Detection and Localiztion of Short Gamma-ray Bursts

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What are Gamma Ray Bursts

- Most energetic explosions in the universe ever happened after Big Bang with energies about 10^{52} - 10^{54} ergs released within a few seconds primarily in gamma ray frequencies.
- Detected by Vela satellites which were primarily built by USA to monitor nuclear activities of Soviet Union and other countries signing Nuclear Test Ban Treaty.
- Last for several milliseconds to few minutes - Long and Short Gamma Ray Bursts.
- Light curve, in the first half, greatly evolves with time. Luminosity at peak and the sharpness (or 'spikiness') of peaks are correlated to the total energy output.
- GRB Afterglow

Basic Observational facts

- Prompt emission
- Spectrum - Non thermal, peaks at order of $100KeV$.

$$N(\nu) = N_o(h\nu)^{\tilde{\alpha}} e^{h\nu/E_o} \text{ for } h\nu < (\tilde{\alpha} - \tilde{\beta})E_o \quad (1)$$

$$N(\nu) = N_o[(\tilde{\alpha} - \tilde{\beta})]^{(\tilde{\alpha}-\tilde{\beta})E_o} \text{ for } h\nu > (\tilde{\alpha} - \tilde{\beta})E_o \quad (2)$$

For most GRBs $\nu F_\nu \propto \nu^2 F_\nu$ and peaks at $E_p = (\tilde{\alpha} + 2)E_o$. Despite these general features, wide variation exists.

Basic Observational Facts

- Temporal properties -
  - T_{90} and T_{50}
  - Bursts are composed of individual pulses that form the overall light curve
  - Each pulse consists of a fast rise and and exponential decay with rough ratio of durations as $1:3$
  - Low energy emission is delayed wrt high energy emission
  - Low energy light curves are wider
  - Higher energy pulses are more symmetric with shorter lags
  - Pulse become soft as it decays
- Polarization - Evidence of some polarization is established, but its time evolution and the effect of dust in host galaxies is yet to be studied.

Challenges of detection

- GRBs are unpredictable and last for very short time. Thus very difficult to detect and localize an event
- Afterglow needs to be recorded as soon as the GRB occurs to properly study the evolution
- Lot of coordination across different telescopes is needed to study GRB properly
- Since gamma ray photons are energetic, GRBs emit far lesser photons than an equivalent energy source at lower wavelengths. This leads to the need to have high exposures and hence the spatial resolution decreases
- Need for a suitable material for detector as gamma rays pass through almost all materials.

Detection Technology

- Gamma rays are studied by looking at the interaction between the gamma ray and the detector.
- Types of interaction between gamma ray photon and material-
  - Compton scattering by the electrons before escaping the material/getting completely absorbed
  - Pair production and annihilation

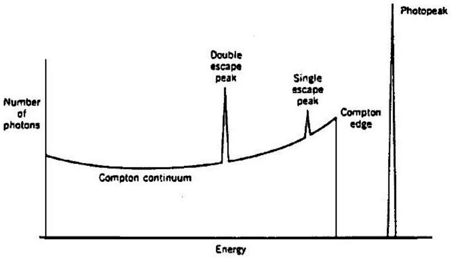


Figure : Interaction of gamma ray with detectors [2]

Gamma ray Detectors

- Compton Scattering detectors
- Pair telescopes
- Air Cherenkov detectors

CZTI components and placement

- Total detector area of $976 cm^2$ through the use of 64 modules arranged in four identical and independent quadrants
- CZT detector is interfaced to a radiator plate which maintains an operating temperature of 0 to 15 deg Celsius by passive cooling.
- Instrument is mounted on the satellite deck with the radiator plate looking in the direction of the satellite's positive Yaw axis.
- Collimators above each detector module restrict the Field of View to 4.6 x 4.6 (Full Width at Half Maximum) at photon energies below 100 keV. At energies above that the collimator slats and the coded mask become progressively transparent.
- For Gamma Ray Bursts, the instrument behaves like an all-sky open detector.

