Swift/BAT GRB Temporal Analysis

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ASTR 288C, Lecture 9, 2018/10/29
This week’s homework - Proposal

• Create the next half of the proposal, submit by midnight (11:59 pm) on next Tuesday (11/06) for review
  – Even for people doing projects with the same title, each person has to design your own method.
    • As always, you are encouraged discuss with each other, but need to have your own design using your own judgment of what is good for your project.

• 2 weeks later:
  – Proposal results: accepted vs revision
  – The top accepted proposal will get a small prize
This week’s homework  
- Proposal

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  – Proposal results: accepted vs revision (no rejection!)
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This week’s homework
- Proposal

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Research project:
- Look into problems that no one knows the answer yet.
- Need to find your own solution and convince others.

- 2 weeks later:
  - Proposal results: accepted vs revision (no rejection!)
  - The top accepted proposal will get a small prize
This week’s homework  
- Proposal

<table>
<thead>
<tr>
<th>Date</th>
<th>Lecture</th>
<th>Lab</th>
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<tbody>
<tr>
<td>11/05</td>
<td>Swift/BAT GRB spectral analysis</td>
<td>Spectral fitting</td>
</tr>
<tr>
<td>11/06</td>
<td></td>
<td>(11:59 pm - Submit final proposal)</td>
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<tr>
<td>11/12</td>
<td>Scientific proposal</td>
<td>Discuss student proposal (Project start)</td>
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<tr>
<td>11/19</td>
<td>Dedicated time for research projects</td>
<td>Individual research</td>
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<tr>
<td>11/26</td>
<td>Science communication</td>
<td>Individual research (Turn in paper draft)</td>
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<tr>
<td>12/03</td>
<td>Dedicated time for research projects</td>
<td>Individual research</td>
</tr>
<tr>
<td>12/10</td>
<td>Oral presentation</td>
<td>(Final paper submission)</td>
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- This project needs to be finished in ~ 4 weeks
  – Clearly lay out your schedule in your proposal.
  – Each week for the individual research, we will review your work schedule.
**Example:**

**Title:** Increasing high redshift GRB detection.

**Science rationale:** Increase the number of high redshift GRB detections to better constrain the star-formation history in the early universe.

**Project goal:** Explore the detectability of high redshift GRBs based on the GRB spectral characteristics.

<table>
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<tr>
<th>Date</th>
<th>Proposed goal</th>
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<tbody>
<tr>
<td>11/19</td>
<td>Finish simulating BAT GRB light curves at different redshifts</td>
</tr>
<tr>
<td>11/26</td>
<td>Finish estimating BAT GRB detectability and spectral indices at different redshifts. Finish paper draft.</td>
</tr>
<tr>
<td>12/03</td>
<td>Finish summarizing the changes GRB detectability as a function of spectral index at different redshift.</td>
</tr>
<tr>
<td>12/10</td>
<td>Oral presentation</td>
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</table>

- This project needs to be finished in ~ 4 weeks
  - Clearly lay out your schedule in your proposal.
  - Each week for the individual research, we will review your work schedule.
This week’s homework
- Proposal

• Proposal will be judged based on
  – Clarity: clearly state your scientific goal and method
  – Feasibility (in ~ 4 weeks)
  – Relevant to Swift (use of Swift data). Specifically, use at least 3 of the following items:
    • Swift BAT GRB catalogs
    • Temporal/Timing analysis
    • Spectral analysis
    • Statistical analysis
    • Coding
  – Creativity
  – Riskiness/difficulty
This week’s homework
- Proposal

• Your final project will be judged by:
  – Completeness
  – Difficulty
  – Creativity
  – Quality of writing
  – Quality of oral presentation
Gamma-ray telescopes

- Gamma ray photons are extremely energetic
  - Penetrate/interact with almost all the material
  - Hard to focus
Imaging in gamma rays
Coded-mask aperture

- Energy range: 15-350 keV
- Position accuracy: ~3 arcmin (depends on the source brightness)
- Field of View: ~1.4 sr

Credit: NASA's Imagine the Universe and NASA/Swift
Imaging in gamma rays
Coded-mask aperture

Credit: NASA's Imagine the Universe and NASA/Swift
4.3. CODED APERTURE ANALYSIS FOR X-RAY ASTRONOMERS

For an observer with experience in X-ray astronomy, coded aperture analysis with BAT may appear to be similar to their experiences, but they are not. This section gives a description of some of the major differences.

BAT has no focussing optics. This means that most of the familiar analysis operations of X-ray and optical astronomy do not apply.

The BAT has two distinct spaces: detector space and sky space. The BAT software is used to convert from detected counts to sky fluxes. Figure 4.4 compares the two kinds of images.

