BAT data analysis tutorial

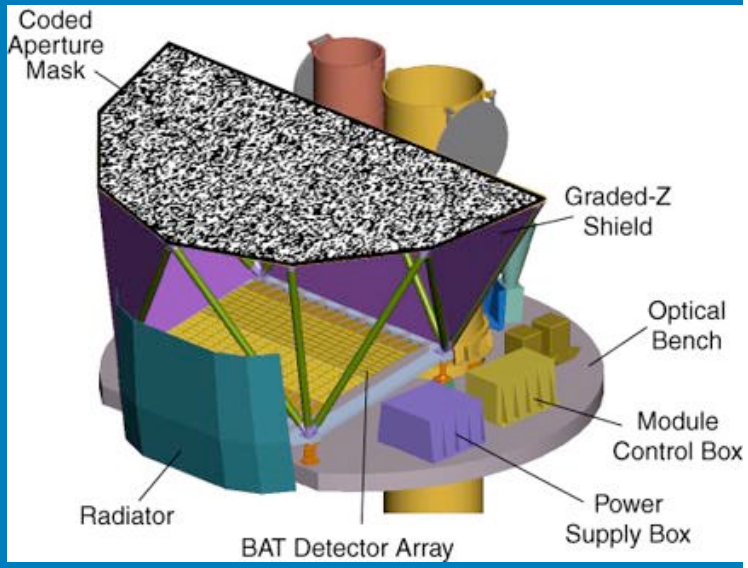
Marco Ajello

Overview

- BAT instrument overview
  - Coded Mask Aperture, Trigger, Performances, GRB LCs
- BAT GRB data
- BAT software
- BAT GRB analysis

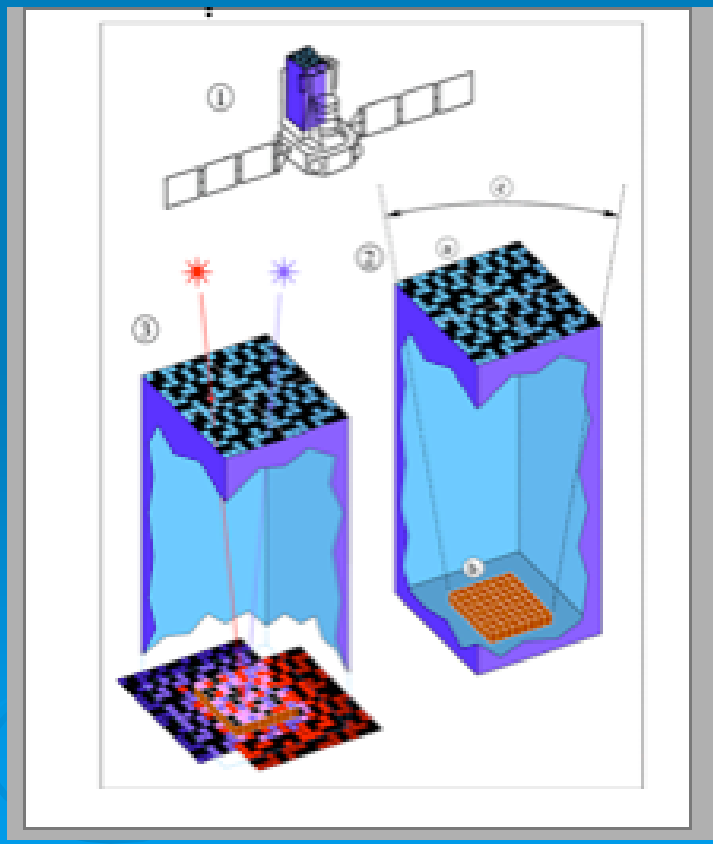
Burst Alert Telescope

- 32768 CdZnTe
- [15-150 keV]
- ~2 sr FOV
- Detector area 5200 cm^2
- Pos. accur. ~1-4arcmin
  - >10sigma and <45deg-> 0.5'
- BKG rates < 17kcts
- 100 μs Timing res



Coded Mask Apertures

- Until focussing X-ray optics (Simbol-X) are available Coded Masks are the best way to detect and image hard X-ray photons
- They are "indirect and inefficient"
- Advantages:
  - The only way to detect HX-ray !!
  - Large FOV -> good for monitoring
  - Mask Weight. Tech provides automatic bkg subtraction
- Disadvantage:
  - Sources are bkg for each other
  - Insensitive to extended sources
  - ~arcmin angular resolution (hole size)



