GRB simulations

Nicola Omodei

INFN Pisa

Data Challenge 2 Close Out Meeting
31-May 2 June 2006, GSFC
LAT and GBM Gamma-Ray Bursts

- Same bursts generation for LAT and GBM detectors
- ASTRO takes care of the position of the burst with respect to the LAT zenith.

XML library

GRB simulator

Fit the GBM spectrum with the Band function

GRB_xxx.DEF
GRB_xxx.PAR
GRB_xxx.lc

GBM simul.sw

GRB_xxx.DEF
GRB_xxx.PAR
GRB_xxx.lc

GBM simul.sw

For each GBM detector

PHA,RSP,BKG

observationSim

Flux

FluxSvc/GLEAM

FT1 Tree

ANALYSIS
The basic idea

- High level simulator.
- The basic idea is to describe the spectrum \((N_{ph}/cm^2/kev/s)\) as a function of the energy (keV) and time (s) (stored in a two dimensional histogram - TH2D)
- SpectObj provides common tools for interfacing the models with the LAT software (via flux)
- SpectObj applies also the EBL attenuation (L.C. Reyes, J.McEnery) to GRB spectra
- GRB physical model: based on the fireball model (colliding shells, shocks dynamics, acceleration of electrons, Synchrotron and Inverse Compton emission)
- GRBobs model: distributions from BATSE observations, spectrum parameterized with the Band model and extrapolated to high energy.
- GRBtemplate reads the spectrum from an ASCII file (easy accommodate different models). (See M. Battelino’s talk)
- Pulsars (Max’s talk)
The DC2 model: the GRB phenomenological simulator

- Original IDL code from Jay Norris
  - Pulse shape: double exponential shape, “pulse paradigm”
    - FWHM, rise time, decay time, “peakedness” (Norris, 96)
  - Pulses combined accordingly with a “bimodal” distribution
    - Interval between pulses and interval between “events of pulses”

\[
I(t, e) = \begin{cases} 
\exp\left[-\frac{|t - t_0|/\sigma_r(e)}{\gamma}\right], & t \leq t_0 \\
\exp\left[-\frac{|t - t_0|/\sigma_d(e)}{\gamma}\right], & t > t_0 
\end{cases}
\]

- Band model spectral shape, $E_p$ drawn from the BATSE catalog
  - Combined with the pulse shape gets a time evolving time

@ INFN Pisa
The GRBobs parameters

1. Starting time of the bursts (from the simulation start)
2. Duration of the burst
3. Fluence (erg/cm^2) (or peak flux) of the GRB between 50 - 300 keV
4. Redshift
5. Low energy spectral index
6. High energy spectral index
7. Minimum photon energy (MeV)
8. GBM flux? (1 or 0)
9. Delayed/extended emission (see later…)
10. Intrinsic cut-off (GeV)

GRBobs_user_library.xml

```xml
<!-- $Header -->
<!--************************************************************************** -->
<source_library title="GRBobs_user_library">
  <source name=" GRB_00000 ">
    <spectrum escale="MeV">
      <SpectrumClass name="GRBobsmanager" params="1000 , 16.79 , 9.22e-06 , 8.442 , -1.183 , -2.33 , 30 , 1 , 0 , 0 , 0 , 0 "/>
      <use_spectrum frame="galaxy"/>
    </spectrum>
  </source>
</source_library>
```
Generating the XML library

• How do we can generate thousands of GRBs in agreement with the observations?

Fluence
Peak Flux

Duration (T90)

alpha, beta

Redshift

$GRBOBSROOT/xml/GenerateXMLLibrary.C

GRBobs_user_library.xml
Input distributions

- It is a ROOT macro that creates a xml library drawing the parameters from the observed distributions.
- The position of the bursts is random in the sky

<table>
<thead>
<tr>
<th>Duration [s]</th>
<th>Fluence_{50,300}[\text{erg/cm}^2]</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1" alt="Histogram" /></td>
<td><img src="image2" alt="Histogram" /></td>
</tr>
</tbody>
</table>

- ![Histogram](image3)  
- ![Histogram](image4)

- SFR (Porciani & Madau '01)
- Binary Mergers (Fryer '99)
GRBobs

- Comparison with the BATSE catalog:
  - Bimodal distribution in duration and fluences for long and short bursts
  - Fluence - Duration correlation
The DC2 Bursts

http://www.slac.stanford.edu/exp/glast/ground/LATSoft/DC2/DC2_grb.html
DC2 bursts sky map

- GBM trigger
- Not GBM trigger
Viewing angles

- GBM trigger
- Not GBM trigger, mainly at > 120° (Earth occultation)
Fluence Distribution

• Human interference?
• There are bursts with high redshift and intense fluence...
Generated Spectral Indexes

Low Energy Spectral Index ($\alpha$)

- Entries: 64
- Mean: -1.019
- RMS: 0.3423

High Energy Spectral Index ($\beta$)

