AMEGO: All-sky Medium Energy Gamma-ray Observatory

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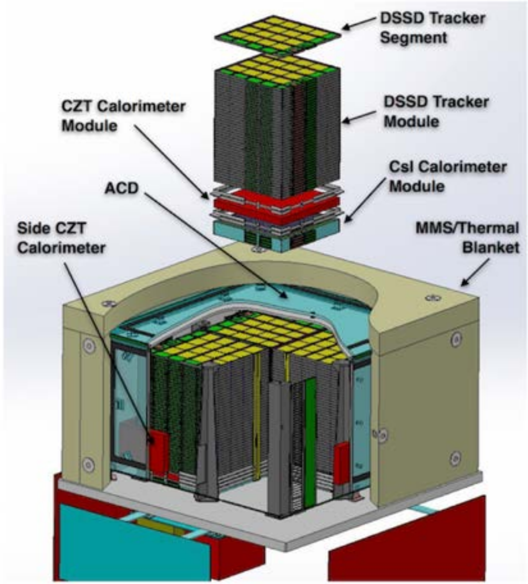
for the *AMEGO* team

Starting from the end: What is AMEGO ?

Compton-Pair Gamma-ray Telescope



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**

CdZnTe Imaging 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

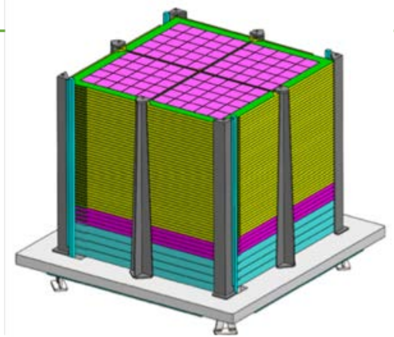
- **6 planes of 1.5cm x 1.5 cm CsI (Tl) bars**

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
- Use fine segmentation of all detecting elements to provide the best particle tracking and event identification

AMEGO Instrument Summary

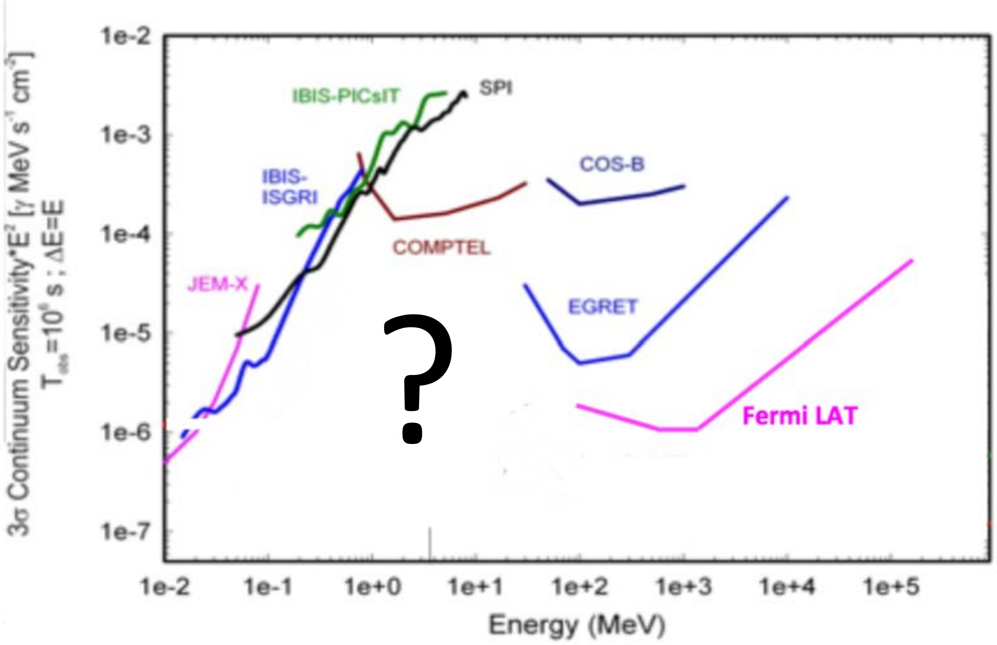
Energy Range	200 keV -> 10 GeV
Angular resolution	3° (3 MeV), 6° (10 MeV), 2° (100 MeV)
Energy resolution	<1% (< 1 MeV), 1-5% (1-100 MeV), ~10% (1 GeV)
Field of View	2.5 sr (20% of the sky)
Line sensitivity	$<6\times10^{-6}$ ph cm^{-2} s^{-1} for the 1.8 MeV ^{26}Al line in a 1-year scanning observation
Polarization sensitivity	<20% MDP for a source 1% the Crab flux, observed for 10^6 s
Continuum sensitivity (MeV cm^{-2} s^{-1})	3×10^{-6} (1 MeV), 2×10^{-6} (10 MeV), 8×10^{-7} (100 MeV)



NOW: Why this AMEGO?

