BAT Data Analysis Software

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Overview

- How does the BAT work?

- Dispelling some "X-ray Astronomy" Misconceptions

- BAT Flight Products
  - GRB
  - Survey

- Analysis tasks
  - Detection of new sources (imaging)
  - Analysis of known sources
  - "Science housekeeping"

- Products to expect

How Does the BAT Work?

- Coded mask casts "unique" shadowgram for each point on sky

- Mask tiles 5 mm random; cut-outs for mechanical support

- Detector array; 4 mm on 4.2 mm pitch; 32k detectors w/ gaps

- Point spread function ~17' FWHM; centroiding <1' for bright sources

- Detecting new sources, analyzing known sources both require correlating the mask pattern with the detected counts

BAT Mask
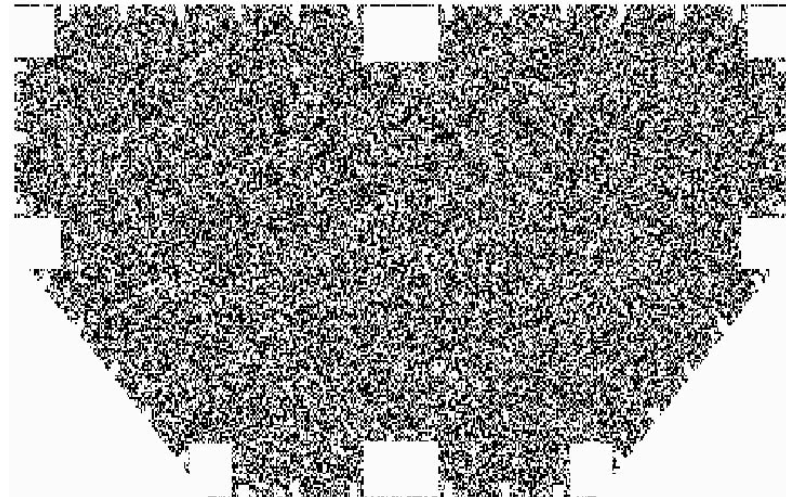
BAT Detectors

BAT Mechanical Layout

2.4 m

Mask

41.036

h = 1.0 m

Detectors

(3.082)
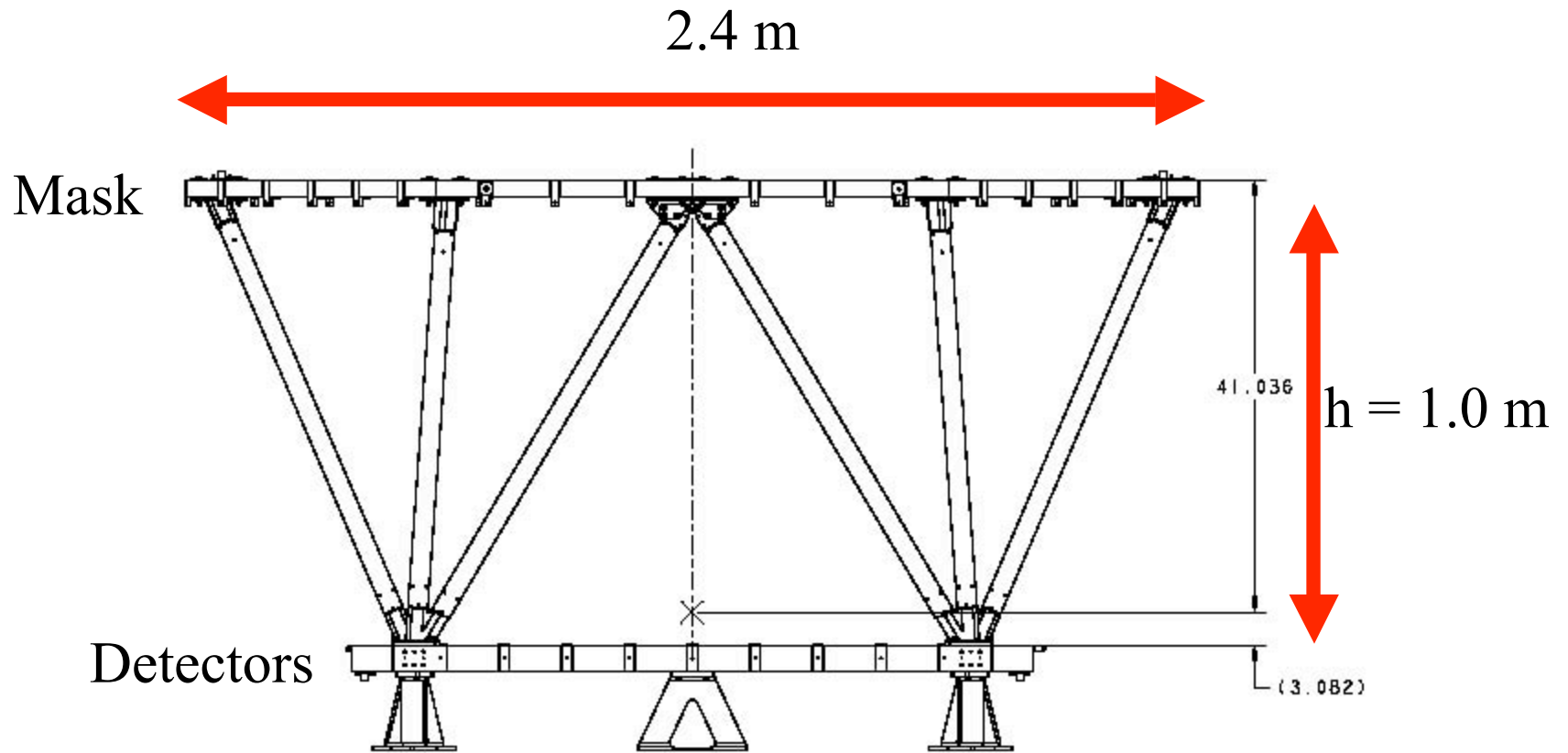
Avoiding "X-ray Astronomy" Misconceptions

