Measurements of GRB prompt emission polarization with AstroSat-CZTI

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On behalf of AstroSat-CZTI team

Workshop on GRBs: Prompt to Afterglow
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PROMPT EMISSION POLARIMETRY OF GAMMA RAY BURSTS WITH *ASTROSAT* CZT-IMAGER.

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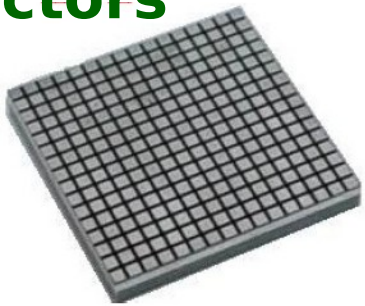
ABSTRACT

X-ray and Gamma-ray polarization measurements of the prompt emission of Gamma-ray bursts (GRBs) are thought to be an important tool to decisively test the various models of GRBs. Although there are some reports of hard X-ray polarization measurements of the prompt emission of the GRBs, they are yet to provide robust inputs for the GRB models due to the extreme difficulty of measuring them and quantifying their significance. *AstroSat*, India's first multi-wavelength satellite dedicated for astronomical studies, was launched on 2015 September 28. CZT-Imager

Hard X-ray Polarimetry with Astrosat - CZT-Imager

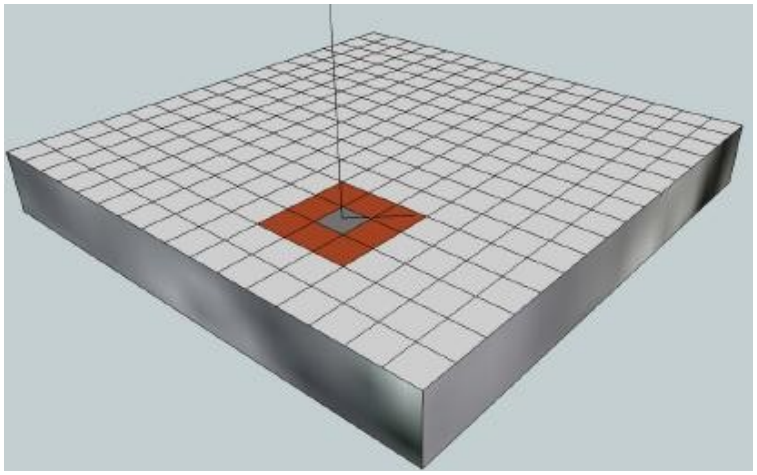
pixelated CZT detectors



Orbotech CZT modules

- 4 x 4 cm^2 (16 x 16 pixel)
- 5 mm thick
- Total 64 modules (16 in 4 quadrants)

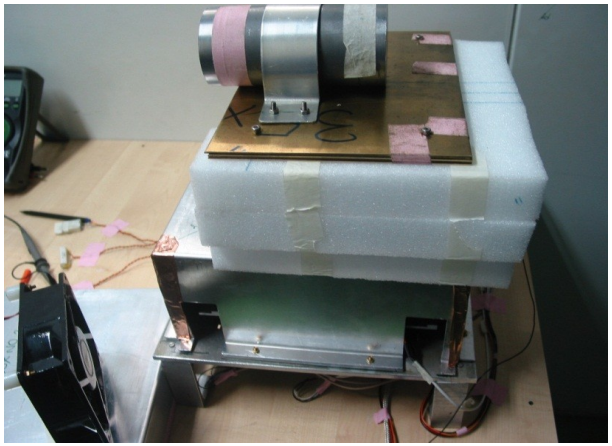
Pixilated detectors can measure polarization



Compton scattering in one pixel and **absorption of the scattered photon in another pixel** constitute the azimuthal angle histogram

