GammaMeV

e-ASTROGAM

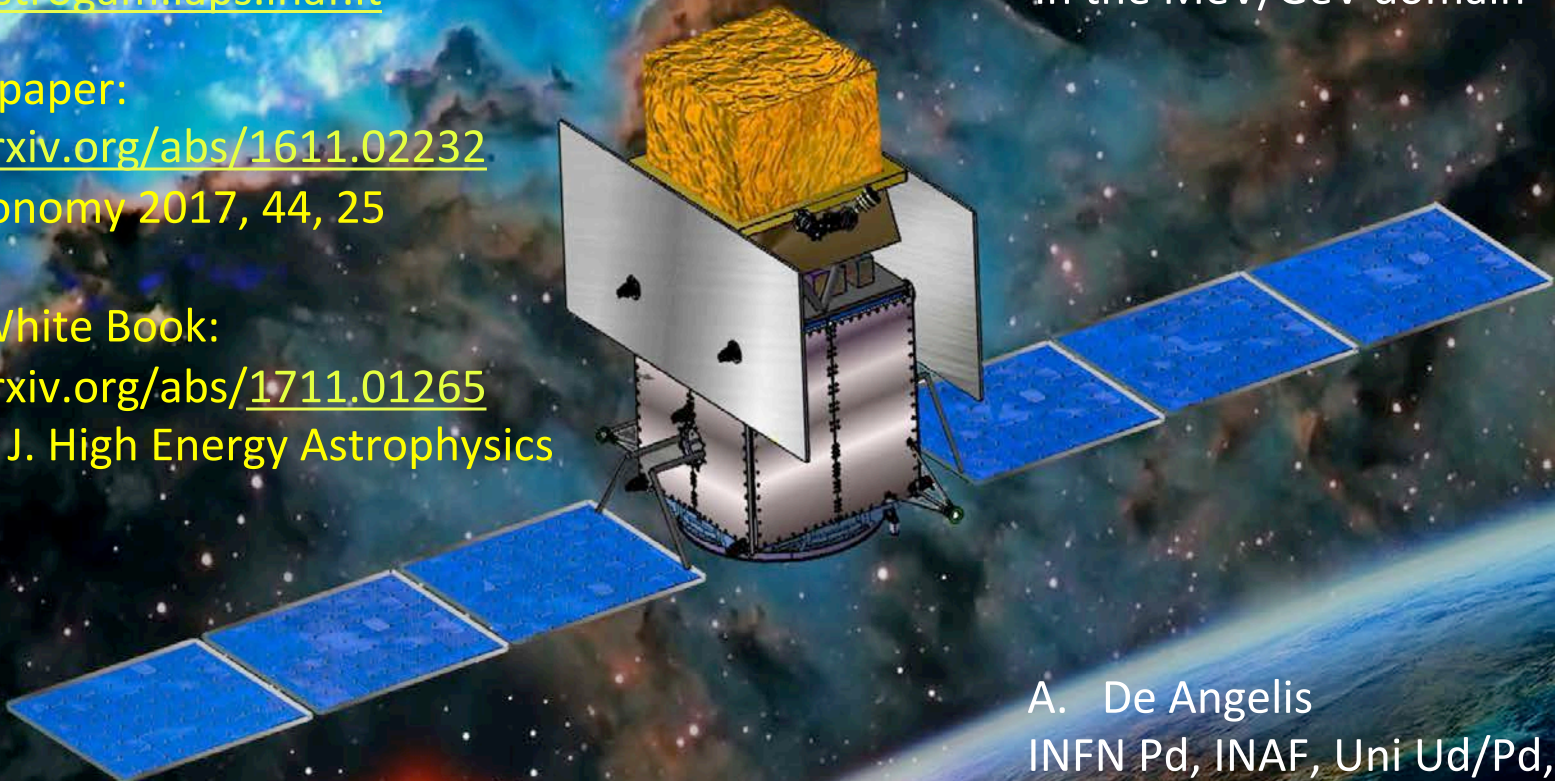
at the heart of the extreme Universe

An observatory for gamma rays
In the MeV/GeV domain

http://eastrogam.iaps.inaf.it

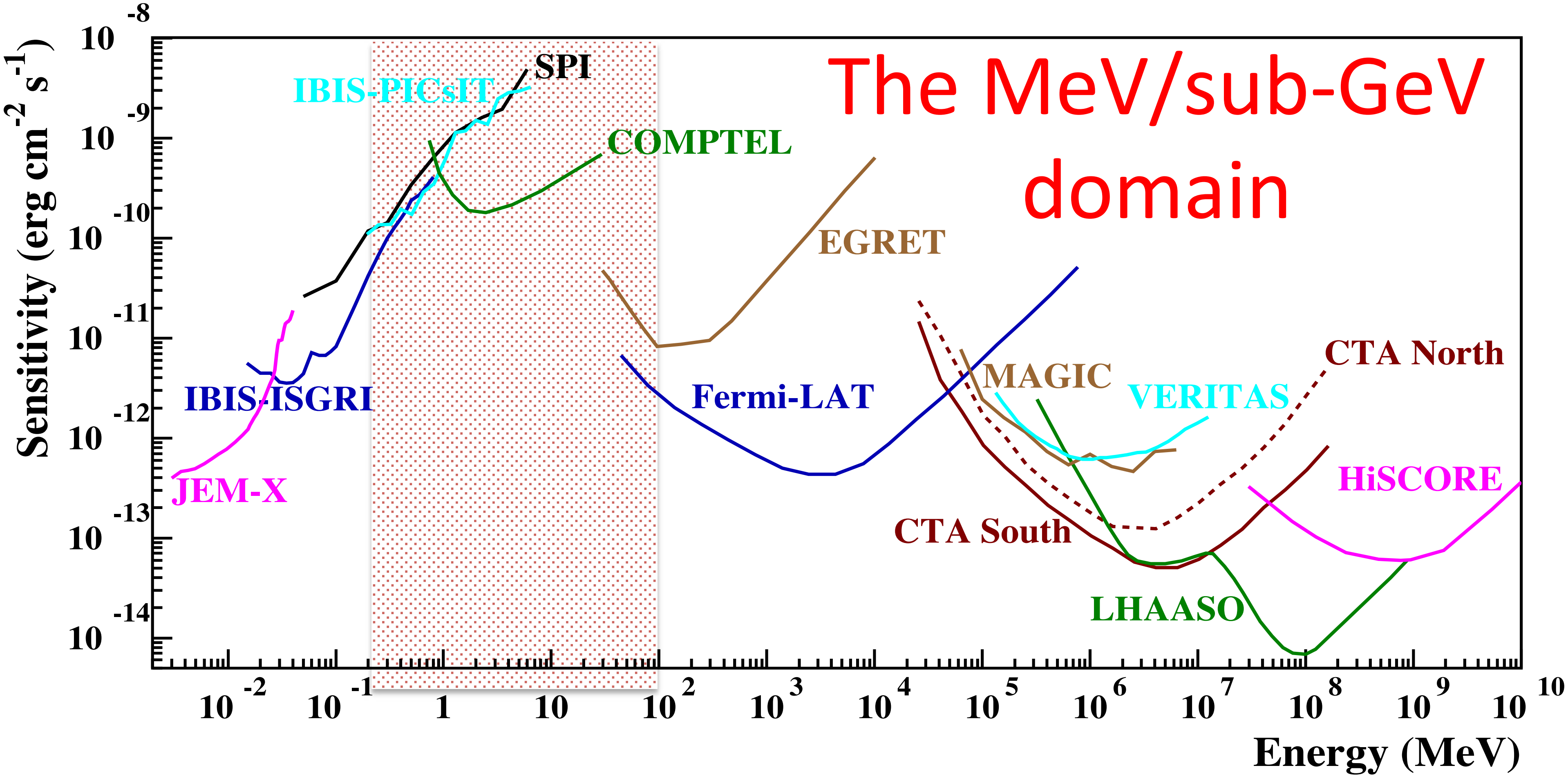
Detector paper:
https://arxiv.org/abs/1611.02232
Exp. Astronomy 2017, 44, 25

Science White Book:
https://arxiv.org/abs/1711.01265
Subm. To J. High Energy Astrophysics



A. De Angelis
INFN Pd, INAF, Uni Ud/Pd, LIP Lisboa
July 2018

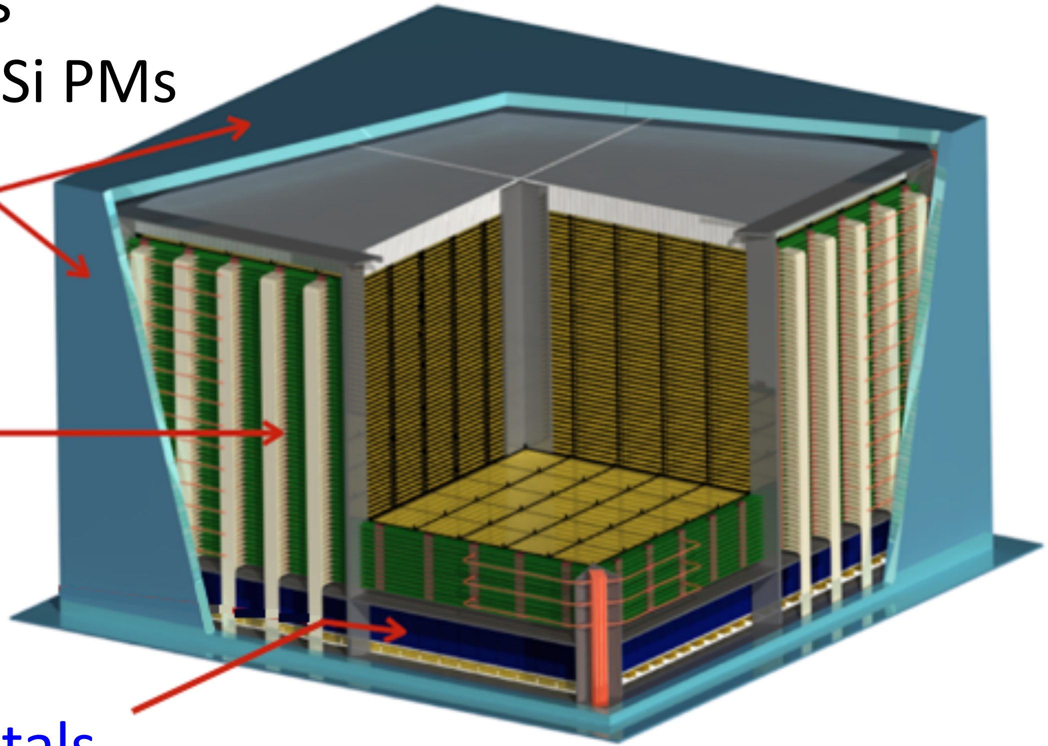
The MeV/sub-GeV domain



- 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...)
- Transition energies of atomic nuclei fall in this range, which thus is as important for HE astronomy as optical astronomy is for phenomena related to atomic physics
- Electromagnetic counterparts of NS-NS fusions have cutoffs in the MeV region

e-ASTROGAM and similar designs

Anti-Coincidence System
to veto charged particles
plastic scintillators readout by Si PMs
+ Time of Flight

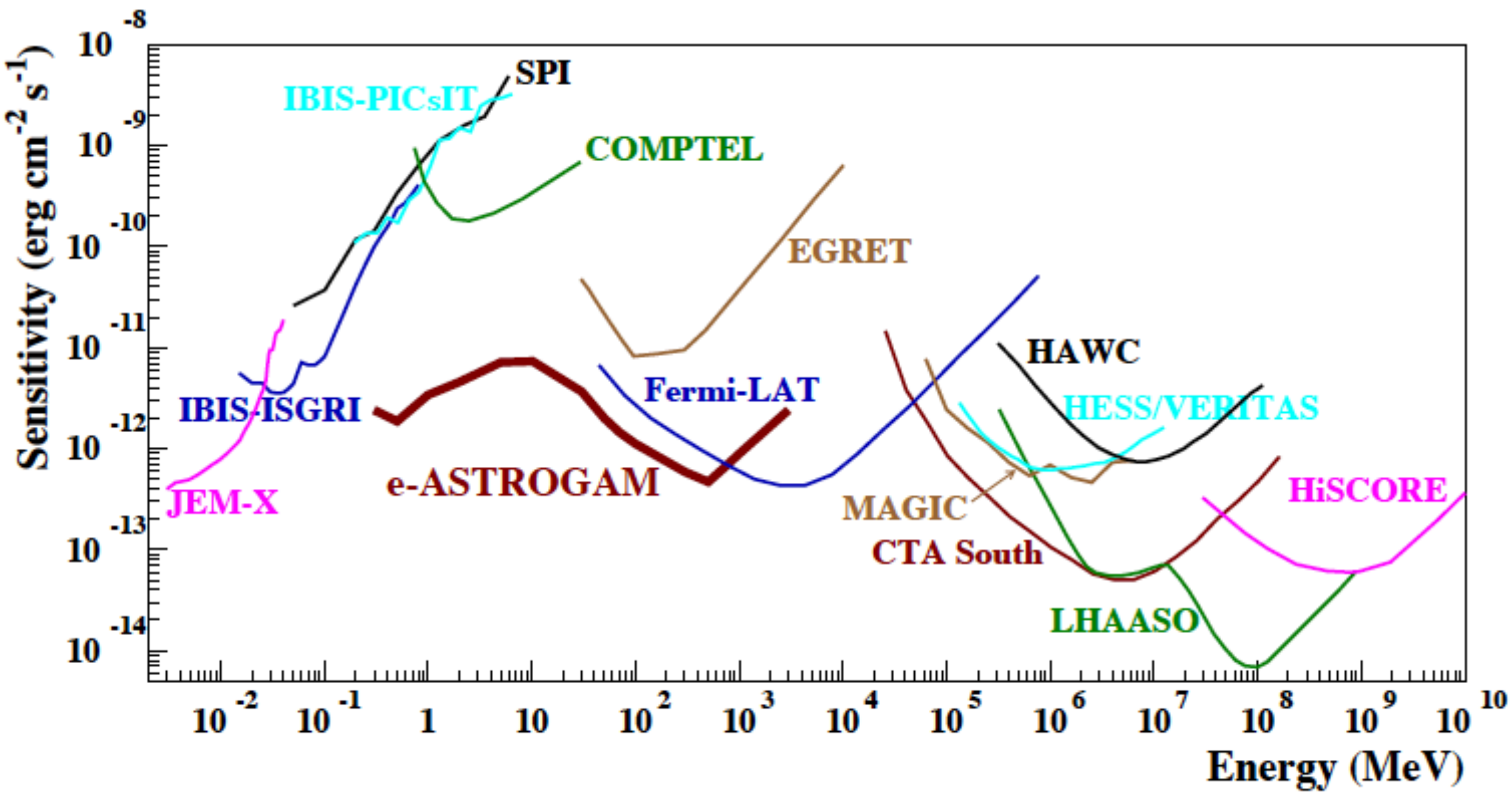


Tracker – DS Si strip detectors
for spectral resolution
& 3-D resolution
$1 m^2$, 500 µm thick, 0.3 X_o tot

