Measuring GRB Polarization using AstroSat CZTI

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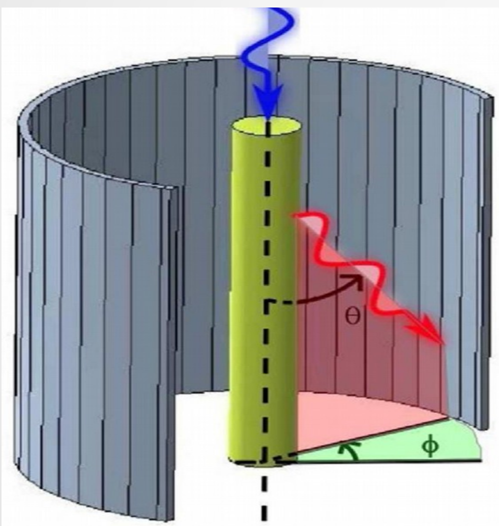
On behalf of AstroSat-CZTI Team

Gamma Ray Bursts – Prompt to Afterglow
7 July 2017, NCRA

COMPTON POLARIMETER

- Compton scattering – Direction of scattered photon depends on polarization angle of incident photon.

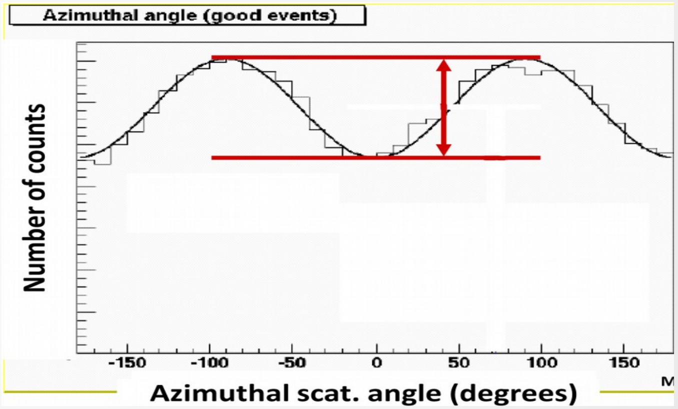


$$\frac{d\sigma}{d\Omega} = (\frac{{r_o}^2}{2})(\frac{v'^2}{{v_o}^2})(\frac{v'}{v_o} + \frac{v_o}{v'} \; - 2sin^2\theta cos^2\phi)$$

COMPTON POLARIMETER

$$C(\phi) = A\cos(2(\phi - \phi_0 + \frac{\pi}{2})) + B$$

$$\mu = \frac{A}{B}$$



$$P = \frac{\mu_P}{\mu_{100}}$$

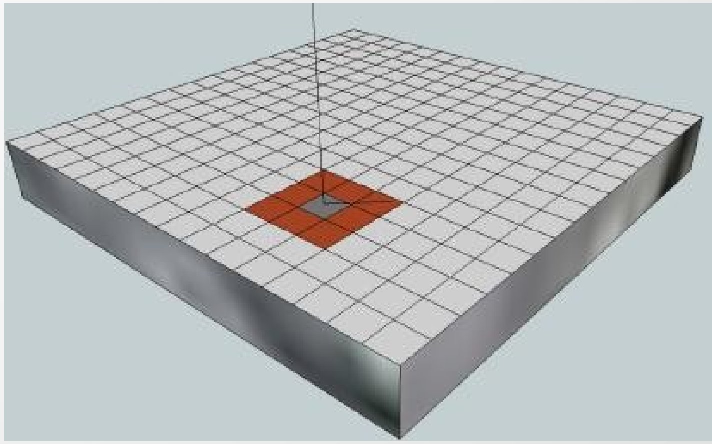
$$MDP = \frac{4.29}{\mu_{100} R_{src}} \sqrt{\frac{(R_{src} + R_{bkg})}{T}}$$