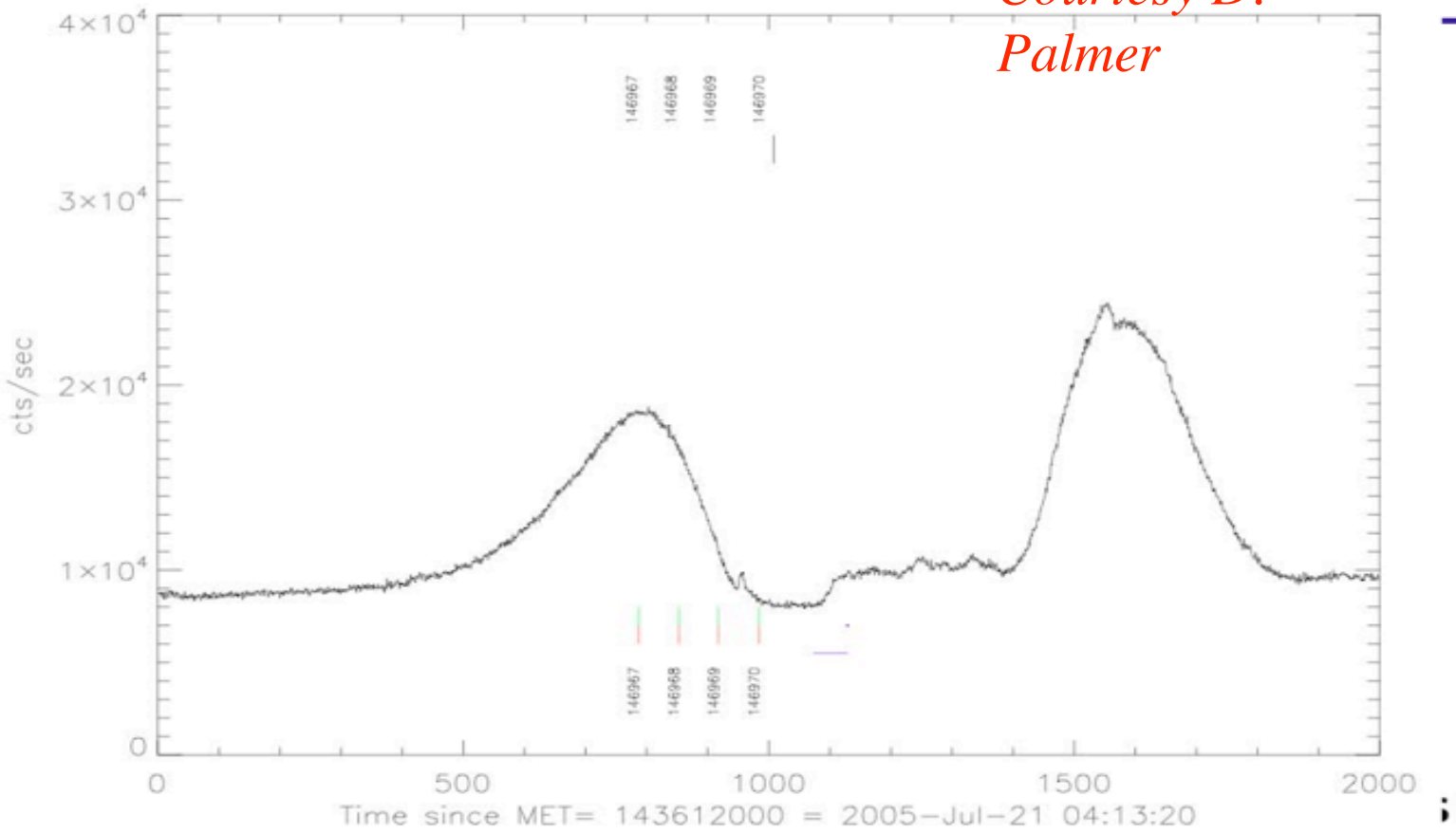
BAT Trigger

- 2 Trigger types: rate & image (adapted from HETE-2)
- Rate:
  - Short triggers (<64ms) : 4 energies (over 320 ms) (dominated by CR showers)
    - Find maxima on 4-64 ms timescale
  - Long triggers (>64ms) : 4 energies
    - One sided: bkg before current time
    - Double sided: bkg before and after
    - Three sided
- Image (15-50keV):
  - 64 s image : Anything new is called a GRB
  - 320s image (full obs): Anything new is called a transient (not slewing)