Calorimeter – CsI(Tl) crystals
readout by Si drift detectors for best ΔE/E,
8 cm (4.3 Xo)

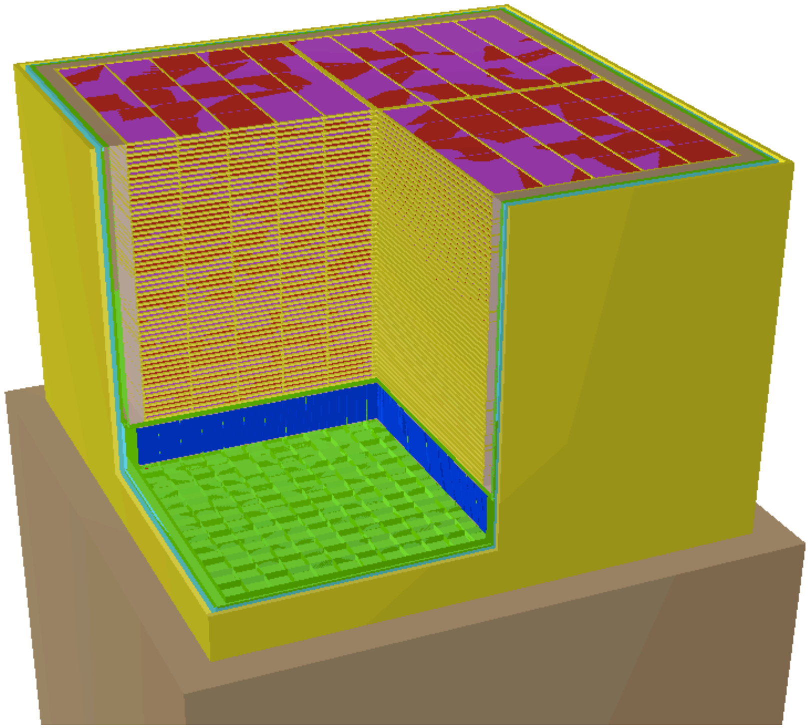
e-ASTROGAM performance

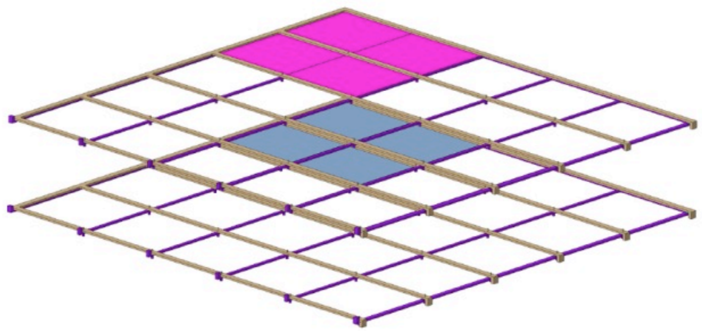
1. Excellent sensitivity in the 1-50 MeV energy range
2. γ-ray polarization for both transient and steady sources
3. Unprecedented angular resolution (e.g., ~ 10' at 1 GeV)
4. Large field of view (~ 2.5 sr) ⇒ efficient monitoring of the γ-ray sky
5. Sub-millisecond trigger and alert capability for transients



e-ASTROGAM: silicon tracker (INFN)

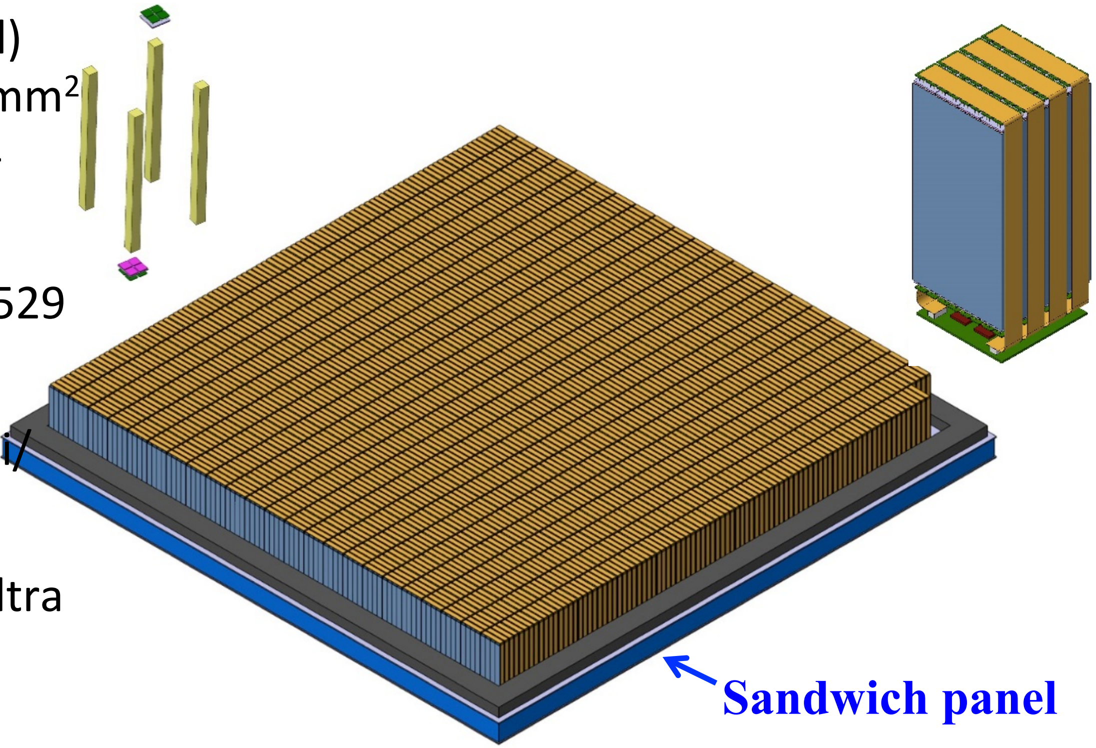
- 4 towers, 56 layers of 5×5 double sided Si strip detectors each (5600 DSSDs)
  - Each DSSD has a total area of 9.5×9.5 cm^2, a thickness of 500 µm and pitch of 240 µm (384 strips per side)
  - The DSSDs are wire bonded strip to strip to form 5×5 2-D ladders
- Spacing of the Si layers: 10 mm
  - Each 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)

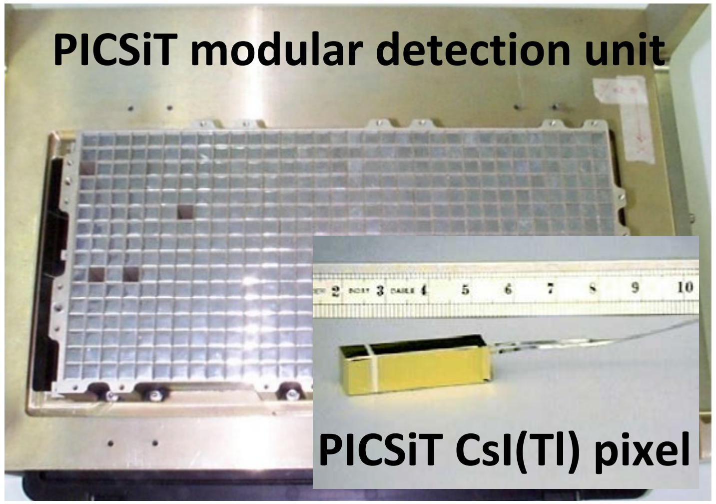


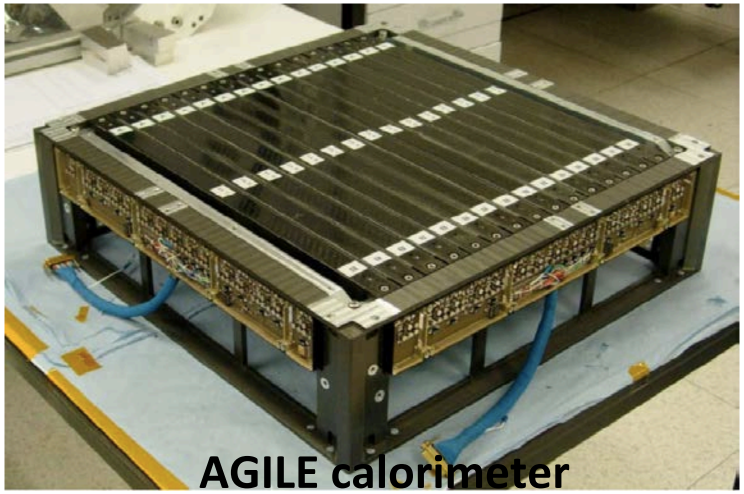


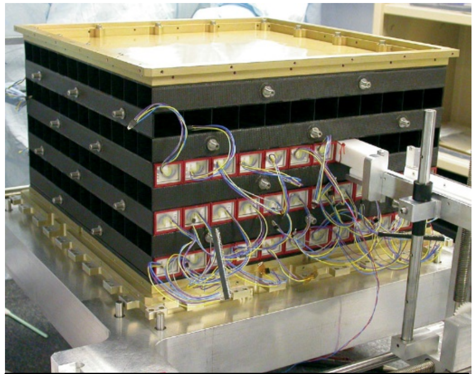
e-ASTROGAM: calorimeter

- 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)



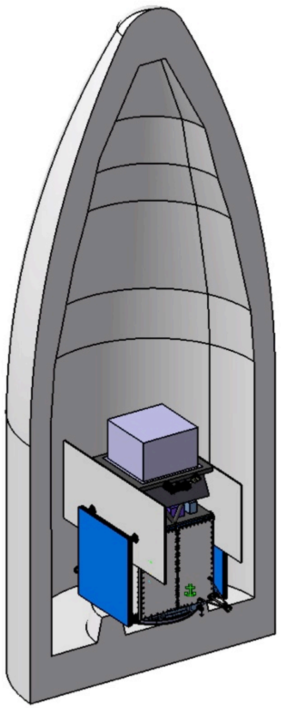





Fermi cal. module

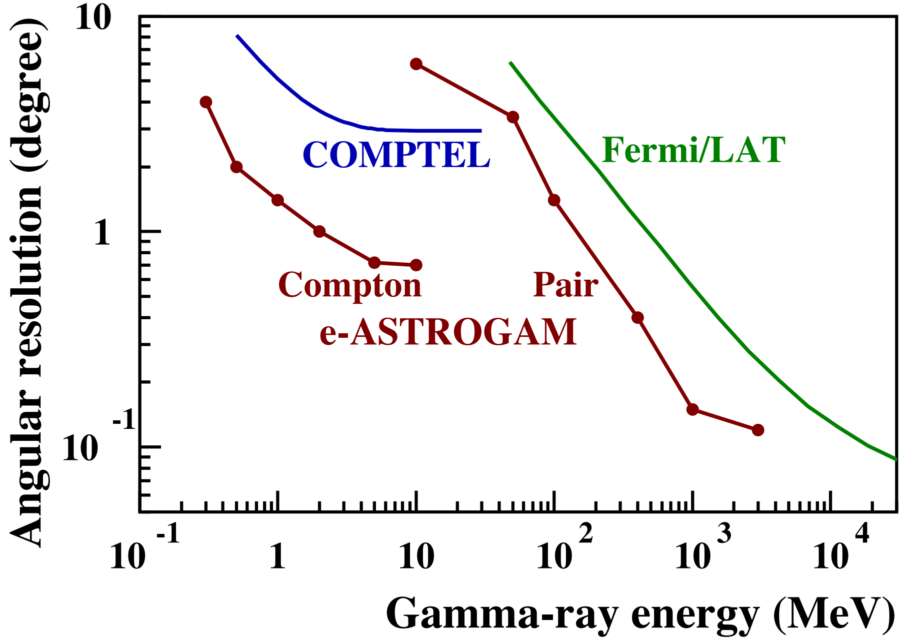
e-ASTROGAM in summary

- Large FoV, scanning & pointing modes
- Proven and robust technology
  - AGILE, 11 years; Fermi, 10 years
- Proven capability to separate signal from background
- No consumables