Sensitivity for currently available measurements in MeV-GeV γ-rays

Motivation

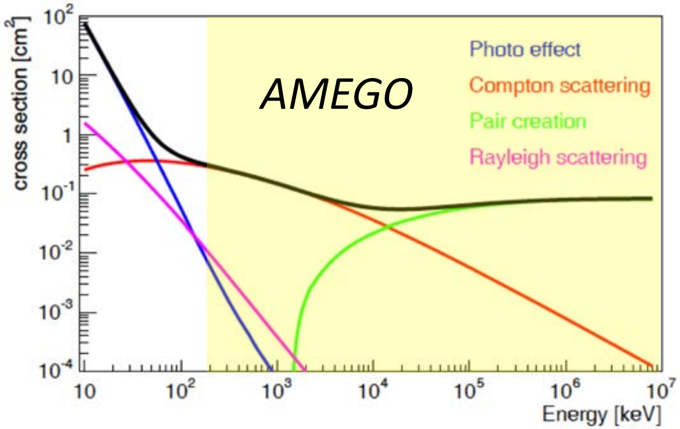


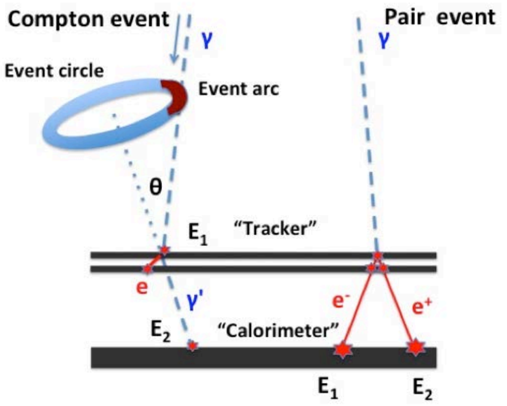
Guaranteed discovery space!

But why this gap ?

Detecting MeV Gamma-rays: Gamma-ray Interactions with Matter

"Impossible energy range"



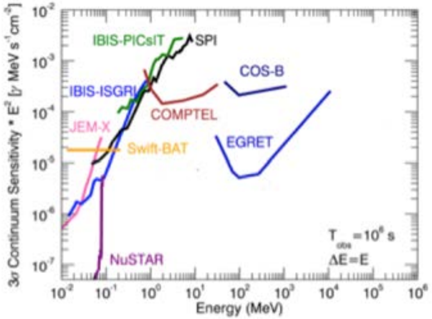


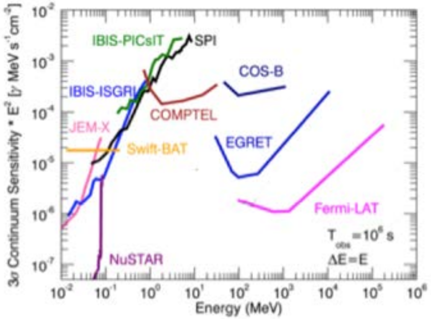
- **From 1 to ~100 MeV two photon – matter interaction processes compete: Compton scattering and pair-production**
- **To fill the "MeV Gap" we need to consider both Compton Scattering and Pair Production**
- **At low energy pair-production components (e^+ and e^-) suffer large multiple scattering, causing large uncertainty in the incident photon direction reconstruction**
- **Materials undergo activation on orbit by cosmic rays: artificial background below ~10 MeV**

Excellent results from Fermi, much exceeding the expectations: What Fermi LAT has done on high-energy γ-ray sky map for 8 years of operation

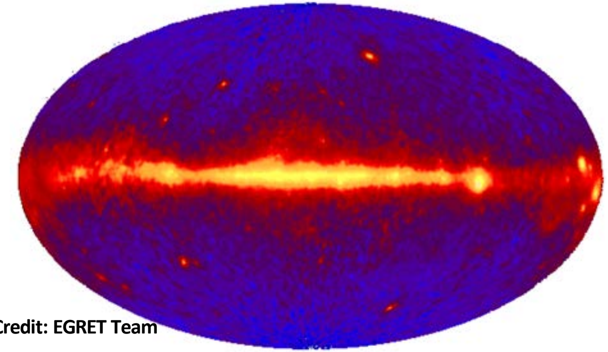
Motivation

(considering only discovery of new sources of γ-radiation)





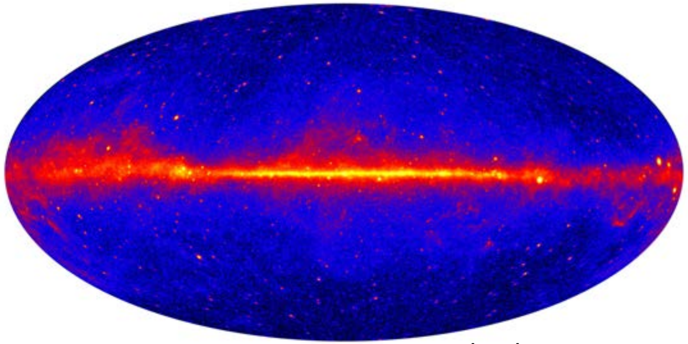
EGRET All-Sky Map Above 100 MeV



Credit: EGRET Team

~200 Sources Detected

***Fermi*-LAT All-Sky Map Above 1 GeV**



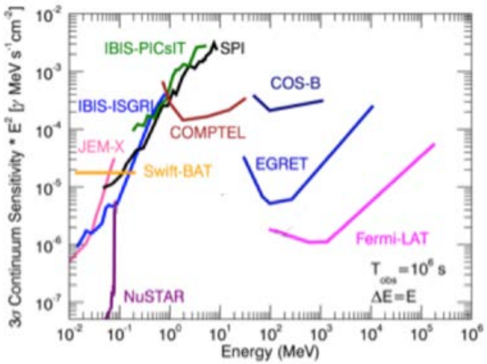
Credit: NASA/DOE/Fermi LAT Collaboration

