

Astrophysics with Gamma Rays in the MeV Region: e-ASTROGAM and AMEGO

**Dave Thompson, NASA/GSFC, for the e-ASTROGAM and
AMEGO Collaborations**

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e-ASTROGAM Collaborations**

Outline

**Introduction to MeV astrophysics – Dave
e-ASTROGAM plans and status – Dave**

**Science goals for an MeV mission – Julie
AMEGO plans and status – Julie**

e-ASTROGAM and AMEGO

Similar science goals
Similar detector technologies
Overlapping participant lists
Similar time frame (late 2020s)

Why two projects?

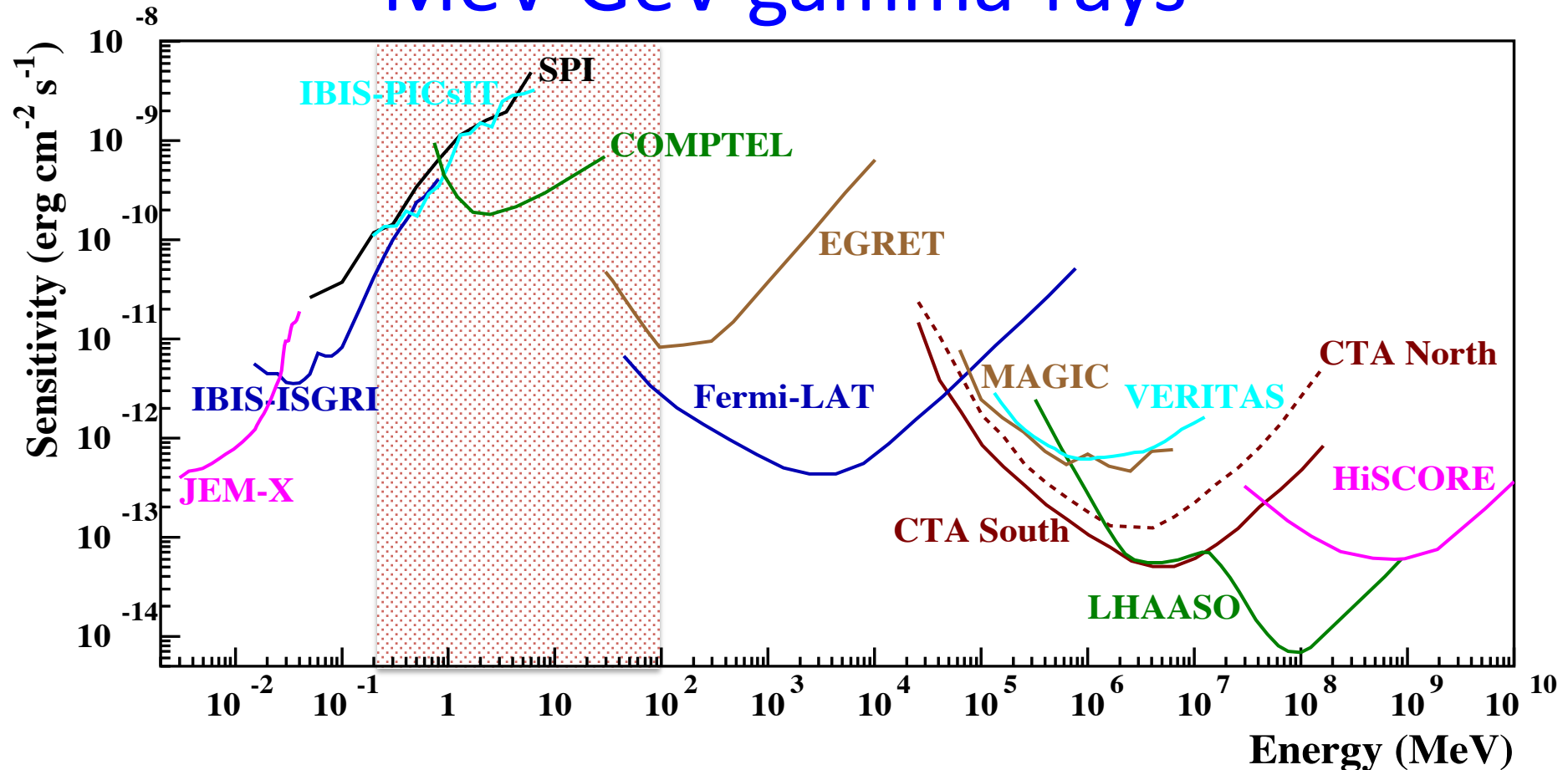
The science for e-ASTROGAM and AMEGO is sufficiently compelling that we did not want to miss any opportunity to have a mission selected and launched.

e-ASTROGAM has already been proposed in response to the ESA M5 call.

AMEGO is being prepared to respond to a probe-class call from NASA.

GammaSIG Meeting, AAS-Washington, Jan. 2018

MeV-GeV gamma-rays



- Poorly covered part of the electromagnetic spectrum: 0.1-100 MeV
- Many objects have peak emissivity in this range (GRBs, blazars, pulsars...)
- The MeV range is the domain of nuclear gamma-ray lines (supernovae, nucleosynthesis and Galactic chemical evolution). MeV astronomy is for nuclear physics what optical astronomy is for atomic physics.
- Transition range between thermal and non-thermal sources.