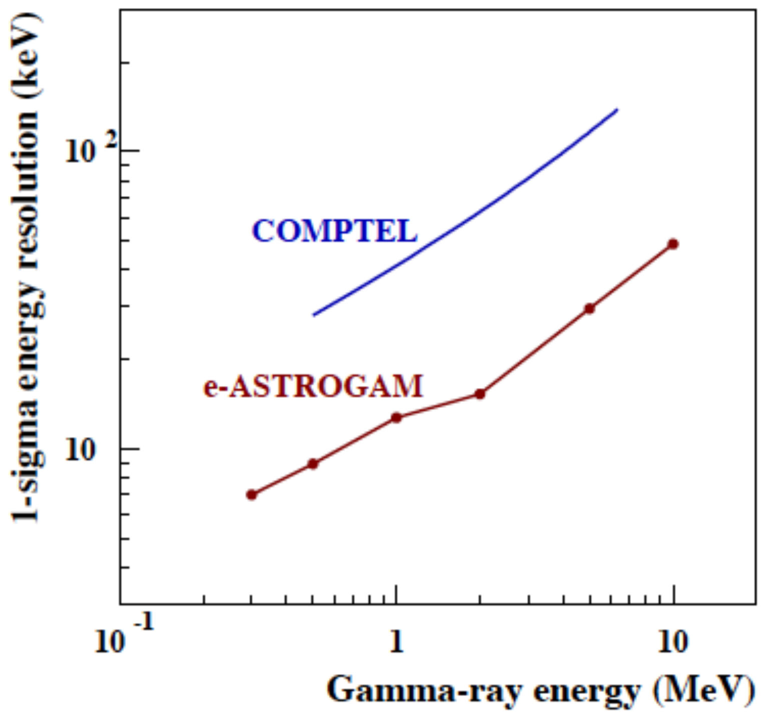
Angular resolution

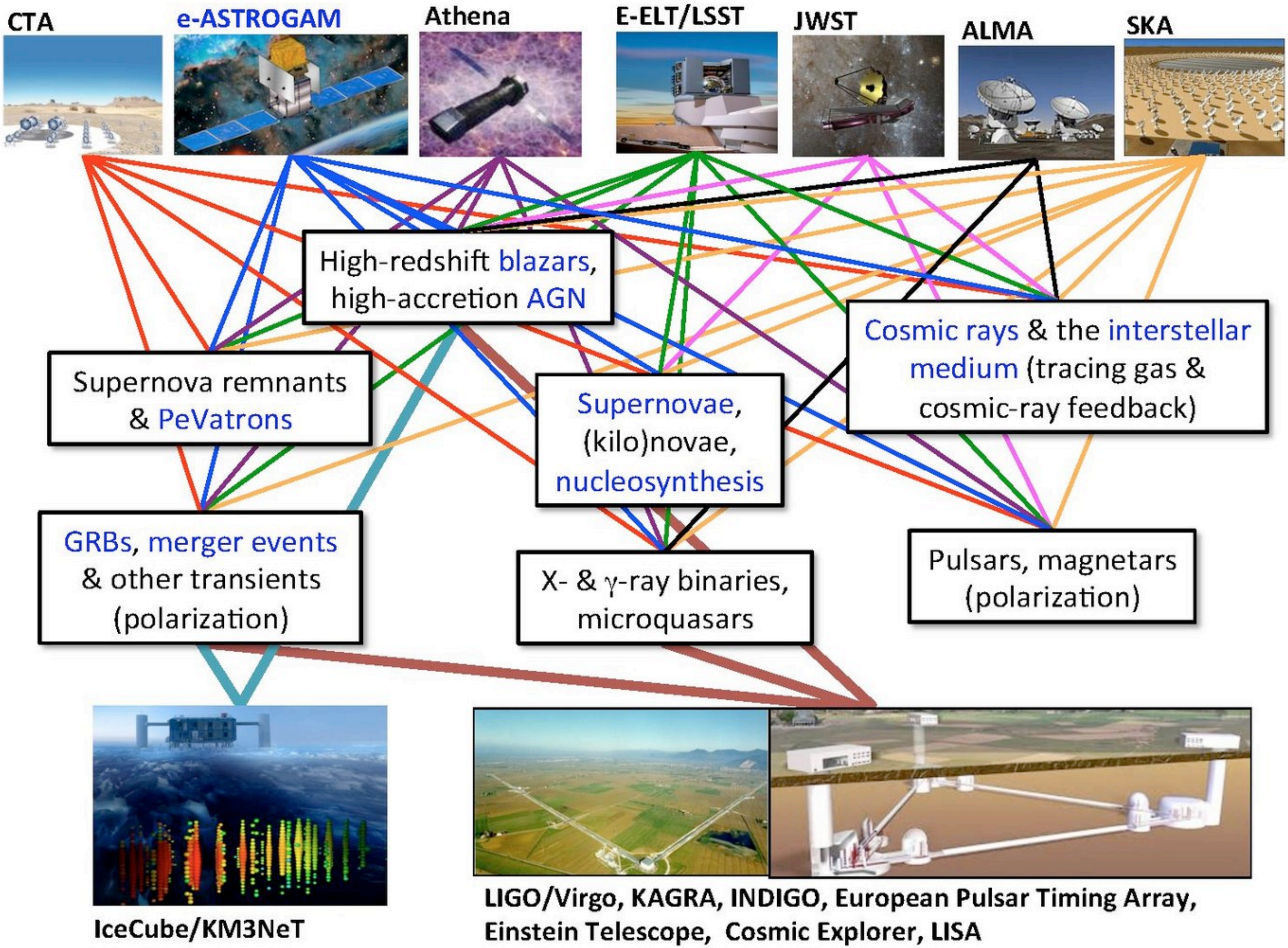
- Angular resolution improved close to the physical limits



Energy resolution

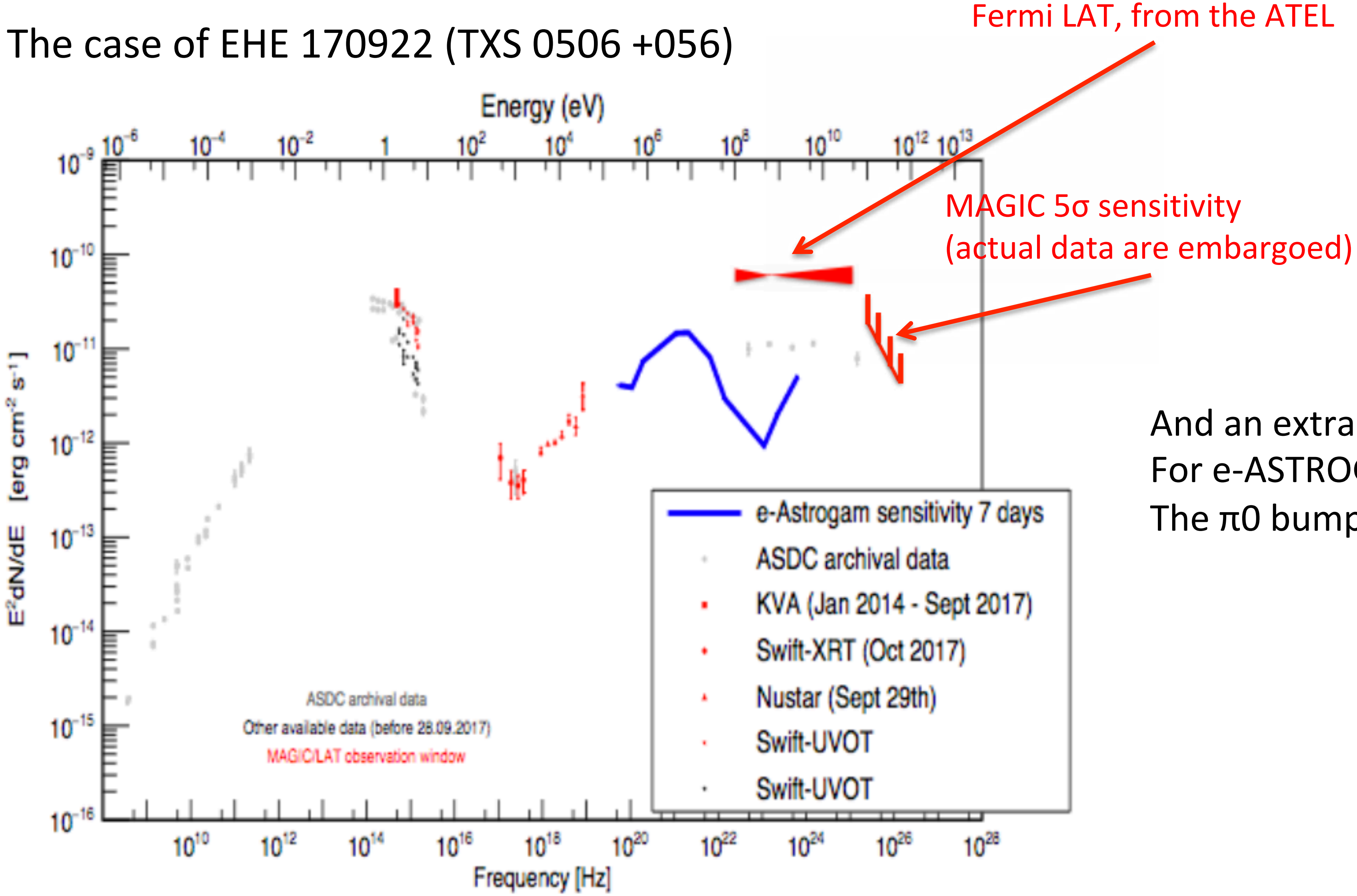
ΔE/E (Gamma-ray imager)	2.5% at 1 MeV 30% at 100 MeV
ΔE/E (Calorimeter burst)	< 25% FWHM at 0.3 MeV < 10% FWHM at 1 MeV < 5% FWHM at 10 MeV




CTA
e-ASTROGAM
Athena
E-ELT/LSST
JWST
ALMA
SKA
High-redshift blazars, high-accretion AGN
Supernova remnants & PeVatrons
Cosmic rays & the interstellar medium (tracing gas & cosmic-ray feedback)
Supernovae, (kilo)novae, nucleosynthesis
GRBs, merger events & other transients (polarization)
X- & γ-ray binaries, microquasars
Pulsars, magnetars (polarization)
IceCube/KM3NeT
LIGO/Virgo, KAGRA, INDIGO, European Pulsar Timing Array, Einstein Telescope, Cosmic Explorer, LISA

Multimessenger Astronomy: Neutrinos

- Are AGN sources of VHE neutrinos and thus of UHECR?
- The case of EHE 170922 (TXS 0506 +056)



And an extra lever arm
For e-ASTROGAM:
The π0 bump

Multimessenger Astronomy: Gravitational Waves

- wide FoV, prompt detection, localization
- detection of (1.2 − 18) NS-NS mergers/year with GW after KAGRA + INDIGO (and NS-BH?)

