Future Gamma-ray Missions of Various Shapes (mostly square) and Sizes

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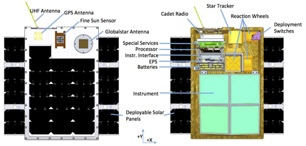
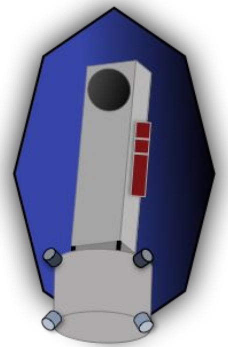
Goddard SPACE FLIGHT CENTER

Context: GW170817/GRB170817A

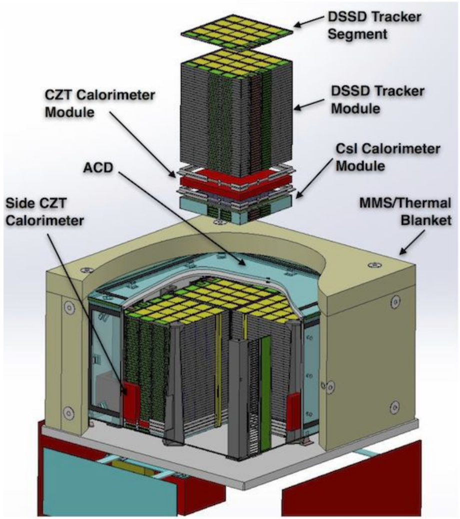
- Neutron Star mergers produce short duration gamma-ray bursts (GRB)
- GW170817/GRB170817A is the first confirmation, though it may be a rare unusual event (very nearby)
- A **kilonova was detected** in a galaxy at 40 Mpc **11 hours post merger** and **monitored for weeks in the X-ray, UV, Optical, IR, and Radio**
- The resulting **light curves and spectroscopic time series** revealed **BNS mergers are the likely source of heavy r-process elements**
- More than **70 papers** were published! Multi-messenger detection leads to **a new era of astrophysics**
- The three missions I'm about to highlight all advance our knowledge of these events

BurstCube





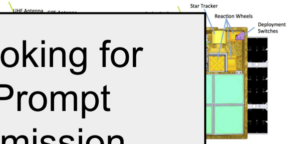
Nimble



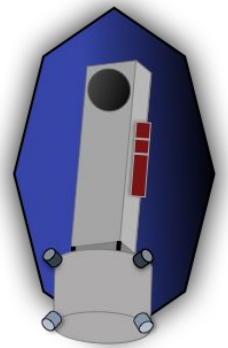
AMEGO

(biased) Menu of three missions (ok, they're all pretty much square)

BurstCube



Looking for Prompt Emission



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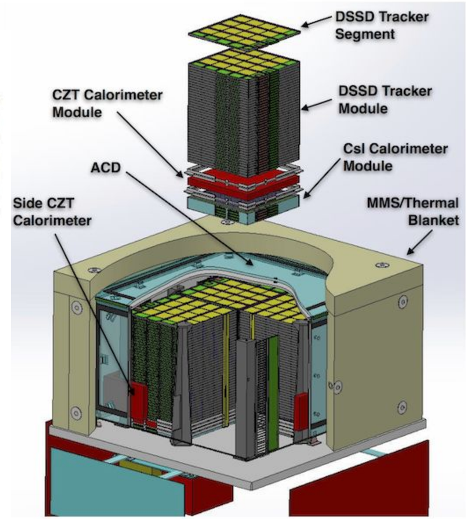
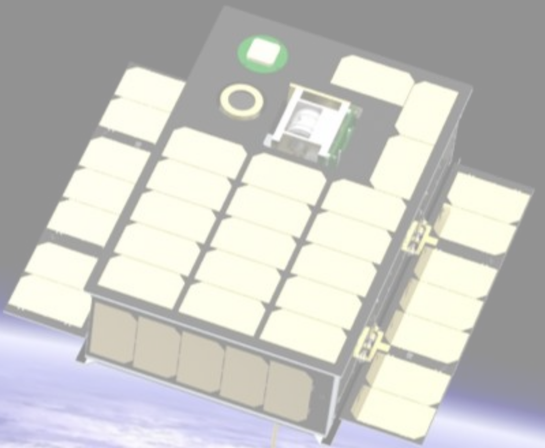


AMEGO

(biased) Menu of three missions (ok, they’re all pretty much square)

BurstCube

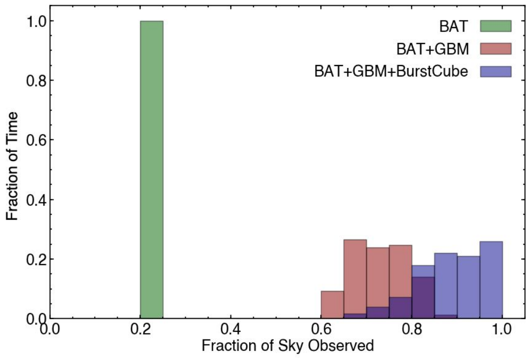
A CubeSat for Gravitational Wave Counterparts

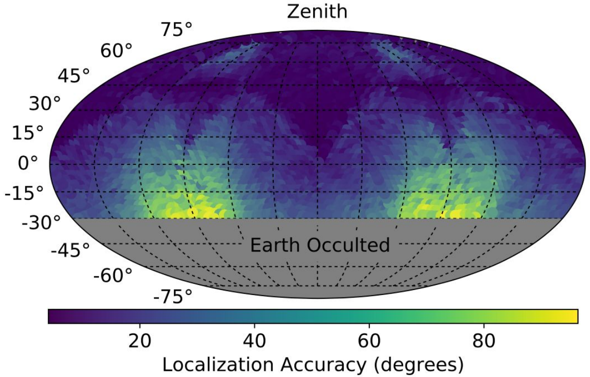


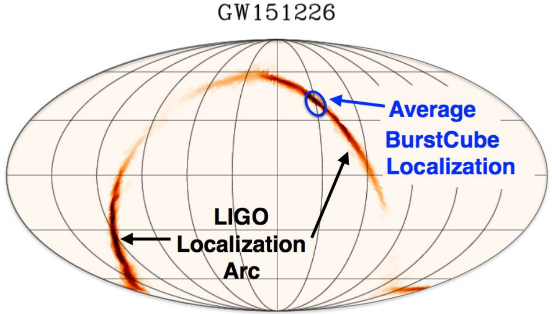
Jeremy S. Perkins (NASA/GSFC), Judith L. Racusin (NASA/GSFC), Michael S. Briggs (UAH), Georgia de Nolfo (NASA/GSFC), John Krizmanic (NASA/GSFC/CRESST), Regina Caputo (NASA/GSFC/CRESST), Julie E. McEnery (NASA/GSFC), Peter Shawhan (UMD), David Morris (UVI), Collaborators: Valerie Connaughton (USRA), Dan Kocevski (NASA/MSFC), Colleen Wilson-Hodge (NASA/MSFC), Michelle Hui (NASA/MSFC), Lee Mitchell (NRL), Sheila McBreen (UCD), & Dieter Hartmann (Clemson)

BurstCube Science

- BurstCube will **increase the sky coverage** and **provide localizations** for short (<2 s) GRBs, especially important in the current era of GW discoveries.
- BurstCube will study GRBs (long and short) from the **entire unocculted** sky
    - Providing spectra, localization, and light curves
- BurstCube will also detect solar flares, magnetar flares, and other hard X-ray transients, as well as persistent sources via occultation analysis

