Exposure Calculations for EGRET and GLAST

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Introduction

Accurate calculation of exposure is essential for obtaining calibrated fluxes and intensities. The method used to calculate exposures for EGRET is described, along with some likely differences between GLAST and EGRET approaches. The principal differences between EGRET and GLAST for exposure calculations are the observing modes (pointed for EGRET vs. scanning for GLAST), the time-of-flight trigger system in EGRET, and the map-based likelihood analysis that is standard for EGRET analysis. For GLAST, a flexible, rapid method for generating exposure is desirable. A proposed implementation is described.

EGRET

For EGRET, exposures are calculated by the program INTMAP using "exposure history" files as input. Exposure history files are timelines for each viewing period, with an entry every time EGRET changed its triggering telescope mode. The time-of-flight triggering system in EGRET has an upper section and a lower section, each a 4×4 plane of scintillator tiles. From the combination of the upper and lower tiles hit, EGRET had a crude idea of the direction of an event before it even triggered a readout. In order to reduce deadtime (and increase the spark chamber gas lifetime), EGRET constantly updated the "allowed" combinations of upper and lower tiles for triggering. Modes that contained the Earth's limb, or the earth itself, were disabled. The effective area depended on which modes are enabled.

Typically, exposure history files for EGRET contain one entry for every three or four minutes, although when EGRET was occulted by the earth, the entries span more than 20 minutes. The entries include spacecraft position and orientation, time, livetime, viewing direction, and trigger mode. (EGRET was inertially pointed, so the orientations varied very little between entries.) Part of the exposure history file for viewing period 14.0 is shown in Table 1 (ExposureTable.doc). Exposure history files are ~ 200 kbyte for a typical ~ 2-week viewing period.

EGRET (cont'd)

Exposure maps for EGRET are generally constructed for entire viewing periods by integrating the projection of the (effective area)×(live time) product on the sky, interpolating between entries in the exposure history file. INTMAP allows the user to specify the inclination angle limits for the map; because EGRET observations are pointed, inclination angle limits correspond to limits on the region of the sky in the exposure map.

Note also that exposure maps calculated by INTMAP are for user-specified energy ranges, generally the (10) ranges used for the standard EGRET analysis. Because the effective area depends on energy, in order to calculate the exposure for a given energy range, an input spectrum must be assumed ***and is thus implicit in the exposure calculations***.

References

Bertsch, D. L., et al. 1989, Proc. Gamma-Ray Observatory Science Workshop, ed. W. N. Johnson (Greenbelt: NASA), 2-52 (trigger modes, data system)

Thompson, D. J., et al. 1993, ApJS, 86, 629 (calibration)

GLAST

For analysis of GLAST data, especially for unbinned likelihood analysis, the ***explicit dependence of the exposure on energy and inclination angle*** (from simulations and calibrations) will be needed (rather than the averages over energy bands and integrals over inclination angle ranges that sufficed for EGRET).

Also, GLAST will be operated in scanning mode, covering a large swath of the sky in every ~ 90-minute orbit, and the data will constantly be searched for flaring sources on short-time intervals. For these reasons, a method to generate exposure maps on-the-fly, without an implicit source spectrum, is desirable.

Most of the work for the calculation of the exposure is in projecting the effective-area arrays on the sky. This is true for EGRET as well as GLAST. The problem can be reduced to interpolations in a lookup table, however, if a rather large database of exposure information is maintained. The exposure database would have two components:

1. A time-ordered list of livetime for fixed time intervals (say 30 s), as well as some kind of status word to indicate the instrument operation mode. A 30-s time interval corresponds to approximately a 2-degree advance of GLAST in its scanning orbit.

2. A spatially-addressable database that for each ~ 2×2 square degree patch of the sky stores the angle and azimuth from the instrument pointing direction for each of the same time intervals. The zenith angle is also stored.

(The patches of sky may be defined using the same indexing scheme that will be used to subdivide the sky for the photon database, by selecting an index deep enough so that the regions of the sky are ~ 4 square degrees in size. The actual photon database may need finer spatial subdivisions for some regions of the sky, but meaningful exposure differences would not exist below this angular scale.)

Using the two components of the database, and a tabulation of the effective area as a function of azimuth, inclination, and energy, the exposure can be calculated quickly for any time interval, region of the sky, energy range, zenith angle range, or event type (e.g., front section vs. back section of GLAST). Here the exposure should be considered a function of energy, direction on the sky, and inclination angle and azimuth, rather than just a 2-dimensional map:

Effective_area_table ({Az & θ} wrt s/c, Energy, Event_type) +
Database (T_interval, LAT_mode, sky region, {Az & θ} wrt s/c, _ zenith angle)
⇒ Exposure (Energy, RA, Dec, Event_type)

An exposure matrix would be generated in this way:
1. For the specified range of time, the livetimes are retrieved.

2. For each spatial cell within the specified region of the sky, inclination angles and azimuths for the same time range are extracted and combined with the livetimes to define an array of observation time as a function of inclination angle and azimuth. This array is multiplied by the effective area array (a function of inclination angle, azimuth, and energy) to define the exposure in each cell.

3. The exposure arrays for each cell are then reprojected into a user-specified coordinate system and grid to make the exposure matrix for input to other analyses.

The same approach could have been usefully applied to EGRET, although the large database, estimated at 40 Gbyte/year* for GLAST, would have been difficult to manage. Also, because EGRET observations were pointed, rather than scanning, and the analysis was based on individual pointings, the EGRET data have natural divisions into viewing periods.

*Estimate of size of GLAST Exposure Database: 10^4 bins on the sky, 10^6 time intervals, and 4 bytes for each entry. The time-ordered list of livetimes and instrument modes for each 30-s time interval will require ~ 5 bytes per time interval, ~ 5 Mbyte/year. For each time step and grid point on the sky, store inclination angle, azimuth, and zenith angle. 1° resolution is adequate. Store all 3 bytes per grid point and time interval. Allow 1 extra byte per cell. Bottom line: for 2×2 degree cells we will need ~ 40 Gbyte/year.