Instruments optimizations for low energy Gamma-ray detection

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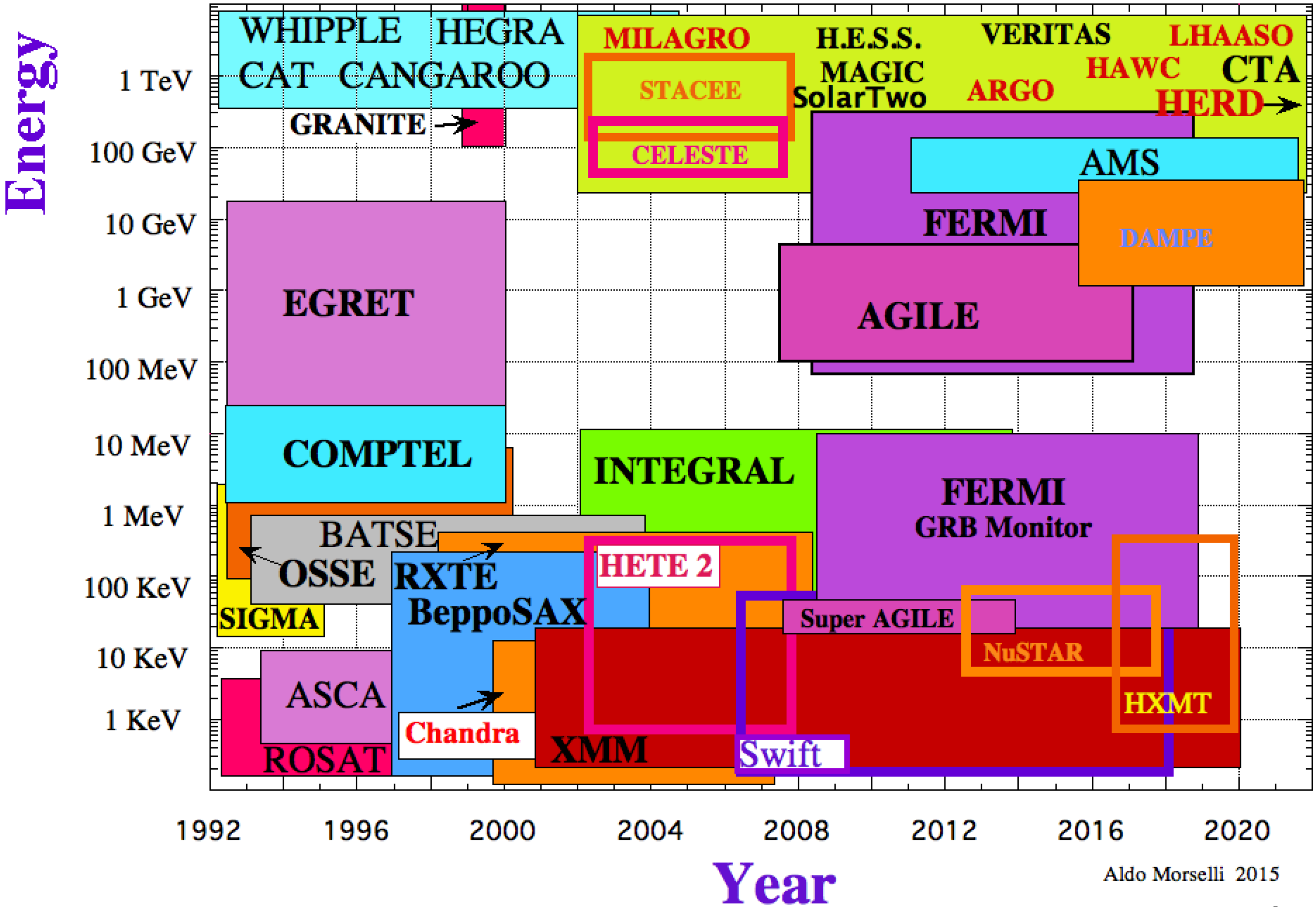
Sezione INFN di Roma II

RICAP 2018


Energy
1 TeV
100 GeV
10 GeV
1 GeV
100 MeV
10 MeV
1 MeV
100 KeV
10 KeV
1 KeV
WHIPPLE HEGRA
CAT CANGAROO
GRANITE
MILAGRO
STACEE
CELESTE
H.E.S.S.
MAGIC
SolarTwo
VERITAS
ARGO
HAWC
LHAASO
CTA
HERD
AMS
FERMI
DAMPE
EGRET
AGILE
COMPTEL
INTEGRAL
FERMI
GRB Monitor
BATSE
OSSE
RXTE
BeppoSAX
HETE 2
SIGMA
Super AGILE
NuSTAR
HXMT
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Chandra
XMM
Swift
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1992
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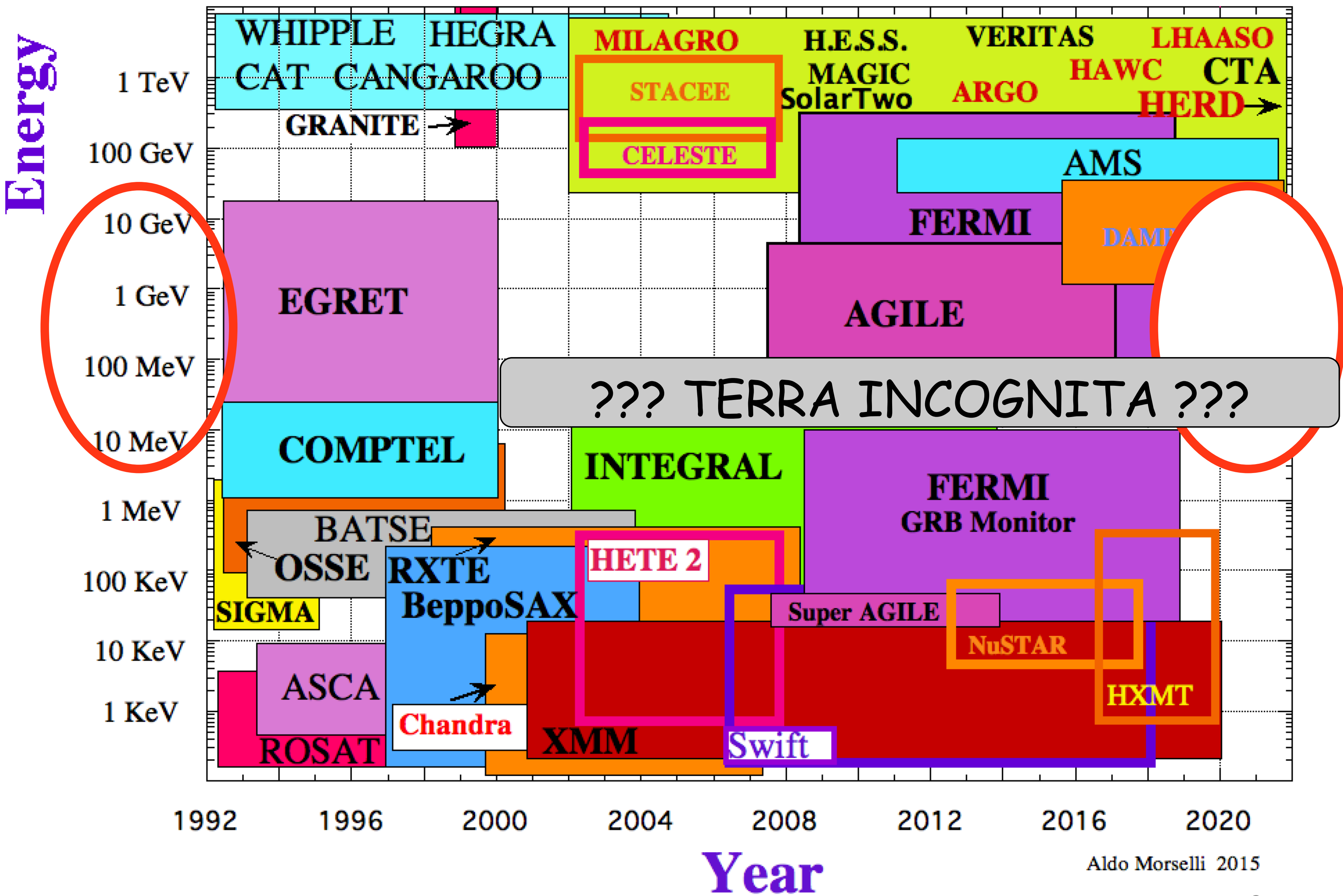
Year
Aldo Morselli 2015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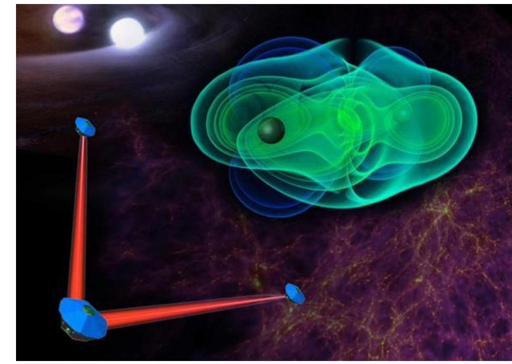
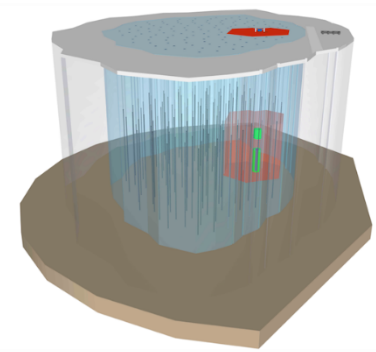
MeV-GeV γ-ray telescope core science motivation

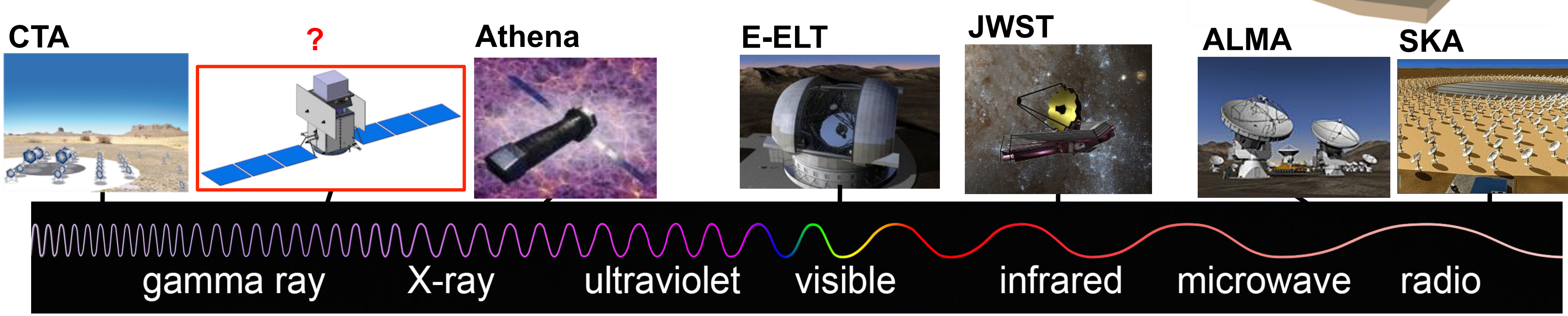
- Processes at the heart of the extreme Universe (AGNs, GRBs, microquasars): prospects for the Astronomy of the 2030s
  - Multi-wavelength, multi-messenger coverage of the sky (with Ligo/Virgo, CTA, SKA, eLISA, ...), with special focus on transient phenomena
- The origin of high-energy particles and impact on galaxy evolution, from cosmic rays to antimatter
- Nucleosynthesis and the chemical enrichment of our Galaxy