PROSPECTS OF X-RAY POLARIMETRY WITH CZTI

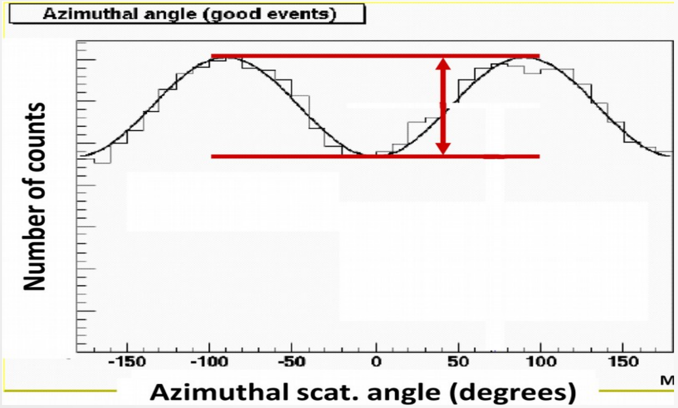
- The double pixel events arising from the **Compton scattering of a photon in one pixel and absorption of the scattered photon in another pixel** constitute the basic polarization event.

- The azimuthal angle of the Compton scattering is determined from the **direction of center of the scattering pixel to the center of the absorbing pixel** with reference to a pre-defined instrument reference plane.

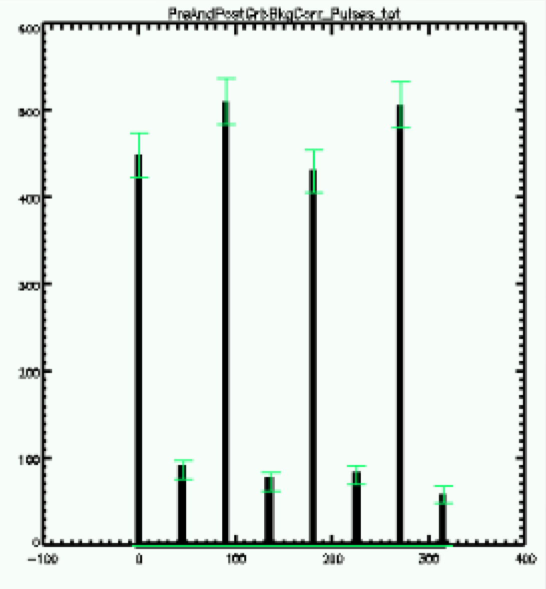
- The histogram of the azimuthal angle distribution can then be used to determine modulation factor and polarization angle.



Expectation



Reality

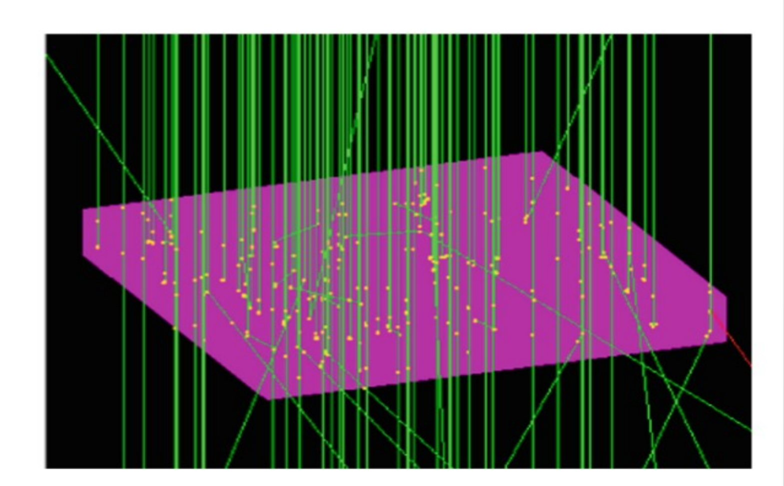


REASON – UNPOL MODULATION

- Azimuthal angle bins are unequal which leads to an inherent modulation pattern in the azimuthal angle distribution – correction using unpolarized beam modulation.

- Geant4 simulation (only CZTI) for unpolarized radiation.

