The GLAST Scientific Mission

Resolve the gamma-ray sky: unidentified sources and diffuse emissions

Study of solar flares

Particle acceleration mechanisms in active galactic nuclei and pulsars

Origin and mechanism of Gamma-ray bursts
Gamma-ray Bursts

- Occur in cosmologically distant galaxies (~ several Gpc)
- Gamma-ray energy \( \sim 10^{51} \) ergs, similar to total supernova energy
- Gamma-ray production associated with highly relativistic outflow
- Some (perhaps all) associated with rare form of supernova explosion

LANL Vela satellite detects first GRB (1967)

BATSE suggests extragalactic origin of GRBs (early 1990s)

BeppoSAX observes X-ray afterglow and confirms extragalactic origin of GRBs (1997).

Optical afterglow from supernova linked to GRB (2001)

HST observes host galaxy for GRB event (1999).
Gamma-ray Burst Origins

- Black hole/accretion disk outflow produces a relativistic $e^+/\gamma$ jet along the rotation axes

- Internal shocks between shells of different velocities produces gamma-ray bursts

- External shocks between outward moving shells and surrounding medium generate afterglow

P. Meszaros, AIP conference proceedings 587, 143 (2001)
The GLAST Instrument

LAT pair-production telescope

GLAST burst monitors

Complete GLAST 4 x 4 Array of Towers

Gamma Ray

Some Dimensions are Distorted for Clarity of Presentation

16 Gaps of 0.035 rad len conv

2 Gaps without Converters

Imaging Calorimeter [10 it]

9.5 cm

208 mm Pitch

Si Strip Detector

Preamps Mounted on Vertical Edge of Tray

Tray

Lead

Silicon

High-Energy BGO Detector (1 of 2)

Low-Energy NaI (TI) Detectors (3 of 12)
The GLAST Burst Monitor

The primary objective of the GBM is to augment the GLAST mission scientific return from gamma-ray bursts

- extend the energy range of burst spectra down to 5 keV, coupling the unknown high energy regime with the known low energy regime
- provide real time burst locations over a wide field of view, with sufficient accuracy to repoint the spacecraft (+ dissemination of burst locations to the ground)
- general burst search with production and publication of a burst catalog
GBM Simulation: Purpose

The GBM simulation will characterize the instrument response to direct source photons, photons scattering from the spacecraft body, and photons scattering from the earth's atmosphere, for arbitrary source/earth geometry. GBM is a distributed system embedded in a complex environment, accurate simulation is the key to make GBM a useful instrument.
GBM Simulation: Specifications

🌟 **Definition:** Multi-purpose software suite that computes the physical and instrumental response of the GBM detectors

- Primary purpose: generate detector response functions critical to analysis of flight science data
- Other uses: instrument design, interpretation of calibrations, design of flight and ground analysis algorithms/software

🌟 **Technique:** GEANT4 simulation

- Verified through, and incorporating results from experimental calibration

🌟 **Major Components**

- Mass model (geometry + composition)
- Incident particle distributions
- Radiation transport physics
- Instrumental/calibration effects
- DRM database
- DRM synthesizer/generator
GBM Simulation: Architecture

- **gbmsim**: GBM instrument physical simulator
- **calsim**: Instrumental/calibration effects & data packager
- **atmosim**: Atmospheric scattering simulator
- **arpack**: Atmospheric scattering data packager
- **drmgen**: Application-specific DRM generator

- Integrated package that will encompass all GBM instrument response software and data needs
- Configuration controlled (e.g. - CVS) as a single deliverable package with component software/data modules
- All packages (and their dependencies) will use GNU compilers — mainly g++
- All data files have headers with detailed job tracking data
GBM Simulation: Architecture

Detector/Atmosphere Simulation

- gbmsim
  - Mass model
- atmosim
  - Mass model

Cmds., Aux. data

DRM/ARM database and application specific DRM generator

- caldb
- drmgen
- drmdb
- armdb
- Spectrum or DRM
- Spectrum or ARM

Calib. params.

