

Fermi GBM Orbital Background Subtraction Tool

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1 Introduction

The Fermi Gamma-ray Burst Monitor (GBM) has 14 scintillation detectors that view the entire unocculted sky. This provides the ability to detect GRBs and other transients wherever they may occur, but causes a high background level. The typical technique used to estimate the background for a GBM source interval is to select background intervals to either side of the source interval and interpolate with a polynomial. This generally works well for source intervals of a few hundred seconds duration or less, and sometimes up to $\sim 1\text{k}$ seconds, but becomes progressively less satisfactory for longer intervals. One alternative technique is to obtain background spectra from orbits on preceding and following days when the spacecraft was at a similar geomagnetic position in its orbit. This method was successfully used for a similar wide-FoV instrument, BATSE on the Compton Observatory (Connaughton, et al. 2002). Fitzpatrick et al. (2012) describe the science of the orbital background subtraction method and tests of how well it works for Fermi GBM data.

In its normal Sky-Survey mode Fermi reaches approximately the same orbital position at ± 24 hours or ± 15 orbits, however, because Fermi normally rocks its viewing direction in Sky-Survey mode, the spacecraft orientation at these times will not match that of the source interval. Alternatives are to use data from ± 30 orbits, or from ± 14 and ± 16 orbits. It is generally better to use a symmetrical pair or pairs of orbits to cancel out precession effects. The GBM data for a particular orbit might have extra flux from high solar or magnetospheric activity and therefore be unusable for the orbital background technique. An additional complication occurs for bright GRBs that cause an Autonomous Repoint Request. The consequent change in pointing direction does not occur in the matching orbits. These issues are discussed in more detail in Fitzpatrick et al. (2012).

While still uncommon, since 2012 the number of Fermi Target of Opportunity (ToO) observations with inertial pointings towards fixed sky directions has increased. If the source and background data for the orbital background method occur during the inertial pointing, the method can be used. In this case, offset regions of ± 15 could be used. Conversely, if the ToO caused some of the spacecraft orientations to differ, the method will

be less useful. Since December 2013, probably to be continued for one year, the Sky-Survey mode has been modified with inertial pointings to give enhanced exposure towards the Galactic Center, as described as Option 4 at http://fermi.gsfc.nasa.gov/ssc/proposals/alt_obs/obs_modes.html. We have not tested the Orbital Background Technique with data collected during this alternative observing strategy.

The tool has two primary windows, an Options Window that is used to input choices about the data to be analyzed and a Results Window that displays time histories and spectra of the source and background. The Results Window has buttons for additional analysis steps described below, including the export of background files that can be used with spectral analysis packages such as *rmfit* and *XSPEC*.

The main code is contained in *orbsub.py*. *osv.py* is the gui interface to this code. *osv* incorporates portions of the GBM occultation code in order to calculate times of source visibility (Wilson-Hodge et al., 2012).

2 Installation and Uninstalling

Dependencies: *osv* is written in Python and has the following dependencies:

- Python (version 2.7 recommended)
- argparse python module (included in python versions ≥ 2.7)
- matplotlib python module
- numpy python module
- pyfits python module
- wxPython (wxWidgets) python module

Note: for the Mac, if you are using MacPorts, the modules are available as ports `py27-matplotlib`, `py27-numpy`, `py27-pyfits` and `py27-wxpython-3.0`.

If you do not have sudo privileges, the dependencies can be installed locally. Simply pick a folder, install them there, then point the environment variable `PYTHONPATH` to that location. For example (assuming you are using bash), if they are installed in `~/pythonDeps`, then you put `export PYTHONPATH=$PYTHONPATH:~/pythonDeps` in your `.bashrc`.

Installation:

1. Untar the *osv* folder (perhaps *osv_v1.1*)
2. To run the programme, type `python PATH_TO_OSV_FOLDER/osv.py` in a terminal. If this is your first time running the programme you may want to run the configure script. To do so, type `python PATH_TO_OSV_FOLDER/osv.py doConfig`. This will

request you to enter the default values for things such as time intervals, data folders and data type. All of these values can be reset at run time.

3. If you want to reset these values at a later point, type `python PATH_TO_OSV_FOLDER/osv.py doConfig`

Uninstallation:

- To uninstall; simply remove the source folder

3 Usage

Enter `python PATH_TO_OSV_FOLDER/osv.py` to start the Orbital Background Subtraction Tool. The Options Window (Figure 1) allows you to select the data to analyze and other options. After you have made your selections, click “OK”, and the tool will perform its calculations and then display the main Results Window (Figure 2).

In the Options Window you must enter a value for `tZero` – this defines the base time of the source interval and should be in GBM MET (Mission Elapsed Time). You should also enter a range about `tZero`. This defines the time interval of data for which the background will be calculated and output.

