Detector Triggers and Burst Populations

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WHAT IS BURST DETECTOR SENSITIVITY?

- A detector’s sensitivity is the threshold intensity at which a burst could have been detected.
- Rate trigger—the standard trigger looks for statistically significant increases in the detector’s count rate
  - The counts are binned over an energy range $E$ and an accumulation time $t$.
  - The background is estimated from the counts accumulated over a longer period beforehand. The fluctuation scale $s$ is the square root of the expected background in $t \times E$.
  - A statistically significant increase is a predetermined number of $s$.
- Complications:
  - May require a trigger in multiple detectors; for flat detectors with different orientations this introduces a variable threshold
  - After a rate trigger, may require that imaging finds a point source
HOW IS SENSITIVITY MEASURED?

- The most accurate sensitivity measure is the intensity the trigger measures, i.e., the peak count rate averaged over $\Delta E$ & $\Delta t$. But counts=instrumental, photons=physical. Because of imperfect efficiency and energy resolution, a spectrum is needed to translate this into a peak photon flux. Why translate to $\Delta E$, not some other energy range?

- Note that peak photon flux may not be the most interesting intensity measure physically.

- Because bursts are not constant for seconds, and burst lightcurves differ at different energies, peak fluxes over $\Delta E_1$ & $\Delta t_1$ and $\Delta E_2$ & $\Delta t_2$ cannot be compared directly.

- A numerically better (=smaller) sensitivity over a different $\Delta E$ & $\Delta t$ does not mean that fainter bursts can be detected.

- The number of bursts and their type depends on the detector and its trigger.
How Many Bursts Are There?

- Since the entire burst population has not been sampled, the answer depends on $E$ & $t$.
- BATSE provided the best determination of the burst rate.
  - Initial report of 800 bursts/yr/sky underestimated the observing efficiency
  - Current number is 666 bursts/sky/yr above BATSE’s threshold
  - BUT, this threshold was not sharp. BATSE was ~82% complete above $f=0.3$ ph/cm$^2$/s.
- Correcting for completeness, etc., the burst rate is 550 bursts/yr/sky for $t=1.024$ s and $E=50-300$ keV above $f=0.3$ ph/cm$^2$/s.
  - BATSE actually had $t=0.064$, 0.256, and 1.024 s.
  - Usually $E=50-300$ keV, but other energy bands tried.
- But what does this mean in terms of hard bursts? Soft bursts? Long bursts? How can we estimate the burst rate of a detector with different energy sensitivity (e.g., Swift)?
• Usually trigger sensitivity $1/\Delta t$
• But peak fluxes are usually smaller on longer timescales
• Therefore, increasing $\Delta t$ does not mean that bursts a factor of $\Delta t$ can be detected
• Could there be populations of very long or very short bursts that are not detected?
• Studies of untriggered BATSE bursts did not find many very long bursts.
• A study of the 100 brightest BATSE lightcurves using all possible $\Delta t$ shows:
The average increase in sensitivity relative to \( t=1 \) s is only a factor of 1.6!
There were not a large number of bursts where the greatest sensitivity was for small $\Delta t$. 
ENERGY DEPENDENCE

- How do we compare detectors with different efficiencies and trigger $\tau E$?

- Use a fiducial peak photon flux $F$—i.e., always use the same energy band.
  - A spectral shape must be assumed
  - I propose 1-1000 keV to cover hard and soft spectra

- Study sensitivity as a function of the spectrum’s hardness. Burst spectra can be approximated as

$$N \ E^{\alpha} \exp[-E/E_0] \text{ at low energy}$$

$$N \ E^{\beta} \text{ at high energy}$$

The peak of $E^2 N \ f_\alpha$ occurs at $E_p=(2+\alpha)E_0$. $E_p$ is a measure of spectral hardness.

- To eliminate the dependence on $\tau t$, use $\tau t=1$ s.
Bursts will populate the $E_p$-F plane, while the detector sensitivity is a curve through the $E_p$-F plane.

There remains a residual dependence on the high and low spectral indices, $\beta$ and $\alpha$.

Because of varying background and (in some cases) the requirement that $\geq 2$ detectors trigger, detector sensitivity will vary with time and over the FOV. I use the maximum sensitivity (minimum F).

$E_p$ and F are for the peak of the lightcurve. Unfortunately, rarely are spectral fits presented for this peak. Thus we do not have the data to populate the $E_p$-F plane with bursts. But hardness ratio-intensity plots indicate general trends.
Solid line—$a = -1, b = -2$; dashed line—$a = -0.5, b = -2$; dot-dashed line—$a = -1, b = -3$. 
SWIFT—INCREASED LOW E SENSITIVITY

Solid line—$a = -1, b = -2$; dashed line—$a = -0.5, b = -2$; dot-dashed line—$a = -1, b = -3$. 
Solid line—$a = -1, b = -2$; dashed line—$a = -0.5, b = -2$; dot-dashed line—$a = -1, b = -3$. 
Kippen et al., 2002, Woods Hole GRB Workshop. Note that $F$ and $E_p$ are reversed.
SUMMARY

• Detector sensitivities with different sets of $E$ and $t$ cannot be compared directly.
• A variety of accumulation times $t$ will increase a detector’s sensitivity, but not by large factors.
• Detector comparisons should be done in the $E_p$-$F$ plane.
• BATSE found that the burst rate is 550 bursts/yr/sky for $t=1.024$ s and $E=50-300$ keV above $F=0.3$ ph/cm$^2$/s. This translates into a rate for a region of the $E_p$-$F$ plane.
• Swift and BATSE will have comparable sensitivities above $E_p=100$ keV, while Swift will be much more sensitive at low energies.
• As expected, the GBM NaI detectors will be significantly less sensitive than BATSE.
• The LAT will be interested in high $F$, high $E_p$ bursts.
FLUX RATIO FOR DIFFERENT ENERGY BANDS

Solid line—$a = -1$, $b = -2$; dashed line—$a = -0.5$, $b = -2$; dot-dashed line—$a = -1$, $b = -3$. 
Expected GBM Detection Rate

- Assume triggering on 50–300 keV band in $\Delta t=1$ s time bins. A 4.5$\Delta t$ increase in the 2nd brightest detector is equivalent to $\sim$6.5$\Delta t$ in the LAT FOV. This results in a threshold peak flux of $f_0=0.814$ ph s$^{-1}$ cm$^{-2}$.

- Based on the BATSE-observed burst rate $N_{\text{sky}}=(0.814/0.3)^{-0.8} \times 550=\sim250$ bursts/sky/year

- Different $\Delta t$ increases detection rate by $\sim$50%, giving $N_{\text{sky}}=\sim370$ bursts/sky/year
  - Within 55° FOV $\sim80$ bursts/year
  - Within 72.5° FOV $\sim130$ bursts/year
  - Within $\sim$1/2 sky, $\sim185$ bursts/year.
Empirical LAT Detection Rate

- Extrapolate BATSE spectra to LAT energy band:
  1) The Preece et al. (2000) catalog of ~5500 time resolved spectral fits from 156 high flux, high fluence bursts
  2) The spectral fits to ~1400 bursts by Mallozzi et al.

- The number of bursts is normalized by BATSE rate. The high energy spectral index is forced to be <-1.8. Spectral extrapolations are folded with the LAT effective area for different inclination angles, and the results are integrated over inclination angle.

- Limitations: too few strong bursts, incompleteness at faint end, lack of spectral resolution.
Empirical Prediction

![Graph showing empirical prediction of bursts per year versus counts per burst. The graph compares the Mollozzi Sample and the Preece Sample.]