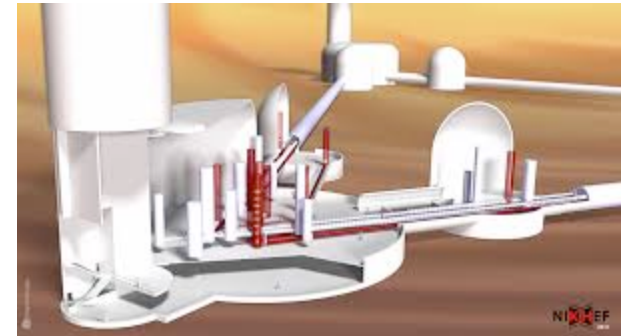
Where does the sensitivity in the MeV region make the difference?

- The hard X-ray and GeV skies look different: only 9% of the GeV pulsars and 5% of the GeV AGN have been detected around 100 keV; conversely, only 9% of the hard X-ray sources seen by INTEGRAL and Swift BAT have been detected by Fermi LAT.
- Marked spectral breaks must exist in the MeV band for most gamma-ray sources.

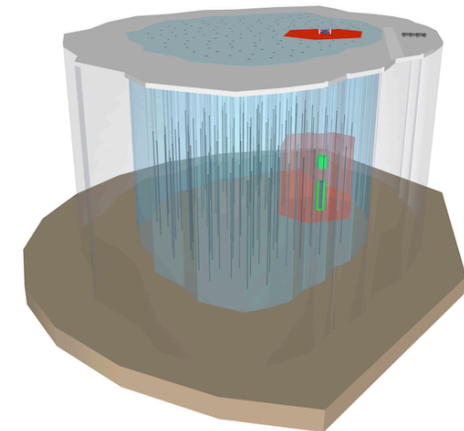
Core science motivation

1. Processes at the heart of the extreme Universe (AGNs, GRBs, microquasars): prospects for the Astronomy of the 2030s
 - MW, multi-messenger coverage of the sky (with CTA, SKA, ET, LISA, ν 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

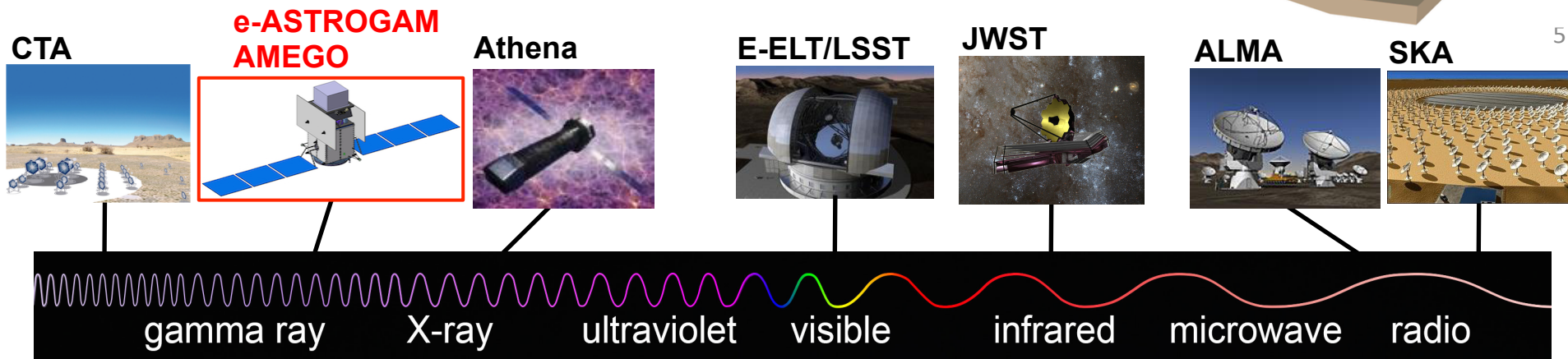
ET, CE, LISA... – Gravitational waves



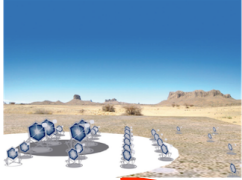
Km3Net/IceCube-Gen2 - ν



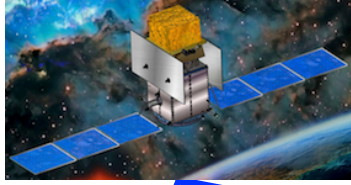
Science details in Julie's talk



CTA



e-ASTROGAM



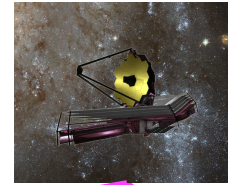
Athena



E-ELT/LSST



JWST



ALMA



SKA



High-redshift blazars,
high-accretion AGN

Supernova remnants
& PeVatrons

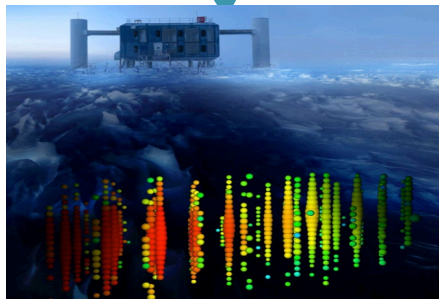
Supernovae,
(kilo)novae,
nucleosynthesis

Cosmic rays & the interstellar
medium (tracing gas &
cosmic-ray feedback)

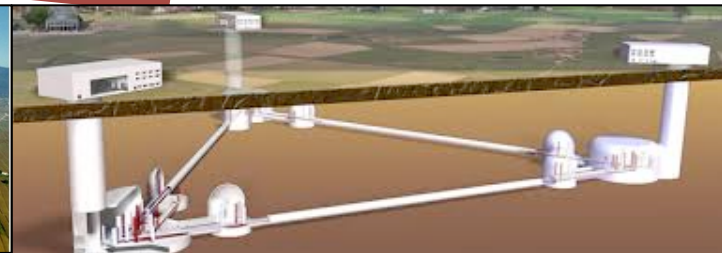
GRBs, merger events
& other transients
(polarization)

