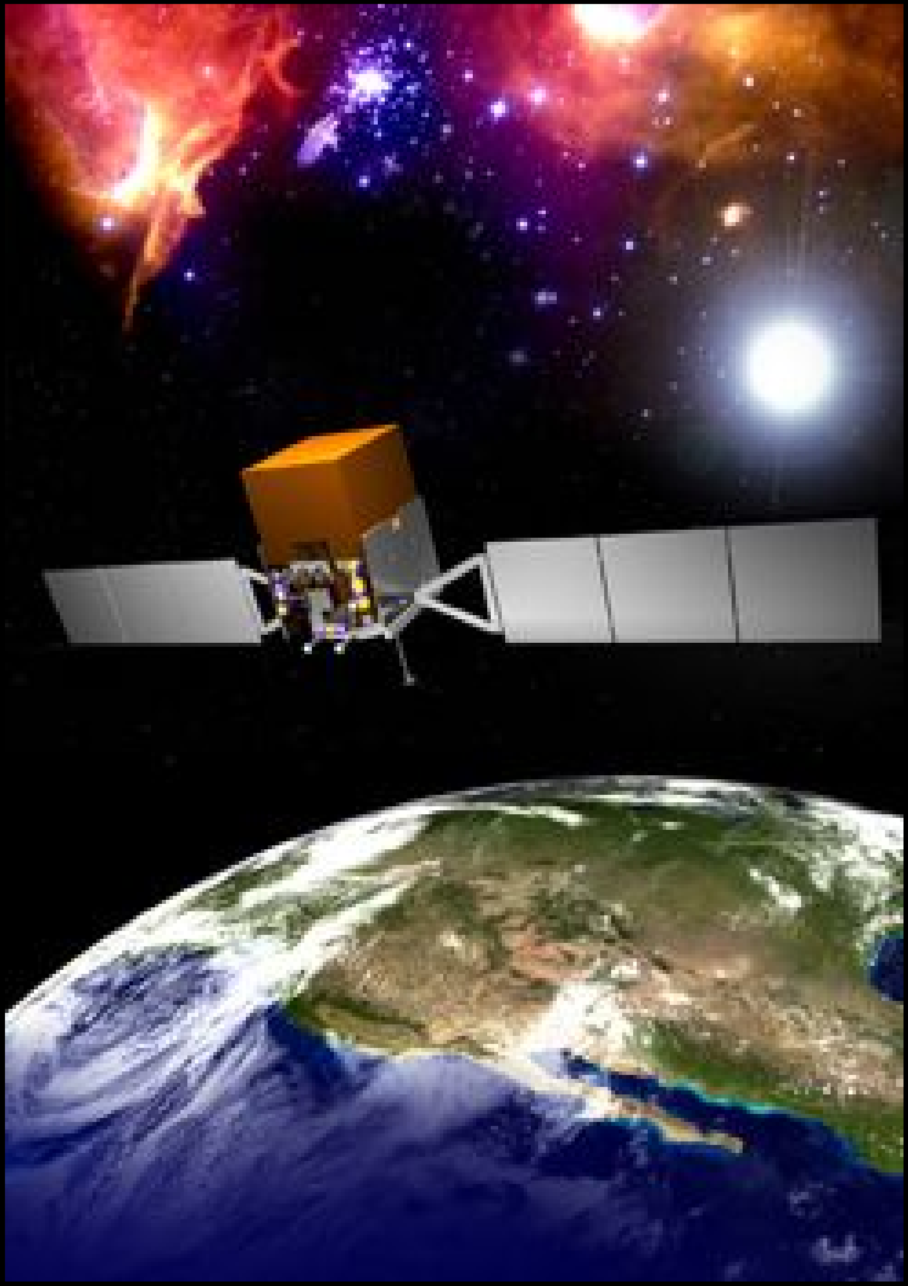


A GEANT4 Simulation System for the GLAST Burst Monitor

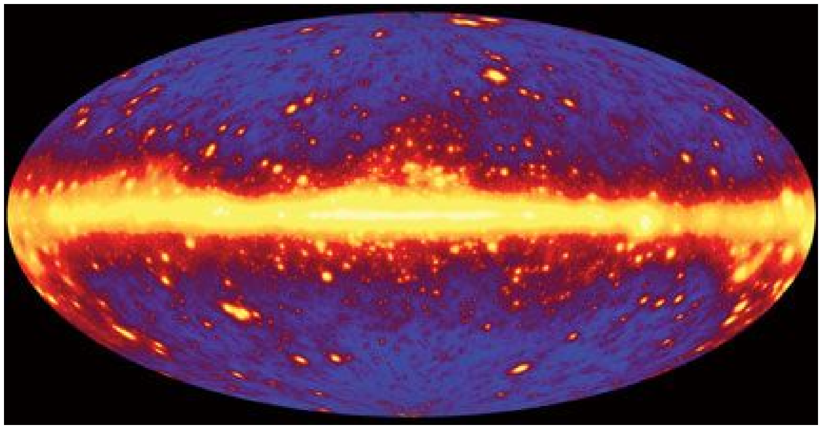
Andrew S. Hoover
R. Marc Kippen

Space and Atmospheric Sciences Group

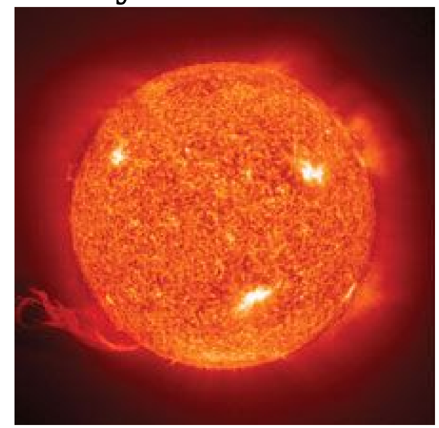
Los Alamos National Laboratory

The GLAST Scientific Mission

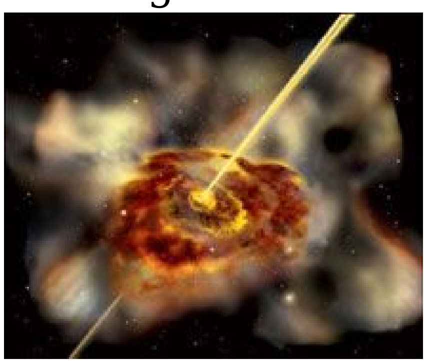
Resolve the gamma-ray sky: unidentified sources and diffuse emissions

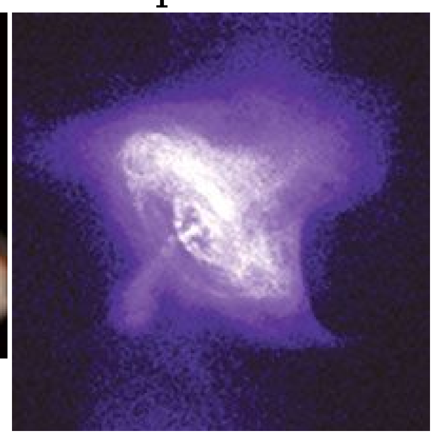


Study of solar flares

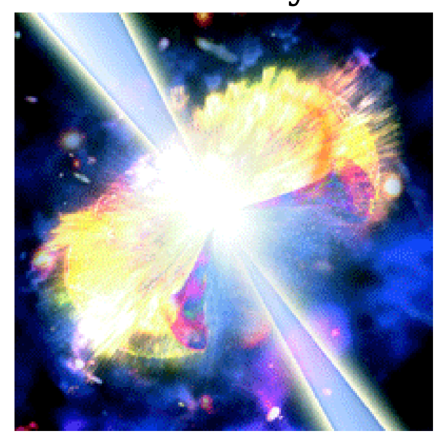


Particle acceleration mechanisms in active galactic nuclei and pulsars





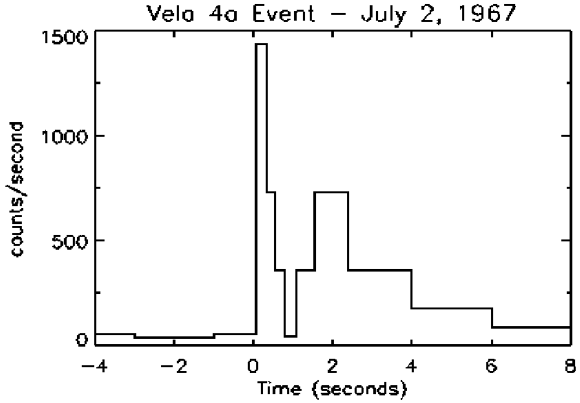
Origin and mechanism of Gamma-ray bursts



Gamma-ray Bursts

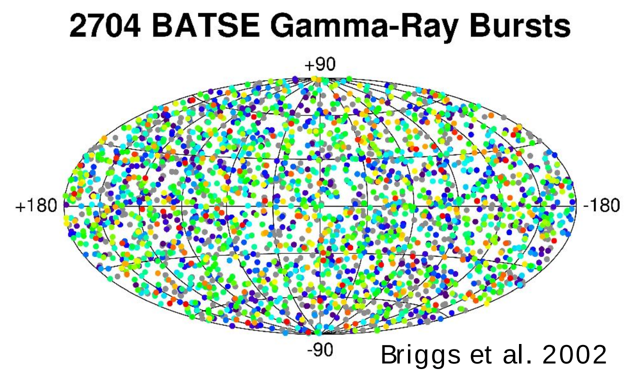
- Occur in cosmologically distant galaxies (~ several Gpc)
- Gamma-ray energy ~10^{51} ergs, similar to total supernova energy
- Gamma-ray production associated with highly relativistic outflow
- Some (perhaps all) associated with rare form of supernova explosion

