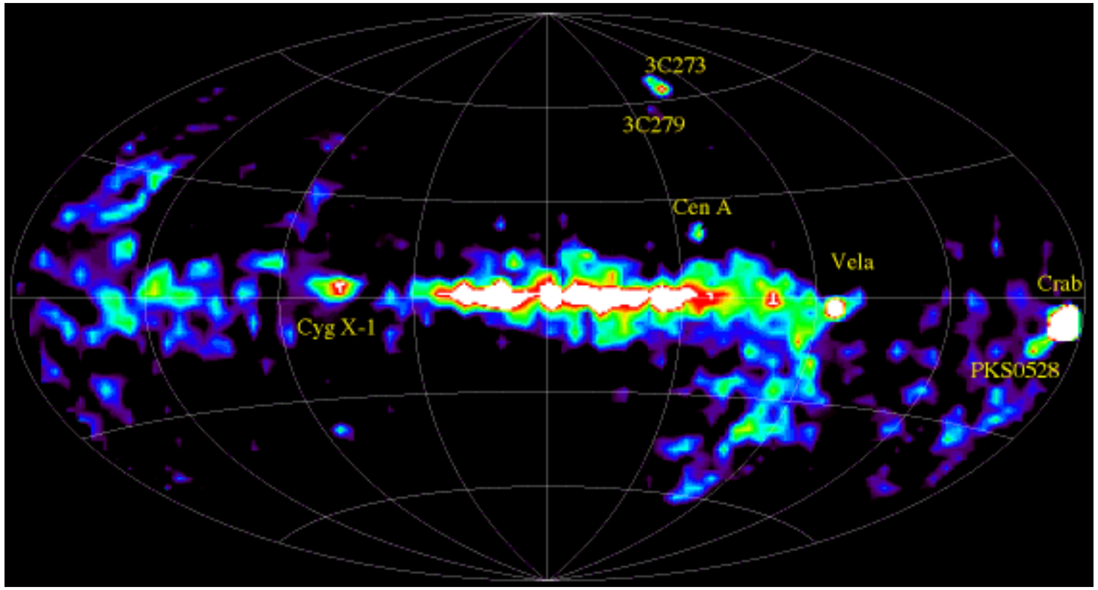
- 0.05-30 MeV
- Radioactive elements map, pulsars, a flaring black hole candidates, blazars, solar flares

The Compton Gamma Ray Observatory



This COMPTEL image is taken at energy of 1.809 MeV, which corresponds to the gamma-ray line produced by the radioactive decay of the ^{26}Al isotope. ^{26}Al has a decay time of a million years, and is produced along with other elements in trace quantities at cosmic sites of nucleosynthesis. Therefore, the sky image in these gamma-rays integrates nucleosynthesis events over millions of years and shows the spatial distribution of these events. From the above image we learn that ^{26}Al-producing events are predominantly Galactic sources. Several localized regions appear prominent (Inner Galaxy, Cygnus, Vela), suggesting that massive stars (via their Wolf-Rayet winds and core-collapse supernovae) are the true sources. The insert shows the spectral information captured by COMPTEL. The ^{26}Al line at 1.809 MeV is clearly seen above the large instrumental background. COMPTEL is the first imaging instrument with a spatial resolution of roughly degrees, and thus made possible this all-sky survey of ^{26}Al radioactivity. The Galaxy is transparent to gamma-rays, therefore this image has, for the first time, shown us the locations of nucleosynthesis and massive stars throughout the Galaxy.

The Compton Gamma Ray Observatory



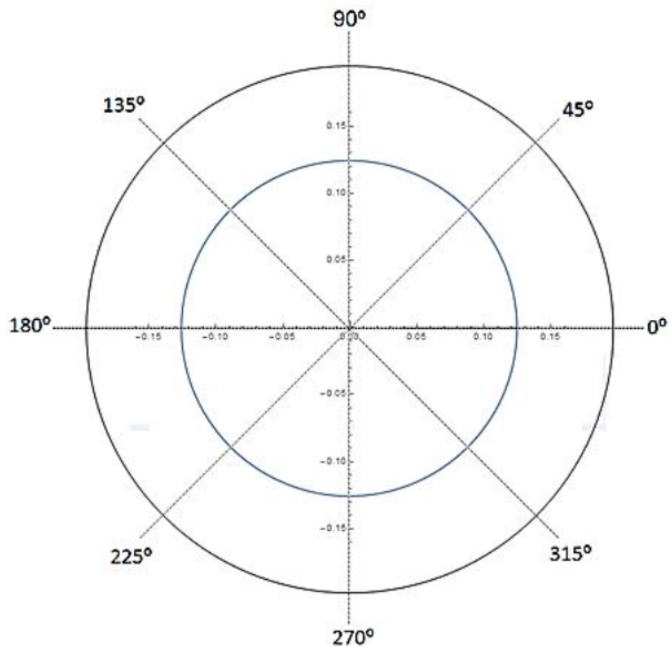
The COMPTEL 1 to 30 MeV all-sky map in continuum gamma radiation represents the results of the first-ever survey of the sky at these energies. The concentration of the emission along the Galactic plane is the most striking aspect of the map. The plane stands out clearly against the rest of the sky indicating that most of the measured gamma-ray fluxes come from regions or objects inside the Galaxy. The dominant Galactic continuum emission seems to come from interstellar space and is visible as diffuse Galactic radiation. Superimposed on the large-scale Galactic emission are point-like sources (like Crab, Vela, Cyg X-1), but many of the Galactic point sources remain unidentified at this time. A significant contribution of unresolved point sources to the apparently diffuse Galactic emission cannot be excluded. At medium and high Galactic latitudes, a few of the gamma-ray blazars, discovered by EGRET, are visible in the COMPTEL map as well. Examples are 3C 273, 3C 279, and PKS 0528+134. The radio galaxy Cen A is also visible at MeV gamma rays. Some of the extragalactic objects detected by COMPTEL are not visible in this map, because they flare up only occasionally: on average they are too weak to be visible in this time-averaged all-sky map.

Compton Polarimetry

Compton Polarimetry

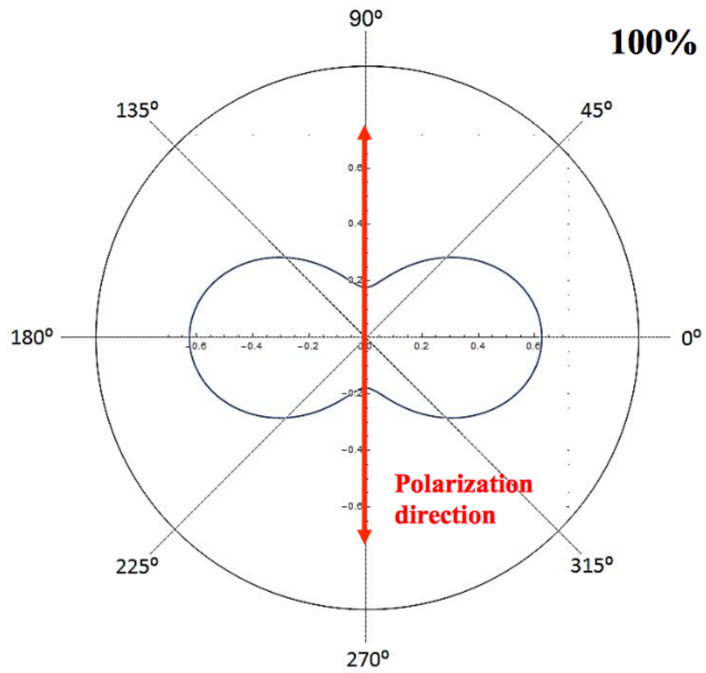
Unpolarized Beam

$$\frac{d\sigma_{KN,U}}{d\Omega} = \frac{1}{2} r_0^2 \varepsilon^2 [\varepsilon + \varepsilon^{-1} - \sin^2\theta]$$



Polarized Beam

$$\frac{d\sigma_{KN,P}}{d\Omega} = \frac{1}{2} r_0^2 \varepsilon^2 [\varepsilon + \varepsilon^{-1} - 2\sin^2\theta\cos^2\eta]$$



Compton Polarimetry

Compton Polarimetry

Polarization modulation factor

Klein-Nishina cross-section for linearly polarized photons:

$$\frac{d\sigma}{d\Omega} = \frac{r_0^2}{2}\left(\frac{E'}{E}\right)^2\left[\frac{E'}{E} + \frac{E}{E'} - 2\sin^2\theta\cos^2\varphi\right]$$

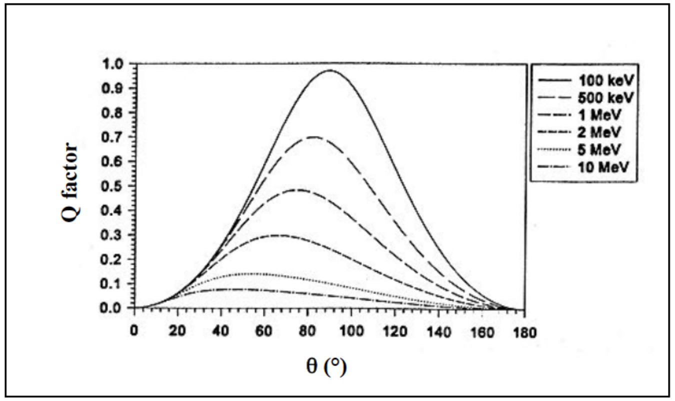
$$Q = \frac{N_\perp - N_\parallel}{N_\perp + N_\parallel} \qquad Q = \frac{d\sigma(\varphi = 90) - d\sigma(\varphi = 0)}{d\sigma(\varphi = 90) + d\sigma(\varphi = 0)}$$

$$Q = \frac{\sin^2\theta}{\frac{E'}{E} + \frac{E}{E'} - \sin^2\theta}$$

Minimum Detectable Polarization 3σ

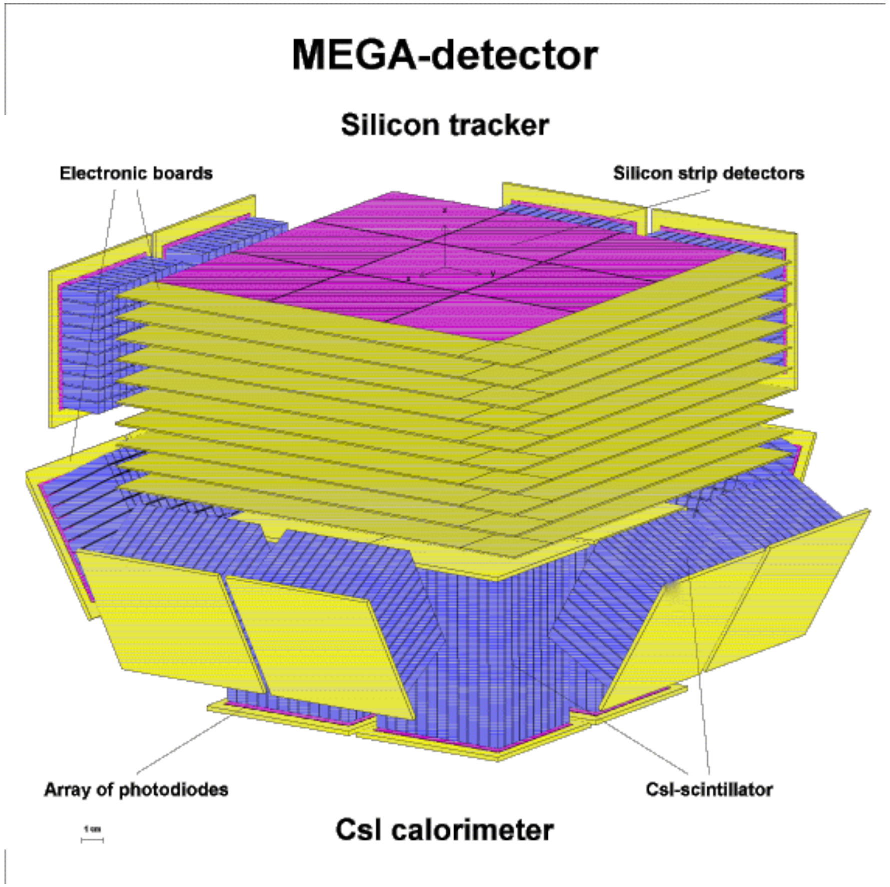
$$MDP = \frac{4.29}{A.\varepsilon.\phi_s.Q_{100}}\sqrt{\frac{A.\varepsilon.(\phi_s + \phi_B)}{T}}$$

φ_s – source flux
φ_B – background flux
Q_{100} – polarimetric modulation factor for 100% radiation
ε – detector double event efficiency
A – detector area
T – observation time



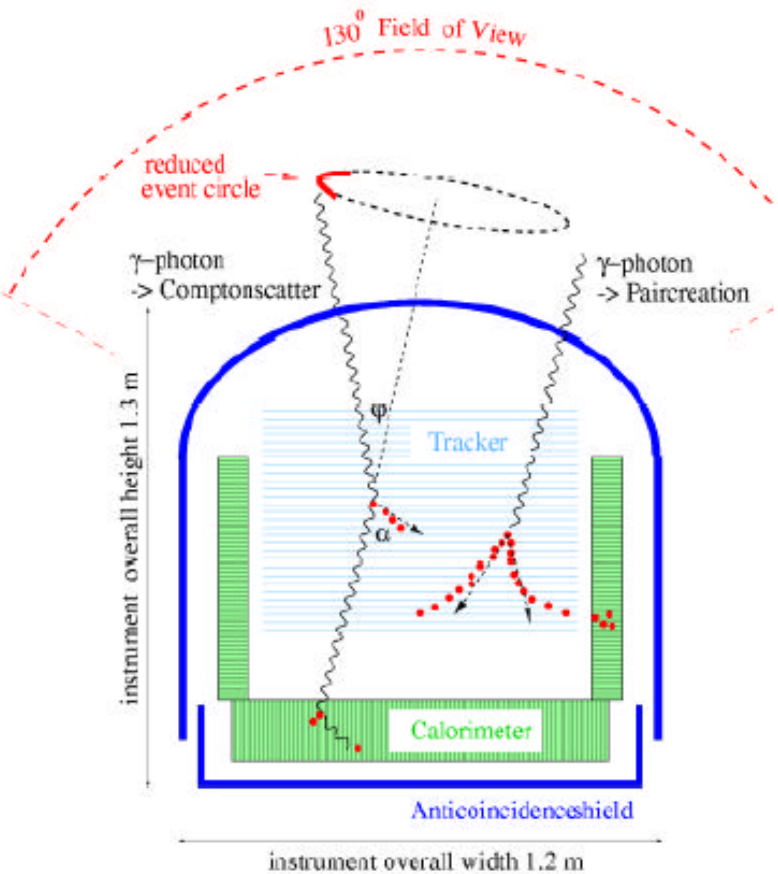
MEGA

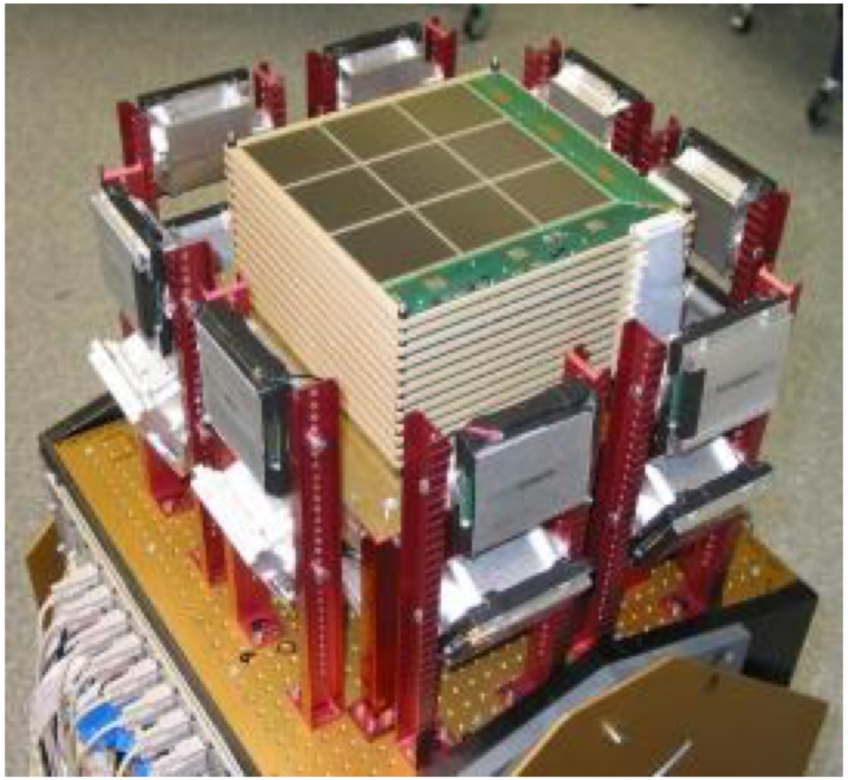
MEGA is planned as a telescope for
Medium **E**nergy **G**amma-Ray **A**stronomy
in the energy range between 400 keV and 50 MeV.
In this energy range MEGA exploits the two dominating interaction mechanisms for gamma rays:
Compton scattering and Pair creation.
MEGA has two detectors: A tracker, consisting of double-sided silicon strip detectors,
and a calorimeter, consisting of highly segmented CsI(Tl) bars. In the tracker the Compton and Pair interactions take place and the direction and energy of the participating electrons and positrons is measured.
In the calorimeters the Compton scattered gamma rays are stopped and thus their energy and direction is determined.