- No focussing optics
- Each detector can be illuminated by **many points on the sky**; and
  Each point on the sky illuminates **many detectors**
- CANNOT "select photons" for a source of interest as in X-ray imagers
- Two distinct spaces:
  - Detector space
  - Sky space
- Transform between two spaces with special cross-correlation software
- BAT is wide field;
  - Shadow patterns for sources in field of view will overlap
- Normally background dominated
  - 1 Crab = ~10% of background

Detector Space
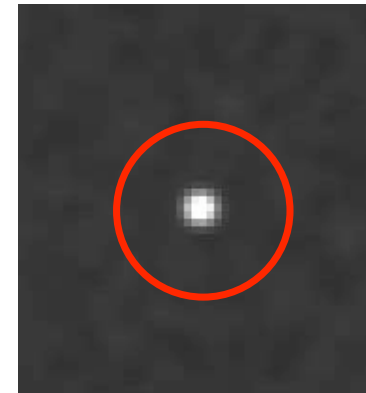
Sky Space
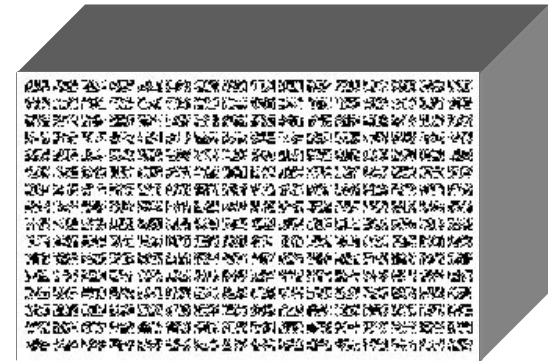
BAT Flight Products

- ## GRB

  - ### Event data - ~10 minutes bracketing burst only

    - High time / energy resolution studies
    - Ability to make light curves / spectra during slew
    - Available at next ground station pass (few hours)

  - ### TDRSS

    - Available in tens of seconds via GCN subscription
    - Alert message for rate triggers
    - Position "Ack" message for confirmed image triggers
    - Light curve: 4-channel bracketing burst
      (includes attitude information, but no background subtraction)
    - Position "Nack" for no image trigger

BAT Flight Products (cont'd)

- ## Survey

  - ### When BAT is not following GRB

  - ### Detector Plane Histograms accumulated on-board, nominal ~5 min interval, 80-channel energy resolution

  - ### Only during pointings

  - ### Individual detector spectra are preserved (variable bin size, oversamples energy resolution)

BAT Flight Products (cont'd)

