ASTR 288C - Lab 5
Swift BAT and XRT data
for gamma-ray bursts (GRBs)

1 HEAsoft and HEASARC

HEASoft (`https://heasarc.nasa.gov/lheasoft/`) is a unified release of commonly used software packages that analyze data from NASA telescopes.

The HEASoft package has been installed on the lab machines. To initialize the software, do the following:

- copy the initializing shell script from `/n/ursa/A288C/alien/headas_caldb_setup.sh` to your home directory.
- type the following command to initialize the HEAsoft environment

  ```
  source headas_caldb_setup.sh
  ```

- check if you successfully initiate the software by typing

  ```
  ftlist
  ```

  If you see the line "Input file name", you have successfully initiated the software. If you see the line "ftlist: Command not found.", the initializing process failed, please contact the instructor.

HEASARC (The High Energy Astrophysics Science Archive Research Center) contains archival data from the high-energy telescopes.

The general HEASARC webpage is at

`https://heasarc.gsfc.nasa.gov/`

The data search entry for the *Swift* telescope is at

`https://heasarc.gsfc.nasa.gov/cgi-bin/W3Browse/swift.pl`

Data on HEASARC are in their raw format. To use the data for scientific purpose, you would need to process/reduce the data using related tools developed by each mission. For Swift-detected GRBs, data from the BAT and XRT have been processed/reduced and are ready to used for research. You can find these data in the BAT GRB catalog and the XRT GRB catalog, as introduced in Section 4 and 5.

Exercise:
Do questions 1(a) to 1(e) in the worksheet.

2 xTIME

Swift records time in the Mission Elapsed Time (MET), which is in unit of seconds with the reference date of January 1, 2001, UTC.

In all of *Swift* data, you will find time recorded in MET, which can be converted to UTC (and vise versa) by the xTIME website:

`https://heasarc.nasa.gov/cgi-bin/Tools/xTime/xTime.pl`

3 FITS file

The Flexible Image Transport System (FITS) format is a standard data format used in astronomy. It is adopted as the format for all data collected by NASA missions. It can store different data types (e.g., image and table) in the same file at different extensions.

Detail information of FITS file can be found at
`https://fits.gsfc.nasa.gov/`

3.1 Useful tool to handle FITS file

3.1.1 FTOOLS

FTOOLS is a package of software to create, examine, and modify data in FITS format. Here are some useful links of FTOOLS:

- A quick tutorial of FTOOLS:

  `https://heasarc.gsfc.nasa.gov/lheasoft/ftools/ftools_quicky.html`

- Useful packages and commands in FTOOLS:

  `https://heasarc.gsfc.nasa.gov/lheasoft/ftools/ftools_subpacks.html`

  Below are some commands that are commonly used:

  - **fstruct**
    Type
    fstruct <filename>

to find out the major structure of the file.

More detail information about *fstruct* can be found at
`https://heasarc.gsfc.nasa.gov/ftools/caldb/help/fstruct.txt`

– **ftlist**

Type

ftlist <filename> <option>

to list the content of the file.

Different options will display different part of the file. In particular, here are two useful options:

* T: display the main content of the file
* K: display the header information of the file.

You can also list only the specified extension. For example, to list only the 2nd extension of the light curve file "sw00767284000b_1chan_1s.lc", type

ftlist `sw00767284000b_1chan_1s.lc`+1 T

or

ftlist `sw00767284000b_1chan_1s.lc`'[1]' T

You can also display specific columns by typing the column names

ftlist `sw00767284000b_1chan_1s.lc`'[1][col TIME; RATE]' T

More detail information about *fstruct* can be found at
`https://heasarc.gsfc.nasa.gov/ftools/caldb/help/ftlist.txt`

– **ftcopy**

You can copy a FITS file to another one with some modification using *ftcopy*.

