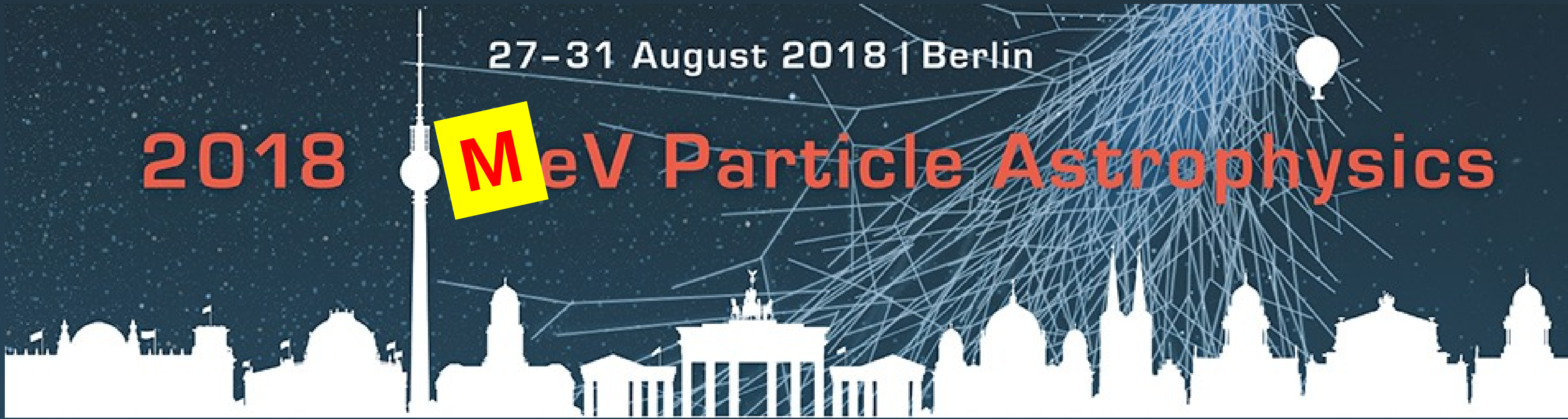


R. Rando[1]

to medium

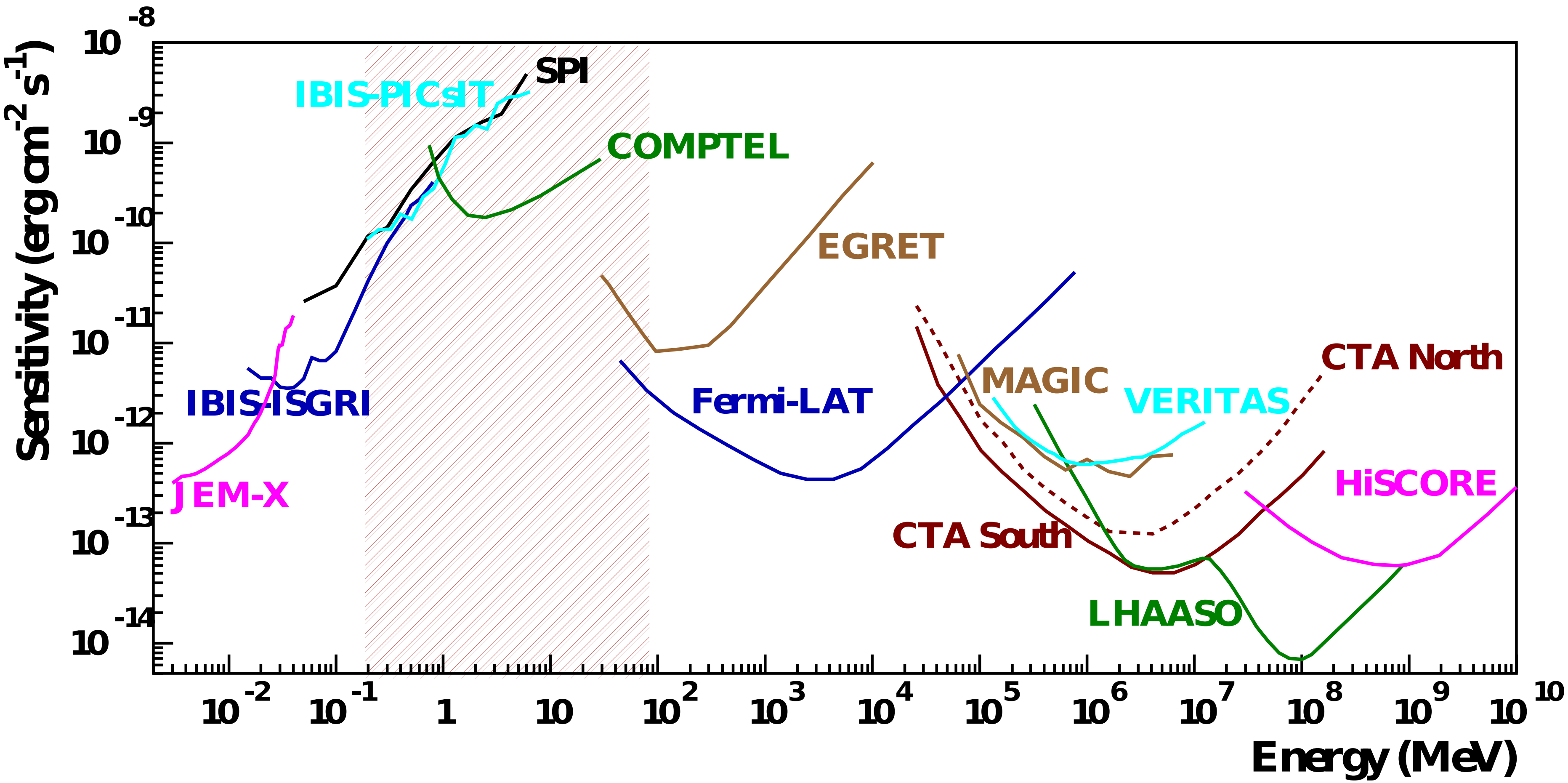
Future space observatories for low energy gamma rays

[1]: University of Padova & INFN Padova

Outline

- MeV observations from space
- Proposed new instruments:
  - e-ASTROGAM
  - AMEGO
  - Science objectives
- COSI
- Nano-scale proposals
- Other technologies
- Conclusion

A poorly covered regime



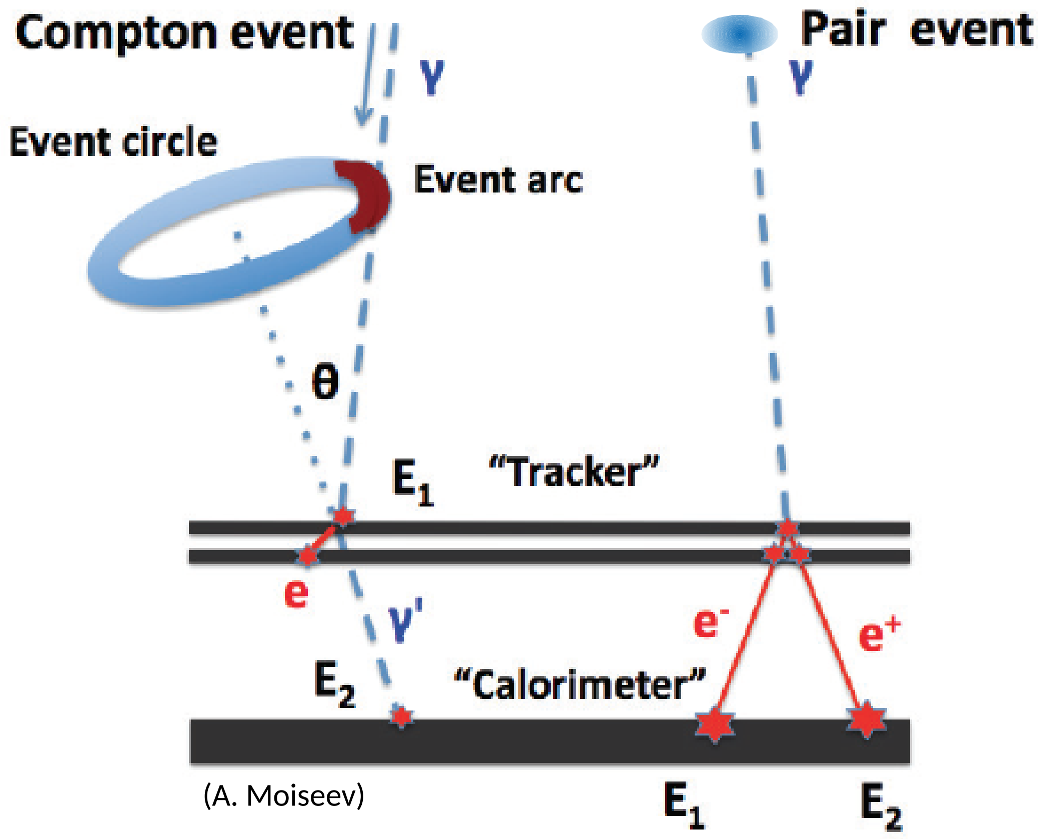
- Worst covered part of the electromagnetic spectrum is 0.1-100 MeV
- Many objects have peak emissivity in this range (GRBs, blazars, pulsars...)
- The MeV range is the domain of nuclear gamma-ray lines (supernovae, nucleosynthesis and Galactic chemical evolution). **MeV astronomy is for nuclear physics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

Why is it so?

- **Compton regime**
  - Require excellent 3D-point resolution and energy resolution
  - Energy and direction recon (TKR and CAL) tightly entwined
- **Pair-production regime**
  - Tracking resolution very important (be wary of multiple scattering)
  - Energy and direction recon (TKR and CAL) loosely entwined
  - Main concern is detector thickness (r.l.)