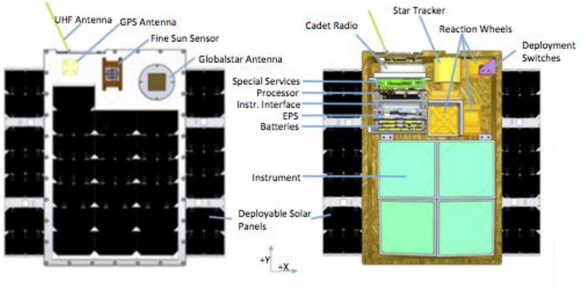


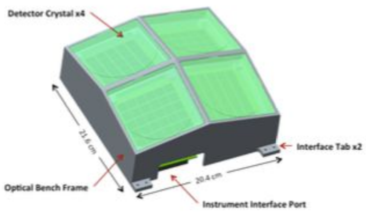


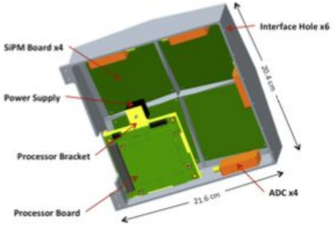


Mission Implementation

- BurstCube is a **6U CubeSat**
- Instrument Package
  - **4 CsI scintillator** crystals coupled to arrays of **low-power** Silicon Photomultipliers (SiPMs) with custom electronics
  - **Localizes GRBs** based on relative intensities in each detector.
- BurstCube will observe the **full unocculted** sky by zenith pointing, recording gamma-ray photons, and triggering on significant rate fluctuations.
- BurstCube will relay data to the ground every **2-12 hours**.
- Trigger data will be **immediately transferred** to the ground via the GlobalStar network or TDRS (TBD).
- The instrument hardware and flight and ground software design r**elies heavily upon heritage** from *Fermi*-GBM.

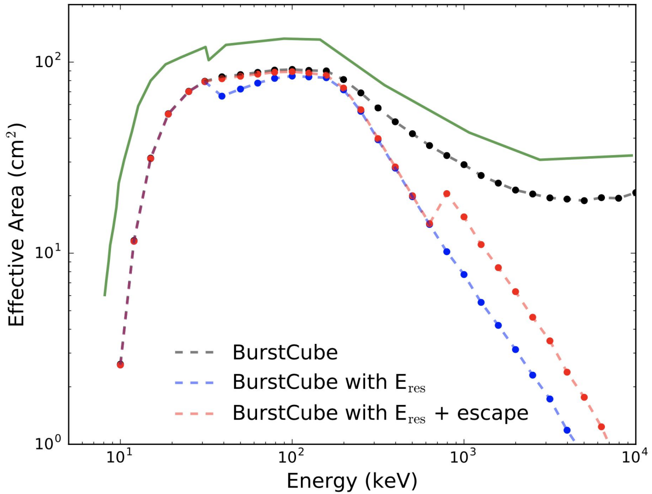




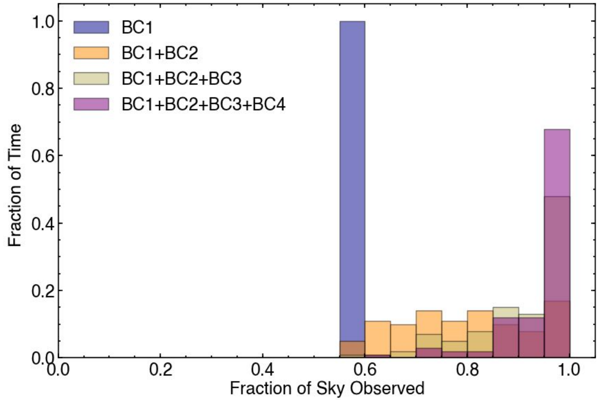


Mission Performance

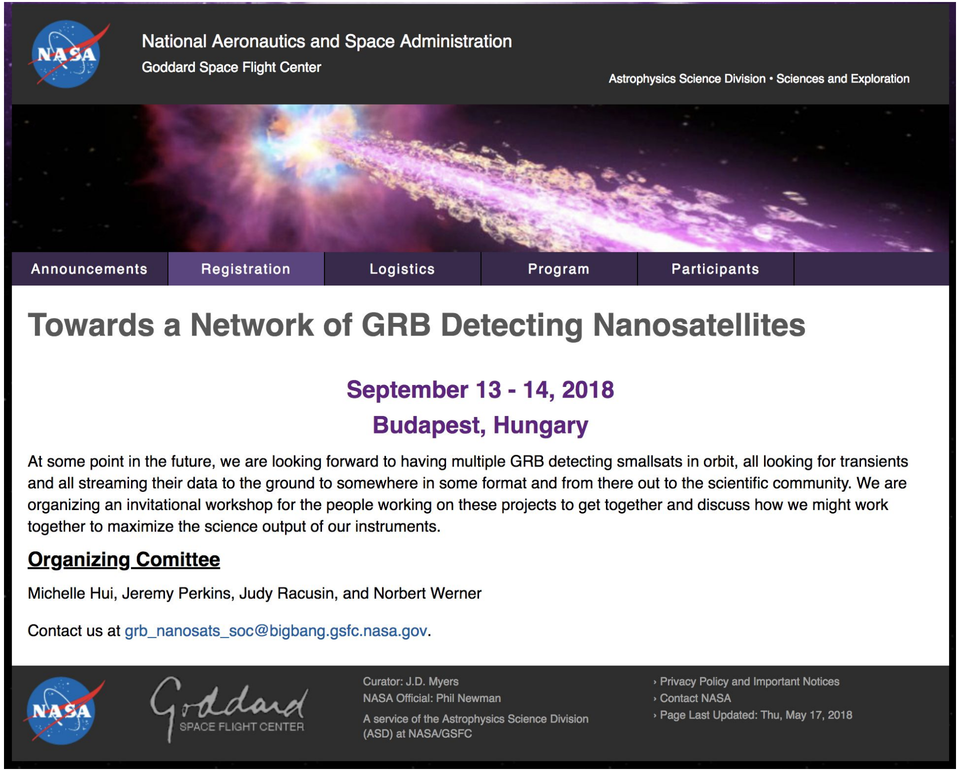
- Continuous Science Operations
- Detect **~24 sGRBs/year**
  - Including **~1 coincident** sGRB-GW/yr
  - Large increase from not having BurstCube
- Detect **> 100 long GRBs/yr**
  - Will result in a significant increase in statistics.
- BurstCube is **funded and will fly in 2021**.
  - In preliminary design now
- The ultimate configuration of BurstCube would be **a set of ~5 CubeSats** (12U) providing all-sky coverage for a very low cost.



Effective area is 67% that of the larger GBM NaI detectors at 100 keV and 15 degree incidence.

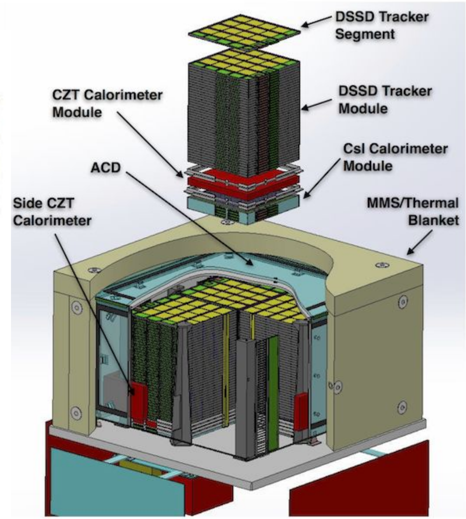


Towards a Network...