For example, if you only want a light curve file that contains data from the BAT trigger time (T0) to 10 s after the trigger time (T0+10 s), you can do so by typing

ftcopy `sw00767284000b_1chan_1s.lc`'[TIME > 524095320.576 && TIME < 524095330.576]' `sw00767284000b_1chan_1s_short.lc`

This will create a new file sw00767284000b_1chan_1s_short.lc that contains only 10 sec of the original light curve file.

More detail information about *fstruct* can be found at
`https://heasarc.gsfc.nasa.gov/ftools/caldb/help/ftcopy.txt`

– **ftmerge**

You can merge two different FITS file by typing

ftmerge *filename1,filename2 outputfile*

More detail information about *fstruct* can be found at
`https://heasarc.gsfc.nasa.gov/ftools/caldb/help/ftmerge.txt`

– **ftsort**

You can sort a FITS file based on values in specific column.

For example, if you would like to sort the the light curve file in time order based on the photon count rate, you can this by typing

```
ftsort sw00767284000b_1chan_1s.lc sw00767284000b_1chan_1s_sort.lc RATE
```

This will create a new file sw00767284000b_1chan_1s_sort.lc with rows in the order of count rate.

You can also use the option "unique=yes" to make sure there is no duplicate numbers in your sorted file. That is, if there are two entries with identical numbers, it will only be listed once in the output file.

More detail information about *fstruct* can be found at
`https://heasarc.gsfc.nasa.gov/ftools/caldb/help/ftsort.txt`

– **the "clobber" option**

When using FTOOLS, you can use the clobber option to specify whether you would like to rewrite the file if it already exist. For example,

```
ftsort sw00767284000b_1chan_1s.lc sw00767284000b_1chan_1s_sort.lc RATE clobber=yes
```

will perform the sorting and write the result to sw00767284000b_1chan_1s_sort.lc even if it already exist. Likewise, you can also set clobber=no to ensure that no exisiting file will be rewritten.

Exercise:

Do questions 1(f) and 1(h) in the worksheet.

3.1.2 fv FITS viewer

The "fv FITS viewer" is a software that can be used for a quick look of the content of a FITS file. It can also make some simple plots of the data.

More information of this software can be found at

`https://heasarc.gsfc.nasa.gov/ftools/fv/`

3.1.3 SAOImage DS9

The "SAOImage DS9" is a imaging and data visualization application that can view FITS file. This is a useful tool to have a quick look of your FITS image.

More information of this software can be found at

`http://ds9.si.edu/site/Home.html`

3.1.4 Python

Python also has a special package (astropy.io.fits) to handle FITS file. We will discuss about this in the python classes.

4 BAT GRB data

The BAT GRB data can be found on the following website:

`https://swift.gsfc.nasa.gov/results/batgrbcat/`

It contains the analysis of up-to-date (within a few weeks) of BAT-detected GRBs. Here are a few important features of the website:

- A quick-look website for each GRB, which displays general information of the burst, its image, light curves, and spectra.
- Data product of each GRB, which contains all the original data of the burst, including event data, light curves and spectra in FITS format.
- Summary tables, which contains tables that summarize the BAT GRB characteristics (e.g., burst durations, spectral fits, fluxes, redshift....etc).

Note that everything in *Swift* is recorded in the *Swift* machine time (MET). You can covert *Swift* MET to regular UTC time using the "xTIME" website (Section 2).

Exercise:

Do question 2 to 5 in the worksheet.

5 XRT GRB data

The *Swift*/XRT GRB catalog can be found at

`http://www.swift.ac.uk/burst_analyser/`

For each light GRB, there is a webpage that shows a quick look of the GRB light curve, spectrum, and spectral fits.

You can also go to the light curve repository page

`http://www.swift.ac.uk/xrt_curves/`

which will allow you to rebin the light curves in different time bin and download the ascii file of the binned light curve data.

Moreover, the Burst Analyser page

`http://www.swift.ac.uk/burst_analyser/`

which presents a quick look light curve from BAT, XRT, and UVOT.

(Optional) Exercise:

Do exercise 6 to 8 in the worksheet.

Lab 5 Worksheet

You are required to hand this worksheet in at the end of the lab.