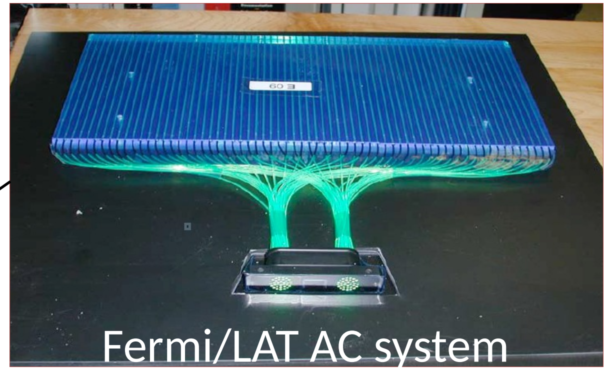
- Difficult to be truly optimal in both regimes across the gap with one detector

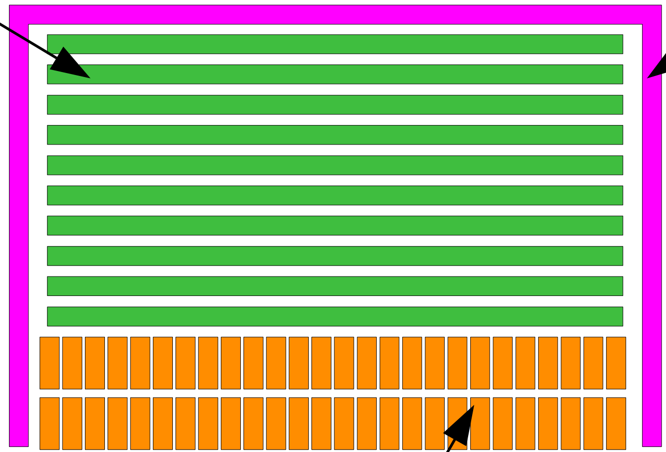
$$\cos\theta = 1 - \frac{m_e}{E_\gamma} + \frac{m_e}{E_\gamma - E_e} = 1 - \frac{m_e}{E_1 + E_2} + \frac{m_e}{E_2}$$



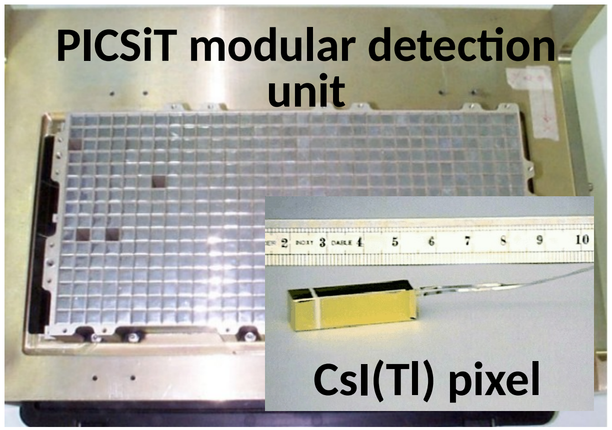
Plans for a MeV-GeV observatory

Tracker (FERMI, AGILE, PAMELA…)
Double sided Si microstrip detectors
No conversion foils: lots of Si!
Analog readout (pulse height)





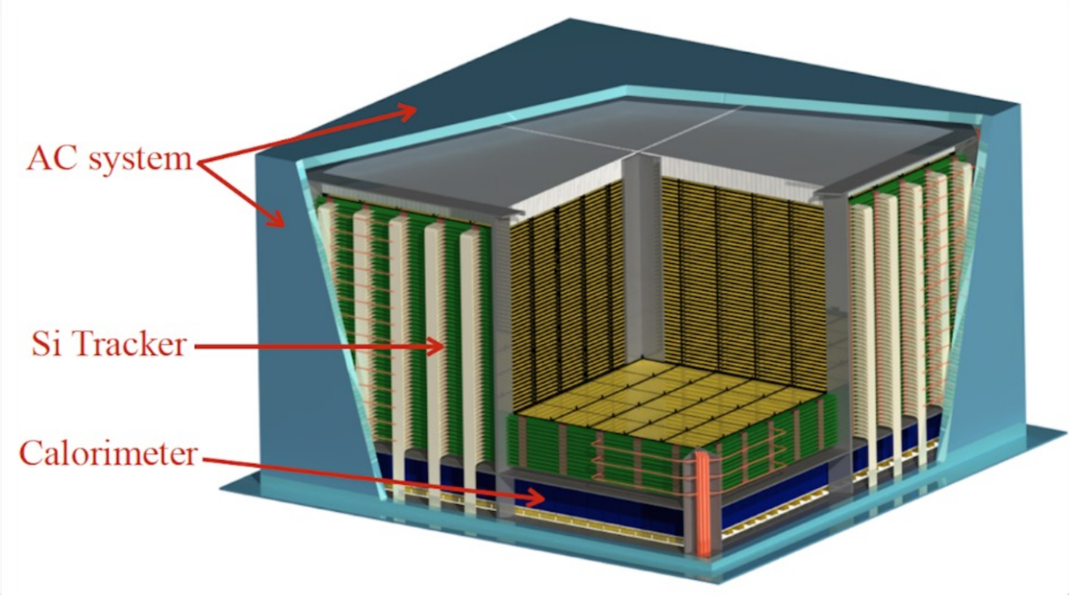
ACD (FERMI, AGILE…)
Not much backsplash at these energies

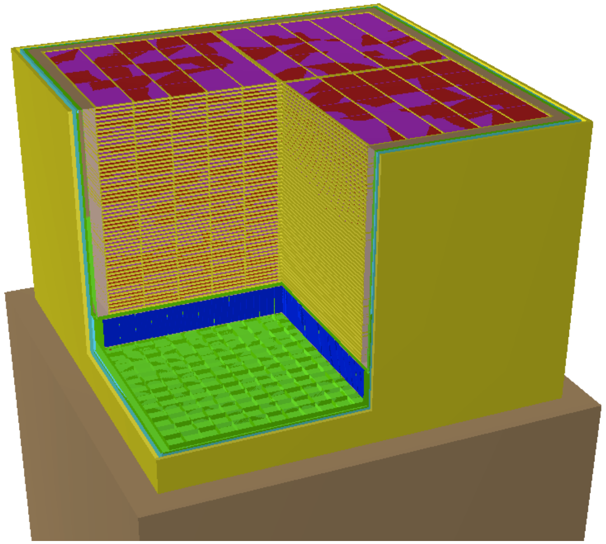


Calorimeter (FERMI, AGILE, INTEGRAL…)
Finely segmented: good position resolution
Bottom-thick for the pair regime

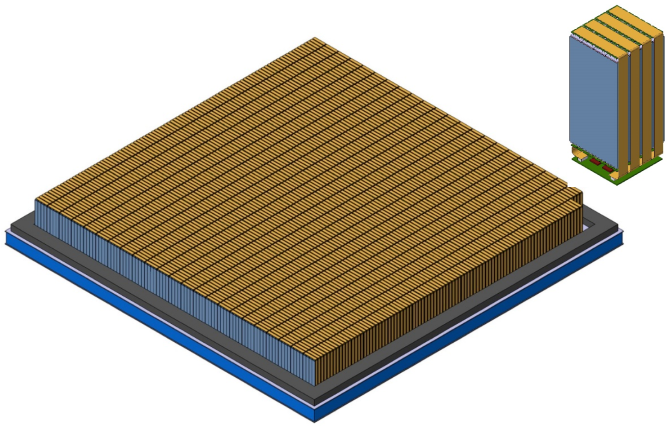
e-ASTROGAM

http://eastrogam.iaps.inaf.it





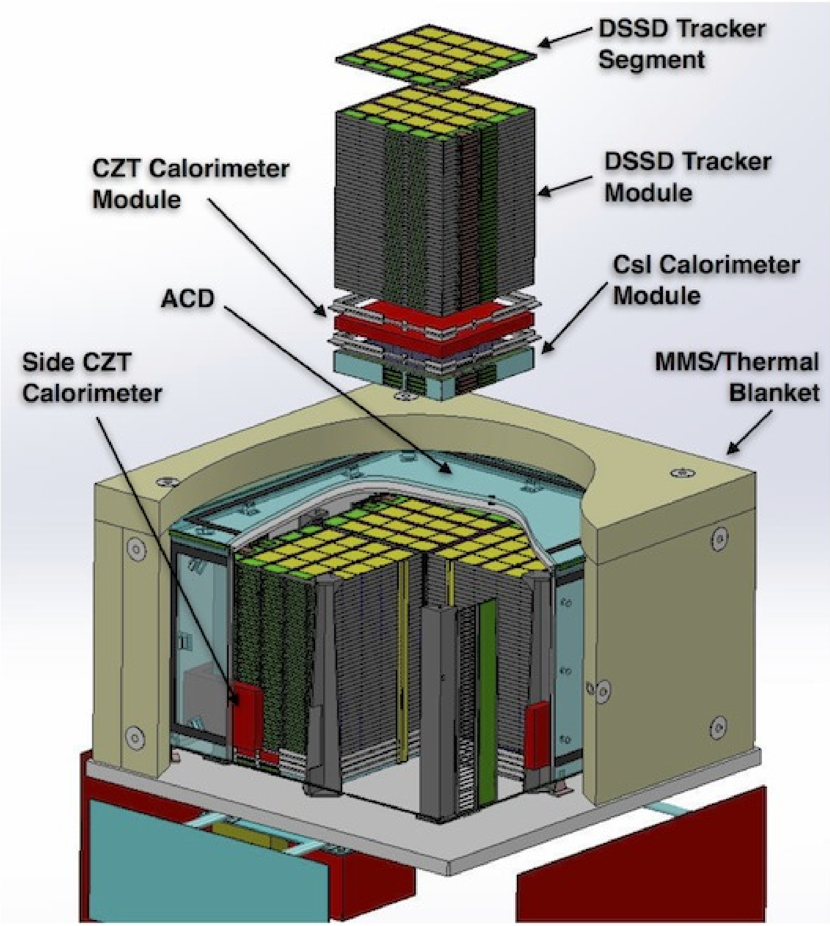
Tracker: 4 towers, 56 layers
5600 DSSD detectors, 500um thick, 240 um strip pitch
Readout: IdeF-X ASICs + ADC (13 bit)
Total 668 W



Calorimeter: 33,856 CsI(Tl) bars in 529 modules
5x5x80 mm^3 bars, SiPM readout
4.3 radiation lengths, ~300 kg of scintillator
Readout based on VEGA ASIC

AMEGO

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



Tracker: 60 layers
DSSD detectors, 500um thick, 500 um strip pitch
Readout: IdeF-X ASICs + ADC (13 bit)