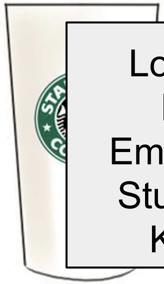
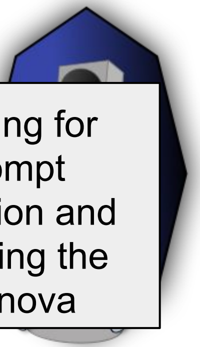
https://asd.gsfc.nasa.gov/conferences/grb_nanosats/

VENTI



AMEGO

GRANDE

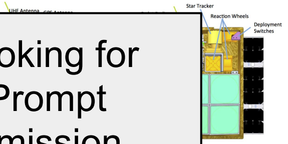



Looking for Prompt Emission and Studying the Kilonova

Nimble

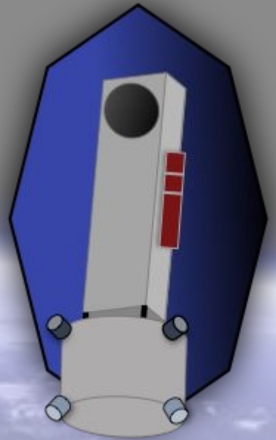
SHORT

BurstCube



Looking for Prompt Emission

(biased) Menu of three missions (ok, they're all pretty much square)



Nimble: The Time Domain Explorer

PI: Joshua Schlieder (NASA/GSFC)

(abstruse GSFC codes included on purpose)
Judy Racusin (661), Maxime Rizzo (667), Brad Cenko (661), Qian Gong (550), Mike McElwain (667), Eric Lopez (693), Giada Arney (693), Jeremy Perkins (661), Allison Youngblood (667), Shawn Domagal-Goldman (699), Padi Boyd (667), Stephen Rinehart (665), Julie McEnery (661), Sarah Logsdon (667)

The Reason to be Nimble: GW170817/GRB170817A

- NASA's ***Fermi*** **detected the GRB** and ***Swift***, ***Hubble***, **and** ***Chandra*** **were key** to the characterization of the kilonova
    - These missions are all in their extended phases
    - Were designed >15 years ago
- Knowing what we know now, **how would we design a mission to detect and characterize binary neutron star mergers?**
    - 1. Detect and localize GRBs
    - 2. Detect and localize kilonova emission
    - 3. Multiwavelength follow-up to monitor and characterize kilonova
    - 4. Space craft with rapid communication and slew capability
- **A single well designed facility could do the work of dozens with improved results**

The Reason to be Nimble: GW170817/GRB170817A

- NASA … were key to the charac…
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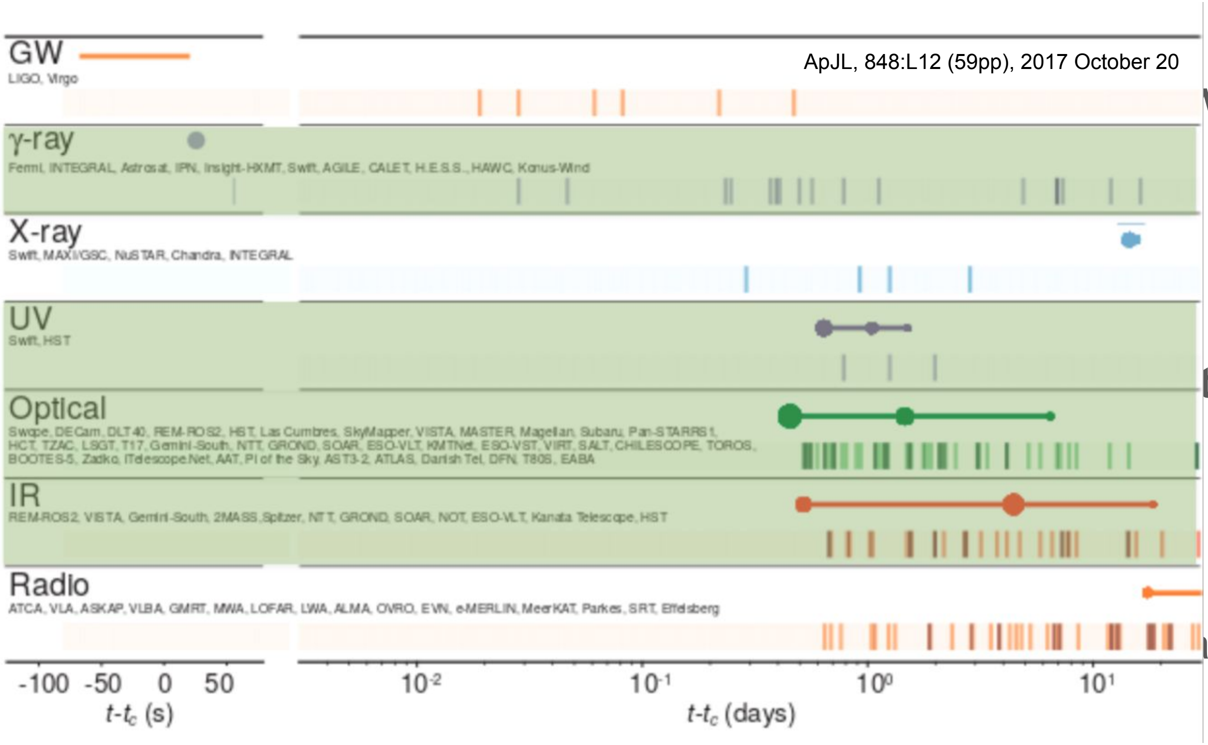
- **A single well designed facility could do the work of dozens with improved results**

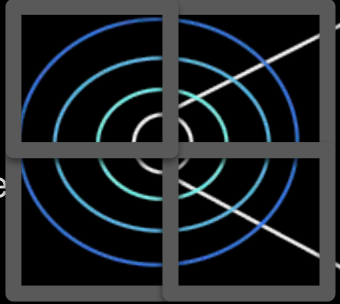


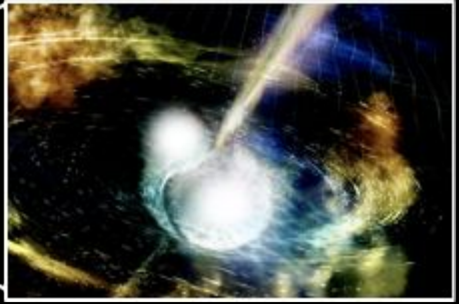
Nimble Executive Summary

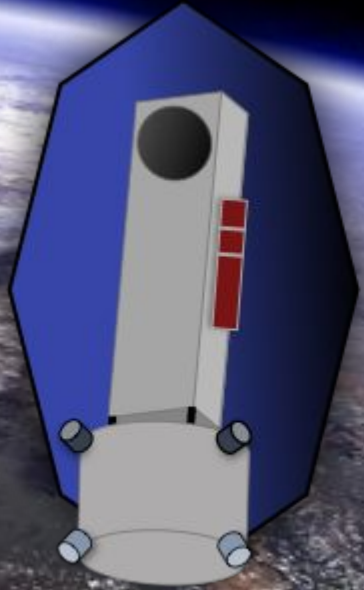
- ***Nimble*** is a SMEX concept that will **detect and localize gamma-ray bursts associated with gravitational wave events,** rapidly slew to **identify their counterparts,** and **perform detailed multiwavelength follow-up for characterization**
- ***Nimble* builds on the heritage of *Swift* and *Fermi*** and **leverages technology from JWST and BurstCube** to provide a new and flexible mission **in the era of multi-messenger astrophysics**
- ***Nimble*** has **two instruments**
    a. **High-Energy All-Sky Monitor (HAM)** - CsI scintillators with Silicon photomultipliers
        i. GRB light curves and rough localization
    b. **Small UV-Optical-IR Telescope (SUVOIR)** - 30 cm telescope with wide and narrow field capabilities
        i. Wide field for detection and localization of GRB counterparts
        ii. Narrow field for detailed multiwavelength characterization
- ***Nimble* is optimized for EM counterparts to GW events**, but the **multiwavelength nature** of multi-messenger science makes it **a flexible mission capable of broad science**

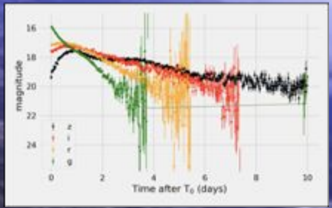
Nimble Concept of Operations

Prompt detection and rapid follow-up of high energy transients - focus on EM counterparts to gravitational wave events









High-energy All-sky Monitor (HAM)

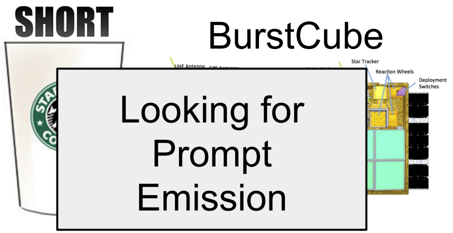
- Similar to GBM/BurstCube
  - CsI scintillation crystals with silicon photo-multiplier (SiPM) detector arrays
  - ~100-1000 keV energy sensitivity
  - 5 deg radius localization
  - Continuously monitor large portion of sky for gamma-ray transients

Small UV-Opt-IR Telescope (SUVOIR)

- 30 cm aperture
- Wide and Narrow field modes
- 2 channels - UV/Opt, Opt/IR
  - 250 - 2500 nm wavelengths

Nimble Secondary Science
(or ‘why is an exoplanet scientist leading this mission?’)