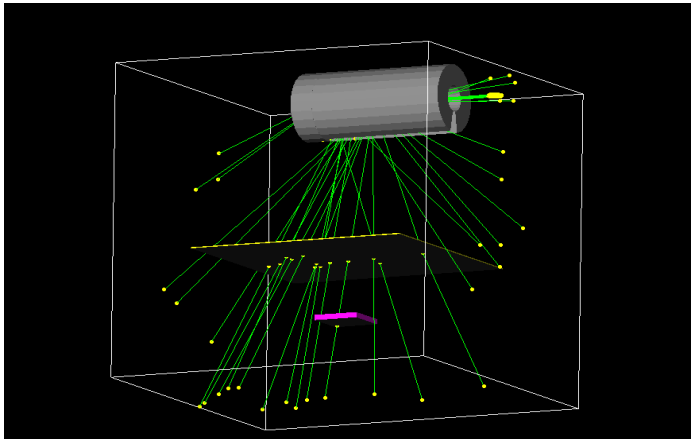
Hard X-ray Polarimetry with CZTI

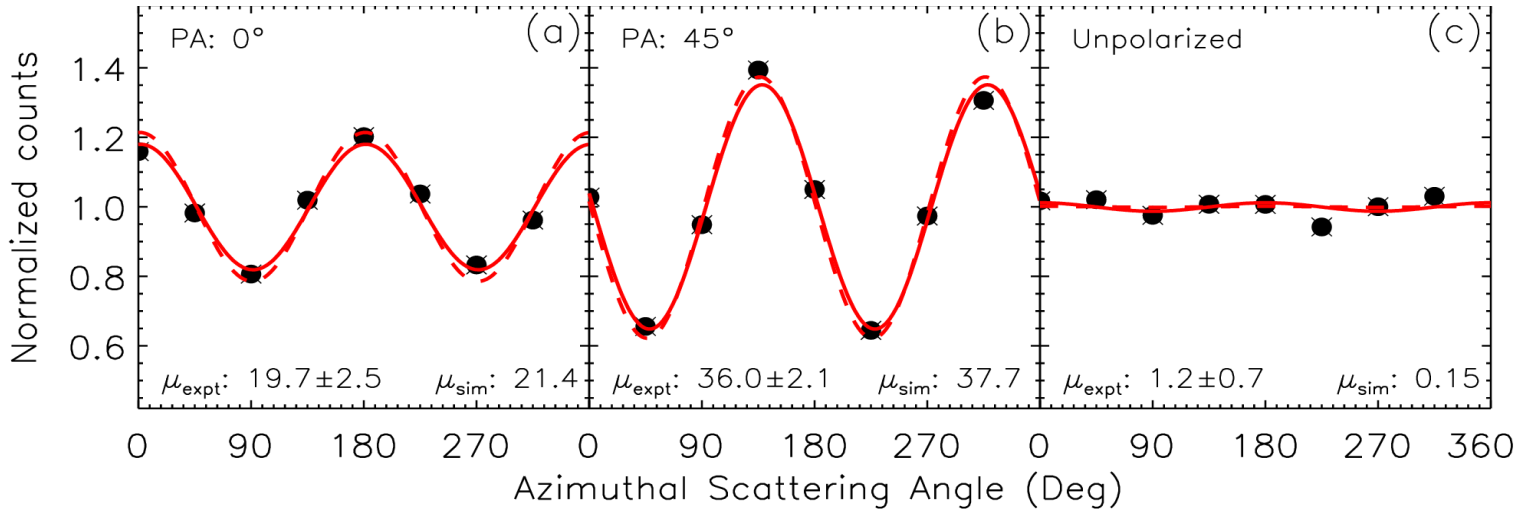
Observed Modulation for Polarized Beam



Polarization expt with CZTI using Ba133 (356 keV) source

Geometry used in simulation



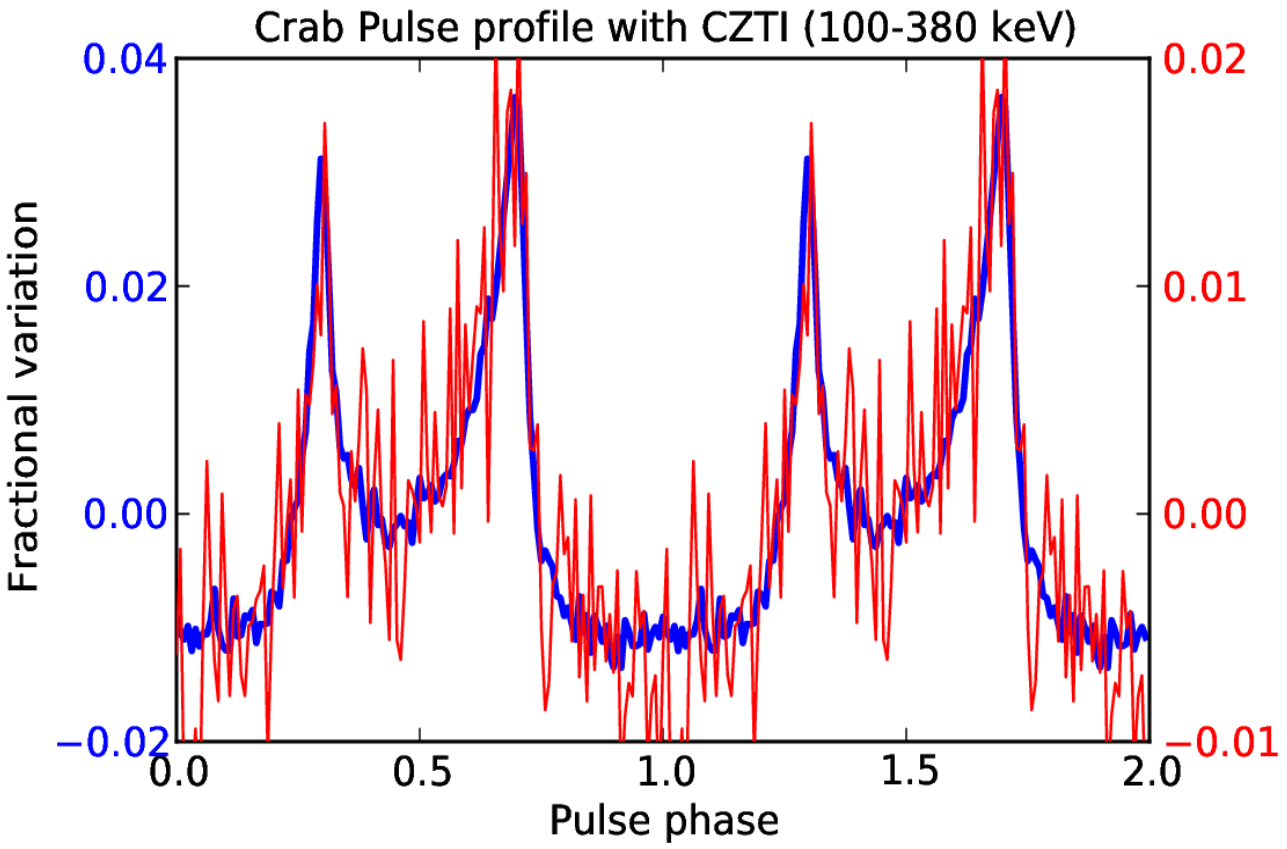


CZTI does have polarization measuremnt capability

Chattopadhyay et al 2014 **Vadawale et al 2015**

Crab Polarimetry with CZTI

CZTI flight data



Total Exposure : 550 ks

RED :Pulse profile in Compton events (adjacent double pixel events satisfying Compton criteria)

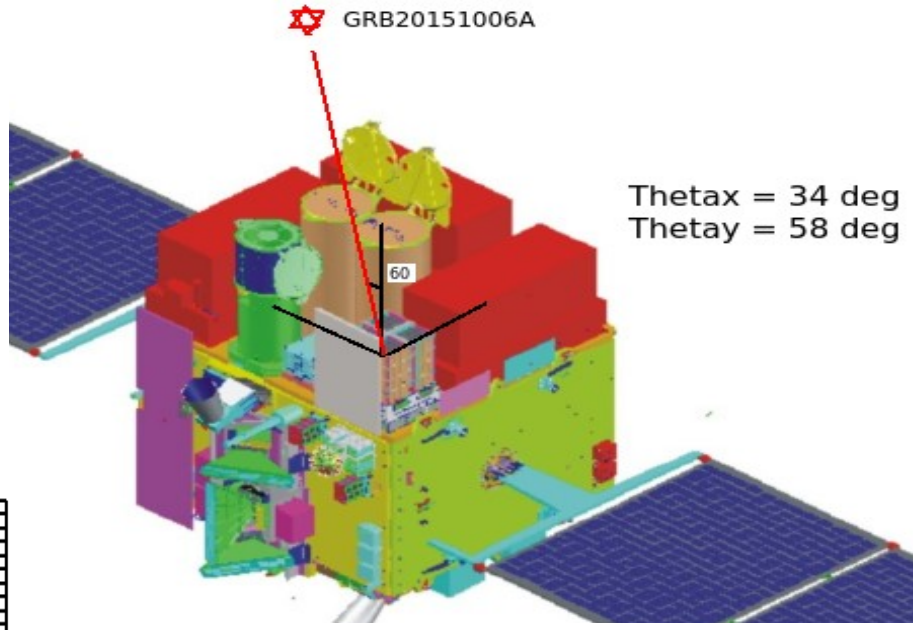
BLUE : Pulse profile in Single pixel events