http://www.gamma.mpe-garching.mpg.de/MEGA/mega.html
Check

MEGA





http://www.gamma.mpe-garching.mpg.de/MEGA/mega.html

ACT project

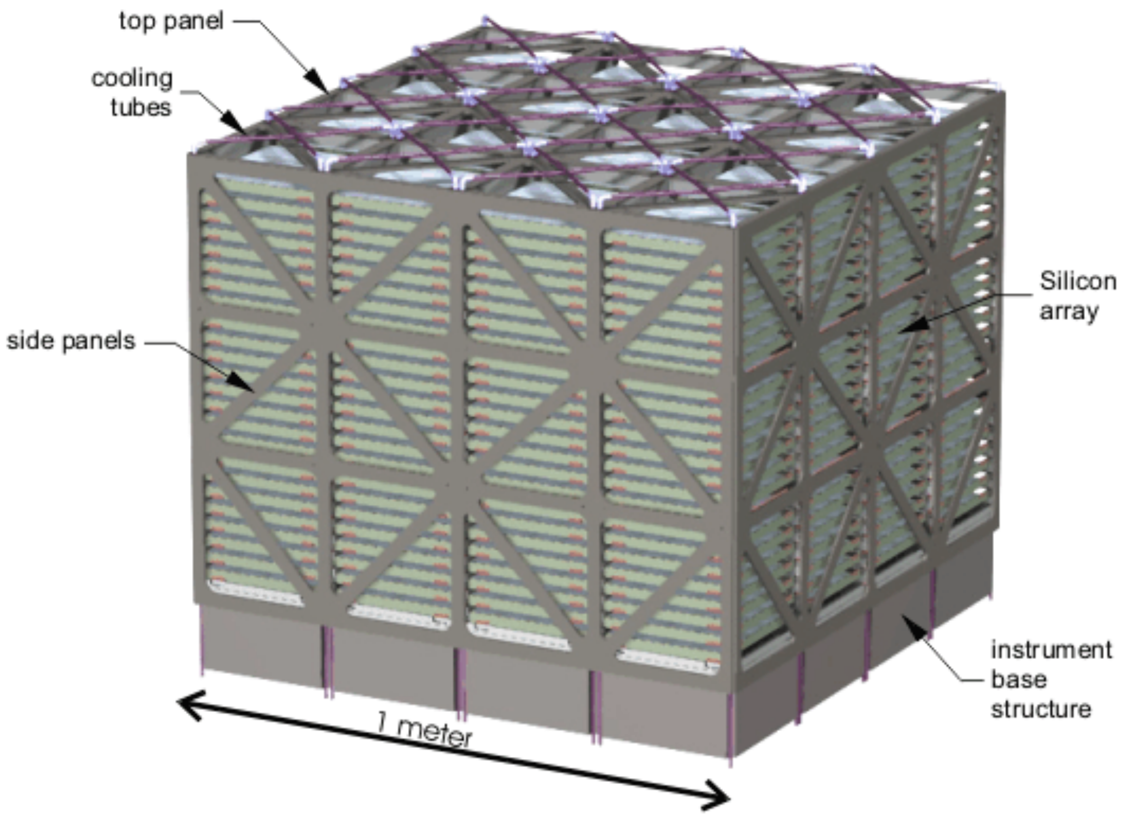
ACT Science Requirements

Energy Range	0.2 - 30 MeV Compton mode
Energy Resolution	< 10keV FWHM @ 1 MeV
Field of View	> 4 steradian
Angular Resolution	1 deg
Source Localization	5 arcmin for bright sources
Line Sensitivity in 1.0E6 sec	1.0E-7 ph/(cm2s) (narrow) 5.0E-7 ph/(cm2s) (broad)
Continuum Sensitivity	1.0E-5 ph/(cm2sMeV) @ 0.5 MeV
Polarization Sensitivity	1%, 2.0E-3 ph/(cm2sMeV) 10%, 2.0E-4 ph/(cm2sMeV)

These science requirements are expected to translate to an instrument with effective area on the order of 1000-3000 cm2, a position resolution in the detectors of 1mm3, energy resolution of 1% (0.5-2.0 MeV) or better, and possibly recoil electron tracking capabilities for electron energies < 0.5 MeV. The concept study will look at a variety of possible detector technologies for implementing such a Compton telescope. Candidate detectors include, but are not limited to, CZT strip detectors, Si strip detectors, Ge strip detectors, liquid Xe, and gaseous Xe (or Ar) microwell detectors.

http://boggs.ssl.berkeley.edu/act/index.html

ACT project



The baseline instrument (pictured above) is built from thick Silicon(Li) detectors, and measures roughly 1 m x 1 m in frontal area. The individual detectors are ~7 mm thick, and measure 10 x 10 cm in area using technology in crystal growth and lithium drifted silicon, or Si(Li). Detectors are assembled in tower structures, each containing a small 4x4 array of detectors and stacked 24 layers deep. Readout electronics for the detectors are distributed along the four side walls of each tower.

New MeV concepts

National Aeronautics and Space Administration
Goddard Space Flight Center

Astrophysics Science Division • Sciences and Exploration

Home | Registration | Directions/Hotel | Program | Participants

Future Space-based Gamma-ray Observatories

March 24-25, 2016
Goddard Space Flight Center
Building 34, Rooms W150 & W120A/B

The medium energy γ-ray band accessible from space contains a wealth of scientific promise from the study of γ-ray bursts and active galaxies, dark matter annihilation and decay, particle acceleration and cosmic ray production in Galactic and extragalactic sources, cosmic ray interactions in the Milky Way, rotation powered pulsars and magnetars, acceleration processes in the Sun and more. Our appetite for this science has been whetted by many recent exciting results from Fermi (at higher energies) and NuSTAR (at lower energies) and is based on studies of the MeV sky by CGRO/COMPTEL and INTEGRAL. Progress in this exciting field has been limited largely by the challenges of building sufficiently capable instruments to detect these γ rays as they interact by Compton scattering and pair production. The detailed scientific questions within these areas are addressed by a range of different performance optimizations such as flux and polarization sensitivity, angular and energy resolution, photon counting statistics, background rejection, and field of view. Different technical and hardware approaches result in different optimization of these performance parameters.

We will meet March 24-25 at Goddard Space Flight Center in Greenbelt, MD to discuss the Science Drivers for new space-based gamma-ray missions, as well as technologies and instruments concepts for new gamma-ray experiments. This workshop is a continuation of the discussions from the previous Future Gamma-ray workshop.

http://asd.gsfc.nasa.gov/conferences/fgo2/

Compton Astrophysics

Astrophysics of low/medium Energy γ - rays

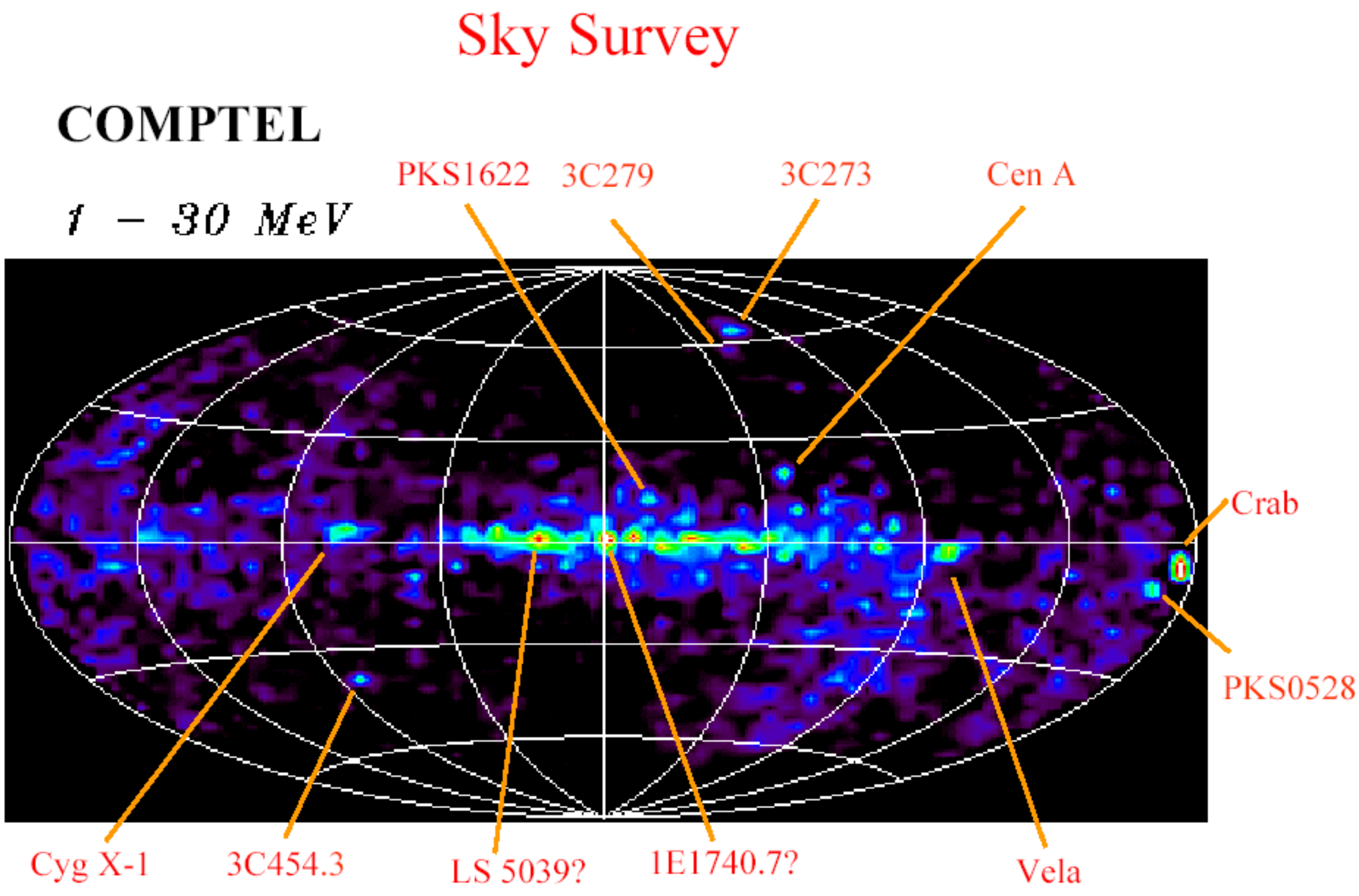
The energy range from a few 100 keV to several 10 MeV is scaled by the electron rest mass $m_o c^2 = 0.511$ MeV

- continuous γ-ray spectra from sites of high-energy particle acceleration are mostly produced in e-m interactions:
  Bremsstrahlung, inverse Compton scattering, Synchrotron
  Many of these sources have their maximum Luminosity at MeV energies

and by the nuclear energy levels

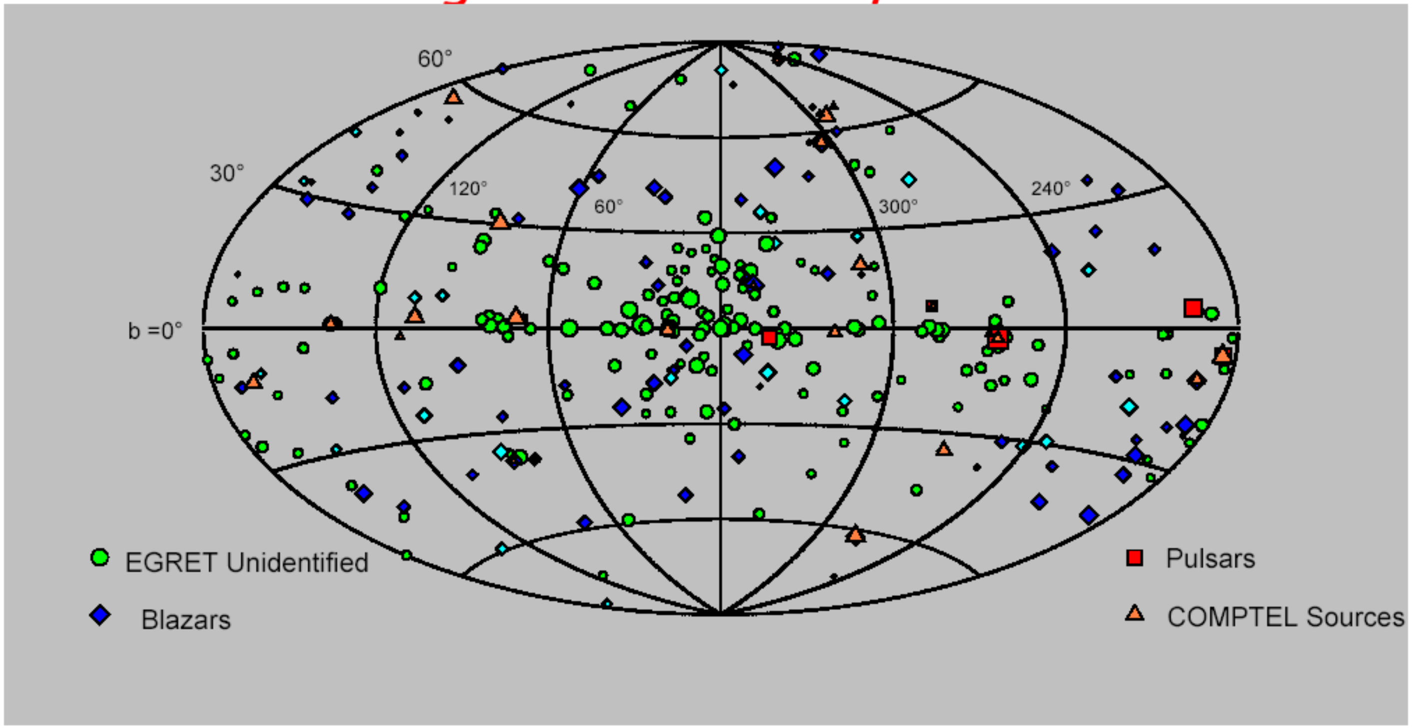
- Signatures of cosmic radioactivity through γ-ray lines: the direct observation of nucleosynthesis, i.e. the creation of the elements,

Compton Astrophysics



Compton Astrophysics

Catalog of Gamma-Ray-Sources



3. EGRET Catalog: (3EG) Hartman et al, 1999 ApJS, 123, 79	271 Sources 80-90 AGN 6-8 PSR ~170 Unid..	1. COMPTEL Katalog: Schönfelder et al., 2000 A&AS, 143, 145	32 constant Srces. 39 transient 11 AGN 3 PSR 4 EGRET Unid.

Compton Astrophysics

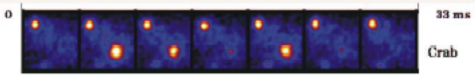
Cosmic Accelerators:

- Accretion on compact objects (relativistic jets):

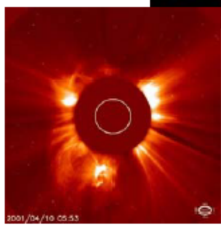
  AGN, μBlazars, Binaries

- Explosions and Shocks: GRBs, SNRs, mass. stellar winds, ISM
  Novae, Supernovae