- **(Full Transparency: I think exoplanets are cool)**
- **Characterize Known Transiting Exoplanets**
  - **Multiwavelength transit photometry**
    - Confirm and characterize known exoplanets in the era of *TESS*
  - **UV to IR exoplanet transit spectroscopy**
    - How does atmospheric temperature, structure, and composition change with planet properties?
    - What are the roles of clouds and hazes?
    - How does stellar activity affect the interpretation of atmosphere measurements?
- **High energy transients**
  - (basically all of the secondary science mentioned for the BurstCube mission)

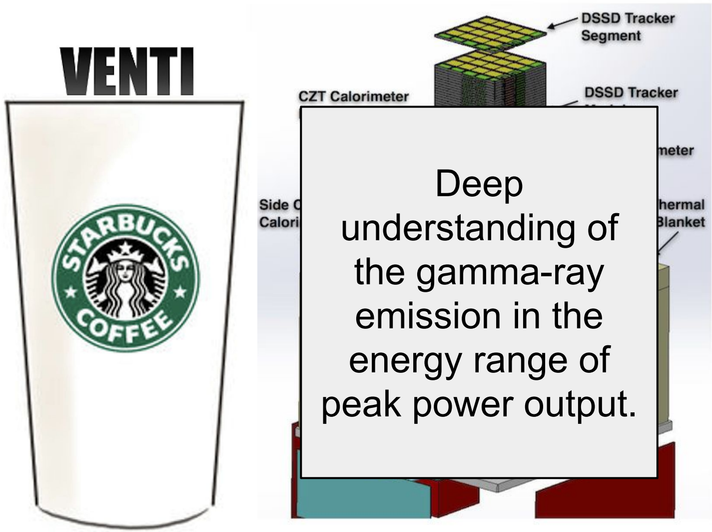


BurstCube

Looking for Prompt Emission

Looking for Prompt Emission and Studying the Kilonova

Nimble



Deep understanding of the gamma-ray emission in the energy range of peak power output.

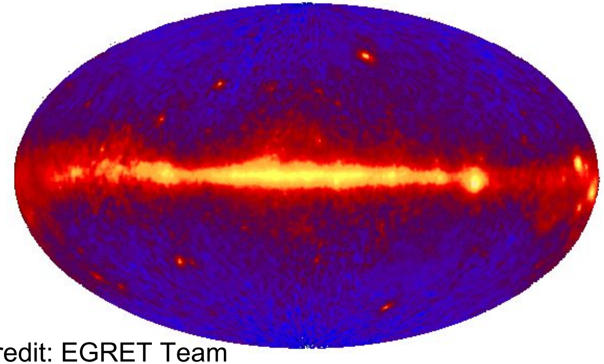
AMEGO

(biased) Menu of three missions (ok, they're all pretty much square)


AMEGO
All-sky Medium Energy Gamma-ray Observatory


VENTI
STARBUCKS COFFEE

EGRET All-Sky Map Above 100 MeV

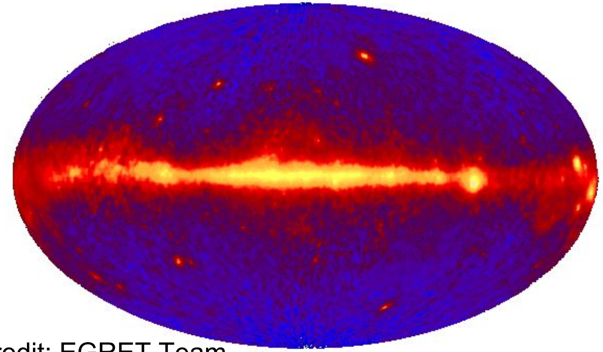


Credit: EGRET Team

~300 Sources Detected

Why Look in the MeV Range?

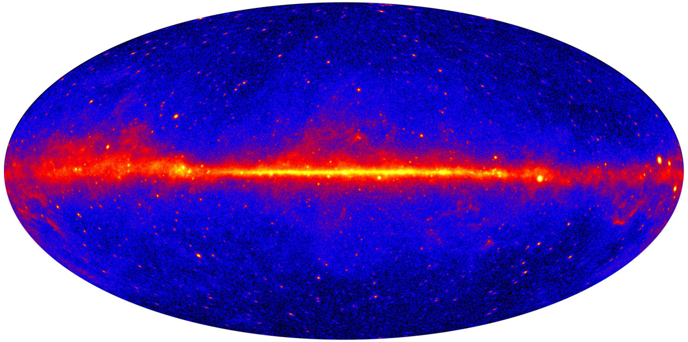
EGRET All-Sky Map Above 100 MeV



Credit: EGRET Team

~300 Sources Detected

Fermi-LAT All-Sky Map Above 1 GeV



Credit: NASA/DOE/Fermi LAT Collaboration

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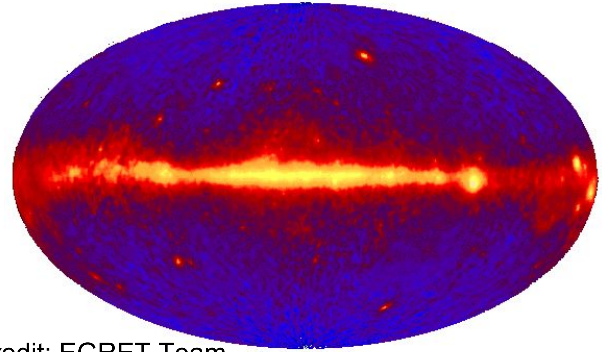
Why Look in the MeV Range?

EGRET All-Sky Map Above 100 MeV



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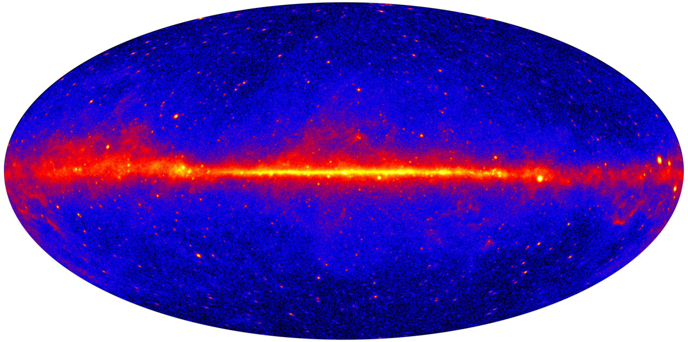
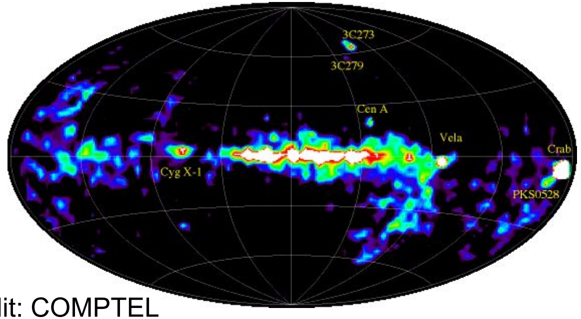


Credit: NASA/DOE/Fermi LAT Collaboration

~3000 Sources Detected

COMPTEL All-Sky Map 1 - 30 MeV

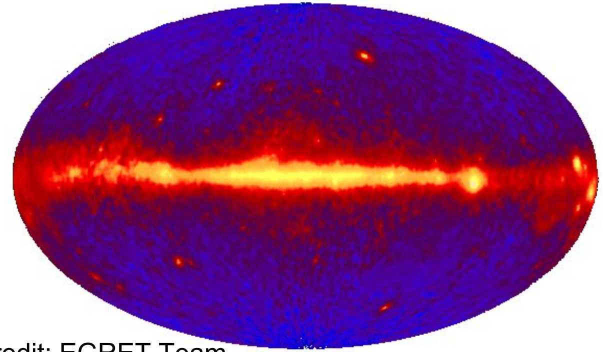


Credit: COMPTEL Collaboration

Tens of Sources Detected

Why Look in the MeV Range?