CZTI components and placement

- CZTI carries a Cesium Iodide (TI) based scintillator detector operated in anti-coincidence with the main CZT detector and it is called the Veto detector.
- Gap of about 8 cm between the base of the collimator slats and the detector plane, in order to accommodate a radioactive calibration source module in each quadrant
- The four quadrants are electrically independent and communicate, digitally, only with the Processing Electronics (PE) box
- The PE handles all interfaces (including detector interface) and houses the onboard software designed for the optimum performance of the payload.

Modes of Operation

- Normal Mode
- SAA mode
- Shadow mode
- Secondary Spectral mode

Background estimation

- Primary background noise are cosmic diffuse gamma rays and gamma-rays originating from the satellite structure (spallation background) due to the interaction of cosmic rays
- To distinguish these background counts from the real source counts a slab of CsI is placed under each block of CZT
- The high energy photons which deposit energy in CsI as well as CZT are rejected by anti coincidence techniques and hence do not contribute to the background counts in CZT
- Photons which deposit partial energy in CZT but do not interact in the CsI block generate background counts

Detecting and Localizing Short Gamma-ray Bursts

- **Necessity:** Further study of SGBs in afterglows. To have a better understanding of the whole family of GRBs and astrophysical transients in extremity.
- **Challenges:** One-time event. Lasts for several ms. Rarer than LGBs. Hidden under noise and background effects. Large area detector- large FOV - less precision.
- **Motivation:** No efficient automated algorithm to detect and remove noises for detecting SGBs. Include space, time, energy (and if possible polarization) simultaneously.

Detecting and Localizing Short Gamma-ray Bursts

Process

- *Detection of Noise:*
  1. Detction of peaks in the light curve beyond $n\sigma$ (μ and hence σ to determine)
  2. Construction of Detector Plane Histogram (DPH) and identify noise
- *Localization:*
  1. Simulate DPH for all possible combinations of θ_x and θ_y
  2. Compare DPH of detected SGB with simulation
  3. In case of mismatch in confidence interval infer systematics.

Histogram of difference in time stamps

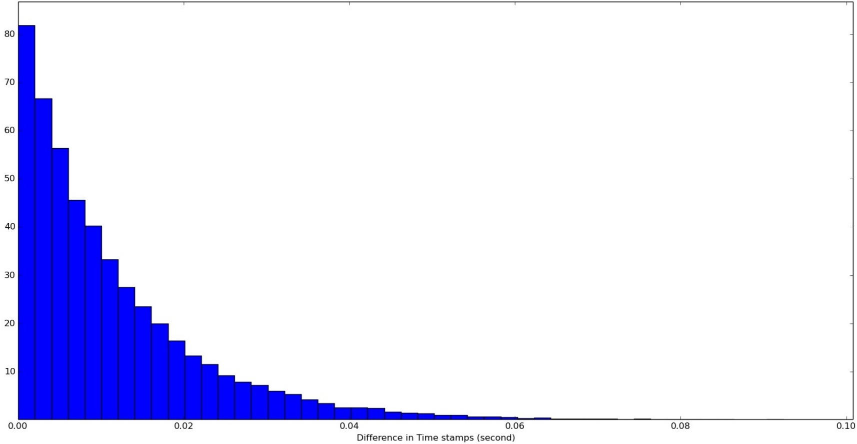


Figure : Histogram of difference in time stamps (in sec) in First Quadrant

Histogram of difference in time stamps (Continued..)