- ## Rates
  - Full array: 1 sec & 64 ms (4-channel) light curves
  - Per-quadrant rates: 1.6 s (4-channel) light curve
  - "Mask tagged" rates:
    - 1.6 s (4-chan) light curves
    - Up to three sources of interest per field (including GRB)
    - Ground processing to reconstruct background subtracted rates
  - Primarily in ready-to-use formats (OGIP light curves)
- ## Housekeeping
  - BAT electronics are self-calibrated (autonomous pulser + Am-241 calibration spectrum)
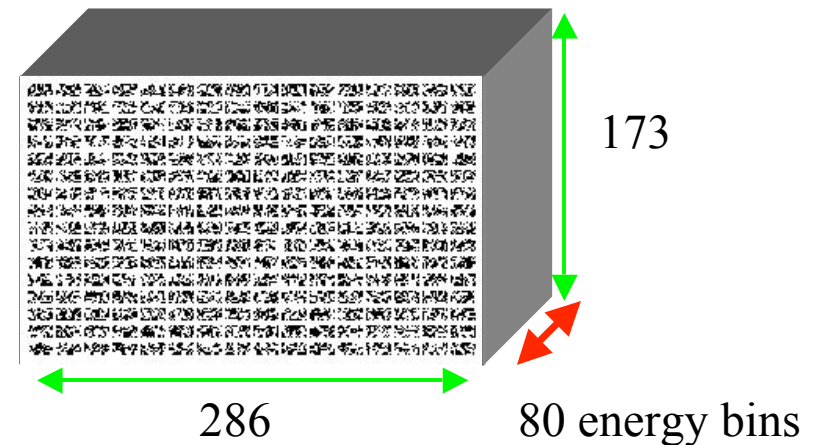 - Array diagnostics (currents, voltages, temperatures)

Main New BAT Data Types

Detector Plane Image (DPI) Detector Plane Histogram (DPH)

1 energy band

173

286

173

286 80 energy bins
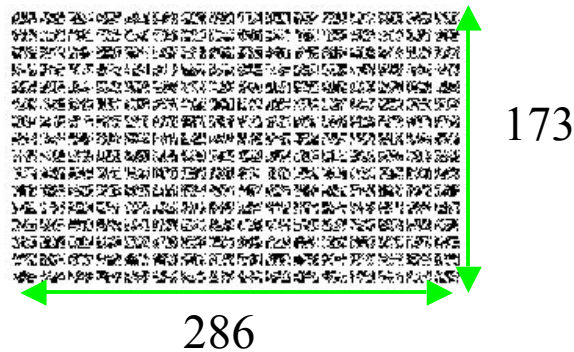
- Other formats similar to standard X-ray missions:
 Events, rates, etc.

Main BAT Analysis Tasks

- Detection of new / known sources
  - `batfftimage`: Sky images
  - `batcelldetect`: Source detection

- Analysis of already-detected sources
  - `batmaskwt{evt,img}`: Mask shadow computation
  - `batbinevt`: Extraction of light curves, spectra