The Options Window will allow you to specify a directory for the data. The data files should be arranged in subdirectories of this directory, with the subdirectories named by date: `yymmdd`. Each subdirectory should contain the GBM **daily** FITS files for the datatype (either CTIME or CSPEC) and detectors you wish to process, along with the GBM Spacecraft Position History file, `glg_poshist_all_yymmdd_v00.fit`. Several days will be necessary in order to have the data of your source interval and the offset background intervals. If the necessary data is missing, `osv` will offer to generate a bash script that will download the data from the Fermi Science Support Center. This script will be saved in the current working directory and can be run by typing `source osv_dl_script.sh` at the command line.

Under “Data Options”, select either CSPEC or CTIME, then click “Detector Selection” to select which detectors you wish to analyze. Under “Background regions”, enter the “orbits offset”, normally either “30” or “14 16”. These values automatically imply pre- and post-orbits (i.e, \pm).

Providing the coordinates of the source, RA & Declination (in decimal degrees), is optional. If provided, the tool will be able to calculate the angular separations between the detector normals and the source direction as a function of time, and also the separation between the Fermi Z-axis (or LAT boresight) and source direction as a function of time. These plots are selected from the “Plot” button of the Results Window, as options “Plot Detector Angles” and “Plot S/C Pointing”.

Under “Misc Options”, you can specify the *Output File Stem*. This is the string that will be prefixed to the names of any output files. This is also an optional parameter.

Table 1: Keyboard bindings

Key Command	Action
CTRL-d	dismiss – exits the programme
CTRL-l	View the log
CTRL-z	back detector
CTRL-x	forward detector
CTRL-w	plot pointing
CTRL-q	plot detector angles
CTRL-v	select intervals
CTRL-s	save lookups (all detectors)
CTRL-a	load lookups (all detectors)

After you have made your selections, click “OK”, the tool will perform its calculations, then after a delay, the Results Window ([Figure 2](#)) will appear displaying the source data overlaid with the calculated background. Both a time history and spectrum are displayed. The source data is plotted as a green histogram, the background with red. The negative and positive components of the background can be compared by clicking “Plot backgrounds separately” in the “Plot” Menu. If the source coordinates were passed, then some time intervals will be color-coded. A green fill indicates intervals for which the source-detector angle is $< 60^\circ$, 90° for NaI and BGO respectively. A red fill indicates times when the source is occulted by the Earth.

You can cycle through detectors with CTRL-z and CTRL-x: the available keyboard bindings are listed in [Table 1](#). On a Mac, use Command instead of Ctrl. Similarly to *rmfit*, sub selections of data can be made. Click on “Select”, then “select” in the sub-menu. You can make selections on both the lightcurve and spectral plots. Once you are done, click outside the axes of the plot to disable selections and cause the tool to update the other plot based on the selection. For example, if you select a smaller time interval, the spectrum plot will update to display the spectra for that interval. “Select”, “Clear” will restore the previous selections. The current selections can be saved to a file by clicking “Save Selections” in the “Select” menu. These selections can later be reloaded by clicking “Load Selections” in the “Select” menu.

The Export button allows you to export PHA, PHAII and also text (ASCII) lightcurves. The PHA and PHAII background files can be used with other analysis tools such as *rmfit* and *XSPEC*. When exporting PHA files, any selections that have been made are applied.

Advanced Usage In addition to the GUI interface, the results window can be launched directly from the command line. The full list of command line options can be seen by typing `python PATH_TO_OSV_FOLDER/osv.py -h` at the command line. As an example, to get the CSPEC background for detectors n5 and b0 at a tzero of 297996962, you would type `osv 297996962 --CSPEC --dets 5 12 .`

The programme also provides a means of downloading daily data from the *Fermi* ftp

server. To use this, type `python PATH_TO_OSV_FOLDER/osv.py getData date`, where **date** is the date in YYMMDD format. As an example, to download the position history file, and cspec data for detectors n5 and b0 for a give date, you would type `python PATH_TO_OSV_FOLDER/osv.py getData --poshist --cspec --dets 5 12 YYMMDD`.

3.1 Using the exported files

RMFIT `rmfit` supports PHA background files from that contain a single spectrum. By selecting the “Export”, “PHA” option, `osv` will output a `.PHA1` and a `.BAK1` file. Load both files into `rmfit`. Make the window for the `.PHA1` file the active window and select “Options”, “Import Background”. From the menu that appears, select the `.BAK1` file and click “Accept”.

XSPEC To load a PHA file “example_file.PHA1” and the corresponding background file “example_file.BAK1” into `xspec` type:

```
XSPEC12>data example_file.PHA1
XSPEC12>data example_file.BAK1
```

To load the first, and tenth through twentieth time bins of a PHAII file (“example_file.PHA”) and the corresponding background spectra “example_file.BAK” into `xspec` type:

```
XSPEC12>data example_file.PHA{1,10-20}
XSPEC12>backgrnd example_file.BAK1{1,10-20}
```

The following will load all spectra from the PHAII file:

```
XSPEC12>data example_file.PHA{*}
XSPEC12>backgrnd example_file.BAK1{*}
```