- Rotation of NS: pulsars



- electro-magnetic dissipation: solar flares

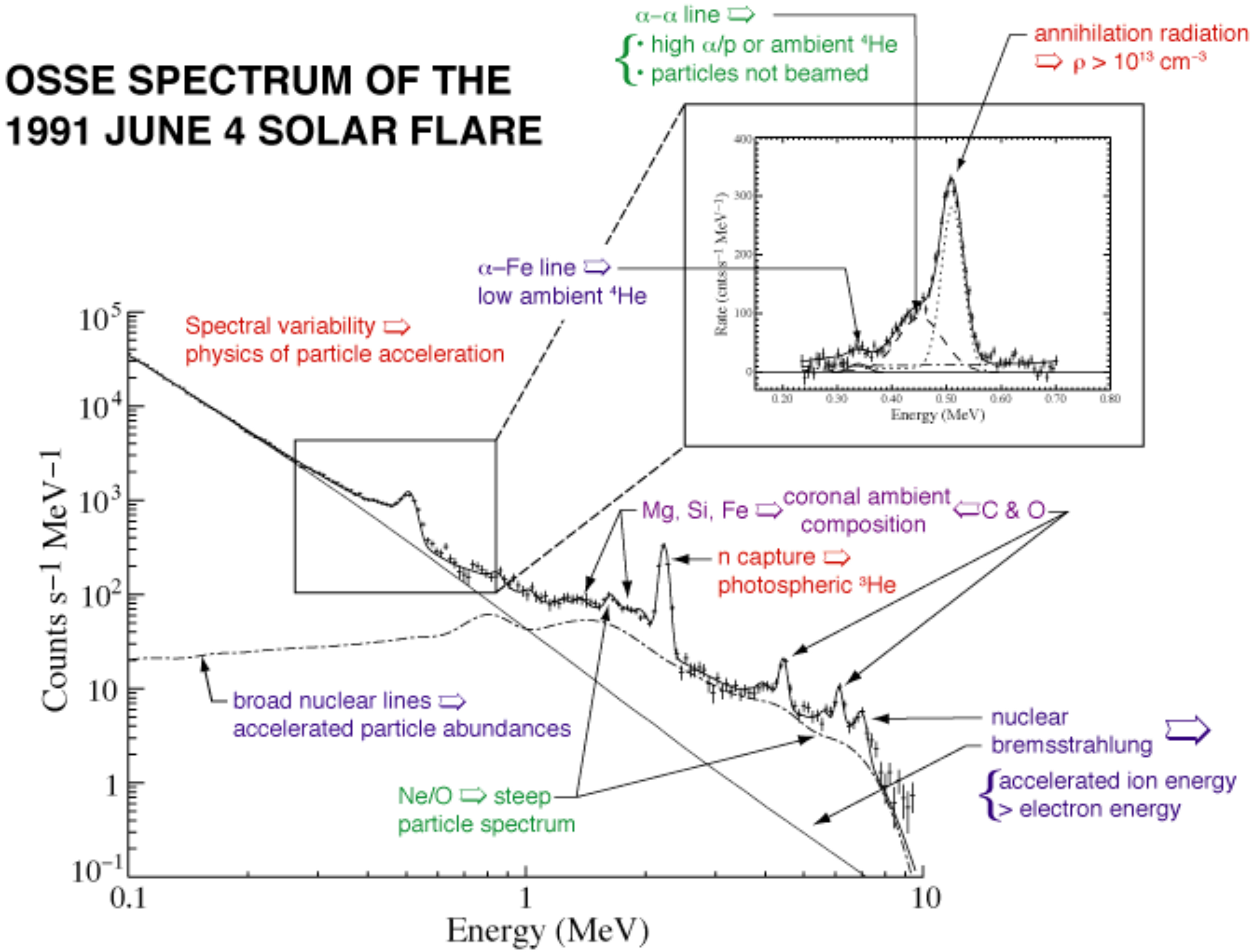


Compton Astrophysics

Origin and characteristics of astrophysically important γ-ray lines

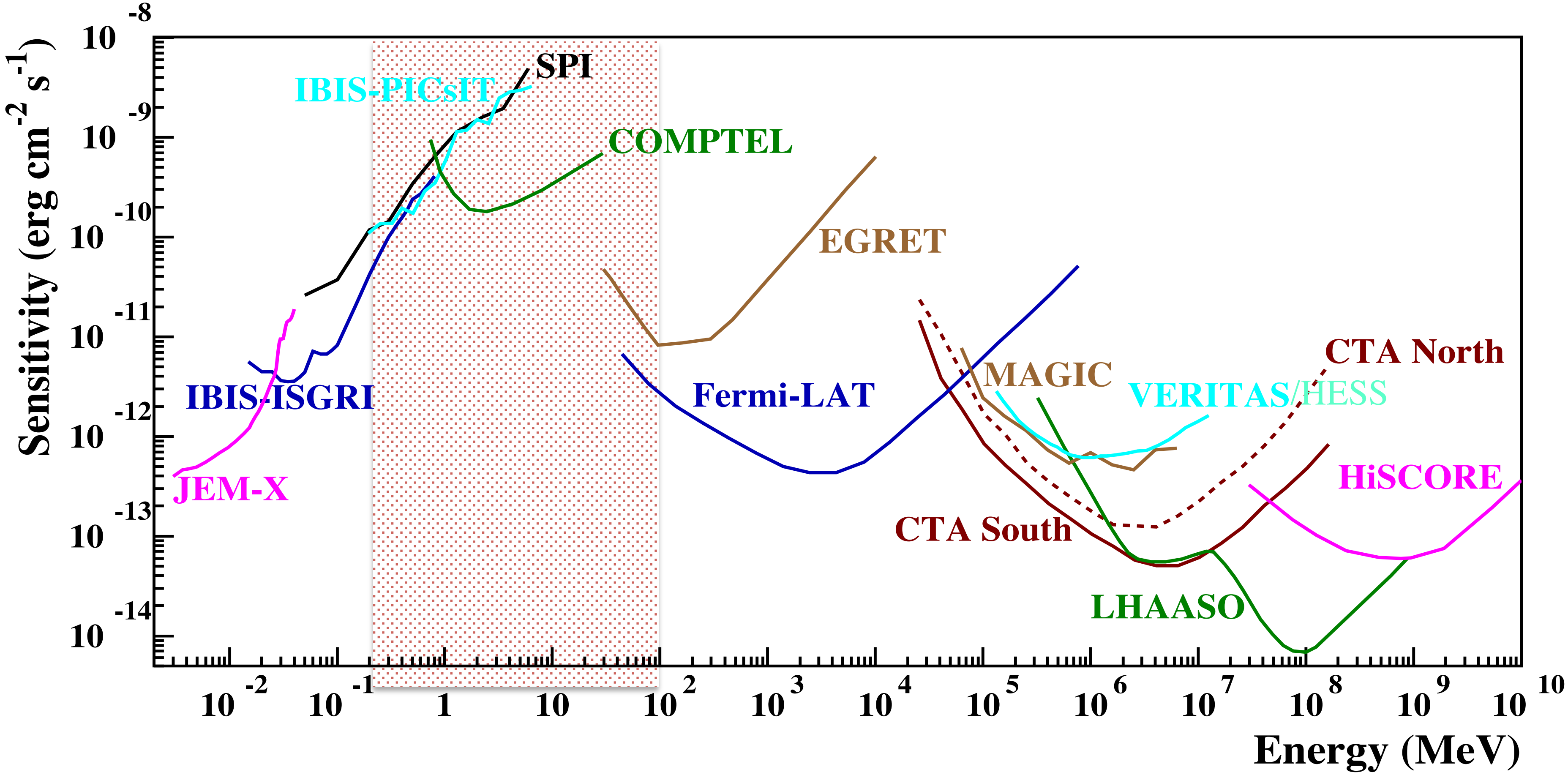
Isotope	Energy	$t_{1/2}$	origin
^{57}Ni	1378 keV	2.14 d	SN
^{56}Ni	812 keV	8.5 d	SN
^{56}Co	847 keV 1238 keV	111.5d	SN
^{22}Na	1275 keV	3.8 yr	Novae
^{44}Ti	1157 keV	79 yr	SNR
^{26}Al	1809 keV	1Myr	AGB and massive stars (O & WR), Novae, core-collapse SNe
$^{12}C^*$ $^{16}O^*$	4.4 MeV 6.1 MeV	prompt	cosmic ray induced ISM lines, flares
e^+, e^-	511 keV		β^+ activity, jet sources, PSR, Novae, flares etc.
$n+p \rightarrow d$	2.21 MeV		flares, flare stars?

Solar Flares lines



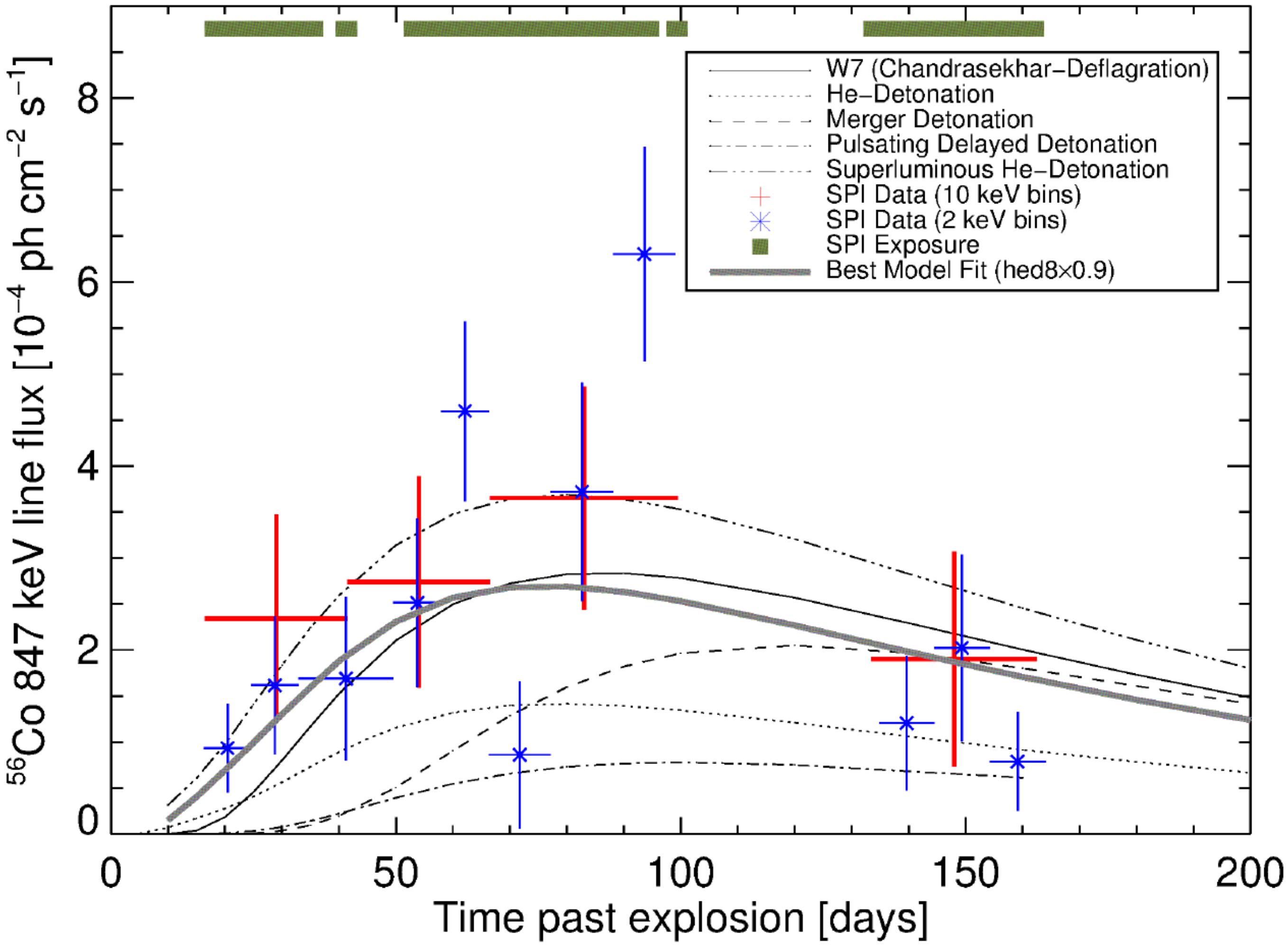

e-ASTROGAM
at the heart of the extreme Universe
http://eastrogam.iaps.inaf.it
An observatory for gamma rays
In the MeV/GeV domain
Lead proposer: A. De Angelis
Co-lead proposer: V. Tatischeff

The MeV/GeV domain



- Worst covered part of the electromagnetic spectrum (only a few tens of steady sources detected so far between 0.2 and 30 MeV)
- Many objects have their peak emissivity in this range (GRBs, blazars, pulsars...)
- Binding energies of atomic nuclei fall in this range, which therefore is as important for HE astronomy as optical astronomy is for phenomena related to atomic physics

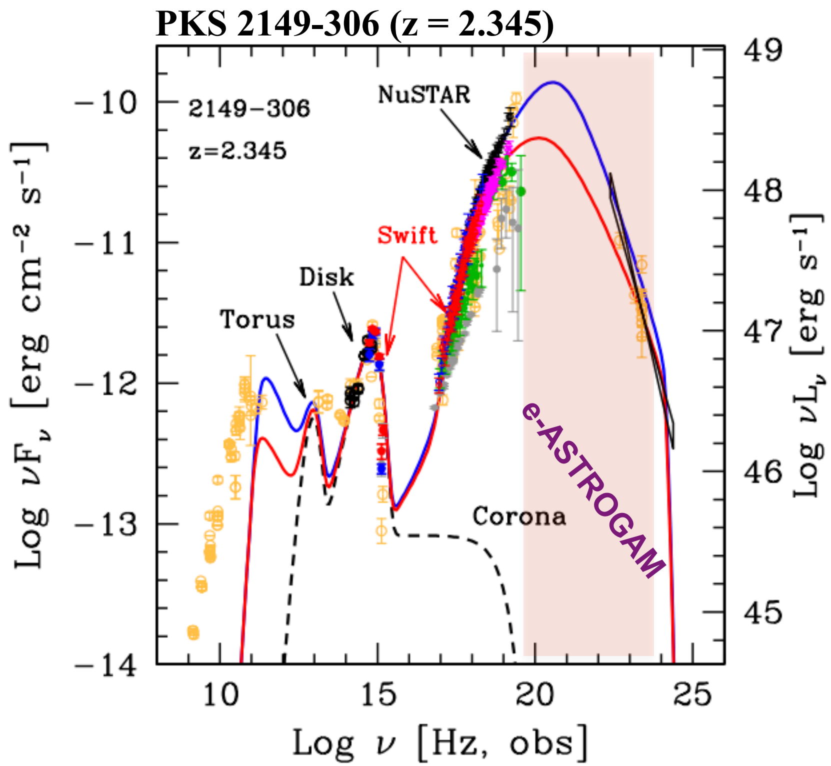
SPI gamma-ray observations of SN2014 J

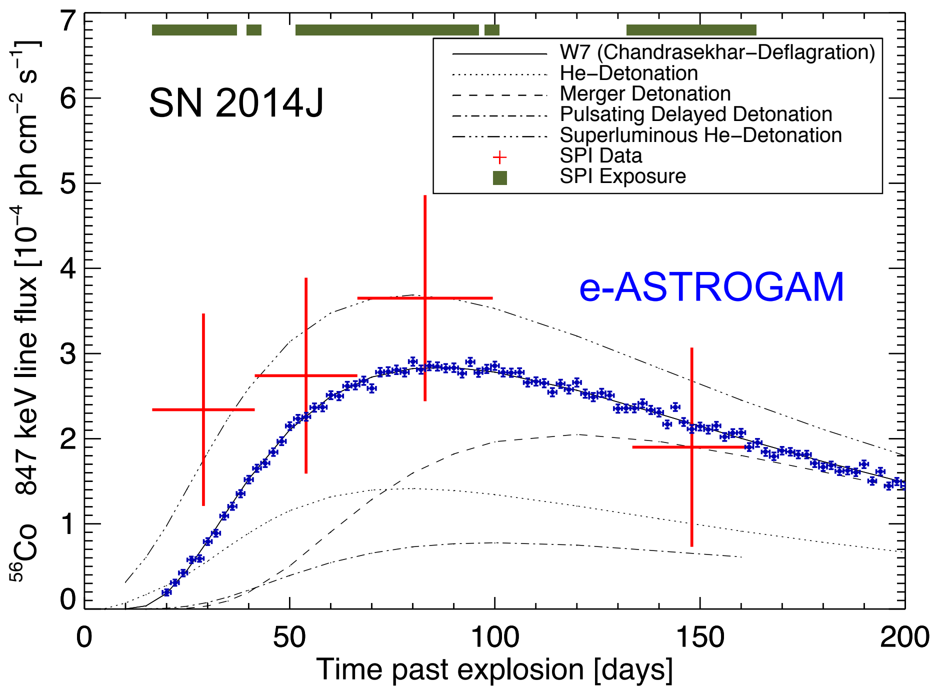


Core science motivations for a γ-ray mission in the MeV/GeV

1. **Processes at the heart of the extreme Universe (AGNs, GRBs, microquasars): prospects for the Astronomy of the 2030s**

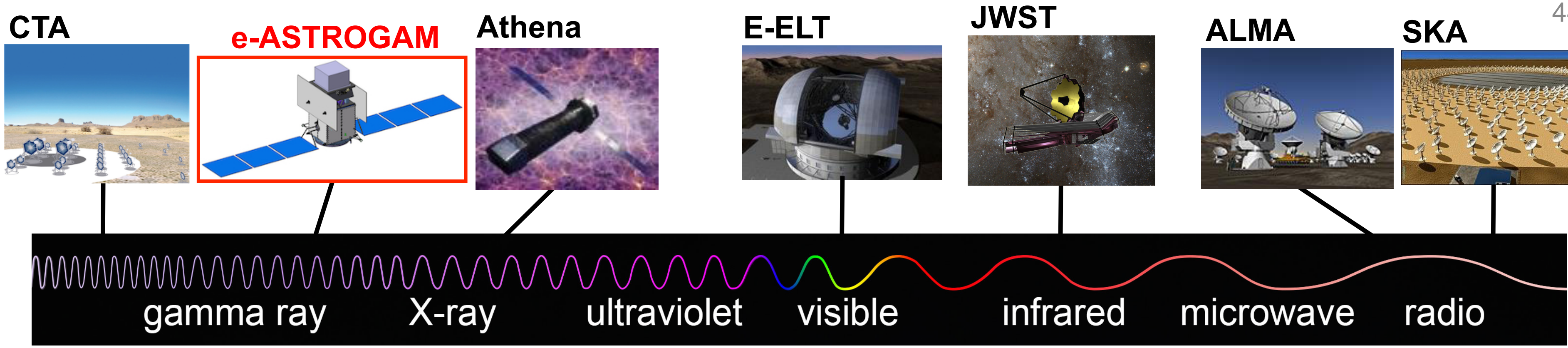
2. **The origin and impact of high-energy particles on galaxy evolution, from cosmic rays to antimatter**





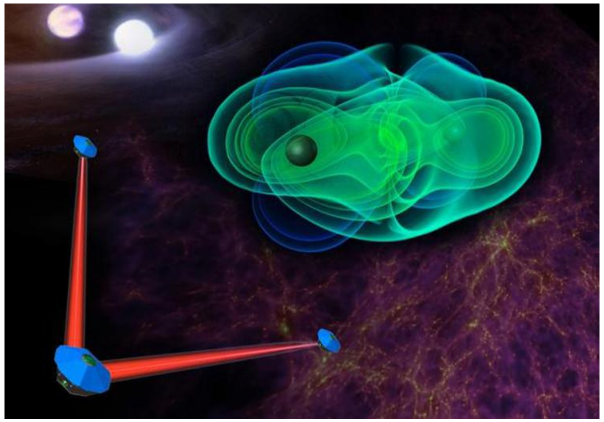
3. **Nucleosynthesis and the chemical enrichment of our Galaxy**

e-ASTROGAM: γ-ray astronomy in context

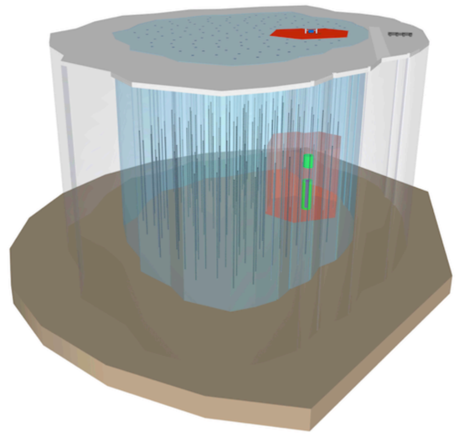


New Astronomies:
gravitational waves
neutrinos

eLISA – Gravitational waves



Km3Net/IceCube-Gen2 - ν



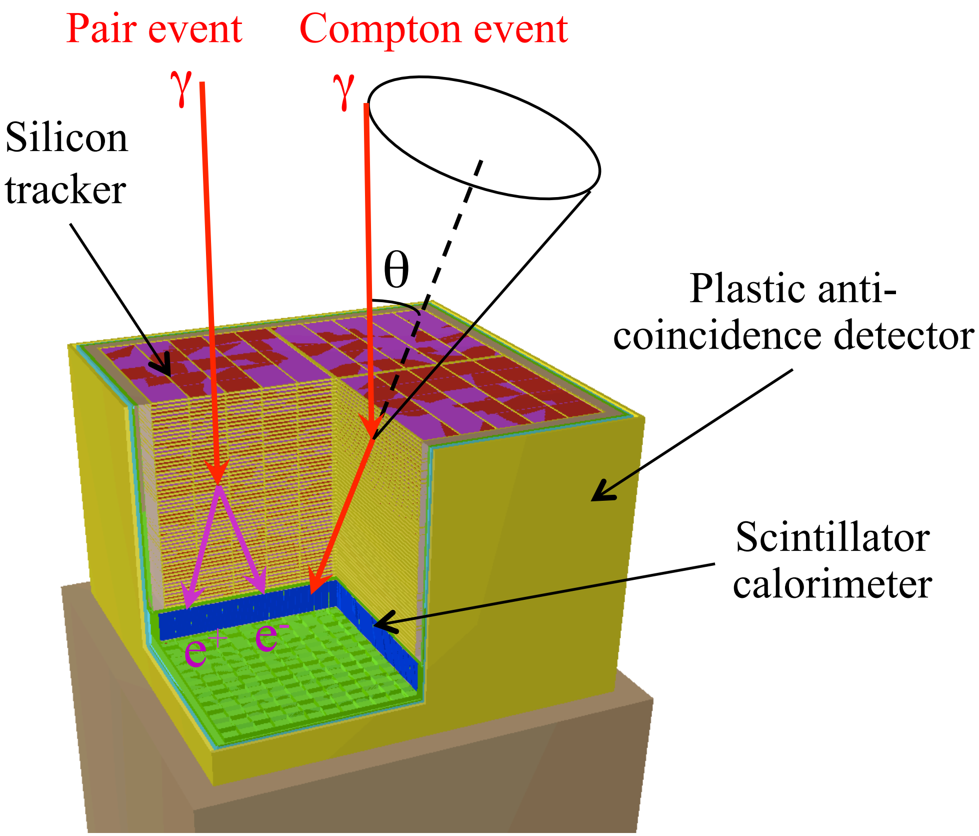
- e-ASTROGAM will be a sensitive, wide-field γ-ray space observatory operating at the same time as facilities like SKA and CTA, as well as eLISA and neutrino detectors, to get a coherent picture of the transient sky and the sources of gravitational waves and high-energy neutrinos

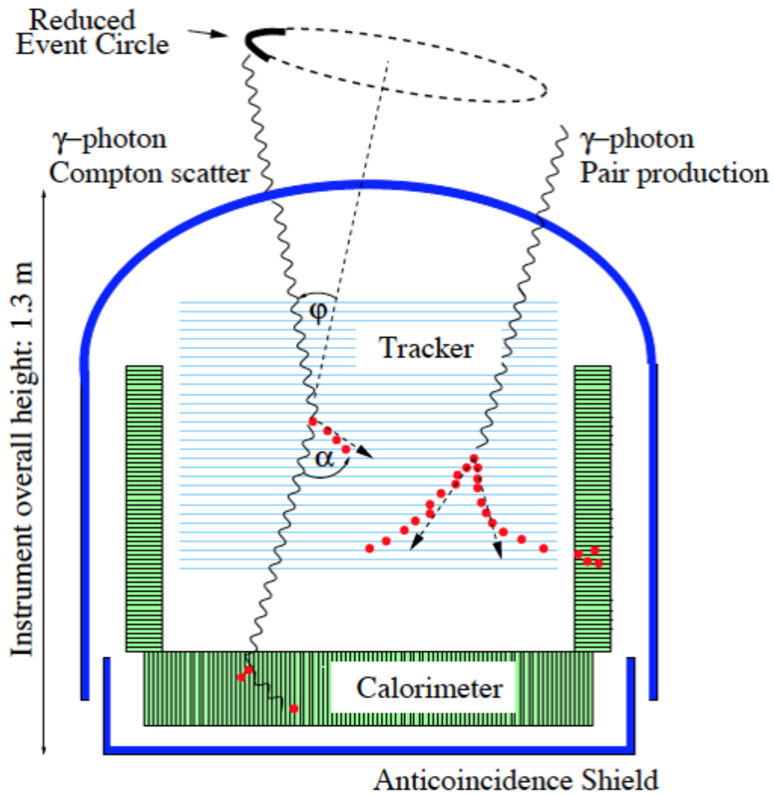
e-ASTROGAM scientific requirements

1. Achieve a sensitivity better than that of INTEGRAL/CGRO/COMPTEL by a factor of 20 - 50 – 100 in the range 0.2 – 30 MeV
2. Fully exploit gamma-ray polarization for both transient and steady sources
3. Improve significantly the angular resolution (to reach, e.g., ~ 10’ at 1 GeV)
4. Achieve a very large field of view (~ 2.5 sr) ⇒ efficient monitoring of the γ-ray sky
5. Enable sub-milisecond trigger and alert capability for transients

The Instrument

How to measure gamma rays in the MeV-GeV?