- Scientific housekeeping
  - `batdrmgen`: spectral response
  - `bathotpix`: filtering for noisy pixels
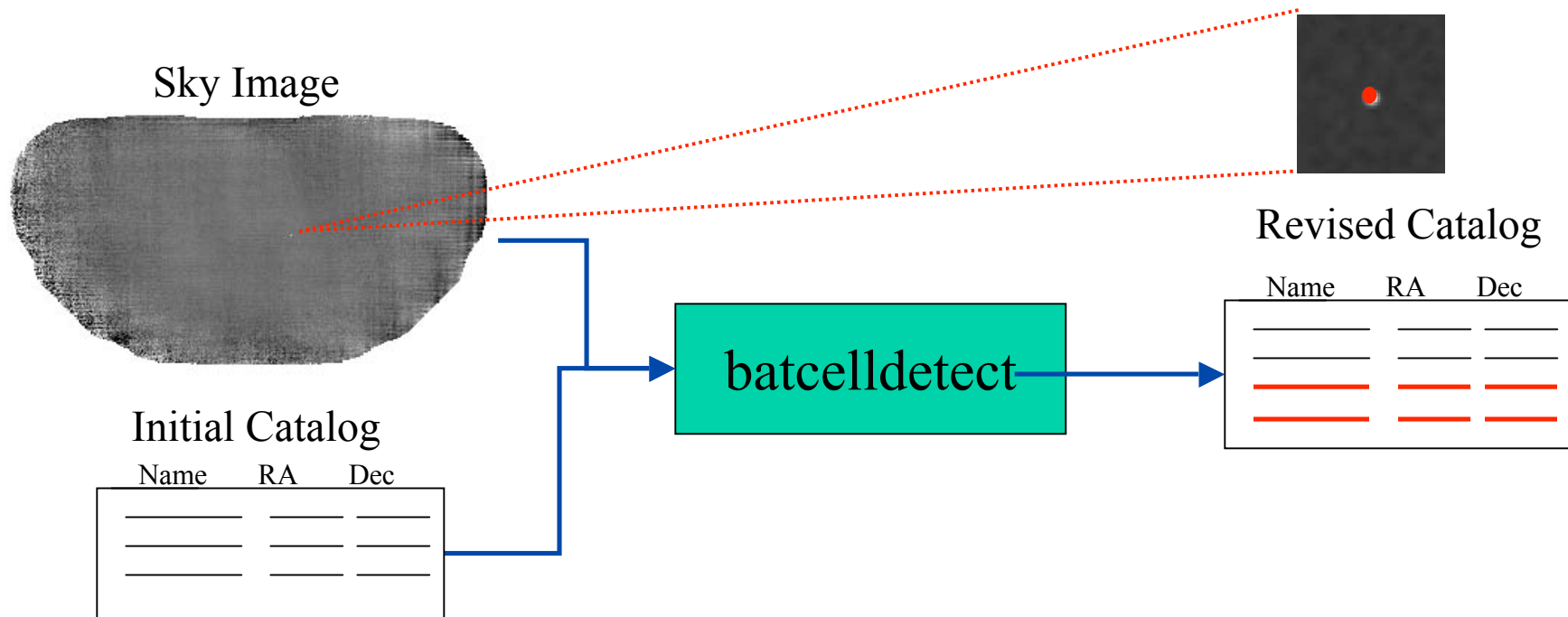 - `batfftimage`: partial coding map

batfftimage: Sky Images

Aperture Pattern

DPI

batfftimage

Sky Image
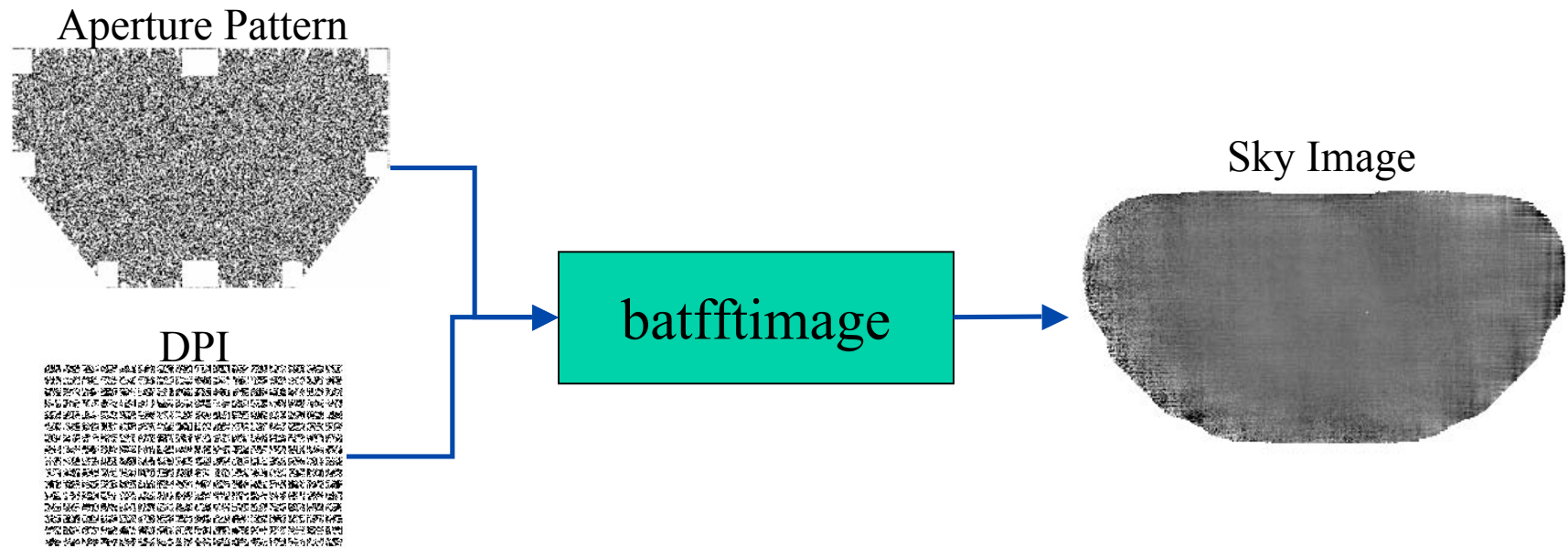
- Cross correlate mask aperture pattern with detector image (search all possible points on sky)
- Standard viewing with fv or ds9
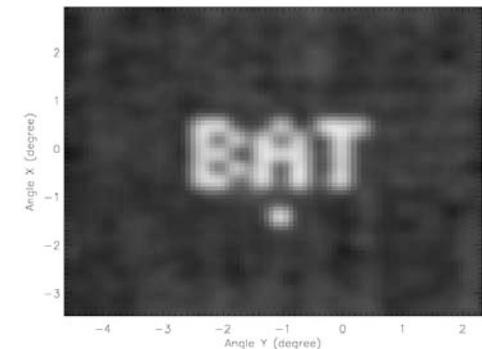
batcelldetect: Detect Sources