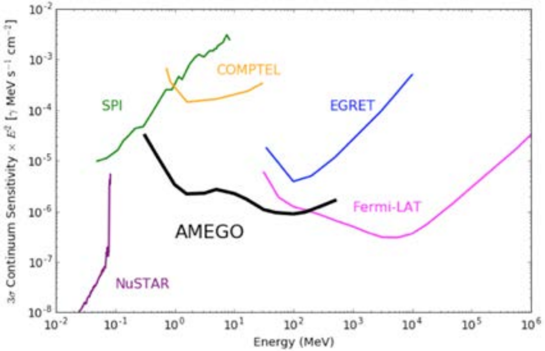
>5000 Sources Detected, 5 different catalogs

What we can expect from AMEGO:

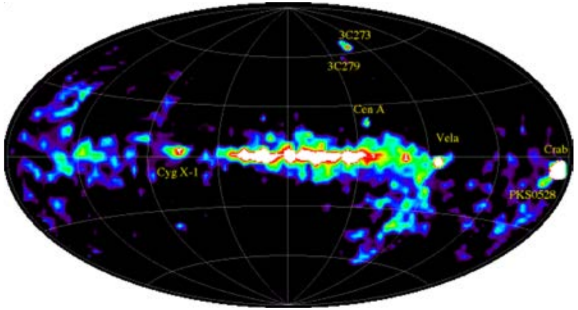
Motivation

(considering only discovery of new sources of γ-radiation)





COMPTEL All-Sky Map 1 - 30 MeV



Credit: COMPTEL Collaboration

Tens of Sources Detected

We expect at least a similar progress as from EGRET to Fermi-LAT

What Science is there?

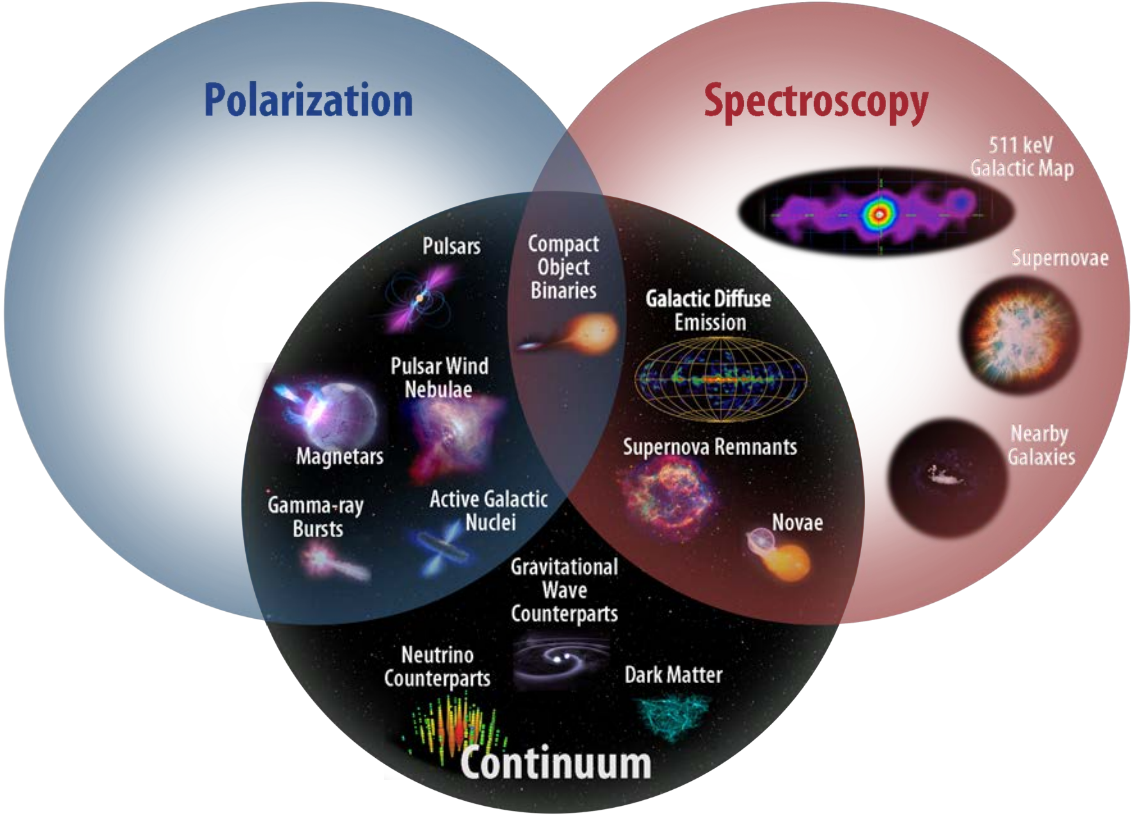
Essentially all topics in high-energy astrophysics will benefit from the capabilities provided by AMEGO, including four broad scientific objectives:

- **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;**

- **MeV Spectroscopy: Measure the properties of element formation in dynamic systems;**
- **Dark Matter: Test models that predict dark matter signals in the MeV band.**

AMEGO Overlapping capabilities (Venn diagram)

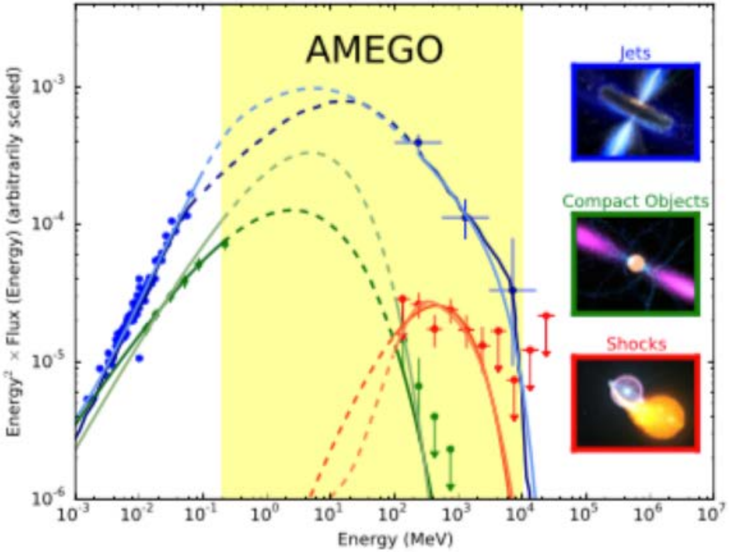


Extreme Astrophysics

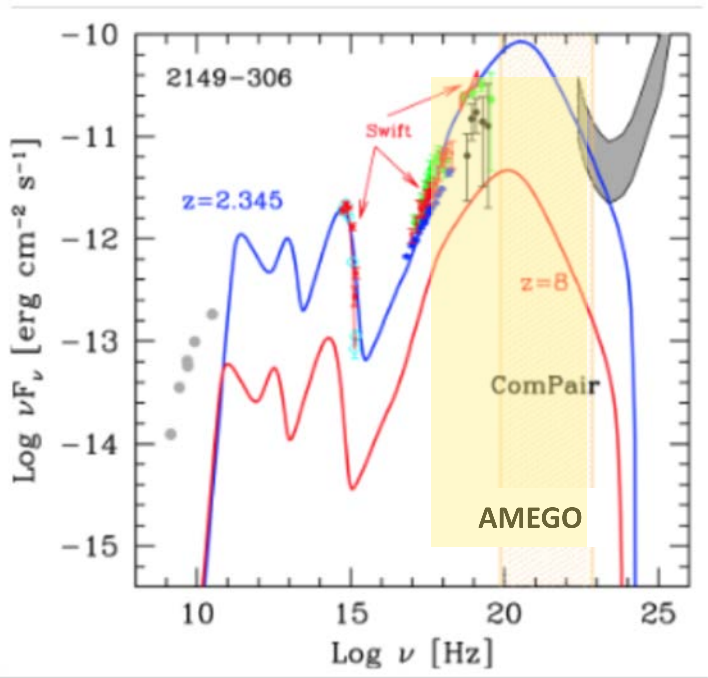
Understanding how the Universe works requires observing astrophysical sources at the wavelength of *peak* power output

- **Peak power is crucial for establishing source energetics**
- **Fermi, NuSTAR, and Swift BAT have uncovered source classes with peak energy output in the poorly explored MeV band**

A critical energy band - Spectral features such as breaks, turnovers, cutoffs, and temporal behavior, which are critical to discriminate between competing physical models, occur within the MeV energy range.