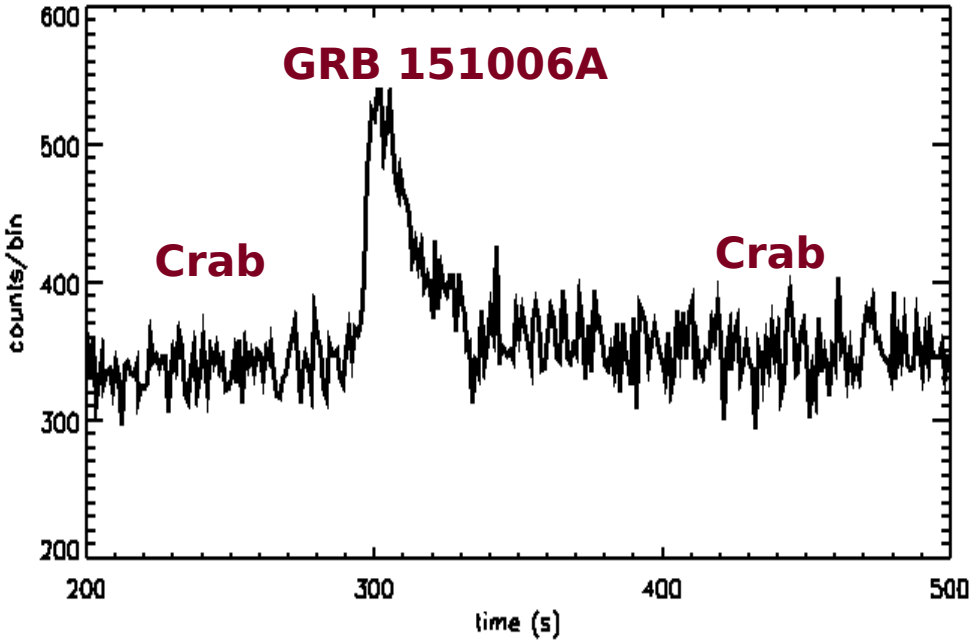
Validation of the Event selection

CZT-Imager : An Open Detector in Hard X-rays

Transparent collimators and supporting structures of CZTI at energies > 100 keV

Ideal large area detector to detect transcient sources and GRBs





GRB search triggered by BAT / Fermi detection

GRB position from BAT

GRB Polarization : Basics

CZTI had detected ~ 50 GRBs during first year

- 11 are suitable for polarization analysis (fluence > 1e-5 erg / cm^2)
- 18 such GRBs from BAT / Fermi database ... CZTI detects 60% of the bright GRBs

Modulation detection in GRB is relatively easy

- Accurate background available pre / post GRB
- High signal-to-noise

Estimation of accurate polarization fraction is difficult a GRBs are highly off-axis

- Requires modulation curves for both 100% and completely unpolarized X-rays from the location of GRB
- Obtained by extensive Geant4 simulations with the mass model of full spacecraft
- Computationally expensive

GRB Polarization : our sample

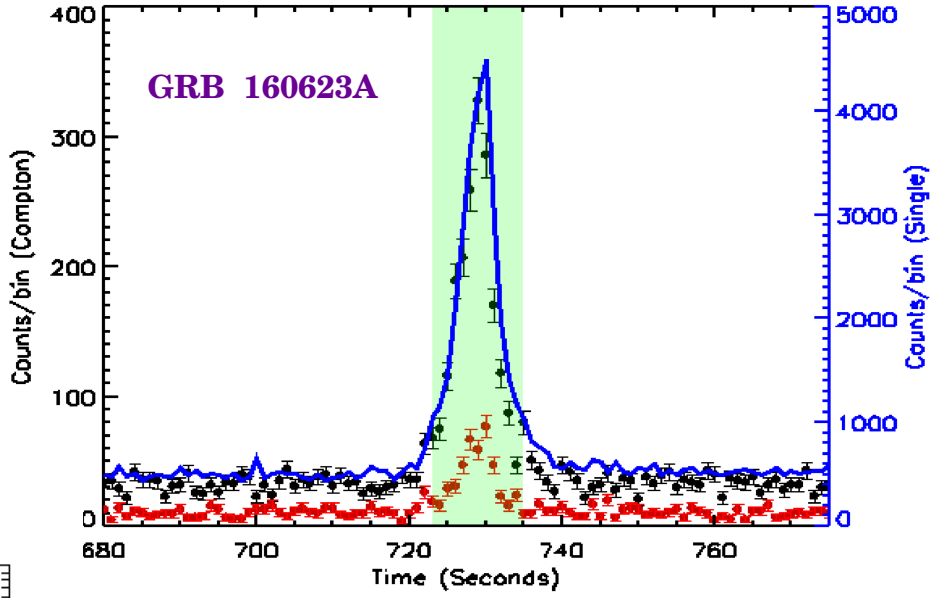
	Fluence (10^-5 ergs / cm^2) in 10 – 1000 keV
GRB 151006A	2.5
GRB 160106A	5.6
GRB 160131A	6.8
GRB 160325A	4.78
GRB 160509A	48.7
GRB 160607A	3.9
GRB 160623A	18
GRB 160703A	1.6
GRB 160802A	8.8
GRB 160821A	47
GRB 160910A	12.3