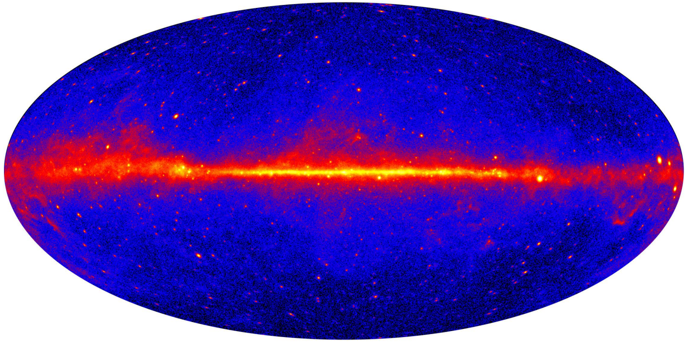
EGRET All-Sky Map Above 100 MeV



Credit: EGRET Team

~300 Sources Detected

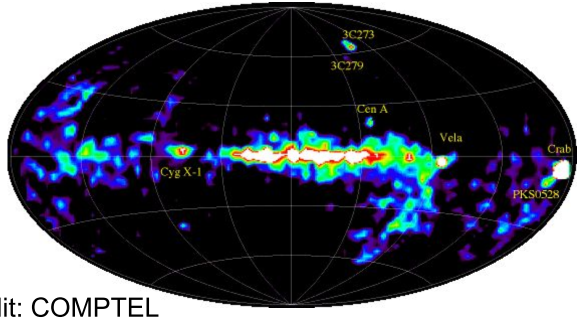
Fermi-LAT All-Sky Map Above 1 GeV



Credit: NASA/DOE/Fermi LAT Collaboration

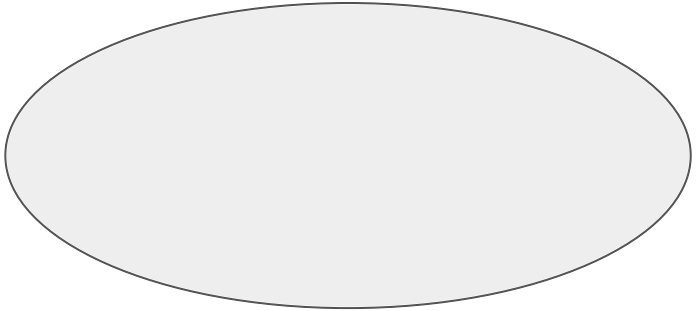
~3000 Sources Detected

COMPTEL All-Sky Map 1 - 30 MeV



Credit: COMPTEL Collaboration

Tens of Sources Detected



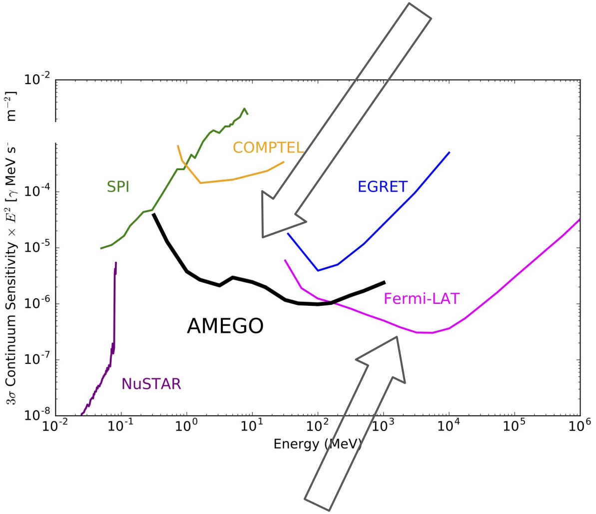
Why Look in the MeV Range?

Guaranteed Discovery Space

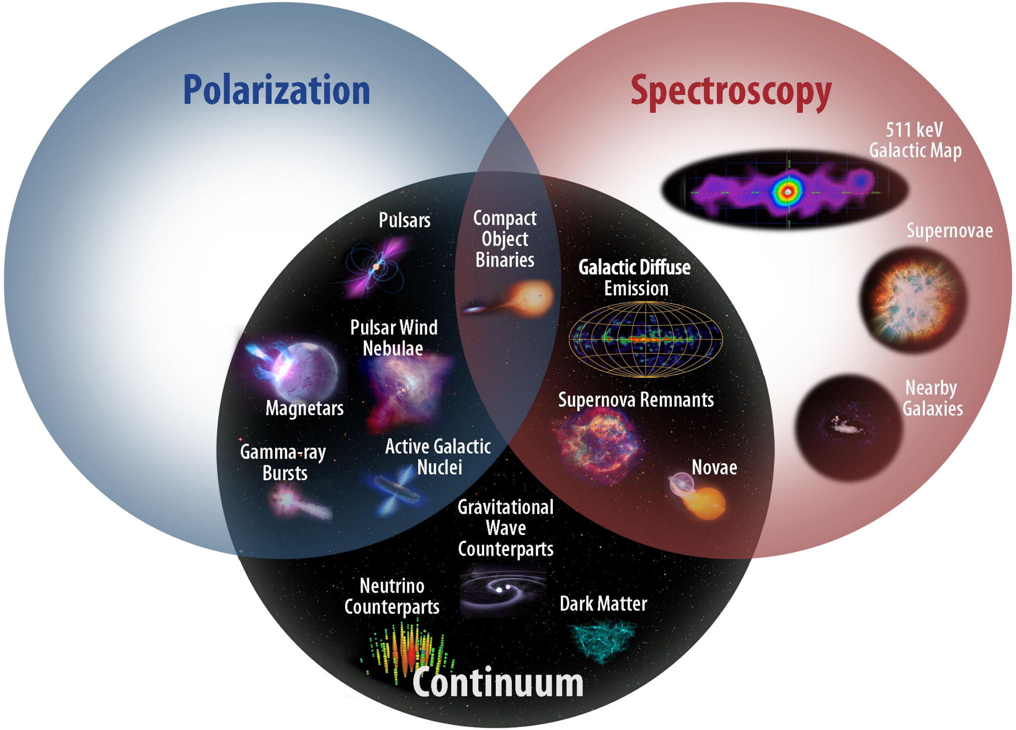
The MeV range is **prime discovery space**.

It is a **key piece** to the high-energy view of the Universe.