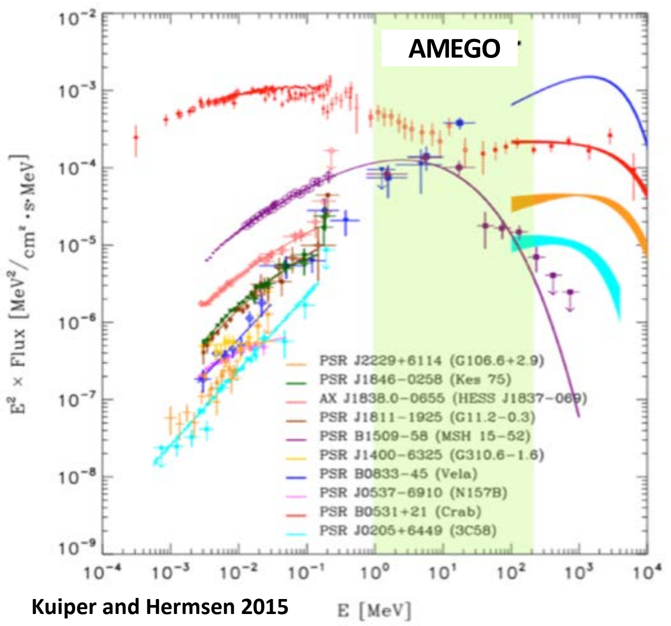
MeV Blazars



- Among the most powerful persistent sources in the Universe
- Large jet power, easily larger than accretion luminosity
- Host massive black holes, near 10^9 solar masses or more
- Detected up to high redshift – early Universe
- Evolution of MeV blazars is stronger than any other source class – i.e. maximum density might be very early on. Variability!
- AMEGO will detect >500 MeV blazars

  with ~100 at z>3

MeV γ–ray pulsars



Kuiper and Hermsen 2015

Selected Pulsars (~200 gamma-ray pulsars are known). Some of shown pulsars are magnetars

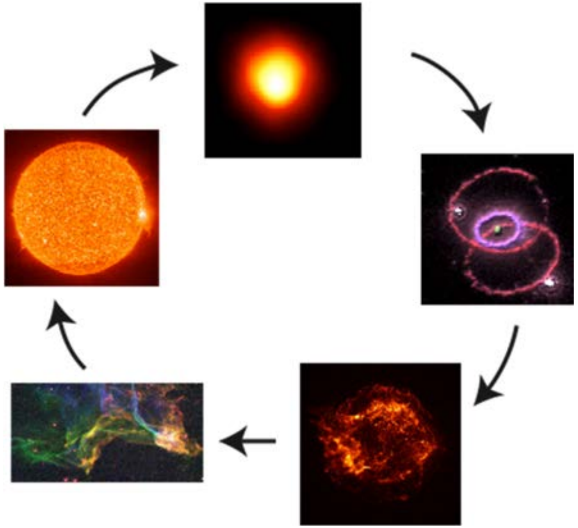
- **Pulsars seen in hard X-ray but not by Fermi-LAT, peak lies in MeV band**
- **11 MeV pulsars known**
  - **Extremely energetic Edot > 10^{36} erg**
- **Possible "hidden" population of energetic soft gamma emitting pulsars**
- **Emission might probe different part of the magnetosphere than GeV**
- **AMEGO will be able to reveal these pulsars**

Gamma-ray Spectroscopy

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

- Electron-positron annihilation radiation
  - $e^+ + e^- \rightarrow 2\gamma$ (0.511 MeV)
- Nucleosynthesis
  - Giants, core callapse SNe (^{26}Al, ^{44}Ti)
  - Supernovae (^{56}Ni, ^{57}Ni, ^{44}Ti)
  - ISM (^{26}Al, ^{60}Fe)
- Cosmic-ray induced lines
  - Sun
  - ISM

Life Cycles of Matter



AMEGO with its <1% energy resolution and large effective area will be capable to provide critical data in gamma-ray lines

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)

Mystery of Un-Identified Sources

About one third (or > 1,000) of Fermi-LAT sources remain unidentified

WHO ARE THEY ?

- Localization error
- Dark Matter clumps
- New source class

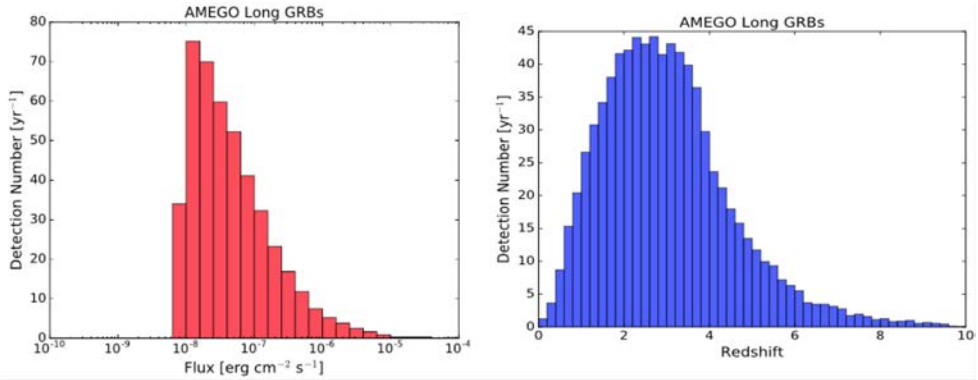
- Below 200 MeV, AMEGO with highly improved sensitivity, will discover many new sources and possibly source classes

>50% of Fermi-LAT catalog sources have a peak below the Fermi-LAT band

AMEGO and GRB

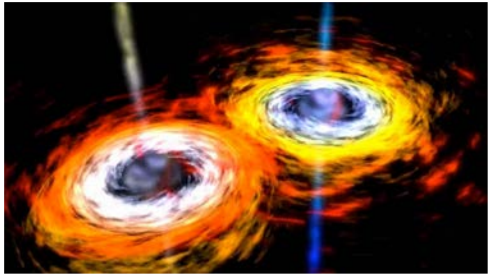
Excellent detector for GRB: high energy and angular resolution, large A_{eff}. **What to expect?**