LANL Vela satellite detects first GRB (1967)

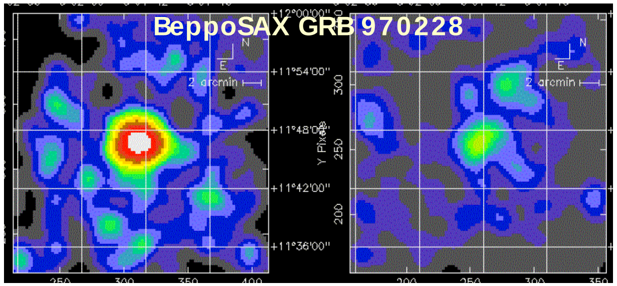


Klebesadel, Strong, & Olsen 1973

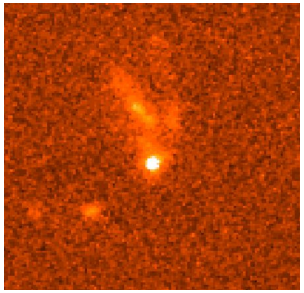
BATSE suggests extragalactic origin of GRBs (early 1990s)



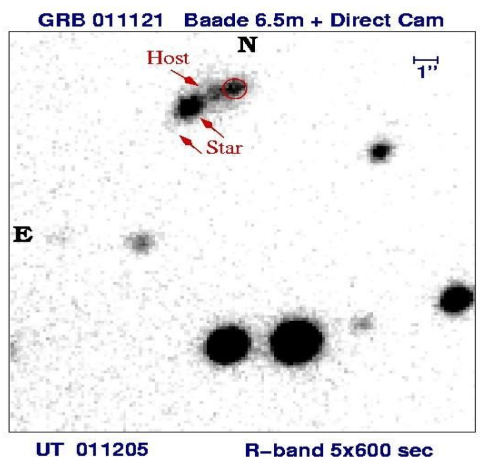
BeppoSAX observes X-ray afterglow and confirms extragalactic origin of GRBs (1997).



HST observes host galaxy for GRB event (1999).



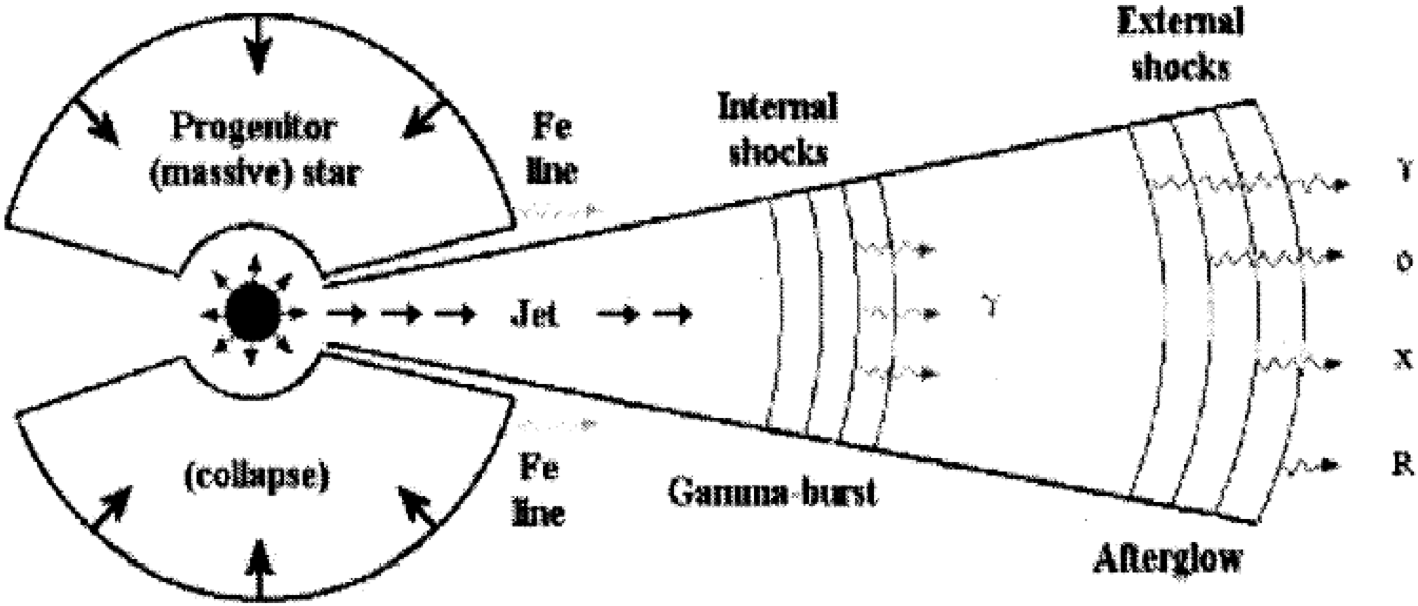
Optical afterglow from supernova linked to GRB (2001)



Garnavich, et al. 2002

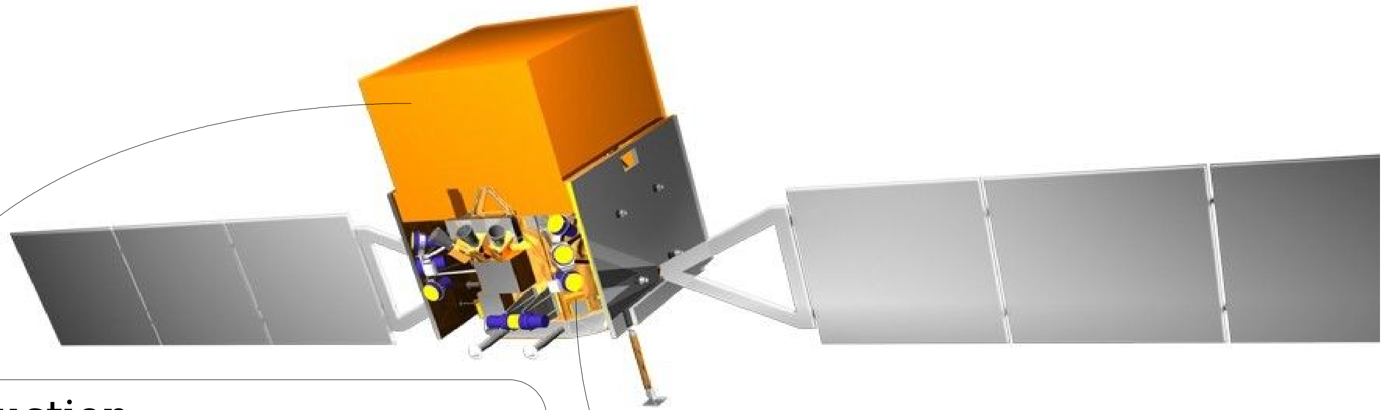
Gamma-ray Burst Origins

- Black hole/accretion disk outflow produces a relativistic $e^{\pm}/\gamma$ 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