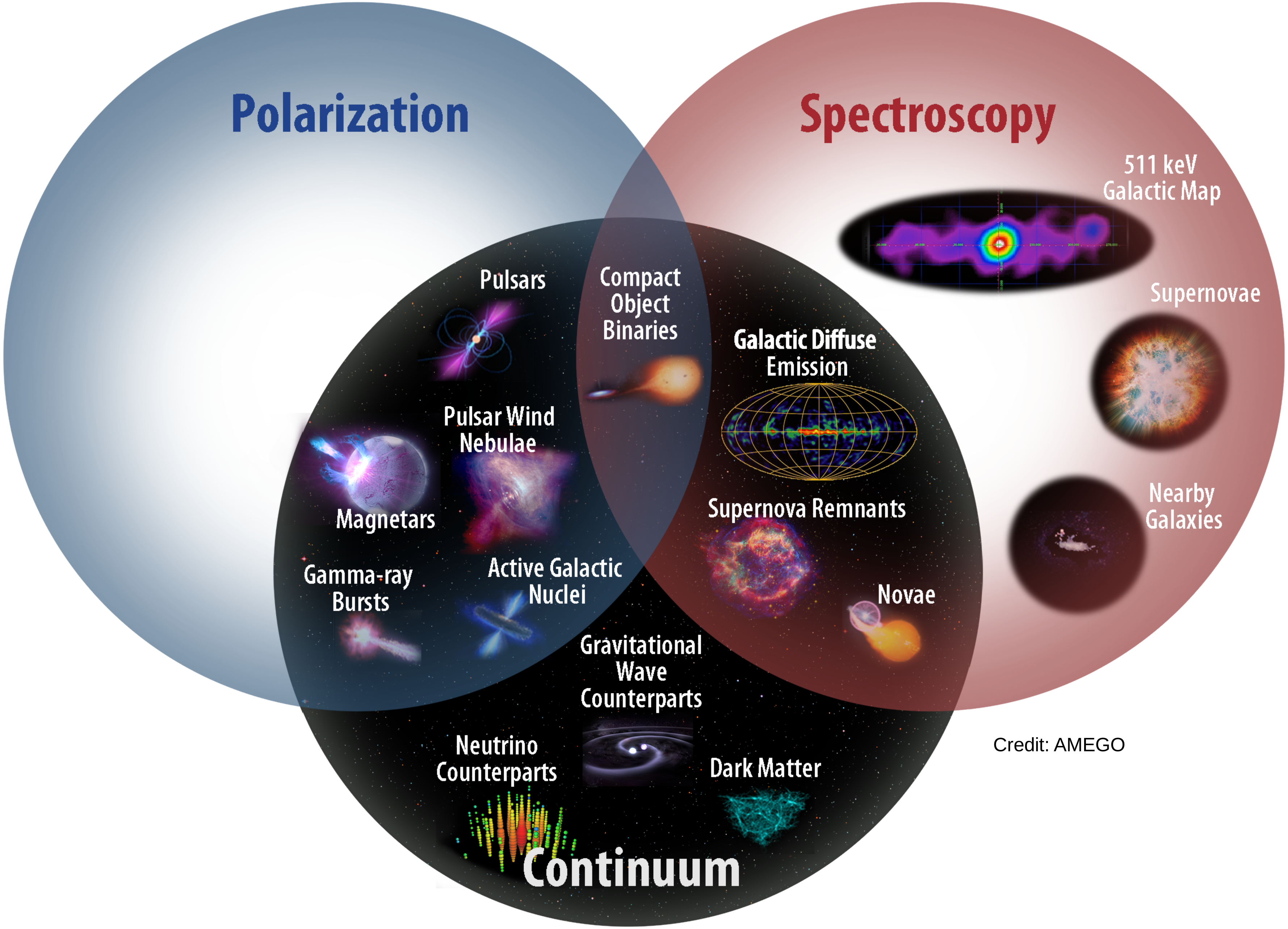
CsI bottom Calorimeter:
15*15*38 mm^3 bars in 6 layers
SiPm readout

CZT bottom&side Calorimeter:
6*6*20 mm^3 bars, virtual Frisch-grid setup
Sub-mm spatial resolution, <1% energy resolution (at 662 keV) even with low-quality crystals

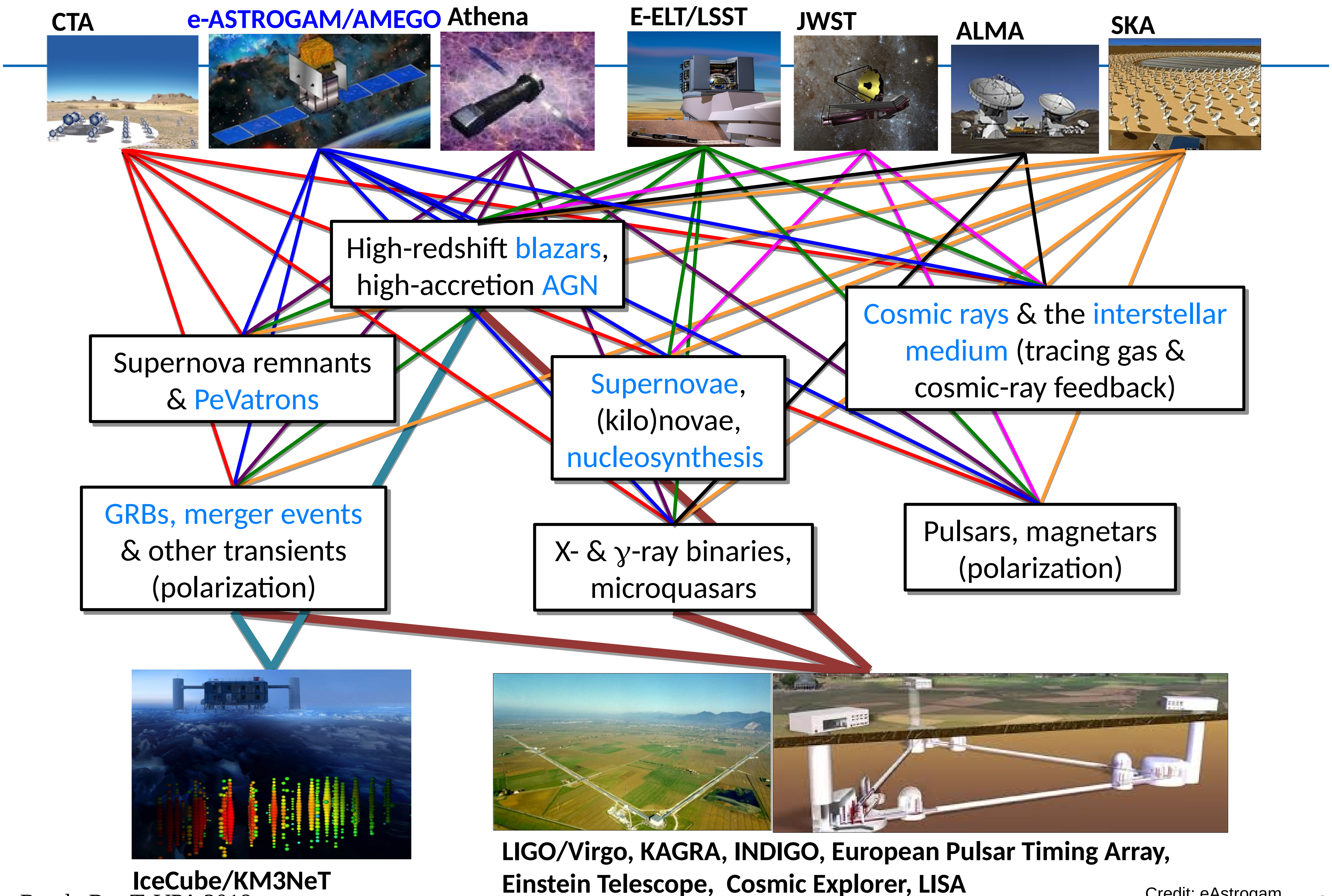
Developing **prototypes** of all subsystems
Test beam of all subsystems in late 2018 / 2019
Balloon flight in 2019

See S. Griffin:
"Status of the AMEGO Subsystem Development"