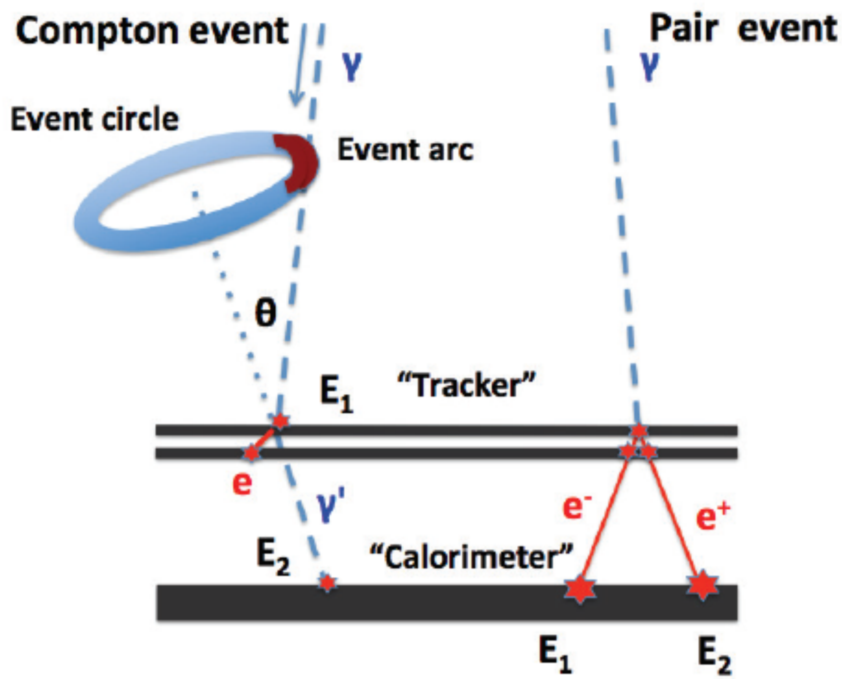


- **Tracker** – Double sided Si strip detectors (DSSDs) for excellent spectral resolution and fine 3-D position resolution (1m^2, 500 μm thick, 0.3 Xo in total)
- **Calorimeter** – High-Z material for an efficient absorption of the scattered photon ⇒ CsI(Tl) scintillation crystals readout by Si drift detectors or photomultipliers for best energy resolution. 8 cm (4.3 Xo)
- **Anticoincidence detector** to veto charged-particle induced background ⇒ plastic scintillators readout by Si photomultipliers

Detection of (sub)MeV-GeV gamma-rays

- Compton regime
  - Require excellent 3D-point resolution and energy resolution
  - Event reconstruction with 2 points and 2 energy measurements!
- Pair regime
  - Tracking resolution is most important
  - Dominated by Multiple Scattering effect
  - Main concern is detector layer thickness
- Difficult to be truly optimal in both regimes across the gap with one detector

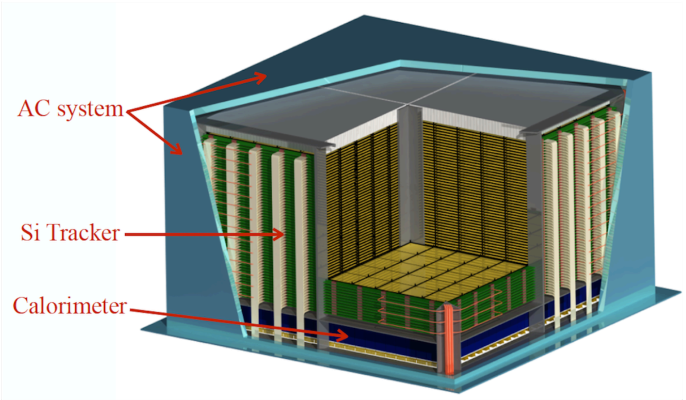
$$\cos\theta = 1 + \frac{m_e}{E_\gamma} - \frac{m_e}{E_\gamma - E_e} = 1 + \frac{m_e}{E_1 + E_2} - \frac{m_e}{E_2}$$



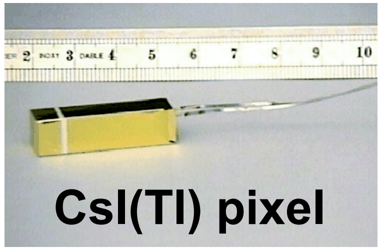
$$\sigma_\theta = \frac{13.6}{\beta p} z \sqrt{\frac{x}{x_0}} \left[1 + 0.038 \ln\left(\frac{x}{x_0}\right)\right]$$

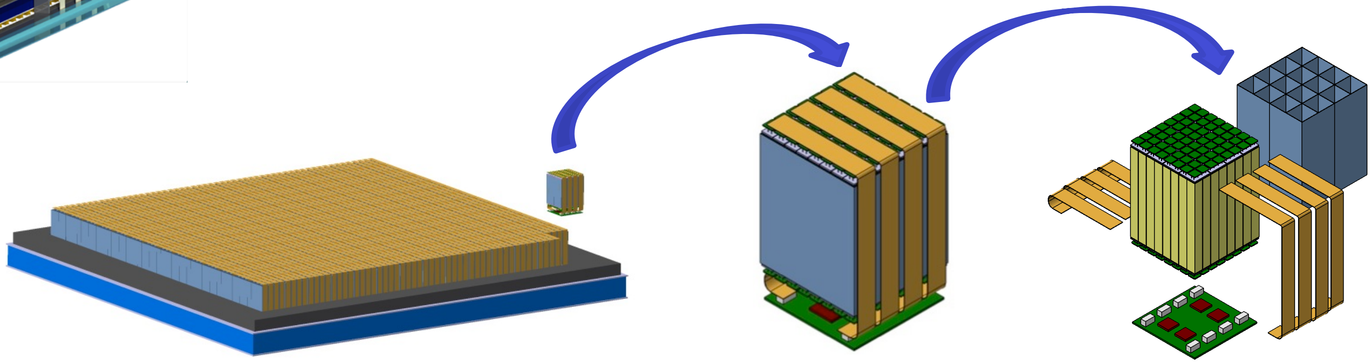
p in MeV

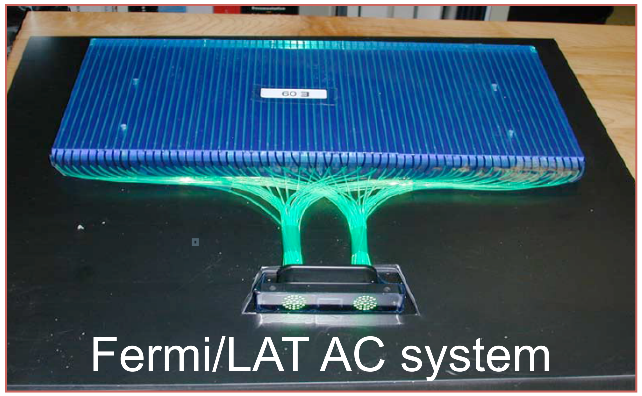
e-ASTROGAM: the payload



- **Tracker**: 56 layers of 4 times 5×5 DSSDs (5 600 in total) of 500 μm thickness and 240 μm pitch
- DSSDs bonded strip to strip to form 5×5 ladders
- Light and stiff mechanical structure
- Ultra low-noise front end electronics



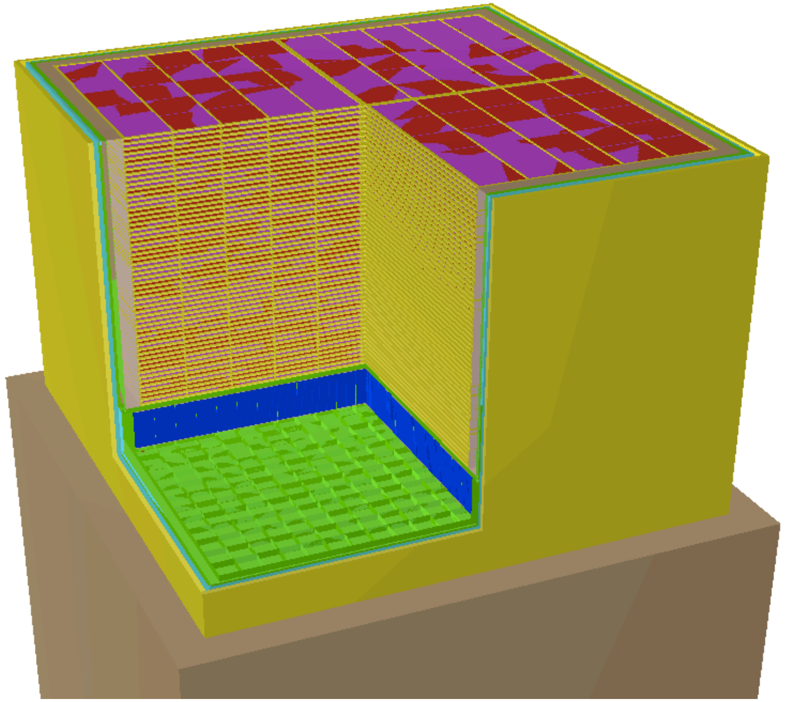


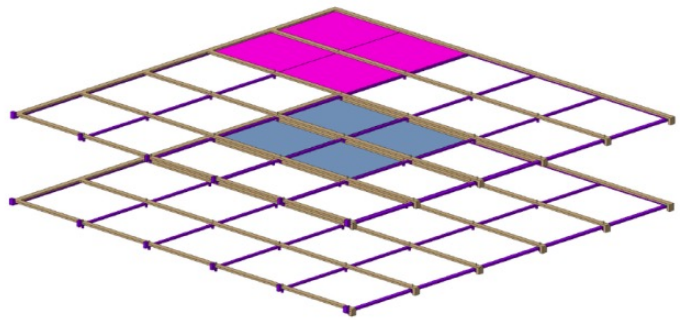


- **Calorimeter**: 33 856 CsI(Tl) bars coupled at both ends to low-noise Silicon Drift Detectors
- **ACD**: segmented plastic scintillators coupled to SiPM by optical fibers
- **Heritage**: AGILE, Fermi/LAT, AMS-02, INTEGRAL, LHC/ ALICE…

e-ASTROGAM: silicon tracker

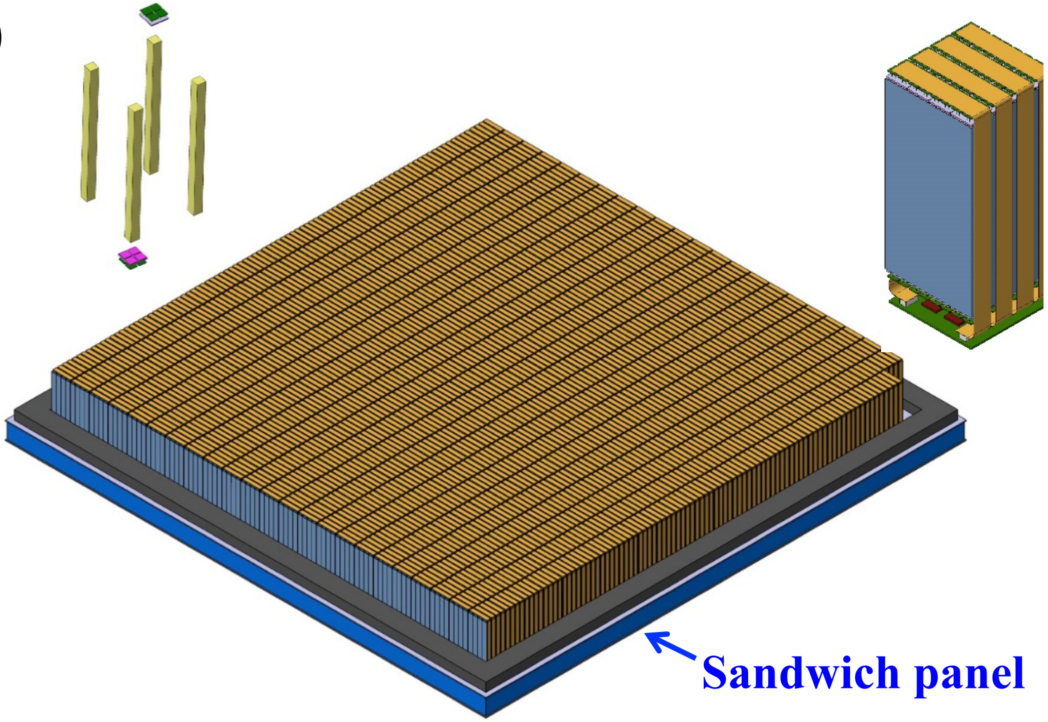
- 4 towers, 56 layers of 5×5 double sided Si strip detectors each (5600 DSSDs)
  - Each DSSD has a total area of 9.5×9.5 cm^2, a thickness of 500 μm and pitch of 240 μm (384 strips per side)
  - The DSSDs are wire bonded strip to strip to form 5×5 2-D ladders
- Spacing of the Si layers: 10 mm
  - Each layer held by a very light mechanical
    - two frames sandwiching the Si detectors
- DSSD strips connected to ASICs through a pitch adapter
  - 26 880 IDeF-X ASICs (32 channels each)
    - 860160 electronic channels
    - 12 IDeF-X ASICs each side
  - The analog output signals of IDeF-X will be converted to digital signals with the OWB-1 ADC
    - 5 OWB-1 ADCs each side
- Power budget = 688 W (800 mW/channel)

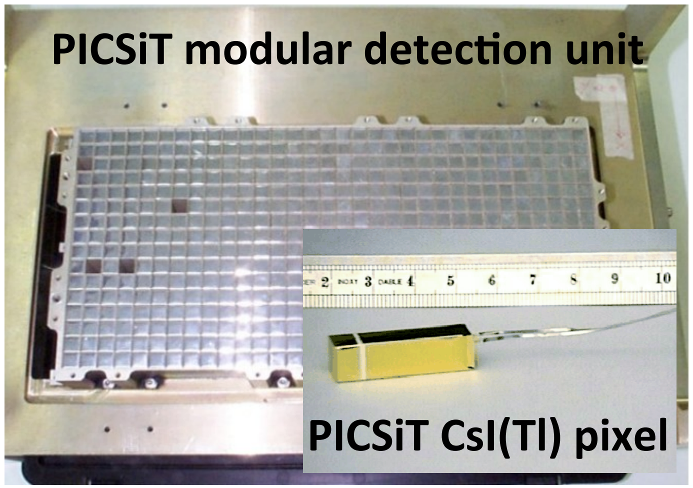


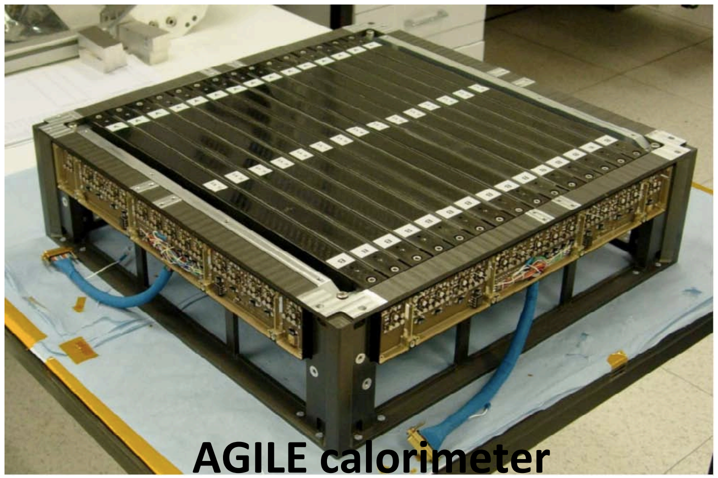


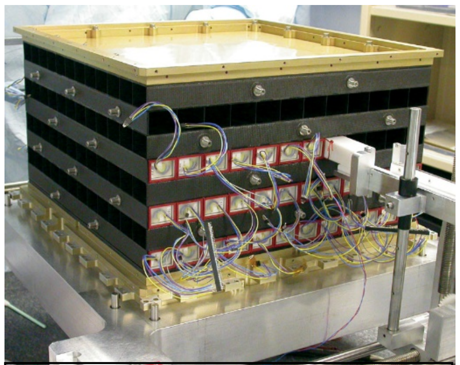
e-ASTROGAM: calorimeter

- Pixelated detector made of 33 856 CsI(Tl) scintillator bars of 8 cm length and 5×5 mm^2 cross section, glued at both ends to low-noise Silicon Drift Detectors (SDDs)
- Calorimeter formed by the assembly of 529 (23×23) modules
- **Heritage**: INTEGRAL/PICsIT, AGILE, Fermi/LAT, LHC/ALICE
  - FEE ASIC: modified version of the ultra low-noise VEGA ASIC (INFN)