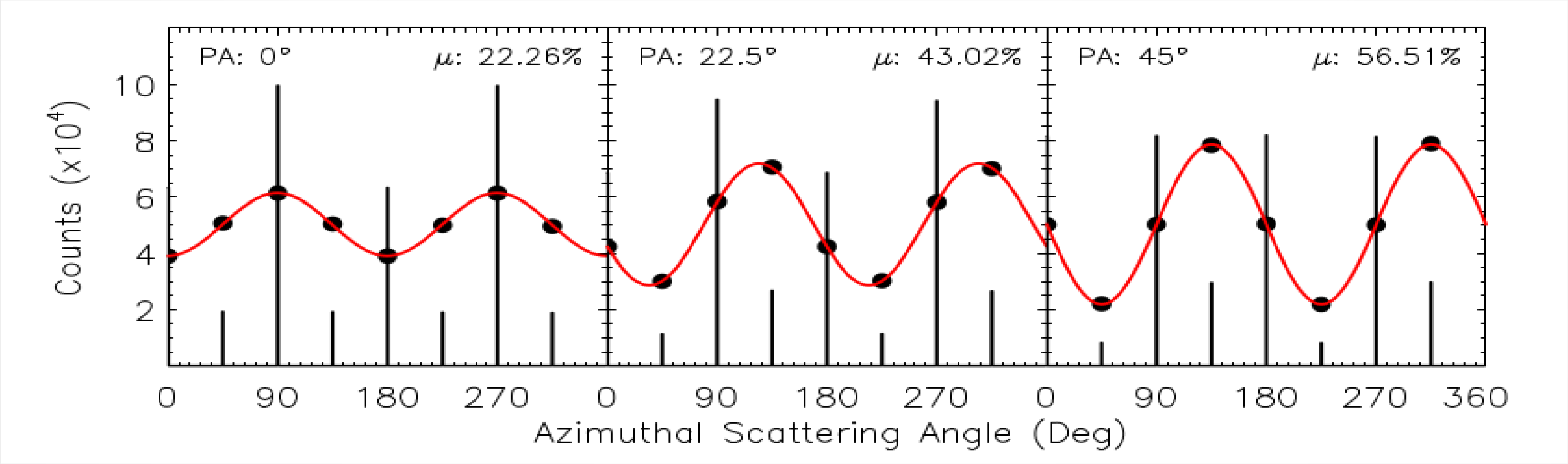
$$N_{i,corrected} = \frac{N_{i,pol}}{M_{i,unpol}} \overline{M}_{unpol}$$

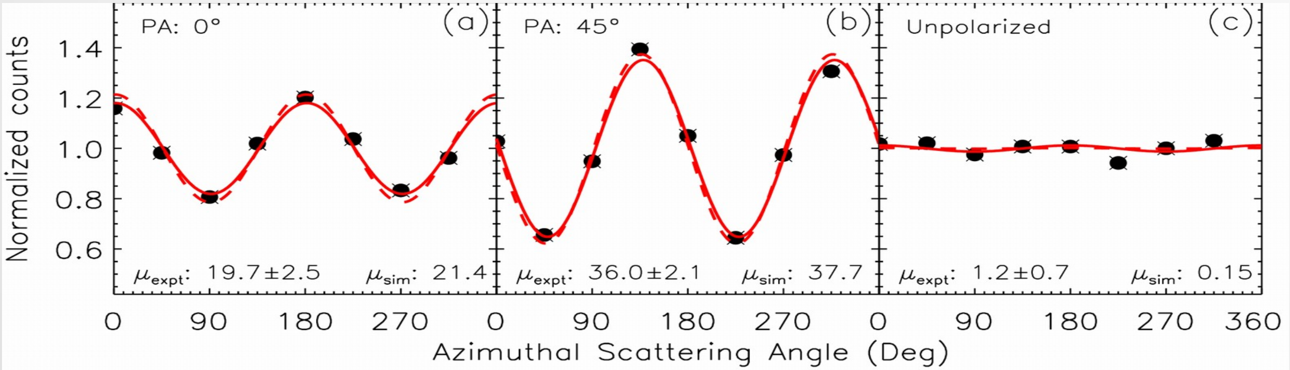


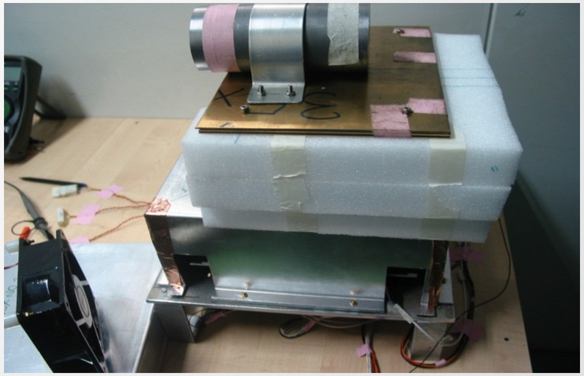
T. Chattopadhyay et al 2014

HARD X-RAY POLARIMETRY USING CZTI

Polarization expt with CZTI using
Ba133 source at different polarization angles.