Sky Image

Revised Catalog

Name	RA	Dec

Initial Catalog

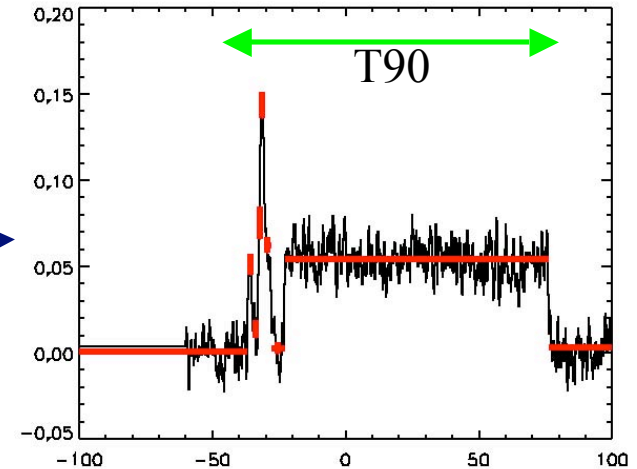| Name	RA	Dec

batcelldetect

- Detect new sources with celldetect algorithm (sliding filter), specialized for gaussian noise
- Fit PSF of detected sources
- Input: template catalog (INTEGRAL catalog accepted)
- Output: revised catalog with fluxes

battblocks: GRB segmentation and duration
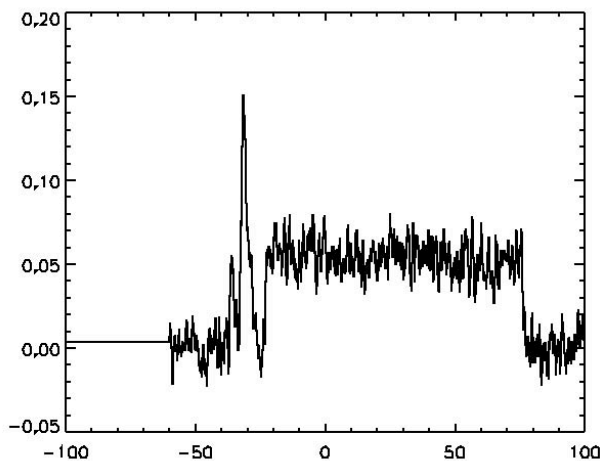
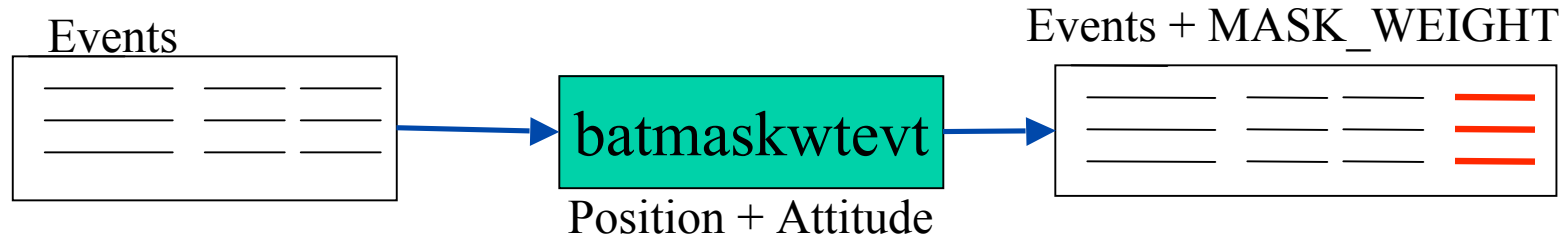Light curve or Events → battblocks → Bayes Blocks & Duration GTIs