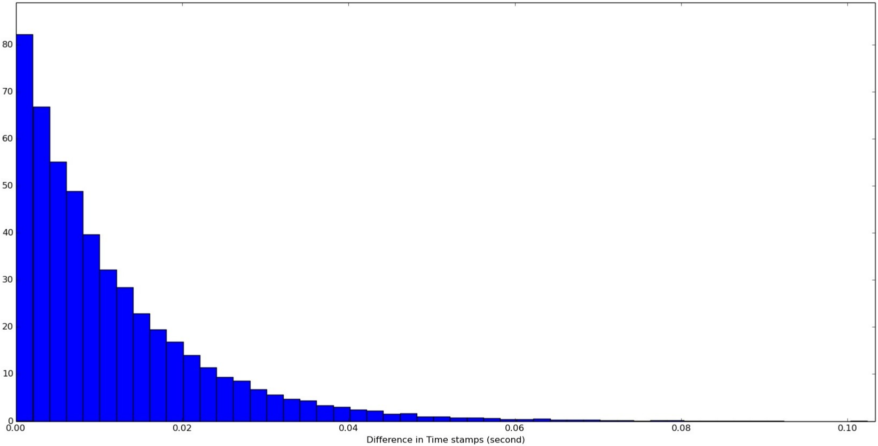


Figure : Histogram of difference in time stamps (in sec) in Second Quadrant

Histogram of difference in time stamps(Continued..)

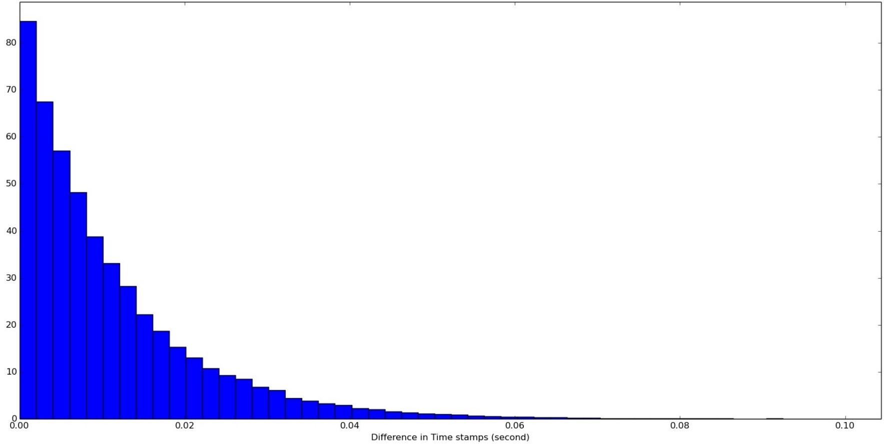


Figure : Histogram of difference in time stamps (in sec) in Third Quadrant

Histogram of difference in time stamps(Continued..)