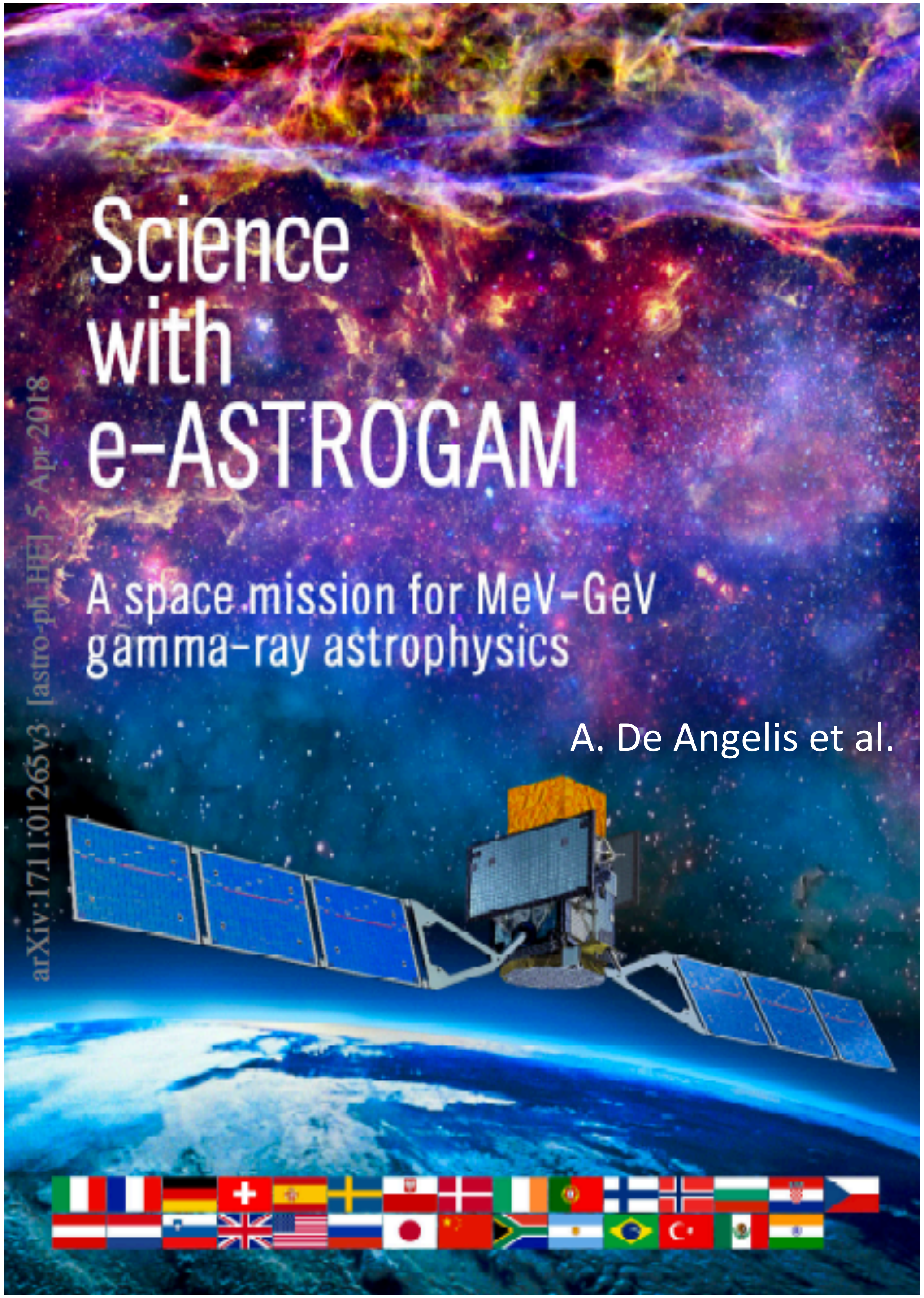





Fermi cal. module

Science with e-ASTROGAM

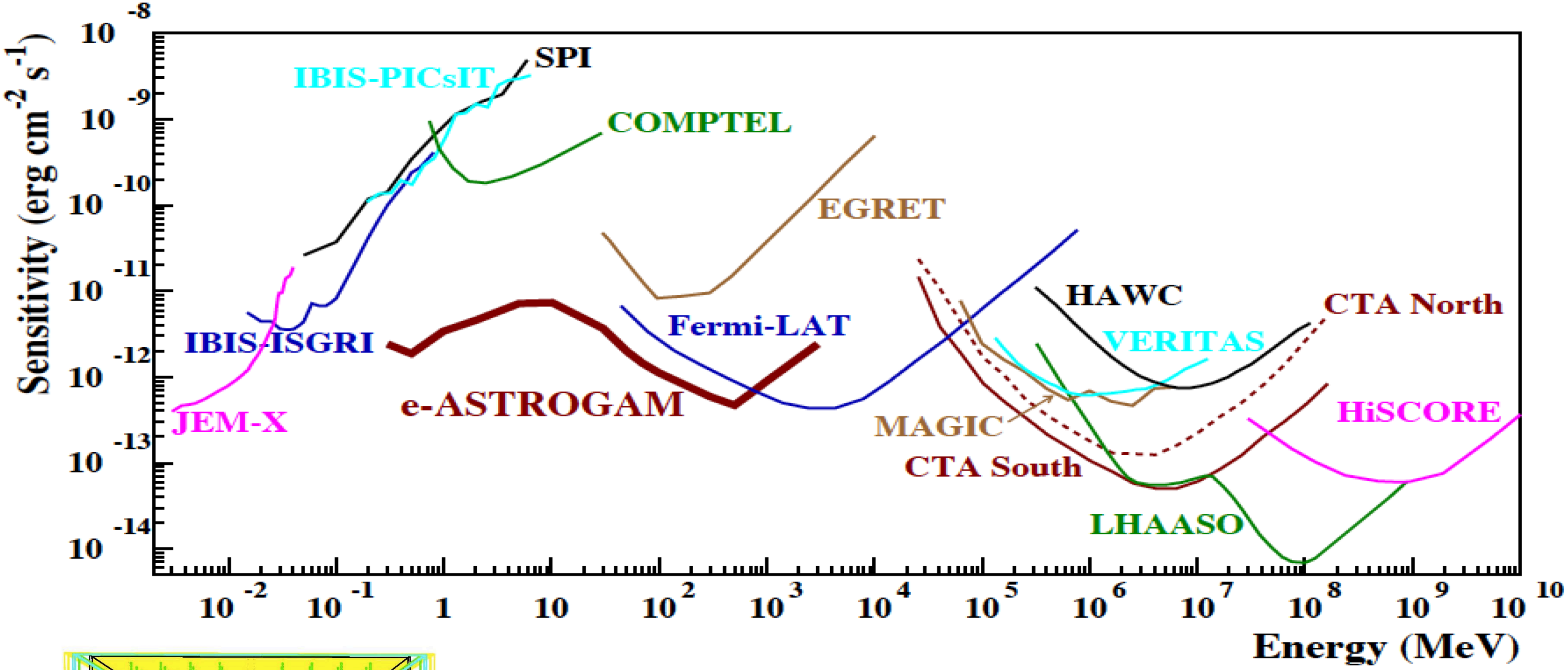
See https://arxiv.org/abs/1611.02232 (Exp. Astronomy)
and https://arxiv.org/abs/1711.01265 (JHEAP)

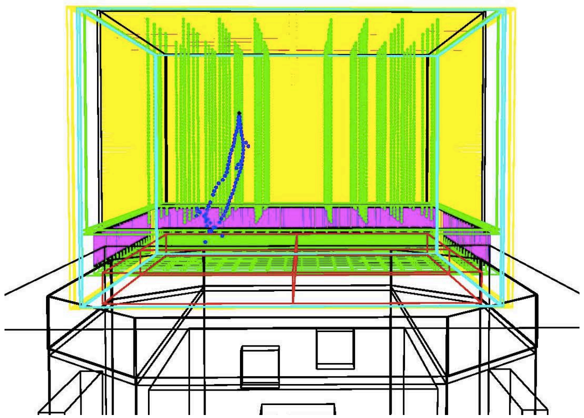


A. De Angelis∗,[1,2,3,4] V. Tatischeff∗,[5] I. A. Grenier∗,[6] J. McEnery∗,[7] M. Mallamaci∗,[1] M. Tavani,[8,9,10] U. Oberlack,[11] L. Hanlon,[12] R. Walter,[13] A. Argan,[14] P. Von Ballmoos,[15] A. Bulgarelli,[16] A. Bykov,[17] M. Hernanz,[18] G. Kanbach,[19] I. Kuvvetli,[20] M. Pearce,[21] A. Zdziarski,[22] J. Conrad,[23] G. Ghisellini,[24] A. Harding,[7] J. Isern,[25] M. Leising,[26] F. Longo,[27,28] G. Madejski,[29] M. Martinez,[30] M. N. Mazziotta,[31] J. M. Paredes,[32] M. Pohl,[33] R. Rando,[1,34] M. Razzano,[35,36] A. Aboudan,[34,2] M. Ackermann,[37] A. Addazi,[38] M. Ajello,[26] C. Albertus,[39] J. M. Álvarez,[40] G. Ambrosi,[41] S. Antón,[42,43] L. A. Antonelli,[44] A. Babic,[45] B. Baibussinov,[1] M. Balbo,[13] L. Baldini,[35,36] S. Balman,[46] C. Bambi,[38,47] U. Barres de Almeida,[48] J. A. Barrio,[49] R. Bartels,[50] D. Bastieri,[34,1,51] W. Bednarek,[52] D. Bernard,[53] E. Bernardini,[54,37] T. Bernasconi,[13] B. Bertucci,[41,55] A. Biland,[56] E. Bissaldi,[57,31] M. Boettcher,[58] V. Bonvicini,[28] V. Bosch-Ramon,[32] E. Bottacini,[1,34] V. Bozhilov,[59] T. Bretz,[60] M. Branchesi,[61,62] V. Brdar,[63] T. Bringmann,[64] A. Brogna,[11] C. Budtz-Jørgensen,[20] G. Busetto,[34] S. Buson,[7] M. Busso,[41,55] A. Caccianiga,[24] S. Camera,[65,66,67,68] R. Campana,[16] P. Caraveo,[69] M. Cardillo,[8] P. Carlson,[21] S. Celestin,[70] M. Cermeño,[39] A. Chen,[71] C. C Cheung,[72] E. Churazov,[73,74] S. Ciprini,[44,41] A. Coc,[5] S. Colafrancesco,[71] A. Coleiro,[75,76] W. Collmar,[77] P. Coppi,[78] R. Curado da Silva,[79] S. Cutini,[44,41] F. D'Ammando,[80] B. De Lotto,[81] D. de Martino,[82] A. De Rosa,[8] M. Del Santo,[83] L. Delgado,[18] R. Diehl,[77] S. Dietrich,[84] A. D. Dolgov,[85,86] A. Domínguez,[49] D. Dominis Prester,[87] I. Donnarumma,[8] D. Dorner,[88] M. Doro,[1,34] M. Dutra,[89] D. Elsaesser,[90] M. Fabrizio,[44,91] A. Fernández-Barral,[1] V. Fioretti,[16] L. Foffano,[34,1] V. Formato,[41] N. Fornengo,[65,66] L. Foschini,[24] A. Franceschini,[34] A. Franckowiak,[37] S. Funk,[92] F. Fuschino,[16] D. Gaggero,[50] G. Galanti,[24] F. Gargano,[31,57] D. Gasparrini,[44,41] R. Gehrz,[93] P. Giammaria,[91] N. Giglietto,[57,31] P. Giommi,[94] F. Giordano,[31] M. Giroletti,[80] G. Ghirlanda,[24,95] N. Godinovic,[96] C. Gouiffés,[97] J. E. Grove,[98] C. Hamadache,[5] D. H. Hartmann,[26] M. Hayashida,[99] A. Hryczuk,[64] P. Jean,[15] T. Johnson,[100] J. José,[101] S. Kaufmann,[102] B. Khelifi,[103] J. Kiener,[5] J. Knödlseder,[15] M. Kole,[13] J. Kopp,[104] V. Kozhuharov,[59] C. Labanti,[16] S. Lalkovski,[59] P. Laurent,[105] O. Limousin,[106] M. Linares,[101] E. Lindfors,[107] M. Lindner,[63] J. Liu,[108] S. Lombardi,[44,91] F. Loparco,[31,57] R. López-Coto,[1] M. López Moya,[49] B. Lott,[109] P. Lubrano,[41] D. Malyshev,[110] N. Mankuzhiyil,[111] K. Mannheim,[88] M. J. Marchã,[112] A. Marcianò,[38] B. Marcote,[113] M. Mariotti,[1] M. Marisaldi,[114] S. McBreen,[12] S. Mereghetti,[69] A. Merle,[115] R. Mignani,[116,117] G. Minervini,[8] A. Moiseev,[118] A. Morselli,[10] F. Moura,[79] K. Nakazawa,[119] L. Nava,[24,28,120] D. Nieto,[49] M. Orienti,[80] M. Orio,[121,2] E. Orlando,[29] P. Orleanski,[122] S. Paiano,[2] R. Paoletti,[35] A. Papitto,[91] M. Pasquato,[2] B. Patricelli,[123,35] M. Á. Pérez-García,[39] M. Persic,[120] G. Piano,[8] A. Pichel,[124] M. Pimenta,[4] C. Pittori,[44,91] T. Porter,[29] J. Poutanen,[107] E. Prandini,[34,1] N. Prantzos,[125] N. Produit,[13] S. Profumo,[126] F. S. Queiroz,[127] S. Raino,[31,57] A. Raklev,[64] M. Regis,[65,66] I. Reichardt,[128] Y. Rephaeli,[129,130] J. Rico,[30] W. Rodejohann,[63] G. Rodriguez Fernandez,[10] M. Roncadelli,[131] L. Roso,[132] A. Rovero,[124] R. Ruffini,[133] G. Sala,[101] M. A. Sánchez-Conde,[134] A. Santangelo,[135] P. Saz Parkinson,[136,137] T. Sbarrato,[95] A. Shearer,[138] R. Shellard,[48] K. Short,[50] T. Siegert,[77] C. Siqueira,[63,139] P. Spinelli,[31] A. Stamerra,[140] S. Starrfield,[141] A. Strong,[77] I. Strümke,[142] F. Tavecchio,[24] R. Taverna,[34] T. Terzić,[87] D. J. Thompson,[7] O. Tibolla,[102] D. F. Torres,[143,144,145] R. Turolla,[34] A. Ulyanov,[12] A. Ursi,[8] A. Vacchi,[81] J. Van den Abeele,[64] G. Vankova-Kirilova,[59] C. Venter,[58] F. Verrecchia,[44,91] P. Vincent,[146] X. Wang,[147] C. Weniger,[50] X. Wu,[13] G. Zaharijaš,[148] L. Zampieri,[2] S. Zane,[149] S. Zimmer,[150,13] A. Zoglauer,[151] and the e-ASTROGAM collaboration

White Book published in arXiv/JHEAP
Wide interest from the scientific community

e-ASTROGAM: performance assessment

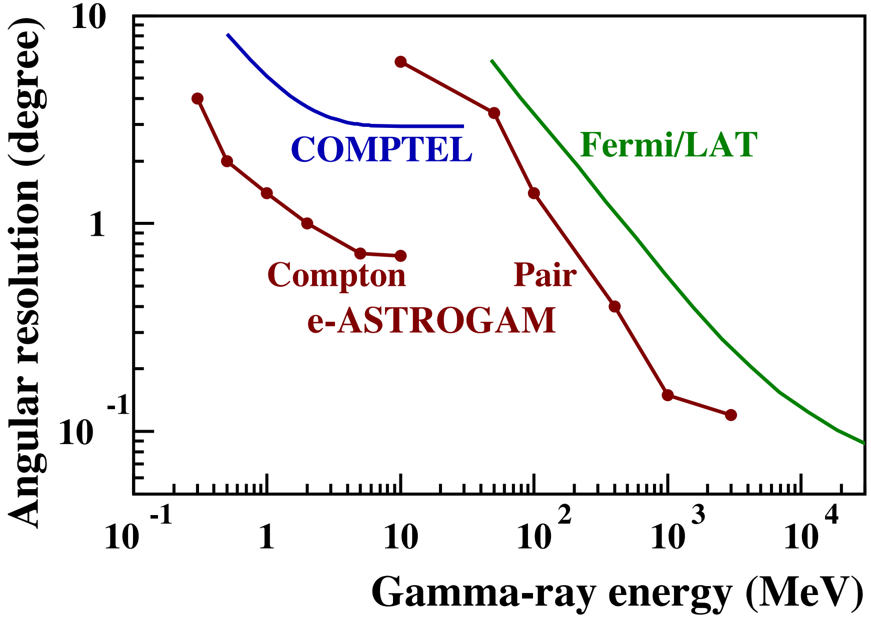




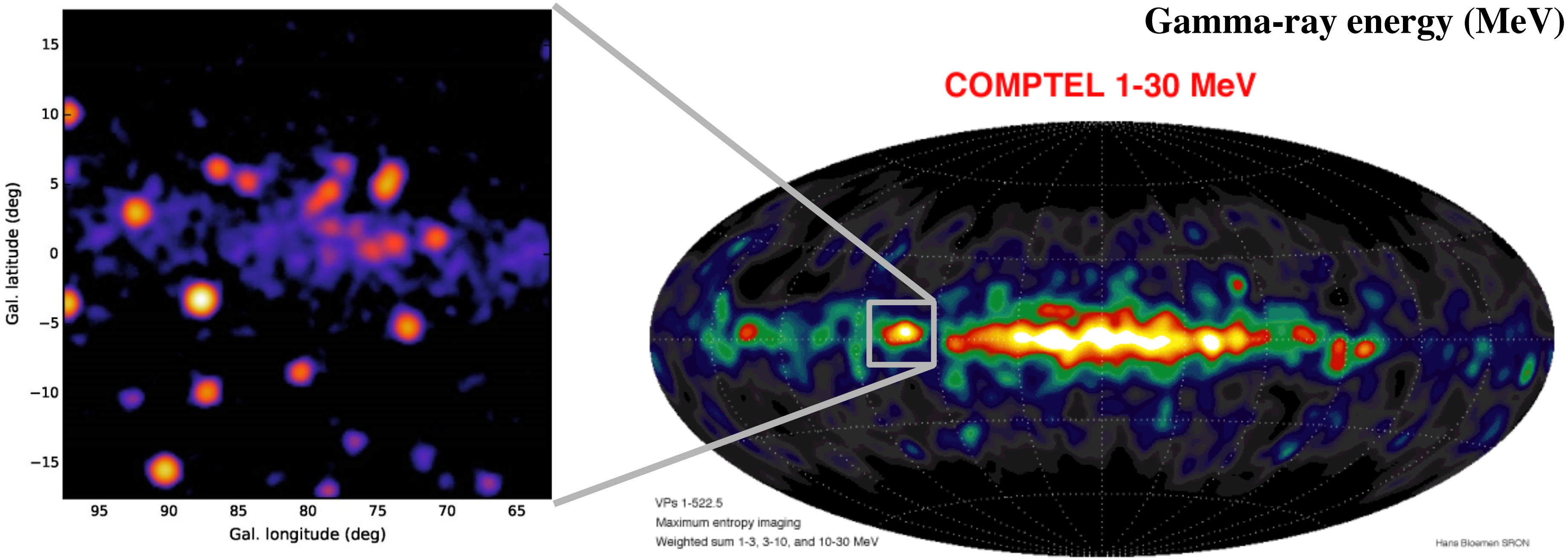
- e-ASTROGAM performance evaluated with **MEGAlib** (Zoglauer et al. 2006) and **Bogemms** (Bulgarelli et al. 2012) − both tools based on Geant4 − and a detailed numerical mass model of the gamma-ray instrument