X- & γ -ray binaries,
microquasars

Pulsars, magnetars
(polarization)



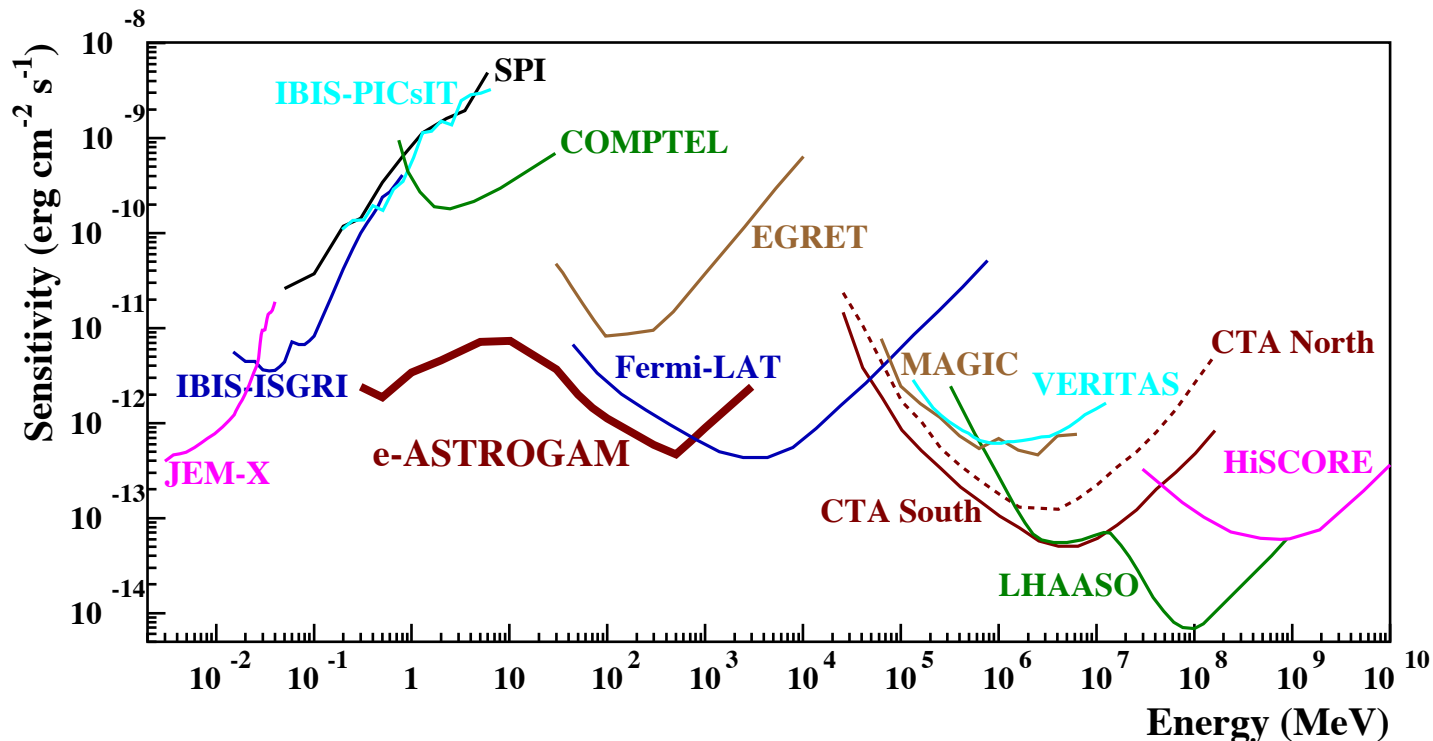
IceCube/KM3NeT



LIGO/Virgo, KAGRA, INDIGO, European Pulsar Timing Array,
Einstein Telescope, Cosmic Explorer, LISA

e-ASTROGAM/AMEGO scientific requirements

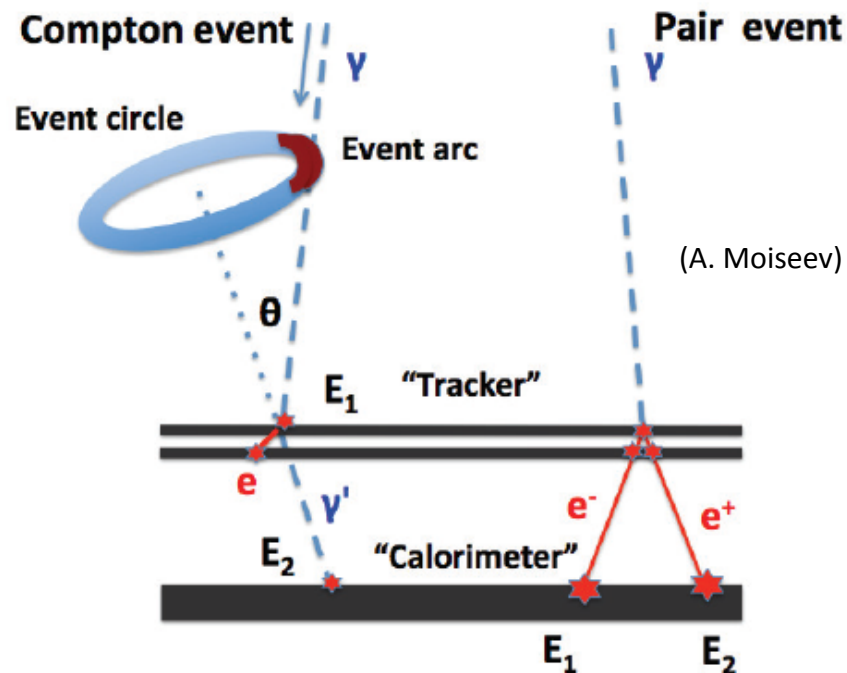
1. Achieve a **sensitivity** better than INTEGRAL/CGRO/COMPTEL by a factor of 20 - 50 – 100 in the range 0.2 – 30 MeV
2. Fully exploit gamma-ray **polarization** for both transient and steady sources
3. Improve significantly the **angular resolution** (to reach, e.g., $\sim 10'$ at 1 GeV)
4. Achieve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