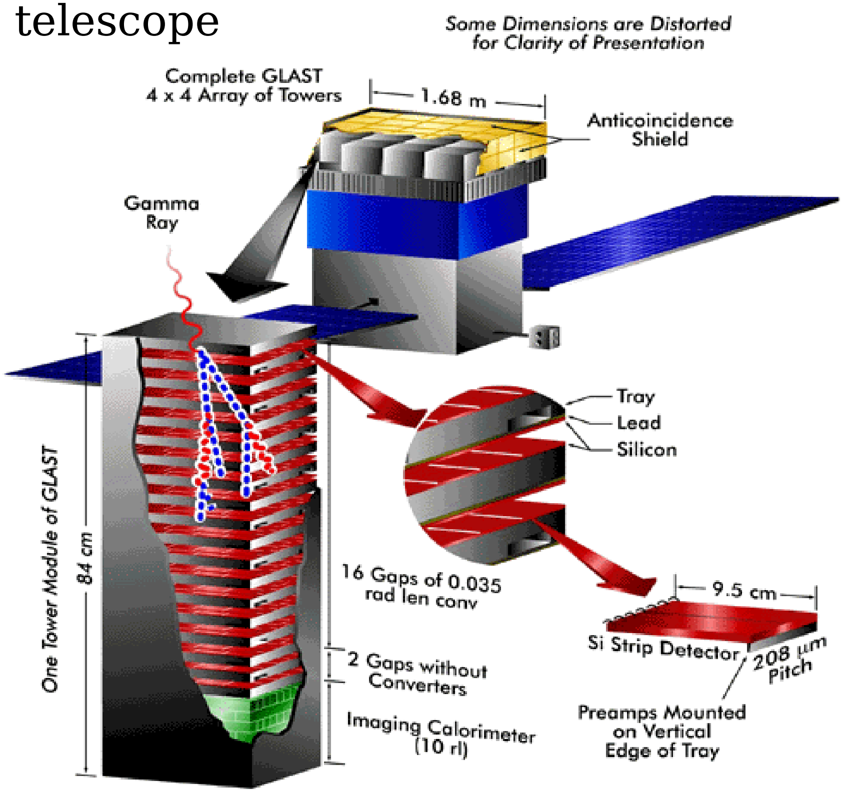


P. Meszaros, AIP conference proceedings **587**, 143 (2001)

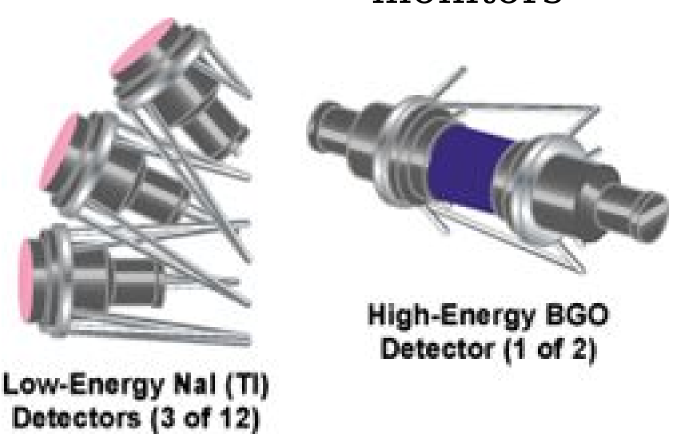
The GLAST Instrument



LAT pair-production telescope



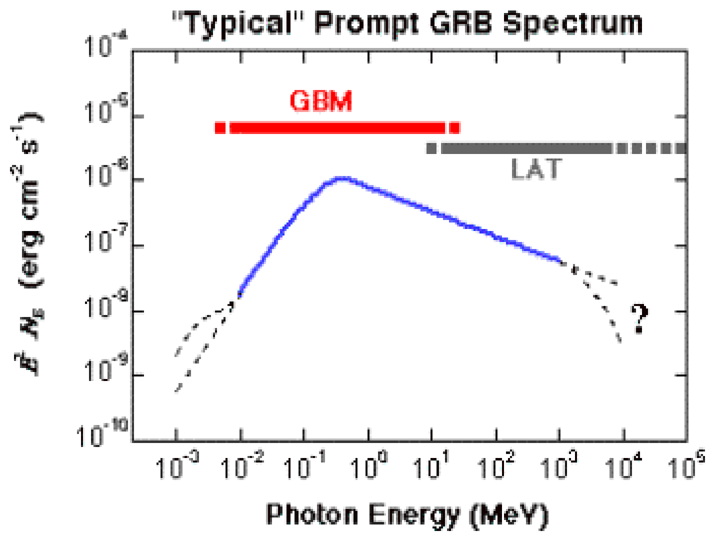
GLAST burst monitors

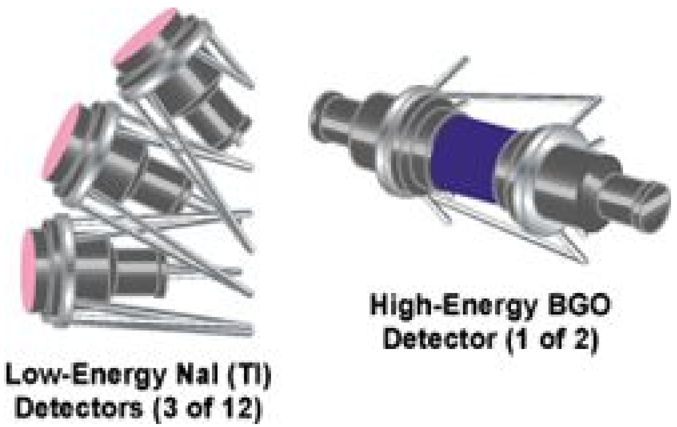


The GLAST Burst Monitor

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

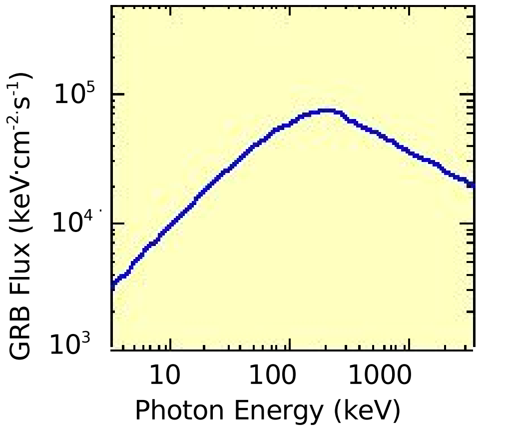




GBM Simulation: Purpose

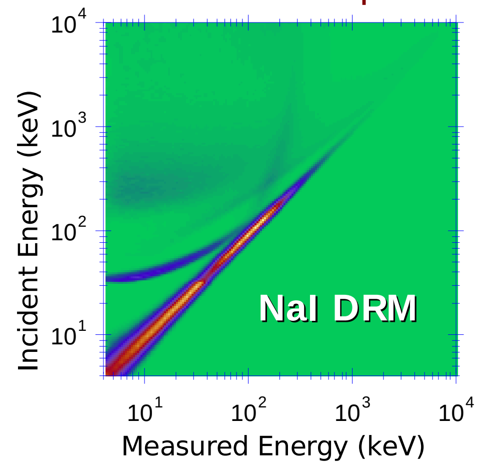
The GBM simulation will characterize the instrument response to direct source photons, photons scattering from the spacecraft body, and photons scattering from the earth's atmosphere, for arbitrary source/earth geometry. GBM is a distributed system embedded in a complex environment, accurate simulation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

GRB Photon Spectrum



*

Instrument Response



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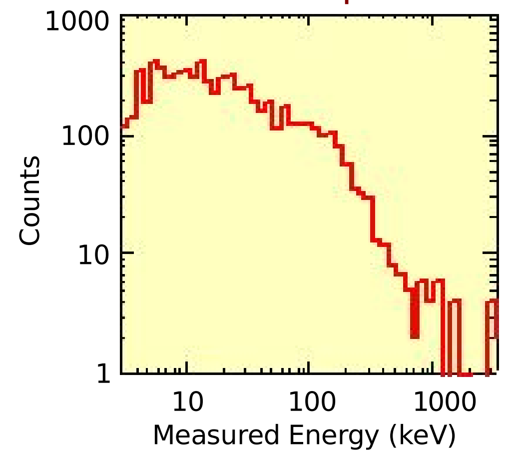
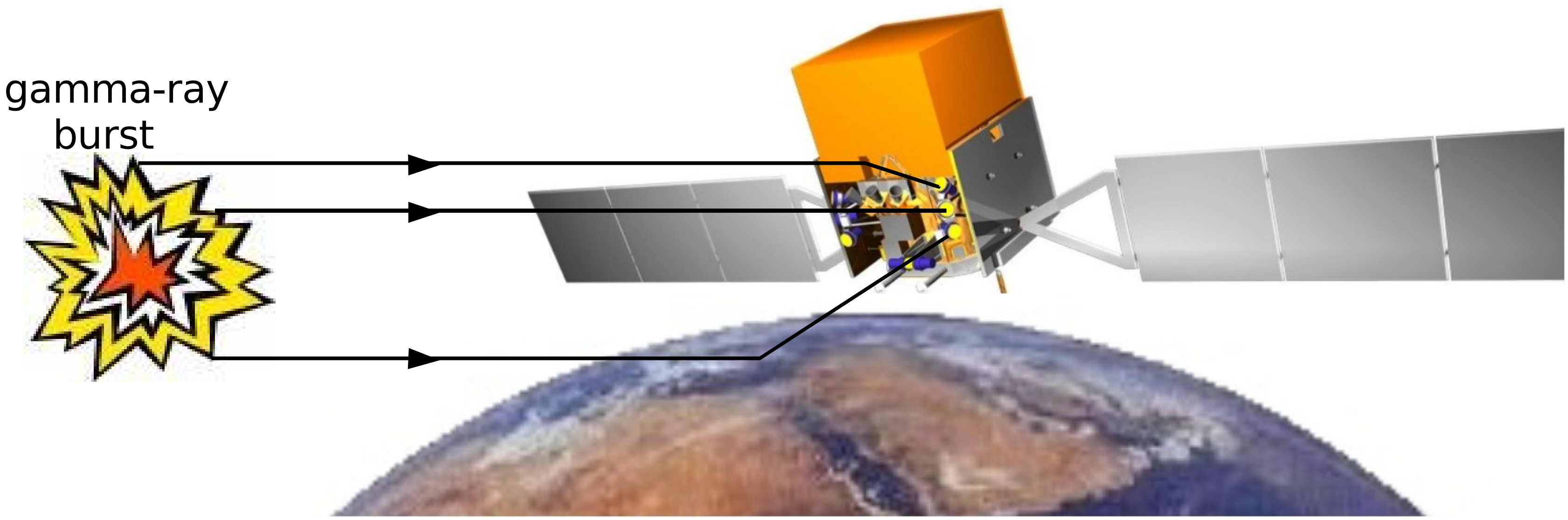
Measured Spectrum