- 440 long GRB/year (determined using method of Lien et al 2014)
  - ~20 long GRB/year with z>6, all with sub-degree localization
- Polarization! - 20% MDP for brightest 1% of AMEGO GRB
  - AMEGO observations will probe the GRB emission mechanism and jet composition localization
- ~80 short GRB/year (by scaling short/long ratio from GBM)
  - **Important implications for gravitational wave counterpart searches !**



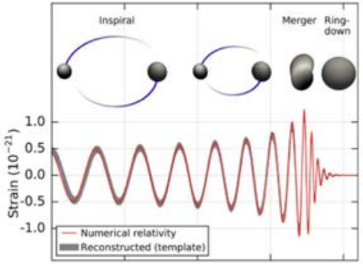
Finally we are moving to the most exciting opportunity for AMEGO:

Multimessenger Astrophysics – studying the Universe using high energy neutrinos and gravitational waves in synergy with gamma-ray observations

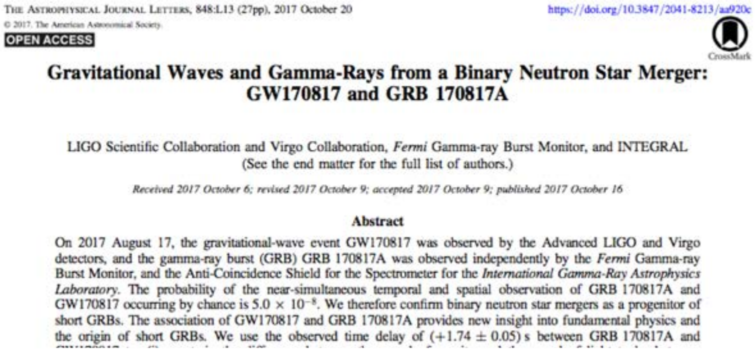


- **Neutrinos are produced in regions with extreme particle acceleration**
- **Gravitational waves are produced in regions with enormous energy release**
- **Gamma-ray observatories are the most natural path to connecting this “new astronomy” to known astrophysical objects**

AMEGO: We no longer be simply looking for astrophysical counterparts of gravitational waves or neutrino sources, but will instead be focusing on understanding the nature of these enigmatic objects and using the unique multi-messenger data as a probe of fundamental physics.



- So far contributions from gamma-ray observations to multimessenger astrophysics:
  - gamma-ray lines seen from SN1987A, a nearby neutrino source (Matz et al., Nature, 1988)
  - a gamma-ray burst from the neutron star merger event GW170817A (Abbott et al, 2017)
  - a gamma-ray flare from the active galaxy TXS 0506+056, the first identified counterpart to a high-energy neutrino source (by IceCube Collaboration, 2018)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Gravitational Waves and Gamma-Rays from a Binary Neutron Star Merger: GW170817 and GRB 170817A

LIGO Scientific Collaboration and Virgo Collaboration, *Fermi* Gamma-ray Burst Monitor, and INTEGRAL
(See the end matter for the full list of authors.)

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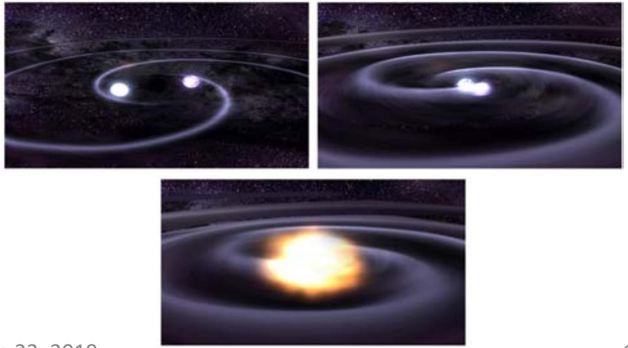
Abstract

On 2017 August 17, the gravitational-wave event GW170817 was observed by the Advanced LIGO and Virgo detectors, and the gamma-ray burst (GRB) GRB 170817A was observed independently by the *Fermi* Gamma-ray Burst Monitor, and the Anti-Coincidence Shield for the Spectrometer for the *International Gamma-Ray Astrophysics Laboratory*. The probability of the near-simultaneous temporal and spatial observation of GRB 170817A and GW170817 occurring by chance is 5.0×10^{-8}. We therefore confirm binary neutron star mergers as a progenitor of short GRBs. The association of GW170817 and GRB 170817A provides new insight into fundamental physics and the origin of short GRBs. We use the observed time delay of $(+1.74 \pm 0.05)$ s between GRB 170817A and