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 Coulomb scattering
 - Main concern is detector layer thickness
- Difficult to be truly optimal in both regimes across the gap with one detector

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



e-ASTROGAM

at the heart of the extreme Universe

<http://eastrogam.iaps.inaf.it>

Detector paper:

<https://arxiv.org/abs/1611.02232>

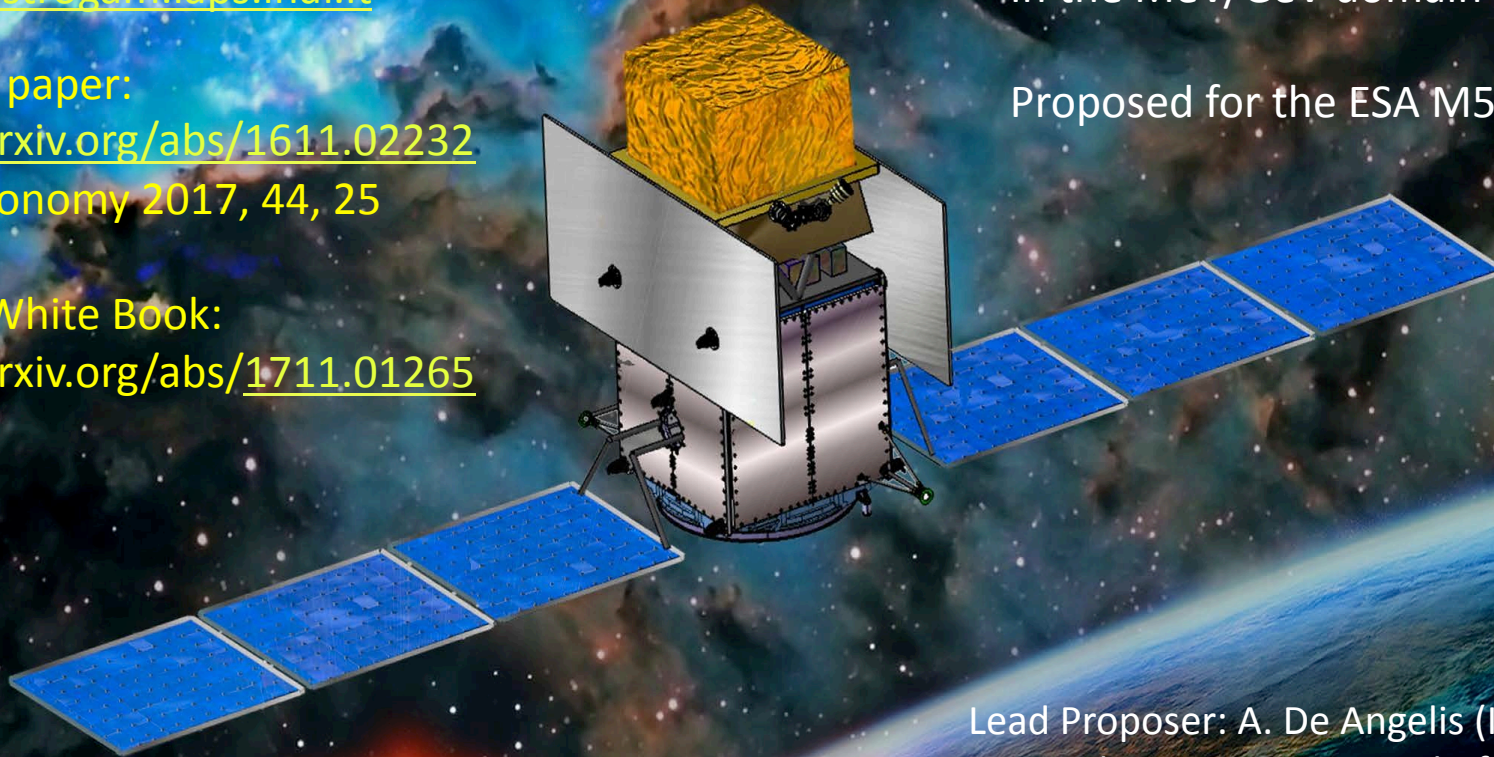
Exp. Astronomy 2017, 44, 25

Science White Book:

<https://arxiv.org/abs/1711.01265>

An observatory for gamma rays
In the MeV/GeV domain

Proposed for the ESA M5 Call



Lead Proposer: A. De Angelis (Italy)
Co-Lead Proposer: V. Tatischeff (France)