eLISA – Gravitational waves



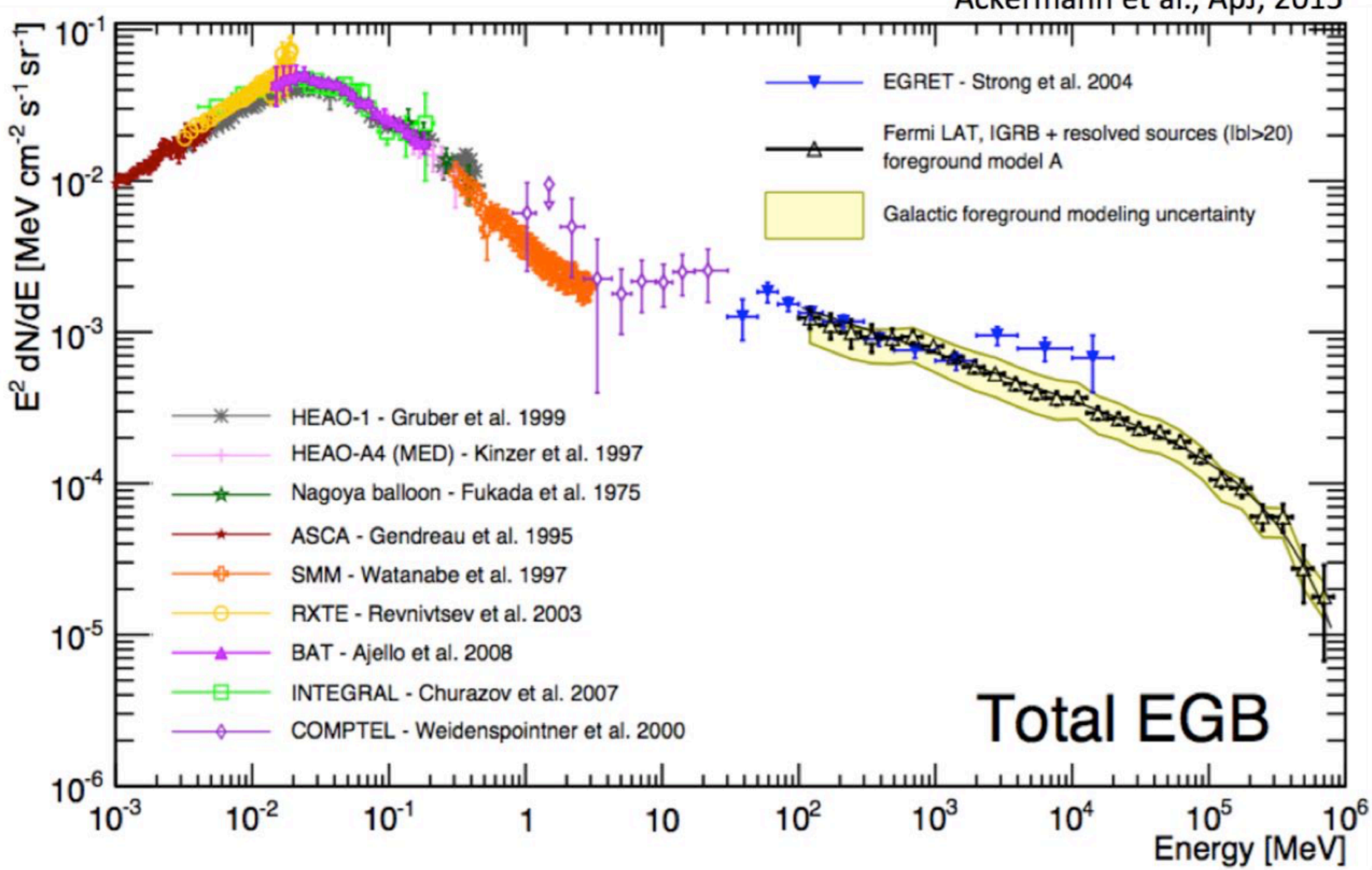
Km3Net/IceCube-Gen2 - ν





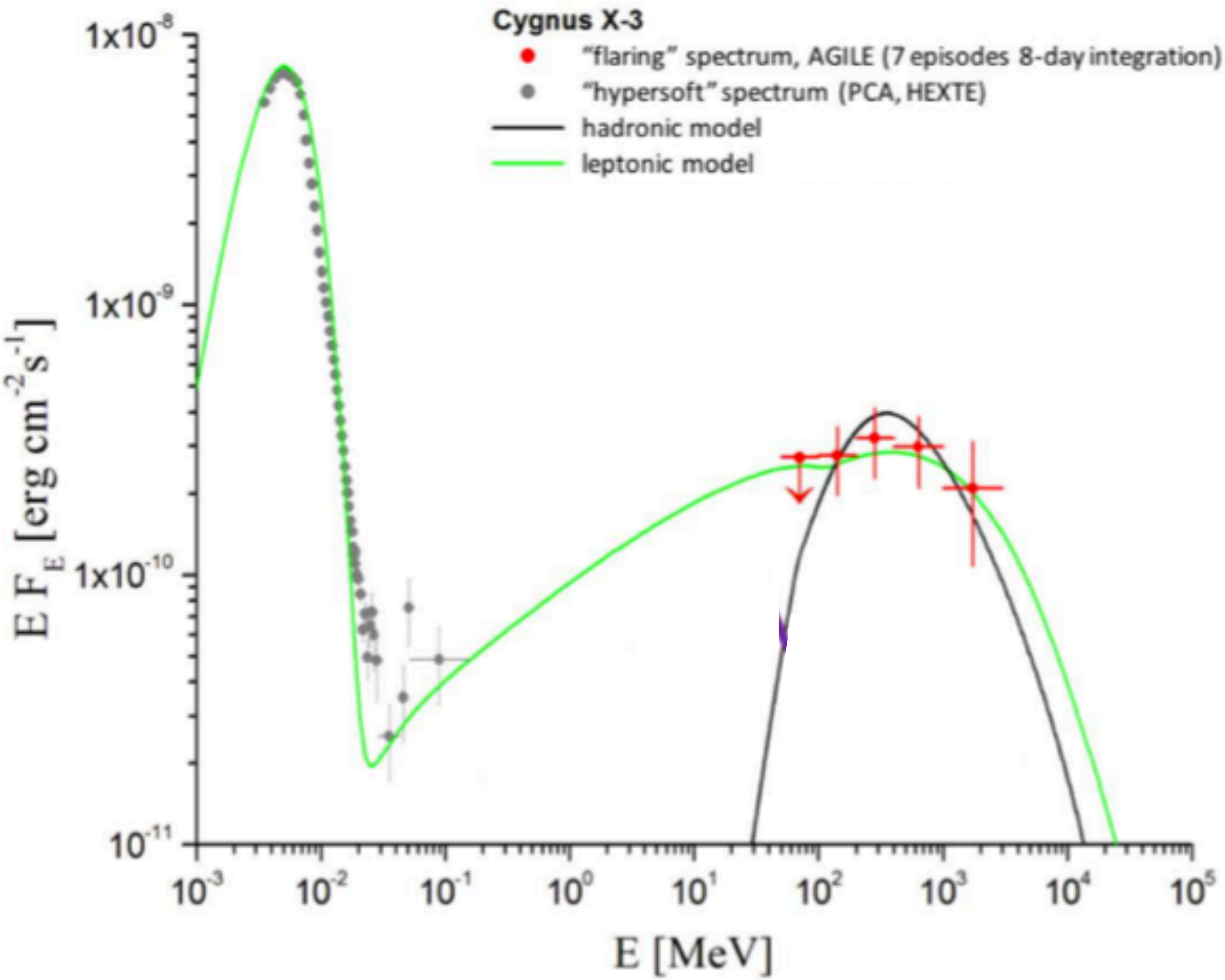
The extragalactic gamma-ray background

Ackermann et al., ApJ, 2015



Largest uncertainties in the 1 MeV to 100 MeV range

Spectral energy distribution of Cyg X-3 during the γ-ray flaring activity in 2011



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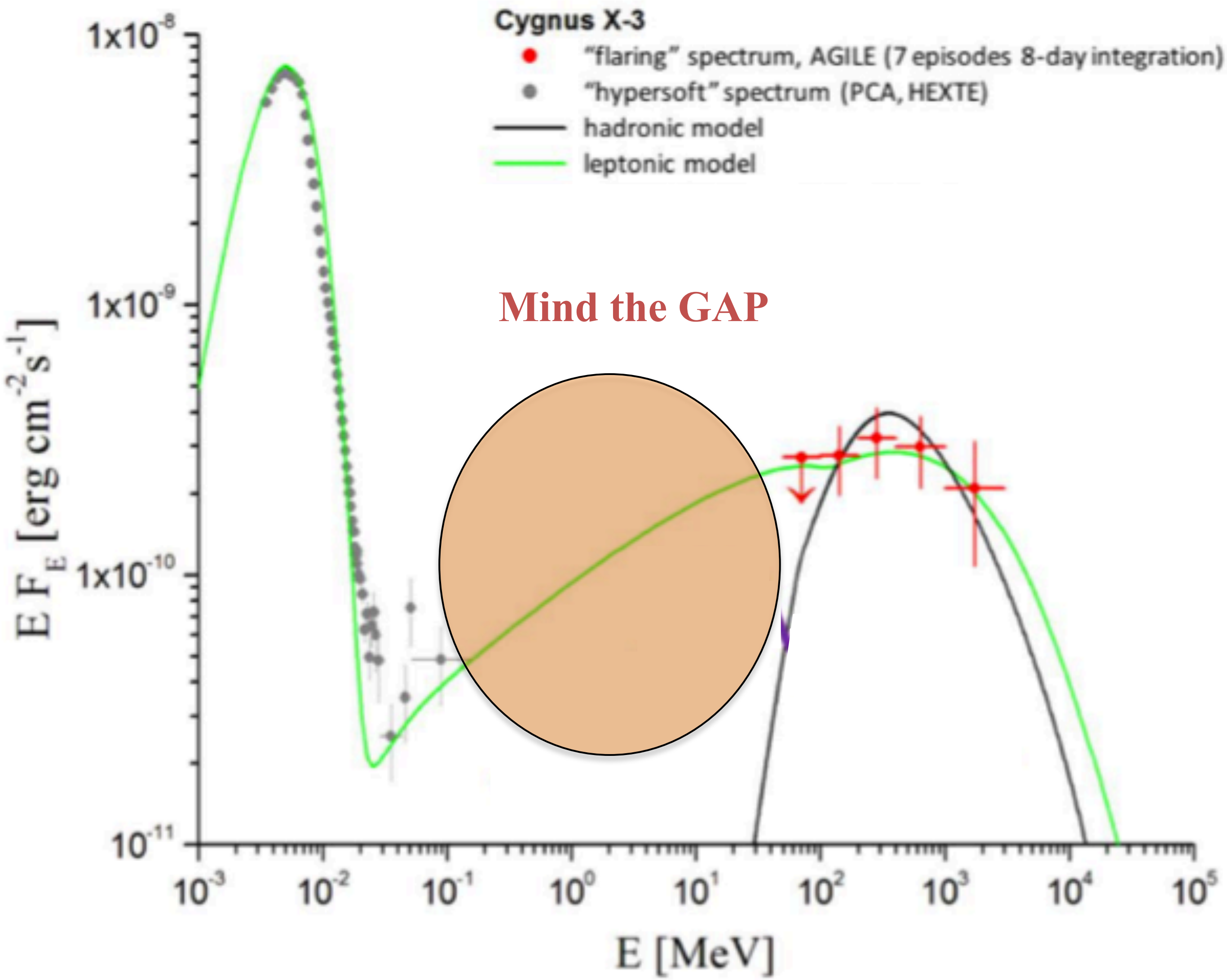
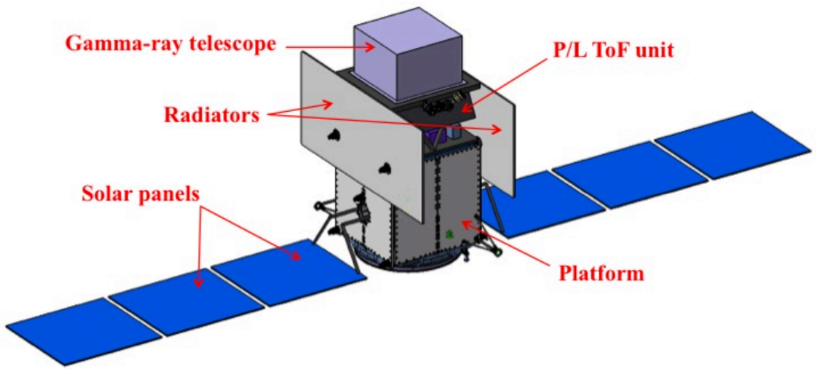
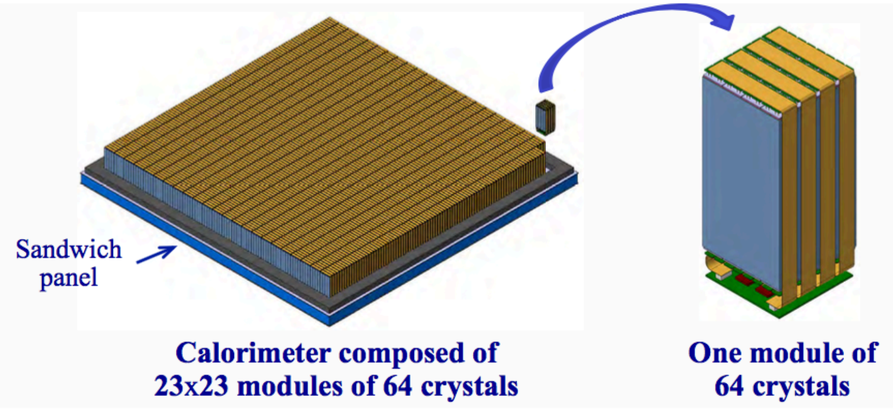