- Segment GRB with Bayesian cost function (Scargle 1998)
- Burst duration and fluence measures
  - T50/T90/Peak intervals
- Output is GTI file, can use for binning or filtering in further analysis
- Not limited to BAT data

Specific Source Analysis

- Assumes you know source of interest (i.e. at least the position)
- Step 1: compute mask shadow weighting pattern for this position (`batmaskwtevt` or `batmaskwtimg`)
- Step 2: compute cross correlation to produce light curves or spectra (batbinevt)
- "Weighted" = Background subtracted

Step 1: Mask weight calculation

- ## Events: batmaskwtevt

Events   batmaskwtevt   Events + MASK_WEIGHT

Position + Attitude

- ## Survey: batmaskwtimg

batmaskwtimg

Position + Attitude

Mask weight map
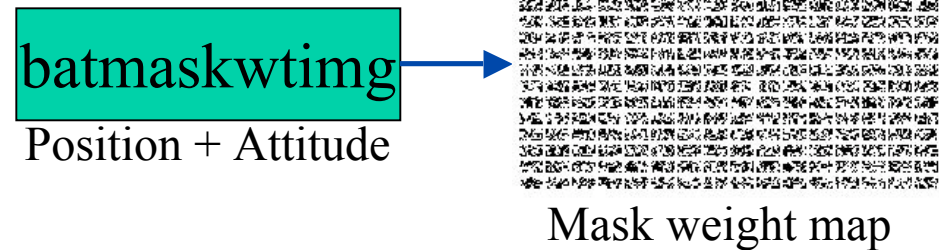
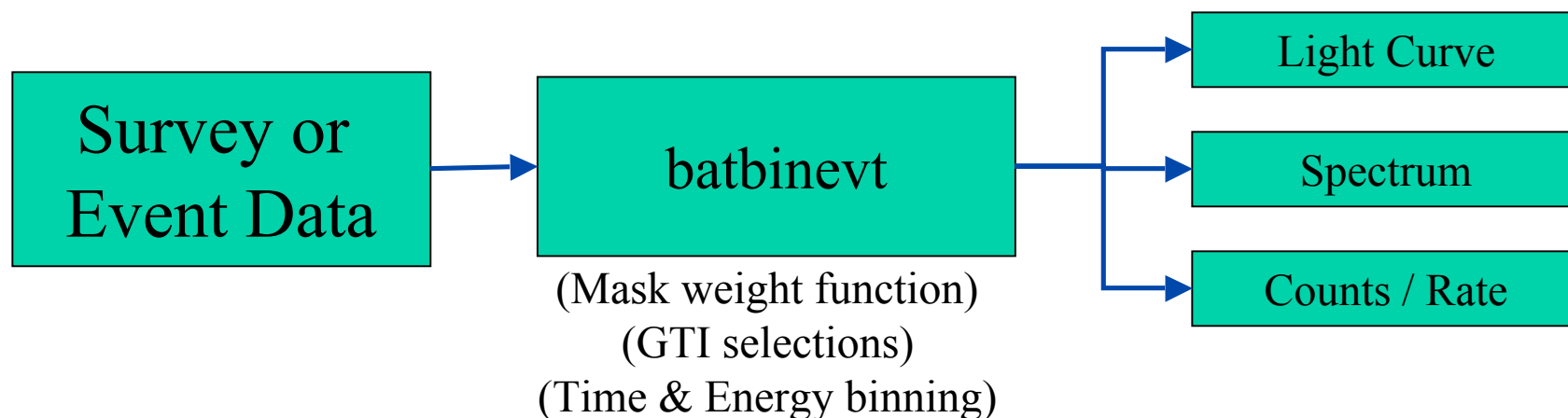# Step 2: Flux (batbinevt cross correlation)

```
┌──────────────┐        ┌──────────────┐        ┌─────────────────┐
│  Survey or   │───────▶│              │───────▶│   Light Curve   │
│  Event Data  │        │   batbinevt  │───────▶│    Spectrum     │
│              │        │              │───────▶│  Counts / Rate  │
└──────────────┘        └──────────────┘        └─────────────────┘
```