SV Vadawale et al 2015

PROMPT EMISSION POLARIZATION

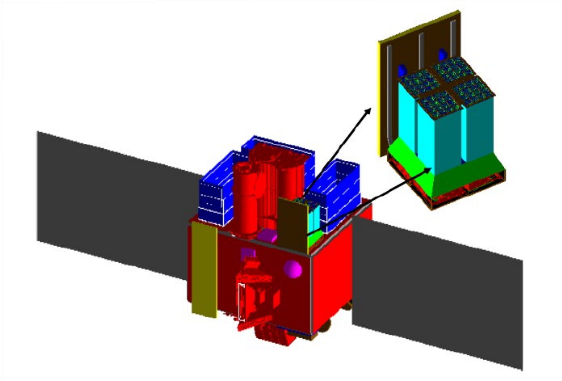
- Several key questions concerning the **nature of the central engines** of the relativistic jets and the jets themselves remain poorly understood
- Can not answer with the spectral and light-curve information collected, polarization of the prompt γ-ray emission can tell about the mechanism generating GRBs
- Inverse Compton (ICS) and Synchrotron (SR) are the mechanisms underlying the prompt γ-ray emission in the CB model and the ‘standard’ FB model
- Source of polarization of the prompt γ-ray emission in GRBs: ICS and SR

GRB POLARIZATION SO FAR

GRB Name	Instrument	Polarization fraction	Reference
GRB 021206	RHESSI	80±20 %	Coburn & Boggs (2003)
GRB 021206	RHESSI	< 4.17 %	Rutledge & Fox (2004)
GRB 021206	RHESSI	41^{+57}_{-44} %	Wigger et al. (2004)
GRB 930131	CGRO/BATSE	>35 %	Willis et al. (2005)
GRB 960924	CGRO/BATSE	>50 %	Willis et al. (2005)
GRB 041219A	INTEGRAL/SPI	98 ±33 %	Kalemci et al. (2007)
GRB 041219A	INTEGRAL/SPI	96 ± 40 %	McGlynn et al. (2007)
GRB 041219A	INTEGRAL/IBIS	43 ± 25 %	Götz et al. (2009)
GRB 061122	INTEGRAL/SPI	<60%	McGlynn et al. (2009)
GRB 100826A	IKAROS/GAP	27 ± 11 %	Yonetoku et al. (2011)
GRB 110301A	IKAROS/GAP	70 ± 22 %	Yonetoku et al. (2012)
GRB 110721A	IKAROS/GAP	80 ± 22 %	Yonetoku et al. (2012)
GRB 061122	INTEGRAL/IBIS	>60 %	Götz et al. (2013)
GRB 140206A	INTEGRAL/IBIS	>48 %	Götz et al. (2014)

CZTI ONBOARD ASTROSAT, 28 SEPTEMBER 2015

- CZTI - simultaneous X-ray spectroscopy and imaging over 20 – 200 keV
- Total geometric area of 1024 cm^2, Coded Aperture Mask
- Each module 4 cm × 4 cm and 5 mm thick, pixilated into 16 × 16 array of pixels, each pixel has size of ~2.5 mm × 2.5 mm and 5 mm thick
- Transparency increases > 100 keV
- **Such pixelated detector plane can be used for hard X-ray polarization measurements based on the principle of Compton scattering, by measuring azimuthal distribution of simultaneous events in two adjacent pixels**



GRB POLARIZATION USING CZTI

- GRB Prompt emission - complete picture of the GRB requires understanding of the inner part of the jet.
- Corresponding to the peak output of GRBs – Compon polarimetry.
- CZTI - all sky GRB monitor and highly polarized GRB prompt emission - makes GRBs one of the suitable targets for CZTI polarimetry.
- 47 GRBs detected by CZTI over a span of one year, from 28 th September 2015 till 10 th September 2016 were analyzed.

HOW TO MEASURE?