Filling the GAP in the MeV region

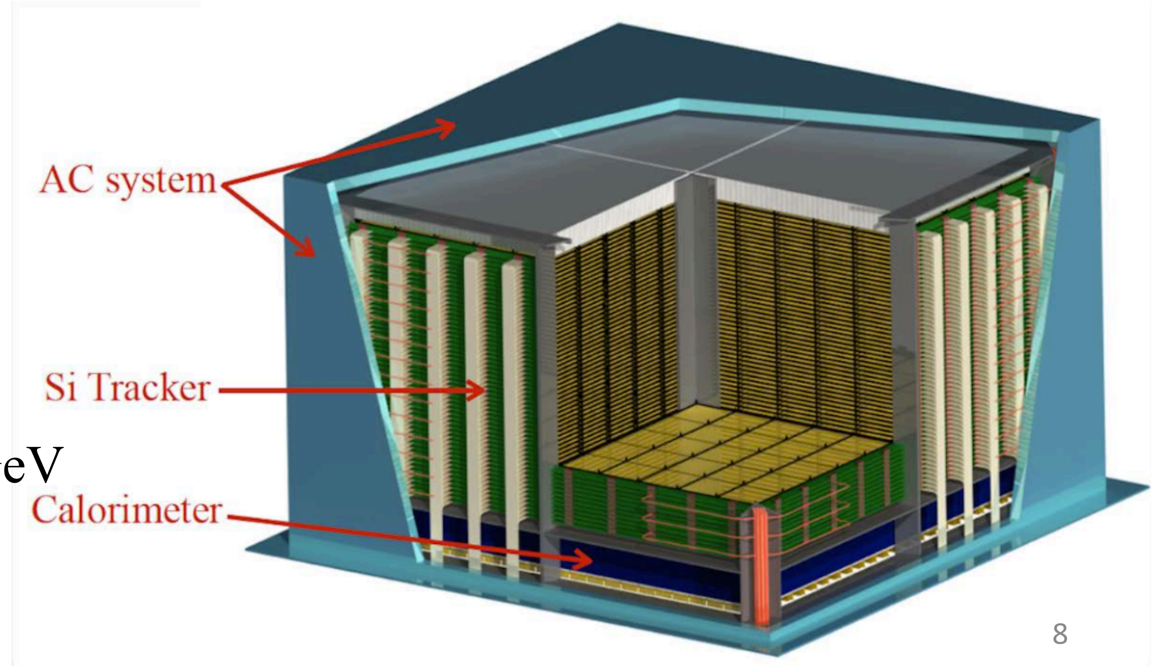
The e-ASTROGAM concept





- 3 years mission + 2 years extension
- P/L mass: 300 kg
- Satellite mass: 800 kg
- Very high TRL > 5-6

- Silicon tracker
- Energy range: 150kev – 3 GeV
- FoV > 2.5 sr

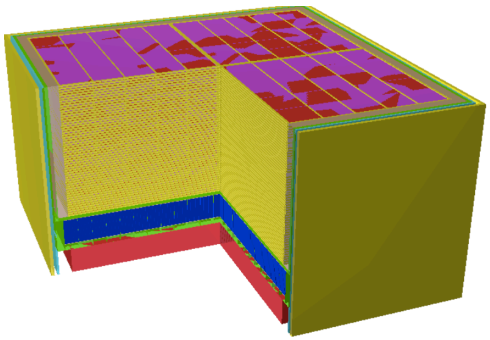


arXiv:1711.01265

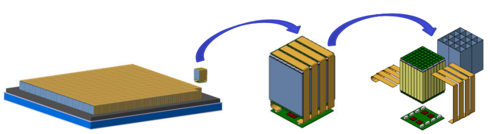
Filling the GAP in the MeV region

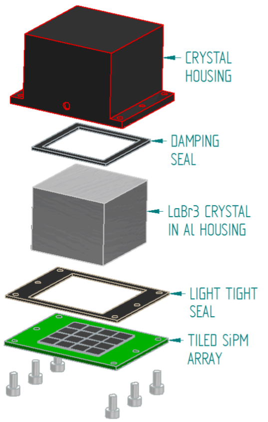
Instrument overview

- **Tracker**: 56 layers of 4 times 5×5 double sided Si strip detectors = 5600 DSSDs
  - Each DSSD has an area of 9.5×9.5 cm2
  - Thickness of 500 μm
  - A strip pitch of 240 μm
  - Spacing of the Si layers: 10 mm



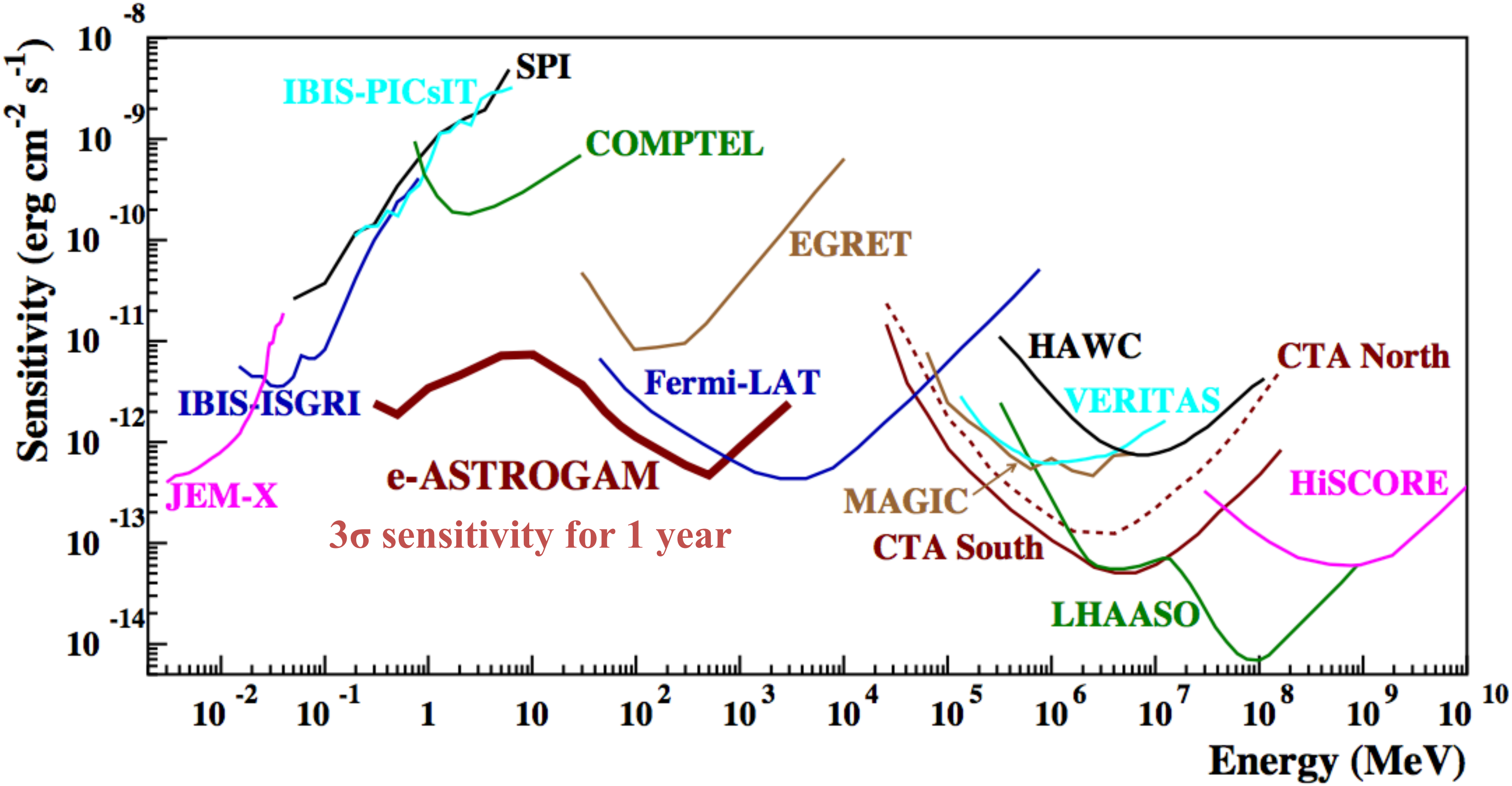
- **Calorimeter**: pixelated detector made of 8 464 CsI(Tl) bars of 8 cm length and 10×10 mm^2 cross section.





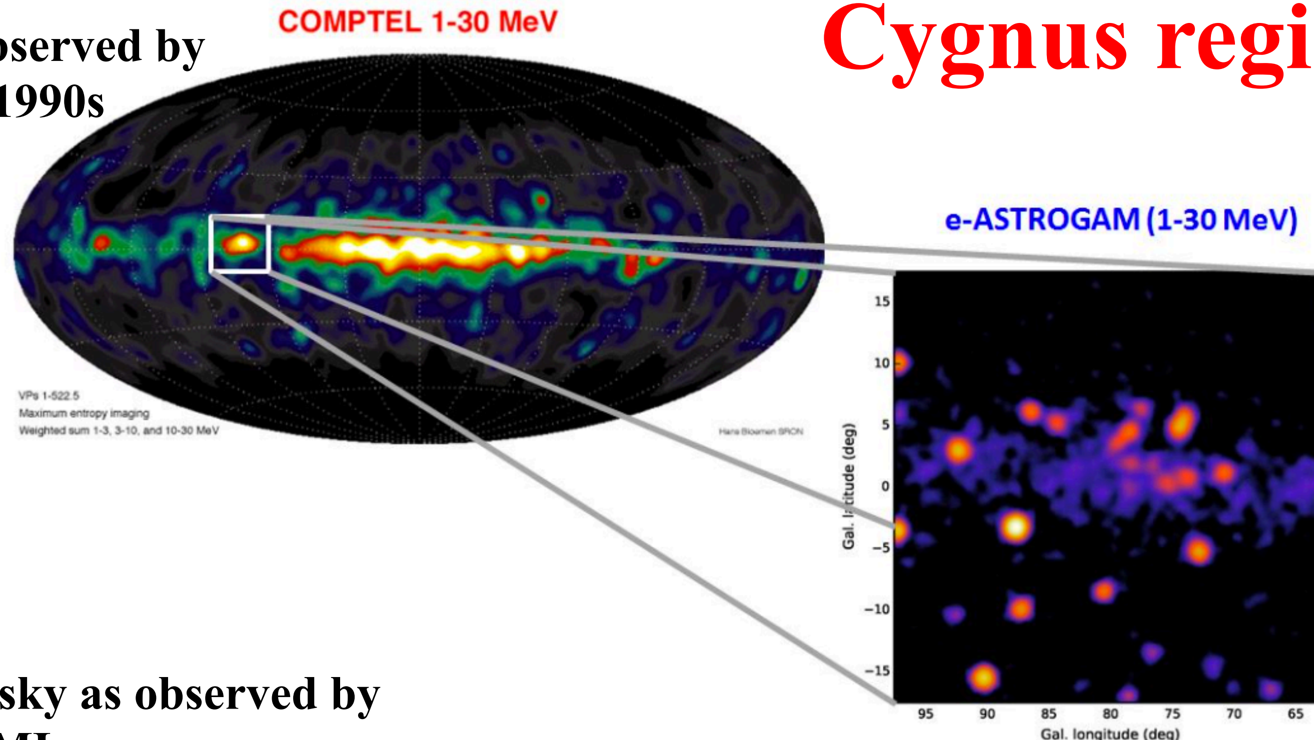
- **ACD**: segmented plastic scintillators coupled to SiPM by optical fibers