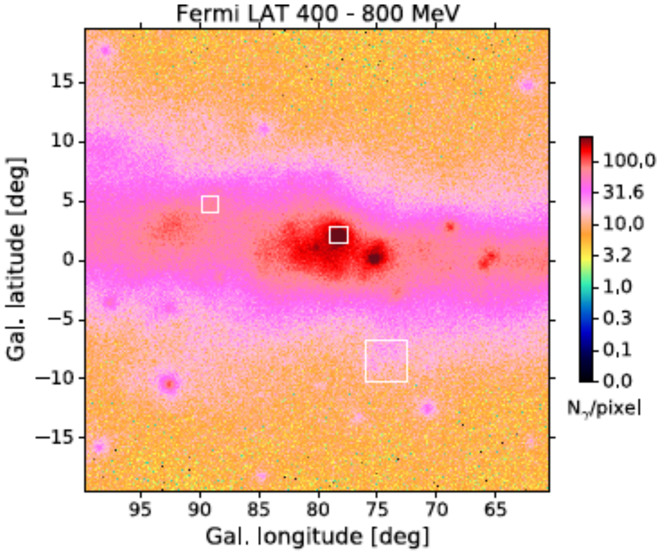
Angular resolution

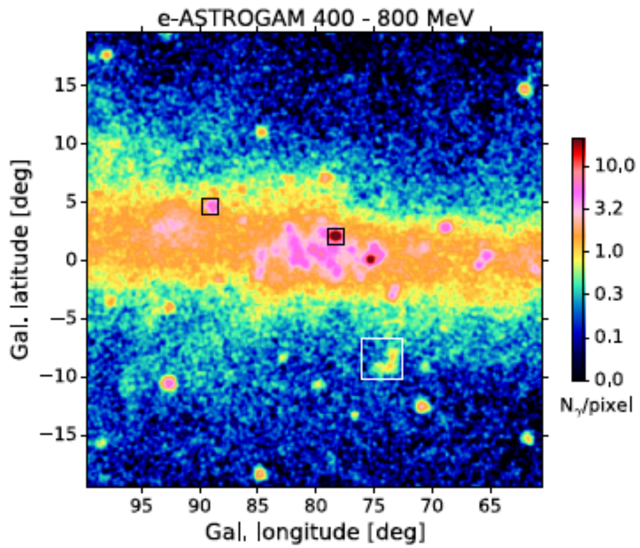
- Angular resolution improved close to the physical limits



Cygnus region in the 1 - 3 MeV energy band with the e-ASTROGAM PSF (extrapolation of the 3FGL source spectra to low energies)

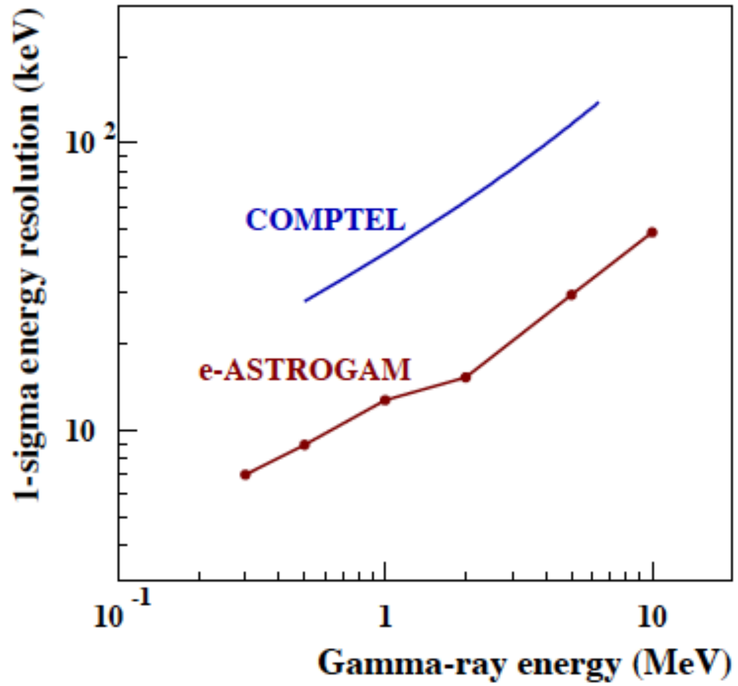






Energy resolution

ΔE/E (Gamma-ray imager)	2.5% at 1 MeV 30% at 100 MeV
ΔE/E (Calorimeter burst)	< 25% FWHM at 0.3 MeV < 10% FWHM at 1 MeV < 5% FWHM at 10 MeV



Key instrument characteristics: a summary

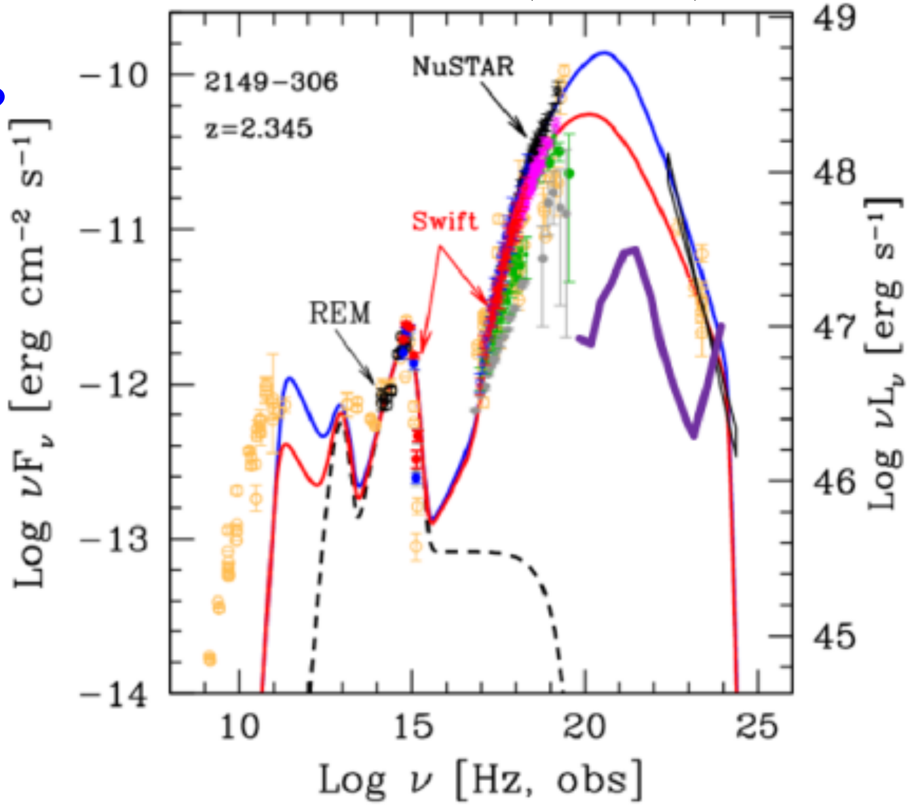
- Best PSF in MeV-GeV
  - Resolve sources
- Calorimetric measurements of MeV lines with high resolution:
  - Positron detection (511 keV line)
  - Measurements of isotopic contents, with highest sensitivity
  - Hadronic collisions of LECR with molecular clouds
- Capability of measuring polarization (marks Compton interactions at the sources and magnetic fields)
- SED resolution in the GeV range: allows to reconstruct the "pion bump", characteristic of the decay $\pi^o \rightarrow \gamma\gamma$ and thus an indicator of hadronic processes

e-ASTROGAM core science topic #1

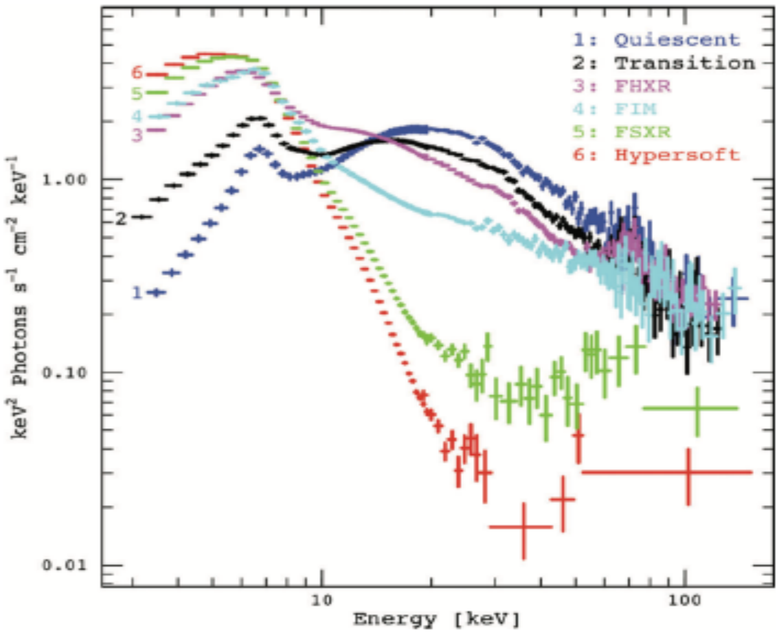
At the heart of the extreme Universe

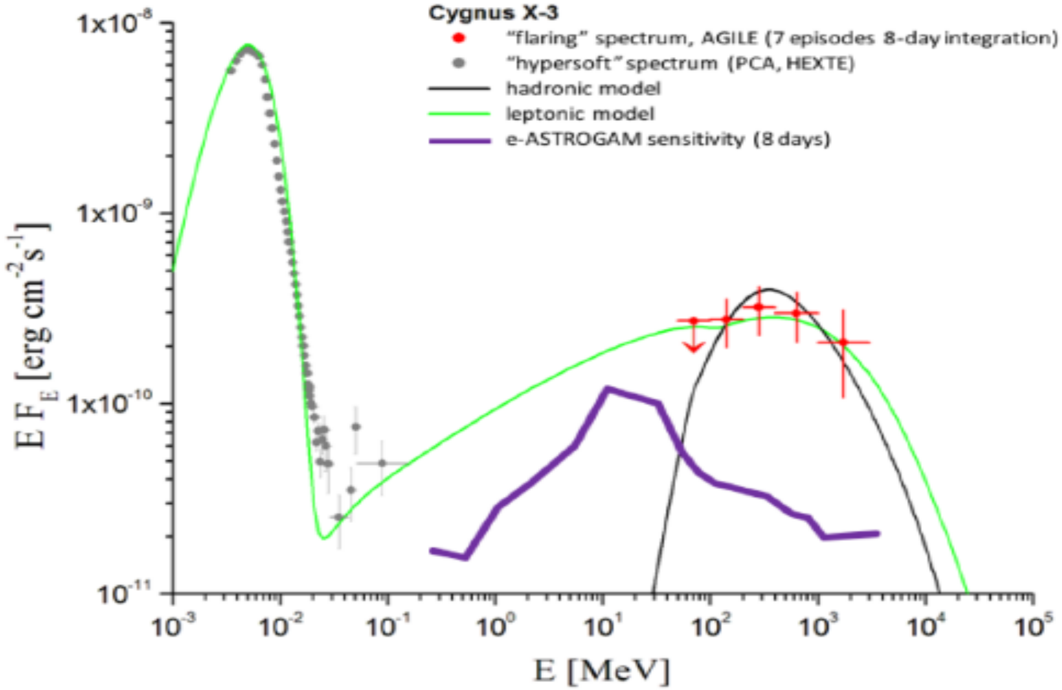
- *Launch of ultra-relativistic jets in **GRBs**? Ejecta composition, energy dissipation site, radiation processes?*
- *Can short-duration GRBs be unequivocally associated to **gravitational wave** signals?*
- *How does the accretion disk/jet transition occur around supermassive black holes in **AGN**?*
- *Are BL Lac blazars sources of **UHECRs** and high-energy **neutrinos**?*

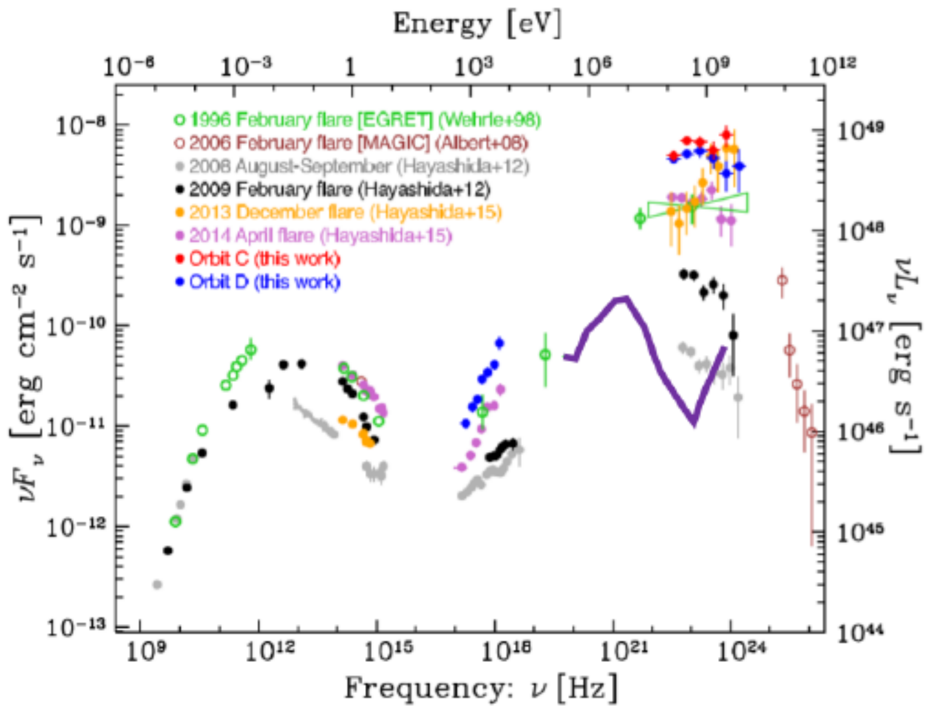
PKS 2149-306 (z = 2.345)



✓ With its wide **field of view**, unprecedented **sensitivity** over a large spectral band, and exceptional capacity for **polarimetry**, **e-ASTROGAM** will give access to a variety of extreme **transient** phenomena







Relativistic jets; flares

Figure 5: SED from a collection of different spectral states of the FSRQ 3C 279 showing a dramatic gamma-ray flaring activity, including the minute-timescale episode detected by Fermi in June 2015 [13]. The purple solid line is the 3σ e-ASTROGAM sensitivity calculated for a 50 ks exposure.

Gamma-ray bursts; the new Astronomy

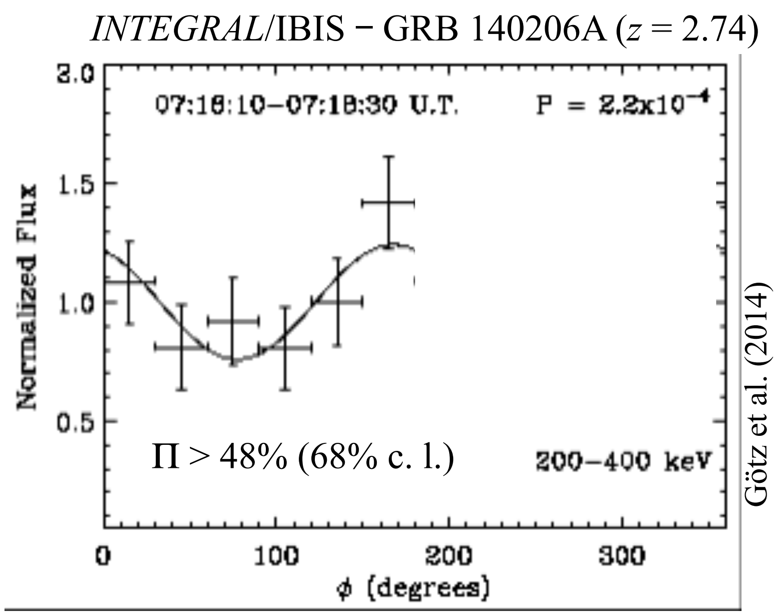
- Threshold at 30 keV using the Calorimeter
- 200 GRB/year detected
  - Localized within 0.1-1 deg, and the information can be processed onboard
  - 42 GRBs/year with a detectable polarization fraction of 20%;
- Possible detection of electromagnetic counterparts of impulsive GW events
  - MeV likely to be the threshold (Patricelli et al. 2016)
  - Possible associations GRB/GW
- MeV good target also for the counterparts of neutrino bursts

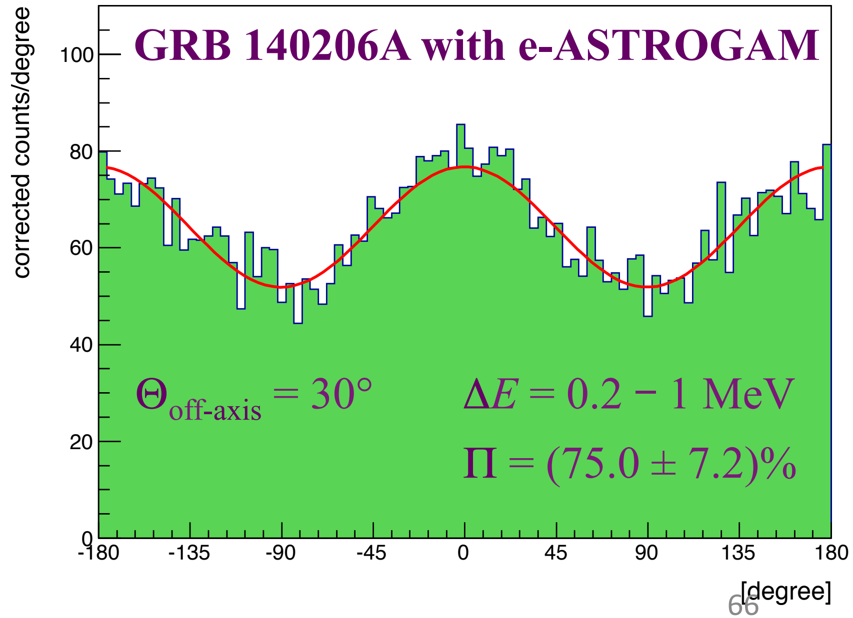
Gamma-ray polarization

- γ-ray polarization in **objects emitting jets** (GRBs, Blazars, X-ray binaries) or with **strong magnetic field** (pulsars, magnetars) ⇒ magnetization and content (hadrons, leptons, Poynting flux) of the outflows + radiation processes

