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To my friend, David.
“That’s just the way it’s done.”
Burst Alert Telescope (BAT)

**BAT Detector Array**

- Coded Aperture Mask
- Graded-Z Shield
- Optical Bench
- Module Control Box
- Power Supply Box
- Radiator

**BAT Characteristics**

- E Range: 15 - 150 keV (12-300)
- E Resoln: 7 kev (5)
- Loc Resoln: 1-4 arcmin (1-4)
- PSF: 22 arcmin (21.8)
- 2 steradian field of view
- 32K CZT dets, 5200 cm²
- Autonomous operations
BAT Status

- 4.7 years and still doing fine.
- Still meeting all the Requirements.
- No hardware failures.
  - Except that LHP Heater Controller in 2005 (1 of 4 redundant).
- No degradation in any parameter:
  - GRB Detection Rate is constant.
  - Energy resolution is the same (7 KeV)
  - Increase in number of noisy detectors -- ~20%.
  - False triggers have decreased ("tuned" the trigger criteria).
BAT’s 3 Data Products

• GRBs
  – Stare mode
    • 439 from Dec 04 to July 9, 2009
      – 34 Short Hard Bursts
  – During slews
    • 11 in the 12 months of operations

• Hard X-ray Transients
  – The other things that go bump in the sky.
  – 10’s of triggered SGR events, 100’s untriggered.

• Hard X-ray Survey
  – AGN, Blazars, micro-quazars, BHs, …
BAT is Fast and Accurate

20% False positive on-board.
2% after real-time Ground processing.

50% w/in 18 sec.
75% w/in 40 sec.
90% w/in 175 sec.
Long delays caused by Malindi downlinks.
BAT Enables

- Because of the small error-circles in real time:
  - High redshift bursts:
  - Naked eye burst: 080319B
  - X-ray afterglow structure:
    - Flares
    - Plateau phase
Farthest Object in the Universe

GRB 090423
Z = 8.2
400 Myr

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An Even Farther Object ???

GRB 090709A

Maskweighted Lightcurve (1 s binning)

Counts/sec/det

Time since BAT trigger time [sec] (UT 2009–07–09T07:38:34.5)

Z = 10-ish ?!
BAT Enables

• Because of the small error-circles in real time:
• High redshift bursts:
• Naked eye burst: 080319B
• X-ray afterglow structure:
  – Flares
  – Plateau phase
GRB 080319B
First "naked-eye" Burst

Brightest Swift GRB: 25 ph/cm²/sec

\[ z = 0.937 \ (7.5 \text{ G light yr}) \]

Peak brightness of 5.6 magnitudes!!
(10x brighter than 990123)

*Pi of the Sky – still observing the “A” burst, caught “B” burst at edge of FOV.*
BAT Enables

• Because of the small error-circles in real time:
  • High redshift bursts:
  • Naked eye burst: 080319B
• X-ray afterglow structure:
  – Flares
  – Plateau phase
Typical Swift X-ray Lightcurves

50% with bright early component

~40% with flares

David Band Symposium, Jul09
The Flexible BAT

• BAT is able to adapt to the unknown.
  – But a lot of that unknown was scoped by David Band during the BATSE era.

• Produces a series of information to the spacecraft, the other 2 instruments, and the ground.

• Trigger criteria that cover a large dynamic range of phase space: time, energy, detector regions, and background.

• Changeable trigger criteria.

• Changeable data products.
BAT Post-Launch Enhancements

• DONE:
  – BAT Slew Survey (capturing the event data).
  – Long Image-triggers (>64 sec) changed from Transients to GRB response. (Going for hi-z bursts)
  – Catalog source-class Swift Response control
  – AT slewing to Known-source Transients
  – Transient Monitor (lightcurves) (ground work)
  – Redshift Prediction (ground work)

• ALMOST DONE:
  – SubThreshold: the fainter, the farther.

• FUTURE:
  – Catalog source-by-source Swift Response control
Lightcurves & Transients

• All-sky monitoring of source variability.
• [http://swift.gsfc.nasa.gov/docs/swift/results/transients/](http://swift.gsfc.nasa.gov/docs/swift/results/transients/)
• 718 objects monitored/public
  – ~114 are routinely/daily detectable by BAT.
• Pointing-by-pointing and Daily-average lightcurves
• 7 previously unknown sources (msec pulsar, 2 BH, …)
• ~68 ATELs published
• Future:
  – 2-day, 4-day, & 8-day averaged lightcurves.
  – Automating the search/discovery of transient behavior.
  – Into HEASARC
Example of NEW Source

- **Swift J1756.9-2508** msec pulsar
- Discovered in the Daily Image Mosaics
  - Lightcurve came afterwards.

![Graphs showing Swift J1756.9-2508 data with marks indicating Discovery.](image)
BAT Slew Survey (1of2)

- Harvard: Antonio Copete and Josh Grindlay (Harvard)
- Look for GRBs (& transients) when Swift is slewing (~15%).
- More sky coverage per day; each slew is 2-3x BAT FOV.
- Capture event-by-event data during slews:
  - 120 sec only (ie only part of the slew).
  - 40-60% of the slews each day.
- Somewhat better sensitivity due to systematics removal.
- Several trigger criteria:
  - single slew, and multi-slew time domains
  - Various Energy-band criteria: 15-50, 50-150, & 15-150 keV.
- Not real-time (hours delay).
New GCN Notice type for these detections: BAT_Slew_Pos

Discoveries:

- GRB 070326: “first light” (T+3.8 mo)
- GRB 080123: “flare” on the AT slew of a BAT-triggered burst (T+6 days)
- GRB 080130: essentially normal ops mode (T+11 hr)
- GRB 080605
- MXB 0656-072
- GRB 080613B
- GRB 080702B
- GRB or something else?
- GRB 081025
- GRB 081203B
- GRB 081211B
BAT to the Future

• Subthreshold bursts
  – Finds the bursts in the noise
  – Turning down the threshold: 6.5 --> ~5.6 sigma
  – Merit parameter controlled via scripts so the good Burst and Planned targets are not clobbered.
  – Shortened observation interval -- first orbit only.
  – XRT detection used to valid the good from the bad/noise.
  – Automated: Swift --> GCN --> U.Leicester --> GCN --> World
  – 2 GRBs in about 2 months of testing
  – Will go public in about a month
David Knew

- Understood the ramifications of BAT being softer than BATSE
  - The 15-150 keV vs 50-300 keV.
  - Lower E_Peaks, higher z.
- A little off on our low energy deficiency
  - But even we still do not understand that cause
- Predicted our sensitivity would be “around 90/yr”
  - We see 95/yr
How to do Autonomous Telescopes

Non-Robotic Telescope

Autonomous Robotic Telescope

David Band Symposium, Jul09
“That’s just the way it’s done”

David -- my friend.