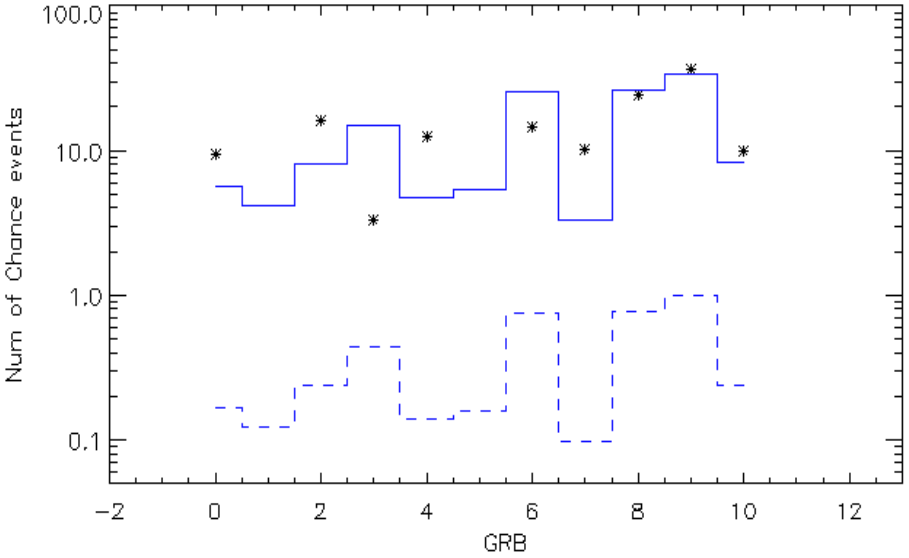
GRB Polarization : Selection of Compton events

Does the GRB show up in Compton events?

Selection of double pixel events in 40 mus time window

Further filetering based on Compton kinematics



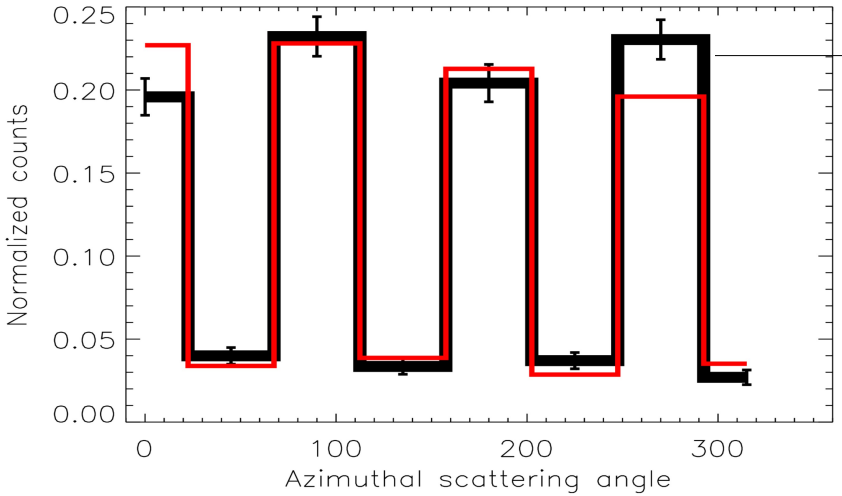


Does the GRB still show up in non-Compton events?

No (RED data points) ... chance events + Compton scattering in non-neighboring pixels

Modeling based on Poisson statistics

GRB Polarization : azimuthal angle distribution



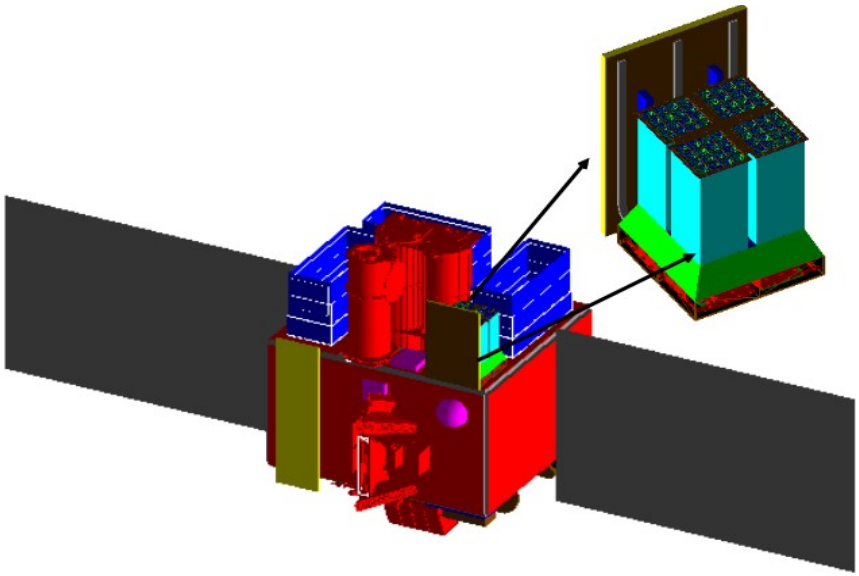
Observed 8 bin azimuthal angle distribution (GRB 160821A)

normalization with modulation curve for unpolarized beam

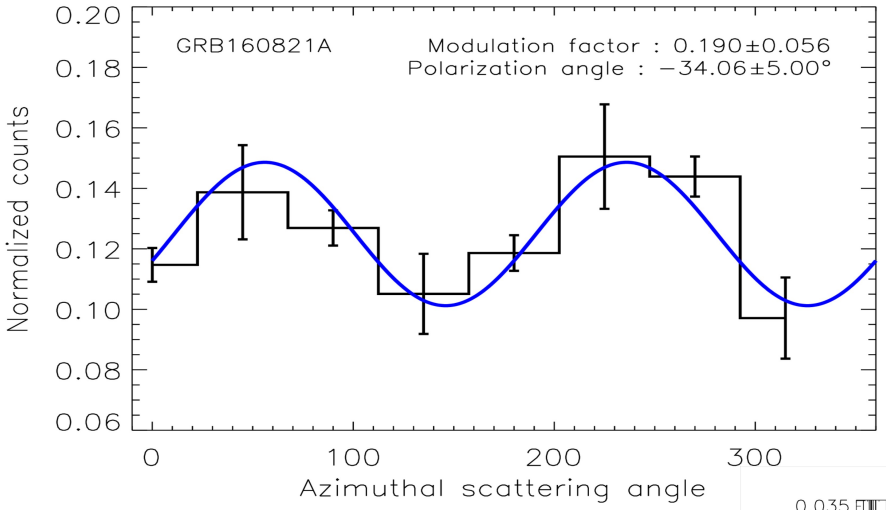
$$N_{i,nor} = \frac{\overline{M}_{unpol}}{M_{i,unpol}} N_{i,obs}$$

N_obs : Observed distribution from actual data (black line)

M_unpol : Unpolarized distribution from simulation (red line)