(Mask weight function)
(GTI selections)
(Time & Energy binning)

- User chooses desired time and energy binning, and output format

- Variable time binning allowed (input using GTI)

- Default units: counts per fully illuminated detector, corrected to on-axis (different pointings should be comparable)

- Pre-launch: 1 Crab = 0.039 ct/s/detector

batbinevt

- BAT-specific task comparable to 'extractor'
- Multi-uses
  - Weighted light curves, spectra
  - Unweighted light curves, spectra, images, reformatted detector plane histograms
  - Unweighted means
    - no background subtraction
    - variations due to other sources included
- Choice of time and energy bins
- Choice of output units (counts or rate)
- Choice of output formats

Cleaning

- Clean-type algorithm (= Iterative Removal of Sources) not fully complete

- Directly fit the detector images with template shadow and background patterns

- Will be enhanced / developed / streamlined as we gain experience with the instrument

Science Housekeeping: Noisy Detectors

- Single noisy detectors can upset correlation
- Disabled detectors create holes in detector plane
- `bathotpix` task detects noisy pixels

  Noisy detector light curve

  - Accepts detector plane image
  - Accept BAT enable/disable map
  - Produces quality mask
- `batfftimage` and `batbinevt` accept this mask and filter data accordingly
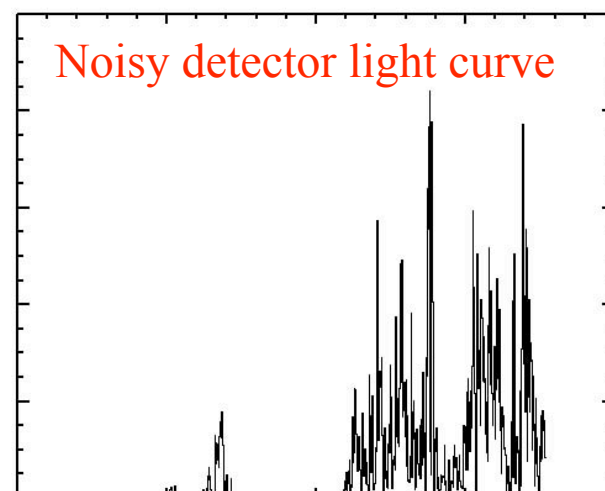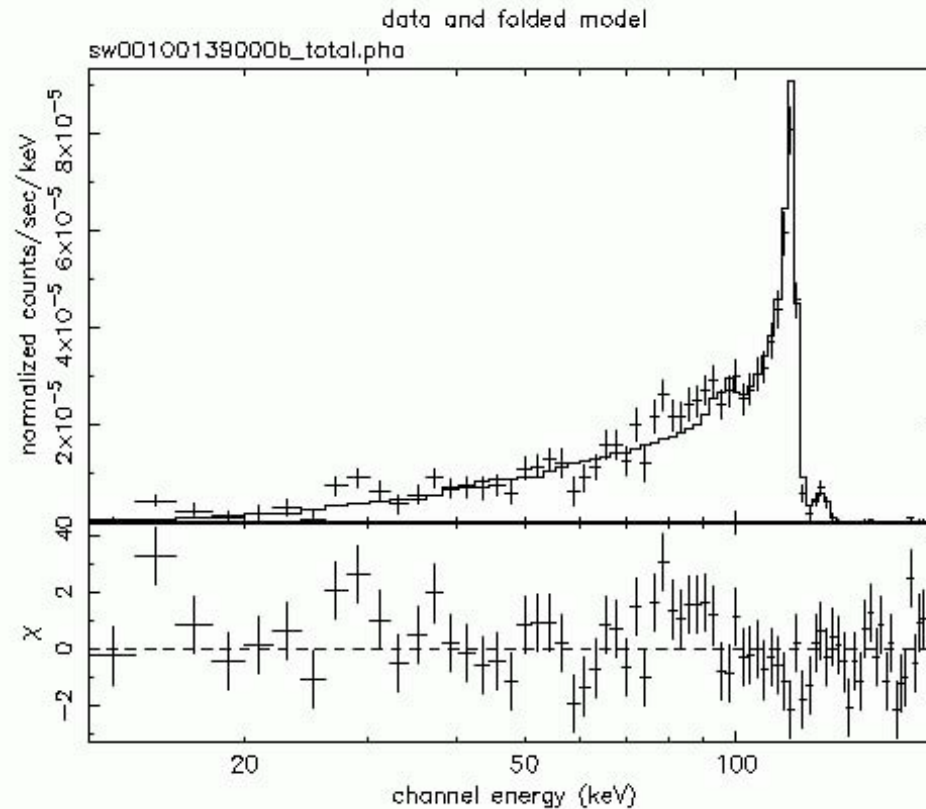
Science Housekeeping: Spectral Response