BAT Trigger

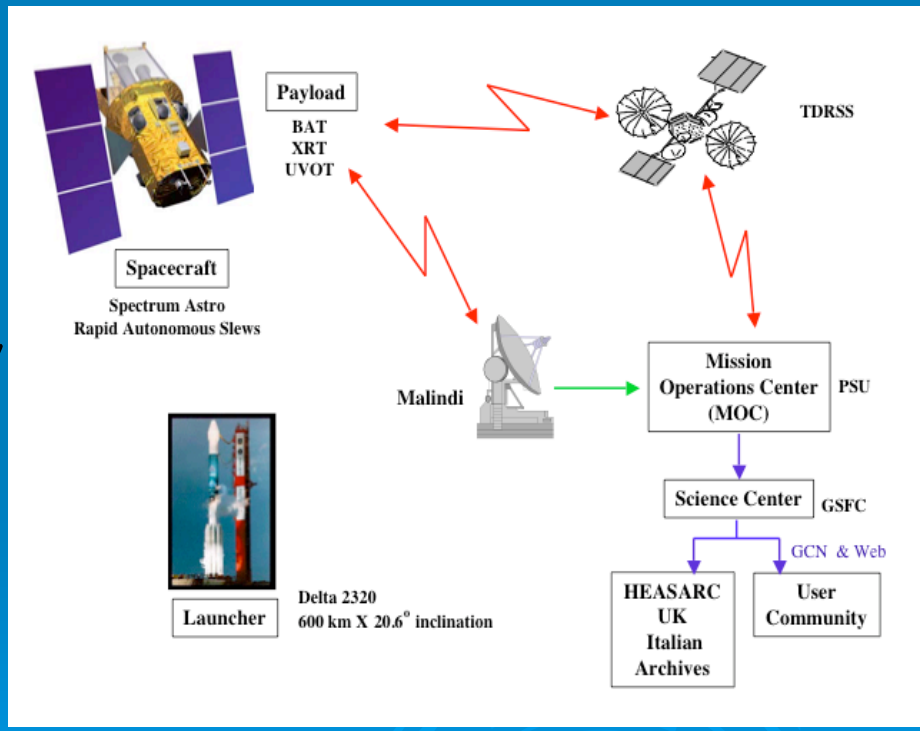
What are we up against? Spot the GRB

Courtesy D. Palmer



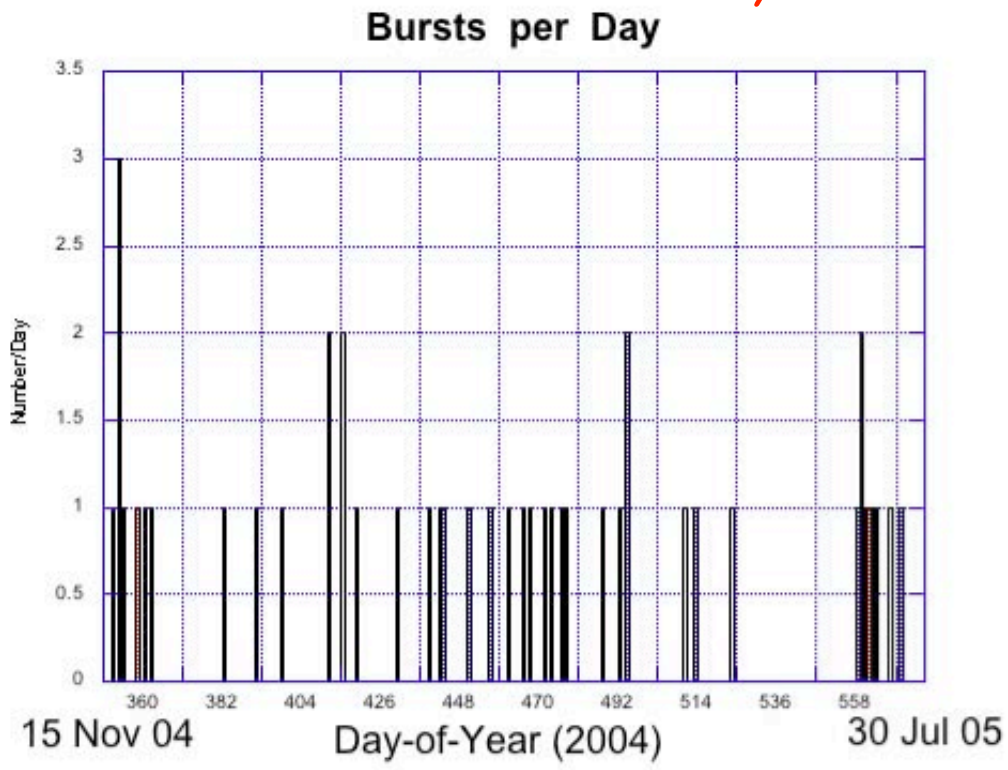
What happens then ?

- GRB data are sent (real time) to the ground via TDRSS and GCN to community
  - Position, slew decision, FOM, XRT position (50%), UVOT source list /image, BAT LC