For each spectrum added, `xspec` should display information on the data, such as: file name, net count rate, number of energy channels and channel type, telescope and instrument names, exposure time. It will load automatically the response file if it is defined in the PHA/PHAII file header and available in the working directory, otherwise you will need to specify the path to the response file:

```
XSPEC12>response example_file.RSP1
```

To load an RSPII file you will also specify the time bin(s) of interest:

```
XSPEC12>response example_file.RSP{1,10-20}
```

4 Example

Along with the distribution of *osv* we include a separate file *osv_example.tar* that contains the files needed to work the example described here. (The example file is provided separately because of its size, 43 MB.) The directory *osv_example* has subdirectories 100610, 100612 and 100612 with the Spacecraft Position History files and NaI 5 CSPEC data for those days. The example is the M2 class solar flare of 2010 June 2. The Fermi observations are described in [Ackerman et al. \(2012\)](#). In this example we analyze the data of GBM detector NaI 5, as shown on the corrected time-history figure http://iopscience.iop.org/0004-637X/748/2/151/pdf/0004-637X_748_2_151.pdf.

Untar *examples.tar* and cd to directory *osv_example.tar*, then enter *osv* to start the background tool. The peak of the flare is at $\approx 00:56:00$ UT, which is GBM MET 297996962. Based on the figure cited in the previous paragraph, we select the time interval -100 to 500 s for analysis. The location of the Sun at this time is RA= 80.03° and Dec= 23.12° . Click on “Detector Selection” and select only NaI 5. These choices are shown in [Figure 1](#). Finally, click “OK”.

The Results Window appears ([Figure 2](#)). The green-shaded interval shows that the angle between the detector normal and the Sun was $<60^\circ$ for the entire requested interval. You can confirm this pointing history if you click “Plot”, then “Plot Detector Angles”. No intervals are shaded red showing that the Sun is visible throughout the entire time plotted. If you repeat the example using MET 297998210, you will see that the source flux decreases at $T_0 = 0$ due to orbital night. Times larger than $T_0 = 0$ are shaded tan, the combination of green for an acceptable detector angle and red for the source being occulted.

5 References

“*Fermi Detection of γ -ray Emission from the M2 Soft X-Ray Flare on 2010 June 12*”, M. Ackermann, M. Ajello, A. Allafort, et al., (2012), *ApJ*, **745**, 144, doi:10.1088/0004-637X/745/2/144, <http://arxiv.org/abs/1111.7026> or <http://iopscience.iop.org/0004-637X/745/2/144/> and erratum at http://iopscience.iop.org/0004-637X/748/2/151/pdf/0004-637X_748_2_151.pdf.

“*BATSE Observations of Gamma-Ray Burst Tails*” V. Connaughton, (2002), *ApJ*, **567**, 1028, doi:10.1086/338695, <http://iopscience.iop.org/0004-637X/567/2/1028>.

“*Background estimation in a wide-Field background-limited instrument such as Fermi GBM*”, G. Fitzpatrick, S. McBreen, V. Connaughton, & M. Briggs on behalf of the GBM collaboration, (2012), <http://arxiv.org/abs/1210.5369>.

“*Three Years of Fermi GBM Earth Occultation Monitoring: Observations of Hard X-Ray/Soft Gamma-Ray Sources*”, C. Wilson-Hodge, et al., *ApJS*, **201**, 33, doi:10.1088/0067-0049/201/2/33, <http://arxiv.org/abs/1201.3585> or <http://iopscience.iop.org/0067-0049/201/2/33/>.

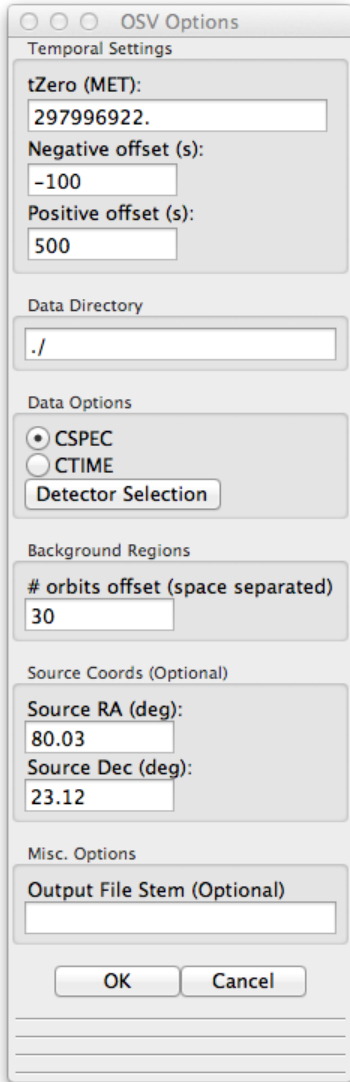


Figure 1: The first window of *osv*, in which options are entered. This figure shows values appropriate for the example of the M2 solar flare on 2010 June 2.

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Figure 2: Results Window: The top panel shows the lightcurve, the bottom shows the count spectrum. The green fill indicates the time interval for which the angle to the source was $< 60^\circ$.