Achievable: Orders of magnitude improvement



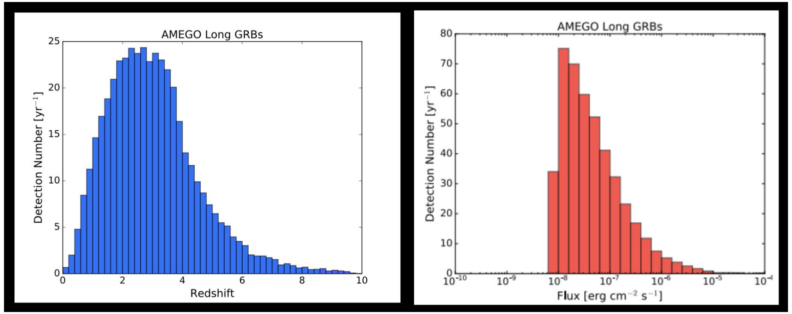
Note: *Fermi*-LAT optimized for 1 GeV



AMEGO will provide a well rounded portfolio of capabilities

Binary NS Mergers with AMEGO: sGRBs

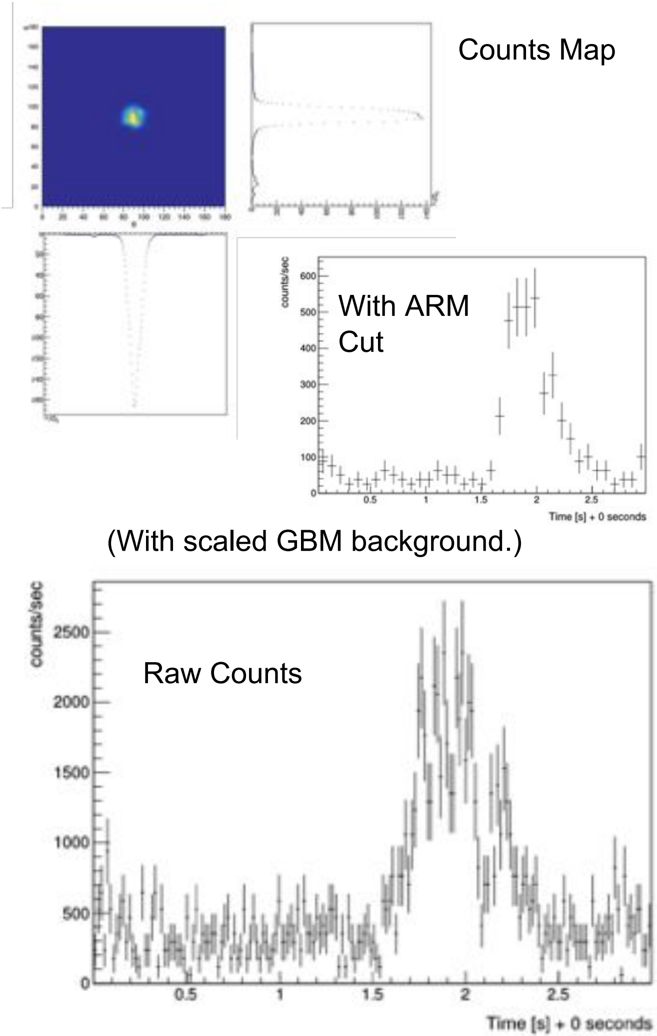
- AMEGO Detections of sGRBs:
  - AMEGO should detect the prompt emission of **~80 sGRBs/year**
  - AMEGO should be capable of **detecting sGRB afterglows** (even if not in FoV at event time)



- AMEGO joint GW-GRB Detections
  - Upgraded 2nd generation interferometers: **~20 joint detections/year** (prompt)
  - Upgraded 3rd generation interferometers: **~80 joint detections/year** (prompt)
  - Additional follow-up detections (afterglow)
  - Provide reasonable localizations for follow-up at other wavelengths

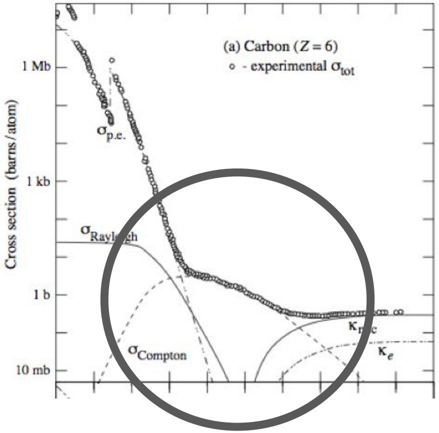
BNS Mergers: AMEGO and GWs

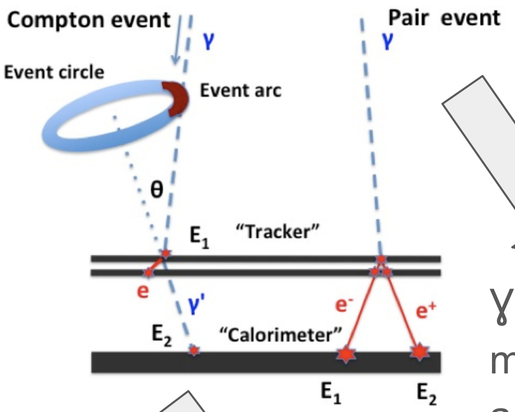
- Population level studies on:
  - **Heavy element enrichment** over the history of the universe
  - How, when, and **why relativistic jets form**, and their collimation and structure
  - The **brightness** of SGRBs and kilonovae as a function of progenitor mass and spin, inclination angle, etc
- If that isn't enough:
  - **~deg localization** for broad-band electromagnetic follow-up
  - AMEGO should be able to detect gamma-rays from **nuclear lines** in Kilonova
  - **Polarization** measurements of the brightest bursts.

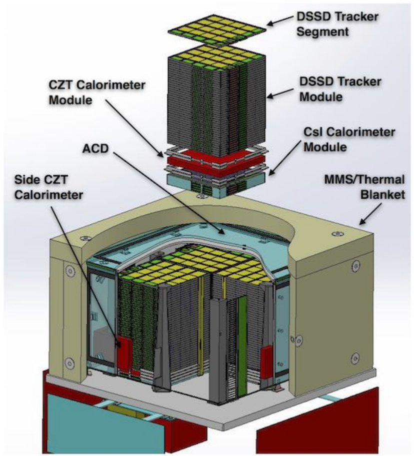


GRB170817A with AMEGO

The Challenge and Proposed Solution







ɣ converts to pair (e-/e+) in a multi-layer Si-strip tracker (no additional conversion material).

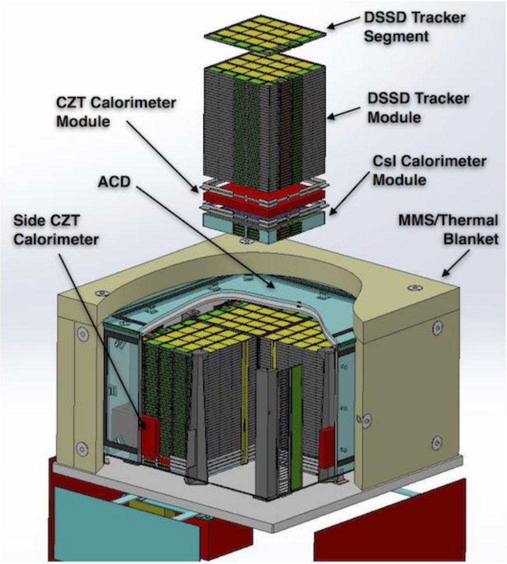
From ~0.1 - 100 MeV two photon interaction processes compete: Compton scattering and pair production cross sections intersect at ~10 MeV (Additionally, large backgrounds exist in this energy range).*

Photon Compton scatters a low-energy e- in Si-strip. Scattered ɣ can be absorbed in the calorimeter.

* This is an understatement.

AMEGO Details

- Use of **well-tested, proven technologies** (Si tracker, CsI calorimeter, Plastic ACD, …)
- Designed to fit within a **probe class** budget:
  - Concept for the 2020 decadal review
- Designed to be **modular** for ease of development, testing, and integration.
- 10 year mission goal (similar to *Fermi*)



Energy Range	0.2 MeV -> 10 GeV
Angular Resolution	3° (1 MeV), 10° (10 MeV)
Energy Resolution	<1% below 2 MeV; 1-5% at 2-100 MeV; ~10% at 1 GeV
Field-of-View	2.5 sr
Sensitivity (MeV s^{-1} cm^{-2})	4×10^{-6}(1 MeV); 4.8×10^{-6}(10 MeV); 1×10^{-6}(100 MeV)

The **AMEGO team** is a cross-section of the high energy astrophysics community and includes experts on the technical and scientific details of the mission. See https://asd.gsfc.nasa.gov/amego/team.html for an updated list.