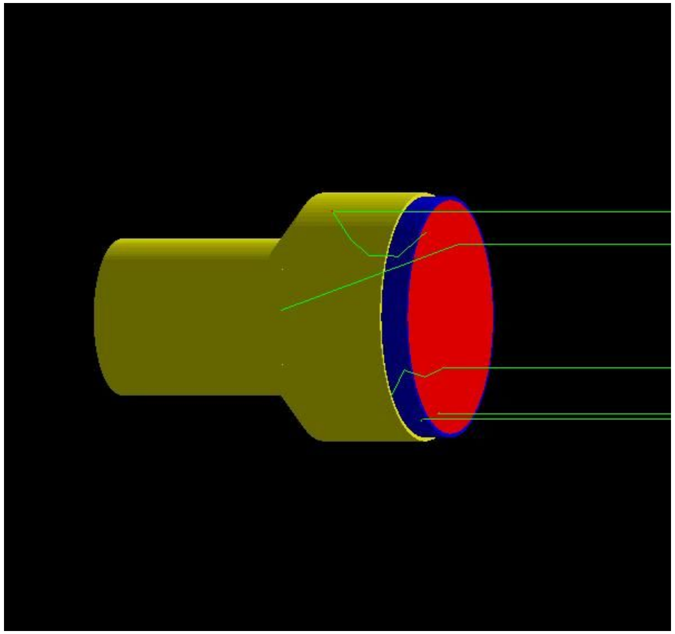




GBM Simulation: Specifications

- **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

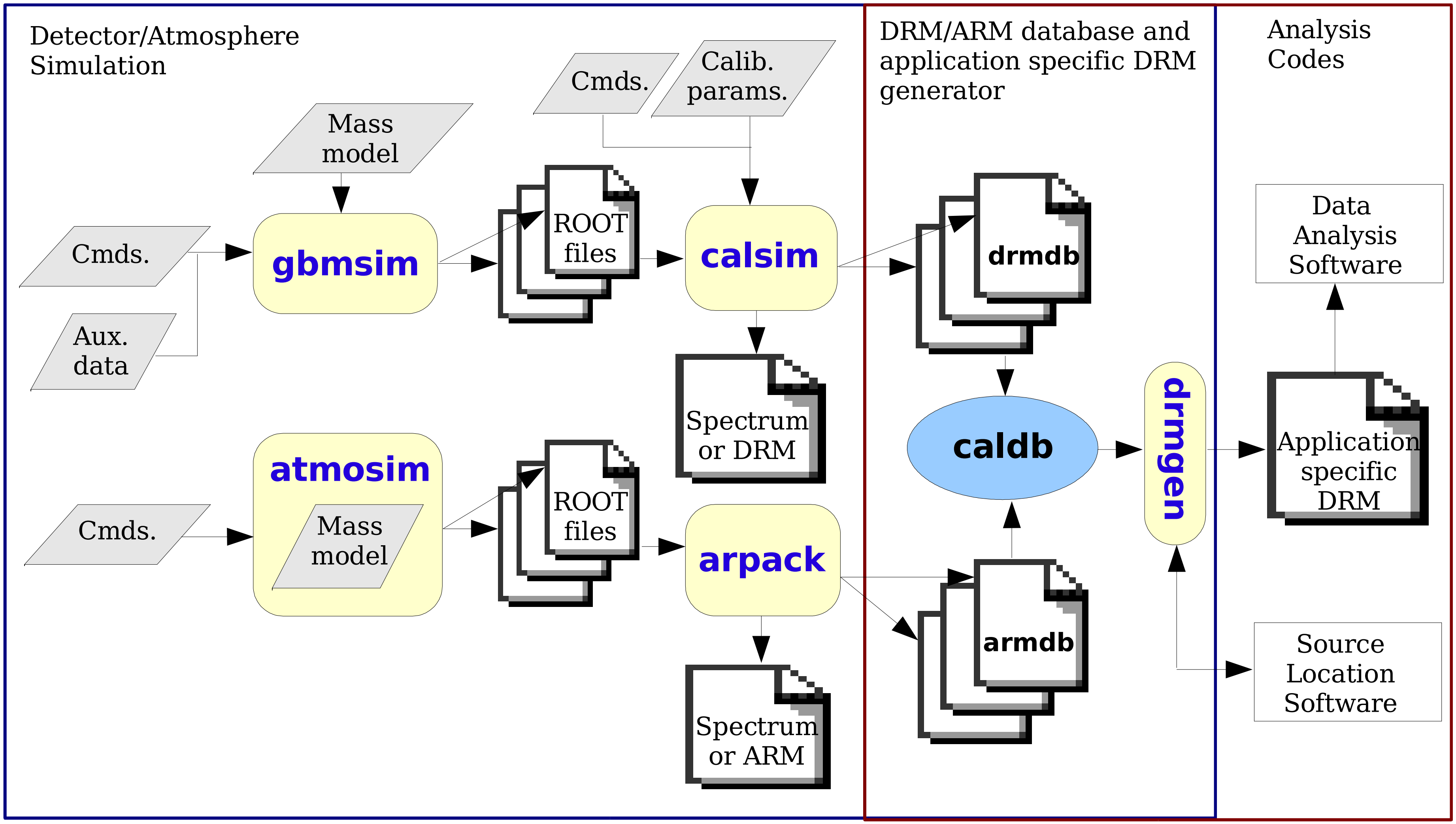
GBM Simulation: Architecture

simulation package

- **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



GBM Simulation Design (1)

gbmsim
GBM instrument
physical simulator

calsim
instrumental/calibration effects
simulator & data packager

gbmsim

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

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

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

calsim

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

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

arpack
atmospheric scattering data packager

Inputs

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

Outputs

- Atmospheric response matrices (ARM; FITS format)