Science



Credit: AMEGO



Credit: eAstrogam

Science white book

e-ASTROGAM:
https://arxiv.org/abs/1711.01265
224 authors
194 pages

AMEGO:
Coming soon

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,[25] J. Isern,[26] M. Leising,[27] F. Longo,[28,29] G. Madejski,[30] M. Martinez,[31] M. N. Mazziotta,[32] J. M. Paredes,[33] M. Pohl,[34] R. Rando,[1,35] M. Razzano,[36,37] A. Aboudan,[35,3] M. Ackermann,[38] A. Addazi,[39] C. Albertus,[40] M. Ajello,[27] J. M. Álvarez,[41] G. Ambrosi,[42] S. Antón-Castillo,[43] L. A. Antonelli,[44] A. Babic,[45] B. Baibussinov,[1] M. Balbo,[46] L. Baldini,[36,47] S. Balman,[48] C. Bambi,[49,50] U. Barres de Almeida,[51] J. A. Barrio,[52] R. Bartels,[53] D. Bastieri,[35,1,54] W. Bednarek,[55] D. Bernard,[11] E. Bernardini,[56,38] T. Bernasconi,[13] A. Biland,[57] E. Bissaldi,[58,32] V. Bonvicini,[29] V. Bosch-Ramon,[33] E. Bottacini,[35,1] 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,[35] S. Buson,[7] M. Busso,[42,65] S. Camera,[66,67,68,69] R. Campana,[16] P. Caraveo,[70] M. Cardillo,[8] P. Carlson,[71] S. Celestin,[72] M. Cermeño,[40] C. C Cheung,[73] E. Churazov,[74,75] S. Ciprini,[44,42] A. Coc,[5] A. Coleiro,[76,77] W. Collmar,[78] P. Coppi,[79] R. Curado da Silva,[80] S. Cutini,[44,42] B. De Lotto,[81] D. de Martino,[82] A. De Rosa,[8] L. Delgado,[18] R. Diehl,[78] S. Dietrich,[83] A. D. Dolgov,[84,85] A. Dominguez,[52] D. Dominis Prester,[86] I. Donnarumma,[8] D. Dorner,[87] M. Doro,[1,35] M. Fabrizio,[44,88] V. Fioretti,[16] L. Foffano,[35,1] N. Fornengo,[66,67] L. Foschini,[24] A. Franceschini,[35] A. Franckowiak,[89] S. Funk,[90] F. Fuschino,[16] G. Gaggero,[53] G. Galanti,[91] F. Gargano,[32,92] D. Gasparrini,[44,42] R. Gehrz,[93] P. Giammaria,[88] N. Giglietto,[58,32] P. Giommi,[94] F. Giordano,[32] G. Ghirlanda,[24,95] N. Godinovic,[45] C. Gouiffès,[96] J. E. Grove,[97] C. Hamadache,[5] D. H. Hartmann,[27] M. Hayashida,[98] A. Hryczuk,[64] P. Jean,[99] T. Johnson,[100] J. José,[101] S. Kaufmann,[102] J. Kiener,[5] J. Knödlseder,[103] M. Kole,[13] J. Kopp,[104] V. Kozhuharov,[59] C. Labanti,[16] S. Lalkovski,[59] P. Laurent,[105] O. Limousin,[106] L. Nava,[24,107] E. Lindfors,[108] J. Liu,[109] S. Lombardi,[44,88] F. Loparco,[32,92] M. López Moya,[52] B. Lott,[110] P. Lubrano,[42] D. Malyshev,[111] N. Mankuzhiyil,[112] K. Mannheim,[87] A. Marcianò,[39] B. Marcote,[113] M. Mariotti,[1] M. Marisaldi,[114] S. McBreen,[12] S. Mereghetti,[115] A. Merle,[116] R. Mignani,[117,118] G. Minervini,[8] A. Moiseev,[119] A. Morselli,[10] K. Nakazawa,[120] D. Nieto,[52] M. Orio,[121,2] E. Orlando,[30] P. Orleanski,[122] S. Paiano,[2] R. Paoletti,[36] A. Papitto,[88] B. Patricelli,[123,36] M. Á. Pérez-García,[40] M. Persic,[107] G. Piano,[8] A. Pichel,[124] M. Pimenta,[4] C. Pittori,[44,88] T. Porter,[30] J. Poutanen,[108] E. Prandini,[35,1] N. Prantzos,[125] N. Produit,[13] S. Rainò,[58,32] A. Rakley,[64] M. Regis,[66,67] I. Reichardt,[126] J. Rico,[127] C. Rodriguez Fernandez,[10] M. Roncadelli,[128] L. Roso,[129] A. Rovero,[124] R. Ruffini,[130] G. Sala,[101] M. A. Sánchez-Conde,[131] A. Santangelo,[132] P. Saz Parkinson,[133,134] T. Sbarrato,[95] A. Shearer,[135] R. Shellard,[51] K. Short,[53] T. Siegert,[78] P. Spinelli,[32] A. Stamerra,[123] S. Starrfield,[136] A. Strong,[78] I. Strümke,[137] F. Tavecchio,[24] R. Taverna,[35] T. Terzić,[86] D. J. Thompson,[138] O. Tibolla,[103] R. Turolla,[35] A. Ulyanov,[12] A. Ursi,[139] A. Vacchi,[81] J. Van den Abeele,[64] G. Vankova-Kirilova,[59] F. Verrecchia,[44,88] P. Vincent,[140] X. Wang,[141] C. Weniger,[53] X. Wu,[142] G. Zaharijaš,[143] L. Zampieri,[2] S. Zane,[144] S. Zimmer,[145] A. Zoglauer,[146] and the e-ASTROGAM collaboration

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-GEO600-KAGRA, SKA, ALMA, E-ELT, TMT, LSST, JWST, Athena, CTA, IceCube, KM3NeT, and LISA.

Observatory

Thousands of sources will be detected, from NSs to BHs, from CRs in gas clouds to SNRs in an energy range never fully explored before, with a vital link to simultaneous GeV emission on board, and all the rest with the "global Observatory" putting together all other facilities .

Extrapolate from 4FGL
in 1 effective year:

- > 1000 (candidate) blazars
- > 100 pulsars
- Several 100's unidentified

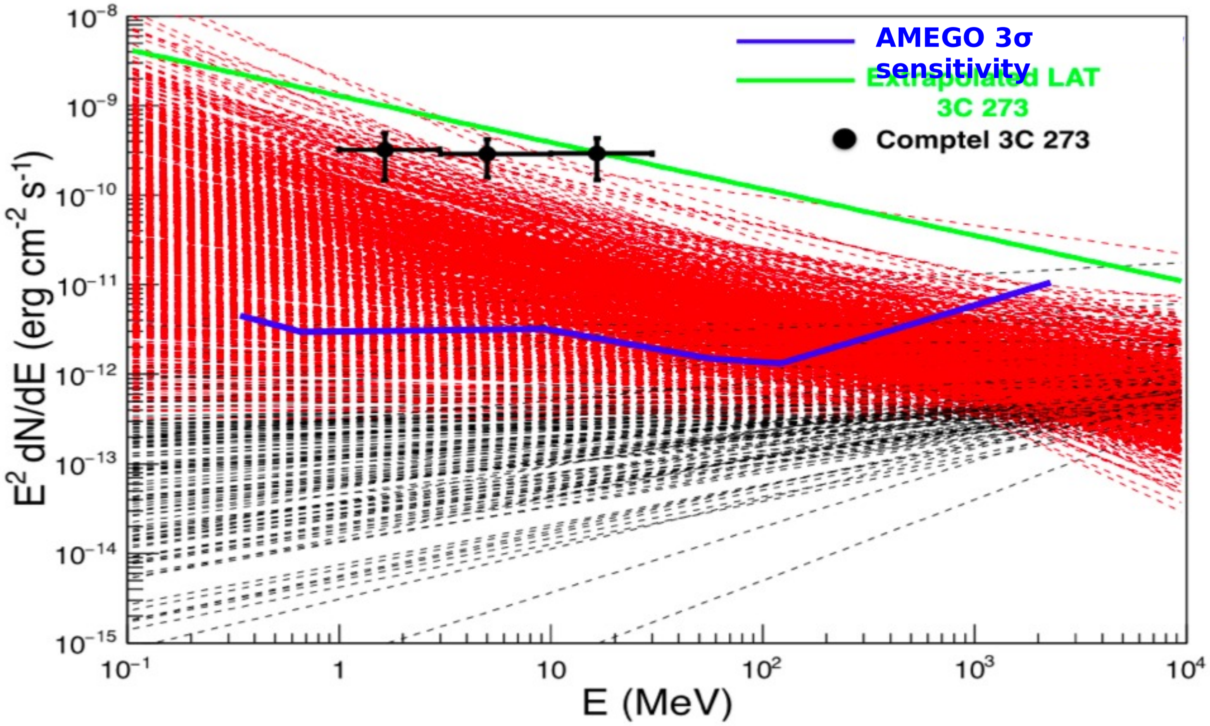
+ resolved SNRs

+ GRBs (later)

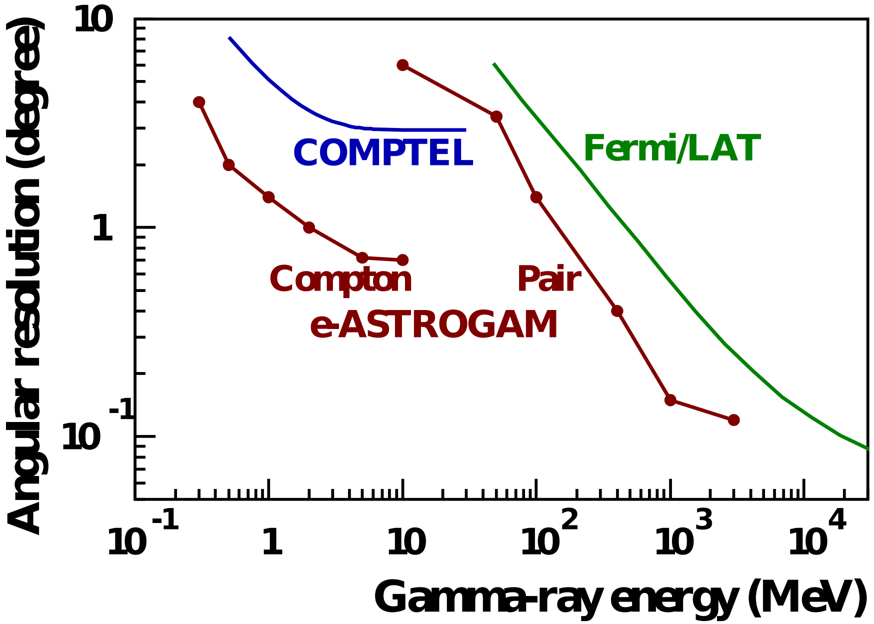
+ a few novae, ~10 supernovae

+ new MeV sources?

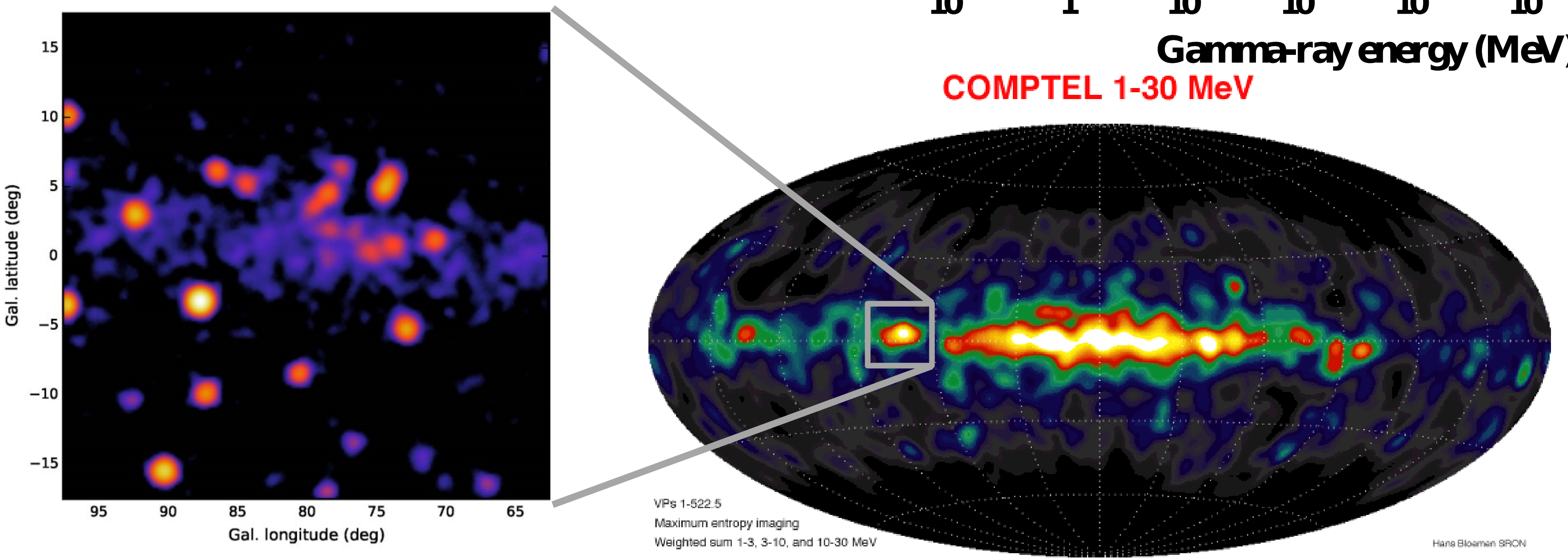
+ new MeV **source classes**?