NASA/GSFC

Julie McEnery (PI), Jeremy Perkins, Liz Hays, Judith Racusin, Dave Thompson, Alice Harding, Brad Cenko, Tonia Venters, John Mitchell, & Georgia de Nolfo

NASA/GSFC/CRESST

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Paolo Coppi

Jagiellonian University

Lukasz Stawarz

The Ohio State University

Tim Linden

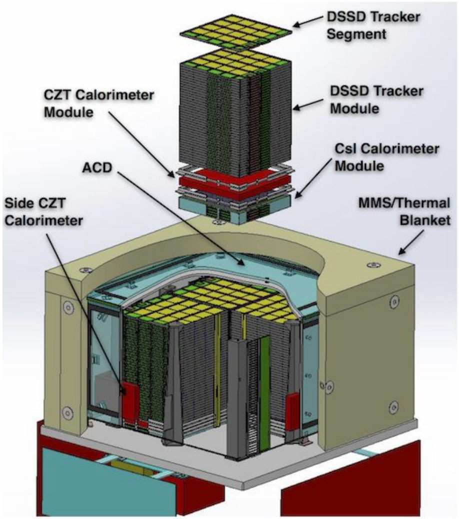
University of Illinois

Xilu Wang

West Virginia University

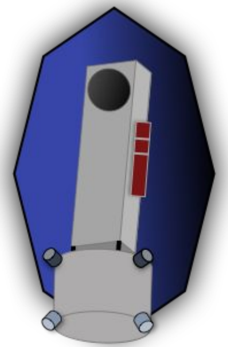
Harsha Blumer

VENTI



AMEGO

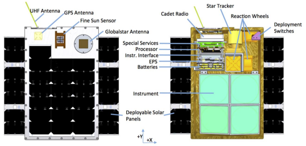
GRANDE



Nimble

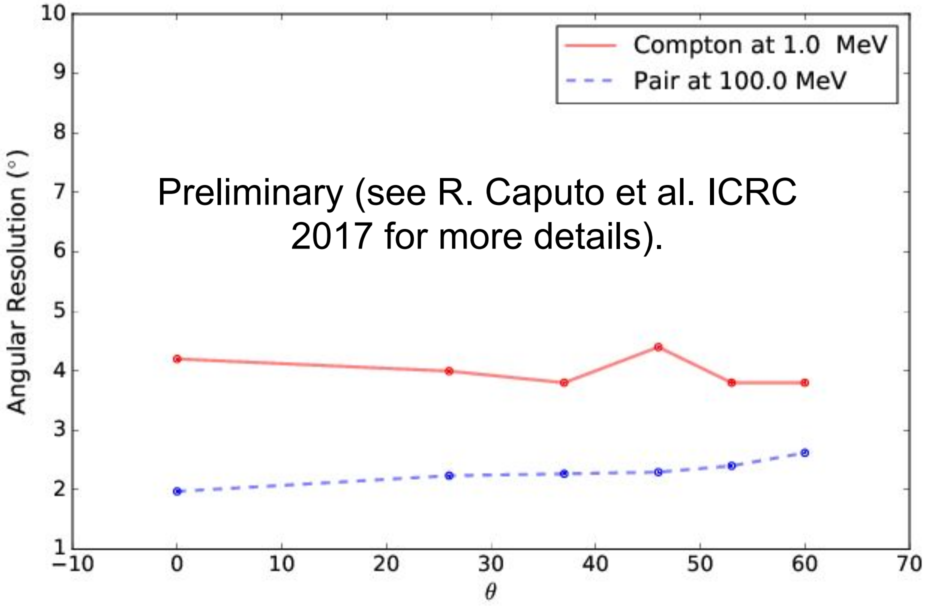
SHORT

BurstCube

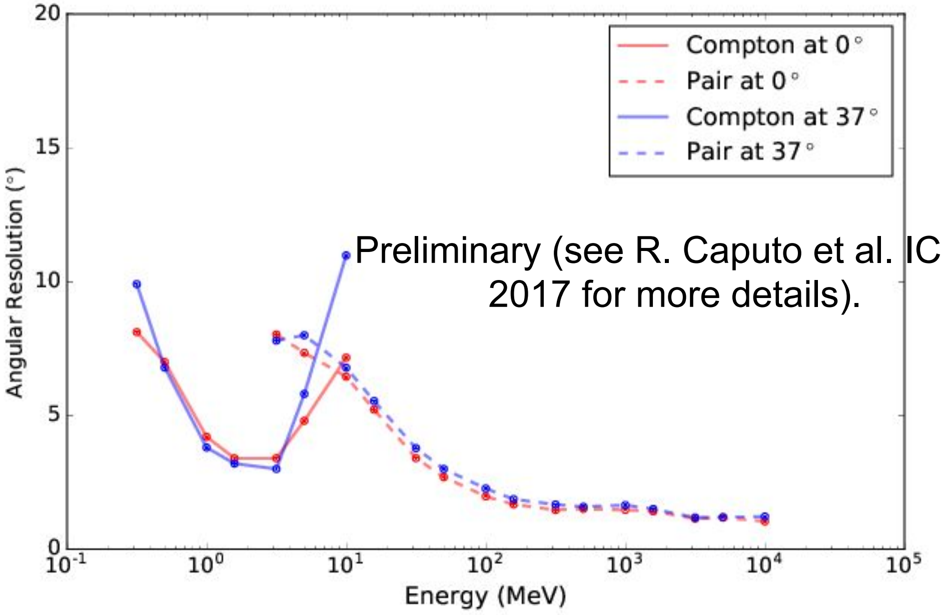


Need to look at the Universe from many different perspectives.