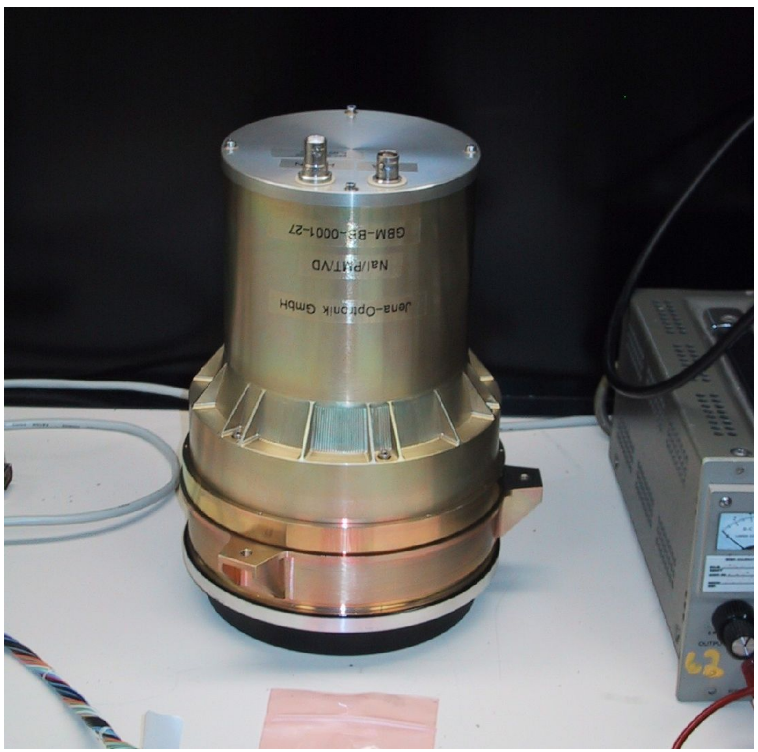
External Dependencies

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

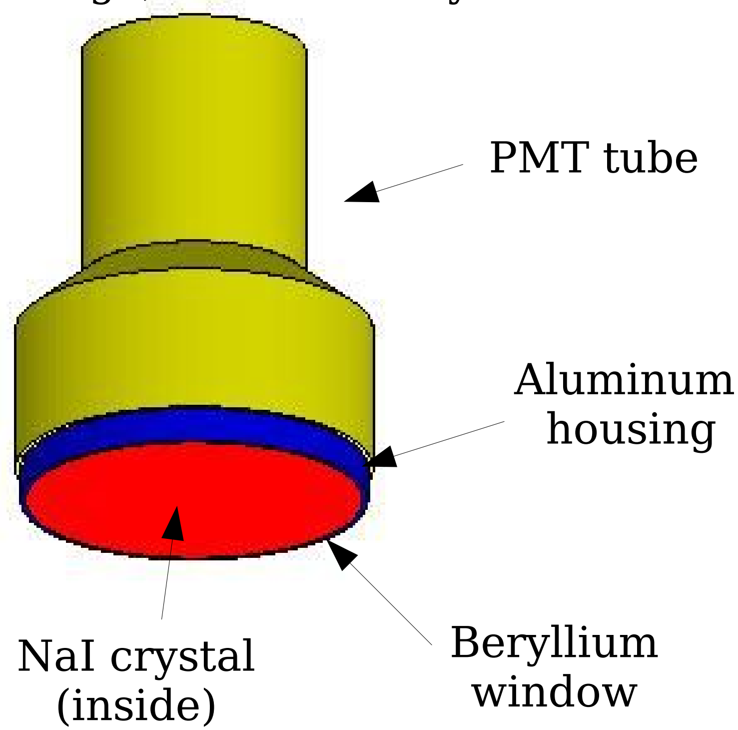
NaI Detectors

- 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

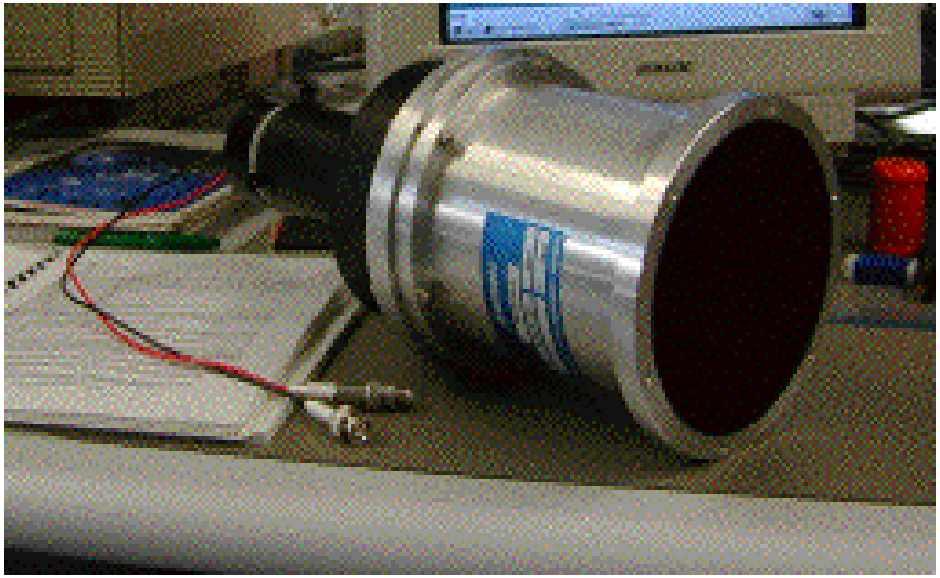


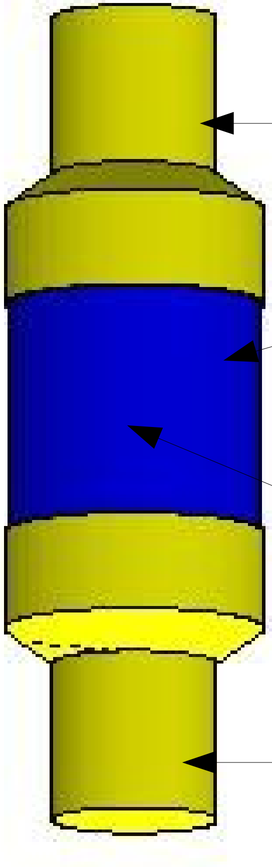
NaI detector (x12): 1.27 cm thick by 12.7 cm diameter; 5 keV to 1 MeV spectral coverage; 0.25 mm Beryllium window



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



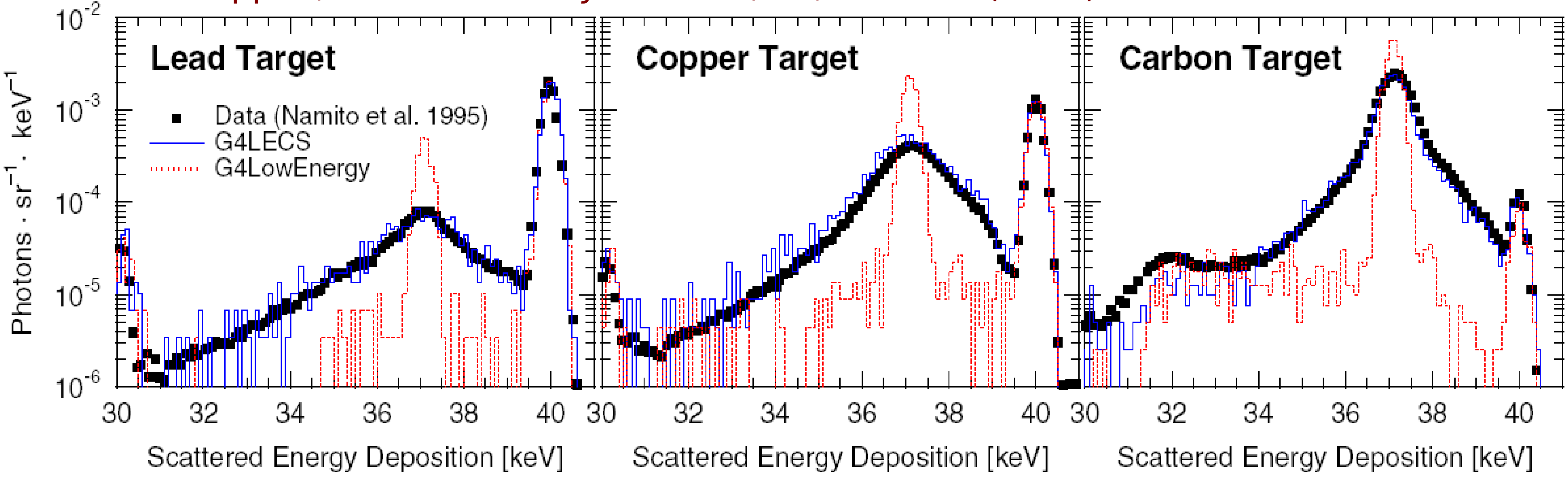


Low Energy Compton Scattering

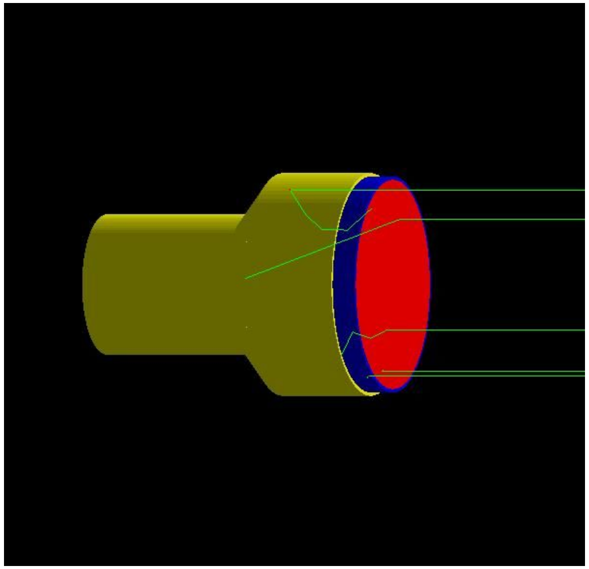
GEANT does not properly handle low-energy Compton scattering, where atomic binding effects are important and cause Doppler broadening

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

R.M. Kippen, *New Astronomy Reviews*, 48, 221-225 (2004)

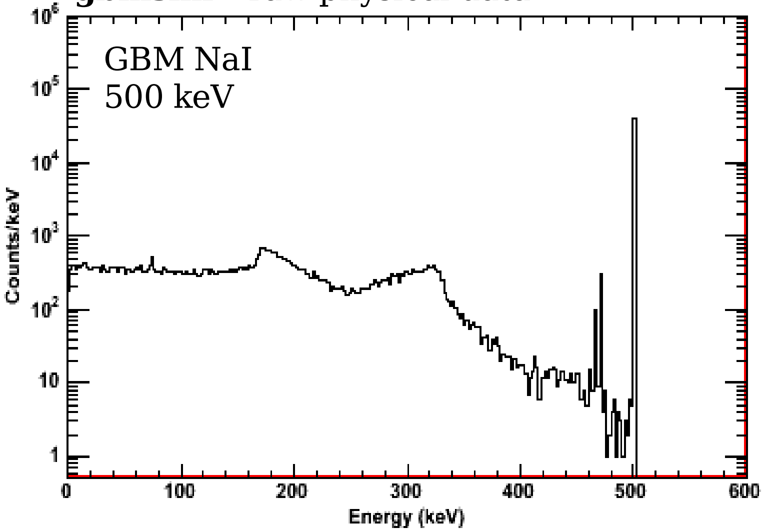


Example: NaI Spectrum

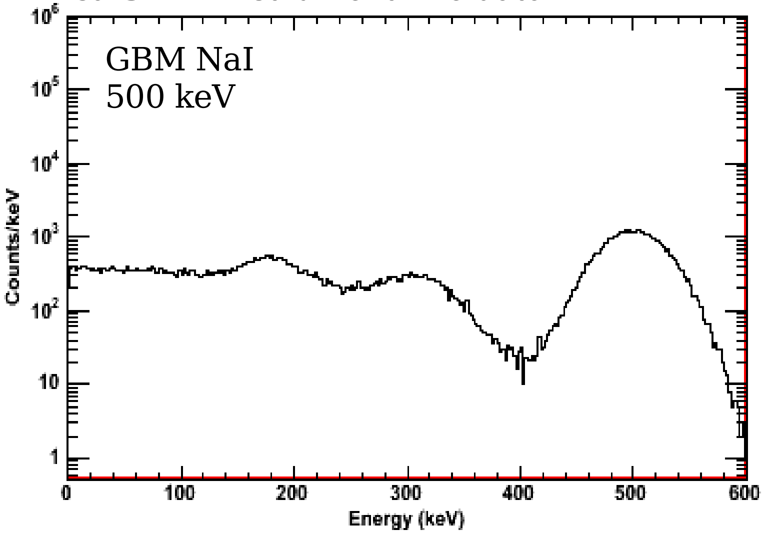


- Simple NaI detector mass model
- Normal incidence, 10^5 recorded events

gbmsim – raw physical data



calsim – instrument-like data



GBM Simulation Design (3)

