AMEGO: All-sky Medium Energy Gamma-ray Observatory

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for the AMEGO team

https://asd.gsfc.nasa.gov/amego/
Gamma-ray Astrophysics

Freq (Hz)  Energy (ev)

Very High Energy (VHE) gamma-rays (aka TeV)
High Energy gamma-rays (aka GeV)
Medium Energy gamma-rays (aka MeV)

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Why gamma-rays?

- High energy photons are produced in different physical processes and carry key information what process is
- Photons propagate through Universe without deflection in magnetic fields and continuous energy losses. Their origination point and spectrum at the source can be directly measured

AMEGO will provide three new capabilities in MeV astrophysics:

- sensitive continuum spectral studies,
- polarization,
- nuclear line spectroscopy.
Sensitivity for currently available measurements in MeV-GeV gamma-rays

Guaranteed discovery space!

But why this gap?

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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.
What do we want to build?

- Wide-aperture instrument with Field-of-View 2.5 sr
- Sensitivity at least 20x of COMPTEL
- Energy range 0.2 MeV → 10 GeV
- Angular resolution <3° for E=1 MeV, ~10° at 10 MeV, and <1.5° at 100 MeV
- Polarization sensitivity in 0.3 – 5 MeV range

- We consider a NASA Probe-class mission to fit within the cost envelope between a Mid-sized Explorer (MIDEX) mission and a large mission.

See also papers by J. Perkins (841, 842), R. Caputo (992, 1407), J. Racusin (949) in this Conference
What Science is there?

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

• Understand the formation, evolution, and acceleration mechanisms in astrophysical jets;

• Identify the physical processes in the extreme conditions around compact objects;

• Measure the properties of element formation in dynamic systems;

• Test models that predict dark matter signals in the MeV band.
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
- AMEGO science objectives focus on cases of extreme astrophysics including:
  - high matter densities
    - strong magnetic fields
    - powerful jets

**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 $\sim 100$ at $z>3$
Extreme Physics of Compact Objects

Compact objects with key energy features in the MeV range include:

- **Magnetars** - strongest magnetic fields in the Universe
- **Pulsars** - neutron stars represent the highest matter densities possible before collapse to a black hole.

Selected Pulsars (200 gamma-ray pulsars are known).

High mass X-ray Binary LS 5039 at superior and inferior conjunction (pulsar or microquasar binary).
Gamma-ray Spectroscopy

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

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

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

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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 Unidentified Sources

About one third 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 source classes

>50% of Fermi-LAT catalog sources have a peak below the Fermi-LAT band.
New Astronomy: Gravitational Waves and Neutrinos

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

- Short GRB thought to be produced by NS-NS merger: prime candidate for GW detection

Great GW150914 event (BH-BH merger):
- did it produce e/m radiation?
- where did it occur?
What Fermi LAT has done on high-energy gamma-ray sky map for 8 years of operation

EGRET All-Sky Map Above 100 MeV

Fermi-LAT All-Sky Map Above 1 GeV

~200 Sources Detected

>3000 Sources Detected

Credit: EGRET Team

Credit: NASA/DOE/Fermi LAT Collaboration

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What we can expect from AMEGO:

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

COMPTEL All-Sky Map 1 - 30 MeV

Tens of Sources Detected
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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

CZT Calorimeter
Measures location and energy of Compton scattered photons, and head of the shower for pair events
- 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 (no passive γ-ray converters as in LAT)
- Use fine segmentation of all detecting elements to provide the best particle tracking and event identification
# AMEGO Instrument Summary

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Specification</th>
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<tbody>
<tr>
<td>Energy Range</td>
<td>300 keV -&gt; 10 GeV</td>
</tr>
<tr>
<td>Angular resolution</td>
<td>3° (3 MeV), 6° (10 MeV), 2° (100 MeV)</td>
</tr>
<tr>
<td>Energy resolution</td>
<td>&lt;1% (&lt; 1 MeV), 1-5% (1-100 MeV), ~10% 91 GeV</td>
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<tr>
<td>Field of View</td>
<td>2.5 sr (20% of the sky)</td>
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<tr>
<td>Line sensitivity</td>
<td>&lt;6x10^-6 ph cm^-2 s^-1 for the 1.8 MeV ^26^Al line in a 1-year scanning observation</td>
</tr>
<tr>
<td>Polarization sensitivity</td>
<td>&lt;20% MDP for a source 1% the Crab flux, observed for 10^6 s</td>
</tr>
<tr>
<td>Continuum sensitivity (MeV cm^-2 s^-1)</td>
<td>3x10^-6 (1 MeV), 2x10^-6 (10 MeV), 8x10^-7 (100 MeV)</td>
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</tbody>
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AMEGO Team – growing and open for joining

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THANK YOU!