Backup Slides



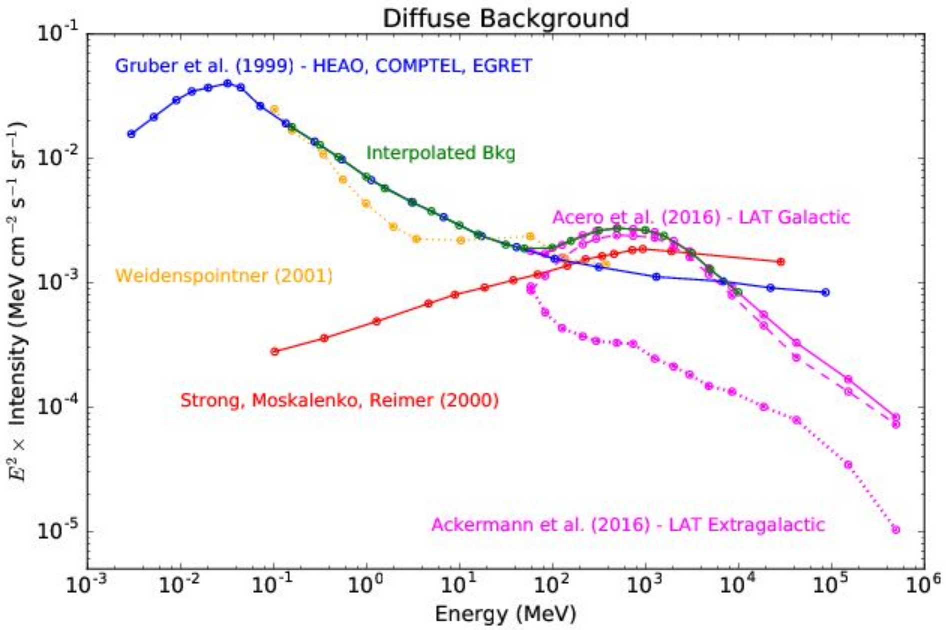
Angular Resolution vs. Theta



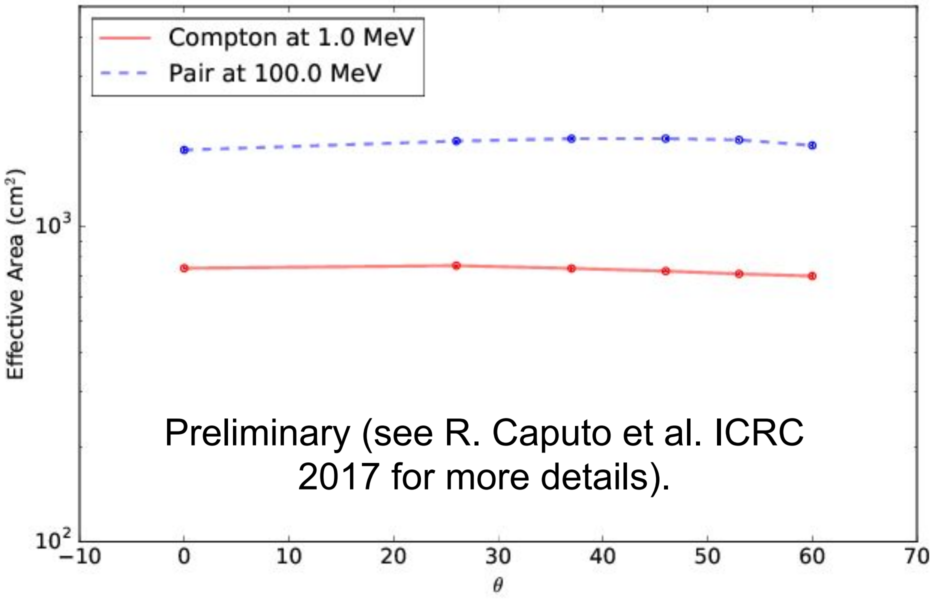
Preliminary (see R. Caputo et al. ICRC 2017 for more details).

Angular Resolution vs. Energy

Preliminary (see R. Caputo et al. ICRC 2017 for more details).

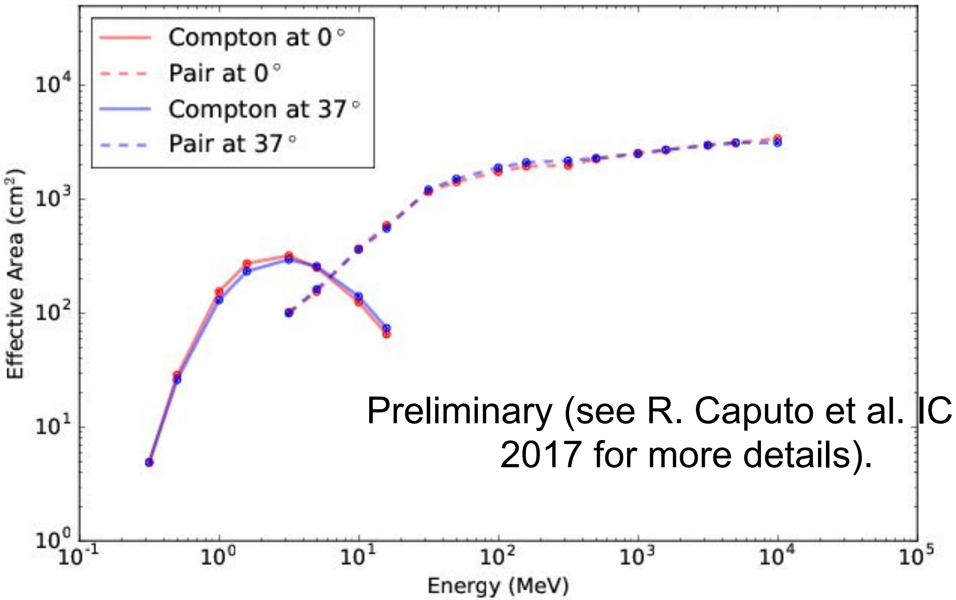


Diffuse Backgrounds



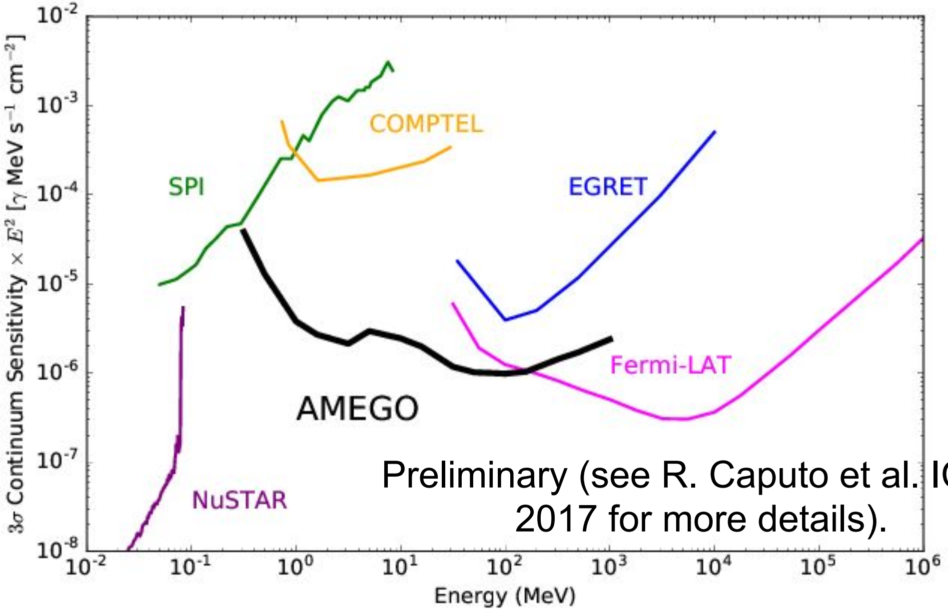
Preliminary (see R. Caputo et al. ICRC 2017 for more details).

Effective Area vs. Theta



Preliminary (see R. Caputo et al. ICRC 2017 for more details).

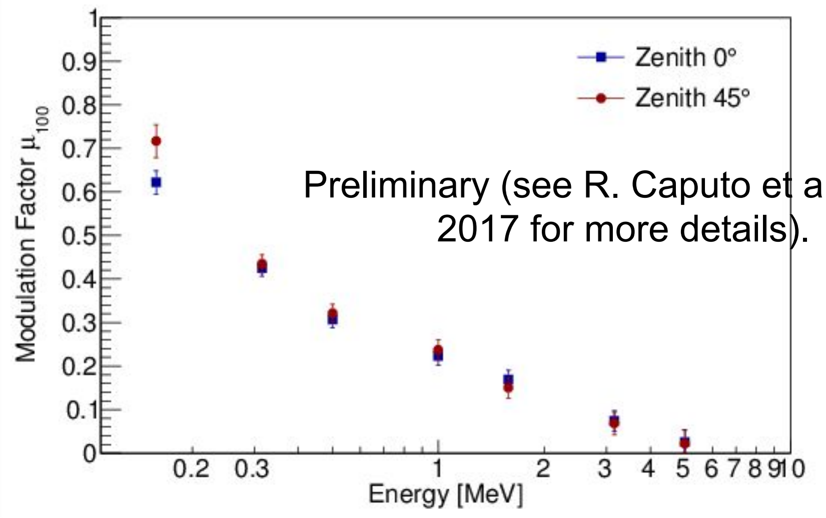
Effective Area vs. Energy



Preliminary (see R. Caputo et al. ICRC 2017 for more details).

Sensitivity

Polarization



Preliminary (see R. Caputo et al. ICRC 2017 for more details).

$$\mathrm{MDP} = \frac{4.29}{\mu_{100} R_S} \sqrt{\frac{R_S + R_{BG}}{T_{\mathrm{obs}}}}$$

In one week, assuming that the source is in the field of view for 10% of the time, AMEGO reaches an MDP of 5% (12%) in the 0.5 - 1 MeV (1 - 2 MeV) energy range.