Another example, Figure 4.5 shows the mask modulation pattern of a bright source, Sco X-1, as detected by BAT. Note however that for all but the brightest sources the mask modulation pattern will not be visible to the naked eye.

Credit: NASA's Imagine the Universe and NASA/Swift

Markwardt et al. (2007)
Angular resolution comparison

Crab Nebula: Remnant of an Exploded Star (Supernova)

Radio wave (VLA)  Infrared radiation (Spitzer)  Visible light (Hubble)

Ultraviolet (Swift/UVOT)  Low-energy X-ray (Chandra)  High-energy X-ray (Integral)

Source: www.srl.caltech.edu
Angular resolution comparison

Crab Nebula: Remnant of an Exploded Star (Supernova)

Radio wave (VLA)  Infrared radiation (Spitzer)  Visible light (Hubble)

Ultraviolet (Swift/UVOT)  Low-energy X-ray (Chandra)  Swift BAT

Source: www.srl.caltech.edu
Mask-weighting analysis

Credit: NASA's Imagine the Universe and NASA/Swift
Mask-weighting analysis

Credit: NASA's Imagine the Universe and NASA/Swift
Mask-weighting analysis

Detector Plane Image (DPI)

Credit: NASA's Imagine the Universe and NASA/Swift
Mask-weighting analysis
Mask-weighting analysis

Incoming light

Mask shadow pattern

Coded aperture mask

Detector plane

Shadow pattern

Credit: NASA's Imagine the Universe and NASA/Swift
Mask-weighting analysis

Mask shadow pattern

Partial coding fraction (pcode): Fraction of illuminated area

Credit: NASA's Imagine the Universe and NASA/Swift
“Background subtraction”

GRB161129A: Raw lightcurve with 1.6 s binning

GRB161129A: mask-weighted lightcurve with 1 s binning
“Background subtraction”

(a) Raw light curve
“Background subtraction”

(a) Raw light curve

(b) Mask-weighted light curve with the GRB location
“Background subtraction”

(a) Raw light curve

(b) Mask-weighted light curve with the GRB location

(c) Mask-weighted light curve with the location of J1820+070
Mask-weighted count

• Definition:

Background subtracted counts per fully illuminated detector for an equivalent on-axis source

Ref: https://swift.gsfc.nasa.gov/analysis/threads/batfluxunitsthread.html
Mask-weighted count

• Definition:
  Background subtracted counts
  per fully illuminated detector
  for an equivalent on-axis source

Illuminated detector $\sim$ enabled detector $\times$ pcode

Ref: https://swift.gsfc.nasa.gov/analysis/threads/batfluxunitsthread.html
Mask-weighted count

• Definition:

Background subtracted counts per fully illuminated detector for an equivalent on-axis source

$\cos(\theta)$ effect

Ref: https://swift.gsfc.nasa.gov/analysis/threads/batfluxunitsthread.html
Processing real data...
Swift BAT data

• Places to download Swift data
  1. HEASARC/Swift site:
     https://heasarc.gsfc.nasa.gov/cgi-bin/W3Browse/swift.pl
     Contains all the Swift data.

  2. BAT GRB catalog:
     https://swift.gsfc.nasa.gov/results/batgrbcat/
     Contains all the BAT GRB products from our standard process.
Swift BAT data

• Places to download Swift data
  1. HEASARC/Swift site:
     https://heasarc.gsfc.nasa.gov/cgi-bin/W3Browse/swift.pl
     Contains all the Swift data.
     Use this one if you’d like to find things beyond standard BAT GRB products. For example, raw light curves at any specific times.
  2. BAT GRB catalog:
     https://swift.gsfc.nasa.gov/results/batgrbcat/
     Contains all the BAT GRB products from our standard process. You should be able to find most of the data you need here.
Now let’s take a look at the BAT GRB catalog webpage
Xtime

• [https://heasarc.nasa.gov/cgi-bin/Tools/xTime/xTime.pl](https://heasarc.nasa.gov/cgi-bin/Tools/xTime/xTime.pl)

• Converting MET to UTC
Processing data

• HEASoft tool:
  https://heasarc.nasa.gov/lheasoft/

• Already installed on the class machine
  – Initializing by
    source headas_caldb_setup.sh
    (or source headas_caldb_setup_bash.sh for bash)
Mask-weighting process

batbinevt infile='00680436000-results/events/sw00680436000b_all.evt' outfile=test.lc outtype=LC timedel=0.004 timebinalg=u energybins='15-350' detmask='00680436000-results/auxil/sw00680436000b_qmap.fits' weighted=YES outunits=RATE ecol=ENERGY gtifile='NONE' clobber=yes

Ref: https://heasarc.gsfc.nasa.gov/ftools/caldb/help/batbinevt.html
Mask-weighting process

