Software for use with Fermi Gamma-ray Burst Monitor (GBM)
Time-Tagged Event Data
with a focus on Terrestrial Gamma-ray Flash (TGF) Analysis

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1 Introduction

Nine programs are provided to display and output Fermi GBM Time-Tagged Event (TTE) data, and also to output the position of Fermi and to perform time conversions. These routines read the GBM FITS data files that are available from the Fermi Science Support Center (FSSC) (`http://fermi.gsfc.nasa.gov/ssc/data/access/gbm/`). The GBM data files use the FITS (Flexible Image Transfer Standard) format for portability and longevity, instead of having the files tied to a particular computer architecture. The software in this package processes TTE data of both triggered TGFs and TGFs contained in continuous (daily) TTE files. The software may also be used as building blocks for your own tools, or to learn about the GBM data so that you can write software "from scratch". This set of tools is written in Fortran and C. We also provide a set of tools in Python.

The programs in this package are:

1. `TTE_Histo_MultiGraphs` plots separate histograms of the data of all 14 GBM detectors.
2. `TTE_Histo_OneGraph` plots a histogram of one or the sum of any number of the detectors.
3. `TTE_ScatterPlot` makes a scatter plot of counts from one or more of the detectors.
4. `TTE_ScatterPlot.GAP` makes a scatter plot that is used to analyze the drift of the GBM clock. This is only necessary if you need timing accuracy of better than a few microseconds.
5. `TTE_Output_CSV` and `TTE_Output_CSV.Merged` output CSV (comma-separated value) files listing TTE events. You can use these to convert the FITS data to CSV text format, so that you can manually inspect the data, or to use CSV files as input to your own software.
6. `MET_to_UTC` converts GBM time to UTC.
7. `Time_to_MET` converts UTC to GBM time.
8. `SC_GeoCoord` outputs the position of the Fermi spacecraft in WGS84 geographic coordinates.

The actual reading of the TTE data is done by `Read_Lvl1_TTE.c`. Most of the routines for the time conversions and position calculations are in `Time_and_Coord_Routines.F90`.

For software or scientific questions or comments, please contact Michael.Briggs@uah.edu.

2 Installation

The software has only been tested with Unix-like operating systems, Linux and Mac OS X.

Untar the distribution file GBM_TTE_TGF_SW.v1.tar. The files are in a main directory `GBM_TTE_TGF_SW` and two subdirectories, `Time_Coord_Utilities` and `TTE_Level1`.

You will need C and Fortran compilers. The programs have been tested with gcc/gfortran. The programs will compile with versions of gcc/gfortran from 4.5 to 5.3. Earlier versions of those compilers are not suitable.

You will also need the cfitsio and dislin libraries. Cfitsio is used to read the FITSIO. Dislin is used for plotting and can be omitted if you don't wish to use the plotting programs.

Cfitsio may be obtained from
`http://heasarc.gsfc.nasa.gov/fitsio/fitsio.html`. Or, in many cases the package manager for your OS will install it for you. For example, you can install it on Macs via package cfitsio of MacPorts.

Dislin requires that you have OpenMotif installed. You can probably install OpenMotif with the package manager of your operating system (e.g., MacPorts package openmotif). Dislin (`http://www.mps.mpg.de/dislin`) can be downloaded from `http://www.mps.mpg.de/dislin/distributions`. For a Mac, you most likely want the file dislin-10.6.darwin.intel.64.tar.gz (or a more recent version). For Linux, most likely you will want the i586_64 distribution, which corresponds to OpenMotif 2.3 / libXm.so.4. Our experience is that most problems with dislin are caused by a mismatch between the dislin version and OpenMotif. There are two versions of OpenMotif with different APIs. If you are having problems with dislin, try: 1) installing a different version of dislin, 2) checking the installed version of OpenMotif, or 3) install a different version of OpenMotif.

You will need to edit the file `DefineCommands.sh` so that the symbols at the top of the file point to the locations of cfitsio, dislin and OpenMotif, and two symbols define the command names for the C and Fortran on your computer. There are directions in the file.

In subdirectories Time_Coord_Utilities and TTE_Level1 compile and link the programs you wish to use via:
`./Make.____.sh`.
These bash command files, one for each program, use the symbols defined in `DefineCommands.sh` to compile and link the programs.

To run the programs, you also need to define two environment variables:
`export PATH_OF_TIME_FILES=your-directory1`

and
`export PATH_OF_SC_POSHIST_FILES=your-directory2`.
The files that should be in these directories are described in the next section.