- CZT pipeline modules: cztgtigen, cztdatasel, cztpixclean and cztevtclean → evt, dblevt clean files → evt, dblevt light curves.

- Compton conditions : dblevts between adjacent pixels are only considered within time stamp, condition on the ratio of energies of the scattered and absorbed pixels.

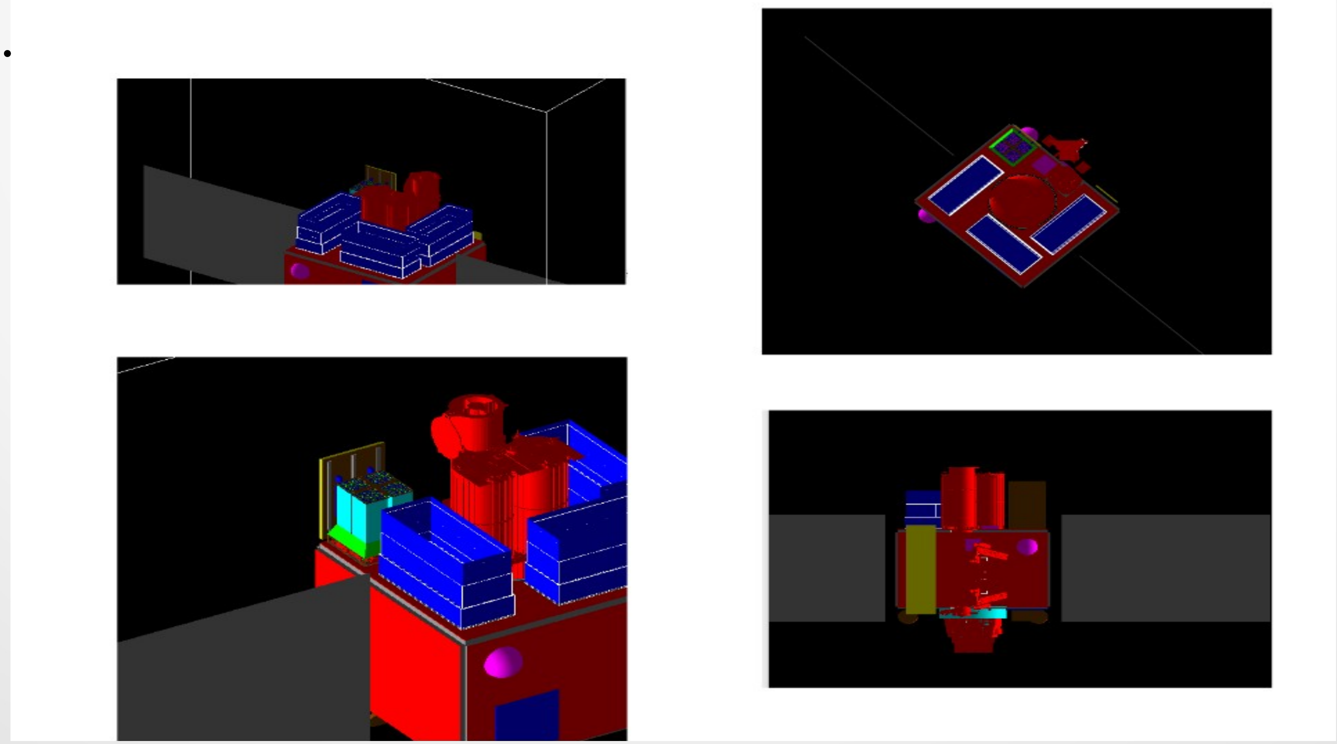
- The 11 GRBs with Compton events > 350 only were considered for further analysis.

HOW TO MEASURE?

- Using the relative position of these detx dety the azimuthal distribution is calculated for the GRB events and for all different backgrounds.
- Histogram of this for the GRB events subtracted from background events gives the azimuthal angle distribution.
- To correct for geometrical effects - corresponding distribution for an unpolarized beam.
- Simulation for unpolarized photons using **AstroSat Mass Model**.