- `batdrmgen`: compute BAT spectral response matrix
  - characterized as a function of source position (source position stored in spectrum file)
- Spectra ("Type II" PHA) and RSP files are usable directly in standard XSPEC

| Spectrum	→	batdrmgen	→	Response Matrix

Example Spectrum (XSPEC Fit)

- Co-57 radioactive source used in environmental testing (shuttered source to simulate GRB)
- Lines at 122 keV & 136 keV

Science Housekeeping: Partial Coding

- "Partial coding" = fraction of detector plane exposed to a source
  - (varies depending on source position)
- `batfftimage`: has pcodemap option
- BAT images, light curves & spectra corrected for partial coding by default

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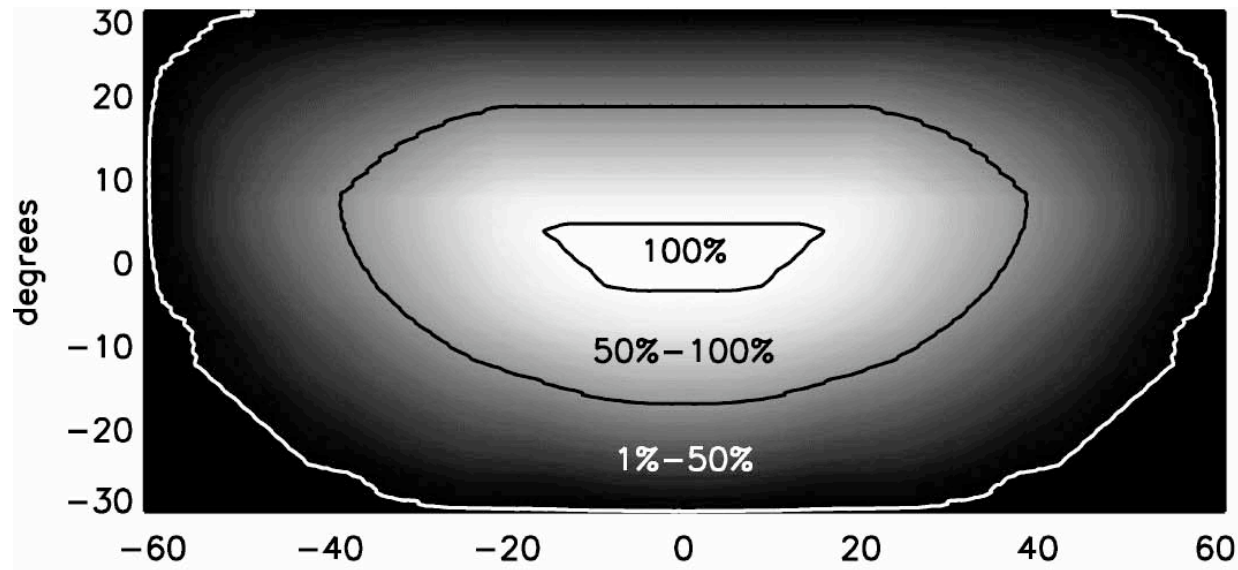
What to Expect

- GRBs
  - Light curves (several time, energy selections)
  - Spectra (several time selections) + responses
  - Images (pre-, during-, post-burst)
  - Duration measures & segmentations
  - Immediate TDRSS products
- Always
  - Standard rates, mask tagged rates per source
  - Survey histograms
  - Possibly flux determinations

Conclusions

- BAT software ready for GRB analysis
  - Source detection and Imaging
  - Temporal analysis
  - Flux / Spectral analysis
- BAT (& Swift) part of HEADAS system
  - Successor to FTOOLS, freely available
  - In development for several years in support of Swift and Astro-E2
- Calibration files delivered by standard CALDB

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