Directory for observational ID 00680436000 (GRB 160325A)

```
batbinevt infile='00680436000-results/events/sw00680436000b_all.evt'
outfile=test.lc outtype=LC timedel=0.004 timebinalg=u
energybins='15-350' detmask='00680436000-results/auxil/
sw00680436000b_qmap.fits' weighted=YES outunits=RATE ecol=ENERGY
gtifile='NONE' clobber=yes
```
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Input and output FITS files

Ref: https://heasarc.gsfc.nasa.gov/ftools/caldb/help/batbinevt.html
Mask-weighting process

batbinevt infile='00680436000-results/events/sw00680436000b_all.evt'
outfile=test.lc outtype=LC timedel=0.004 timebinalg=u
energybins='15-350' detmask='00680436000-results/auxil/
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gtifile='NONE' clobber=yes

Producing light curve (instead of spectrum)

Ref: https://heasarc.gsfc.nasa.gov/ftools/caldb/help/batbinevt.html
Mask-weighting process

batbinevt infile='00680436000-results/events/sw00680436000b_all.evt'
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gtifile='NONE' clobber=yes

Time bin of the light curve (in s)

Ref: https://heasarc.gsfc.nasa.gov/ftools/caldb/help/batbinevt.html
Mask-weighting process

batbinevt infile='00680436000-results/events/sw00680436000b_all.evt'
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energybins='15-350' detmask='00680436000-results/auxil/
sw00680436000b_qmap.fits' weighted=YES outunits=RATE ecol=ENERGY
gtifile='NONE' clobber=yes

Energy band of the light curve (in keV)

Ref: https://heasarc.gsfc.nasa.gov/ftools/caldb/help/batbinevt.html
Mask-weighting process

batbinevt infile='00680436000-results/events/sw00680436000b_all.evt'
outfile=test.lc outtype=LC timedel=0.004 timebinalg=u
energybins='15-350' detmask='00680436000-results/auxil/
sw00680436000b_qmap.fits' weighted=YES outunits=RATE ecol=ENERGY
gtifile='NONE' clobber=yes

weighted=NO
for non-mask-weighted light curve

Ref: https://heasarc.gsfc.nasa.gov/ftools/caldb/help/batbinevt.html
Mask-weighting process

batbinevt infile='00680436000-results/events/sw00680436000b_all.evt'
outfile=test.lc outtype=LC timedel=0.004 timebinalg=u
energybins='15-350' detmask='00680436000-results/auxil/sw00680436000b_qmap.fits' weighted=YES outunits=RATE ecol=ENERGY
gtfile='NONE' clobber=yes

tstart=XXX tstop=XXX
(XXX need to be in MET)

Ref: https://heasarc.gsfc.nasa.gov/ftools/caldb/help/batbinevt.html
Mask-weighting process

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gtifile='NONE' clobber=yes

clobber=yes → overwrite existing output file
clobber=no → won’t overwrite existing output file

Ref: https://heasarc.gsfc.nasa.gov/ftools/caldb/help/batbinevt.html
Find Burst Duration

- Bayesian Block Analysis

Fig. 2.—Bayesian blocks for the same data as Fig. 1, determined as explained in the text. (a) TTE data; (b) TTS data; (c) binned data.
Find burst duration

battblocks infile='00680436000-results/lc/sw00680436000b_bb_4ms.lc'
outfile=test_bb.gti durfile=test_bbdur.gti tlookback=10 bkgsub='YES'
timecol=TIME countscol=RATE errcol=ERROR hduclas3=RATE tpeak=1
clobber=yes

Ref: https://heasarc.gsfc.nasa.gov/ftools/caldb/help/battblocks.html
Find burst duration

Input light curve

battblocks infile='00680436000-results/lc/sw00680436000b_bb_4ms.lc'
outfile=test_bb.gti durfile=test_bbdur.gti tlookback=10 bkgsub='YES'
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Output files:
outfile: the baysian blocks intervals
durfile: records T100, T90, T50, and peak time

Ref: https://heasarc.gsfc.nasa.gov/ftools/caldb/help/battblocks.html
Find burst duration

battblocks infile='00680436000-results/lc/sw00680436000b_bb_4ms.lc'
outfile=test_bb.gti durfile=test_bbdur.gti tlookback=10 bkgsub='YES'
timecol=TIME countscol=RATE errcol=ERROR hduclas3=RATE tpeak=1
clobber=yes

The peak time duration (e.g. find 1-s peak time)

Ref: https://heasarc.gsfc.nasa.gov/ftools/caldb/help/battblocks.html
process.log

• Under the result directory, there is the log file for GRB process:
  e.g., 00680436000-results/process.log

• process.log contains the original processes that have been applied to the burst to create light curves, images, burst durations...etc.

• Good way to figure out what should be the options for specific BAT process command (batbinevt, battblocks).