- Entries: 64
- Mean: -2.328
- RMS: 0.3204
How to run your favorite GRBs
Customizing the library

In `GenerateXMLlibrary.xml`:

```c++
// OPTIONS FOR GENERATING THE XML LIBRARY:
double MinExtractedPhotonEnergy = 30.0; //MeV
long FirstBurstTime = 1000; // Starting time of the first burst
double AverageInterval = 48517; // This corresponds to 650 burst/yr
bool GeneratePF = false; // If true: PF is used to normalize Bursts. If false Fluence is used to normalize Bursts.
bool GenerateRedshift = true; // If false all the bursts are at redshift 0: no EL abs
bool GenerateGBM = true; // If false no GBM output file will be generated
bool GLASTCoordinate = false; // If true the burst is fixed with respect to GLAST

• Put a burst in a specified position:
  `<direction theta="10" phi="0" />
  <galactic_dir l="0" b="0"/>

• Fluence or Peak Flux?
  – If f<10^-3 Fluence, else Peak flux

ROOT[0] .L GenerateXMLLibrary.C
ROOT[1] GenerateXMLLibrary(1000)
```

Notice: 2 known issues:
1- Burst fixed in GLAST frame are moving in the sky!
2- Fixing the direction in the xml file->GBM burst is displaced!
Extra component

- Extra component parameterized in the XML file
- Fixed spectral shape (power law) and temporal profile (exponential)
- Simultaneous high energy extra component
- Delayed emission
- Intrinsic cut-off

\[ \alpha \sim -1 \]

GRB prompt emission

GRB delayed emission

\[ \text{GRB 941017} \]

\[ \text{GRB 940217} \]

\[ \alpha \sim -1 \]

(If Nph==0->No delay emission, if Exp c.o. energy==0 -> No exponential cut-off)
Running **`observationSim`**

xml_files.xml:

...  
$(GRBOBSROOT)/xml/GRBobs_user_library.xml *(this add the GRBobs model library)*

`onlyGRBobs.dat`

...

`GRBobs-1000.dat` *(this add the first 1000 GRBs)*

[omodei@pcglast35 rh9_gcc32opt]$ ./gtobssim.exe
File of flux-style source definitions []: `.../xml_files.dat`
File containing list of source names []: `.../onlyGRBobs.dat`
Pointing history file [none]:
Prefix for output files []: `myGRBs`
Simulation time (seconds) <1 - 4e7> []: `500000`
Apply acceptance cone? [no]:
Response functions <DC2|DC1A|G25> []: `DC2`
Random number seed [293049]:

*added source "GRBobs-1000"

*Generating events for a simulation time of 500000 seconds....

**GRB010101011** redshift = 8.442 t start 1000, tend 1016.79 l,b = 86.91936493, -23.31943965 elevation,phi(deg) = -5.113617166, -2.414066821 Fluence = 9.22e-06 erg/cm^2

**SpectObj:** Generated photons : 137 over 1.21 m^2

...
Running *ObsSim*

- From the GUI of ObsSim you can choose to run your preferred GRBs, as well all the GRB library...
- For Gleam: edit the `jobOptions.txt`:
  - `FluxSvc.source_lib  +="$(SKYMODEL_DIR)/GRBobs_user_library.xml"`;
  - `FluxAlg.sources    += "GRBobs-1000"`;
Conclusions

• Gamma-Ray Bursts have been successfully simulated in the DC2 sky
• We tested a model of a point source with a complex temporal profile, broad band spectra, time evolving.
• Simultaneously generated GBM and LAT data.
• Many things are still to analyze… the DC2 is not ended!

• Meanwhile…
  – Improvement of the models (phenomenological and physical)
  – “Tuned” simulation for relevant GRB-GLAST physics
Future development

- GRBobs: maintenance…simulations & simulations…
- GRB physical model (GRB):
  - Attempt to describe GRBs based on theory (internal shocks, synchrotron emission, inverse Compton emission)
  - Relevant for GLAST (we may want to do some simulations…):
    - Inverse Compton component
    - Internal attenuation
      - Synchrotron Cut-off
      - $\gamma\gamma$ absorption
    - Adding the external shock model
    - Study the possible connection between X-ray flashes and GeV emission
      - (A.Galli, F.Longo et al.)
High energy cut-off

• Notice that: $\Gamma \uparrow$, $E_m \downarrow$; $\Gamma \uparrow$, $E_M \uparrow$

Observation of high energy photons is mainly limited by the opacity of two-photons annihilation into an electron positron pair. (Razzaque, Meszaros, Zhang 2004) For relatively moderate $\Gamma$ factors, this turn over should be accessible to GLAST energy range (Baring 2006)

$$E_{\gamma, pk, th} = \frac{m_e^2 c^4 \Gamma_b^2}{2\epsilon_{\gamma, pk}} \approx 26\Gamma_b^{2.5} \epsilon_{\gamma, 2.7}^{-1} \text{ GeV}$$