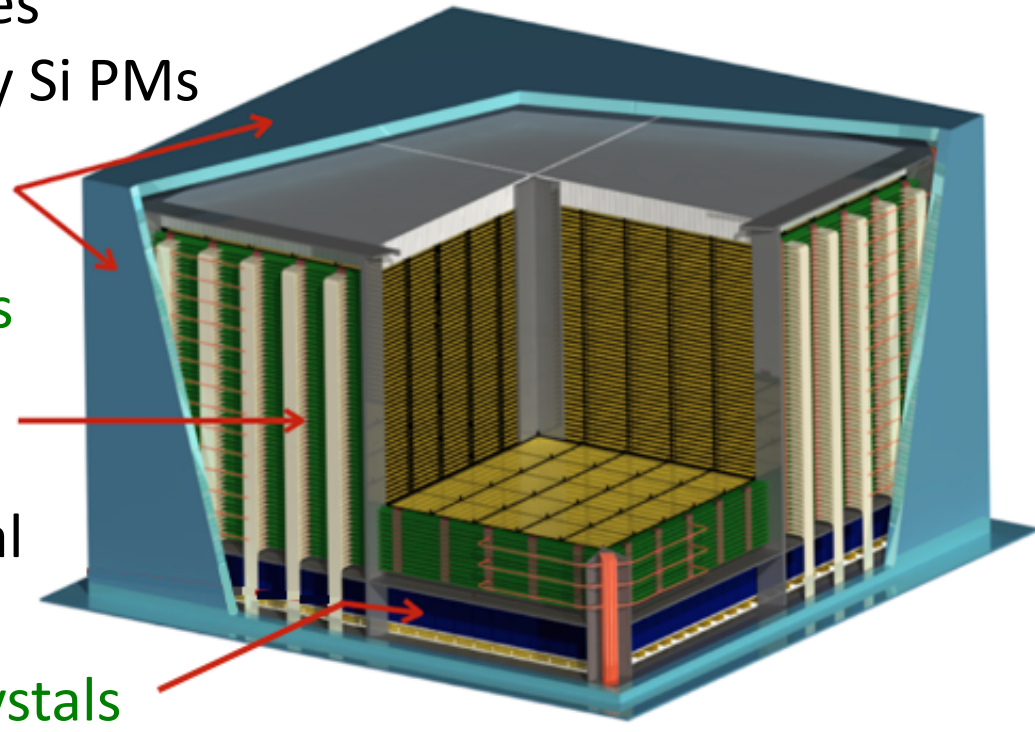
e-ASTROGAM

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
1m², 500 μm thick, 0.3 X₀ total

Calorimeter – CsI(Tl) crystals
readout by Si drift detectors for best $\Delta E/E$,
8 cm (4.3 X₀)

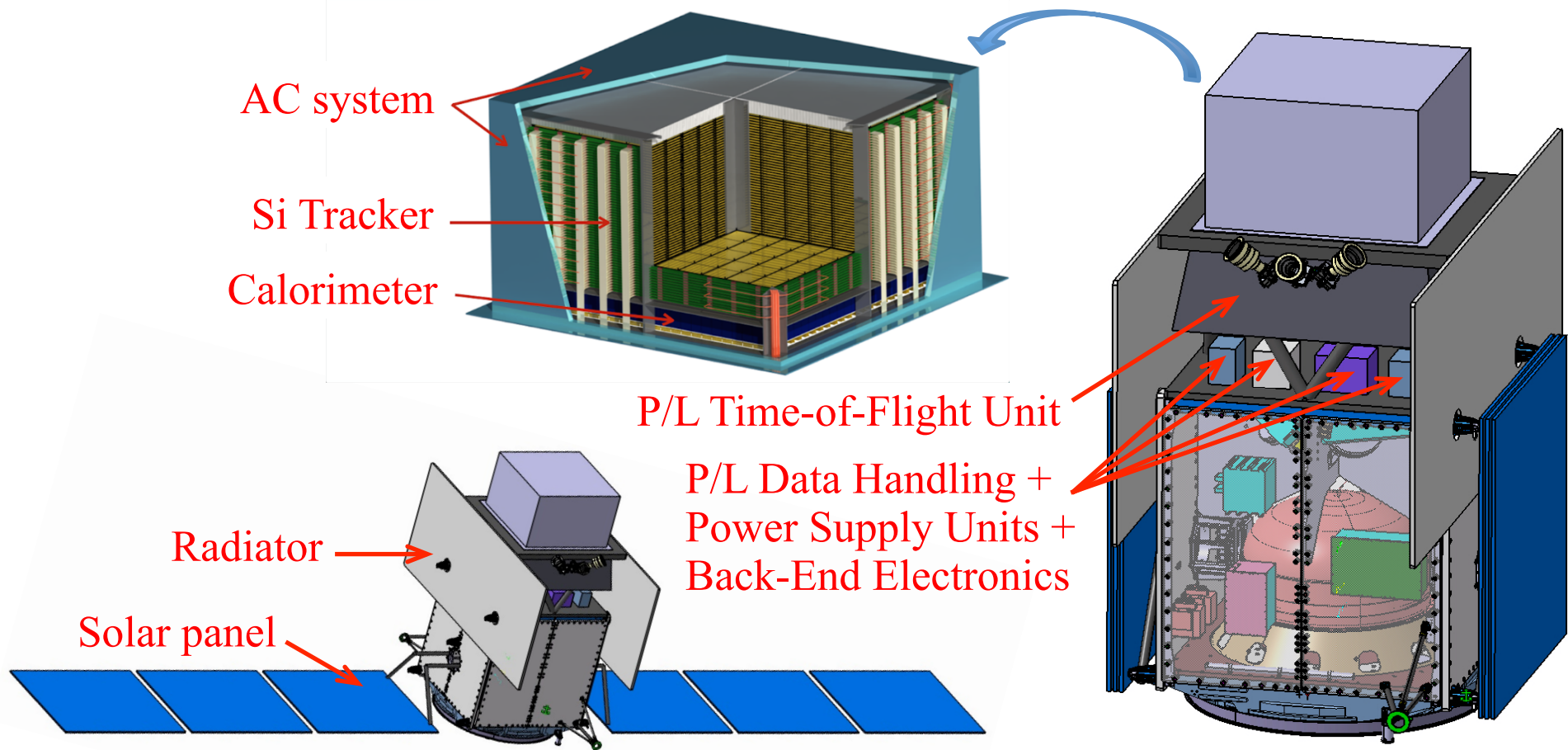


Large FoV, scanning & pointing modes
Proven and robust technology

AGILE, 10 years; Fermi, 9 years; AMS-02, 6 years
Proven capability to separate signal from background
No consumables