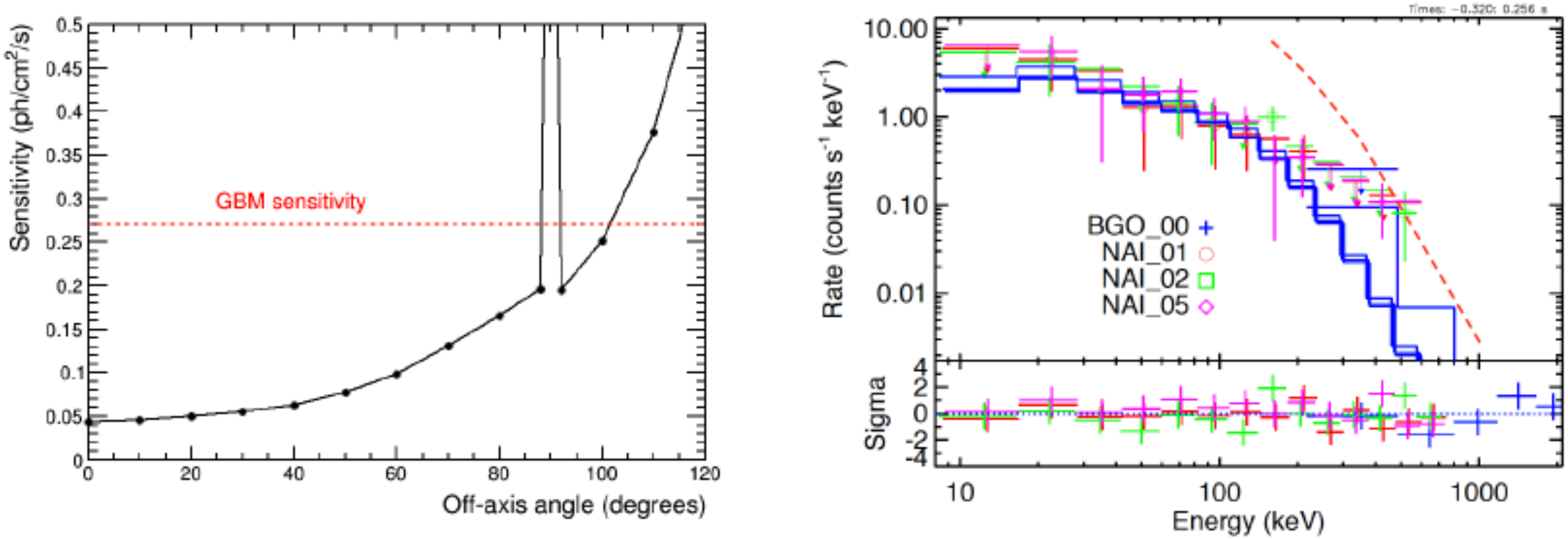


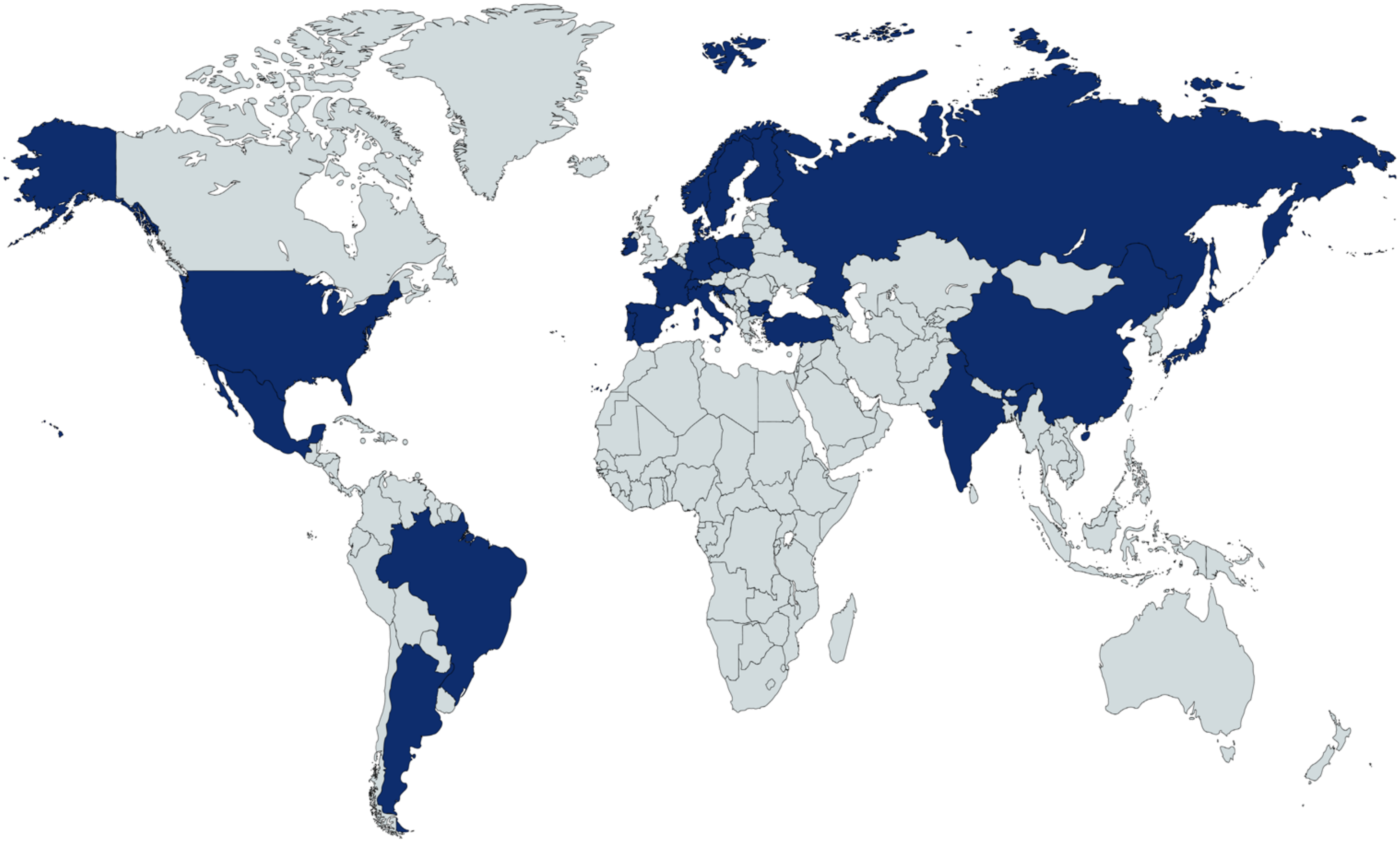
Figure 2.1.2: Left: $6\,\sigma$ sensitivity of e-ASTROGAM to an average GRB on a 1 second timescale in the 0.2–2 MeV band. The sharp loss of sensitivity at 90° incidence is due to gamma-rays crossing the tracker parallel to the silicon detectors. The red line gives the equivalent trigger sensitivity of *Fermi* GBM, adapted from [49]. Right: the flux from the hard component of GRB170817A as recorded from *Fermi* GBM (solid blue line), and a conservative extrapolation (20x) to an on-axis flux (dashed red line).

e-ASTROGAM Observatory science

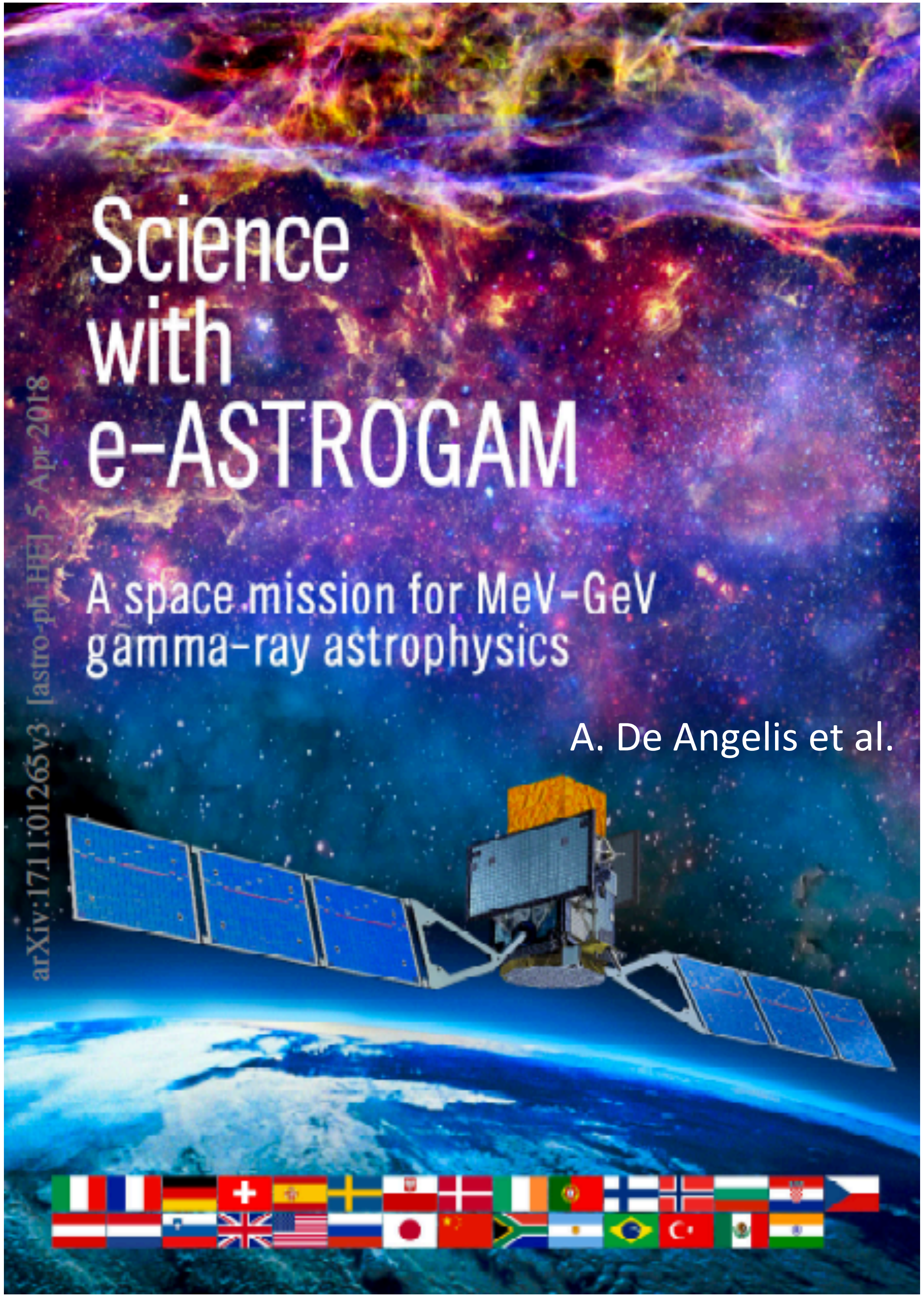
- e-ASTROGAM pointings first focused on core science topics. However a very large number of sources will be detected and monitored.
  - e-ASTROGAM will study thousands of sources both Galactic and extragalactic of which many are expected to be new detections. Therefore, a very large community of astronomical users will benet from e-ASTROGAM data available for multifrequency studies through GI programme managed by ESA.
- e-ASTROGAM will detect with unprecedented sensitivity in the MeV-GeV domain phenomena
  - characterized by rapid and very rapid variability timescales (sub-second, second, minutes, hours): GRB, AGN flares, …
  - steady sources

Type	3-yr	New sources
Total	~ 860-1210	~ 600 (including 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	

Wide interest for e-ASTROGAM



>400 collaborators from institutions in 24 countries; White Book published (>200 pages)



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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]
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A. Caccianiga,[24] S. Camera,[65,66,67,68] R. Campana,[16] P. Caraveo,[69] M. Cardillo,[8] P. Carlson,[21] S. Celestin,[70]
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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]
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D. H. Hartmann,[26] M. Hayashida,[99] A. Hryczuk,[64] P. Jean,[15] T. Johnson,[100] J. José,[101] S. Kaufmann,[102]
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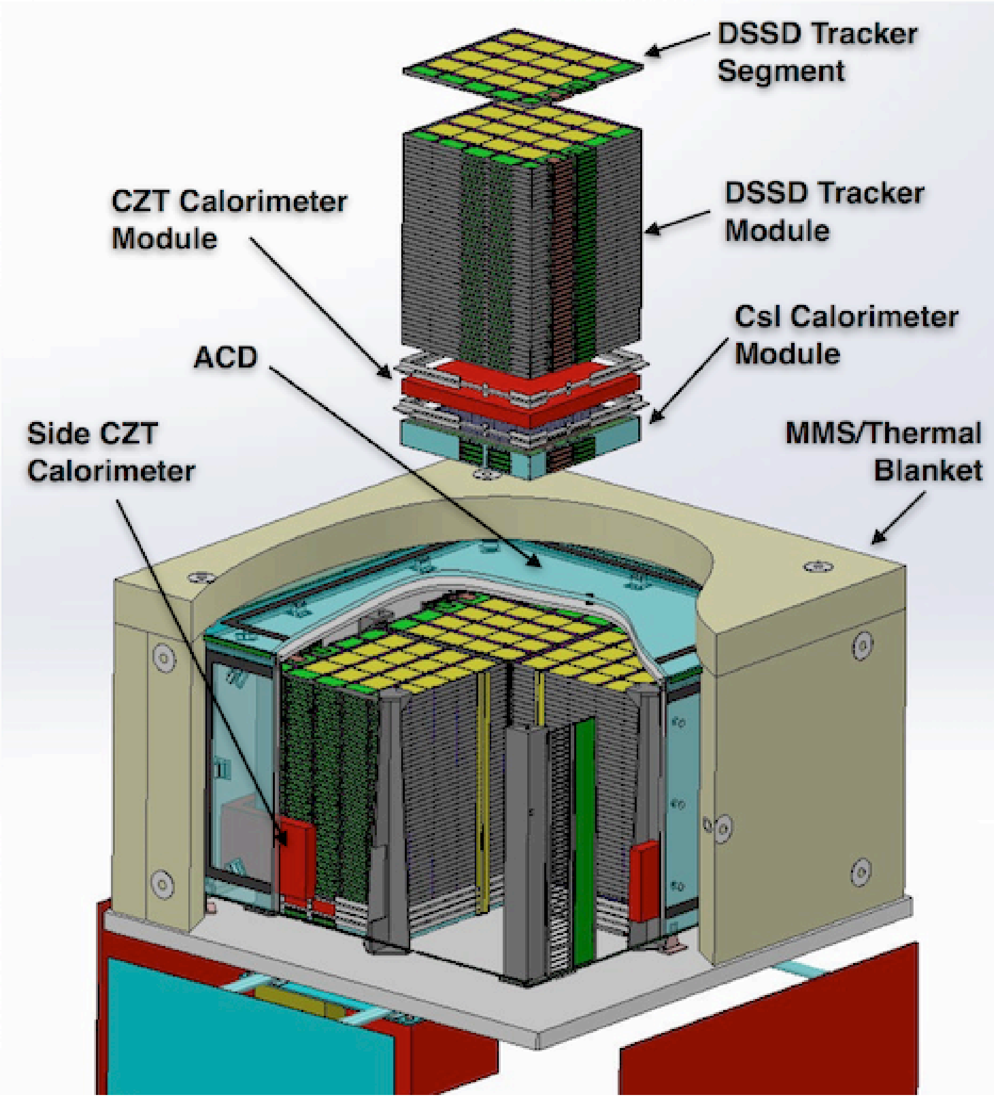
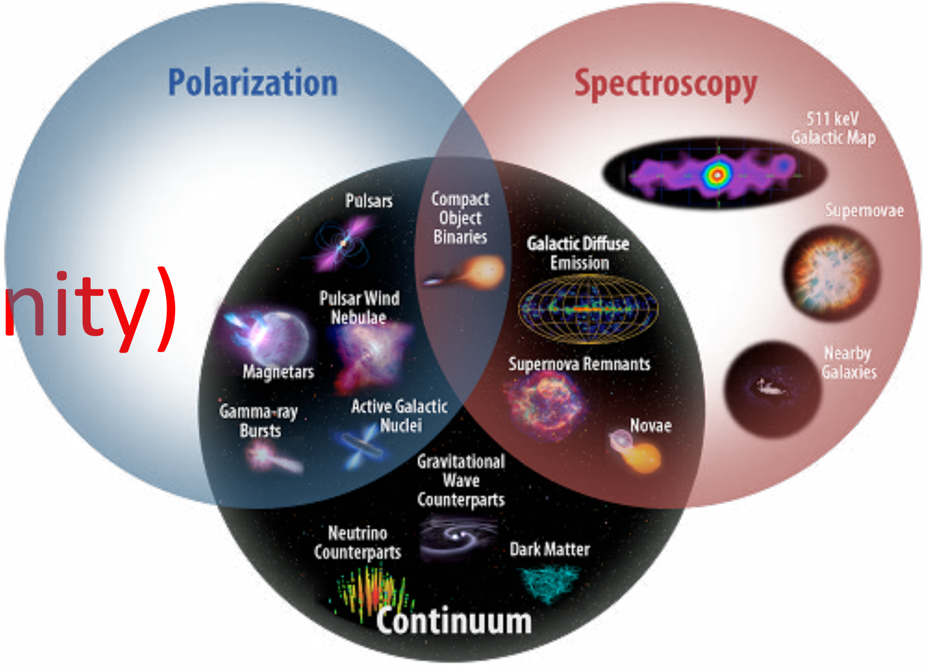
G. Vankova-Kirilova,[59] C. Venter,[58] F. Verrecchia,[44,91] P. Vincent,[146] X. Wang,[147] C. Weniger,[50] X. Wu,[13]
G. Zaharijaš,[148] L. Zampieri,[3] S. Zane,[149] S. Zimmer,[150,13] A. Zoglauer,[151] and the e-ASTROGAM collaboration

White Book published in arXiv
Wide interest from the scientific community

Our sister experiment: AMEGO (NASA)

(two brands, one community)





- ~20% smaller tracker
- CZT calorimeter layer
- In the decadal survey?

