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

Jeremy S. Perkins
NASA/Goddard Space Flight Center
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
(biased) Menu of three missions (ok, they’re all pretty much square)
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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 relies 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.
Towards a Network of GRB Detecting Nanosatellites

September 13 - 14, 2018
Budapest, Hungary

At some point in the future, we are looking forward to having multiple GRB detecting smallsats in orbit, all looking for transients and all streaming their data to the ground to somewhere in some format and from there out to the scientific community. We are organizing an invitational workshop for the people working on these projects to get together and discuss how we might work together to maximize the science output of our instruments.

Organizing Committee
Michelle Hui, Jeremy Perkins, Judy Racusin, and Norbert Werner

Contact us at grb_nanosats_soc@bigbang.gsfc.nasa.gov.

https://asd.gsfc.nasa.gov/conferences/grb_nanosats/
(biased) Menu of three missions (ok, they’re all pretty much square)

- BurstCube
- Nimble
- AMEGO
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
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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)
Looking for Prompt Emission and Studying the Kilonova

Deep understanding of the gamma-ray emission in the energy range of peak power output.
Why Look in the MeV Range?

EGRET All-Sky Map Above 100 MeV

~300 Sources Detected
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Credit: EGRET Team

Fermi-LAT All-Sky Map Above 1 GeV
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Credit: NASA/DOE/Fermi LAT Collaboration
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COMPTEL All-Sky Map 1 - 30 MeV
Tens of Sources Detected
Credit: COMPTEL Collaboration
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COMPTEL All-Sky Map 1 - 30 MeV

Tens of Sources Detected

Credit: COMPTEL Collaboration
Guaranteed Discovery Space

The MeV range is prime discovery space.

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

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.
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).*

* 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*)

<table>
<thead>
<tr>
<th>Energy Range</th>
<th>0.2 MeV -&gt; 10 GeV</th>
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</thead>
<tbody>
<tr>
<td>Angular Resolution</td>
<td>3° (1 MeV), 10° (10 MeV)</td>
</tr>
<tr>
<td>Energy Resolution</td>
<td>&lt;1% below 2 MeV; 1-5% at 2-100 MeV; ~10% at 1 GeV</td>
</tr>
<tr>
<td>Field-of-View</td>
<td>2.5 sr</td>
</tr>
<tr>
<td>Sensitivity (MeV s^{-1} cm^{2})</td>
<td>4x10^{-6}(1 MeV); 4.8x10^{-6}(10 MeV); 1x10^{-6}(100 MeV)</td>
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</tbody>
</table>
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
Alex Moiseev, Regina Caputo, Sara Buson, Roopesh Ojha, Elizabeth Ferrara, Chris Shrader, Amy Lien, Bindu Rani, Andy Inglis, Lucas Uhren, Eric Burns, Sean Griffin, John Krizmanic

GWU
Sylvain Guiriec, Oleg Kargaltsev, Alexander van der Horst, & George Younes

Clemson University
Dieter Hartmann, Marco Ajello, Lih-Sin The, & Vaidehi S. Paliya

NRL
Eric Grove, Richard Woolf, Eric Wulf, Justin Finke, Teddy Cheung, Matthew Kerr, Michael Lovellette, & Alexander Chechtman

UC Berkeley
Steven Boggs, Andreas Zoglauer, Carolyn Kierans & John Tomskick

SLAC
Seth Digel, Eric Charles, Manuel Meyer, & Matthew Wood

Wash. U. in St Louis
Fabian Kislat, Jim Buckley, Wenlei Chen & Henric Krawczynski

UNH
Mark McConnell & Peter Blaser

NASA/MSFC
Colleen Wilson-Hodge, Michelle Hui, & Dan Kocevski

UAH
Michael Briggs

USRA
Valerie Connaughton

OSU
John Beacom

UIUC
Brian Fields & Xilu Wang

UNLV
Bing Zhang

U Delaware
Jamie Holder

Georgia Tech
Nepomuk Otte

UCSC
Robert Johnson & David Williams

Stanford
Nicola Omodei, Igor Moskalenko, Troy Porter & Giacomo Vianello

Argonne National Lab
Jessica Metcalfe

University of MD, College Park
Peter Shawhan

University of MD, Baltimore County
Markos Georganopoulos & Eileen Meyer

North West University, South Africa
Zorawar Wadisangh

Los Alamos National Lab
Lisa Winter, Karl Smith, Alexei V. Klimenko, Richard Schirato, & Lucas Parker

Rice University
Matthew Baring

University of Padova and INFN Padova
Riccardo Rando

Universidad Autónoma de Madrid
Miguel A. Sánchez-Conde

University of Trieste & INFN
Francesco Longo

Hiroshima University
Yasushi Fukazawa, Tsunefumi Mizuno, Hiromitsu Takahashi, Masanori Ohno, & Yasuyuki Tanaka

Brookhaven National Lab
Aleksey Bolotnikov

Harvard-Smithsonian CfA
Dan Castro

University of North Florida
John W. Hewitt

University of Pisa & INFN
Luca Baldini

Yale
Paolo Coppi

Jagiellonian University
Lukasz Stawarz

The Ohio State University
Tim Linden

University of Illinois
Xilu Wang

West Virginia University
Harsha Blumer
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).
Preliminary (see R. Caputo et al. ICRC 2017 for more details).

Effective Area vs. Theta
Effective Area vs. Energy

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

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

Polarization

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