Point source countimuum sensitivity

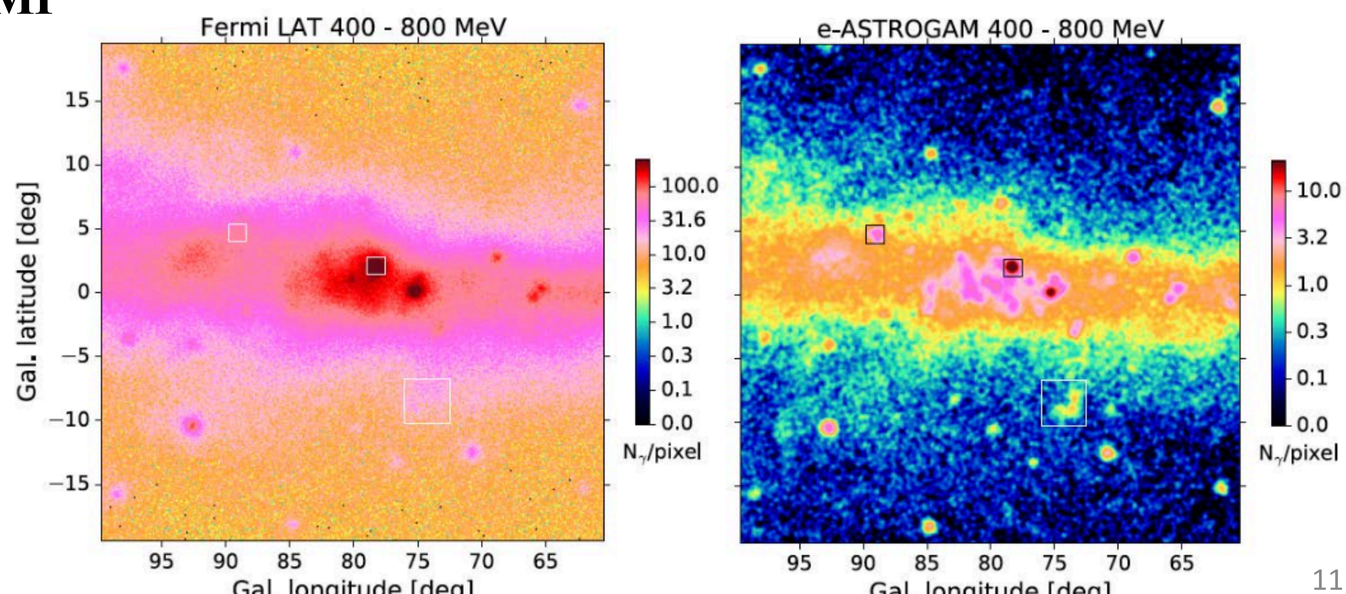


Cygnus region

1- 30 MeV sky as observed by COMPTEL in the 1990s

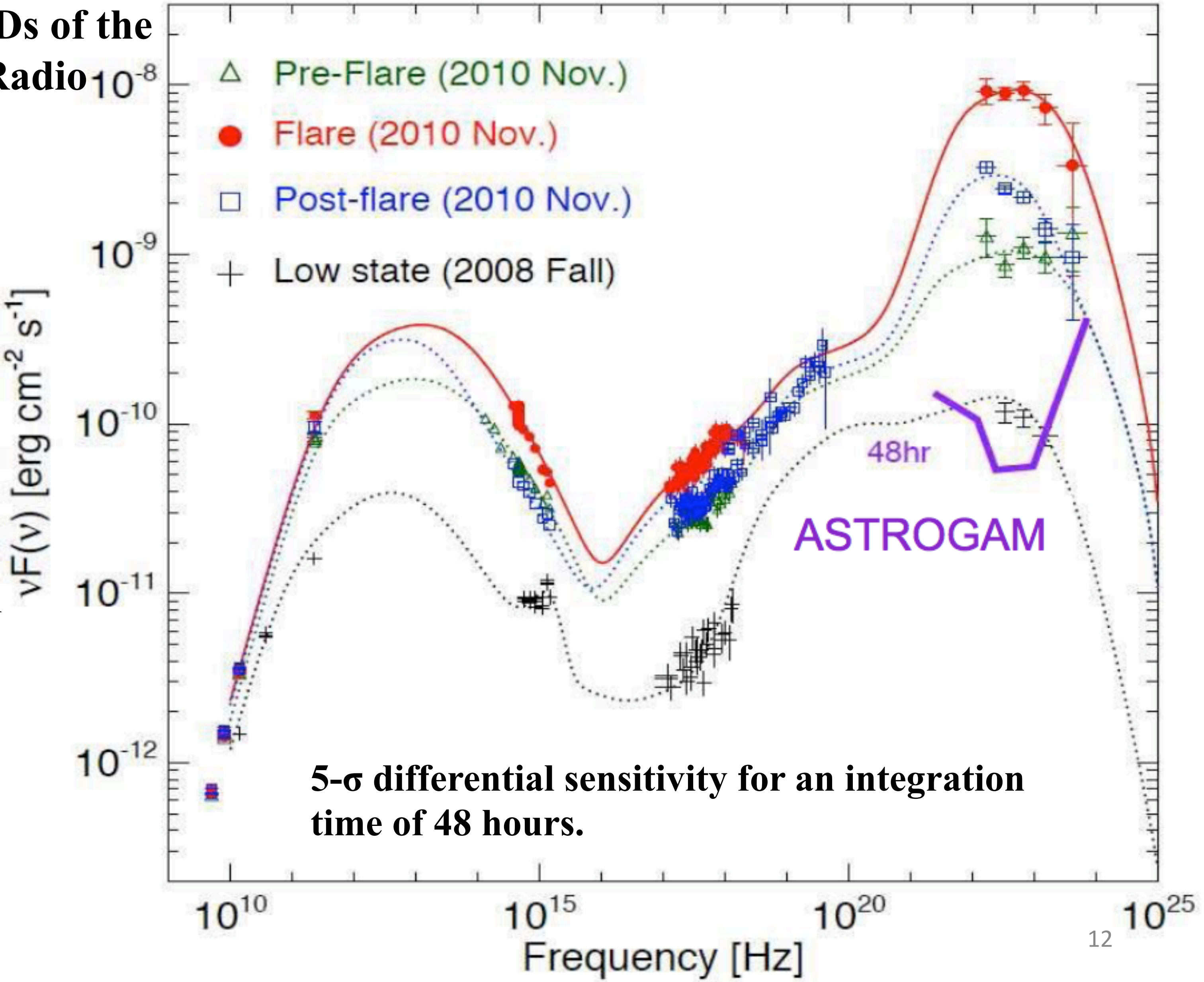


300- 400 MeV sky as observed by 8 year of FERMI



Active Galactic Nuclei

Multi-epoch SEDs of the Flat Spectrum Radio Quasar 3C454.3

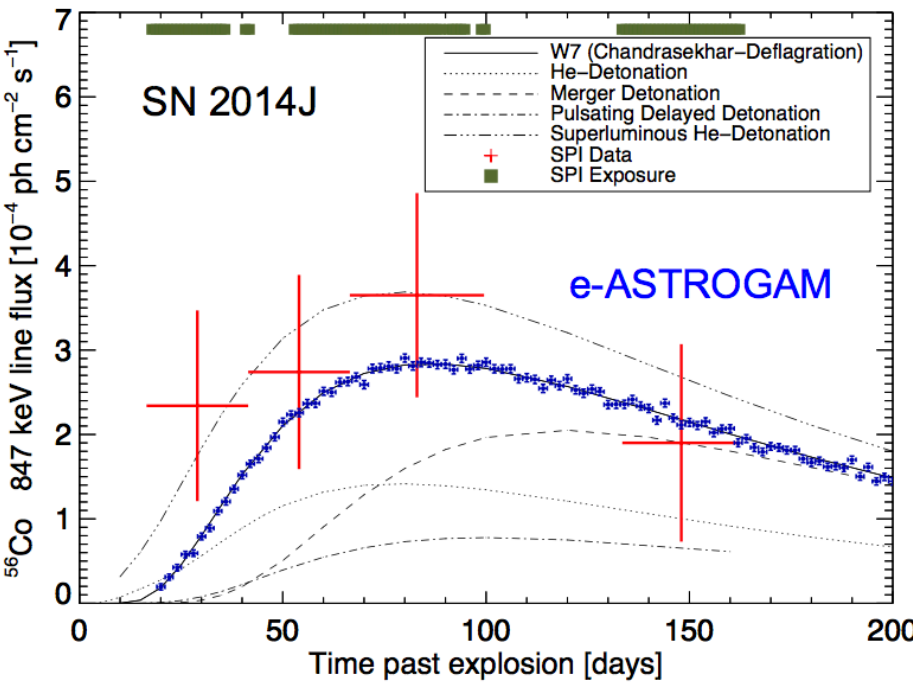


5-σ differential sensitivity for an integration time of 48 hours.

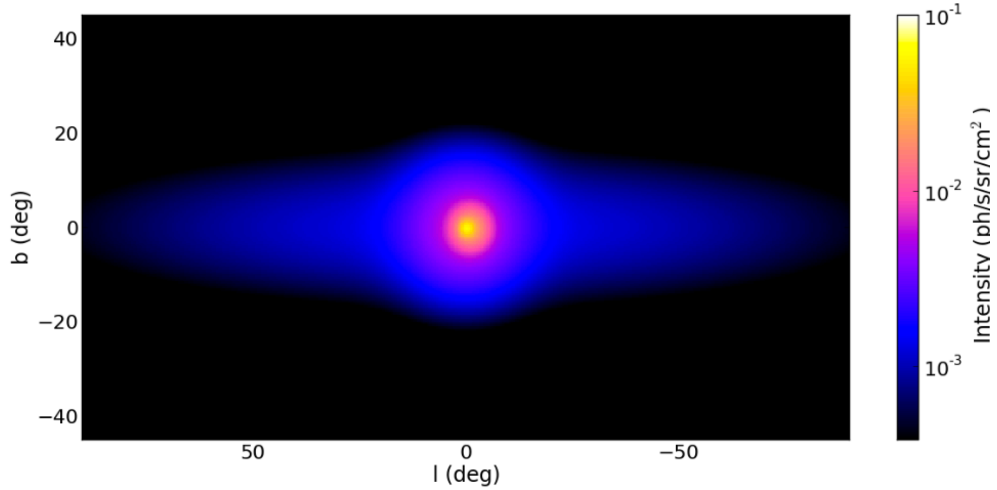
ASTROGAM will allow us to investigate daily (or sub-daily) SEDs during gamma-ray superflares

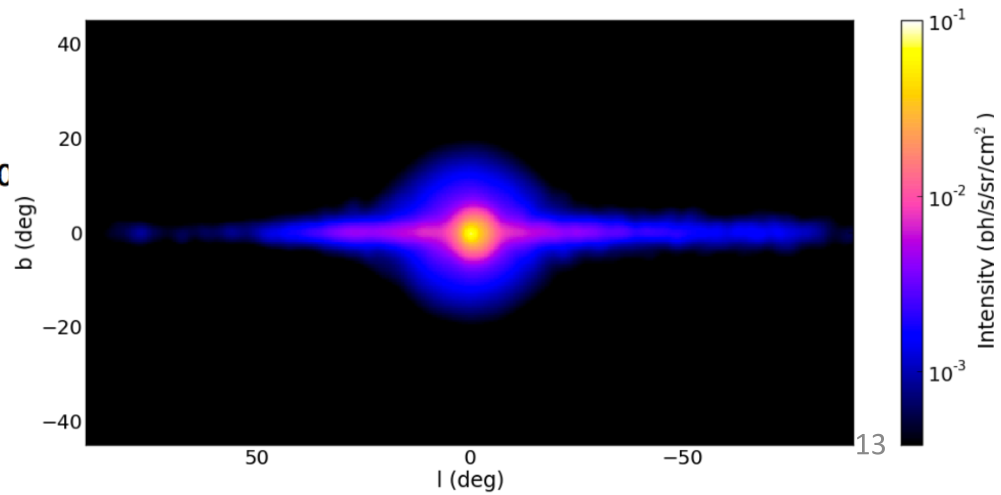
Line sensitivity

Light curve of the 847 keV line from ^{56}Co decay in SN 2014J.