Angular resolution

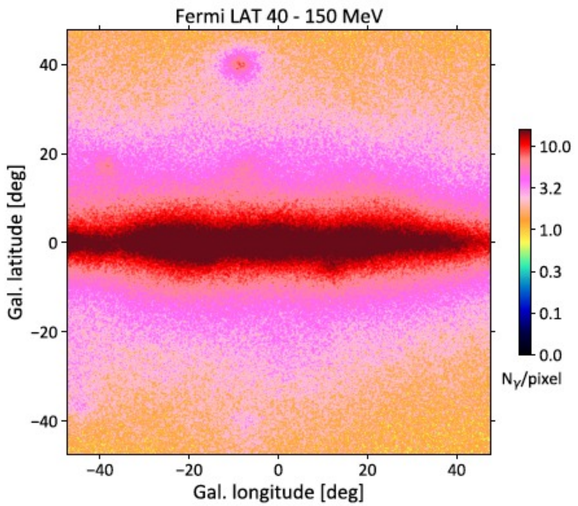


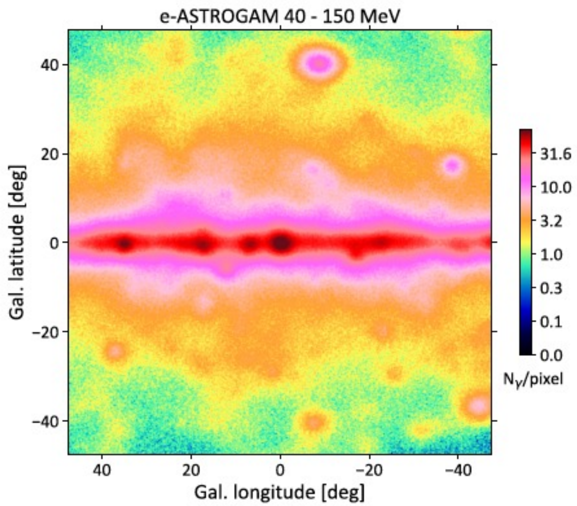
Cygnus region in the 1 - 3 MeV energy band with the e-ASTROGAM PSF (extrapolation of the 3FGL source spectra to low energies)

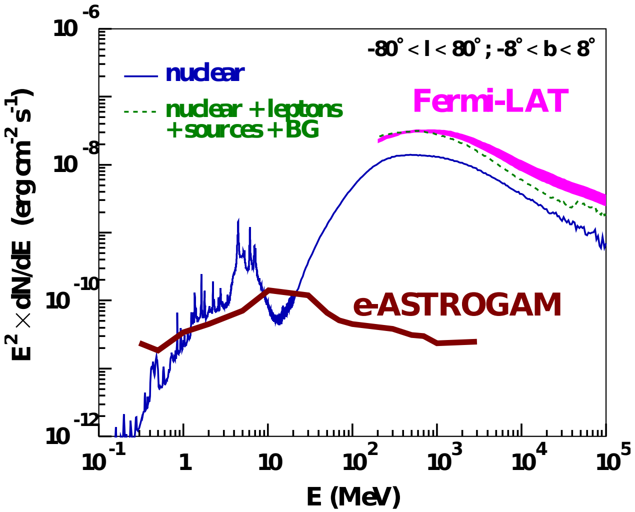


Galactic center

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

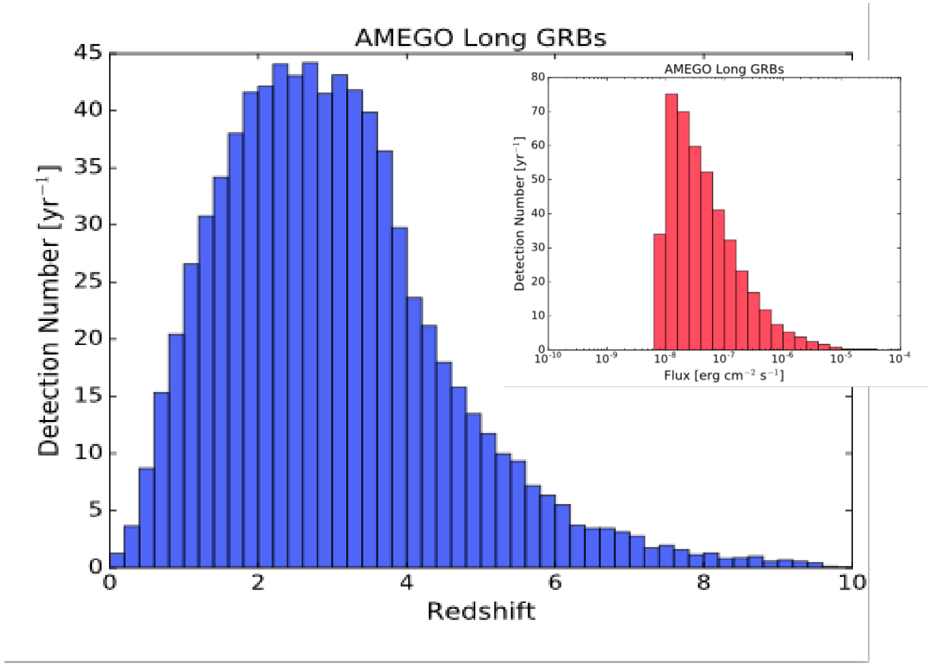






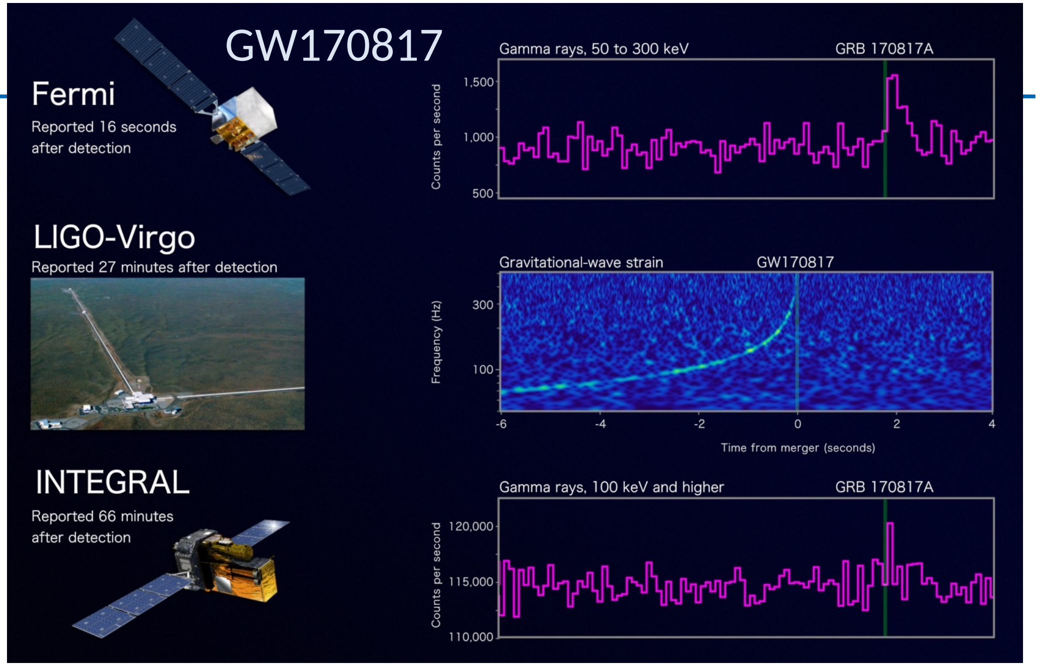
GRBs

- 440 **long** GRB/year (determined using method of Lien et al 2014)
  - 19.2/year with z>6
  - All with localization
- Polarization!
  - 20% MDP for brightest 1% of AMEGO GRBs
- ~80 **short** GRB/year (by scaling short/long ratio from GBM)
  - Important implications for gravitational wave counterpart searches



Instrument (current)	Energy range	GRB/year	localization
Fermi-GBM	8 keV – 40 MeV	240 (trig)	5-15 deg
Swift-BAT	15 keV – 150 keV	90	arcmin
Fermi-LAT	50 MeV – 300 GeV	10	~<0.5 deg
Insight-HMXT	200 keV – 5 MeV		5-15 deg
INTEGRAL-IBIS	15 keV – 10 MeV	2-5	arcmin

Instrument (proposed)	Energy range	GRB/year	localization
AMEGO*	200 keV – 10 GeV	500	0.5-2 deg
TAP/TAO	10 keV – 1 MeV	240	5-15 deg
SVOM-eclairs	4 keV – 120 keV	80	arcmin