3 Data Files

The TTE data files are available from the Fermi Science Support Center (`http://fermi.gsfc.nasa.gov/ssc/data/access/gbm/`), either continuous or trigger TTE. Early in the GBM mission, TGFs were only found by triggering. Later, we implemented an offline search of the new Continuous Time Tagged Event (CTTE) datatype and found weaker and shorter TGFs. The GBM TGF catalog lists, for each TGFs, the corresponding data file. Trigger TTE files begin with "bn" for "Burst Number"; continuous/daily files with "glg". There are several ways to download these files from the the FSSC. Knowing the file name, a convenient method is to use the ftp access, via anonymous ftp logon to `heasarc.gsfc.nasa.gov`, or using a browser with URL `http://heasarc.gsfc.nasa.gov/FTP/fermi/data/gbm/triggers/` for trigger data, or URL `http://heasarc.gsfc.nasa.gov/FTP/fermi/data/gbm/daily/` for continuous / daily data. The trigger data is organized by year, then Burst Number. The daily data is organized by year, month, and day.

If you wish to calculate the spacecraft position, you will need the spacecraft position history file for that day, e.g., `glg_poshist_all_160105_v00.fit` for 2016 Jan 5. These files are available with the continuous / daily data as described in the preceding paragraph. These files should be placed into directory pointed to by the environment variable `PATH_OF_SC_POSHIST_FILES`.

For time conversions, several types of files are necessary. You can start with the files in subdirectory `TimeFiles` – point the environment variable `PATH_OF_TIME_FILES` to that directory.

File `MET_of_LeapSeconds.txt` is necessary to correct leap seconds in the conversions between GBM Mission Elapsed Time (MET) and Universal Time UTC. The version in this distribution has corrections for leap seconds up to the leap second on 2015 June 30. **WARNING**: the file `MET_of_LeapSeconds.txt` must be revised when the next leap second occurs. If that is not done, time conversions after the date of that leap second will be wrong. The date of the next leap second has not been announced.

The Bulletin A and B files are used for the highest accuracy in calculating longitude. This accuracy is not necessary for most purposes. They correct for the slowing rotation of the Earth using the difference between the time systems UTC and UT1. A set of Bulletin files is provided in subdirectory `TimeFiles`. You can obtain additional files, as they becomes available, from the Earth Rotation Service (`http://www.iers.org/IERS/EN/DataProducts/EarthOrientationData/eop.html`). Added files need to follow the name convention of the files already in the `TimeFiles` subdirectory so that the programs can find them.

4 Usage

In directory TTE_Level1:

1. `TTE_Histo_MultiGraphs`
2. `TTE_Histo_OneGraph`
3. `TTE_ScatterPlot`
4. `TTE_Output_CSV`
5. `TTE_Output_CSV.Merged`
6. `TTE_ScatterPlot.GAP`

Each of these programs is invoked by:
`./ProgramName.exe DataFileName`
where `DataFileName` is the name of the TTE data file for the BGO 0 detector, which can be either triggered or continuous (daily) TTE. This file has "_b0_" in the name. The programs will automatically read the data files of the other detectors. They will prompt for input from the terminal.

The first three programs produce plots of the data. `TTE_Histo_MultiGraphs` produces fourteen histograms, one for each of the GBM detectors. `TTE_Histo_OneGraph` produces a single histogram, summing any selection of the detectors. `TTE_ScatterPlot` creates a scatter plot of individual Time-Tagged Events from one or more of the detectors.

The second two programs produce CSV files, which can be used to manually inspect the data, or to provide it to other programs. `TTE_Output_CSV` outputs a separate file for each GBM detector, while `TTE_Output_CSV.Merged` merges the data into a single time-ordered file. Both programs also output separate text files with the energy values of the energy channels. Descriptions of the quantities output are included at the top of each output file.

`TTE_ScatterPlot.GAP` is a special purpose program, which analyzes the performance of the GBM clock. The GBM clock is normally slow by $\sim 15\mu$s per s, but is corrected to GPS accuracy once per second at the times of whole seconds. This causes an apparent jump forward in time. This program plots the TTE data modulo one second in order display this jump so that the clock drift rate applicable to the data file can be determined. Some of the other programs can correct time values using the clock drift value determined by this program. This is only necessary if you need accuracy of better than tens of microseconds.

In directory `Time_Coord_Utilities`:

`MET_to_UTC`: The input is GBM Mission Elapsed Time (MET), which is a count of seconds since 00:00:00 on 2001 January 1. The output is UTC date and time. For example:
`./MET_to_UTC.exe 263649437.985436`
outputs the UTC date/time of 2009-05-10 11:57:15.985436.

`Time_to_MET`: This program will prompt for input of date and time, then calculate the equivalent GBM MET.

SC_GeoCoord: This program will calculate the position of Fermi at specified time. The GBM spacecraft position history file for that day must be located in the directory pointed to by environment variable PATH_OF_SC_POSHIST_FILES. For example:

```
./SC_GeoCoord.exe 263649437.985436
```

provides WGS84 longitude and latitude of 24.0762 and -5.2839 degrees and WGS84 altitude of 556.39 km for the position of Fermi using position history file glg_poshist_all_090510_v00.fit. The TGF sources may be as much as ∼800 km from the nadir of the spacecraft.

Alternatively, to process multiple times:

```
./SC_GeoCoord.exe FileName
```

where the file lists one MET value per line. The program will output the results to the file Fermi_positions.txt.

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