- γ-ray polarization from **cosmological sources** (GRBs, Blazars) ⇒ fundamental questions of physics related to Lorentz Invariance Violation (vacuum birefringence)

✓ e-ASTROGAM will measure the γ-ray polarization of ~ **200 GRBs per year** (promising candidates for highly γ-ray polarized sources)



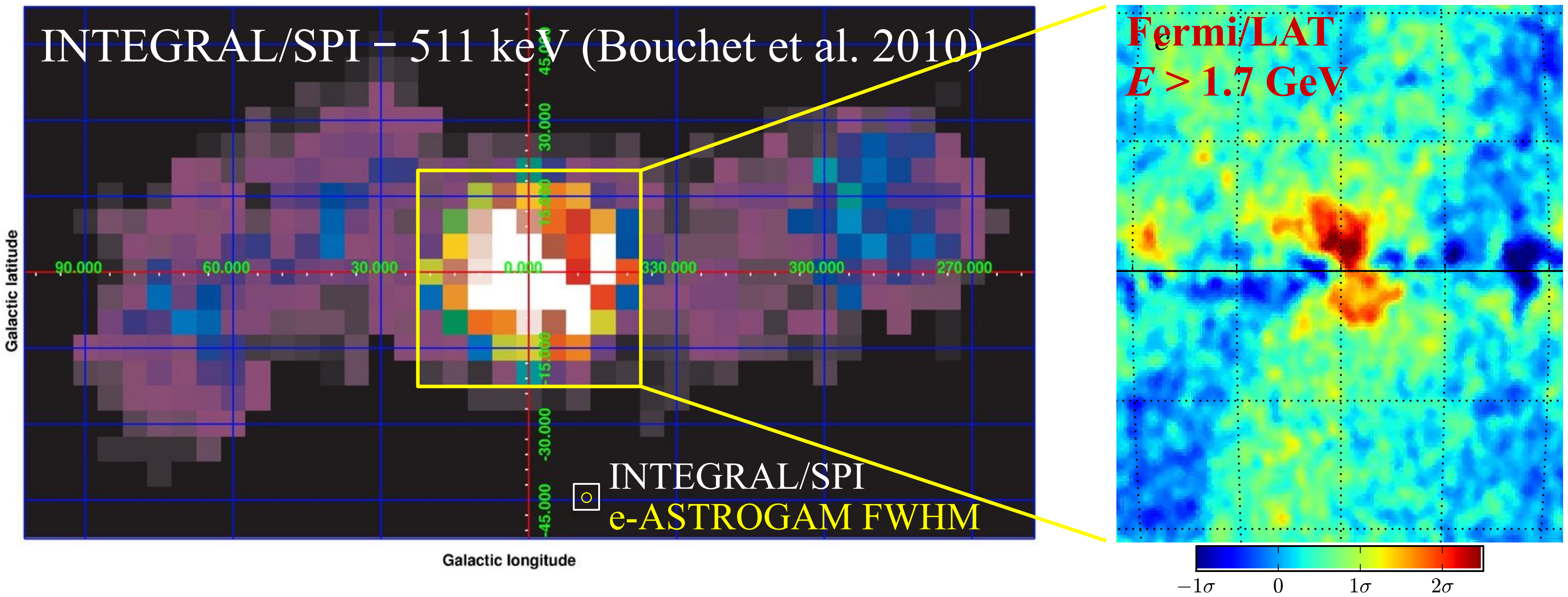


e-ASTROGAM core science topic #2

Origin & impact of HE particles on Galaxy evolution: CR, antimatter, …

- *Origin of the **Fermi Bubbles** and of the **511 keV emission** from the Galaxy's bulge? Are these linked to a past activity of the central **supermassive black hole**? What is causing the **GeV excess** emission from the center region?*

✓ With a **sensitivity** and an **angular resolution** in the MeV − GeV range significantly improved over previous missions, **e-ASTROGAM** will enable a detailed **spectro-imaging** of the various high-energy components

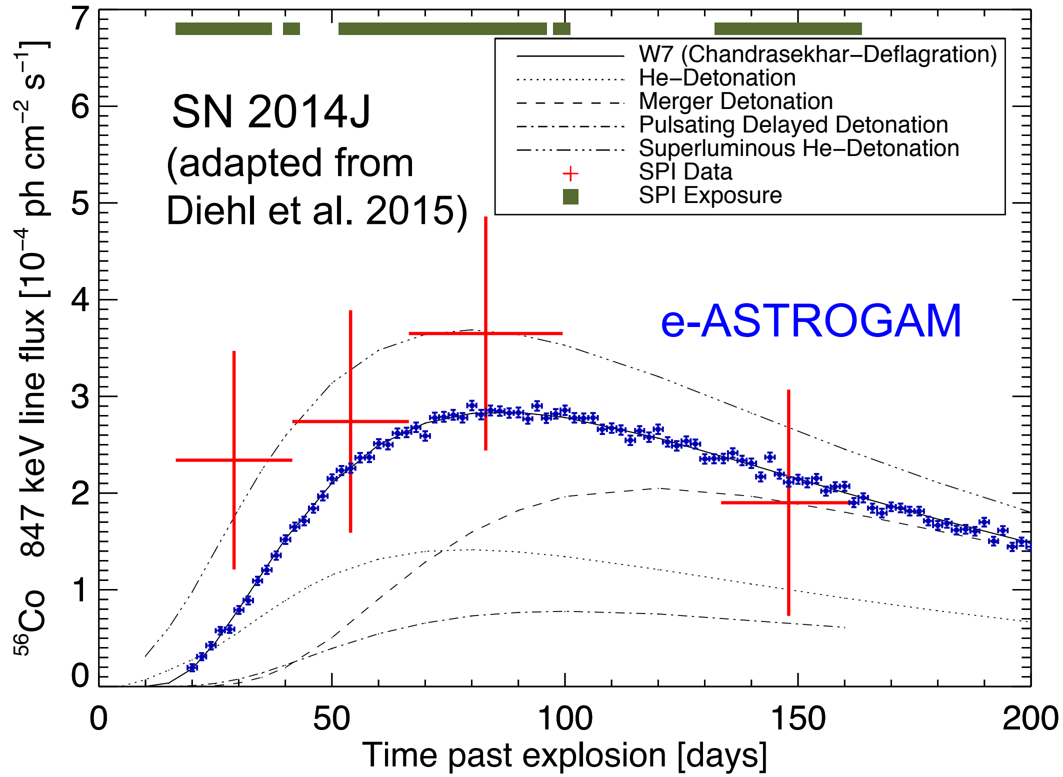


e-ASTROGAM core science topic #3

Supernovae, nucleosynthesis, and Galactic chemical evolution

- *How do thermonuclear and core-collapse SNe explode? How are cosmic isotopes created in stars and distributed in the interstellar medium?*

✓ With a remarkable improvement in **γ-ray line sensitivity** over previous missions, **e-ASTROGAM** should allow us to finally understand the progenitor system(s) and explosion mechanism(s) of **Type Ia SNe** (^{56}Ni, ^{56}Co), the dynamics of **core collapse** in massive star explosions (^{56}Co, ^{57}Co), and the history of **recent SNe** in the Milky Way (^{44}Ti, ^{60}Fe...)



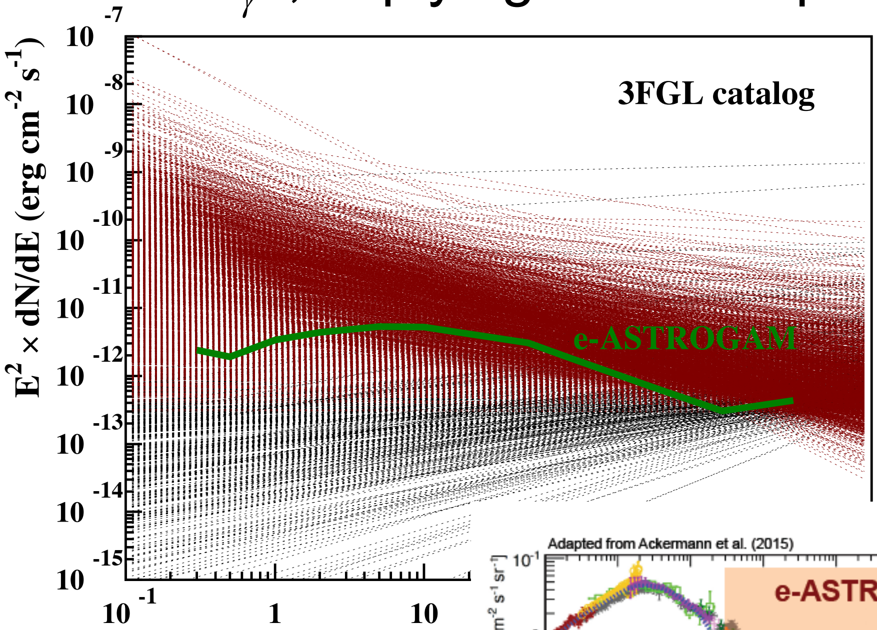
e-ASTROGAM Observatory science

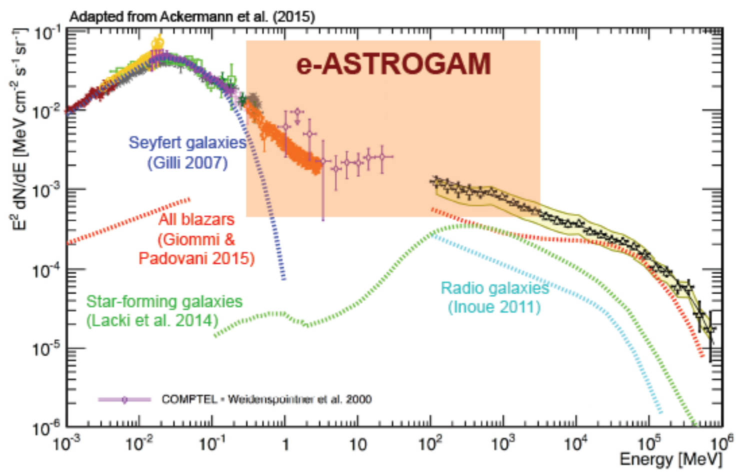
- e-ASTROGAM pointings first focused on core science topics. However a very large number of sources will be detected and monitored.
  - Thousabds of sources both Galactic and extragalactic, many new detections. Therefore, a very large community of astronomical users will benefit from e-ASTROGAM data available for multifrequency studies through GI programme managed by ESA.
- Phenomena and sources
  - characterized by rapid and very rapid variability timescales (sub-second, second, minutes, hours): GRB, AGN flares, …
  - steady
  - unexpected

Type	3 yr	New sources
Total	3000 – 4000	~1800 (including GRBs)
Galactic	~ 1000	~400
MeV blazars	~ 350	~ 350
GeV blazars	1000 – 1500	~ 350
Other AGN (<10 MeV)	70 – 100	35 – 50
Supernovae	10 – 15	10 – 15
Novae	4 – 6	4 – 6
GRBs	~600	~600

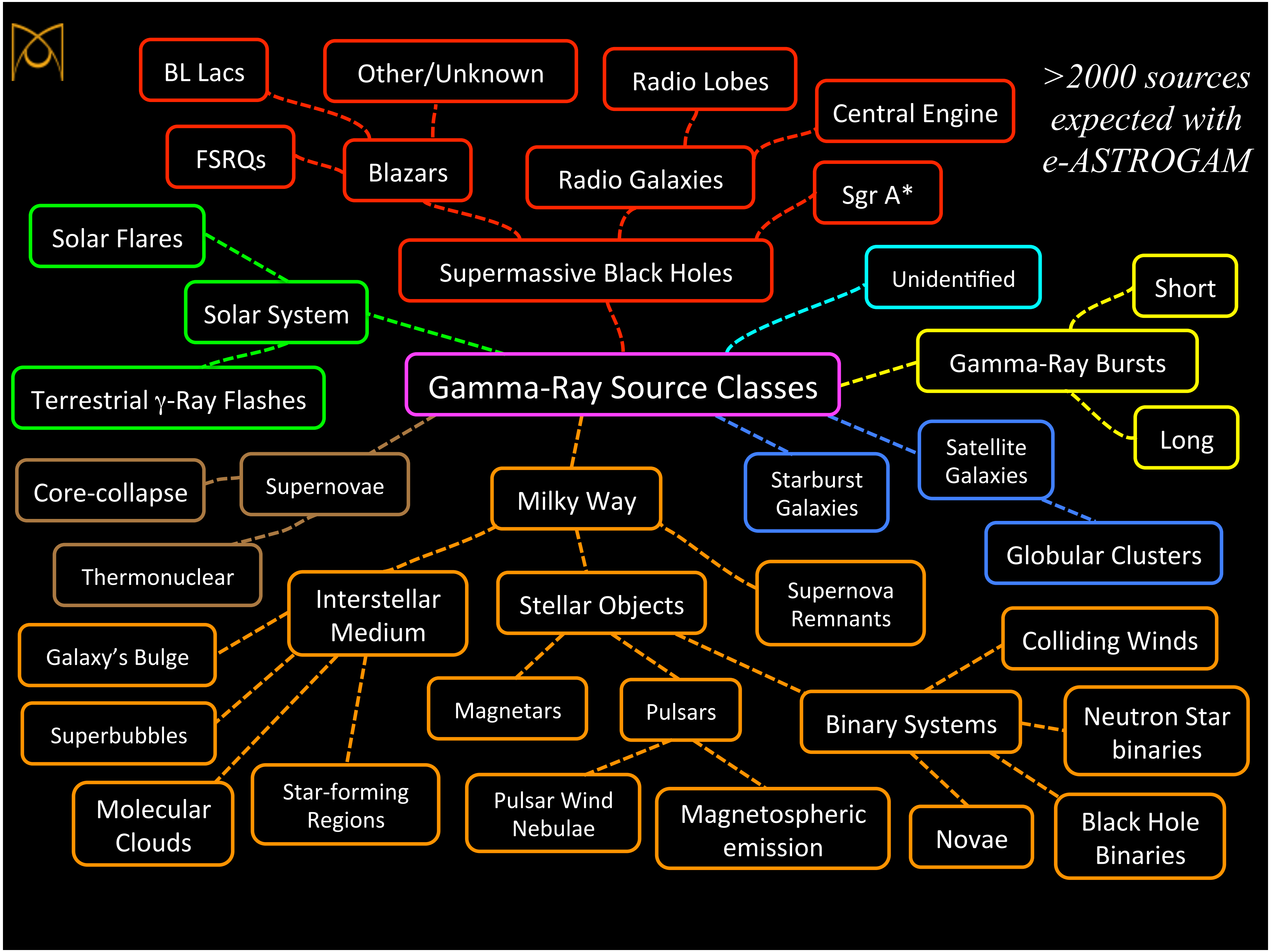
e-ASTROGAM discovery space

- Over 3/4 of the sources from the 3rd *Fermi*-LAT Catalog (3FGL), 2415 sources over 3033, have power-law spectra (E_γ > 100 MeV) steeper than E_γ^{-2}, implying that their peak energy output is below 100 MeV





- These includes more than 1200 (candidate) blazars (mostly FSRQ), about 150 pulsars, and nearly **900 unassociated sources**
- Most of these sources will be detected by **e-ASTROGAM** ⇒ large discovery space for new sources and source classes


BL Lacs
Other/Unknown
Radio Lobes
Central Engine
>2000 sources expected with e-ASTROGAM
FSRQs
Blazars
Radio Galaxies
Sgr A*
Solar Flares
Supermassive Black Holes
Unidentified
Short
Solar System
Gamma-Ray Bursts
Terrestrial γ-Ray Flashes
Gamma-Ray Source Classes
Long
Satellite Galaxies
Core-collapse
Supernovae
Milky Way
Starburst Galaxies
Globular Clusters
Thermonuclear
Interstellar Medium
Stellar Objects
Supernova Remnants
Colliding Winds
Galaxy's Bulge
Superbubbles
Magnetars
Pulsars
Binary Systems
Neutron Star binaries
Molecular Clouds
Star-forming Regions
Pulsar Wind Nebulae
Magnetospheric emission
Novae
Black Hole Binaries

First e-ASTROGAM Science Workshop

- Padova, Feb 28 (start at 13h30)/ Mar 1-2 (end on Mar 2 at 14h)
- Setup a team for a white book (possibly w/ AMEGO)
- Contributed talks & posters on multimessenger astrophysics welcome
- Google “agenda infn e-ASTROGAM workshop”

Second e-ASTROGAM Science Workshop

2nd e-ASTROGAM Workshop, joint to AMEGO Workshop: towards a White Book on MeV Gamma-ray Astrophysics

chaired by Alessandro De Angelis (PD), Riccardo Rando (PD), Julie Mc Enery (NASA Goddard)

from Friday, 13 October 2017 at **10:45** to Saturday, 14 October 2017 at **16:45** (Europe/Rome)
at **Munich (Ambiance Rivoli Hotel)**
Albert-Roßhaupter-Straße 22

Description This scientific workshop, open to contributions, continues the discussion on the e-ASTROGAM (and AMEGO) science: exploration of the Universe in the MeV domain. After the 1st workshop held in Padova in February 2017, we aim at finalizing our "White Book" on the opportunities of astronomy, astrophysics and astroparticle physics from observations of cosmic gamma rays in the MeV domain.

More documentation is available at the homepage http://eastrogam.iaps.inaf.it

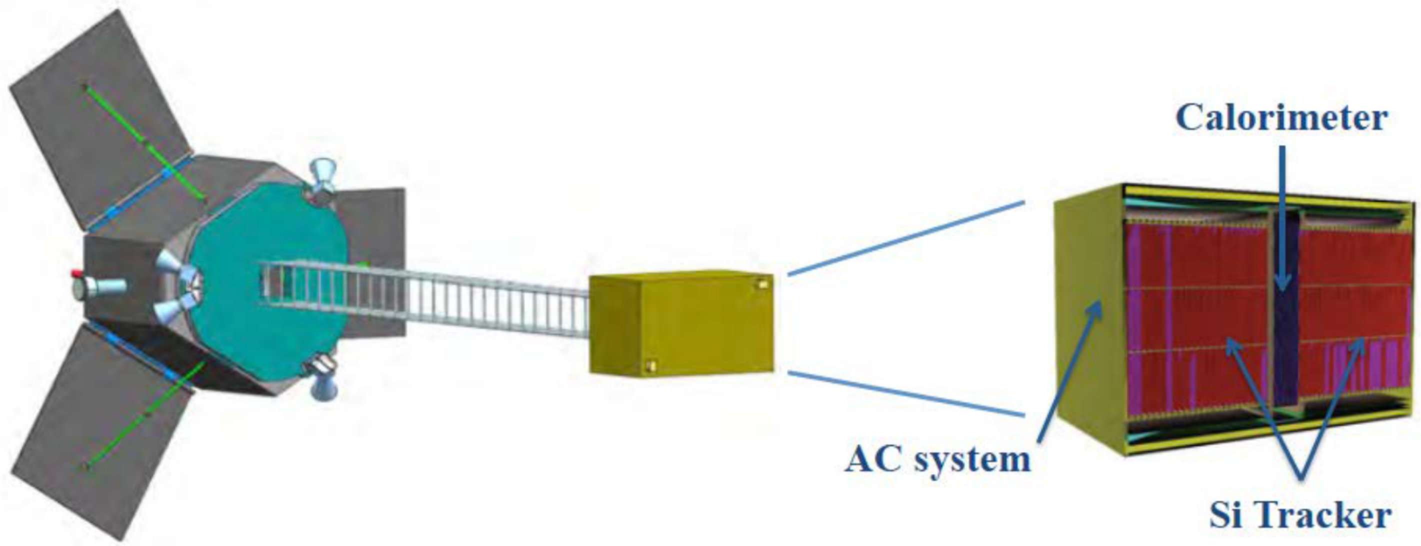
The conference fee covers breaks and renting the room and the facilities. 30 rooms are pre-booked at the hotel at a preferential rate (specify eASTROGAM in the reservation).