drmgen
application-specific
DRM generator

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

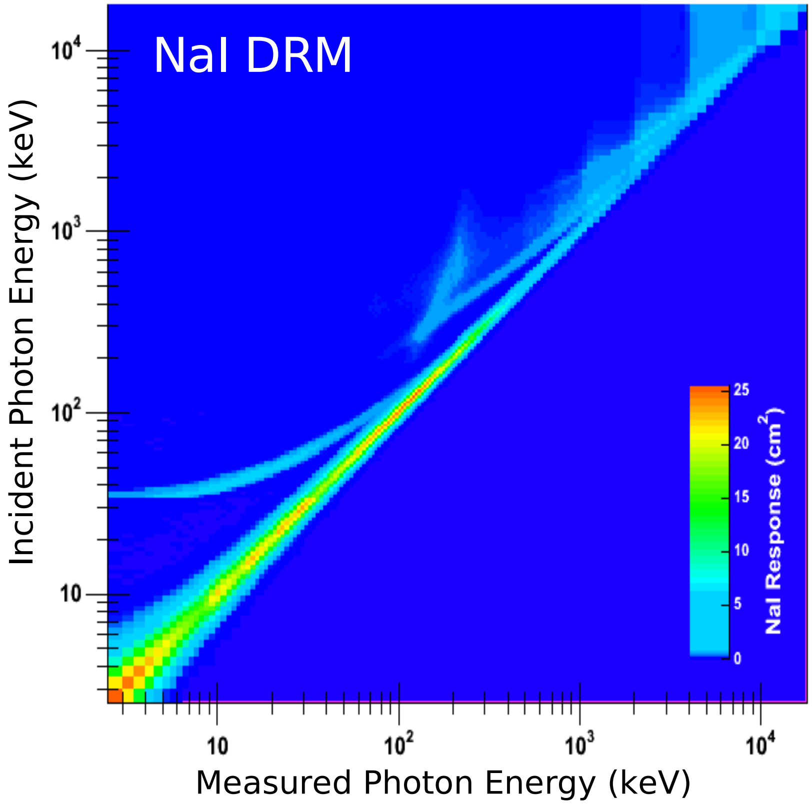
External Dependencies

- CCFits — FITS data file I/O for c++ from NASA/GSFC
- CALDB/CalTools from NASA/GSFC

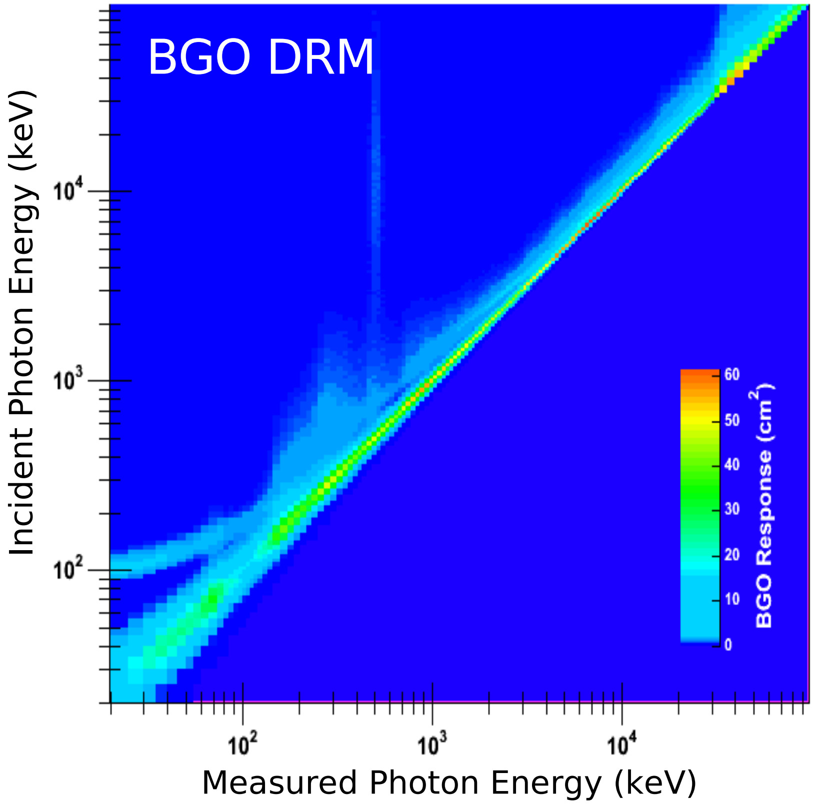
Detector Response Matrix: Example

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

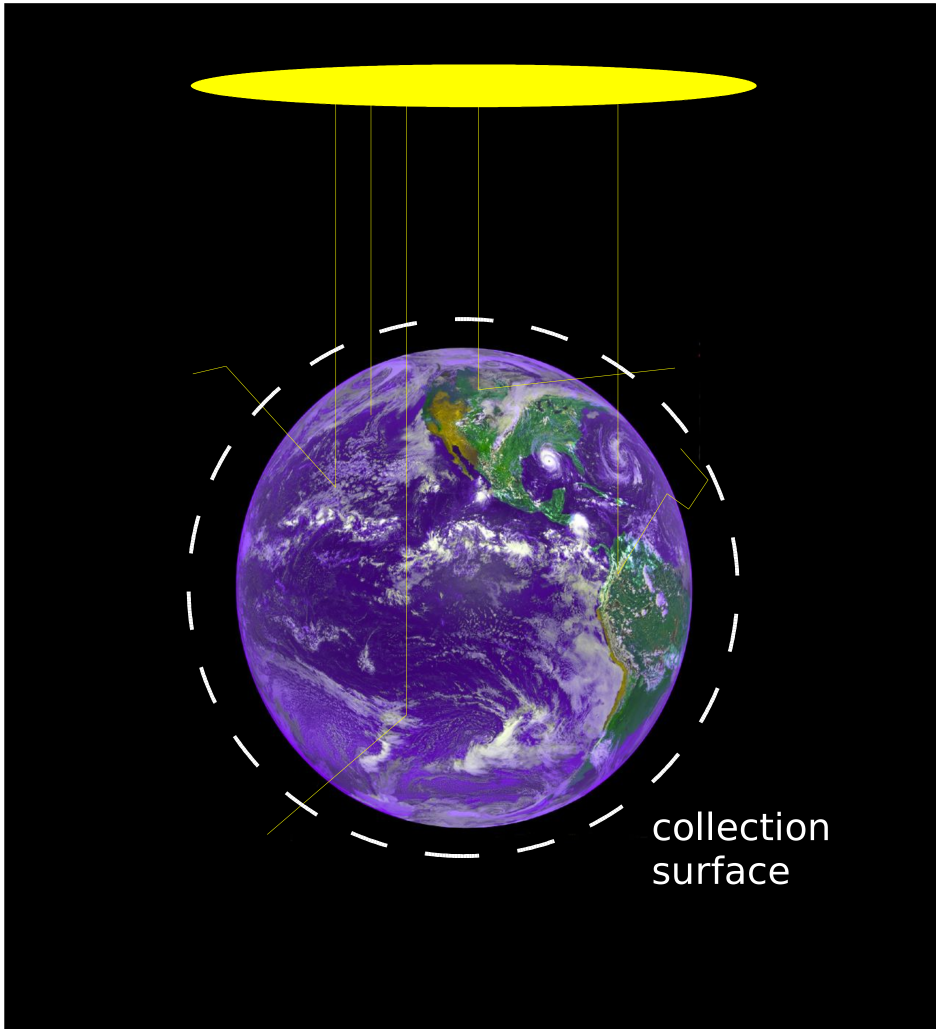
Simulation time = 16.5 hours



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)

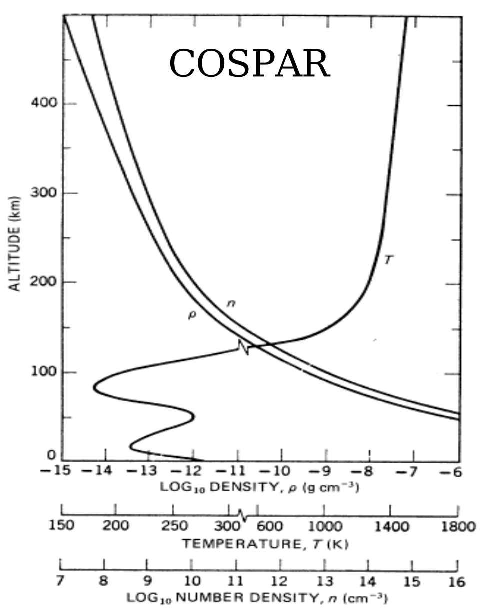
Number and thickness of layers is arbitrary, easily changed

Capable of modeling 0-1000 km

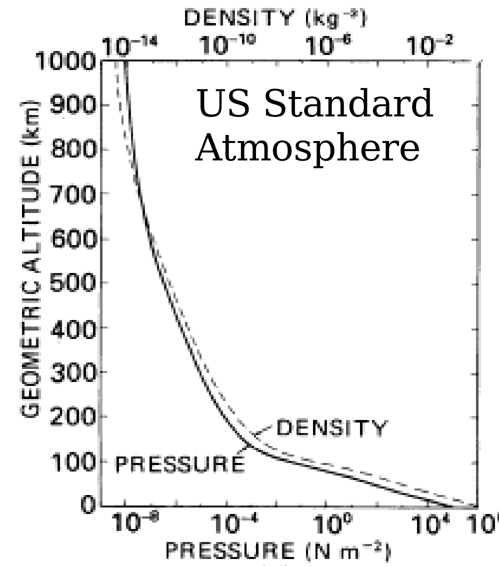
A "plane wave" is incident upon the earth; the direction and energy of scattered photons is recorded when they cross a "collection surface" surrounding the model at the space-craft altitude.