Name:_____ User Name:_____

1. Finding BAT data on HEASARC:

   (a) Go to the HEASARC webpage for the *Swift* data:
   `https://heasarc.gsfc.nasa.gov/cgi-bin/W3Browse/swift.pl`

   (b) For each GRB, there is a "trigger ID" associated with the burst. For example, the trigger ID for GRB170906A is 770957. Find the data for GRB170906A on HEASARC using its trigger ID.

   (c) You will see a list of items that contains the data for GRB170906A, with different last three digits in their "observation ID (obsid)". Select the one with observation ID ending with "000" (obsid=00770957000). The "000" means that this is the first observation performed by *Swift* on this object.

   (d) Under the "Data Product Retrieval" section, unselect "All", and select "Swift BAT Data (bat data)", and press the bottom "Preview and Retrieve".

   (e) Now you will see it listed all the BAT data for these two observations. Select the "BAT Event Data (event)", and press the "Create Download Script" bottom.

   (f) You should see one script starting with **wget**. Copy the script to your personal folder and press enter. These script will download the data to your home directory.

   (g) You should see a directory called "00770957000" being created. This number is the "observation ID (obsid)" of this observation. Within this folder, you will see the event file, sw00770957000bevshsp_uf.evt.gz, under `bat/event`. Use "fstruct" to find out what the columns are in the first extension of the event file. Write down the column names here.

   As you can see, the event data (or sometime called the "event-by-event data) collects information (time, energy, location on the detector plane) for each photon.

   (h) The second extension is the good time interval (GTI) of the event file. Use "ftlist" to display the second extension and find out when does the event data start and end. Write down the start and end time here.

   (i) What are the UTC times that correspond to the start and end times of the event file?

2. Go the the webpage of GRB170810A, answer the following questions:

   (a) When did BAT trigger this burst?

(b) What is the RA and DEC found by the ground analysis (i.e., the "Refined Position")?

(c) What is the signal-to-noise ratio (SNR) found in the image made by the ground analysis?

(d) What is T_{90} (the burst duration that contains 90% of the burst emission)?

(e) When does T_{90} start and end, relative to the BAT trigger time T0?

(f) Using the light curve plot, find out what is the cloesest spacecraft slew time period. Filled out your answer in the following blank space.

The spacecraft was slewing from T0+_____ to T0+_____.
(Write down your answers in second, with accuracy to the tenths place).

3. From the data product site, download the 1-channel light curve in 1-s time bin of GRB170810A to your personal directory by typing the following:

```
cd <your_personal_directory>

wget https://swift.gsfc.nasa.gov/results/batgrbcat/GRB170810A/data_product/00767284000-results/lc/sw00767284000b_1chan_1s.lc
```

Note that the link is the location of the light curve file on the website. *wget* is a useful linux command that downloads files from the website.

4. Using relevant FTOOLS to create a file called "BAT_lc_short.fits" that contains only the light curve data in the T_{90} period. Write down the command you use to do this.

(Tips: because all the FITS file for BAT data use *Swift* MET, you will need to use the corresponding MET for the T_{90} start and end time.)

5. Use "fv" to plot the light curve. To open the file, type

```
fv BAT_lc_short.fits
```

Select the relevant options on the interactive window to plot the TIME column in the x axis and RATE column in the y axis.

6. From the data product site, download the preslew image (i.e., the image with time period before the spacecraft slews) of GRB170810A to your personal directory by typing the following:

```
cd <your_personal_directory>

wget https://swift.gsfc.nasa.gov/results/batgrbcat/GRB170810A/data_product/00767284000-results/img/sw00767284000b_preslew_1chan.img
```

7. Use ds9 to open the image sw00517489000b_preslew_1chan.img by typing the following

```
ds9 sw00517489000b_preslew_1chan.img
```

   Can you find the burst? Point your arrow at the location of the burst, does it match with the RA and DEC reported on the webpage?

8. Find the XRT light curve for GRB170810A.

   (Exercise 6-8 are optional, do these if you have time.)