Observation Simulation with LAT ScienceTools

Jim Chiang
GSSC/UMBC/SLAC

Simulation Tools

- LAT SAS has two sanctioned programs for simulating the gamma-ray sky:
  - **Gleam**: This is the full Monte Carlo simulation and reconstruction code.
  - **gtobssim**: An FTOOL that folds incident photons, drawn from a model of the sky, through the response of the LAT. The instrument response functions (IRFs) are derived from **Gleam** simulations.
- Both programs ingest the same XML source definitions, use the same event scheduler, and read (or calculate) the same orbit and attitude data.
- **gtobssim** processes gamma-rays only, i.e., it does not simulate charged particle backgrounds.

Defining Sources in XML

- **Point sources** that have power-law or broken power-law spectra and steady emission can be defined like this:

```
<source name="Crab Pulsar" flux="0.154">
   <spectrum escale="MeV">
       <particle name="gamma">
           <power_law emin="20" emax="1000000." gamma="2.19"
            ebreak="1500" gamma2="4.89"/>
       </particle>
       <celestial_dir ra="83.57" dec="22.01"/>
   </spectrum>
</source>
```

  The flux is expressed in units of photons $\mathrm{m}^{-2}\,\mathrm{s}^{-1}$ and covers the energy range (`emin`, `emax`).

- **Diffuse sources** can be modeled using a FITS image as a template (These images need not cover the whole sky.) There are two ways to do this:
  1. **MapSource**: A 2D image gives the distribution on the sky and a power-law is used to model the spectrum at all sky locations.

```
<source name="EGRET_diffuse_model">
   <spectrum escale="MeV">
<!-- Total photon flux from the map (#/m^2/s) = 26.56.
     Photon spectral index = 2.1
     Fits file (plate-carree only) = gas_gal.fits
     Minimum photon energy (MeV) = 20.
     Maximum photon energy (MeV) = 2e5
-->
      <SpectrumClass name="MapSource"
       params="26.56,2.1,gas_gal.fits,20.,2e5"/>
      <use_spectrum frame="galaxy"/>
   </spectrum>
</source>
```

2. **MapCube**: For full generality, a 3D cube, pixellated in sky location and energy, can be used to model arbitrary spectral variation across the image.

```
<source name="map_cube_example">
   <spectrum escale="MeV">
<!-- Total photon flux from the map (#/m^2/s) = 1.
     Fits file (plate-carree only) = map_cube_example.fits
-->
      <SpectrumClass name="MapCube"
       params="flux=1.,fitsFile=map_cube_example.fits"/>
      <use_spectrum frame="galaxy"/>
   </spectrum>
</source>
```

   The FITS file must contain a binary table extension listing the energies of each image plane.

Astrophysics-motivated Sources

- Pulsars (Razzano, Harding)
- GRBs (Omodei, Norris, et al.)
  http://glast.pi.infn.it/Nicola/GRB.html
- Dark Matter (Baltz, Wai, Wang; uses **MapCube**)

Some simpler, more generic sources

GaussianSource Incident photons are distributed as a 2D Gaussian projected on the sky. Power-law (PL) spectrum.

Isotropic Photons are generated uniformly on the sky (PL).

PeriodicSource A point source with a sinusoidal light curve. (PL)

Pulsar A pulsar whose light curve is given by an ascii template file. Includes period and pdot, but not barycenter correction effects. (PL)

SimpleTransient A point source with a single active interval during which it has a constant flux. (PL)

TransientTemplate A point source transient whose active state light curve is given by an ascii template file. (PL)

SpectralTransient A point source whose light curve and spectral variation as a function of time are specified as columns in at template file (ascii or FITS). Motivated by blazar modeling.

http://glast-ground.slac.stanford.edu/workbook/science-tools/pages/sciTools_observationSimTutorial/obsSim_Sources.htm

SpectralTransient source

- Either an ascii or FITS binary table can be used to specify flux and spectrum as a function of time in a series of discrete intervals.
- Example input file:

```
# @file testTemplate.dat
# The columns are
# tstart tstop  flux gamma1 gamma2 ebreak/MeV
  0.     0.3     50.   1.7   2.5    300.
  0.5    0.8    100.   1.5   2.2    1000.
  0.8    1.0     10.   2.1   2.1    1000.
```