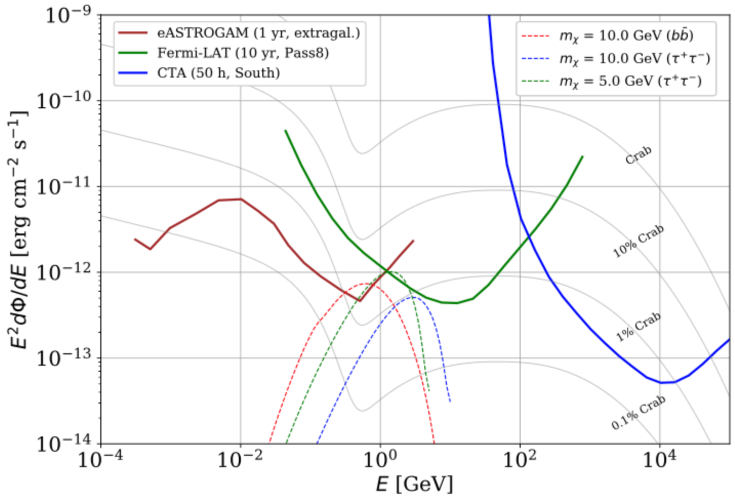


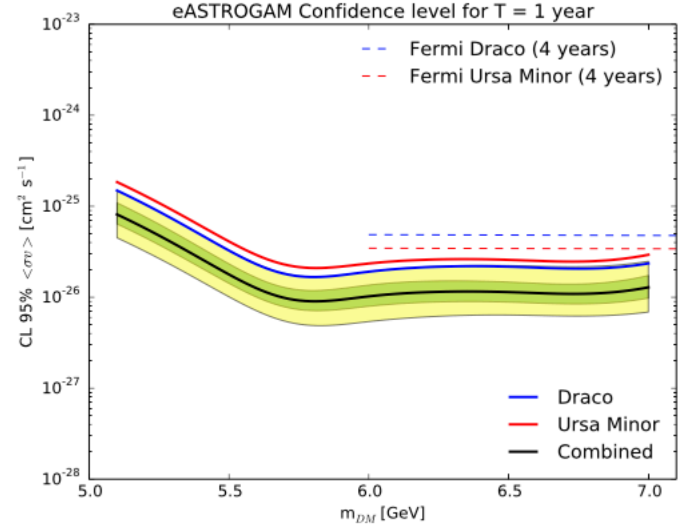
511 keV diffuse line emission

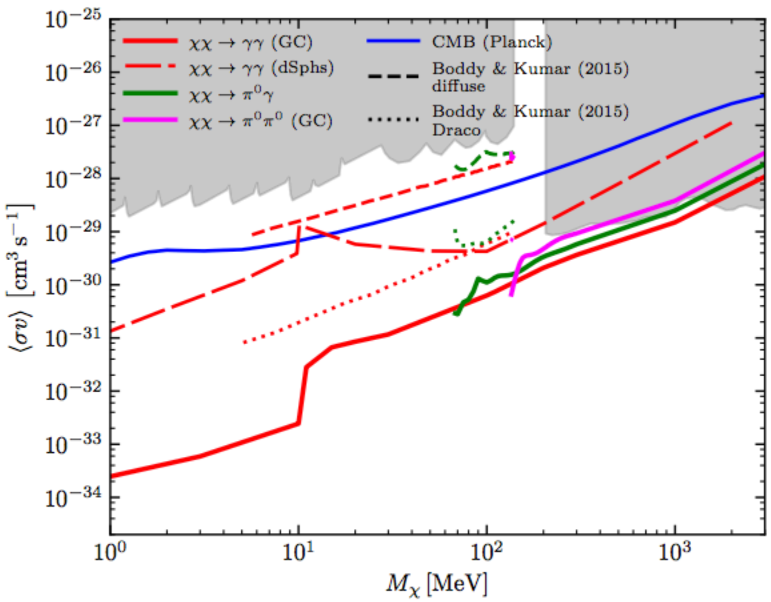


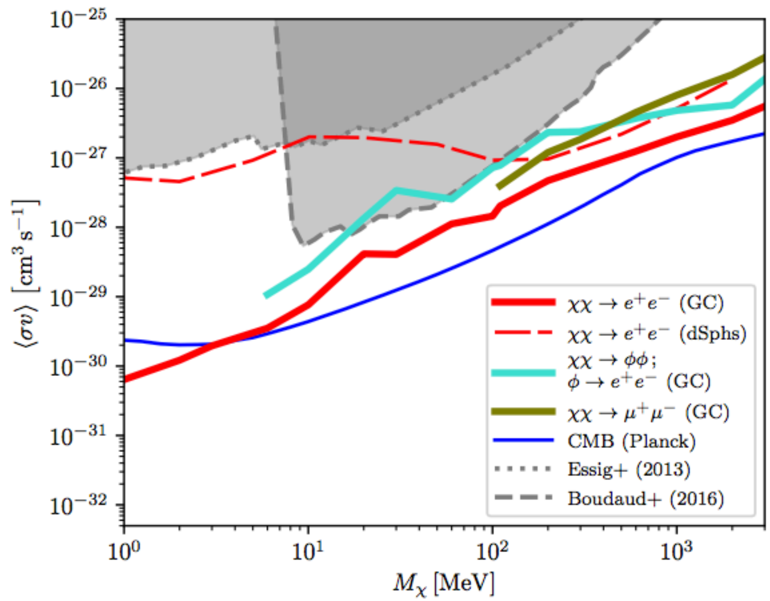


Dark matter in the MeV region









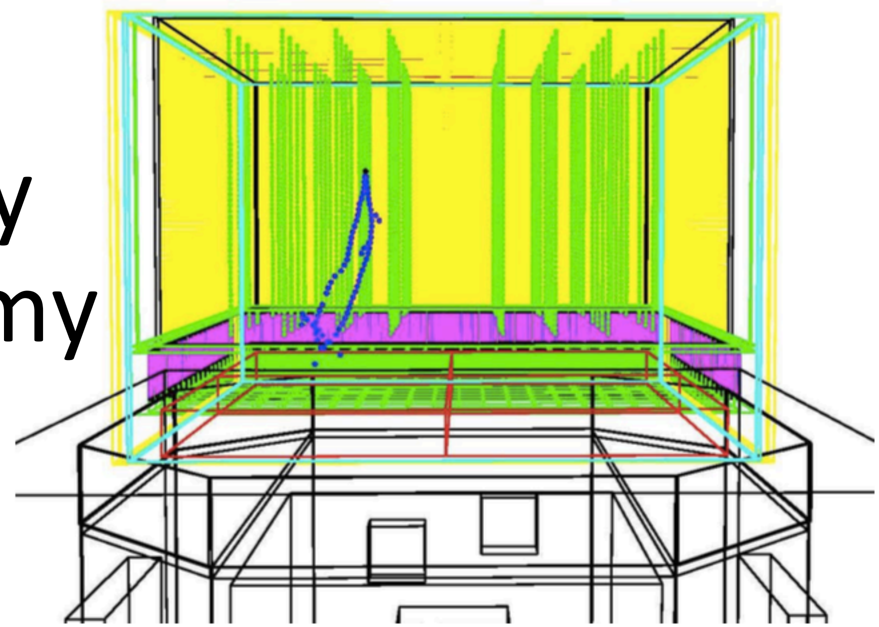
Instrument optimization

The scientic performances of the detector was evaluated with:

MEGAlib

The Medium-Energy Gamma-ray Astronomy library

Andreas Zoglauer
University of California at Berkeley
Space Sciences Laboratory

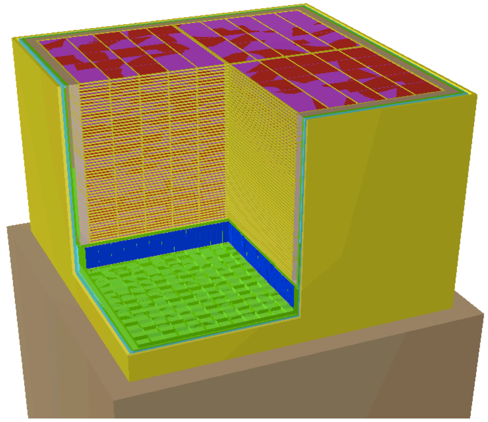


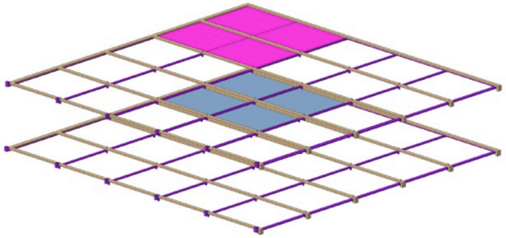
http://megalibtoolkit.com/home.html

MEGAlib tools

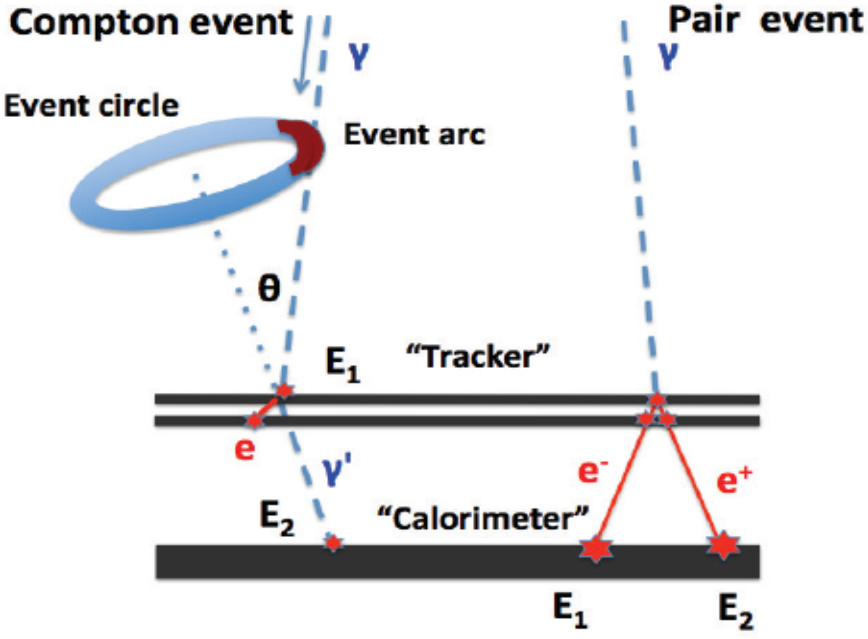
From simulation to Data Analysis

Geant4 toolkit for geometry & physics simulation



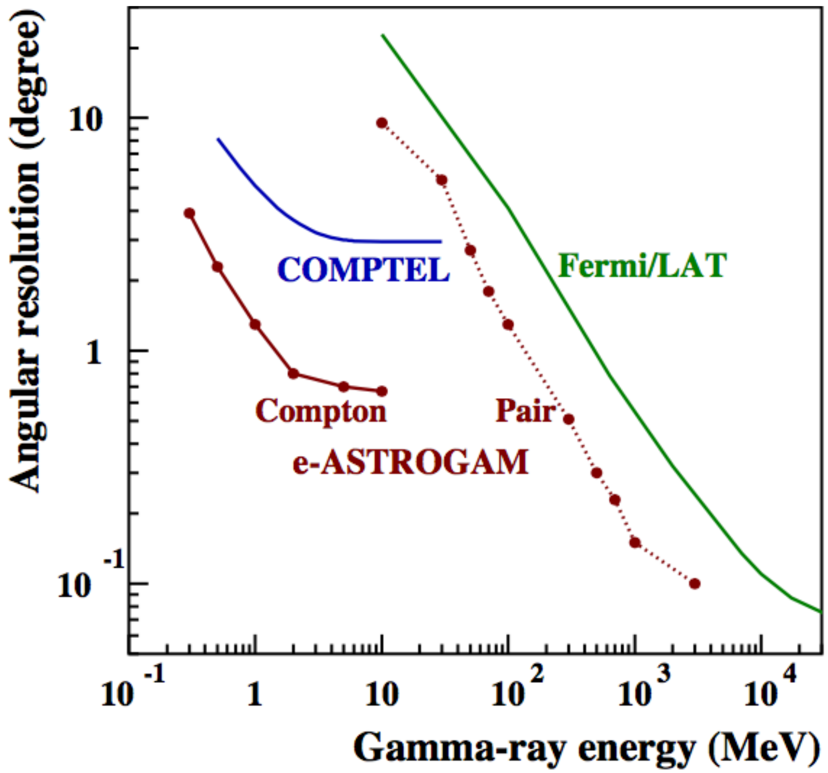


Revan & mimrec to Event reconstruction & Data analysis

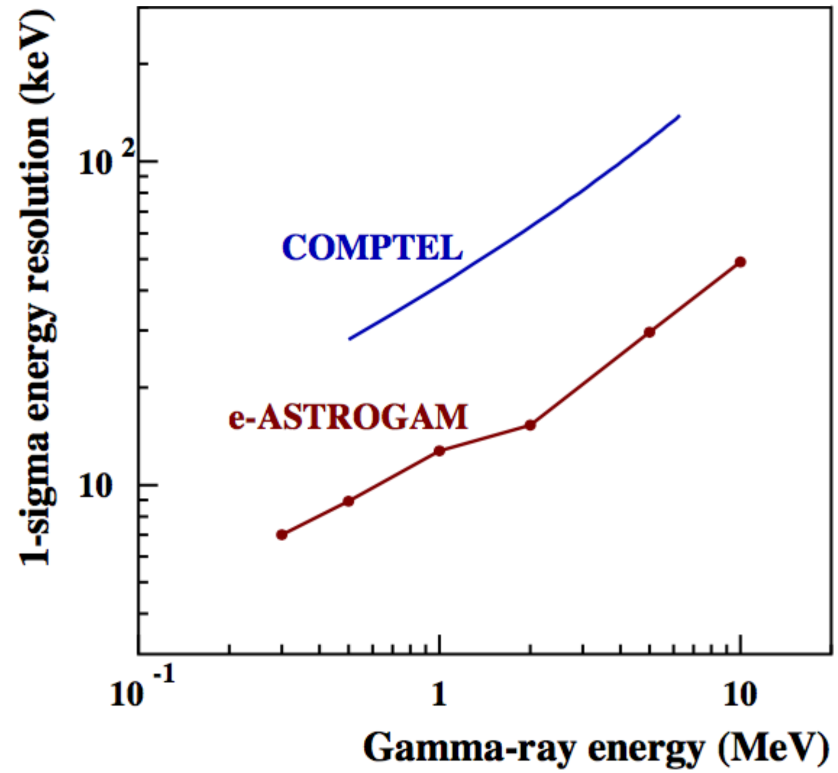


Baseline Performance

Angular Resolution



Energy Resolution



For pair-production energy resolution 20-30%

MEGALib Simulations

Space Parameters – Focus on Compton regime

SIMULATION INPUTS:

Number of triggers: 500000 x 8
Mono Spectrum:
    Energies: [300, 5000] keV
    Zenith angles: [0, 90] degrees

Optimization parameters:

- Thickness: [100, 550] μm
- Number of Layers: 56, 70, 112
- Distance between Layers: 0.5, 0.75, 1.0 cm

Thickness(μm),	Layers,	ΔZ(cm)
250,	112,	0.5
400,	70,	0.75
500,	56,	1.0

→ **0.3 X_0 on axis**

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Thickness(μm),	Layers,	ΔZ(cm)
250,	56,	0.5
400,	56,	0.75
500,	56,	1.0

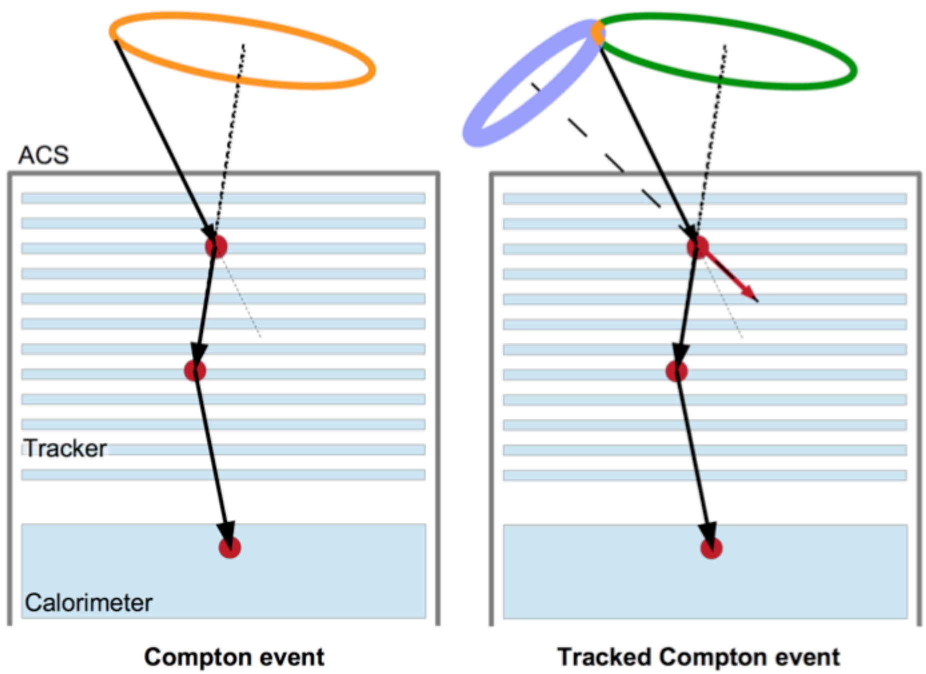
Fix number of layers

MEGALib Simulations

Space Parameters – Focus on Compton regime

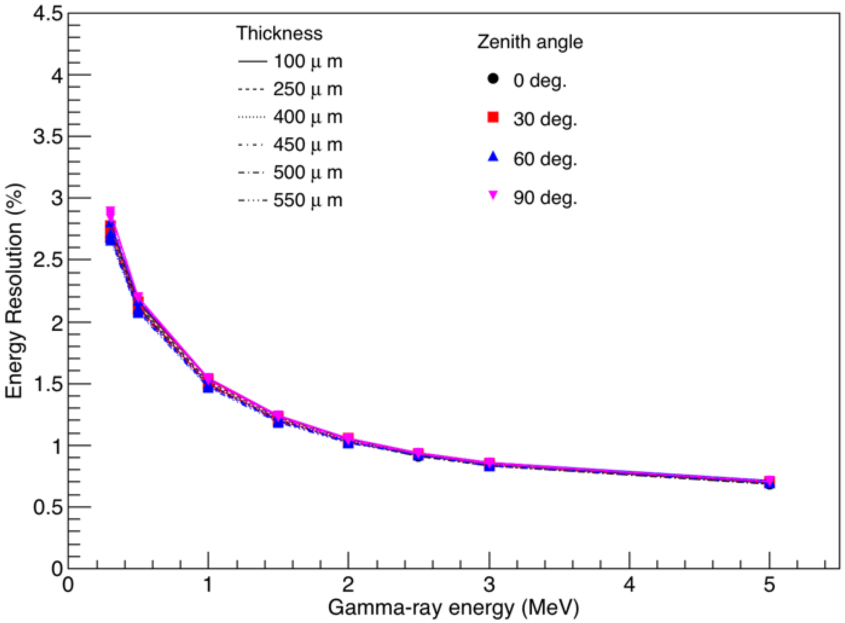
EVENTS CLASSIFICATION:

- Photopeak events -> Energy Resolution.
- Compton events for ARM resolution:
    - No electron tracking
    - Electron tracking