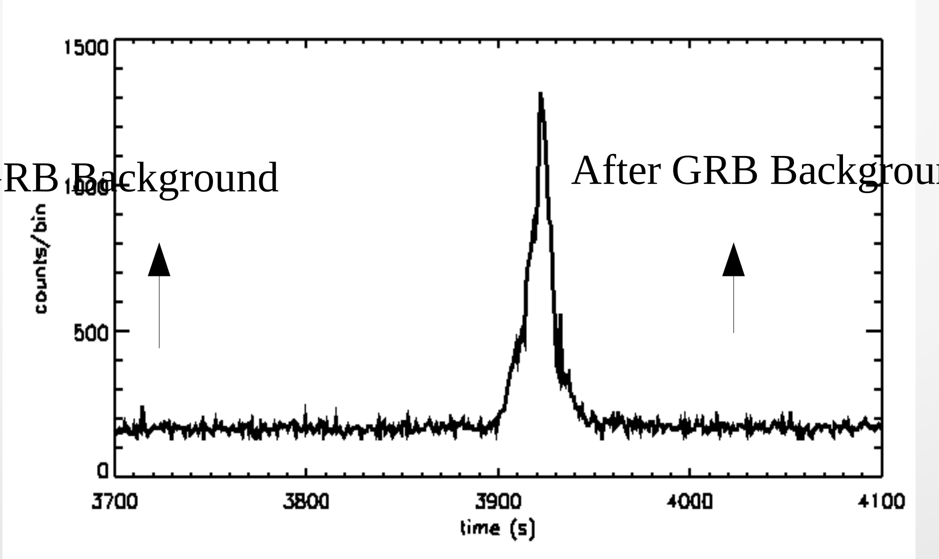
ASTROSAT MASS MODEL

- Interaction positions, energies and all other relevant information are printed as output from mass model.
- Selection of double events, Compton double events and pixelation are done using IDL to get the final Compton double events for unpolarized photons.