GRB Polarization : azimuthal angle distribution



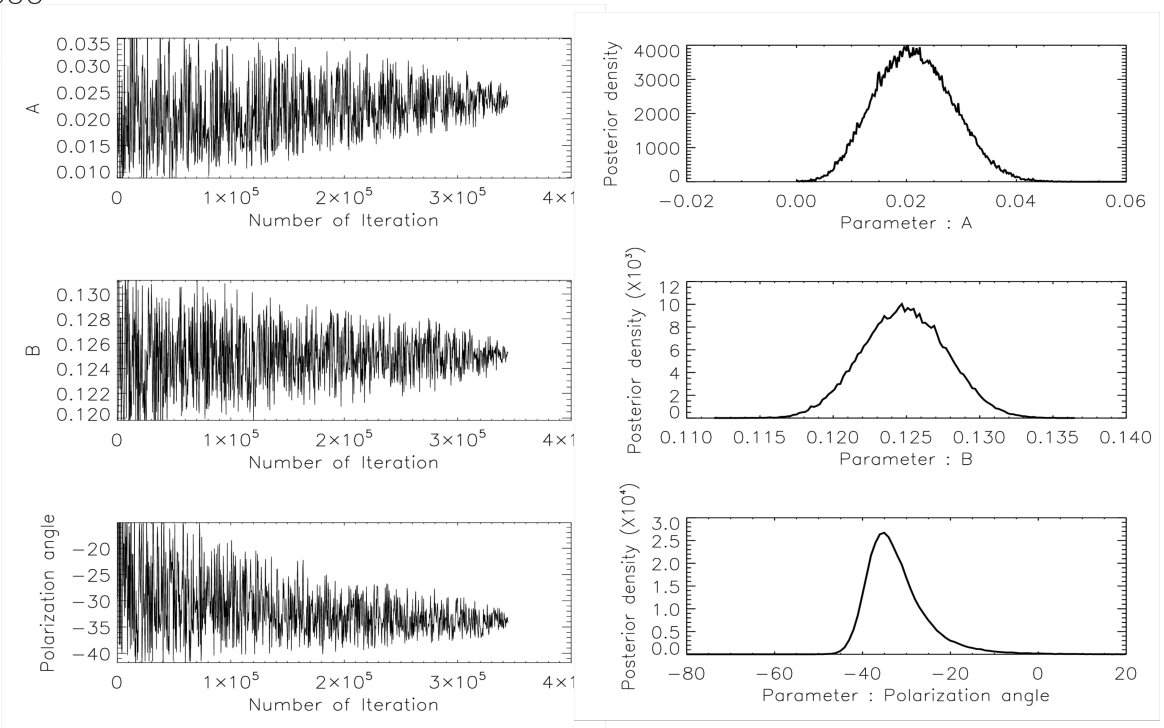
Corrected modulation Curve :
GRB 160821 A (N = ~2500)

Error estimation done based Bayesian approach (MCMC simulation)

---No need of Rice distribution

---Easier / reliable way to estimate the errors on the parameters

----can be used for Bayesian model comparison



GRB Polarization : Systematics uncertainties?

Background selection (pre vs post vs longer vs shorter exposure)

- ~ 1% variation in the modulation

Localization uncertainty

- ~ 3.7 deg for GBM position, 3 arcmin for BAT position, ~ arcsec for XRT
- For most of the CZTI GRBs, localization uncertainty ~ arcmin
- Modulation uncertainty << 1%

pixel to pixel quantum efficiency variation

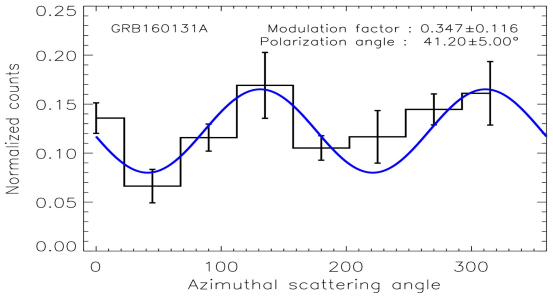
- ~ 5 % pixel – pixel efficiency variation
- Events are selected from full detector area which averages out the variation partly
- ~ 5 % variation in modulation

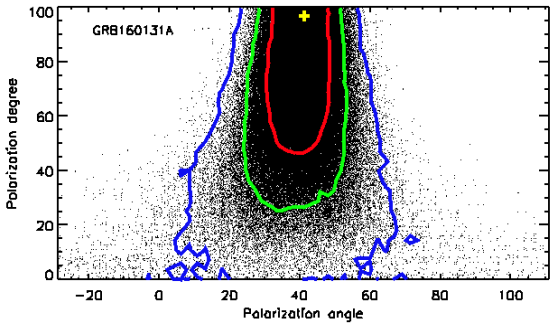
Overall systematic uncertainty < 3%

GRB Polarization : azimuthal angle distribution (> 3 sigma)