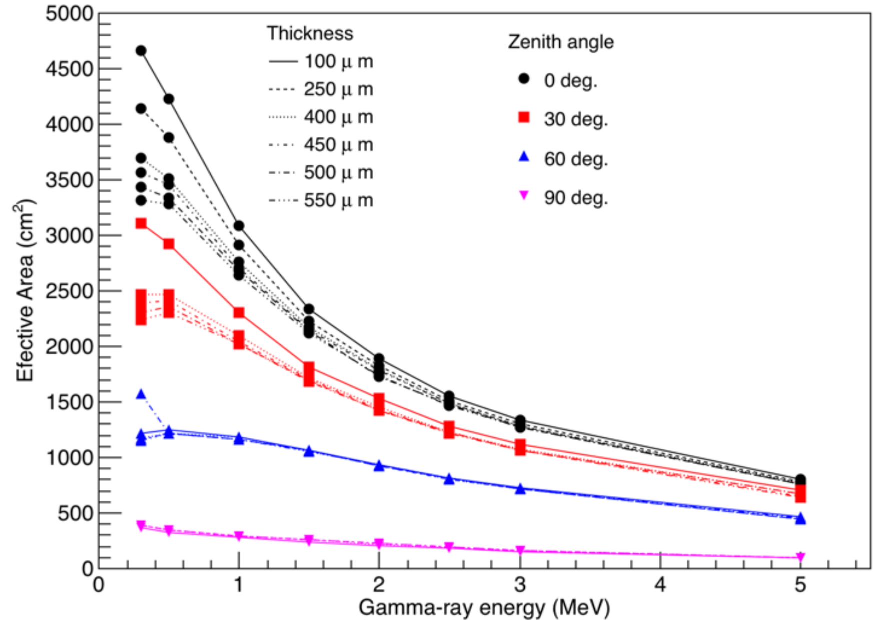


Photopeak Events

Energy Resolution



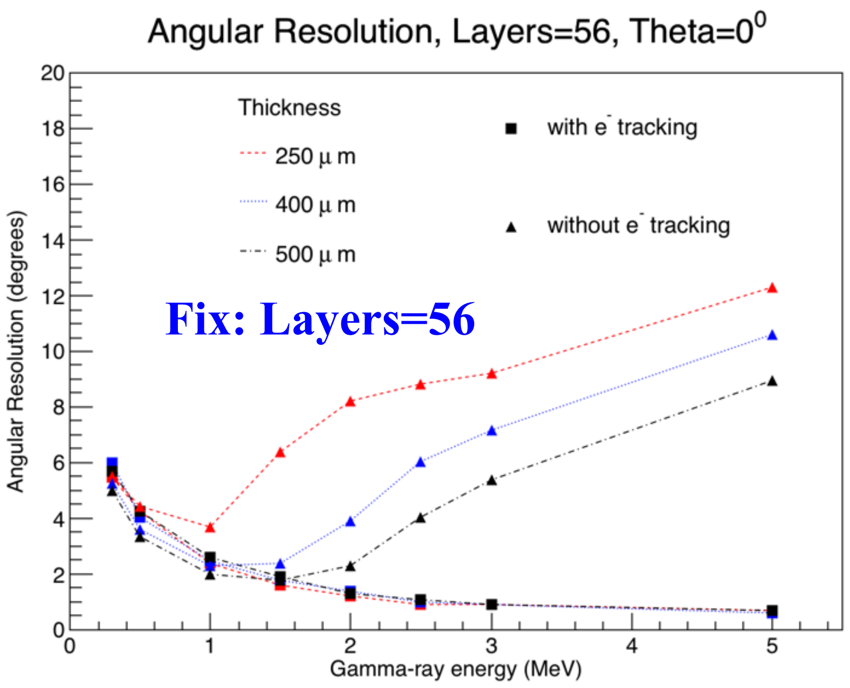
Effective Area

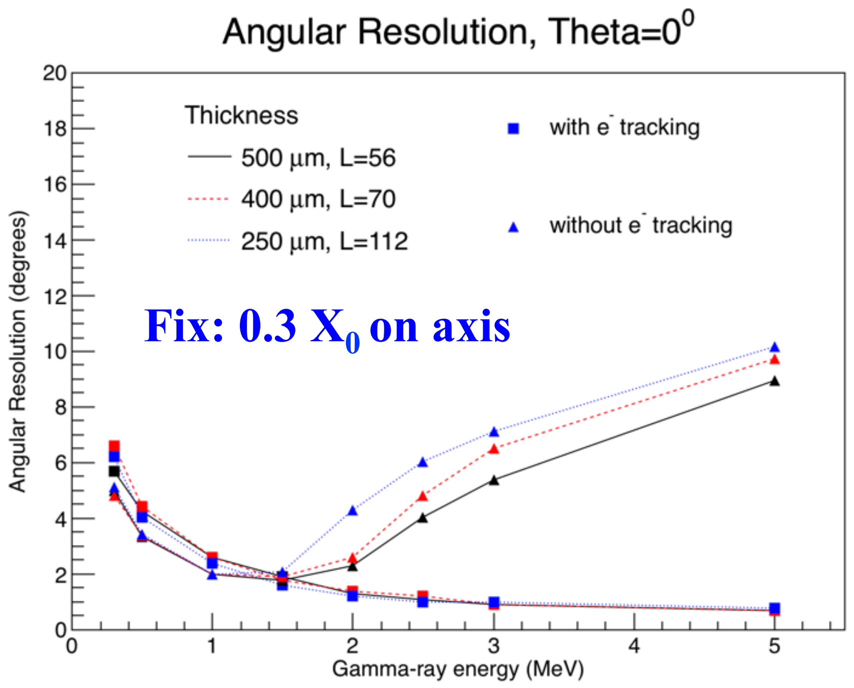


No changes in the energy resolution

Comptons Events

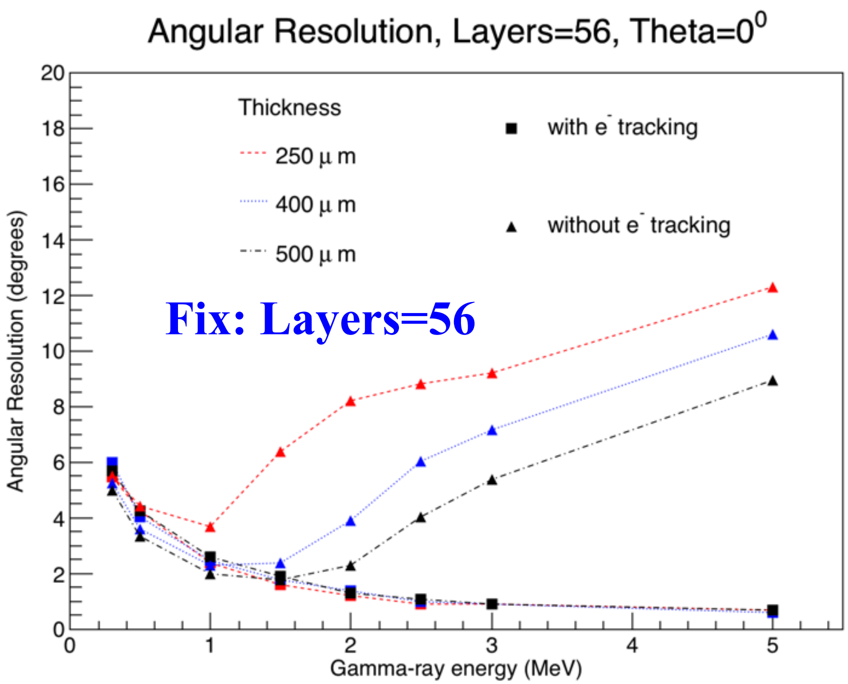
Angular Resolution



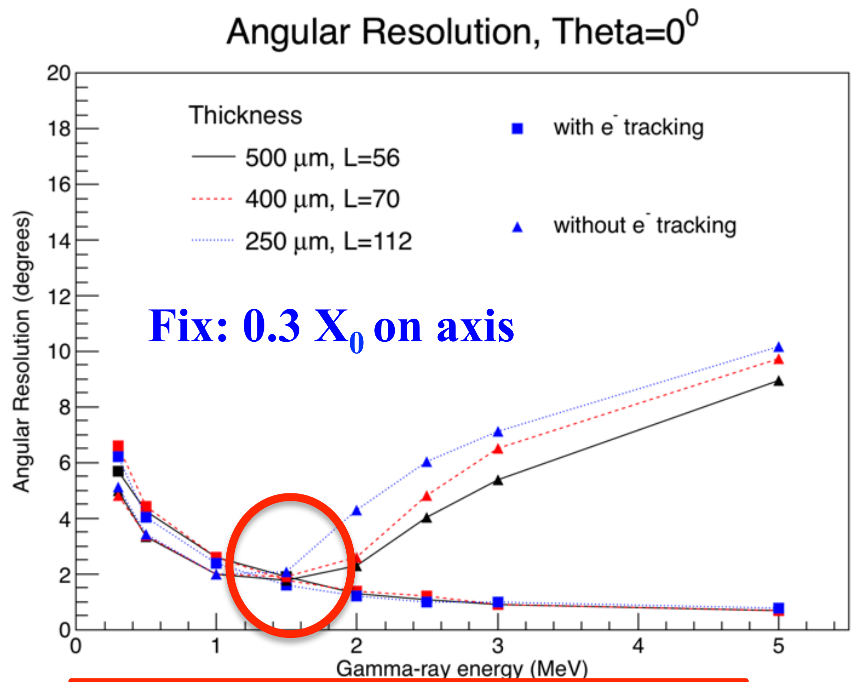


Comptons Events

Angular Resolution



Better angular resolution for:
Depends on the layer's thickness

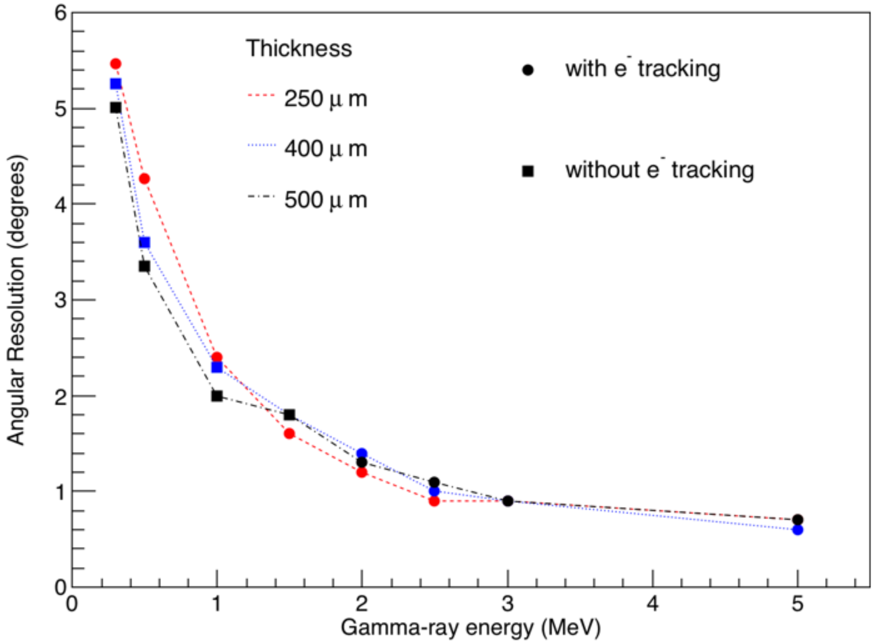


Better angular resolution for:
Without e- tracking < 1.5 MeV
With e- tracking >= 1.5 MeV

Comptons Events

Best angular resolution

Angular Resolution



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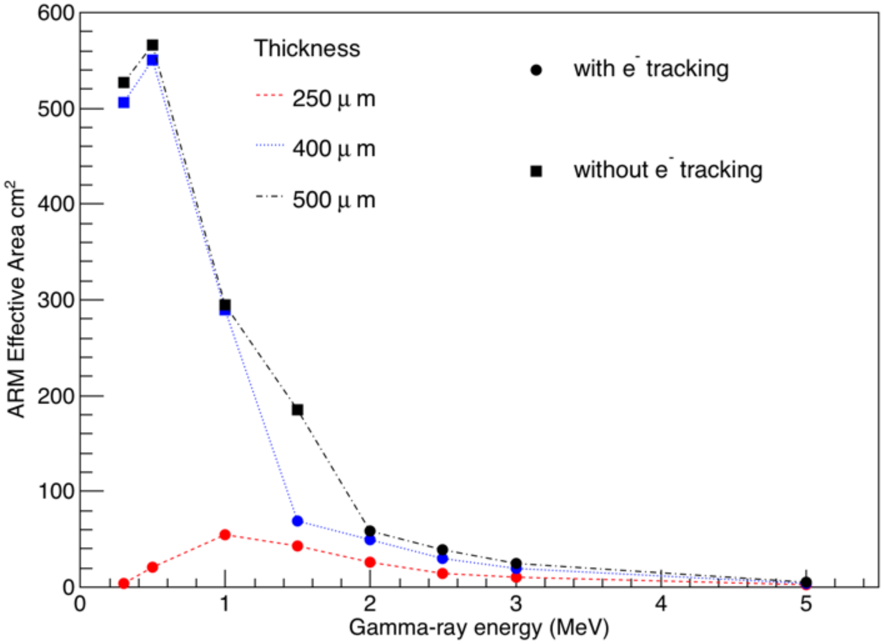
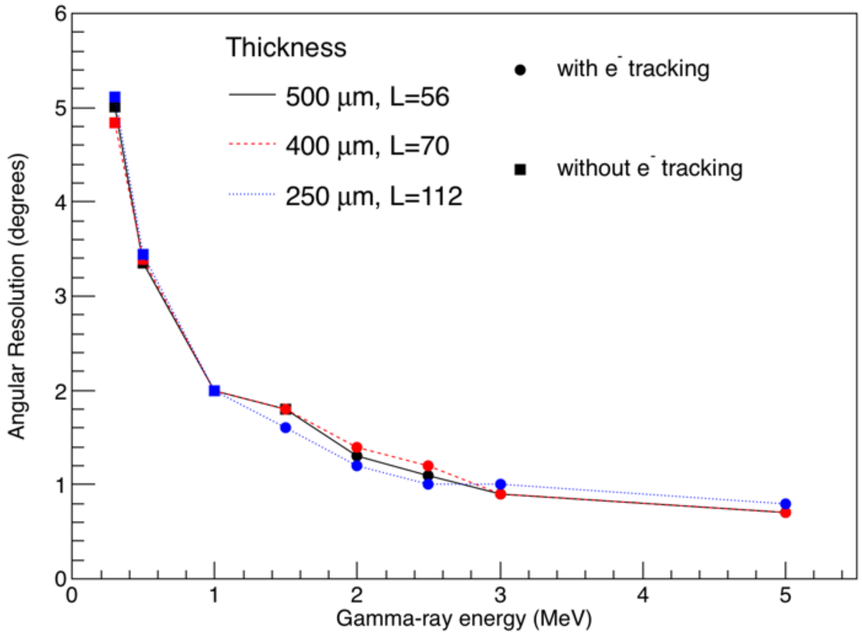