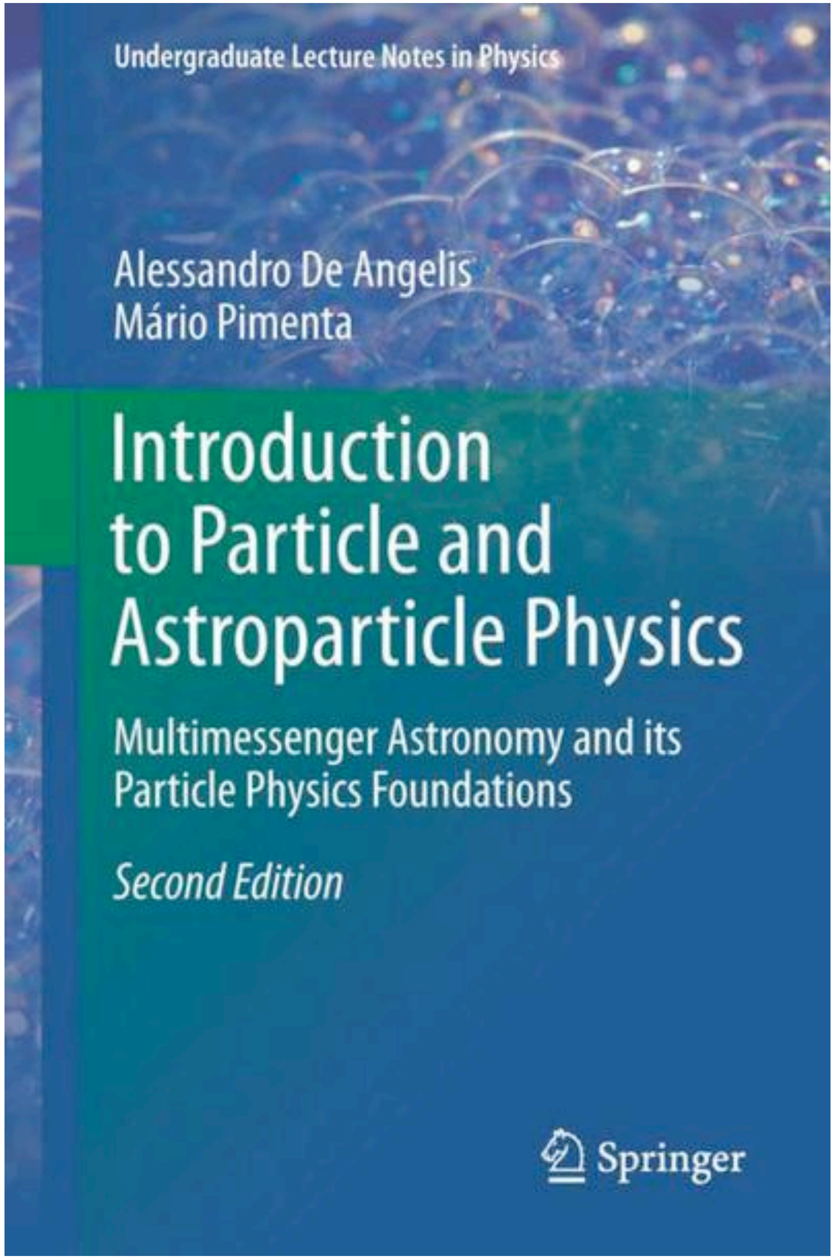
Status of the GammaMeV project

- e-ASTROGAM not selected for ESA M5
  - Excellent report, though; stressed challenging technical solutions
- Next chances:
  - AMEGO: decadal review in 2019
  - Discussions for a possible integration in HERD
  - Discussions for a possible Russian launcher (meeting with the Director of RosCosmos end October)
- Work going on: Improving technical readiness
  - Test beam at CERN in October / balloon at NASA next year

	CTA	FERMI	GAMMAMEV	ALTRE	NOTE	TOT
XIAO			100			
RANDO		50	50	10	Altre= Comm 5	110
BAIBUSSINOV			30			30
DE ANGELIS	50	20	30	10	Altre= Comm 5	110
MALLAMACI	70		30			100
MARIOTTI	70		30			100

BACKUP

A BOOK COMING SOON



- On sale from June 16, 2018
- Provides a balanced, university-level introduction to particle physics, astroparticle physics and multimessenger astrophysics
- Exercises site at the web address

  ipap.uniud.it

Core science motivation

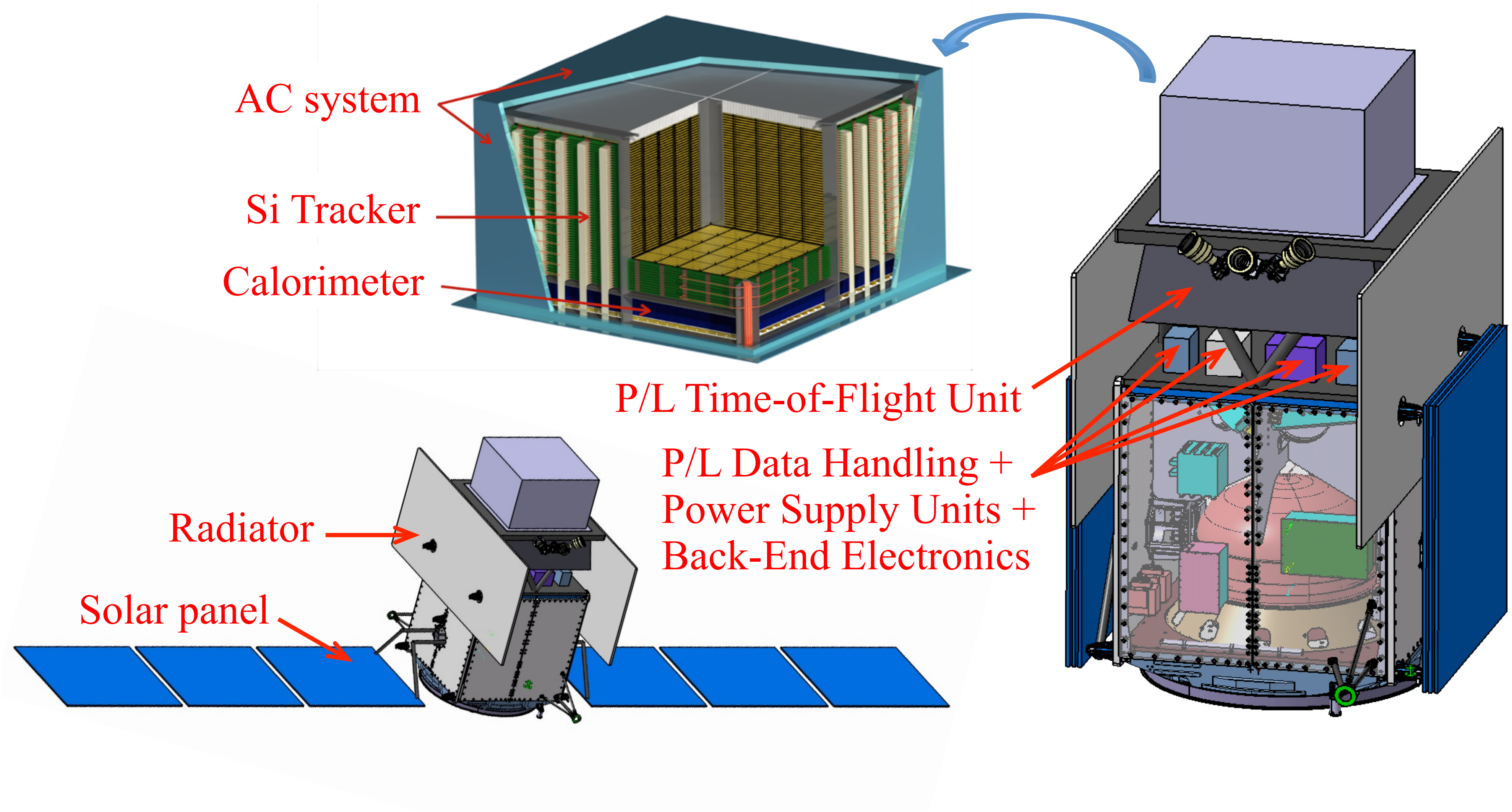
1. Processes at the heart of the extreme Universe (AGNs, GRBs, microquasars): prospects for the Astronomy of the 2030s
   - Multi-wavelength, multi-messenger coverage of the sky (with SKA, JWST, E-ELT, Athena, CTA, ν and GW detectors...), w/ special focus on transient phenomena

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

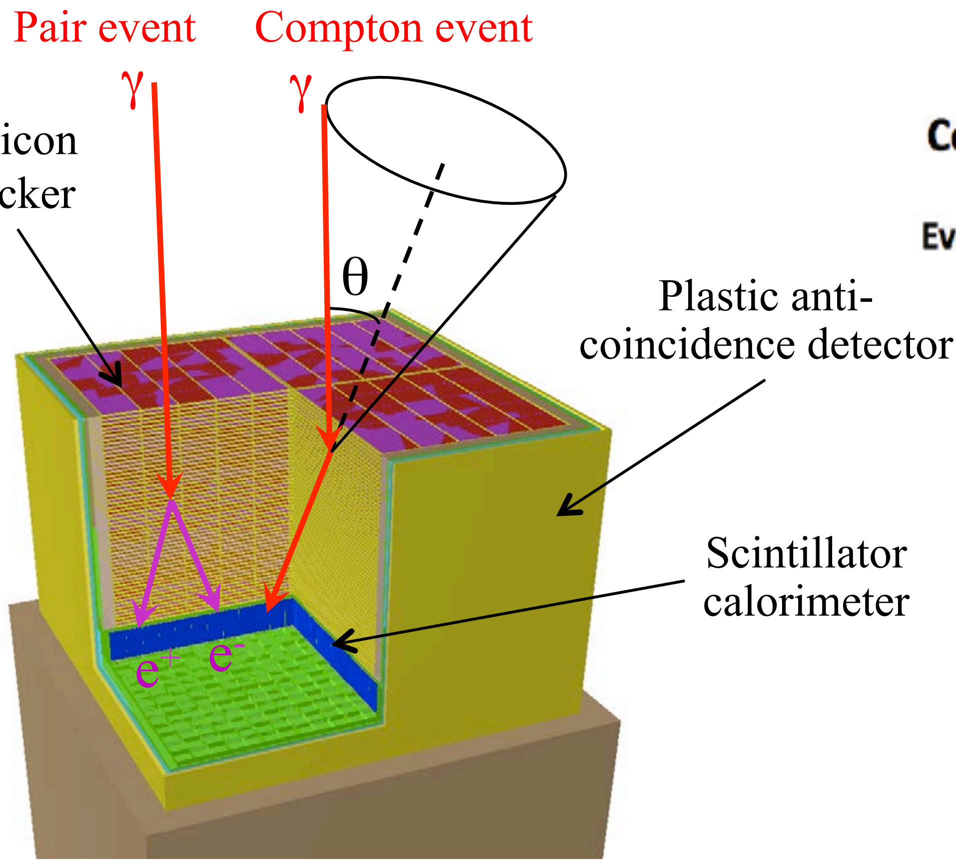
3. Nucleosynthesis and the chemical enrichment of our Galaxy