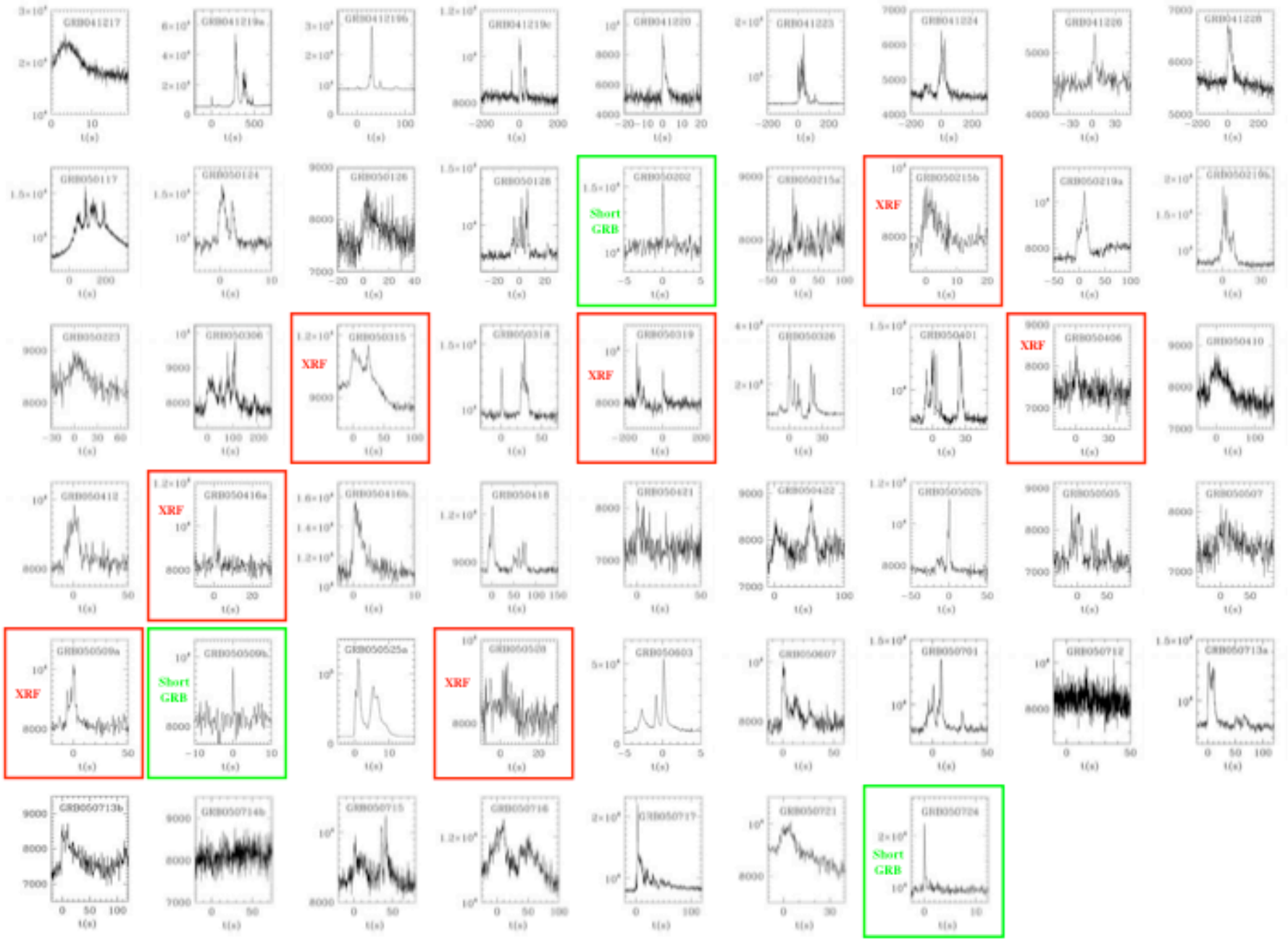
BAT performances

Courtesy S. Barthelmy



GRB rate: ~90 GRBs yr^{-1} measured, 100 yr^{-1} predicted

BAT background: 12 Kcnts/s measured, 17 Kcnts/s predicted

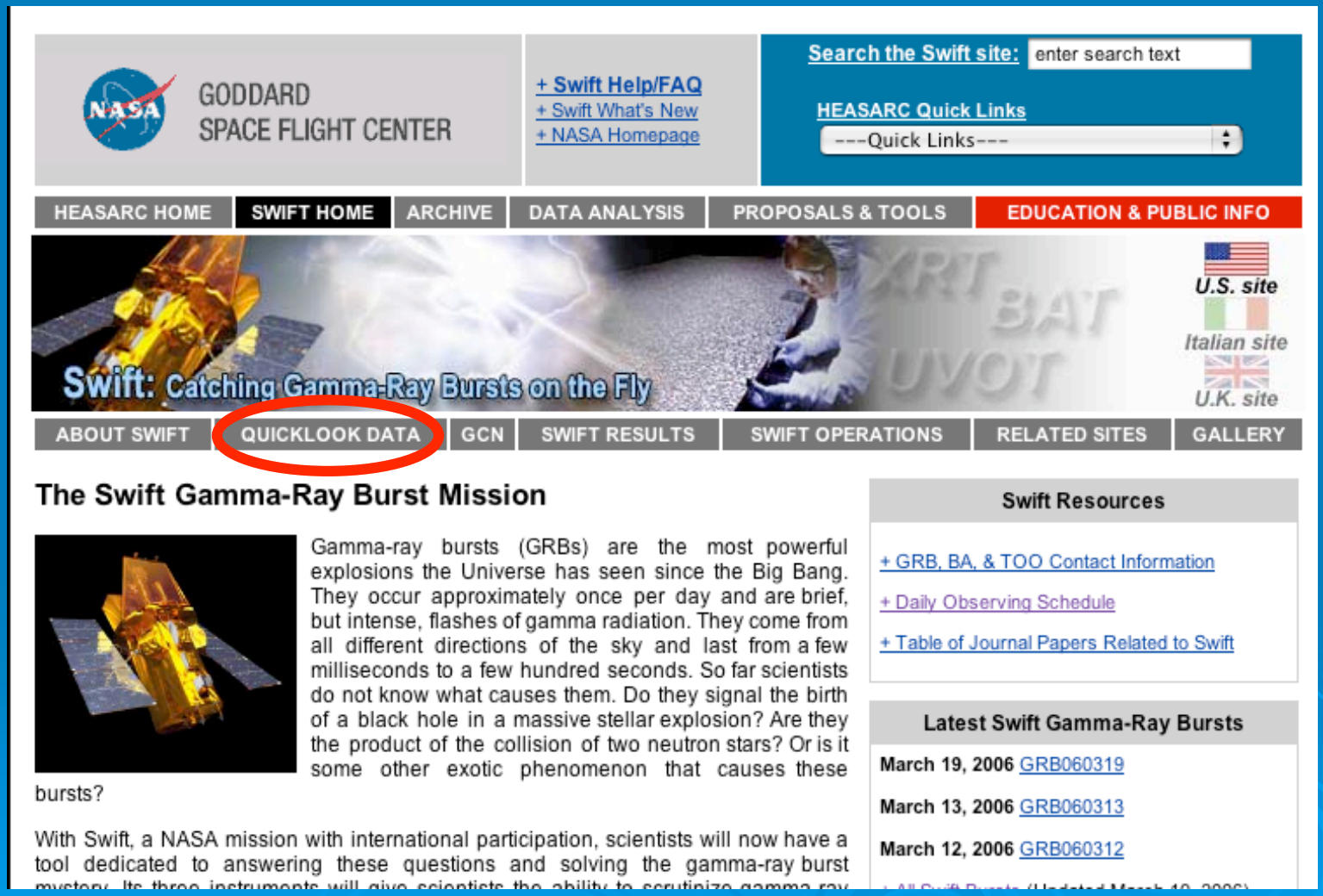


Courtesy Neil Gehrels

BAT GRB DATA (where are they?)

- GRB of the day:
  - http://swift.gsfc.nasa.gov/docs/swift/swiftsc.html and then go to "QUICKLOOK" area
  - Select your GRB
  - Download :
    - AUXIL, BAT directories(+ XRT & UVOT)
- Old GRB ? Use HEASARC:
  - http://heasarc.nasa.gov/db-perl/W3Browse/w3table.pl?tablehead=name%3Dswiftmastr&Action=More+Options

BAT GRB DATA (where are they?)



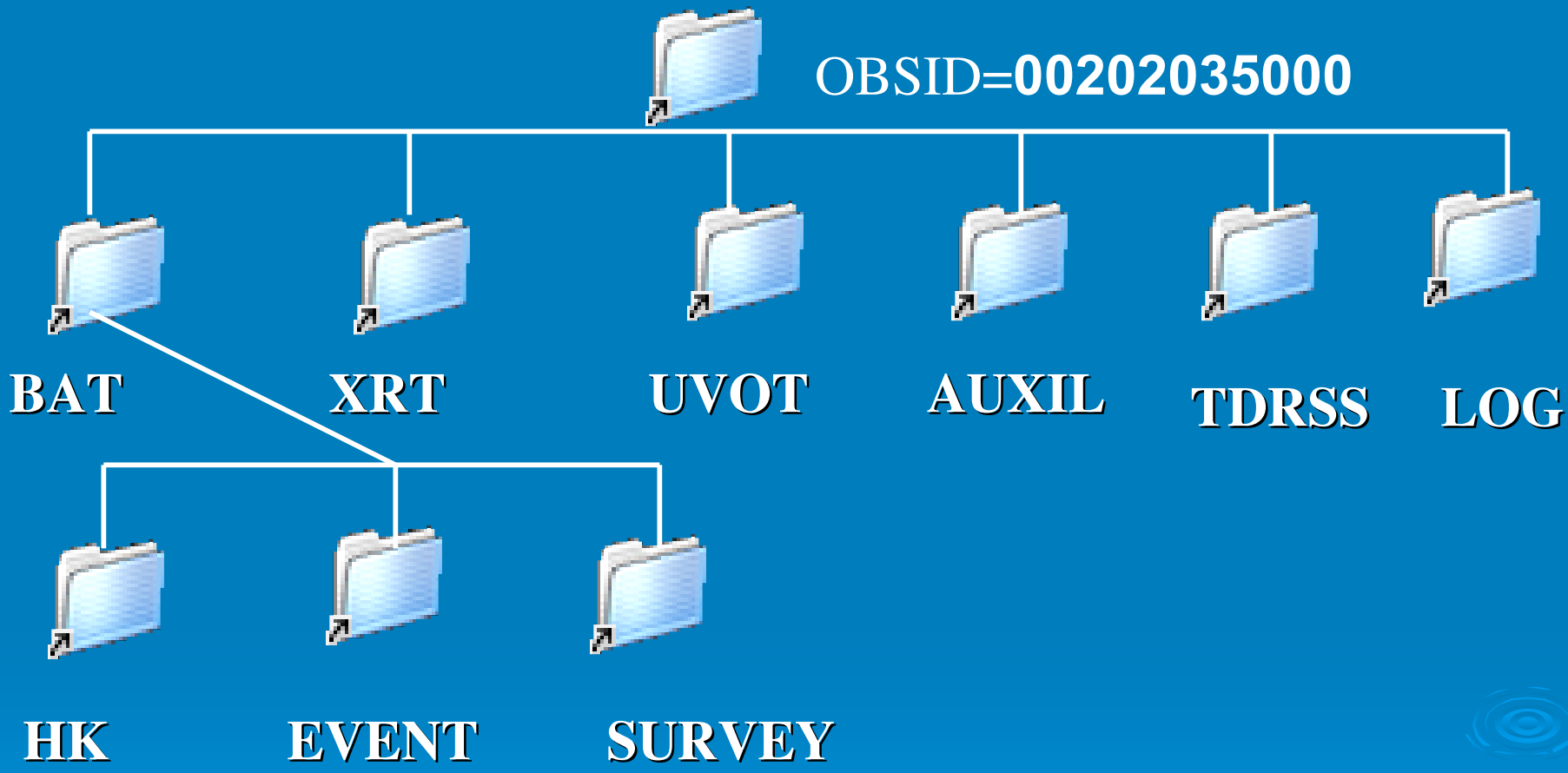
BAT GRB DATA (where are they?)