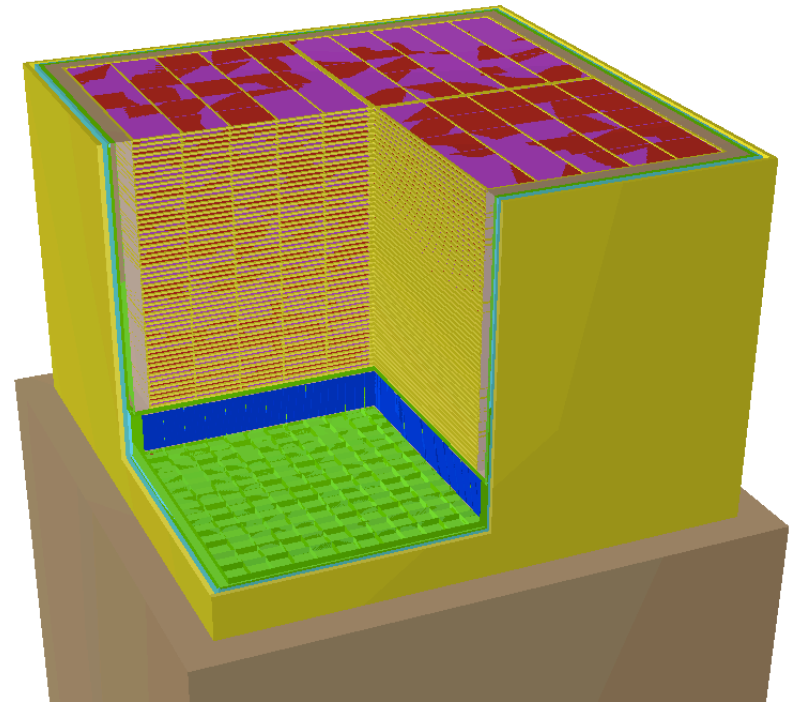
e-ASTROGAM satellite

- 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



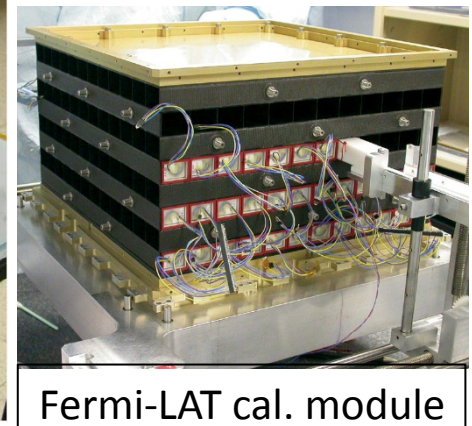
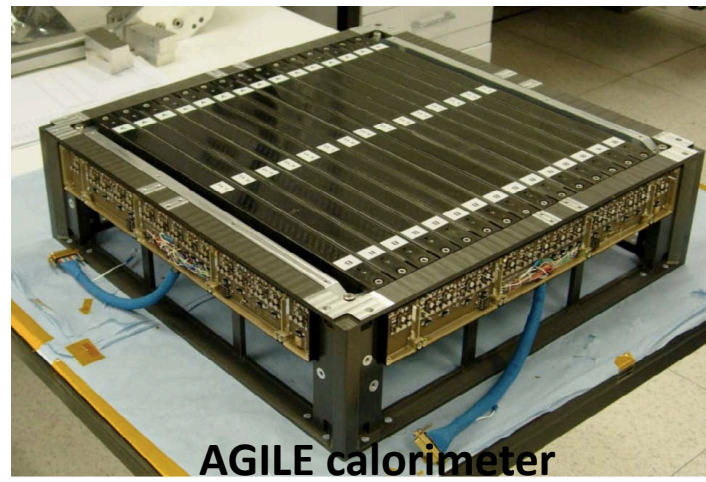
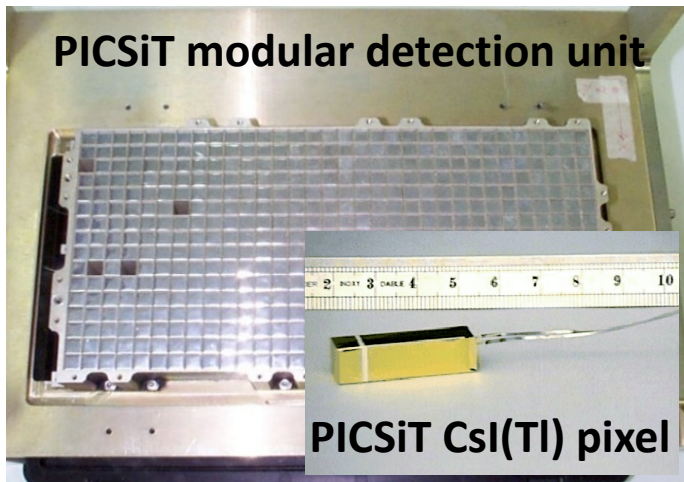
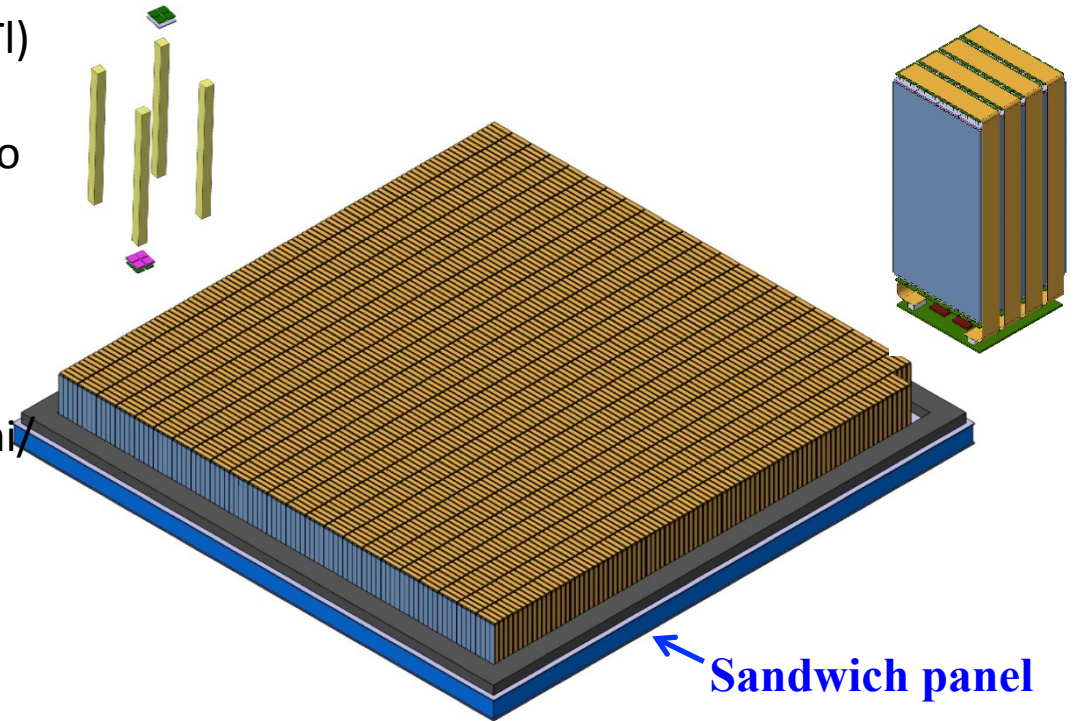
e-ASTROGAM: silicon tracker