GRB 160131A

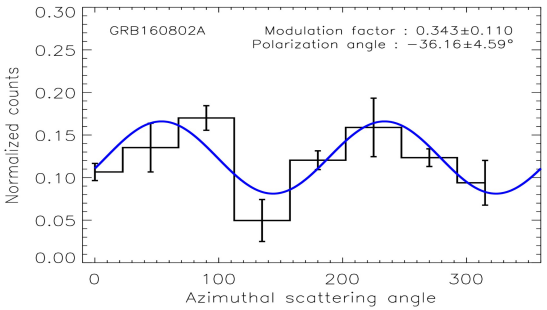
N ~ 724

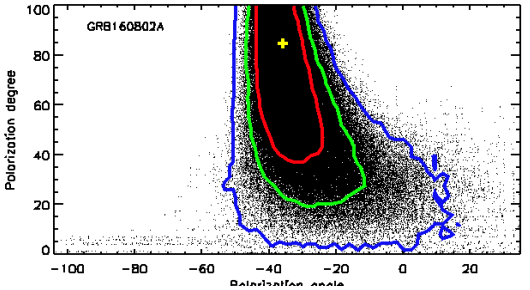




GRB 160802A

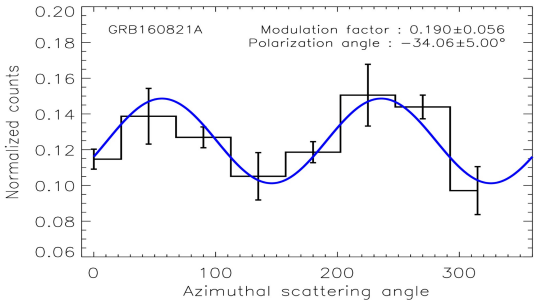
N ~ 901

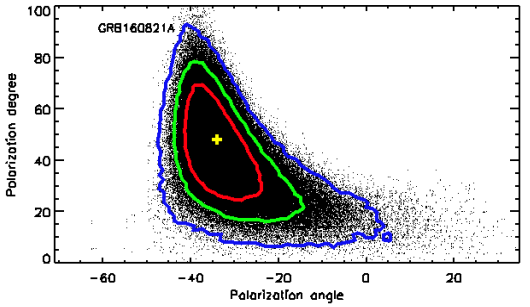




GRB 160821A

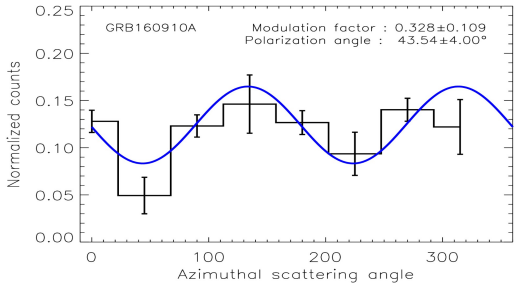
N ~ 2549

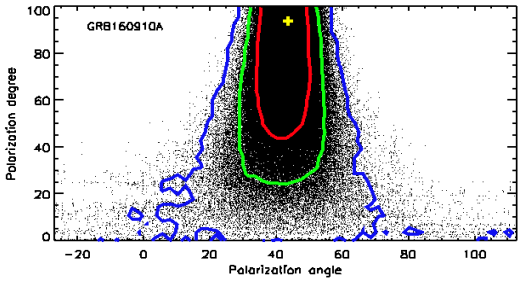




GRB 160910A

N ~ 824

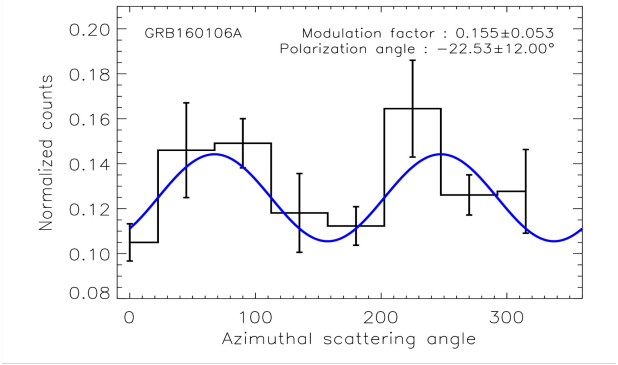


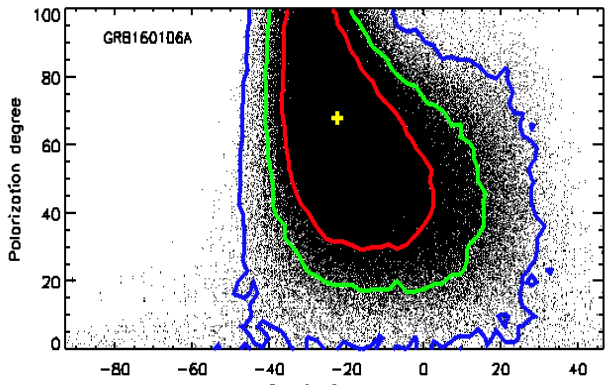


GRB Polarization : azimuthal angle distribution (>~ 2.5 sigma)