Analysis Codes

- Data Analysis Software
- Application specific DRM
- Source Location Software

- ROOT files
- ROOT files
- caldb
- caldb
- caldb

Spectrum or DRM

Spectrum or ARM

ROOT files

ROOT files

ROOT files

ROOT files
**GBM Simulation Design (1)**

**Inputs**
- Instrument+environment mass model (custom GDML file format)
- Commands (interactive command line or command macro file[s])
- Auxiliary data (spatial/spectral dists.)

**Outputs**
- Raw event file(s) (ROOT format)
- Interactive visualizations

**External Dependencies**
- **gbmsim**
  - GBM instrument physical simulator
- **calsim**
  - Instrument/calibration effects simulator & data packager

- GEANT4 — General MC Rad. Transport package from CERN
- ROOT — Data handling/analysis package from CERN
- XERCES — portable c++ XML parser from Apache.org

**Inputs**
- Raw event files (root; from gbmsim or atmosim)
- Commands (interactive command line or command macro file[s])
- Calibration parameters file (ascii)

**Outputs**
- Processed data file(s) (FITS format)
  - e.g., spectra, DRMs, etc.

**External Dependencies**
- ROOT — Data handling/analysis package from CERN
- CCFits — FITS data file I/O for c++ from NASA/GSFC
GBM Simulation Design (2)

**atmosim**
atmospheric scattering simulator

**arpack**
atmospheric scattering data packager

**Inputs**
- Earth atmosphere mass model (internally coded)
- Commands (interactive command line or command macro file[s])

**Outputs**
- Event files (ROOT format)
- Interactive visualizations

**External Dependencies**
- GEANT4 — General MC Rad. Transport package from CERN
- ROOT — Data handling/analysis package from CERN
- CCFits — FITS data file I/O for c++ from NASA/GSFC

**Inputs**
- Event files (ROOT; from atmosim)
- Commands (interactive command line or command macro file[s])

**Outputs**
- Atmospheric response matrices (ARM; FITS format)

**External Dependencies**
- ROOT — Data handling/analysis package from CERN
- CCFits — FITS data file I/O for c++ from NASA/GSFC
NaI Detectors

- In general, the detail of the simulation mass model will be inversely proportional to the distance from the NaI and BGO detectors (NaI/BGO detectors and nearby spacecraft components will be modeled with high precision, internal workings of the LAT and distant spacecraft body with less precision)

- We await detailed drawings and materials specifications, in the meantime we are working with a simplified mass model

**NaI detector (x12):** 1.27 cm thick by 12.7 cm diameter; 5 keV to 1 MeV spectral coverage; 0.25 mm Beryllium window
**BGO Detectors**

**BGO detector (x2):** 12.7 cm thick by 12.7 cm diameter; 150 keV to 30 MeV spectral coverage; viewed by 2 PMTs
Low Energy Compton Scattering

GEANT does not properly handle low-energy Compton scattering, where atomic binding effects are important and cause Doppler broadening.

A GEANT extension called G4LECS (GEANT4 low energy Compton scattering), developed by R.M. Kippen, is used to correct for this deficiency.

Example: NaI Spectrum

- Simple NaI detector mass model
- Normal incidence, $10^5$ recorded events

**gbmsim** – raw physical data

**gbsim**

GBM NaI 500 keV

**calsim** – instrument-like data

**calsim**

GBM NaI 500 keV
GBM Simulation Design (3)

**Inputs**
- DRMdb/ARMdb databases (FITS; from calsim/atmosim)
- Commands (interactive command line, command macro file, or callable)

**Outputs**
- Application-specific DRM (FITS format or memory for callable mode) with or without atmospheric scattering

**External Dependencies**
- CCFits — FITS data file I/O for C++ from NASA/GSFC
- CALDB/CalTools from NASA/GSFC

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**drmgen**
application-specific DRM generator
Detector Response Matrix: Example

Example: development version (no atmospheric response), normal incidence, 100k events per 158 energies

Simulation time = 16.5 hours
Simulation time = 38.7 hours
Atmosphere Model (1)

A full scale earth+atmosphere model was created using concentric spherical shells for the atmosphere layers.

