The BAT Trigger Simulator

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(**Last update:** 2016-03-14 in response to an update in Xspec v12.9.0)

1. Introduction

The BAT trigger simulator was developed to mimic the *Swift*/BAT trigger algorithm, in order to address the selection effects due to the complex trigger algorithm. BAT adopts over 600 different trigger criteria a based on photon count rate and additional image threshold for localization. The detail descriptions of the methods adopted in this trigger simulator can be found in Lien et al. (2014) (Sect. 3.3). Here, we present the code for public use. If there is any problem, please contact Amy Lien (amy.y.lien@nasa.gov).

2. How to use the trigger simulator

0. Prerequisite: HEASOFT[1] (FTOOLS and the *Swift*/BAT analysis tools), *Swift*/BAT Calibration Database[2] (CALDB), and XSPEC v12.9.0[3] (due to a recent change in the "fakeit" command in XSPEC, users with XSPEC version before v12.8.2 need to use "sim_lc_v2_flux_input_file_xspec_v12.8.sh" when performing steps in Section 3).

1. Download everything in this folder (trigger_code_v2_sec), which contain:

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[1] https://heasarc.gsfc.nasa.gov/lheasoft/download.html

[2] http://heasarc.gsfc.nasa.gov/docs/heasarc/caldb/caldb_install.html

[3] https://heasarc.gsfc.nasa.gov/xanadu/xspec/

(a) simple_trigger_input_v2_sec.sh:
the main script that runs the trigger simulator code, with adjustable options.

(b) simple-trigger-mock-v2-sec.c:
the main trigger simulator code called by "simple_trigger_input_v2_sec.sh".

(c) trigger_info_long_sec.dat:
a data file that contains the information of the long trigger criteria.

(d) trigger_info_short_sec.dat:
a data file that contains the information of the short trigger criteria.

(e) trigger_info_image_sec.dat:
a data file that contains the information of the image trigger[4].

(f) Makefile:
A Makefile for compiling the c code

(g) lc/:
A folder that contains a sample light curve for testing and demonstration purpose. There are 36 light curve files in this folder. The ones required to run the trigger simulator are those with names *_sim_quad*.txt. All of them are light curves for the same burst, but in different energy bands and detector quadrants, correspond to those adopted by the trigger criteria. The rest of the files with names like *src*.txt are intermediate products generated by scripts in bat_sim_lc/ (see descriptions below), and are saved for checking.

(h) bat_sim_lc/:
A folder that contains the codes for generating light curves in count with background from the input flux light curve with no background. If you already have the light curves in BAT's count with background (in the corresponding four energy bands and detector quadrants), you can use the trigger simulator immediately and do not need the scripts in this folder. However, if you would like to generate the count light curve from an input flux light curve with different assumptions of burst incident angles, number of active detectors, and backgrounds, you can use the scripts in this folder for such purpose.

2. Compile the c code by the following command:
make simple-trigger-mock-v2-sec

[4]Note: due to the more complex setting for image triggers, there is no complete list of criteria for image trigger (see Lien et al. 2014, for detail explanation). Thus, the criteria listed here are only a subset of image criteria that trigger GRBs more frequently.

3. run the trigger simulation using the main shell script:
   ./simple_trigger_input_v2_sec.sh

   Current setting in the shell script "simple_trigger_input_v2_sec.sh" uses the example light curves in folder "lc/". After step 3, you should see the printout shown in Fig. 1.

   This printout shows (1) a summary of the setting [5]; (2) a list of time steps that successfully trigger the criteria; and (3) a quick summary of the trigger information, including the maximum signal-to-noise ratio and the corresponding time step that gives this signal-to-noise ratio.

```
#########################
## Running trigger code with the following settings:
## Light curve file: GRBtest
## Trigger mode: Long trigger
## Energy band: 15-50 keV
## Time bracket: bg1_dur=41, fg_dur=4, bg2_dur=10, elapse_dur=13 (unit: sec)
## Quadrant info: qd0=1, qd1=1, qd2=1, qd3=1
## Signal-to-noise ratio threshold = 9.949874
## Image threshold = 10.000000
#########################
## Results:
## criterion signal_to_noise_ratio fg_start_time fg_end_time bg_start_time bg_end_time bg2_start_time bg2_end_time signal_to_noise_ratio_4quads
289 1.068288e+01 -1.260000e+00 2.740000e+00 -5.526000e+01 -1.426000e+01 1.574000e+01 2.574000e+01 1.068288e+01
289 1.111814e+01 -2.600000e-01 3.740000e+00 -5.426000e+01 -1.326000e+01 1.674000e+01 2.674000e+01 1.111814e+01
289 1.001678e+01 7.400000e-01 4.740000e+00 -5.326000e+01 -1.226000e+01 1.774000e+01 2.774000e+01 1.001678e+01
## Summary of trigger criterion '289':
## triggered! Max signal-to-noise = 11.118141
## trigger time: -0.260000
## trigger bracket time range: from -54.260000 to 26.740000
#########################
```

Fig. 1.— Example printout after running "./simple_trigger_input_v2_sec.sh"

4. If the test run using the example light curves is successful, you can change the setting in "simple_trigger_input_v2_sec.sh" and use your own light curve and different trigger criteria (the list of criteria and the related information can be found in "trigger_info_long_sec.dat", "trigger_info_short_sec.dat", and "trigger_info_image_sec.dat"). Note that similar to the example light curves, you also need to create a set of light curves in different energy bands ($15-25$, $15-50$, $25-100$, $50-350$ keV) that corresponds to those used by the trigger criteria. In addition, you also need to make a set of light curves for the four detector quadrants, since different trigger criteria use a