GRB 160106A

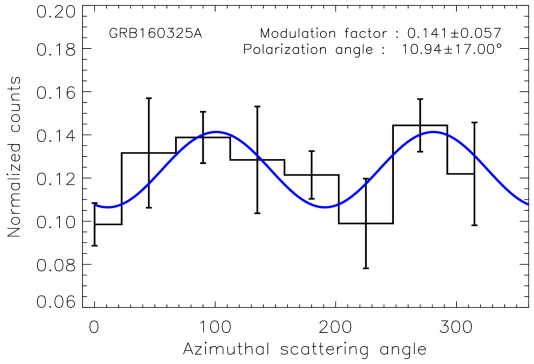
N ~ 950

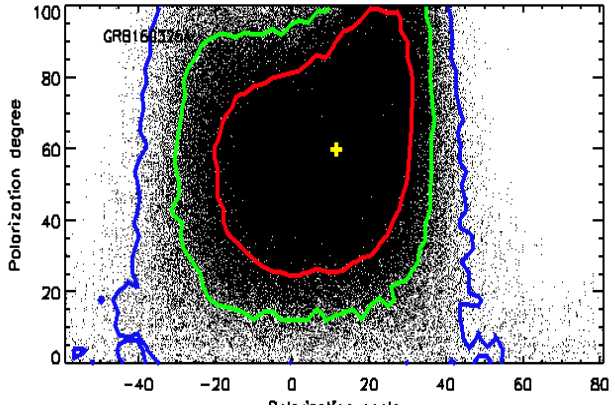




GRB 160325A

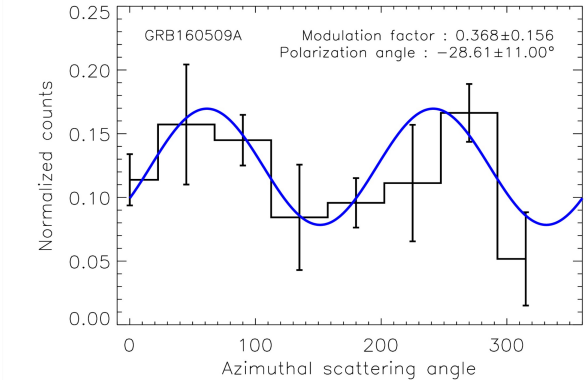
N ~ 835

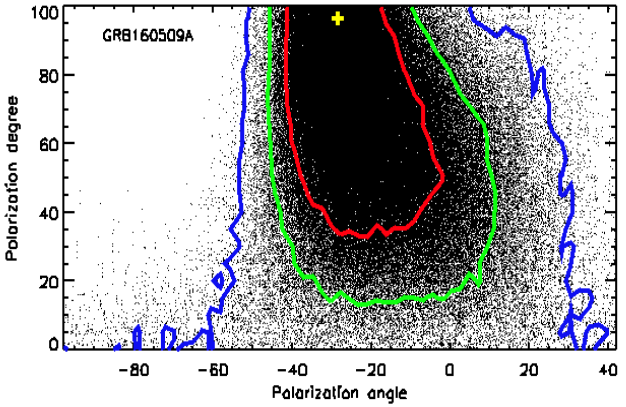




GRB 160509A

N ~ 460

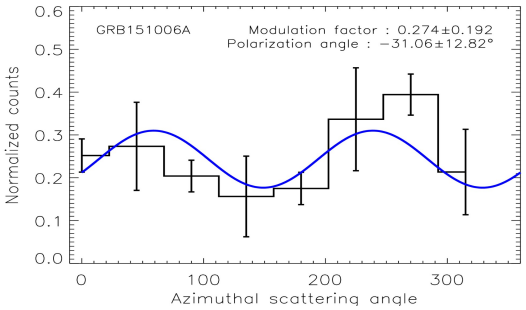


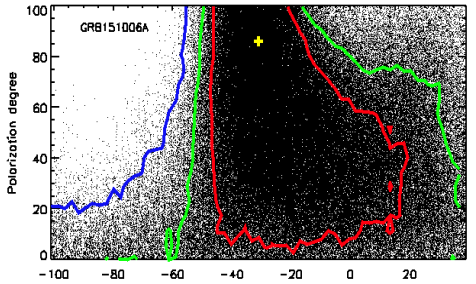


GRB Polarization : azimuthal angle distribution (<~ 2 sigma)