Please note that Quick Look data is by its very nature preliminary, and should be treated with caution.

Check out the *Quick Look status page* for a list of current known problems.

Sequence	Vers	Object	Observed	Processed	Comment
00202035992	012	GRB060319 (UVOT only)	2006-03-19T00:39:46	2006-03-20T01:11:34	1st day UVOT ONLY moc2006-03-20T005000
00202035991	012	GRB060319 (XRT only)	2006-03-19T00:39:46	2006-03-20T01:11:05	1st day XRT ONLY moc2006-03-20T005000
00202035990	013	GRB060319 (TDRSS only)	2006-03-19T00:40:43	2006-03-20T01:09:25	1st day TDRSS ONLY moc2006-03-20T005000
00202035003	006	GRB060319	2006-03-22T01:05:01	2006-03-22T09:44:56	new data moc2006-03-22T093201
00202035003	005	GRB060319	2006-03-22T01:05:01	2006-03-22T07:59:56	new data moc2006-03-22T074701
00202035002	013	GRB060319	2006-03-21T01:00:01	2006-03-22T04:42:50	new data moc2006-03-22T042601
00202035000	023	GRB060319	2006-03-19T00:39:46	2006-03-21T15:06:53	new data moc2006-03-21T143601
00201487015	011	GRB060313	2006-03-17T00:34:10	2006-03-18T04:21:16	new data moc2006-03-18T040101

DATA structure



BAT units definition

- BAT mask-weighted counts (in LC, PHA, Images):
  - Bkg-subtracted counts per fully illuminated detector for an equivalent source on-axis
    - -> mask wt produces automatic bkg subtraction
    - -> normalized by # of enabled dets (..detector..)
    - -> partial coding correction
    - -> flatfielding correction

BAT Software

- batbinevt (for LC, DPI, DPH, PHA)
- bathotpix
- batmaskwtevt
- battblocks
- batfftimage
- batcelldetect
- batdrmgen
- maketime (not BAT soft, but very important)

Why do you want to process BAT GRB data ?

- BAT-team does already everything !
- Burst Advocates have a script which performs the complete analysis
  - It is being discussed if it will be included in future software release (keep monitoring)

Last chance to say that you don't want to learn how to process BAT data…….

Analysis Example: GRB050319

- Imagine you downloaded the data:
  - Access info (trigger time, GRB pos from fsw)
  - Get/Create quality map
  - Define time intervals (tricky !)
  - Extract events
  - Determine duration times
  - Refine GRB position (maybe skipped)
  - Make PHAs and LCs (as many as you want)
  - Make response matrices
  - Use your intelligence to understand if results are correct !!

The files you'll need

- Event :
  - bat/event/sw00111622000bevsh<type>_uf.evt
- Auxiliar:
  - bat/event/sw00111622000bevtr.fits
- Attitude:
  - auxil/sw00111622000sat.fits

Weighting your Events

- This step is generally already done, but if you need or you have refined your GRB position and you need to re-generate your weights:
  - %> batmaskwtevt grb.evt detmask=qmap.fits ra=raGRB dec=decGRB attitude=sat.att auxfile=sat.aux

GRB info

- They are in the header of the EVENT file or in the TDRSS LC
  - Evt file name is : sw00111622000bevsh<type>_uf.evt
    - Type can be:
      - sp = slew pointing
      - sl = slew
      - po = pointing