NRLMSISE-00 (year 2000 release) atmosphere data is used for temperature, pressure, mass density, and element number density in each layer (http://uap-www.nrl.navy.mil/models_web/msis/msis_home.htm).

Number and thickness of layers is arbitrary, easily changed.

Capable of modeling 0-1000 km.

A “plane wave” is incident upon the earth; the direction and energy of scattered photons is recorded when they cross a “collection surface” surrounding the model at the spacecraft altitude.
Atmosphere Model (2)

The G4 model temperature, pressure, and density compare well to COSPAR (1961) and US Standard Atmosphere (1976) (see Zombeck, *Handbook of Space Astronomy and Physics*).
Atmosphere Model (3)

The atmosphere is composed of 7 elements, with varying number density according to altitude.

<table>
<thead>
<tr>
<th>Constituent</th>
<th>$n$ (particles cm$^{-3}$)</th>
<th>$\log_{10} n$</th>
</tr>
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<tbody>
<tr>
<td>$N_2$</td>
<td>$2 \times 10^{18}$</td>
<td>19.3</td>
</tr>
<tr>
<td>$O_2$</td>
<td>$5.4 \times 10^{14}$</td>
<td>18.73</td>
</tr>
<tr>
<td>$H_2O$</td>
<td>$3 \times 10^{13}$</td>
<td>17.48</td>
</tr>
<tr>
<td>$Ar$</td>
<td>$2.4 \times 10^{12}$</td>
<td>17.38</td>
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<tr>
<td>$CO_2$</td>
<td>$8.5 \times 10^{12}$</td>
<td>15.93</td>
</tr>
<tr>
<td>$Ne$</td>
<td>$4.7 \times 10^{10}$</td>
<td>14.67</td>
</tr>
<tr>
<td>$He$</td>
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<td>$1.286 \times 10^{10}$</td>
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<tr>
<td>$CH_4$</td>
<td>$2.5 \times 10^{9}$</td>
<td>12.4</td>
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<tr>
<td>$O_3$</td>
<td>$4.725 \times 10^{8}$</td>
<td>11.075</td>
</tr>
<tr>
<td>$O$</td>
<td>$1.05 \times 10^{6}$</td>
<td>4.025</td>
</tr>
</tbody>
</table>

Water vapour and carbon dioxide fluctuate considerably.
Example (development version)

10k events per 158 energies
Phased Software/Model Development

Software and models require cross-validation with calibration data

Three phases of SIM/DRM sw/model development

- **Design**
  - Simulate prototype detectors

- **Calibration**
  - Simulate three levels of calibration/test
    - Detector level
    - GBM system level
    - On-spacecraft level

- **Operation**
  - In-flight configuration appropriate for analysis of science data
  - DRM generation

Los Alamos National Laboratory

GEANT4 Space Users Workshop  
Nashville, TN  
May 10-12
Some Remarks on GEANT

Strengths

- Flexibility of GEANT4 lets one tailor the application for their specific needs
- GEANT4 can simulate on the scale of nanometers (good for instrument models) or kilometers (good for planetary models)
- Data output format is entirely up to the user
- One can select only the physics processes that are needed, ignore the rest

Concerns

- Speed - we must simulate many energies for many source positions with low detection efficiency
- We have observed infinite loops for at least two geometries (volumes sharing a boundary, cylinder inside a sphere). We are worried about infinite loops appearing in the final geometry, which will be much more complex
- GDML: long term support? Compatibility with XERCES (currently it works with XERCES 2.4.0 but with error messages)
- Reluctance of G4 team to fix geometry/tracking errors
Development Schedule

Development version of simulation code is well underway, using simplified models for the NaI/BGO detectors

Next few months... we expect detailed drawings and material composition information for NaI/BGO assemblies. This will be translated to G4 geometry models, followed by verification with calibration data

2005... we will receive drawings/material information for the spacecraft. Then we create G4 geometry for spacecraft + detectors, also verified with calibration data

2006... incorporate in-flight detector configuration into the simulation

2006... final DRM/CALDB databases

2007... GLAST launch