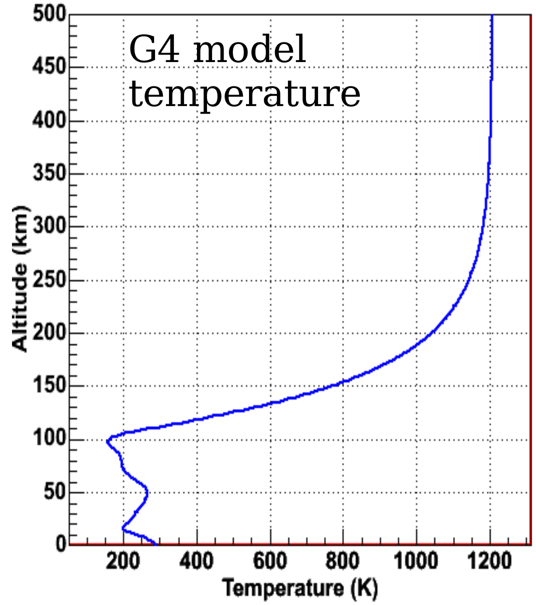
Atmosphere Model (2)

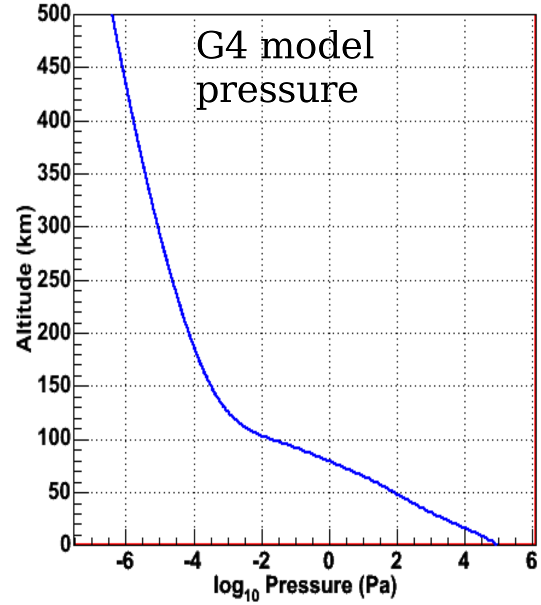
(COSPAR International Reference Atmosphere, 1961.)

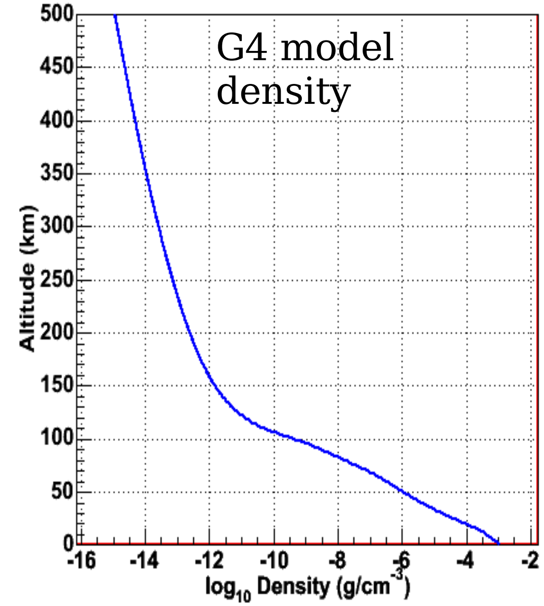


The G4 model temperature, pressure, and density compare well to COSPAR (1961) and US Standard Atmosphere (1976) (see Zombeck, *Handbook of Space Astronomy and Physics*)





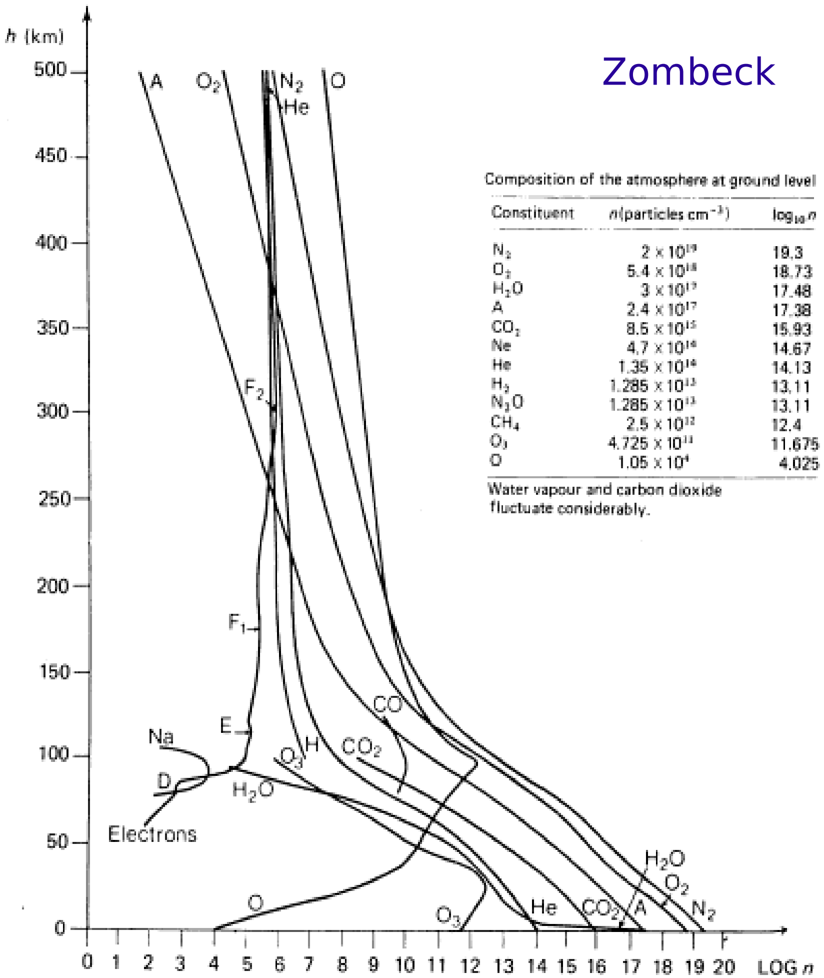




Atmosphere Model (3)

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

Zombeck

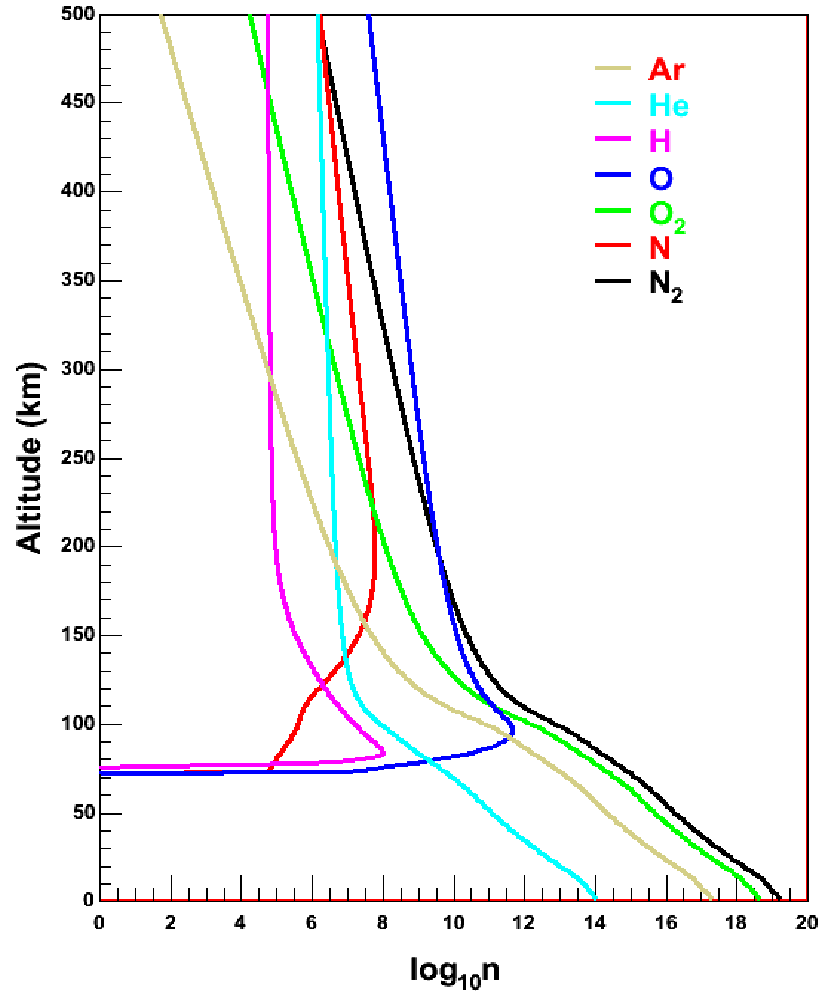


Composition of the atmosphere at ground level

Constituent	n(particles cm^{-3})	$\log_{10} n$
N_2	2×10^{19}	19.3
O_2	5.4×10^{18}	18.73
H_2O	3×10^{17}	17.48
A	2.4×10^{17}	17.38
CO_2	8.5×10^{15}	15.93
Ne	4.7×10^{14}	14.67
He	1.35×10^{14}	14.13
H_2	1.285×10^{13}	13.11
N_2O	1.285×10^{13}	13.11
CH_4	2.5×10^{12}	12.4
O_3	4.725×10^{11}	11.675
O	1.05×10^{4}	4.025

Water vapour and carbon dioxide fluctuate considerably.