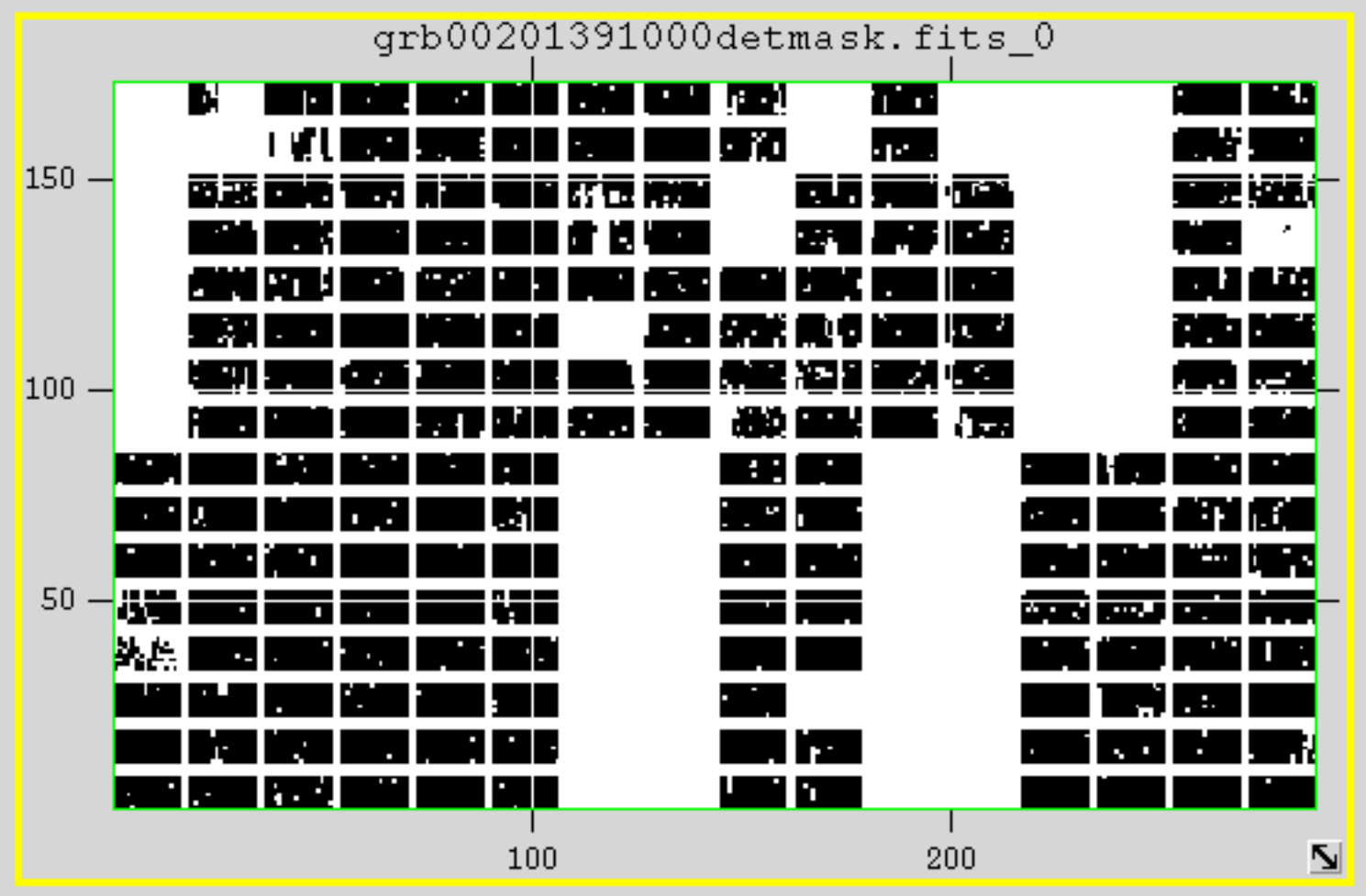
```
HISTORY P13 mode = h
HISTORY END PARAMETER list for bateco
HISTORY
TRIGTIME=        132917477.888 / [s]
TTYPE5   = 'MASK_WEIGHT'         / labe
TFORM5   = '1E      '            / form
```

```
DETSIZEZ=                   0.2 /
BAT_RA  =                154.2017 /
BAT_DEC =                43.54632 /
BAT_XOBJ=     677.800310165806 /
BAT_YOBJ=    -12194.0267695736 /
BAT_ZOBJ=            10000000. /
COORTYPE= 'sky     '           /
```

Quality map

- What's that? A map where:
  - Good pixel are flagged with 0, bad with 1
- How to create it:
  - %> batbinevt grb.evt grb.dpi DPI 0 uniform 15-350 outunits=counts weighted=NO
  - %> bathotpix grb.dpi qmap.fits