[5](1) The foreground, background, and elapse time duration (fg_dur, bg1_dur, bg2_dur, and elapse_dur) listed are the rounded number used in the script, if the duration cannot be divided by the bin size exactly. For example, if the foreground duration of the trigger criteria is 4.096 s, and the light curve bin size is 1 s, the actual foreground duration used would be 4 s. (2) In the "quadrant info", "0" indicates the quadrant counts are not included in the calculation, while "1" means the counts are included.

different combination of the four detector quadrants. The fraction of counts in each detector quadrant is determined by the incident angle of the burst. For example, if the burst is coming in on-axis (relative the the detector plane), the counts are evenly distributed on the whole detector plane, and hence each detector quadrant has 1/4 of the total number of counts. However, if the burst is coming in from an off-axis angle, there will be more counts fall on certain detector quadrants than others. If you only have the flux light curve, you can use the scripts in the folder "bat_sim_lc", which create the light curves needed for the trigger simulator ("simple_trigger_input_v2_sec.sh") from the input flux light curve (see Sect. 3 for detail instructions).

3. Generating light curve in unit of count from the flux light curve

The scripts in this folder generate light curves in count with background from the input flux light curve without background. The codes take into account of the BAT instrumental response, which depends on the burst incident angle relative to the detector plane, and the number of active detectors. Below are detail steps for using the scripts:

1. Providing the input properties of the burst in the files in folder "burst_info":
   (a) "{GRBname}_info.txt"': The information of the burst required by the scripts, which includes
      i. alpha, beta, and Epeak: the paramters from the spectral fit using the Band function (eq. 1 in Band et al. 1993). Note that the original equation in Band et al. (1993) uses the parameter E_0 instead of Epeak, the two can be related by Epeak $= E0\ (2 + \text{alpha})$
      ii. Emin and Emax: the lower and upper range of the energy band of the input flux light curve, in unit of keV. For example. the flux light curve for the test example is made in $15 - 150$ keV, therefore Emin $= 15$ and Emax $= 150$.
      iii. GridID: the special number that corresponds to a certain location on the detector plane, which corresponds to the line of sight of the burst with a certain incident angle. For example, Grid number 17 corresponds to an on-axis burst, and GridID 14 corresponds to an $\sim 56^o$ off-axis event. The correlation is provided in Table 1 in Lien et al. (2014).
      iv. ndet: Number of active detectors of the BAT. The number changes as time as some detectors become noisier and are disabled. Current number (as of 2015) is ~ 20000. Figure 3 in Lien et al. (2014) shows the average number of active detectors as a function of year.

v. obs_bin_size: The time bin size of the input flux light curve "{GRBname}_lc.txt'.

vi. background: The background file name from the library folder "tool_files/bgd". In this folder there are 371 background files made from the background of real BAT-detected GRBs. The script will use the background file with the name entered in "{GRBname}_info.txt"' when adding background fluctuation to the light curve.

vii. spectral_evolution(0:no; 1:yes): The flag that indicates whether or not to include spectral evolution (i.e., allow the burst spectrum to evolve with time). "0" means no spectral evolution; "1" indicates to include spectral evolution. Note that if it is set to "1", the light curve file "{GRBname}_lc.txt" needs to have a third column added to state the Epeak value at each time. In the script, we address the spectral evolution by simply changing Epeak, and keep alpha and beta the same.

(b) "{GRBname}_lc.txt': The flux light curve in the observer's frame. The first column is time; the second column is flux in any specific energy band. If one would like to include spectral evolution, a third column of the Epeak value at each time needed to be added.

2. Run "sim_lc_v2_flux_input_file.sh"
This script calls the main code "sim_lc_v2_flux.sh" that generates the count light curves, with the setting provided in "burst_info". The generated light curves for four detector quadrants in four energy bands will be put in the folder "trigger_code_v2_sec/lc", starting with the same name specified in the "burst_name" set in "sim_lc_v2_flux_input_file.sh". The set of light curves generated are:

   (a) {GRBname}_bat_{energy_band}kev_lc_sim_quad{quadrant_number}.txt: 16 light curves with background in unit of counts, for four energy bands ($15-25$, $15-50$, $25-100$, $100-350$ keV) and four detector quadrants used by the trigger simulator.

   (b) {GRBname}_bat_{energy_band}kev_lc_src_quad{quadrant_number}.txt: 16 light curves without background in unit of counts, for four energy bands ($15-25$, $15-50$, $25-100$, $100-350$ keV) and four detector quadrants. These are intermediate products and are saved just for checking purpose.

   (c) {GRBname}_bat_{energy_band}kev_lc_src.txt: four light curves without background in unit of counts, for four energy bands ($15-25$, $15-50$, $25-100$, $100-350$ keV) but in the whole detector plane (i.e., summed from the light curve from each detector quadrant).

3. The test example are named as "GRBtest". If you successfully run all the scripts, you may change the GRB name to whatever you would like. You would need to specify the

name in the setting of “burst_name” in the main script “sim_lc_v2_flux_input_file.sh”, and also name the files in the “burst_info” accordingly. All the files generated in “trigger_code_v2_sec/lc” will start with the name you set.

Acknowledgments
We thank Scott Barthelmy, David Palmer, and the BAT team for the very helpful inputs and discussions. This project is partially supported by the Swift GI cycle 9 grant.

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This preprint was prepared with the AAS LaTeX macros v5.2.