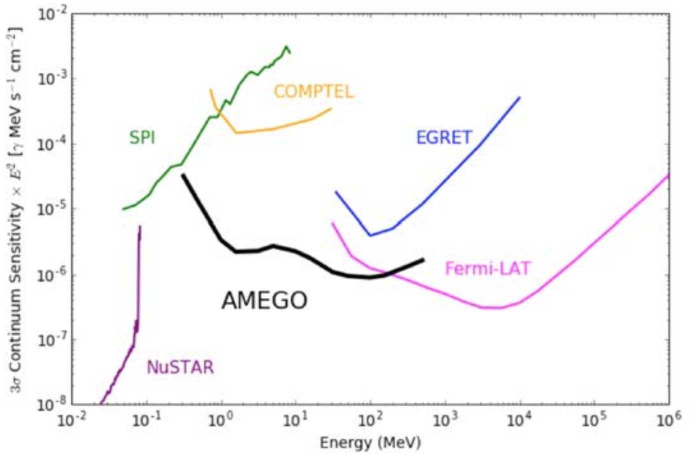


AMEGO
All-sky Medium Energy Gamma-ray Observatory

It is difficult to predict what exact capabilities of the instrument will be the most important for such studies, but AMEGO will be able to provide critical detailed study of these objects:

- **A large field-of-view and all-sky scanning mode of observation (with a possibility to switch to the pointed mode, like Fermi)**
- **Continuum sensitivity from 200 keV to 10 GeV with a factor of >20 higher than COMPTEL on CGRO, and high line sensitivity**
- **High energy and angular resolution**
- **Polarization sensitivity**

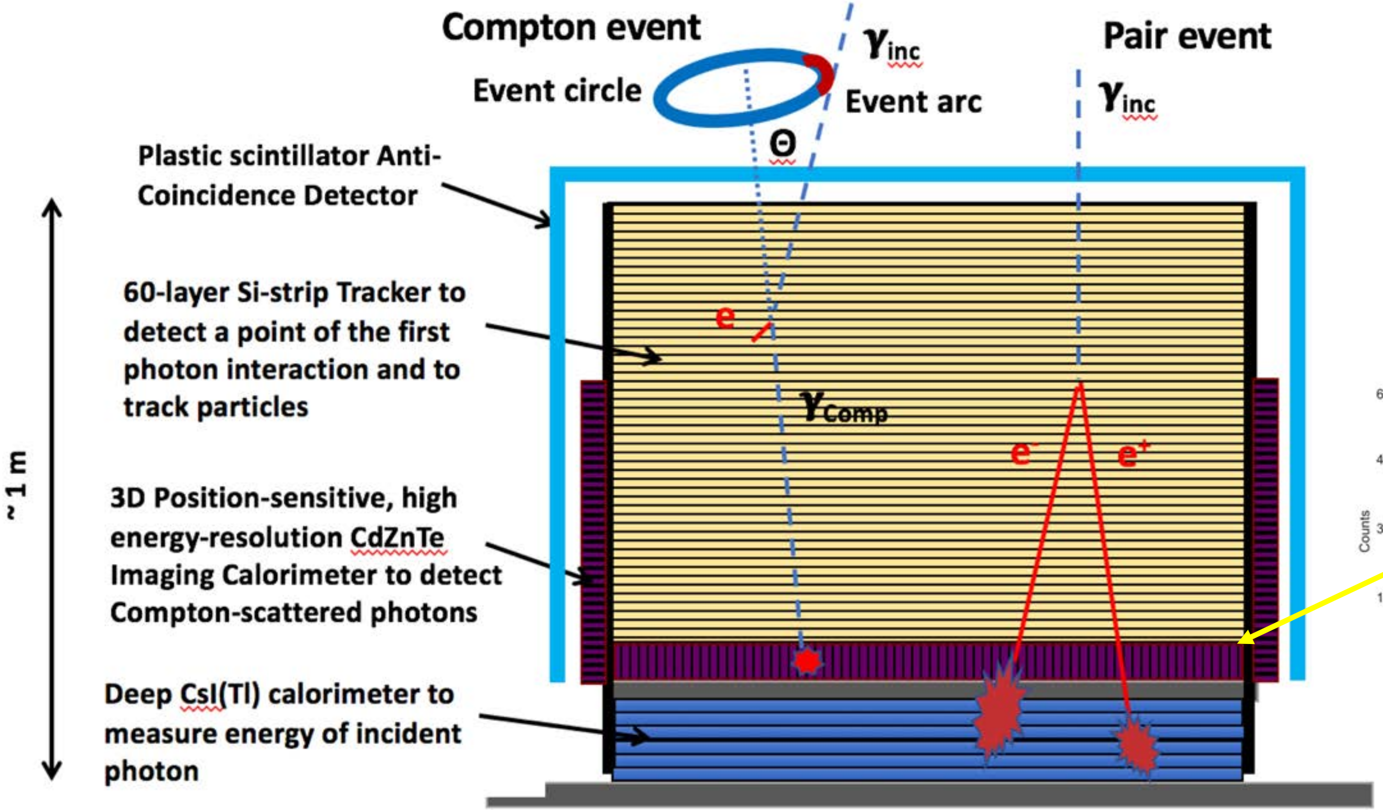
What are we going to build?