Fix the number of layer to 56

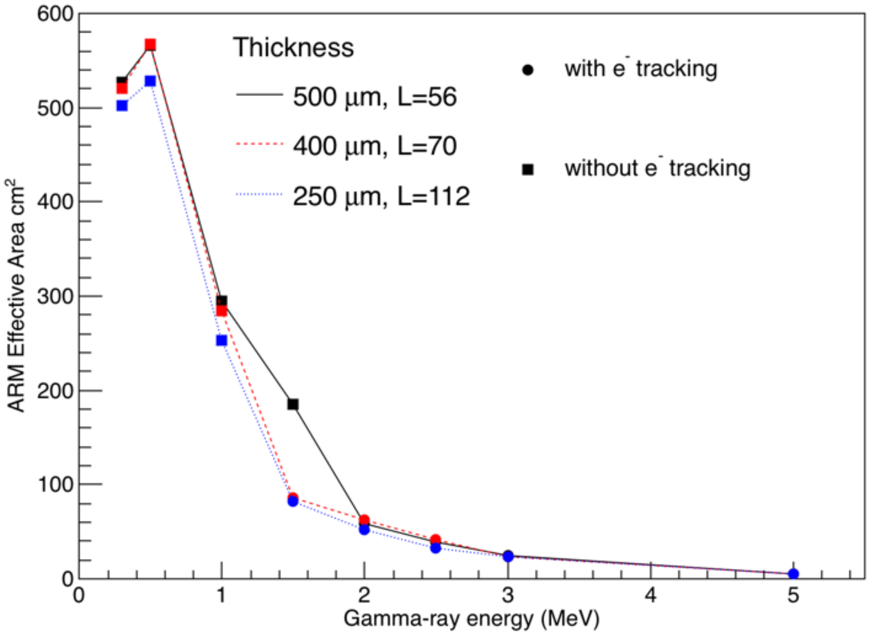
Comptons Events

Best angular resolution

Angular Resolution



Effective Area



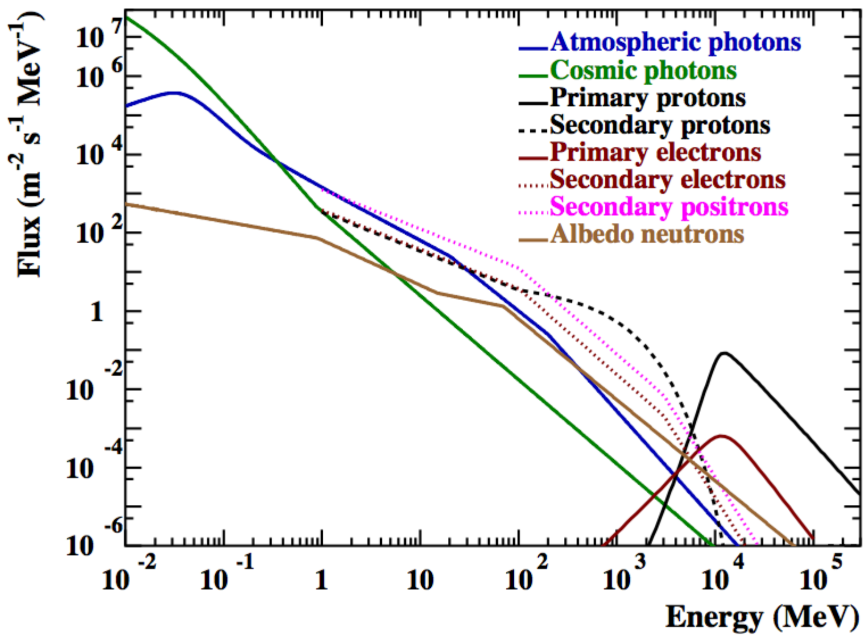
Fix the interaction length to: 0.3 X_0

Sensitivity
Expected background

e-ASTROGAM should be launched into a quasi-equatorial (inclination i < 2.5°) low-Earth orbit (LEO) at a typical altitude of 550 km

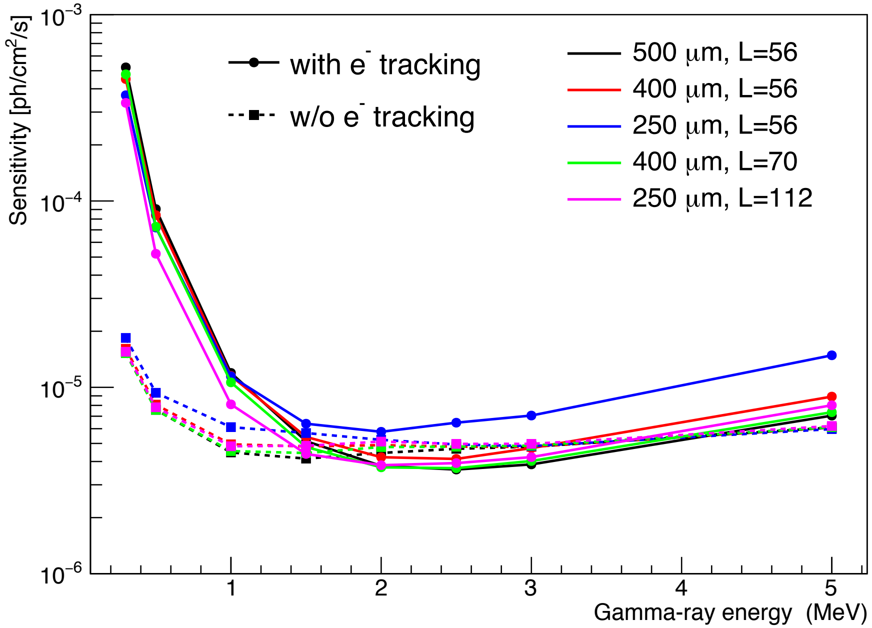
Well know background

To speed up the simulations we have only simulated background photons

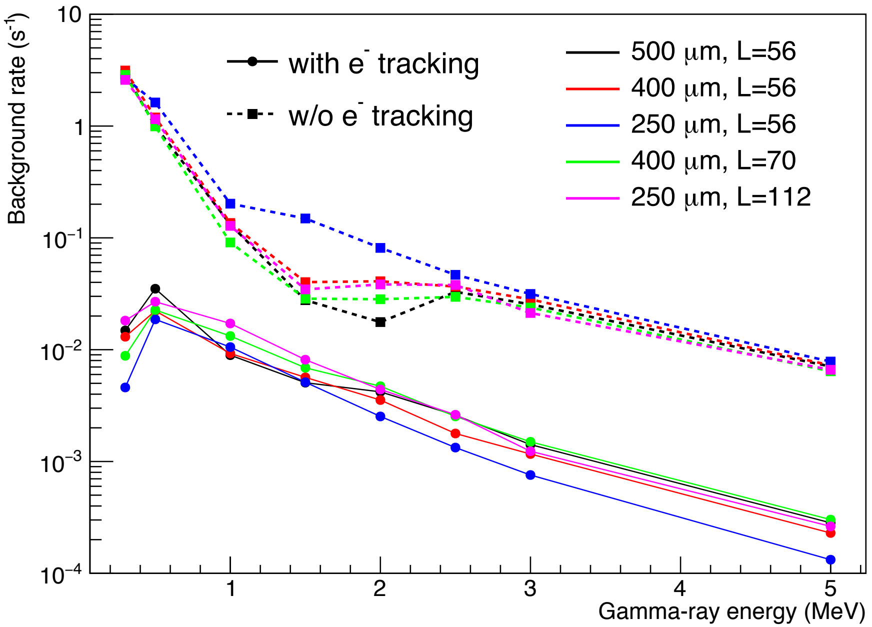


Sensitivity Calculation

Sensitivity, T_{obs}=1year

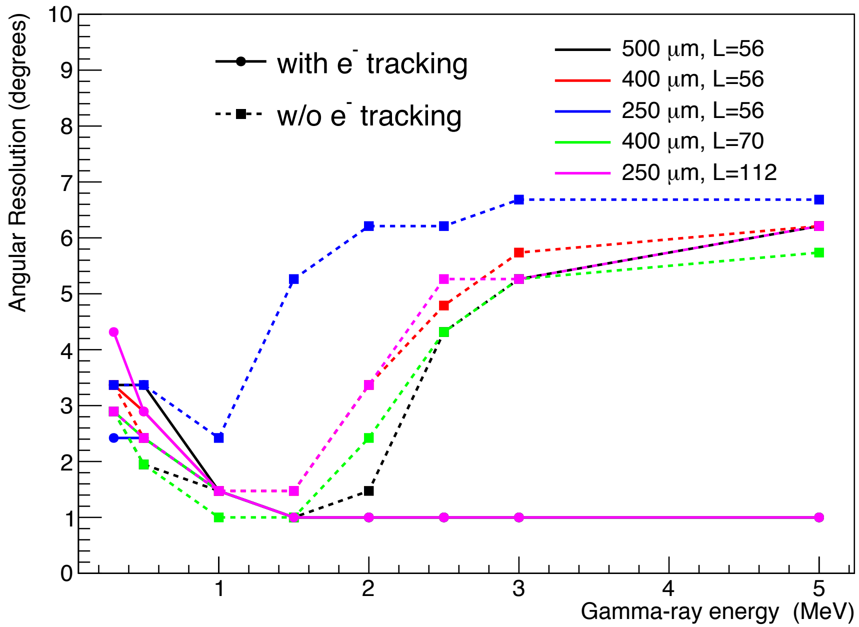


Background rate



Sensitivity Calculation

Angular Resolution



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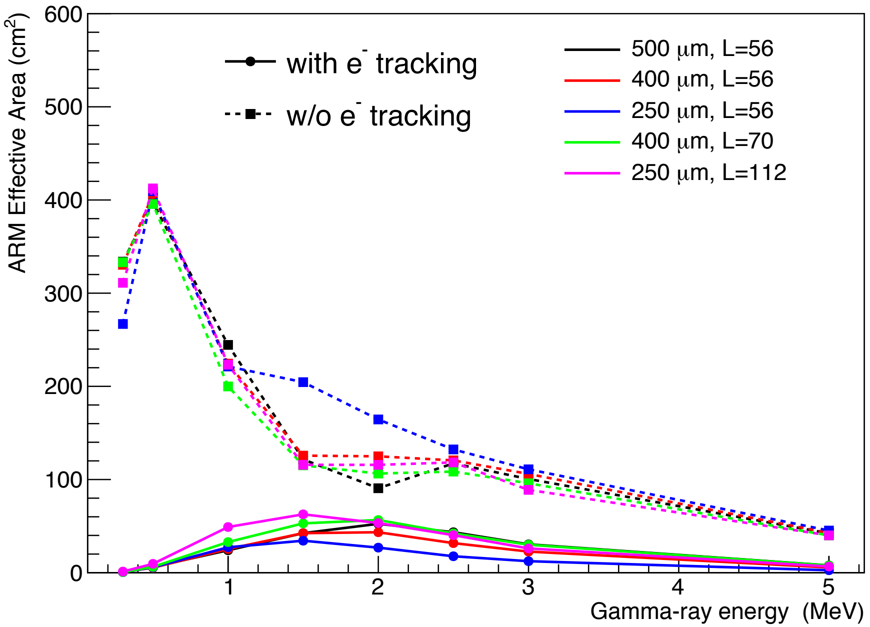

The angular resolution calculated using the Sensitivity give the same results as before within uncertanties

Summary & Conclusion

- Using MEGALib we have simulated the mass model for eASTROGAM telescope.

- The main objective is the optimization of the Si-tracker geometry parameters:
    - Thickness
    - Number of Layers
    - Distance between Layers

- We have studied in the compton regime:
    - The energy & angular resolution
    - The effective area
    - Sensitivity

Summary & Conclusion

- The energy resolution is independent of the geometry parameters choices.

- For the angular resolution:
  - We have to apply rec. CUTs to obtain a good AR.
    - Without e^- tracking approx. $E_0 <\approx 1.5$ MeV
    - With e^- tracking approx. $E_0 >\approx 1.5$ MeV
  - E_0 depends on the thickness when number of layers is fixed.
  - We have found better performance when we keep the radiation lenght constant (0.3 X_0) almost independent of the geometry.

- We have found the same conclusions when we have studied the sensitivity.

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