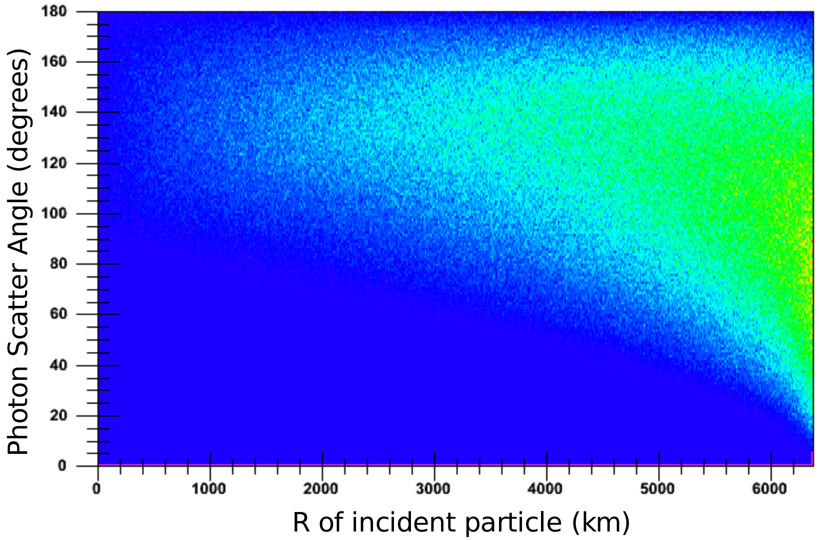
G4 model

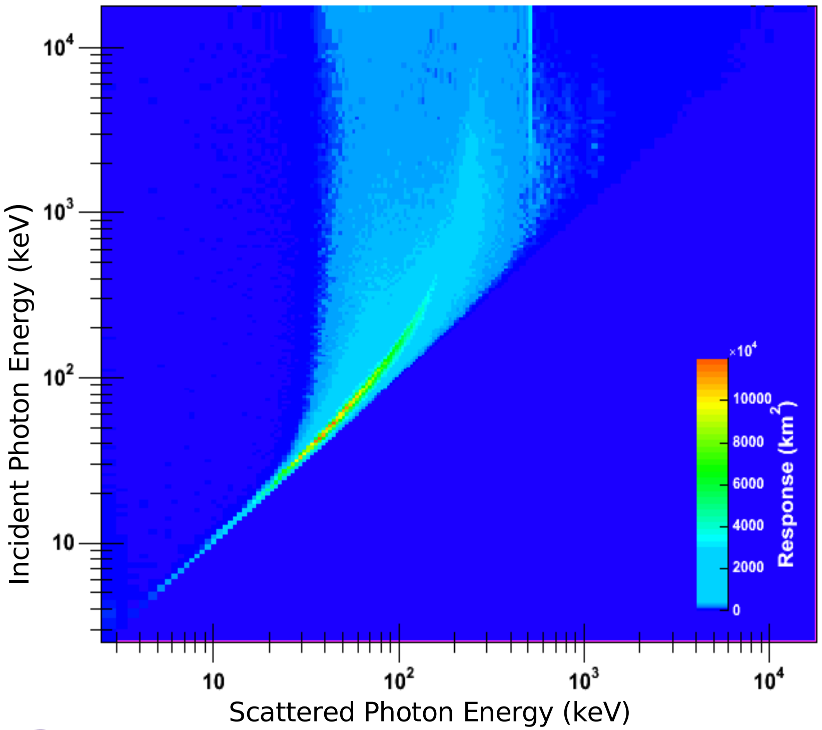


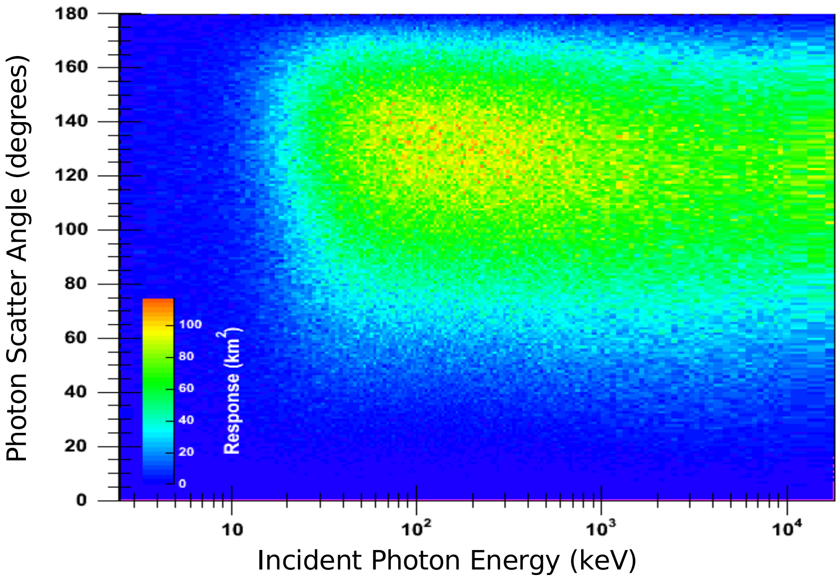
Atmosphere Model (4)

Example (development version)

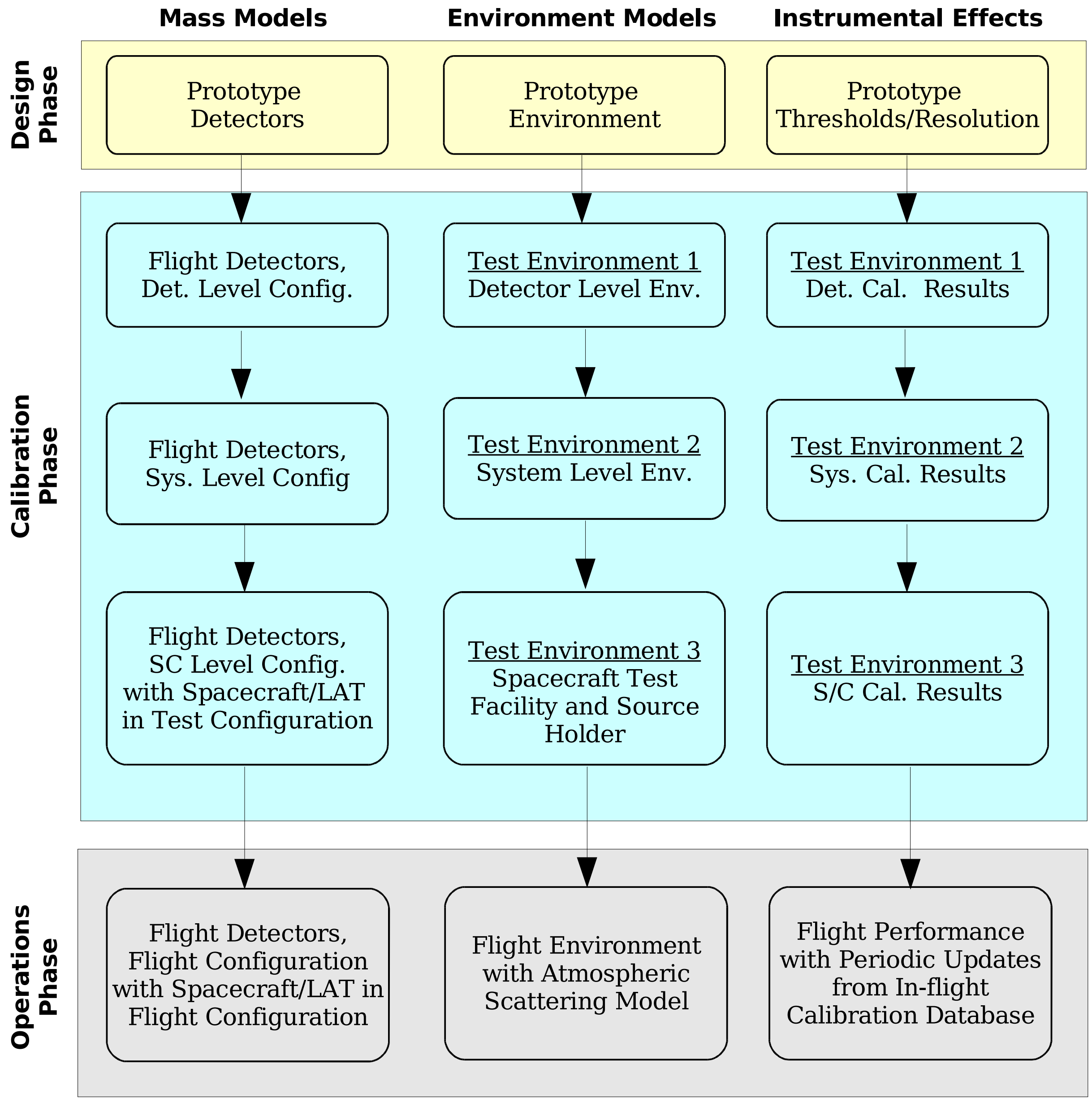
10k events per 158 energies







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

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
- Low-energy Compton scattering – External packages? Penelope? Why not fix G4LowEnergyCompton?
- 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