- 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 cm², 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
- DSSD strips connected to ASICs
 - 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)



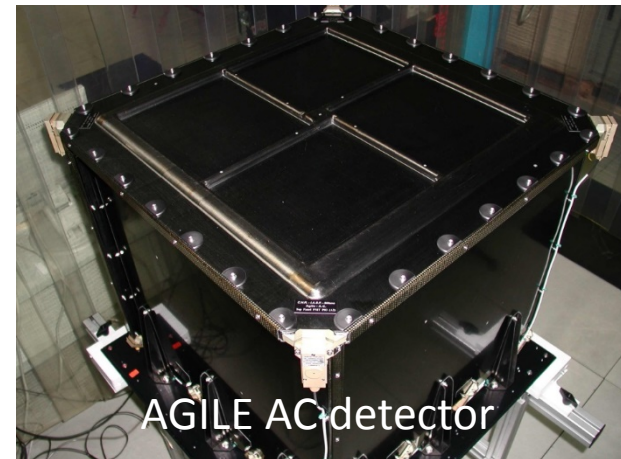
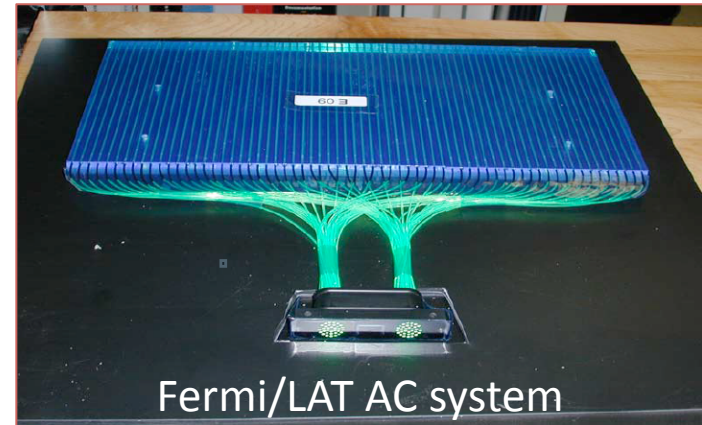
e-ASTROGAM: calorimeter

- Pixelated detector made of 33 856 CsI(Tl) scintillator bars of 8 cm length and 5×5 mm² 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)