- For ascii format, the intervals need not be the same length or even contiguous, but they must be time-ordered. For FITS format, the intervals must be contiguous, and `tstop` times are not used.
- The light curve will be scaled and mean flux will be scaled according to the XML specification.
- A "log-parabolic" spectrum can be used: $dN/dEdAdt = K(E/E_b)^{-\alpha+\beta\log(E/E_b)}$

- An example XML entry:

```
   <source name="spectral_transient">
      <spectrum escale="MeV">
<!-- mean flux = 0.1 (#/m^2/s)
     start time = 0 (MET s)
     stop time = 1e4 (MET s)
     template file name = testTemplate.dat
     emin = 20 (MeV, this is the default)
     emax = 2e5 (MeV, default)
     lc # (in FITS file) = 0 (default)
     z (redshift) = 0 (default) -->
          <SpectrumClass name="SpectralTransient"
          params="1e-1, 0., 1e4, testTemplate.dat,
                  20,2e5,0,0"/>
          <celestial_dir ra="193.4" dec="-5.82"/>
      </spectrum>
   </source>
```

Running the observation simulator

An example session:

```
salathe[jchiang] gtobssim
File of flux-style source definitions [xmlFiles.dat] :
File containing list of source names [source_names.dat] :
Pointing history file [none] :
Prefix for output files [test] :
Simulation time (seconds) <1 - 4e7> [86400] :
Apply acceptance cone? [no] :
Response functions <DC1|DC1A|G25|TEST> [TEST] :
Random number seed [628701] :
added source "Galactic_diffuse"
added source "Extragalactic_diffuse"
added source "Crab_Pulsar"
Generating events for a simulation time of 86400 seconds....
Done.
salathe[jchiang]
```

- The first two prompts are for input files used in the source definitions. For this example,

```
salathe[jchiang] cat xmlFiles.dat
/home/jchiang/ST/observationSim/v5r8p3/xml/3EG_catalog_20-1e6MeV.xml
/home/jchiang/ST/observationSim/v5r8p3/xml/obsSim_source_library.xml
/home/jchiang/ST/celestialSources/GRB/v4r1p9/xml/GRB_user_library.xml
salathe[jchiang]
```

  This file contains a list of XML files containing libraries of sources. This file is optional, and here the default XML files are given, so that if `none` were entered at prompt sources contained in these XML files would still be available. Custom libraries can be appended to this list.

- The list of sources to be simulated are communicated via an ascii file:

```
salathe[jchiang] cat source_names.dat
Galactic_diffuse
Extragalactic_diffuse
Crab_Pulsar
salathe[jchiang]
```

  Providing this file is obligatory. Lines beginning with "#" are treated as comments.

- Two kinds of output files are produced:
  - Event files: `<prefix>_events_xxxx.fits`
  - Spacecraft orbit and attitude files: `<prefix>_scData_xxxx.fits`

  The data are contained in FITS binary tables. The format is described at
  http://glast.gsfc.nasa.gov/ssc/dev/fits_def/definitionFT1.html
  http://glast.gsfc.nasa.gov/ssc/dev/fits_def/definitionFT2.html

- Workbook Documentation:
  http://glast-ground.slac.stanford.edu/workbook/science-tools/sciTools_Home.htm
- A GUI to drive **gtobssim** is available:
  http://confluence.slac.stanford.edu/display/ST/obsSim+GUI

EBL Attenuation

- Thanks to Julie McEnery, Liz Hays, and **Luis Reyes**, we have a variety of extragalactic background light attenuation models from which to choose:
  1. **Salamon & Stecker** (1998 ApJ 493, 547)
  2. **Primack & Bullock** (1999)
  3. **Kneiske et al.** (2004, A&A 413, 807)
  4. de Jager & Stecker (2002, ApJ, 566, 738), "baseline"; valid for $z < 0.3$, $E > 50\,\mathrm{GeV}$
  5. de Jager & Stecker (2002), "fast evolution"; valid for $z < 0.3$, $E > 50\,\mathrm{GeV}$
  6. Bullock (1999, PhD Thesis); Sommerville & Primack (1999, MNRAS, 310, 1087), $E > 100\,\mathrm{GeV}$
  7. BS&P (2004) LCDM update; $E > 100\,\mathrm{GeV}$
- Redshift is specified in **SpectralTransient** XML entry.
- Interface to select the desired model is not yet implemented — Kneiske et al. (2004) is used for now.