Calibration status of Swift BAT
Hard X-ray instrument

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Agenda

- BAT refresher
- Calibration philosophy
- Post-launch results
- Current status

Summary: BAT performance similar to post-launch, small detector gain shifts
Swift BAT

- Coded Mask
- Thermal Radiator
- Loop Heat Pipe (2)
- Detector Array (16 Blocks)
- Tagged Source (2)
- BAT Hardware Mounted on Spacecraft Bus
- Image Processor (2)
- Power Converter Box

Dimensions:
- 44”
- 37”
- 64.5”
### Swift BAT

- **Launched**: November 2004
- **Energy Range**: 15 - 150 keV (nom)
- **Field of View**: 2 Sr, partially coded
- **Spatial Resolution**: 21’ FWHM, centroid to 3’ position information
- **Spectral Resolution**: 3 keV FWHM, average
- **Sensitivity**: 0.2 photons/cm²/sec
- **Timing Accuracy**: 250 usec (knowledge; end-2-end)
- **Timing Resolution**: 100 usec
Calibration Approach

- Extensive pre-launch calibration activities
  - Set of radioactive line sources, primarily to determine gain and detector redistribution

- Post-launch calibration with Crab Pulsar+Nebula
  - In 15-150 keV band, the Crab is the most constant source
  - Refinement based on observations

- Continuing Mission
  - Monitoring of calibration performance
Crab First Light Spectrum
Post Launch Calibration
Philosophy

- Use 30-100 keV band as “good” calibration range
  - This fixes Crab shape and normalization
    - Power law photon index 2.15
    - Normalization 10.17 at 1 keV

- Adjust <30 keV and >100 keV to match canonical spectrum
  - Since launch in 2004, we have not altered the 30-100 keV response parameters
  - Low energy error interpreted as unmodeled passive material in BAT FOV (confirmed by off-axis behavior)
  - High energy error later confirmed to be high energy response modeling error (downscatter from <1 MeV) as well as mis-modeled detector physics MuTau parameters

- Standard analysis inserts systematic errors into spectrum files

- Long Term: Monitor calibration behavior
Post Launch BAT Residuals

![Residuals vs Energy Graph](image_url)
Before/After Correction

Not fitted
Models: $10.17 \times 10^{-15}$
Systematic Error Vector

- Applied to every spectrum with batupdatephakw
Long Term Monitoring

- Routine re-enabling of detectors (S. Barthelmy)
  - Typical number of enabled detectors: 22k of 32k
- Routine yearly calibration observations
  - Monitor flux and spectral shape performance of instrument at all off-axis angles
- On- and off-axis positions of Crab Nebula+Pulsar
  - On-axis
    - ± 30° in Y
    - ± 45° in X
- Work by CM, Amy Lien & Taka Sakamoto
Enabled Detectors
Monitoring Results: Shape

Crab Spectral Calibration

- Dec 16, 2004 - Apr 20, 2005
- Nov 10, 2005 - Nov 15, 2005
- Jan 22, 2009 - Jan 24, 2009
- Jan 20, 2010 - Jan 30, 2010
- Jan 13, 2011 - Jan 24, 2011
- Jan 15, 2012 - Jan 25, 2012
- Feb 20, 2013 - Feb 26, 2013
- Jan 21 - Jan 30, 2014; Feb 27 - Mar 3, 2014

Photon Index

Theta [deg]

2014-05-12
Monitoring Results: Flux

Crab Spectral Calibration

15-150 keV Flux [erg/s/cm^2]

Theta [deg]

Data points represent different dates and periods:
- Dec 16, 2004 - Apr 20, 2005
- Nov 10, 2005 - Nov 15, 2005
- Jan 22, 2009 - Jan 24, 2009
- Jan 20, 2010 - Jan 30, 2010
- Jan 13, 2011 - Jan 24, 2011
- Jan 15, 2012 - Jan 25, 2012
- Feb 20, 2013 - Feb 26, 2013
- Jan 21 - Jan 30, 2014; Feb 27 - Mar 3, 2014
On-Axis Performance

![Graph showing photon index and 15-150 keV flux over time from 2005 to 2014.]

- **Photon Index**
  - Values range from 2.15 to 2.35 with a trend of slight increase over time.

- **15-150 keV Flux [erg cm\(^{-2}\) s\(^{-1}\)]**
  - Values range from 1.7e-08 to 2.3e-08 with a slight variation over time.
Off-Axis (+Y)
Off-Axis (+X)
Centroiding Performance

![Graph showing detected vs true coordinates for different off-axis positions.]
Post Launch Gain Drift
Post Launch Gain Drift

- Array-average gain drift: ~4%
- Individual detector gain scatter: ~2%
- No change in electronics gain or offset
- INTEGRAL/ISGRI reports similar drifts
- We believe this is a gradual detector damage which reduces ability to collect all deposited charge
Gain Drift Corrected
Summary

- BAT 30-100 keV flux normalization and shape, based on pre-launch calibration, have not been “fudged” since launch
  - Post-launch calibration files & software still valid
- Low-energy error modeled as extra passive material
- Continuing performance
  - Detectors routinely re-enabled
  - Detector flux & shape performance constant to within known intrinsic Crab variability levels
  - Detector gain slowly varying (correction files to be announced)