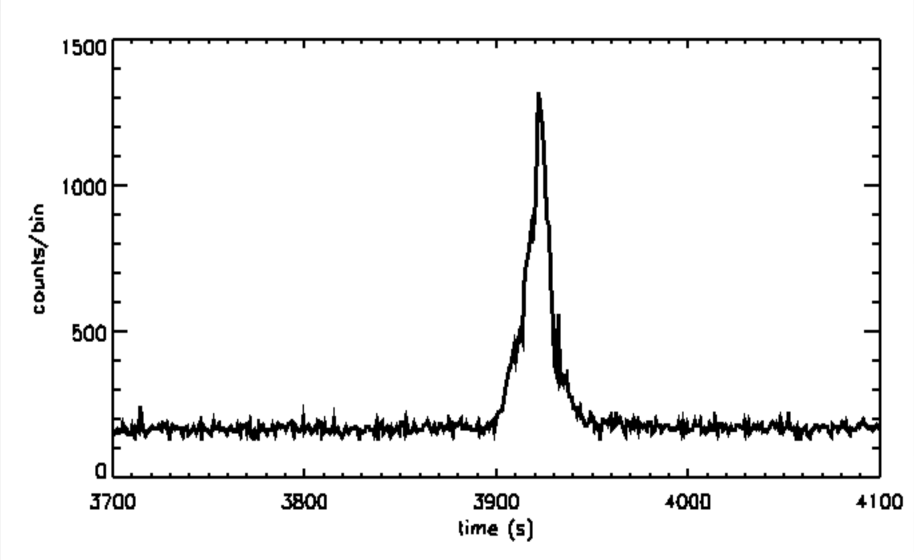


BACKGROUND

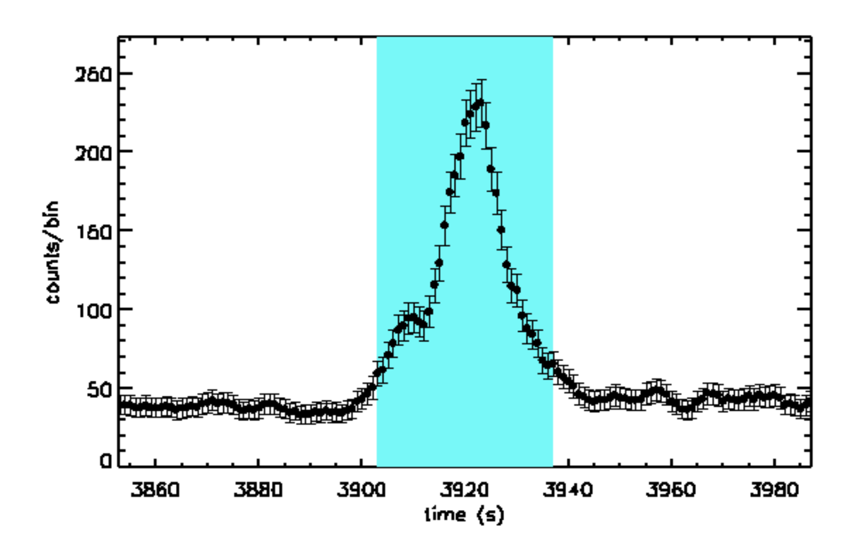
- The observed background count rate is ~ 20-30 cnt/s
- Significant contribution from the earth's albedo radiation and diffuse cosmic X-ray background across the side collimators and supporting structure which go through Compton scattering in CZTI pixels
- The various level of transparency by the collimators and the supporting structures results in an unequal effective area across the detector pixels



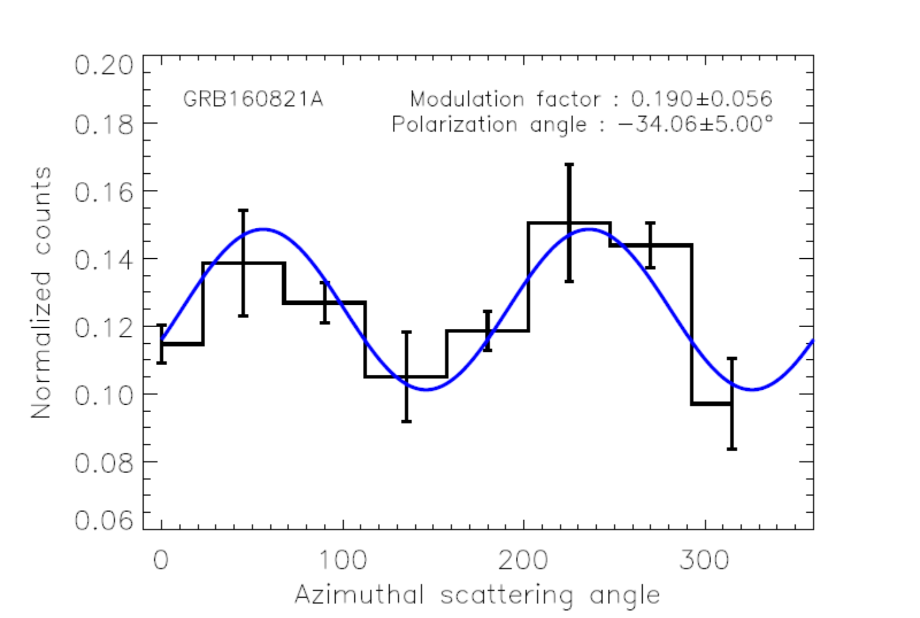
GRB160821A



1500
1000
500
0
counts/bin
3700
3800
3900
4000
4100
time (s)



250
200
150
100
50
0
counts/bin
3860
3880
3900
3920
3940
3960
3980
time (s)



GRB160821A
Modulation factor : 0.190±0.056
Polarization angle : −34.06±5.00°
Normalized counts
0.20
0.18
0.16
0.14
0.12
0.10
0.08
0.06
0
100
200
300
Azimuthal scattering angle

PROCEDURE

Double (40 micro s), single event clean files + livetime

↓

Energy ratio and Neighboring pixel condition for compton events

↓

Selecting GRB (each peak if multiple) and background

↓

Azimuthal distribution for each compton event

↓

Subtracting the background counts

↓

Massmodel simulation for unpolarized radiation

↓

Correct the modulation using unpolarized modulation

PROCEDURE

Fit the modulation with cosine function

↓

Obtain the pol angle from fitting parameters

↓

Massmodel simulation for 100% pol photons at pol angle

↓

Obtain the P

Thank you !!!

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- VSSC: S. Sreekumar, P. Vinod, Essy Samuel, Priya P
- SAC: Arvind Singh, Tanul Gupta

AstroSat Project Team

AstroSat Mission Team

AstroSat Operations Team