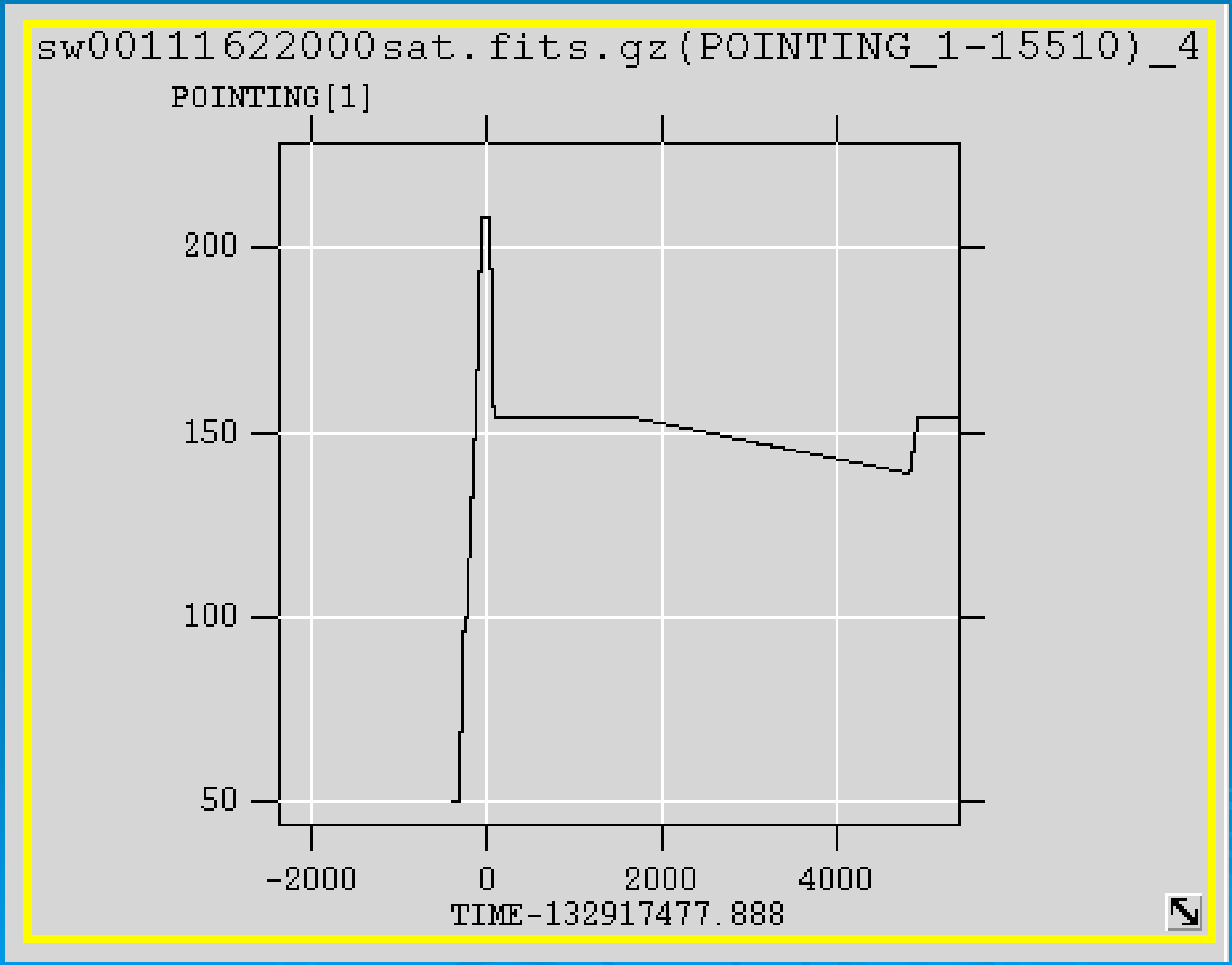
Quality map



Define GTI (why tricky ?)

- Define pre, in, post slew time interval:
  - %>maketime sat.att tenarmin.gti expr="FLAGS==b1xxxxxxx" compact=no prefr=0.5 postfr=0.5
  - %> maketime sat.att slew.gti expr="FLAGS==b00xxxxxx prefr=0.5 postfr=0.5
  - %>ftcopy tenarcmin.gti[STDGTI][START<trigT and STOP>trigT] preslew.gti + opt
  - %> ftcopy tenarcmin.gti[STDGTI][START<trigT] postslew.gti + opt

Define GTI (why tricky ?)



Extract events (easy)

- Pre-slew events:
  - %>extractor grb.evt preslew.evt preslew.gti +opts
- In-slew events:
  - %>extractor grb.evt inslew.evt slew.gti +opts
- Post-slew events:
  - %>extractor grb.evt postslew.evt postslew.gti +opts

GRB durations

- Use battblocks for: T90, T50, Tpeak, TOT
  - Scargle, J. D. 1998, "Studies in Astronomical Time Series Analysis. V. Bayesian Blocks, Astrophys. J., 504, 405
- Make LC from EVTs:

Binning plays a role

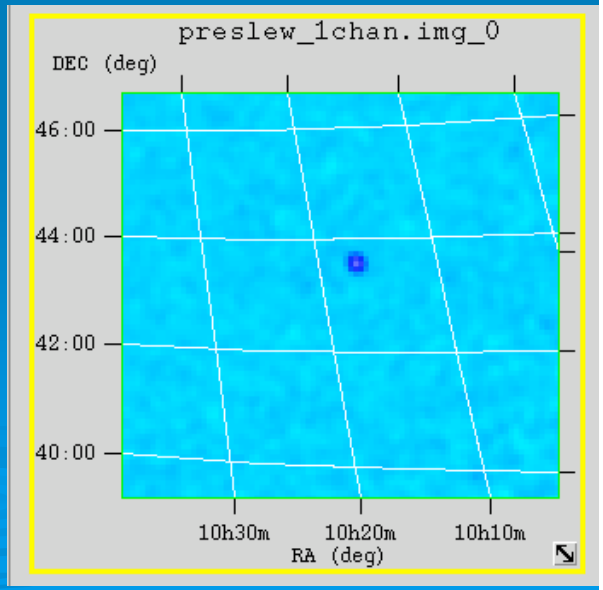
  - %> batbinevt grb.evt tmp.lc LC 0.04 uniform 15-350 weighted=YES
  - %> battblocks tmp.lc bb.gti durfile=dur.gti bkgsub=YES countscol=RATE
- Duration intervals are also in TDRSS

GRB durations

```
-----------------------------------------
  Estimated T90 duration: 149.768 s +/- 0.466039 s
  Estimated T50 duration: 124.148 s +/- 0.064 s
  Estimated Peak Interval: MET   132917479.19600001 +/- 0.500000 s
  Estimated background rate 1:       -0.001 near MET 132917260.898000 s
  Estimated background rate 2:        0.001 near MET 132917640.324000 s
  Estimated total duration: 156.772 s (for data selection)
       (from MET 132917343.796000 to MET 132917500.568000)
  Estimated total fluence: 2.364724 count
  Created GTI with 11 entries
-----------------------------------------
```

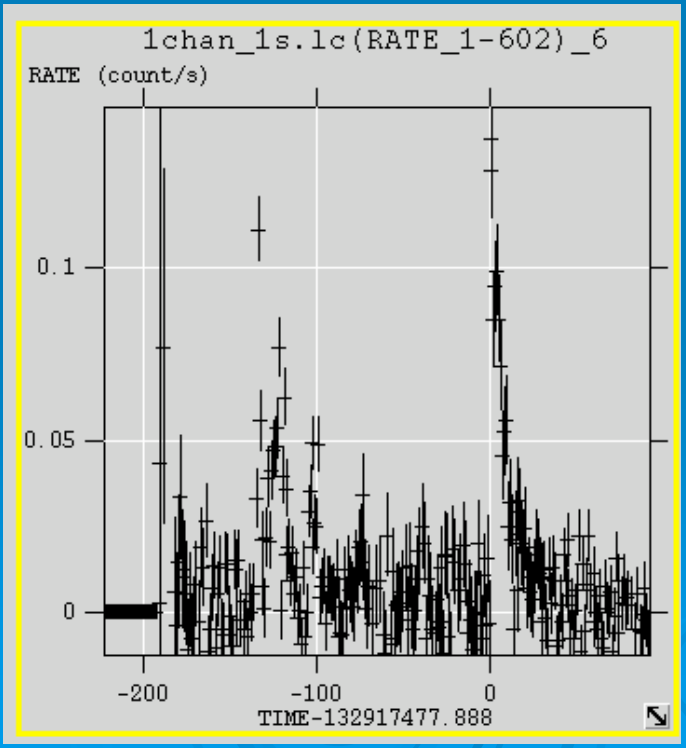
Detect and Refine GRB position

- Make sky image from pre-slew data:
  - %> batbinevt preslew.evt preslew.dpi DPI 0 uniform 15-350 weighted=NO gti=gtiTOT detmask=qmap.fits
  - %> batfftimage preslew.dpi preslew.img attitude=sat.att
- Detect the GRB:
  - %> batcelldetect preslew.img soure.cat incatalog=Xray.cat
  - GRB fsw coords: 154.2017, 43.54632
  - GRB refined: 154.1966, 43.5675