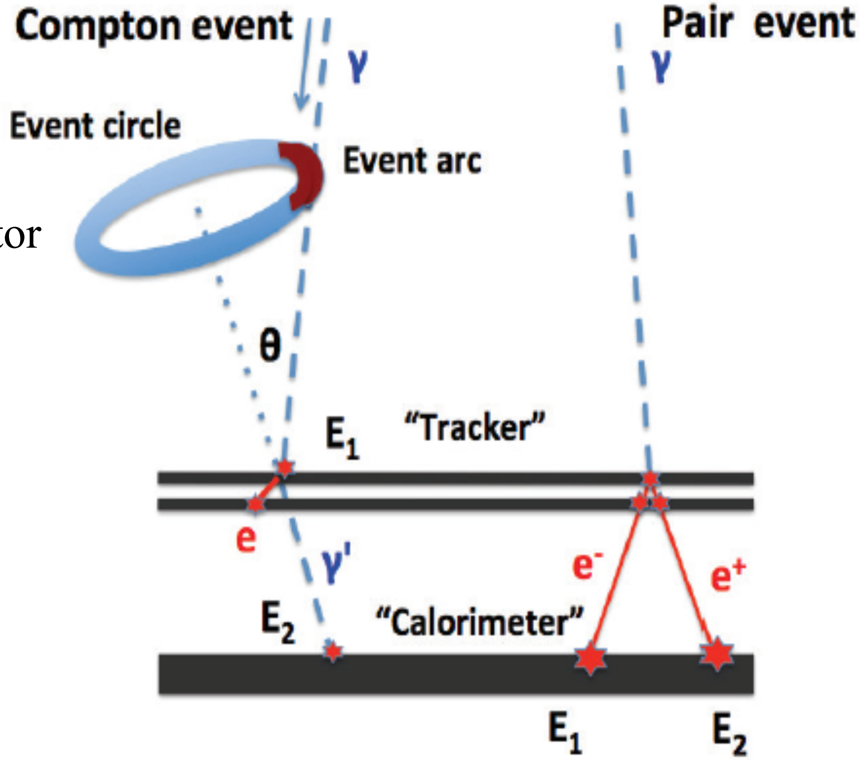
e-ASTROGAM satellite

- Arrangement of the Thales Alenia Space PROTEUS 800
  - Platform developed in the frame of the SWOT CNES/NASA program
- Spacecraft dry mass 2.4 t. Telescope mass 1.2 t



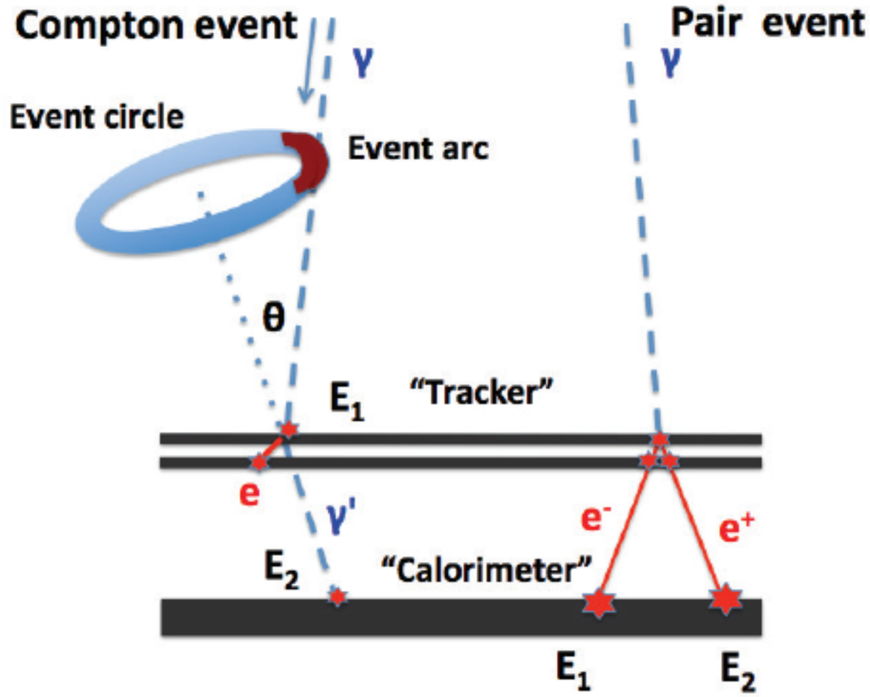
How to measure gamma rays in the MeV-GeV?





- 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

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



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

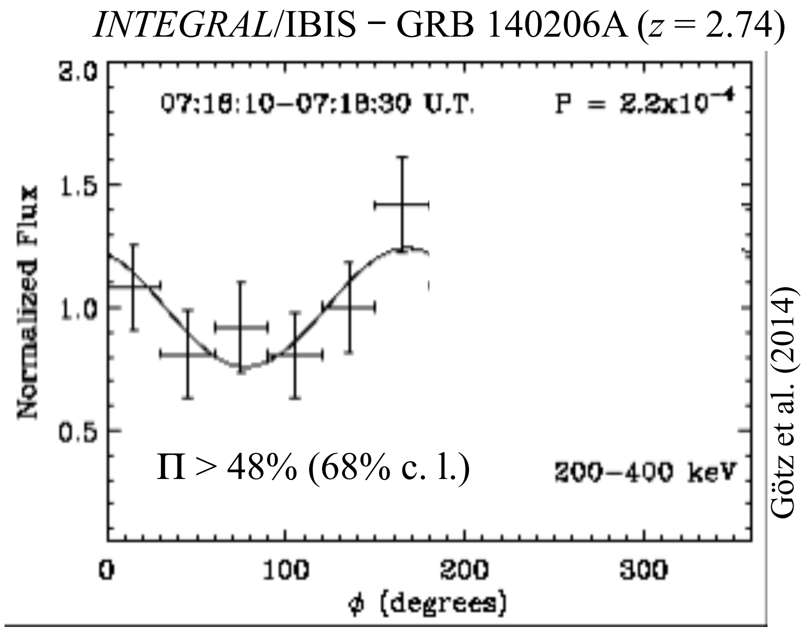
p in MeV

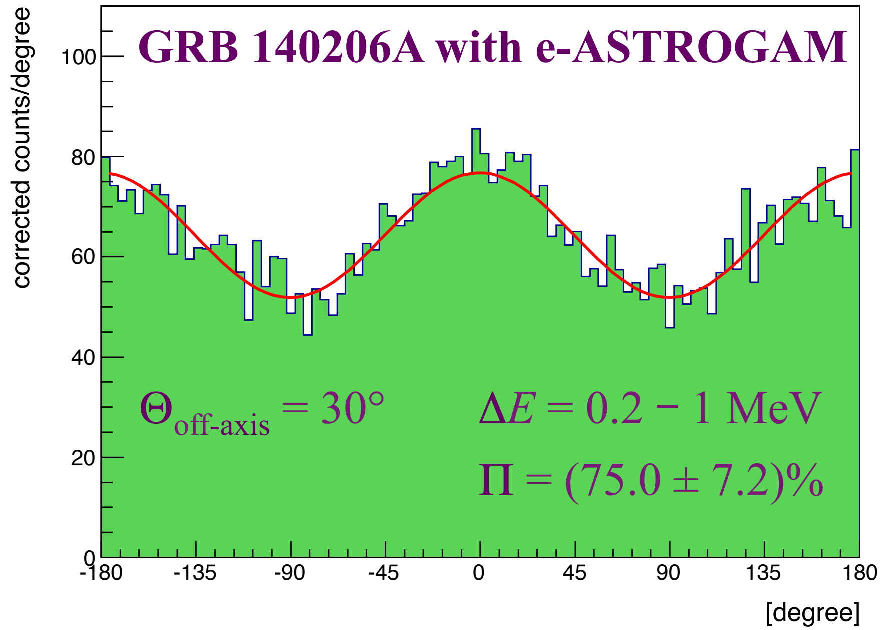
Gamma-ray polarization

- 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)





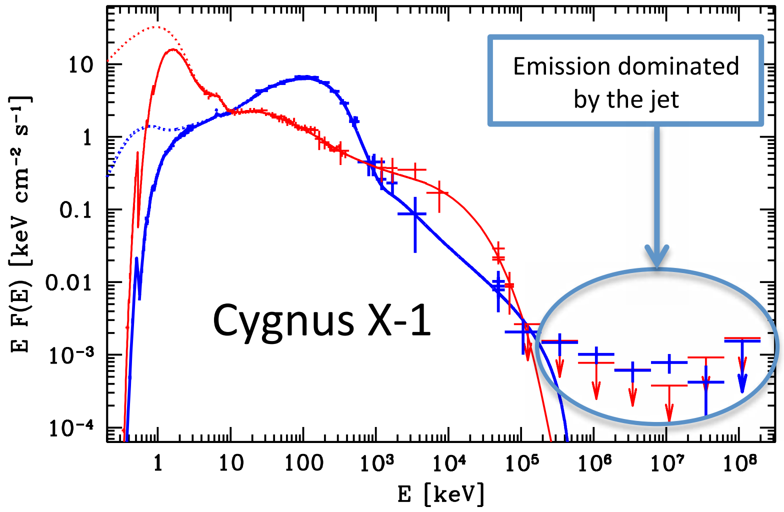
Compact Object Physics

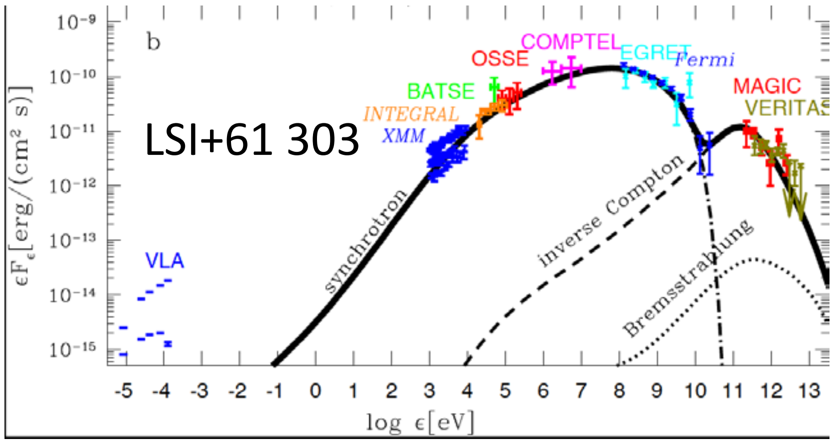
Microquasars and Galactic X-ray sources: how can we contribute ?

- Characterizing the physics behind the MeV-GeV emission when accretion and jets are present (e.g., distinguishing between accretion and jet emission) (Top figure: Cygnus X-1, hard-state and soft state)

- Discerning between accreting (microquasars) and non-acreting sources (pulsar gamma-ray binaries) by their crutially different spectral features in the MeV-GeV range (compare top figure with bottom figure, LSI+61303)

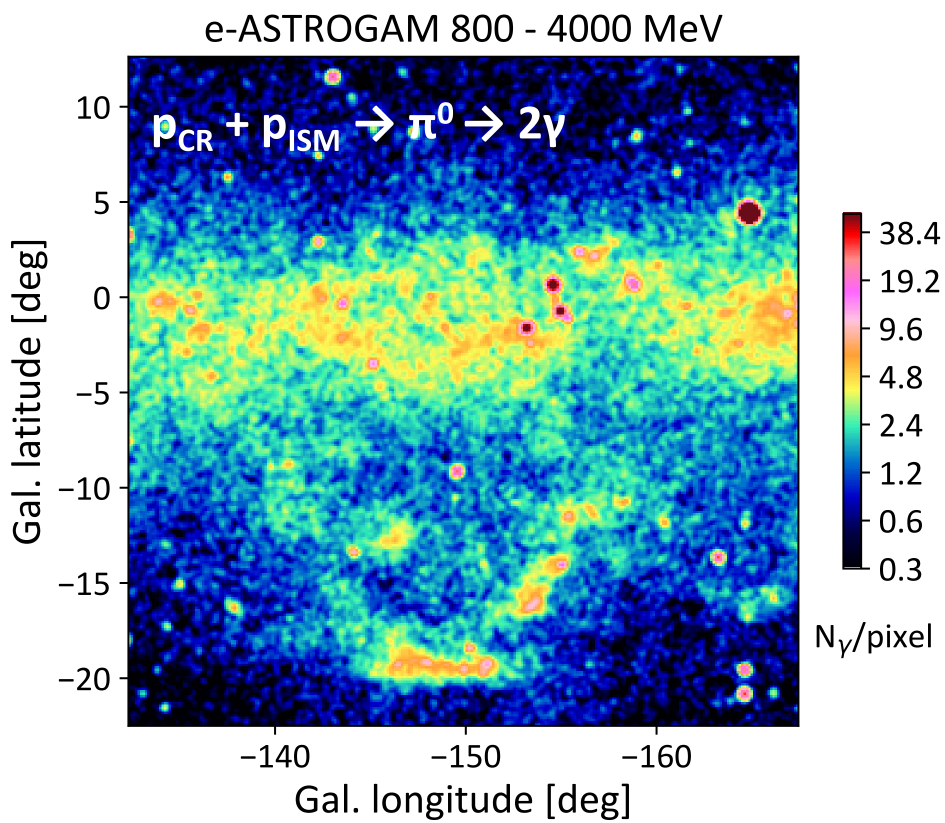
- e-ASTROGAM can discover new gamma-ray binaries, as they are bright at ~ 10 MeV and the sensitivity will be ~100 times better. Peaking at the MeV range (see bottom figure), will allow e- ASTROGAM to unveil the source dominant non-thermal physics.