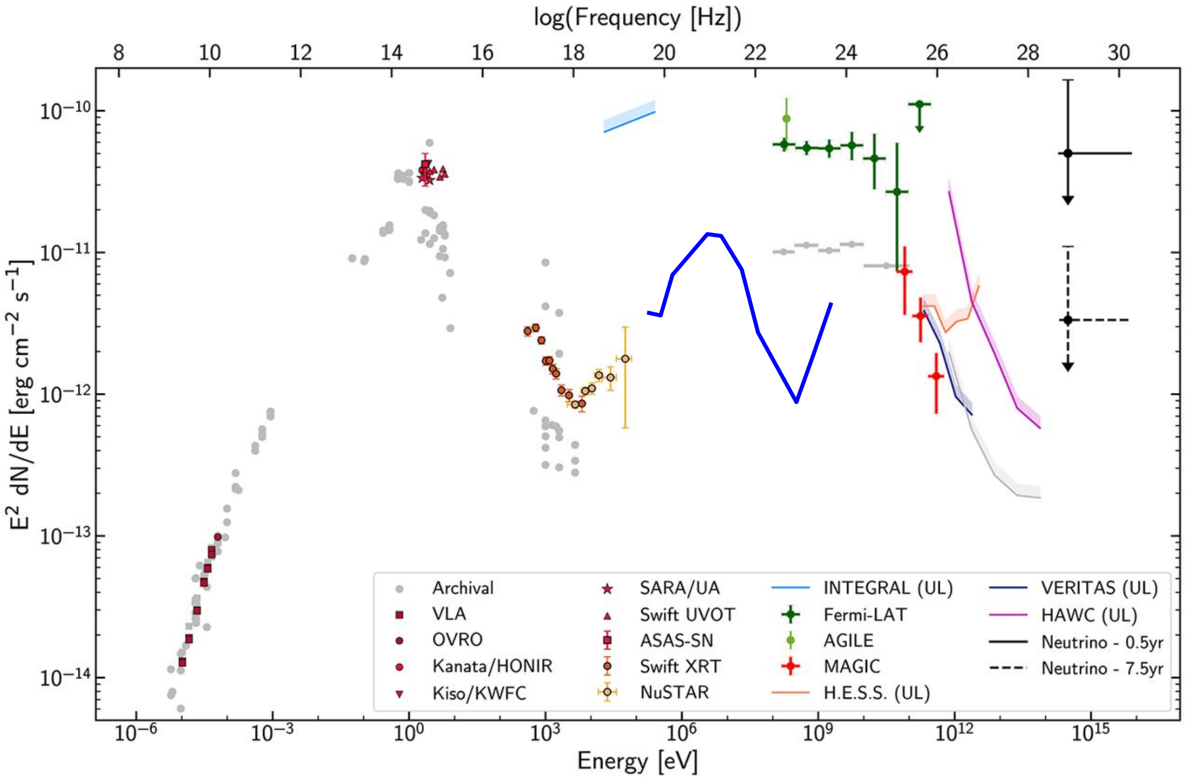


1) Short GRBs association with Gravitational Waves from NS-BH mergers?
2) AGN sources of VHE neutrinos and thus of UHECR?

e-ASTROGAM/AMEGO:

- wide FoV, prompt detection, localization
- detection of (~1 – 20) NS-NS mergers/year with GW after KAGRA + INDIGO
- Emission **lines**

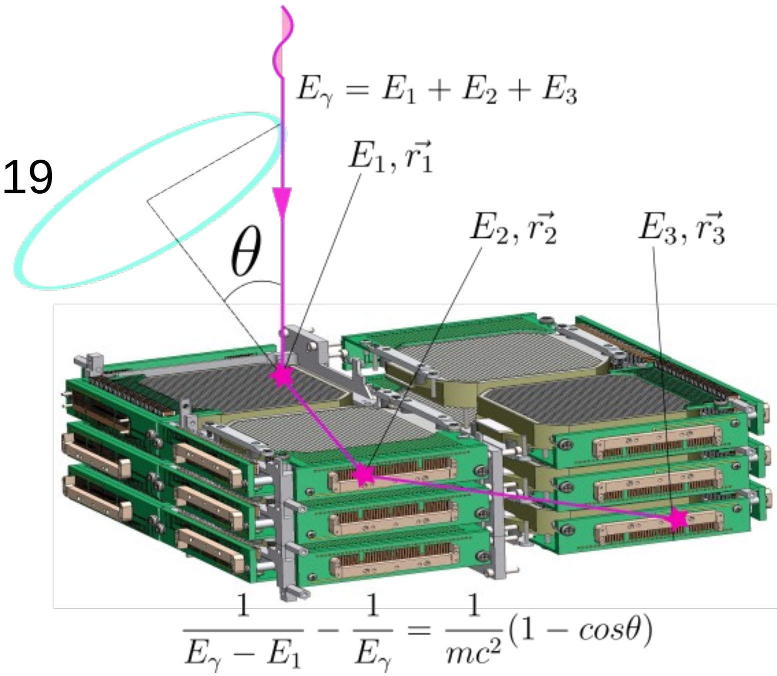
IceCube-170922A (TXS 0506 +056)
+
e-ASTROGAM sensitivity (7 days)

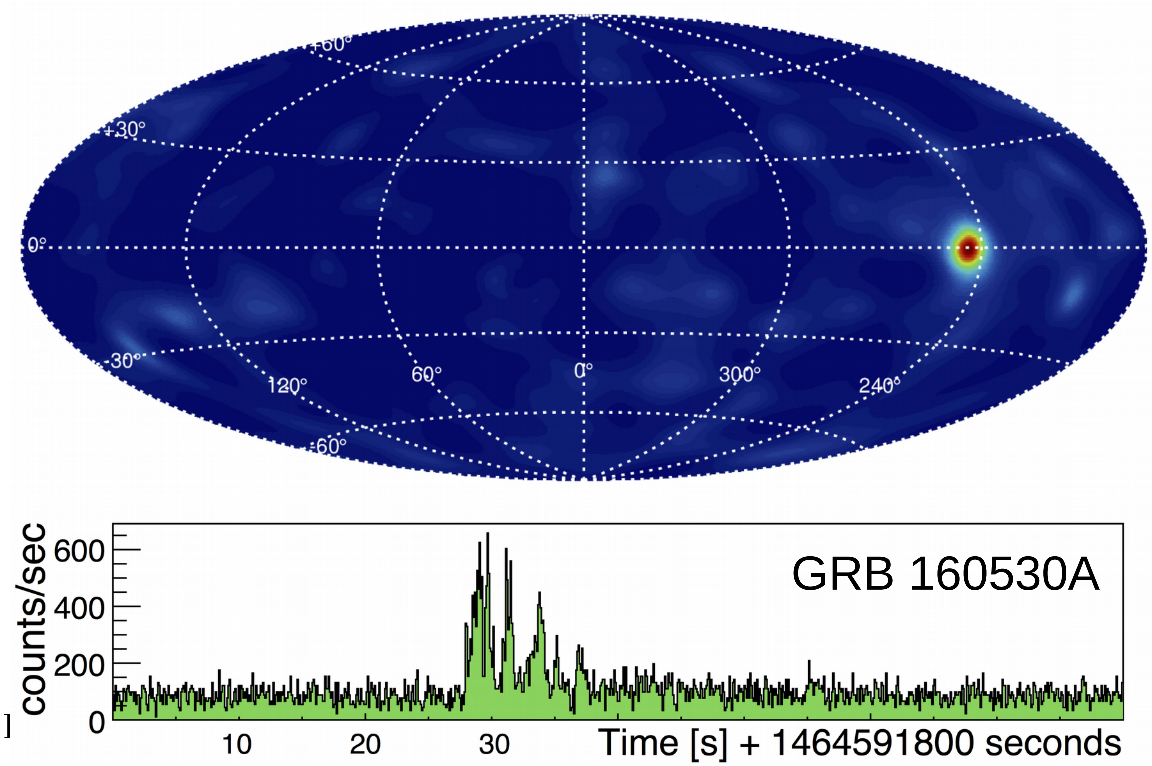


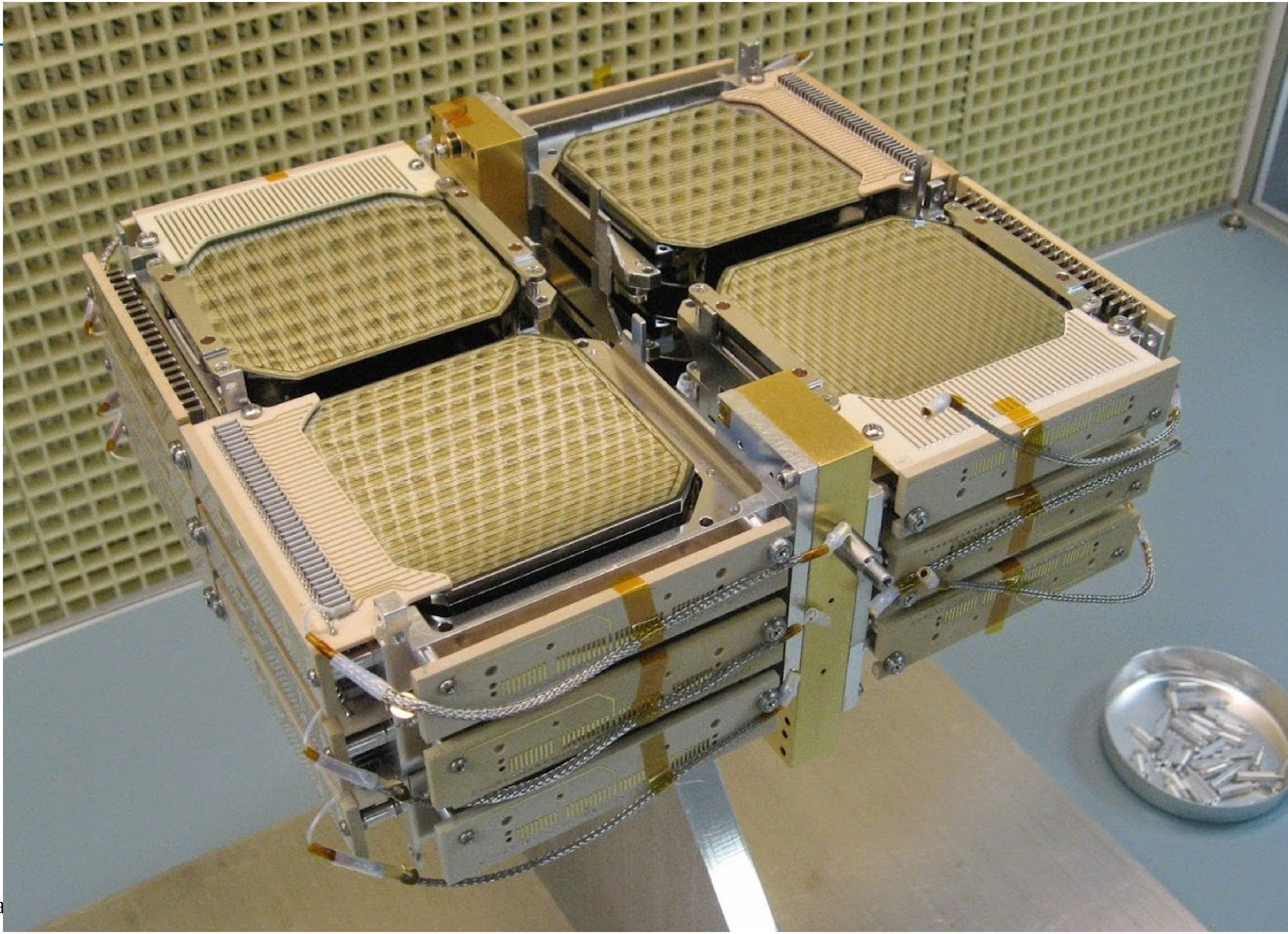
Compton Spectrometer and Imager (COSI)

- Balloon-borne compact Compton telescope
- Germanium detectors @ 83 K
- 0.2 – 5 MeV, energy resolution 2.7 keV @ 662 keV
- Successful flight (46 days) in 2016, next planned for 2019
- Several sources (Crab, Cen A, Cyg X-1, …)
- Long GRB 160530A
- Upper limit on polarization: <46% at 90% c.l.