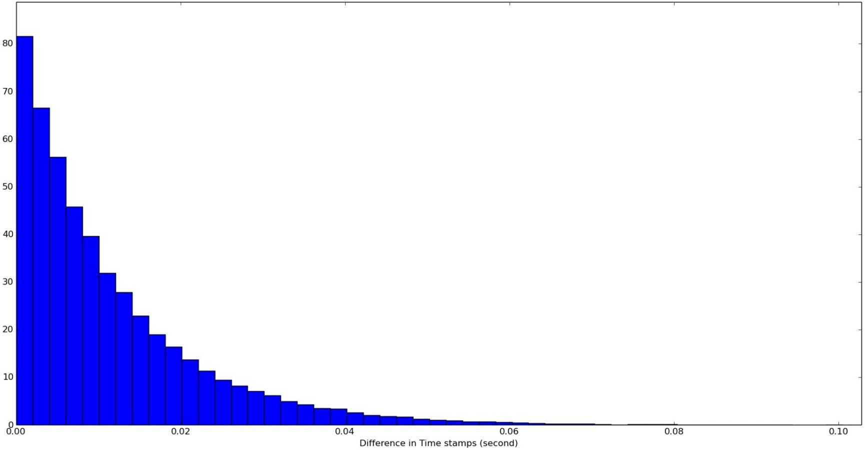


Figure : Histogram of difference in time stamps (in sec) in Fourth Quadrant

Light Curves

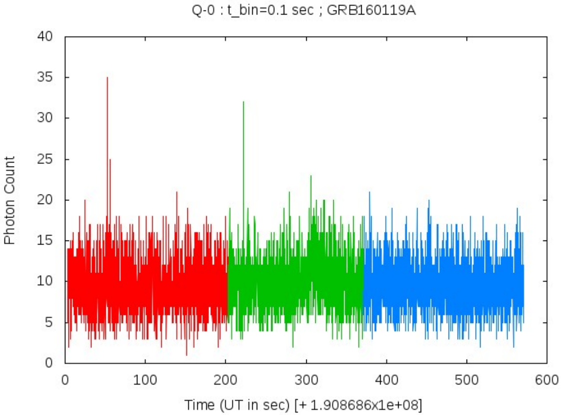
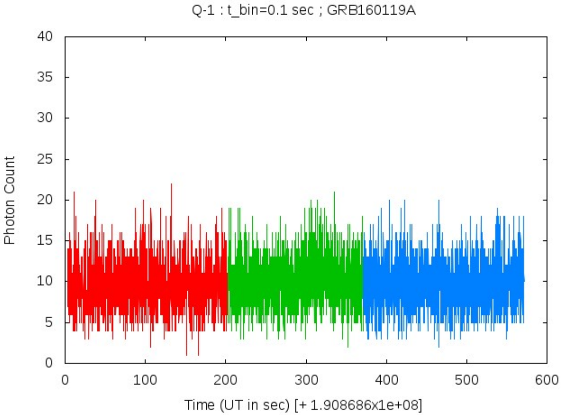


Figure : Light Curve in First Quadrant(Green part is during trigger)

Light Curves (Continued..)



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Light Curves (Continued..)

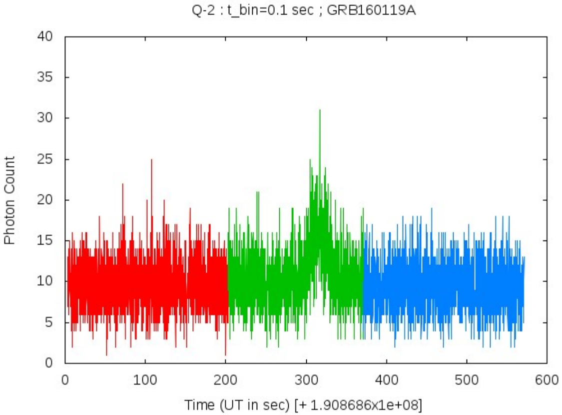

Figure : Light Curve in Third Quadrant(Green part is during trigger)

Light Curves (Continued..)

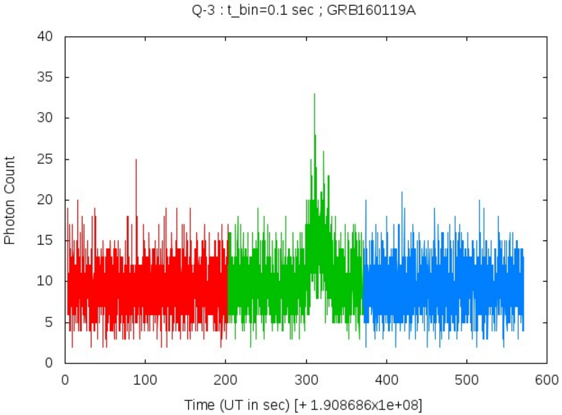

Figure : Light Curve in Fourth Quadrant(Green part is during trigger)

Extension in Higher Dimensions

Basic Principle: Criterion- detected in several pixels nearby (within a certain radius) within a small time interval.

Measure $R_{equiv} = \sqrt{(\frac{d}{d_0})^2 + (\frac{t}{t_0})^2}$ for all events and filter beyond a certain $R_{threshold}$.

Conclusions

Results and Future Possibities:

1. Obtained Light Curve of GRB160119A.
2. Showed Peak detection and DPH construction might give false signals.
3. Idea of automated process to detect and remove noise. If energy included , will be more efficient.

References

- Gamma-Ray Burst Physics, http://www2.astro.psu.edu/users/nnp/grbphys.html
- DETECTION OF GAMMA RADIATION, https://www.jyu.fi/science/opiskelu-ohjeet/fysiikka/tyoosasto/tyoosasto-fysiikka-import/tyoosasto/gamma_radiation.pdf
- Cadmium Zinc Telluride Imager, Astrosat Handbook,Chapter 5, http://astrosat.iucaa.in/czti/documents/cztdocs/v1.6-Chapter5_CZT_06May15.pdf

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Thank you