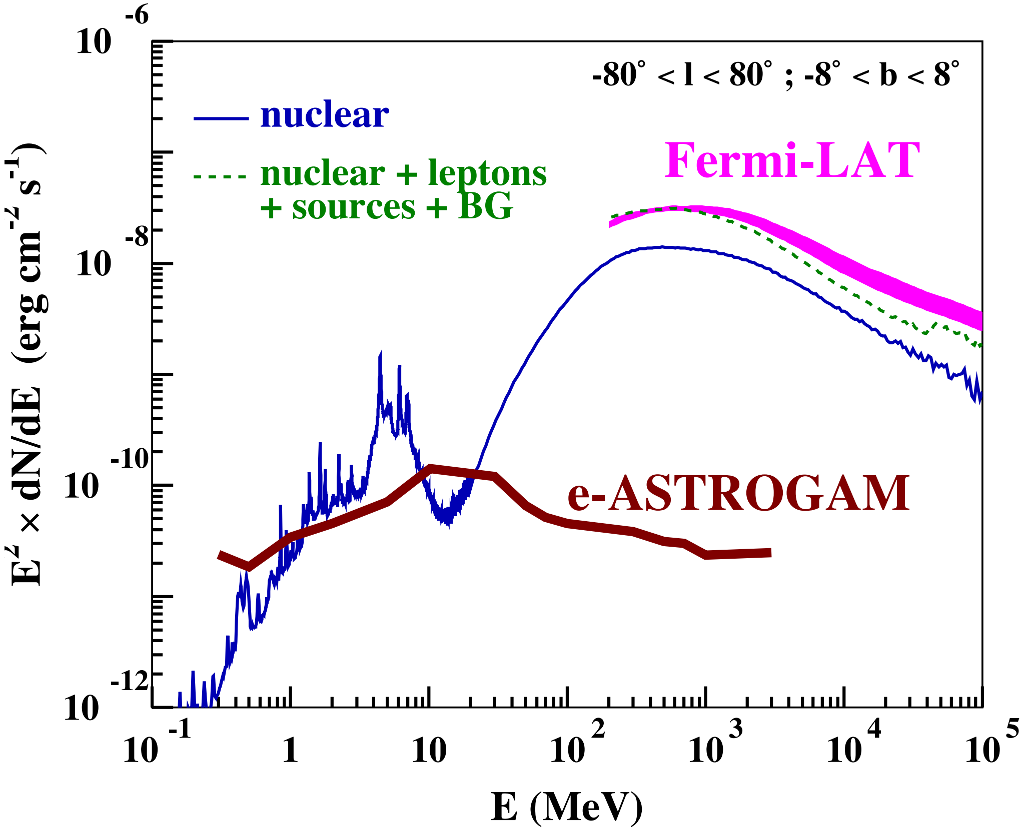




Cosmic rays & the evolution of galaxies

- Understand the CRay feedback on star formation, ISM structures, galactic winds, & B-field growth
- Reveal the GeV (pressure) and sub-GeV (heat, ionization) CRays in the Galactic ISM, & diffusion properties in different environments
- Gauge non-linear gas tracers (dust properties per gas nucleon & CO-to-H_2 ratio) in different environments using CRays





Summary: e-ASTROGAM

Will reveal the hardly explored and rich MeV sky and the GeV sky, detecting thousands of sources, from NS to BHs, from CRs in gas clouds to SNRs in an energy range never fully explored before, with polarimetric measurements

Uncover the largest part of non-thermal particles and their impact on their environment (jets, cosmic-ray feedback)

Detect & localize γ-ray transients for Athena & CTA, and in the era of astronomy's new messengers, GW and neutrinos in particular

The e-ASTROGAM payload is innovative in many respects, but the technology is ready & reliable

Can be the only observatory in space exploring the crucial MeV-GeV region, and will be an important piece contributing to the European leadership in science & technology in a strategic field.

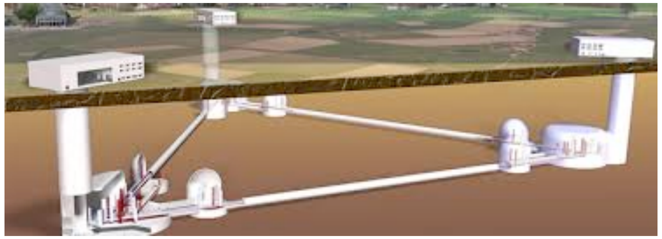
A unique Observatory in synergy with the astrophysics of the 2030s

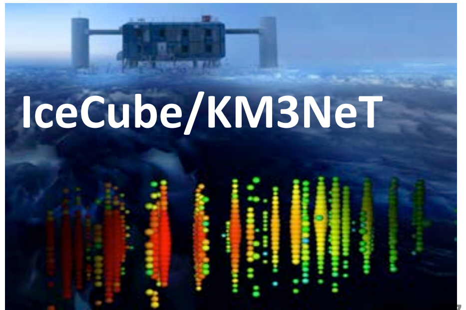
1. Processes at the heart of the extreme Universe (AGNs, GRBs, microquasars): prospects for the Astronomy of the 2030s
    - Multi-wavelength, multi-messenger coverage of the sky (with SKA, JWST, E-ELT, Athena, CTA, ν and GW detectors...), with special focus on transient phenomena

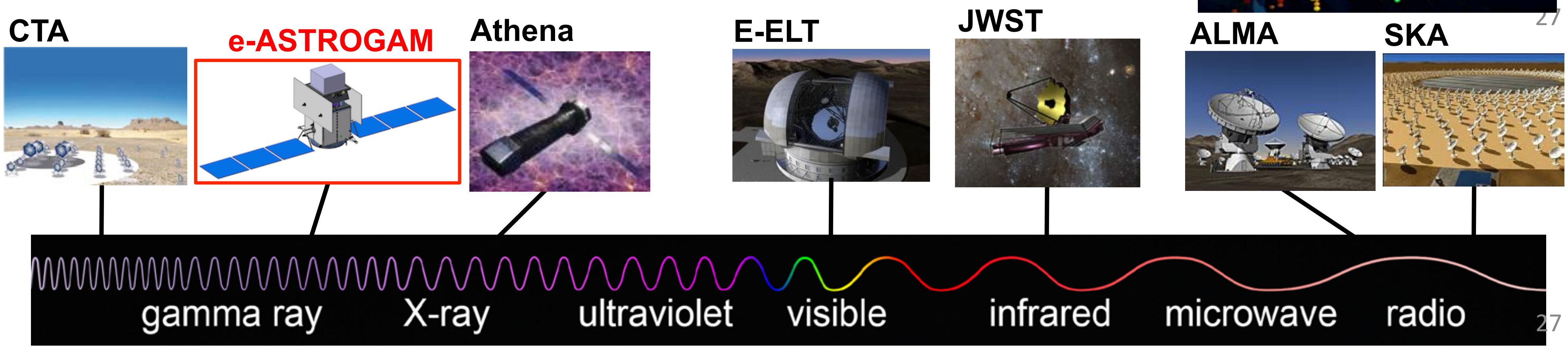
2. The origin of high-energy particles and impact on galaxy evolution, from cosmic rays to antimatter

3. Nucleosynthesis and the chemical enrichment of our Galaxy

Einstein Telescope, Cosmic Explorer, LISA?







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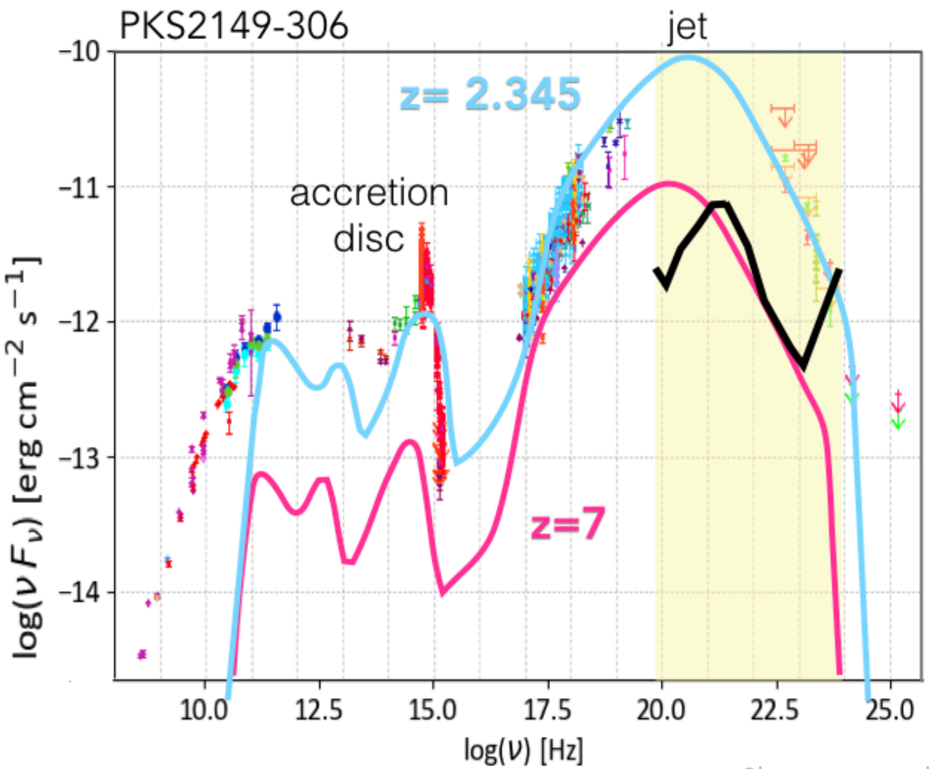
#1 Jets and acceleration from supermassive BHs at high z

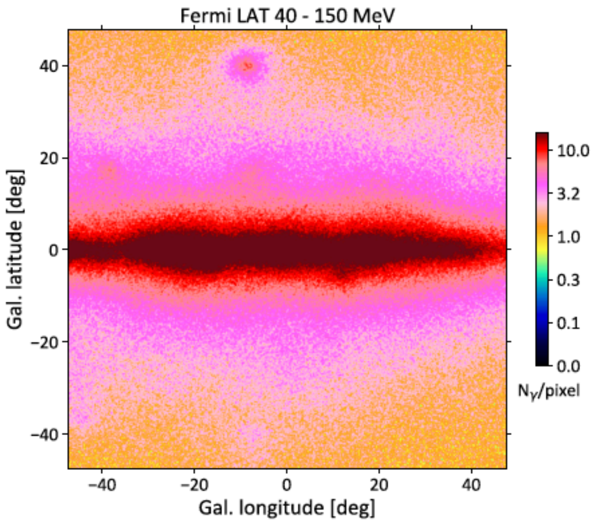
- Why did the most luminous, jetted AGN form earlier? with mass > 10^9 $M_\odot$?
- Jet power vs. accretion power? (L_X Athena, …)
- e-ASTROGAM: > 1000 detections with 60% below 100 MeV

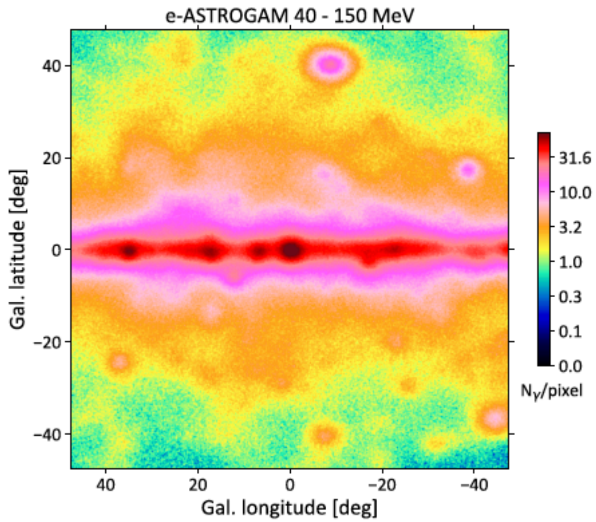


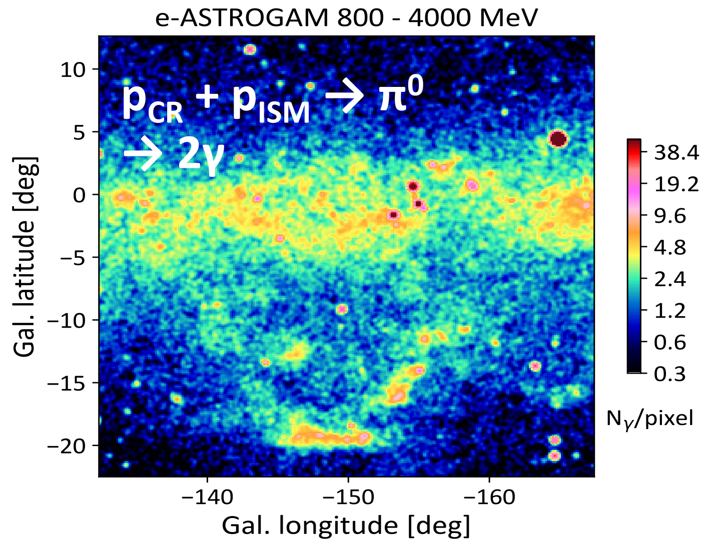
Sbarrato, et al., 2013

#2 Cosmic rays & the evolution of galaxies

- Understand the CRay feedback on star formation, ISM structures, galactic winds, & B-field growth
- Reveal the GeV (pressure) and sub-GeV (heat, ionization) CRays in the Galactic ISM, & diffusion properties in different environments
- A unique tracer of the number of nucleons in all phases of the ISM