Make Light curves

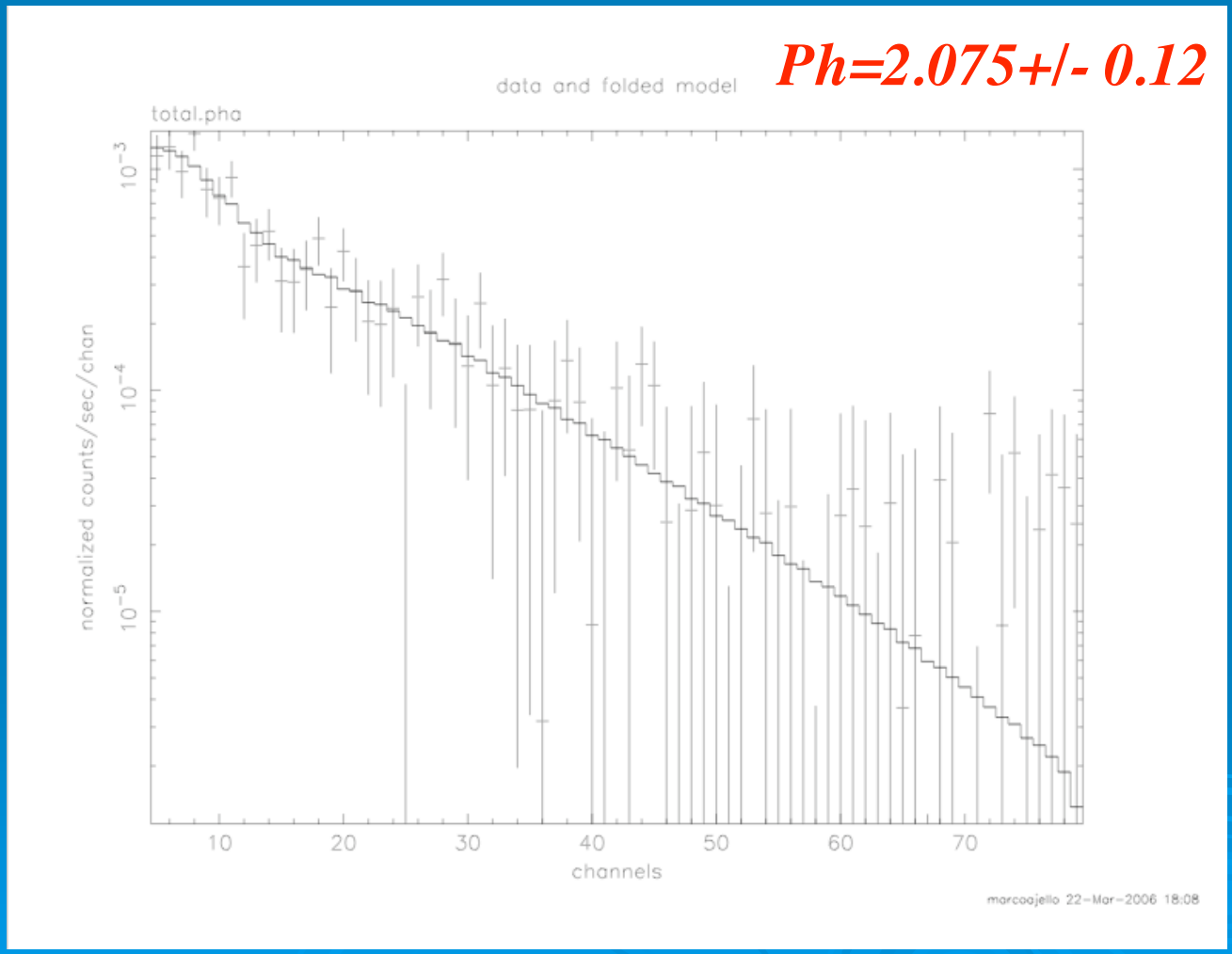
- On all timescales weighted/un-weighted
  - %> batbinevt grb.evt 1chan_1s.lc LC 1 uniform 15-350 detmask=qmap.fits gti=none weighted=YES



Make Spectra (almost at the end)

- T90, T50, Peak, Total
  - %> batbinevt grb.evt total.pha PHA 0 uniform CALDB detmask=qmap.fits
- Change position keywords:
  - %> batupdatephakw total.pha auxfile
- Apply systematic errors:
  - %> batphasyserr total.pha CALDB
- Generate response:
  - %> batdrmgen total.pha total.rsp NONE

Make Spectra (almost at the end)



Fluence

- Peak fluence:
  - %> batbinevt grb.evt peakflu.pha PHA 0 uniform 15-25,25-50,50-100,100-35 outunits=counts gtifile=dur.gti[GTI_PEAK]
- Total fluence:
  - %> batbinevt grb.evt totalflu.pha PHA 0 uniform 15-25,25-50,50-100,100-35 outunits=counts gtifile=dur.gti[GTI_TOT]

Pages to monitor

- http://swift.gsfc.nasa.gov/docs/swift/analysis/
  - BAT user's guide, bug status, BAT digest, BAT analysis thread
- Quick tutorial on how to analyze BAT GRB data (not completely correct):
  - http://www.swift.ac.uk/BAT.shtml

Reminders

- Pay attention to GTI selections: slew/no-slew
- Try several T-binning to assess durations: T90-T50
- Monitor the HEADAS software release for the bat-burst-advocate script