Participants Solen Balman; Juan Abel Barrio; Denis Bernard; Martina Cardillo; Paolo Cumani; Alessandro De Angelis; Domitilla de Martino; Alberto Dominguez; Yongwei DONG; Michele Doro; Fabio Gargano; J. Eric Grove; Elizabeth Hays; Margarita Hernanz; Jordi Isern; Stefan Lalkovski; Manuela Mallamaci; Dmitry Malyshev; Karl Mannheim; Ajello Marco; Manel Martinez; Mario Nicola Mazziotta; Roberto Mignani; Alexander Moiseev; Aldo Morselli; Uwe Oberlack; Josep M. Paredes; Carlotta Pittori; Martin Pohl; Riccardo Rando; Javier Rico; Pablo Saz Parkinson; Andy Strong; Vincent Tatischeff; Marco Tavani; Roberto Turolla; Roland Walter; Silvia Zane; Andrzej Zdziarski

https://agenda.infn.it/conferenceDisplay.py?confId=13913

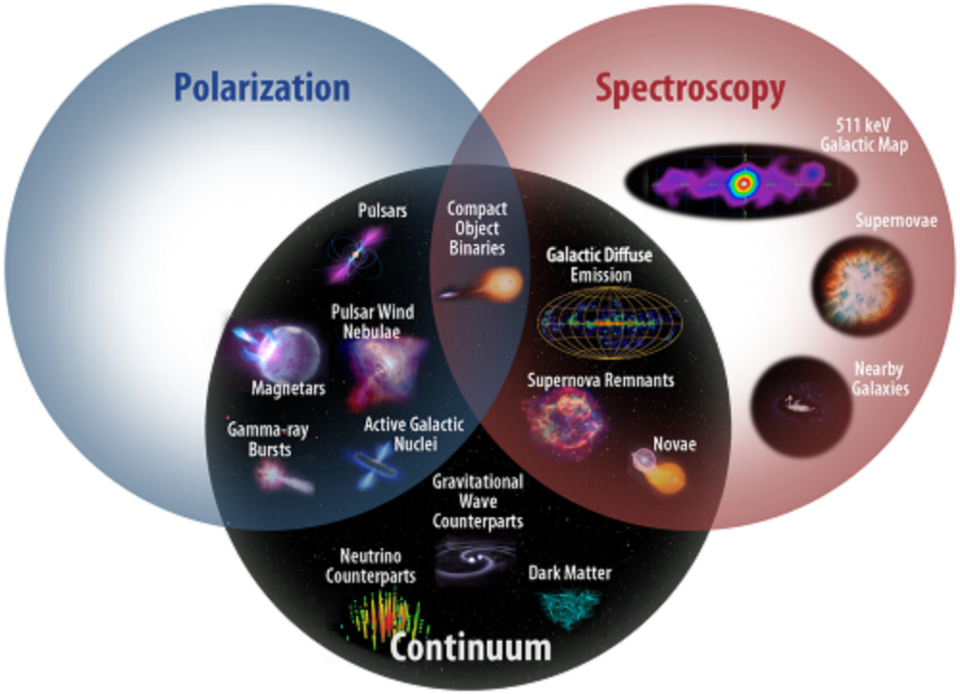
All Sky - ASTROGAM

We were encouraged by several space agencies (ASI and CNES in particular)



- ~8 times smaller than e-ASTROGAM (30cm x 30cm x 25 Si planes on either side of the CAL; CAL is 5 cm deep; 80 kg; to be placed in L2). Monitoring instrument for the MM era

AMEGO, the All-sky Medium Energy Gamma-ray Observatory, is an Astrophysics Probe mission concept designed to explore the MeV sky.



AMEGO

AMEGO Science

Understanding Extreme Environments

Astrophysical Jets

Understand the formation, evolution, and acceleration mechanisms in astrophysical jets

Compact Objects

Identify the physical processes in the extreme conditions around compact objects

Dark Matter

Test models that predict dark matter signals in the MeV band

MeV Spectroscopy

Measure the properties of element formation in dynamic systems

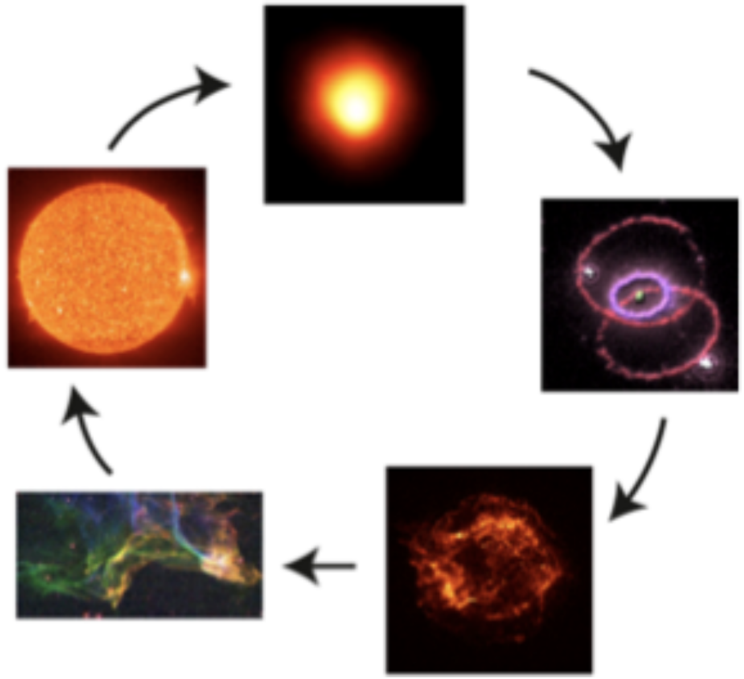
AMEGO

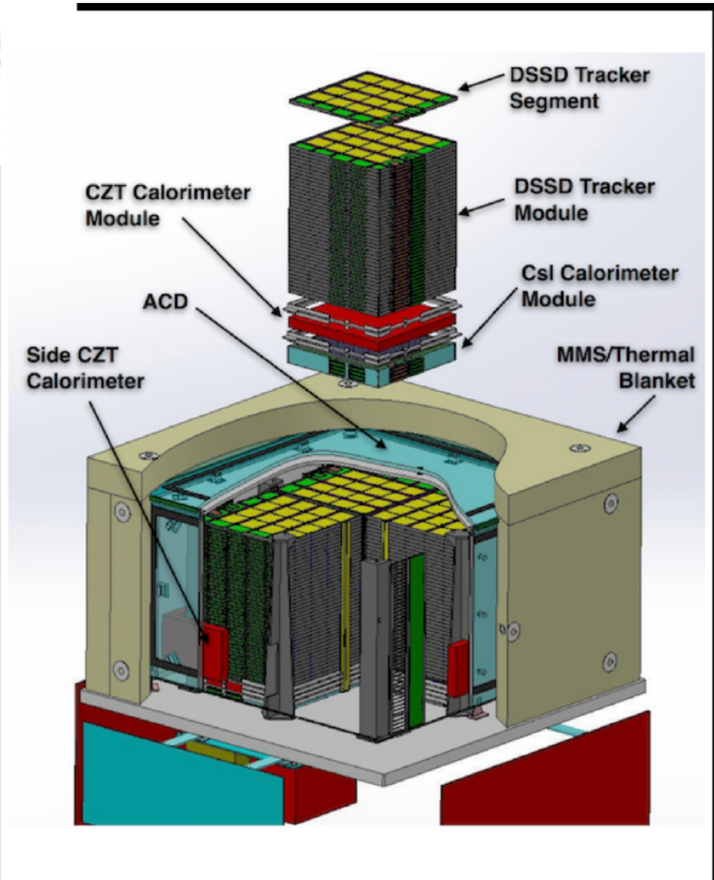
Element Formation in Dynamic Systems

Nuclear lines explore Galactic chemical evolution and sites of explosive element synthesis (SNe)

- Electron-positron annihilation radiation
  - $e^+ + e^-$ -> 2g (0.511 MeV)
- Nucleosynthesis
  - Giants, CCSNe (^{26}Al)
  - Supernovae (^{56}Ni, ^{57}Ni, ^{44}Ti)
  - ISM (^{26}Al, ^{60}Fe)
- Cosmic-ray induced lines
  - Sun
  - ISM

56Ni: 158 keV 812 keV (6 d)
56Co: 847 keV, 1238 keV (77 d)
57Co: 122 keV (270 d)
44Ti: 1.157 MeV (78 yr)
26Al: 1.809 MeV (0.7 Myr)
60Fe: 1.173, 1.332 MeV (2.6 Myr)





AMEGO: All-sky Medium Energy Gamma-ray Observatory

Tracker

Incoming photon undergoes pair production or Compton scattering. Measure energy and track of electrons and positrons

- 60 layer DSSD, spaced 1 cm
- Strip pitch 0.5mm

CZT Calorimeter

Measures location and energy of Compton scattered photons, and head of the shower for pair evens

- Array of 0.6x0.6 x 2cm vertical CdZnTe bars

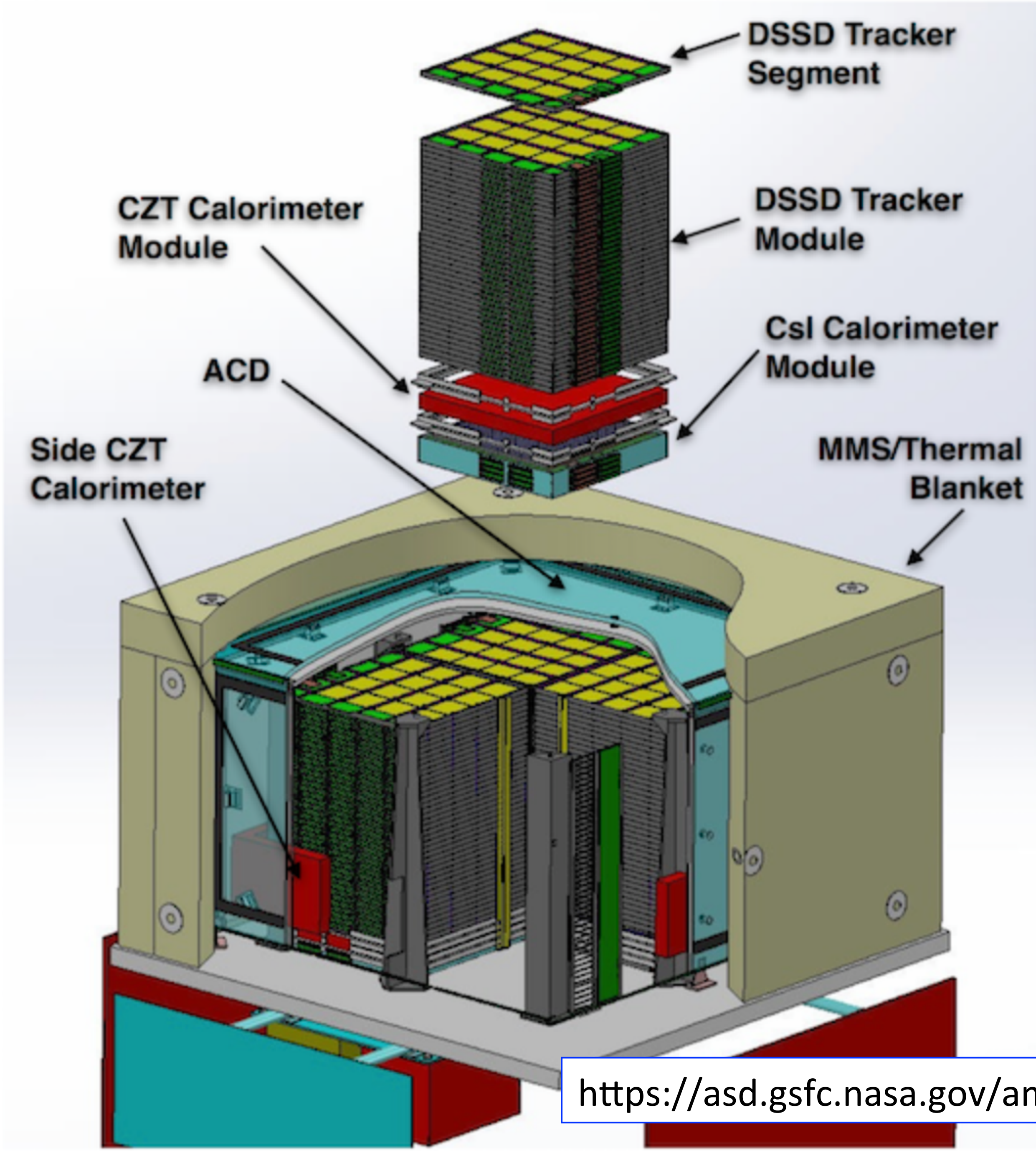
CsI Calorimeter

Extends upper energy range

- 6 planes of 1.5cm x 1.5 cm CsI (Tl) bars

Instrument concept:

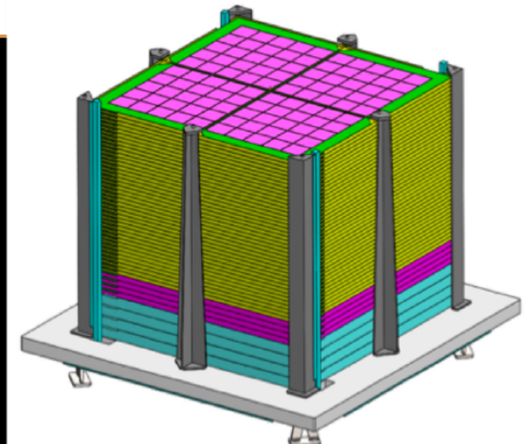
- Maximized performance in 1 MeV – 100 MeV range, with full range 0.2 MeV – 10 GeV
- Simplicity, long-term (~10 years) reliability, max use of already space-qualified technology
- Sensitive to both γ-ray interactions: pair production and Compton scattering
- Minimized amount of passive elements in detecting zone of the instrument (no passive γ-ray converters as in LAT)
- Use fine segmentation of all detecting elements to provide the best particle tracking and event identification



https://asd.gsfc.nasa.gov/amego/

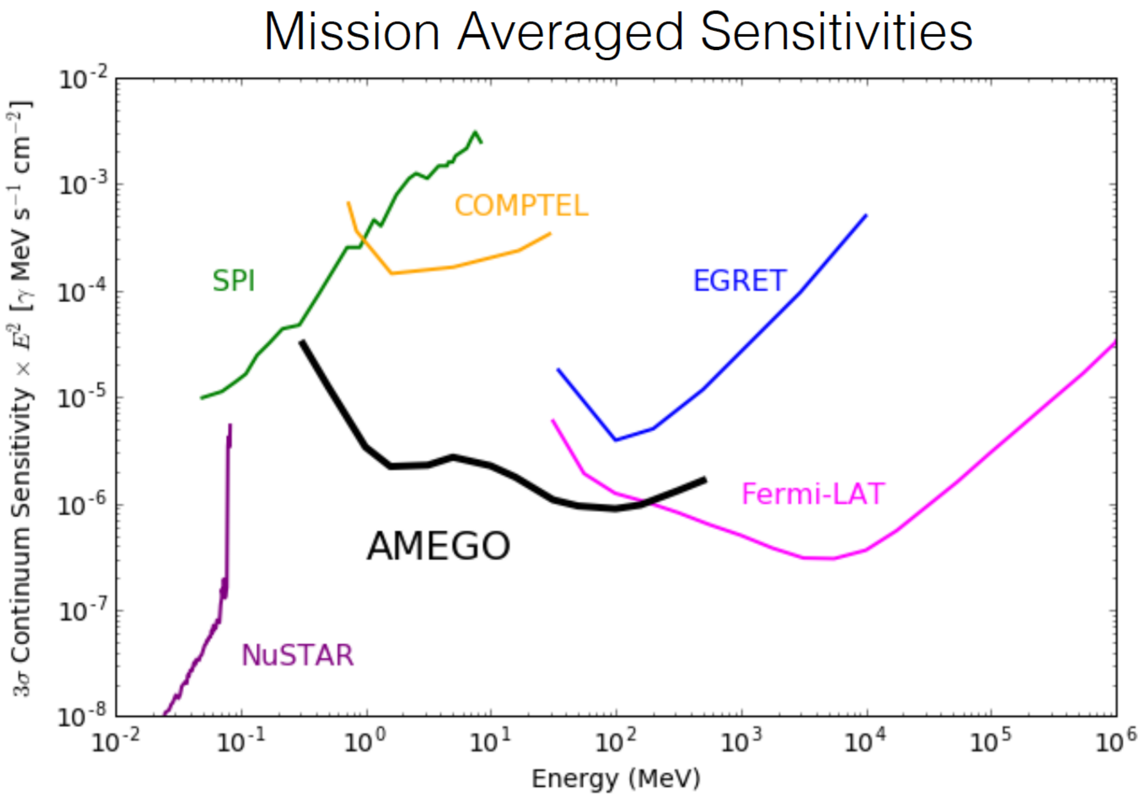
AMEGO Instrument Summary

Energy Range	300 keV -> 10 GeV
Angular resolution	3° (3 MeV), 6° (10 MeV), 2° (100 MeV)
Energy resolution	<1% (< 1 MeV), 1-5% (1-100 MeV), ~10% 91 GeV)
Field of View	2.5 sr (20% of the sky)
Line sensitivity	<6x10^{-6} ph cm^{-2} s^{-1} for the 1.8 MeV ^{26}Al line in a 1-year scanning observation
Polarization sensitivity	<20% MDP for a source 1% the Crab flux, observed for 10^{6} s
Continuum sensitivity (MeV cm^{-2} s^{-1})	3x10^{-6} (1 MeV), 2x10^{-6} (10 MeV), 8x10^{-7} (100 MeV)



AMEGO

AMEGO Capabilities



Summary

- The almost unexplored MeV / GeV gamma-ray band is one of the richest energy domains of astrophysics
- ASTROGAM/AMEGO will fill the gap and they will be essential observatories to study the extreme transient sky in the era of astronomy's new messengers
- ASTROGAM/AMEGO payloads are innovative in many respects, but the technology is ready