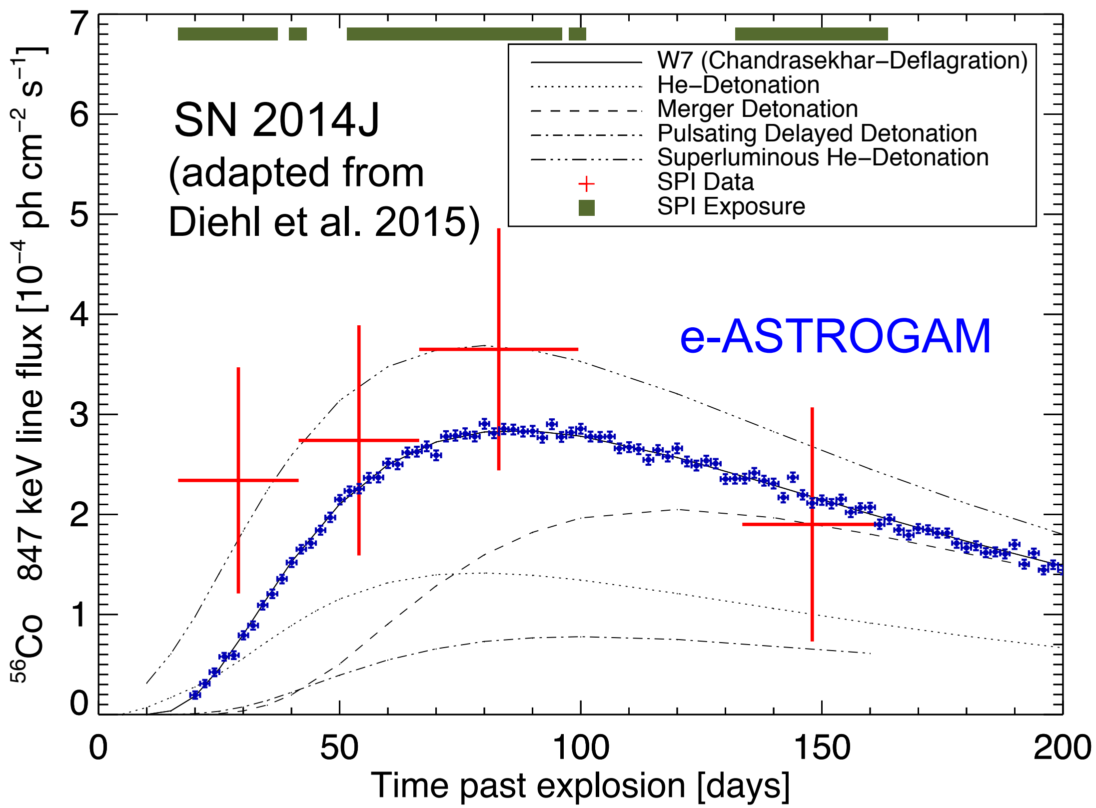


e-ASTROGAM core science topic #3

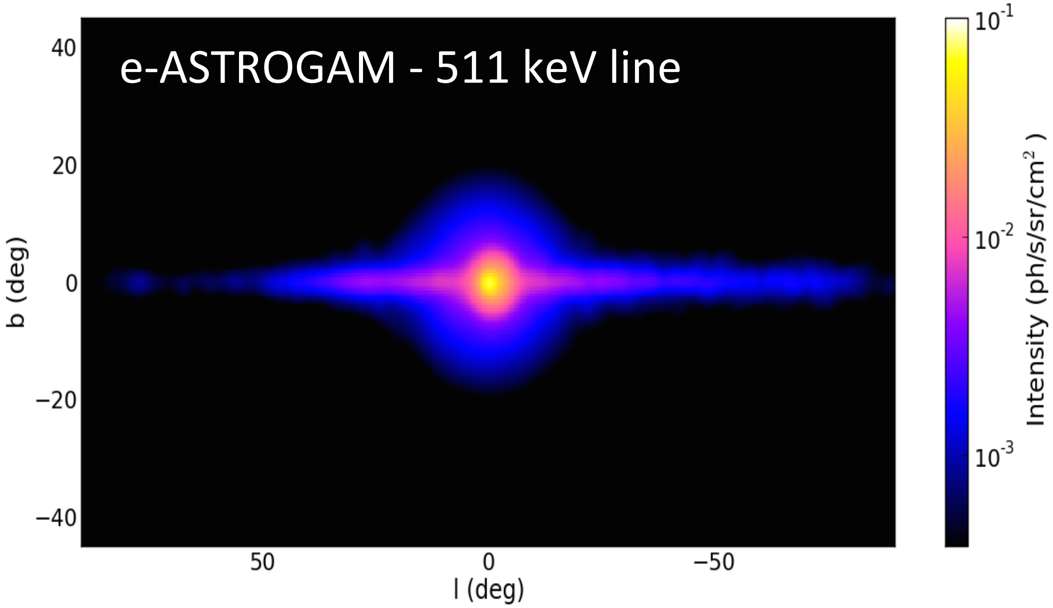
Supernovae, nucleosynthesis, and Galactic chemical evolution

- *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...)



…and the 511 keV line



e-ASTROGAM Observatory science (2)

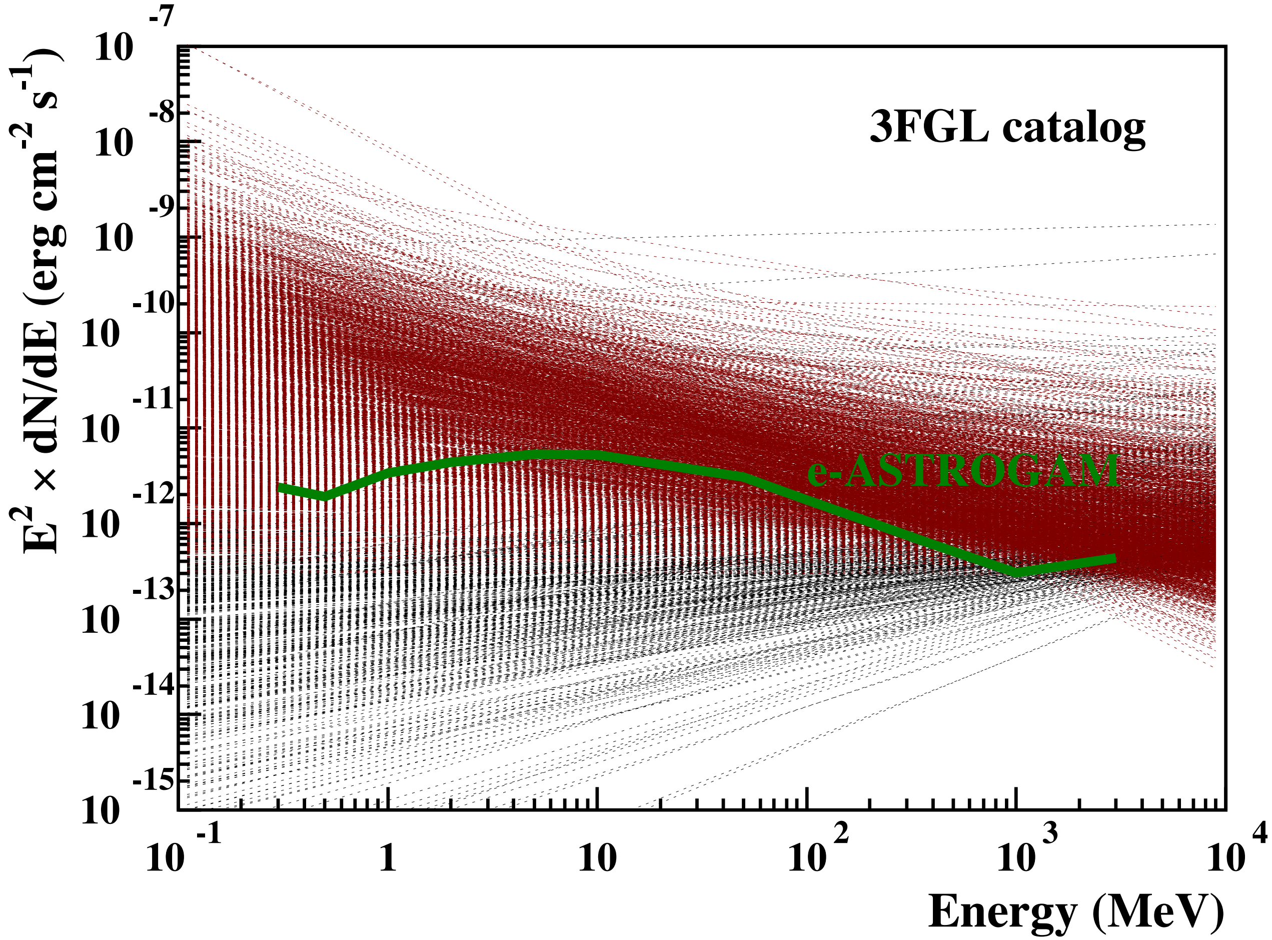
- **Diffuse Galactic gamma-ray background**: e-ASTROGAM can determine the underlying CR population and spatial and spectral variations across the Galaxy.
- **Pulsars** and millisecond pulsars both isolated and in binaries, whose (pulsed or unpulsed) emission will be observable in a spectral range rich in information to discriminate between different particle acceleration models.
- **PWNe**, a product of the interaction between shocked relativistic pulsar winds and the ISM, for which e-ASTROGAM will obtain crucial data on particle acceleration and propagation.
- **Magnetars**, enigmatic and strongly variable compact stars characterized by very strong magnetic elds that exhibit special phenomena exclusively in the MeV energy range.
- **Galactic compact binaries**, including white dwarfs, neutron stars and solar mass black holes whose spectral transitions and outbursts in the MeV range will be systematically monitored by e-ASTROGAM .
- **Classical novae**, that in addition to line emission in the MeV range can also be studied for their surprising and poorly understood gamma{ray emission up to hundreds of MeV, a product of shock interaction of the nova ejecta with the local ISM.

e-ASTROGAM Observatory science (3)

- **Interstellar shocks**, such as the Cygnus cocoon showing the existence of particle acceleration over large distances in the ISM, for which the spectral and angular resolution of e-ASTROGAM will be unique.
- **Blazar population studies** in the MeV range, to be obtained by the detection capability of thousands of sources by e-ASTROGAM.
- **Studies of the propagation of gamma rays over cosmological distances**, for which the attenuation is predicted to be negligible in standard QED - effects of absorption might indicate new physics at work, possibly the existence of axion-like-particles coupling to gamma{rays.
- **Solar flares and contribution to "SpaceWeather"**, that will be studied with unprecedented line emission and continuum capability for theoretical modeling as well as fast reaction for alerts.
- **Terrestrial Gamma-Ray Flashes**, an atmospheric phenomenon with possible environmental impact for which e-ASTROGAM can provide continuous monitoring (including the 511-keV line detection).

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

Impact of e-ASTROGAM

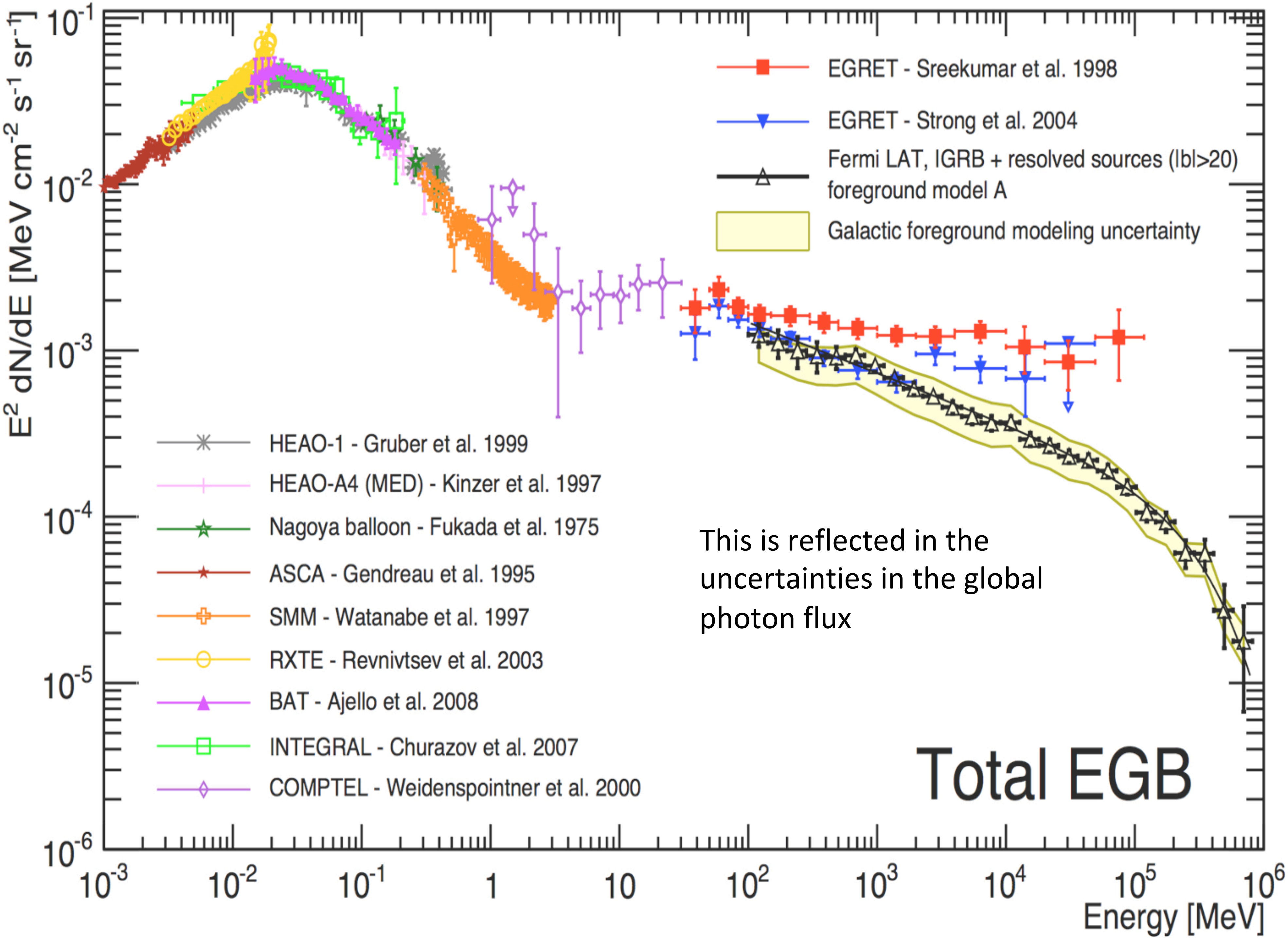
Wide field observatory in the new MeV energy band opens up a large discovery space

The MeV-multiMeV band is crucial for GW and multi-messenger astrophysics (cutoffs of NS-NS and NS-BH mergers)

Breakthrough polarimetric sensitivity achievable for the first time

MeV astronomy is for nuclear processes what optical astronomy is for atomic transitions

Payload innovative in many respects, but the technology is ready & reliable



This is reflected in the uncertainties in the global photon flux