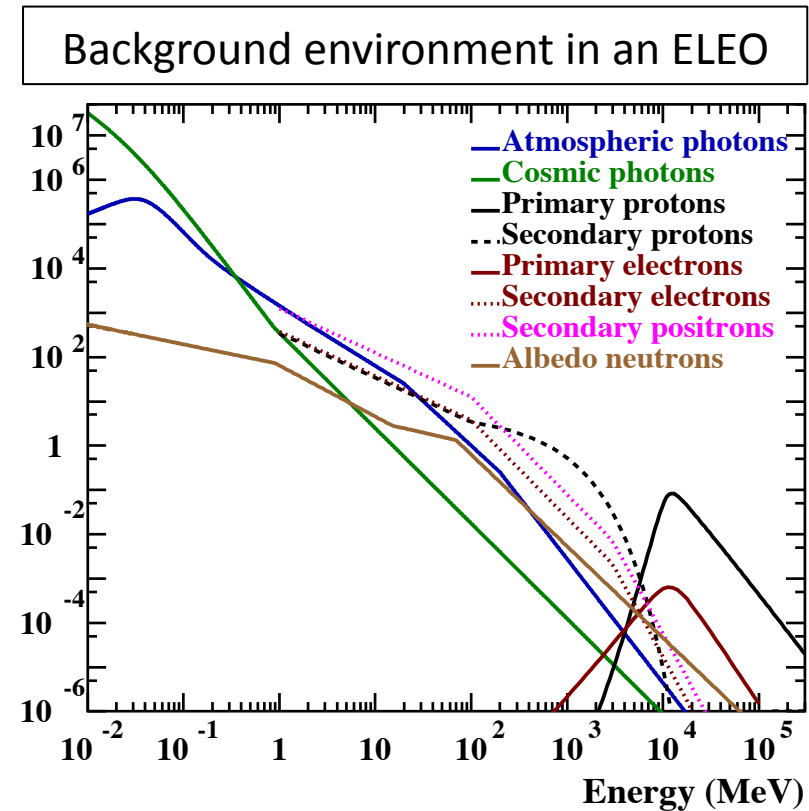
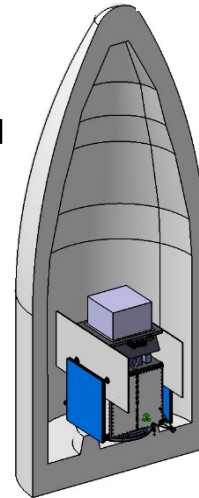
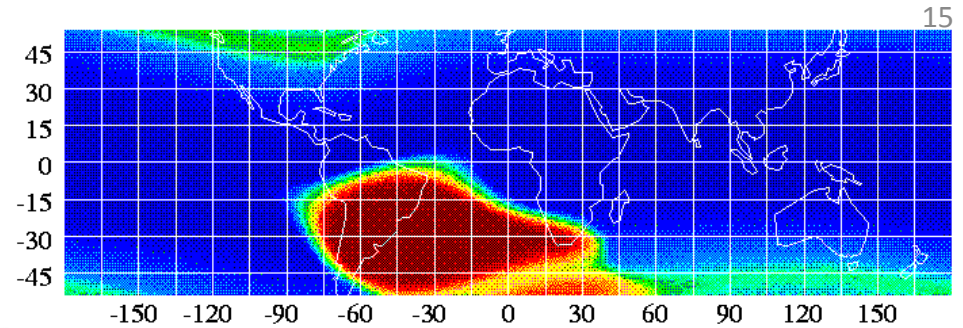
e-ASTROGAM: anticoincidence system

- **Upper-AC** system formed by large panels of plastic scintillators covering 5 faces of the instrument (6 plastic tiles per lateral side and 9 tiles for the top = 33 tiles total)
- Wavelength shifting optical fibers buried in trenches convey the scintillation light to Si photomultipliers
- The SiPM signals are readout by the space-qualified VATA64 ASICs from Ideas[®]
- **Heritage:** Fermi-LAT, AGILE
- **Time-of-Flight** system formed by two scintillator layers separated by 50 cm below the instrument to reject the particle background from the platform
- **Heritage:** AMS, PAMELA



e-ASTROGAM mission profile

- **Orbit** – Equatorial (inclination $i < 2.5^\circ$, eccentricity $e < 0.01$) low-Earth orbit (altitude in the range 550 - 600 km)
- **Launcher** – Ariane 6.2
- **Satellite communication**
 - ESA ground station at Kourou
 - + ASI Malindi station (Kenya)
- **Data transmission** – via X-band (available downlink of 8.5 MHz)
- **Observation modes** – (i) zenith-pointing sky-scanning mode, (ii) nearly inertial pointing, and (iii) fast repointing to avoid the Earth in the field of view
- **In-orbit operation** – 3 years duration + provisions for a 2+ year extension



Science with e-ASTROGAM

A space mission for MeV-GeV gamma-ray astrophysics

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Abstract

e-ASTROGAM (‘enhanced ASTROGAM’) is a breakthrough Observatory space mission, with a detector composed by a Silicon tracker, a calorimeter, and an anticoincidence system, dedicated to the study of the non-thermal Universe in the photon energy range from 0.3 MeV to 3 GeV – the lower energy limit can be pushed to energies as low as 150 keV, albeit with rapidly degrading angular resolution, for the tracker, and to 30 keV for calorimetric detection. The mission is based on an advanced space-proven detector technology, with unprecedented sensitivity, angular and energy resolution, combined with polarimetric capability. Thanks to its performance in the MeV-GeV domain, substantially improving its predecessors, e-ASTROGAM will open a new window on the non-thermal Universe, making pioneering observations of the most powerful Galactic and extragalactic sources, elucidating the nature of their relativistic outflows and their effects on the surroundings. With a line sensitivity in the MeV energy range one to two orders of magnitude better than previous generation instruments, e-ASTROGAM will determine the origin of key isotopes fundamental for the understanding of supernova explosion and the chemical evolution of our Galaxy. The mission will provide unique data of significant interest to a broad astronomical community, complementary to powerful observatories such as LIGO-Virgo-CECORG-KAGRA, SKA, ALMA, E-ELT, TMT, LSST, JWST, Athena, CTA, IceCube, KM3NeT, and LISA.

White Book

224 authors

194 pages

Impact of e-ASTROGAM/AMEGO

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

Crucial energy band for GW and multi-messenger astrophysics

Breakthrough polarimetric sensitivity achievable for the first time

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

STATUS: e-ASTROGAM proposal is in review by ESA, with a selection for Phase A coming no sooner than February.