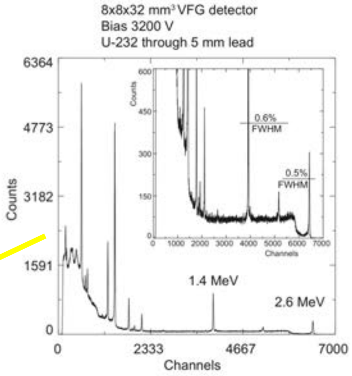


- Compton-Gamma space telescope
- Observing strategy: survey with ~80% sky / orbit
- Wide-aperture instrument with Field-of-View 2.5 sr
- Sensitivity at least 20x of COMPTEL
- Energy range 0.2 MeV → 10 GeV with good energy resolution
- Angular resolution <3^0 for E=1 MeV, ~10^0 at 10 MeV, and <1.5^0 at 100 MeV
- Polarization sensitivity in 0.3 – 5 MeV range
- Well-understood and tested technologies with space heritage

We will be proposing a NASA Probe-class mission

AMEGO Concept and Operation



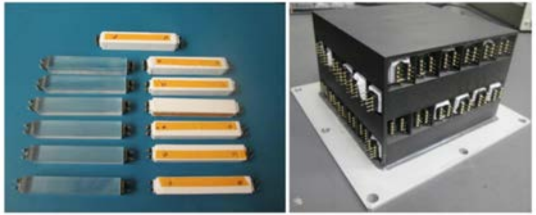


Courtesy of A. Bolotnikov, BNL

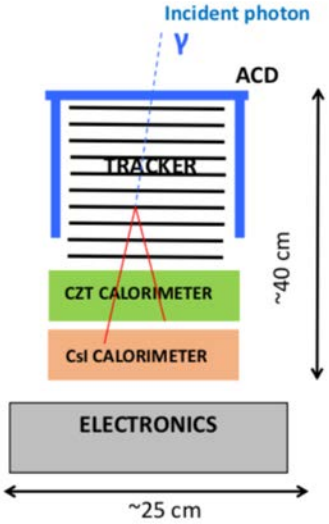
Currently we are building a prototype, which will be tested at the HIGS polarized photon beam (early 2020) and later flown in balloon (mid-2021)

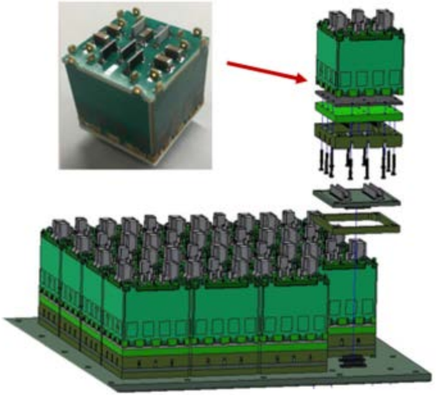
Here are already built subsystems to be integrated in the prototype later this year

Single layer of the tracker



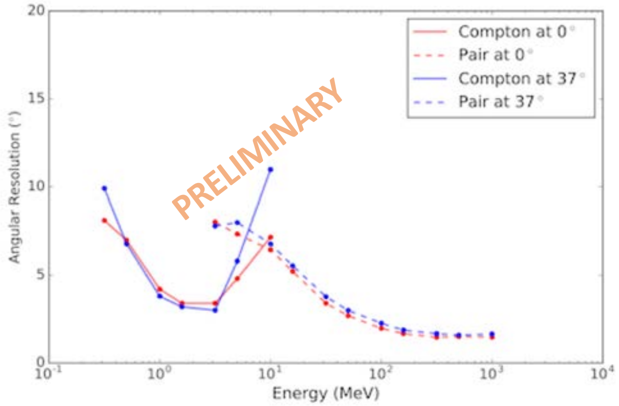
CsI Calorimeter bars and module



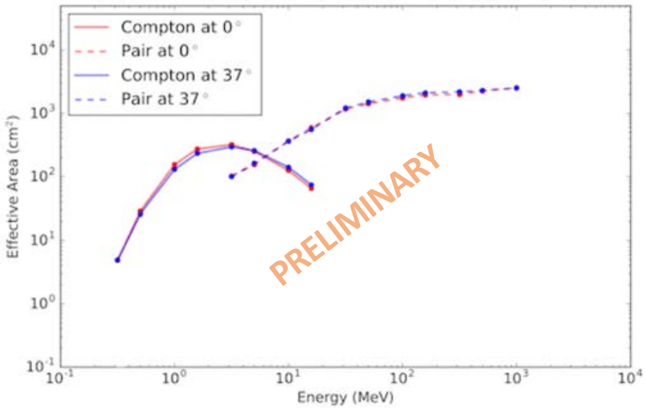


CdZnTe Imaging calorimeter module

AMEGO Performance, obtained with MEGALib simulations



Angular Resolution, in degrees (ARM for Compton events*, PSF 67% event containment for Pair events)



Effective Area in cm^2

*performance for Compton mode includes only tracked events

AMEGO Team – growing and open for joining

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

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