- See also https://arxiv.org/pdf/1705.02652.pdf



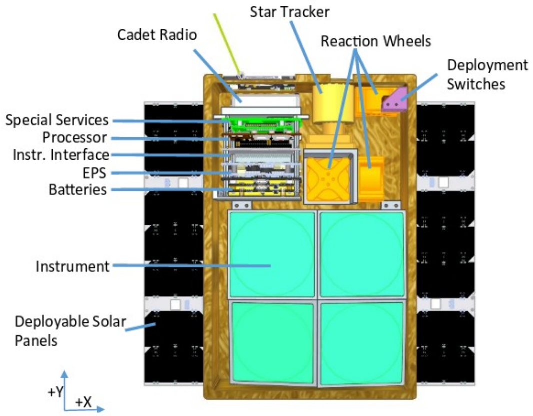




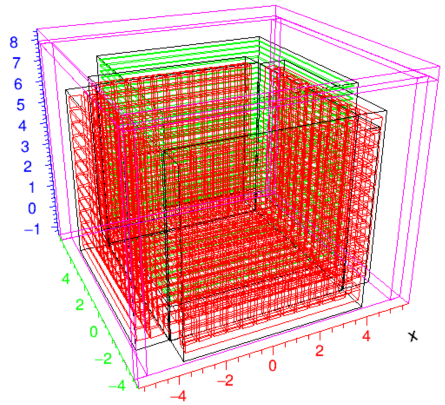
Nano instruments

Small (few liters, few kg), cheap, large FOV, constellations
Very high sky coverage
Optimal for GRBs! Several proposals, a few that I know that reach 1 MeV:

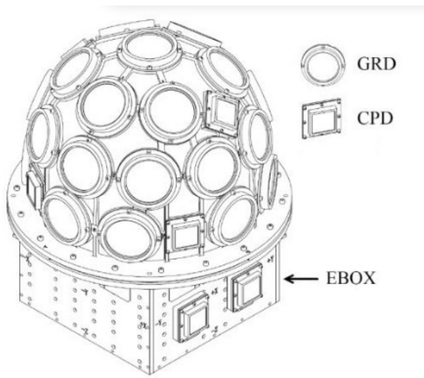
Burstcube



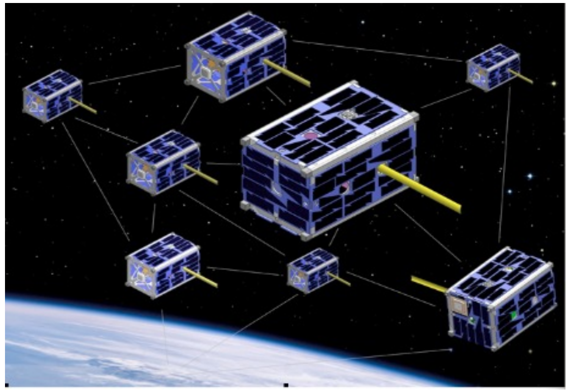
GammaMEV



GECAM



HERMES



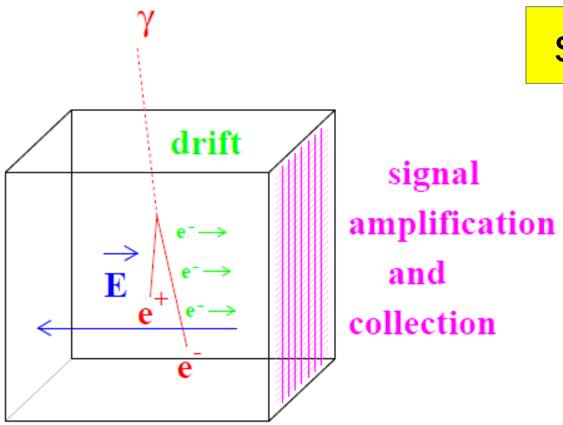
Several more, and many more in the x-ray range
Dedicated workshop in a few weeks:
https://asd.gsfc.nasa.gov/conferences/grb_nanosats

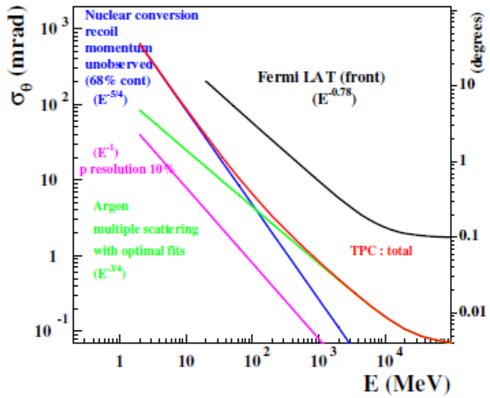
Other technologies

CMOS pixel detector, see talk by H. Yoneda

- HARPO (gas TPC)
  - Polarimetry in the MeV regime demonstrated in test beam

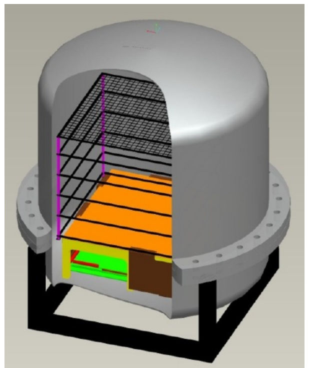
see poster by D. Bernard

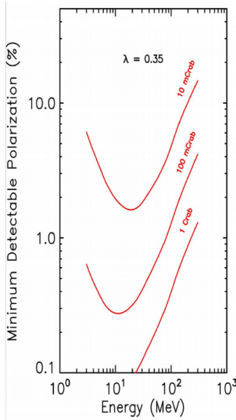




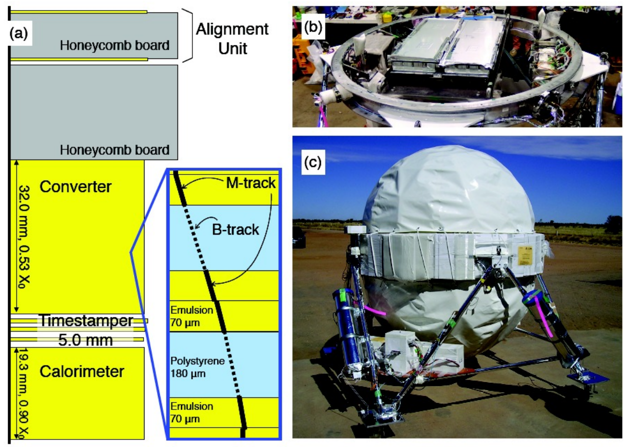
- AdEPT (gas TPC)

see talk by A. Timokhin





- GRAINE (emulsion, balloon flight)



Conclusion

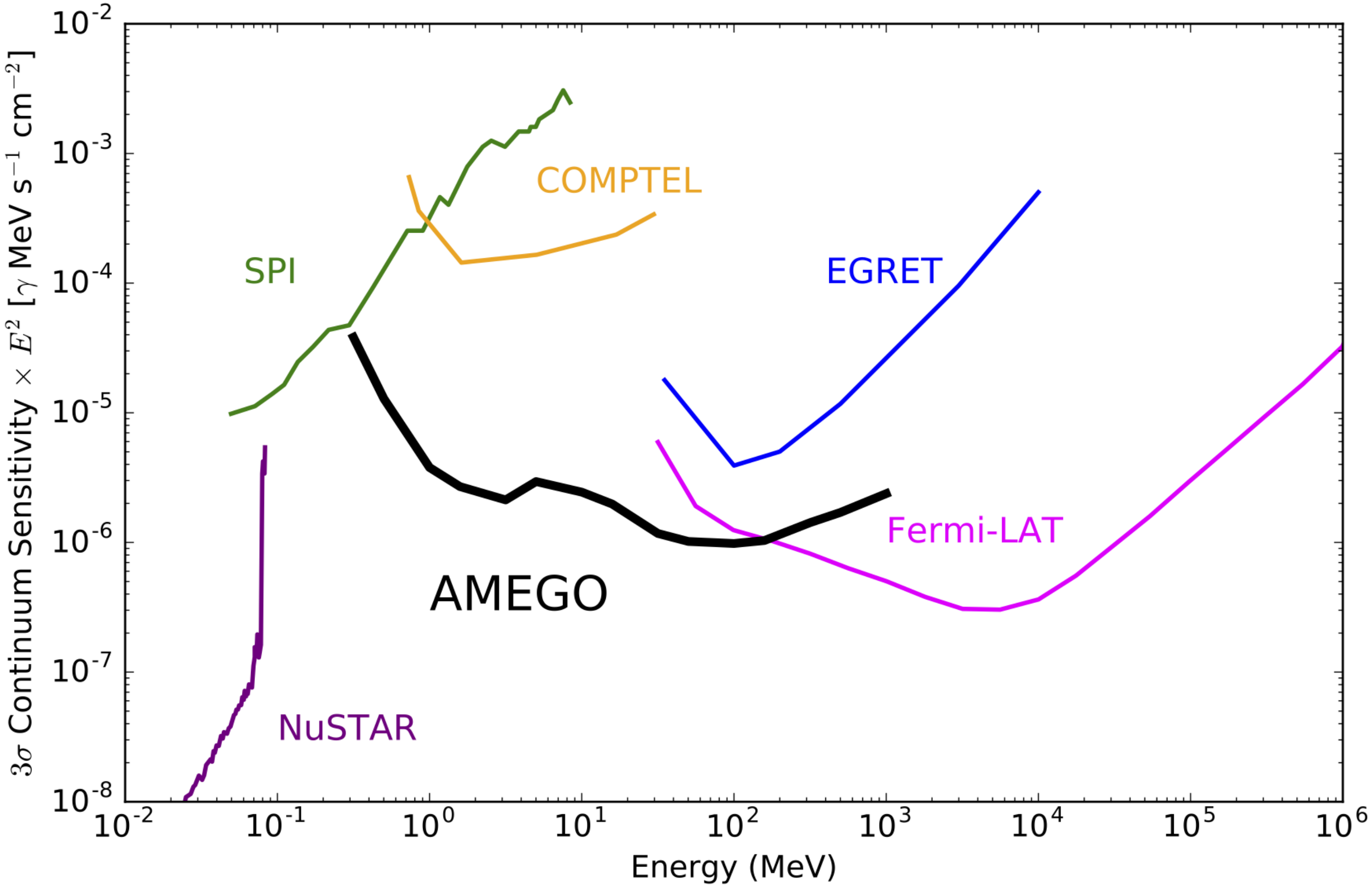
MeV astrophysics:

- ✔ Strong scientific case
- ✔ Lively community

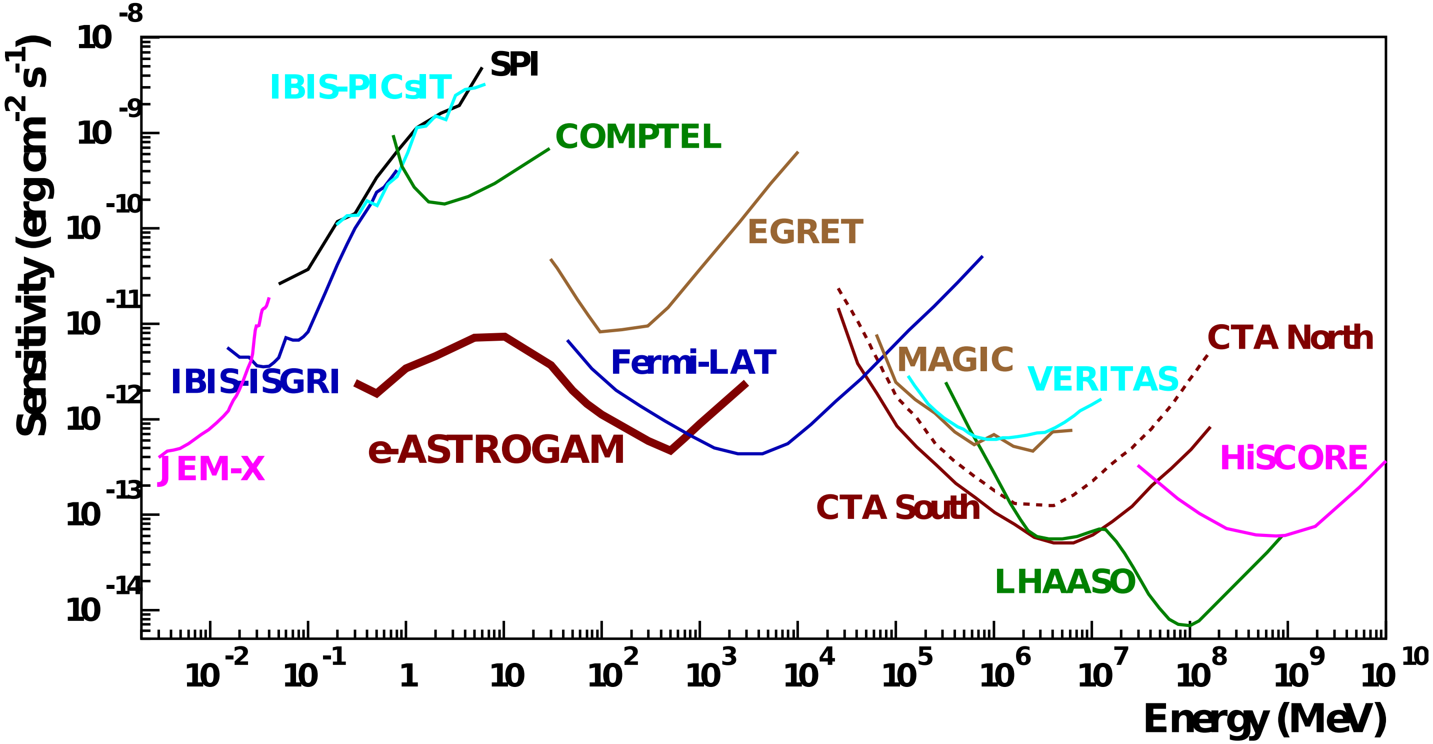
Stay tuned for news

Spares

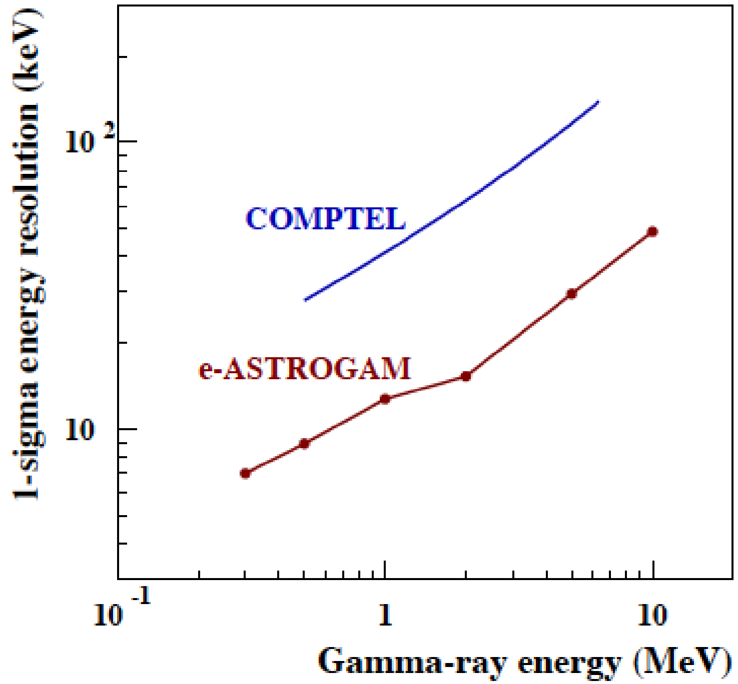
Sensitivity AMEGO



Sensitivity e-ASTROGAM



Eres e-ASTROGAM



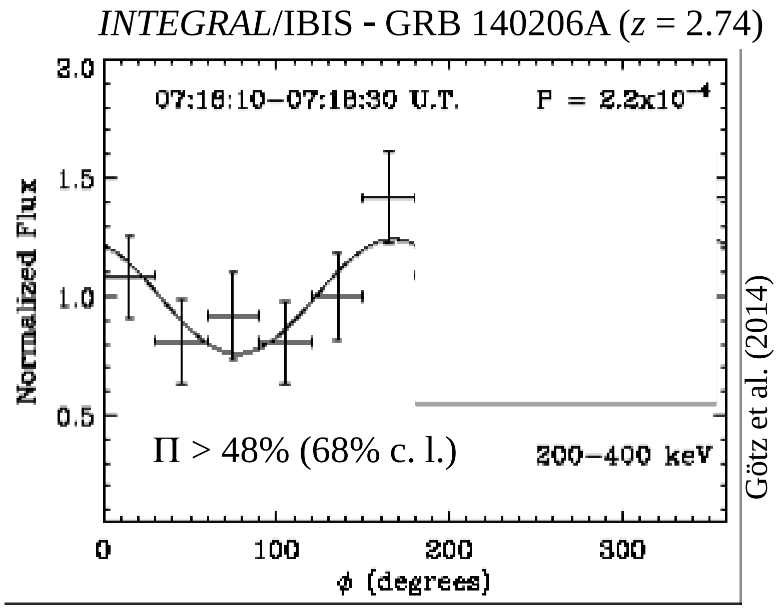
ΔE/E (Gamma-ray imager)	2.5% at 1 MeV 30% at 100 MeV
ΔE/E (Calorimeter burst)	< 25% FWHM at 0.3 MeV < 10% FWHM at 1 MeV < 5% FWHM at 10 MeV

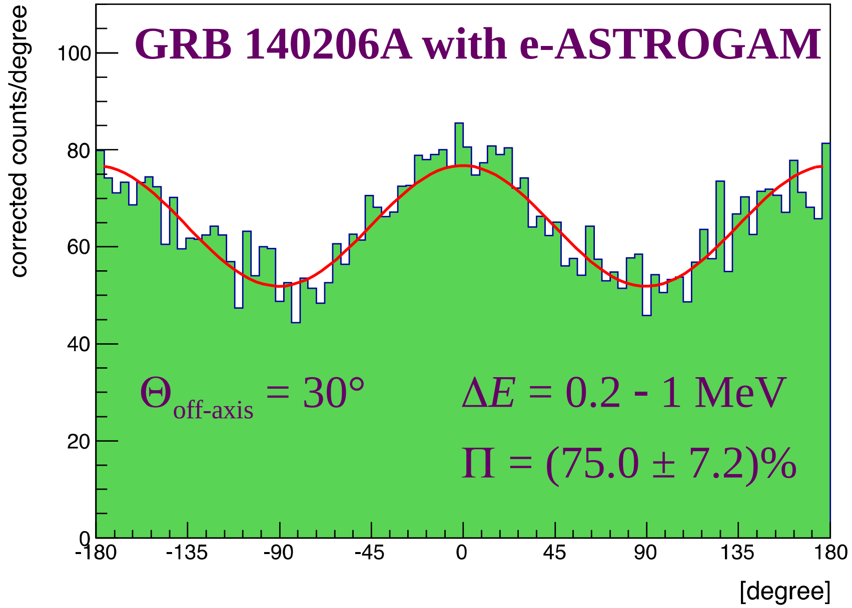
polarization

- 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)





Chemical evolution

- 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