GRB 151006A

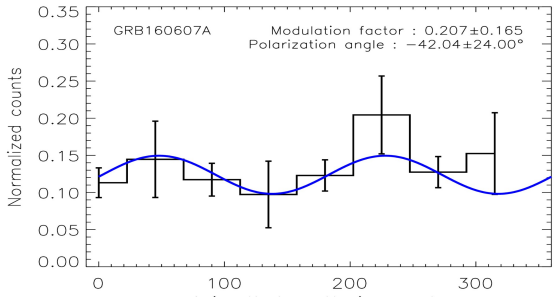
N ~ 459

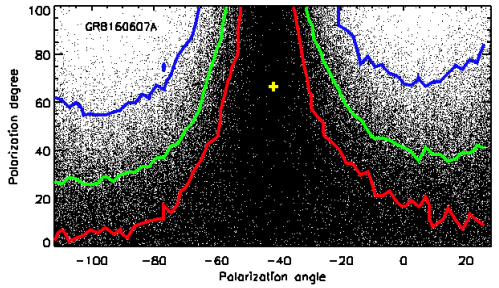




GRB 160607A

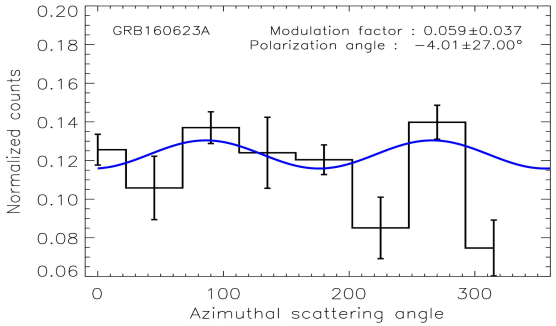
N ~ 447

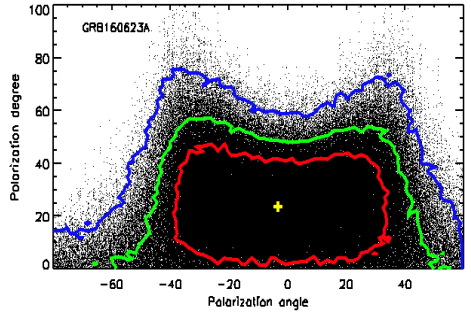




GRB 160623A

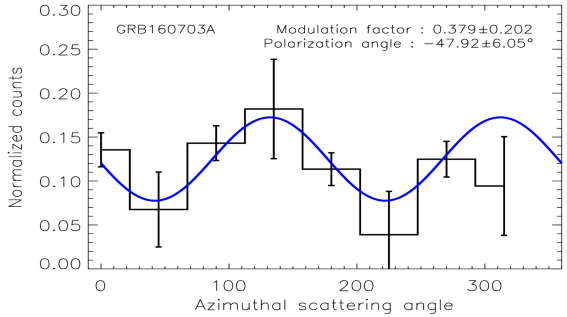
N ~ 1400

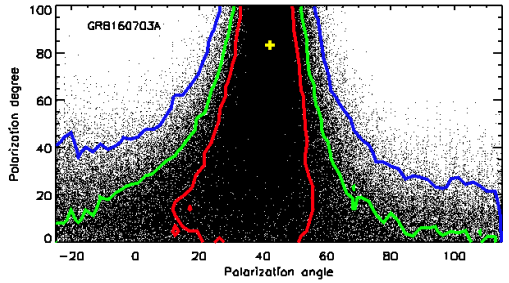




GRB 160703A

N ~ 448

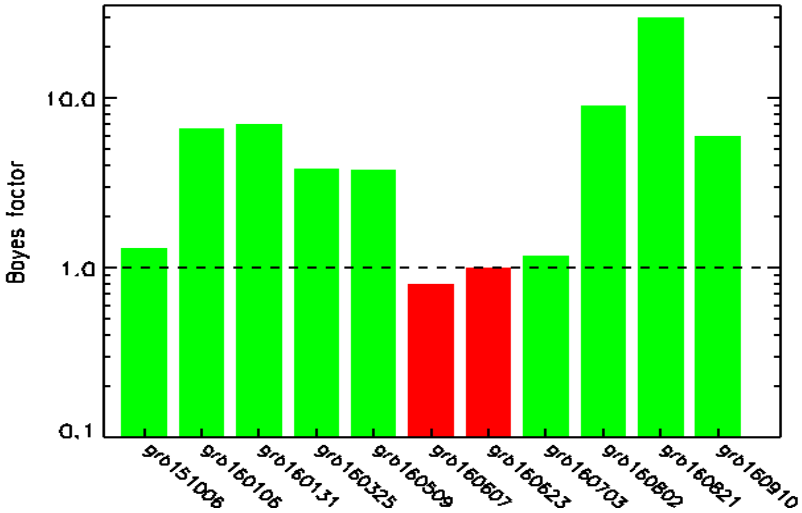


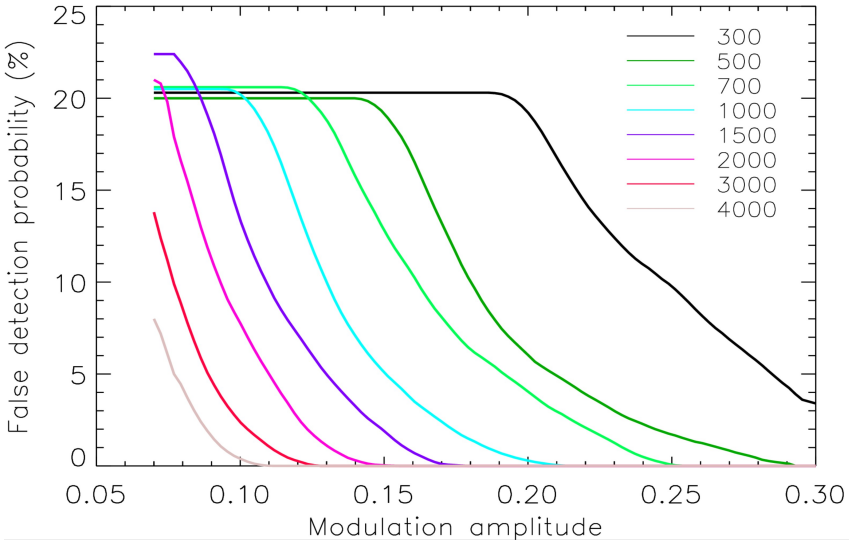


GRB Polarization : firm confirmation of detection

Firm confirmation of polarization detection – Bayes factor !!!

GRBs with Bayes factor < 2 – Upper limit on polarization





Polarization positive definite quantity --- unpolarized photons may give modulation in azimuthal distribution

Offaxis mass model Simulation with unpolarized photons (large no of times)

Chance probaility : no of cases Bayes factor > 2 for a detected modulation amplitude

Chance probability < 2% for a typical GRB

GRB Polarization : final results

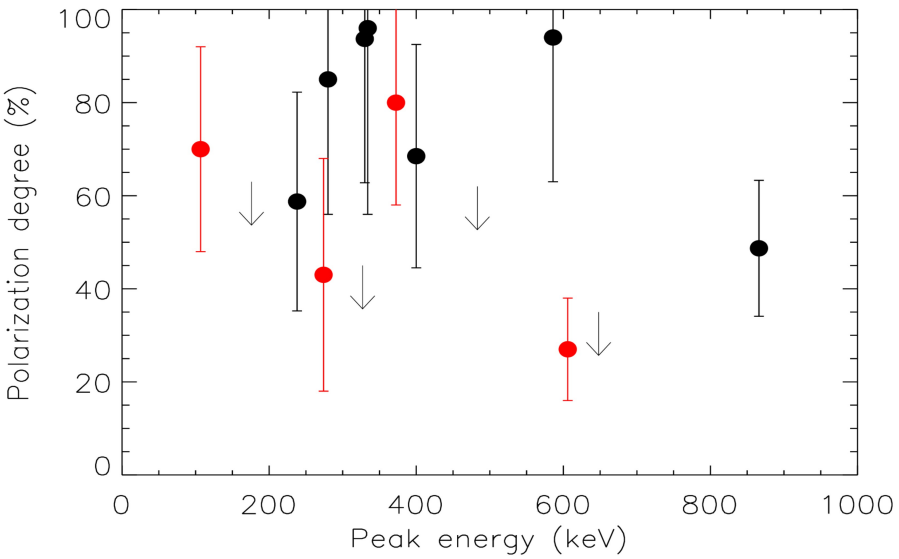
P = observed modulation amplitude / 100% polarized modulation amplitude

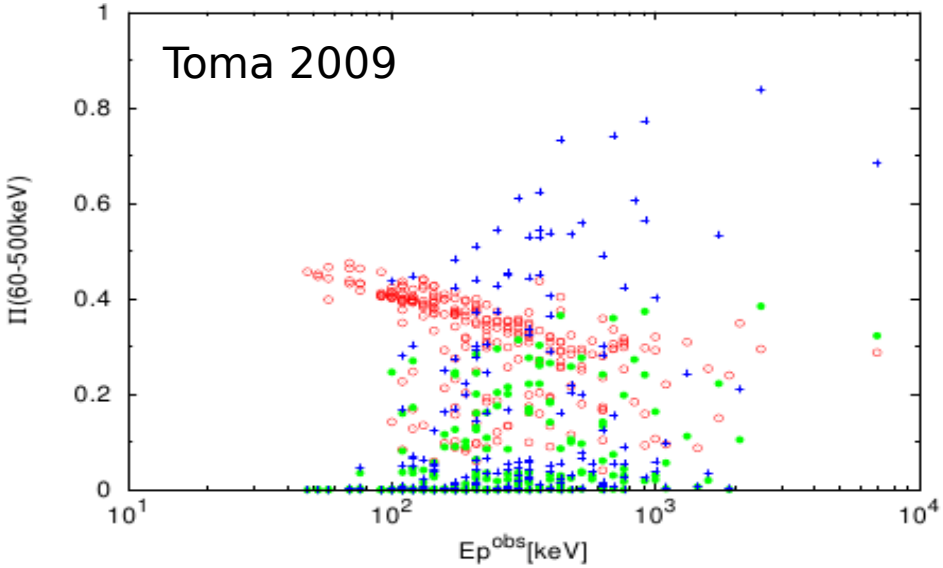
100% modulation amplitude is obtained from mass model simulation

Table 2. Measured polarization fractions and angles for the GRBs

GRB Name	Compton events	PF (%)	PA (°)	Chance Probability (%)
GRB 151006A	459	<62	-31.0±12.8°	4.17
GRB 160106A	950	68.5±24	-22.5±12.0°	3.60
GRB 160131A	724	94±31	41.2±5.0°	<0.1
GRB 160325A	835	58.75±23.5	10.9±17.0°	6.35
GRB 160509A	460	96±40	-28.6±11.0°	<0.1
GRB 160607A	447	<63	-42.0±24.0°	11.15
GRB 160623A	1400	<35	-4.0±27.0°	49.05
GRB 160703A	448	<45	-47.9±6.0°	0.68
GRB 160802A	901	85±29	-36.1±4.6°	<0.1
GRB 160821A	2549	48.7±14.6	-34.0±5.0°	<0.1
GRB 160910A	832	93.7±30.92	43.5±4.0°	<0.1

Statistical properties of polarization





Statistical study of GRB prompt polarization may distinguish the SO / SR / CD models

CZTI is expected to provide a sample >~ 60 GRBs in 5 years lifetime

Many more from POLAR

Similar study like required for CZTI

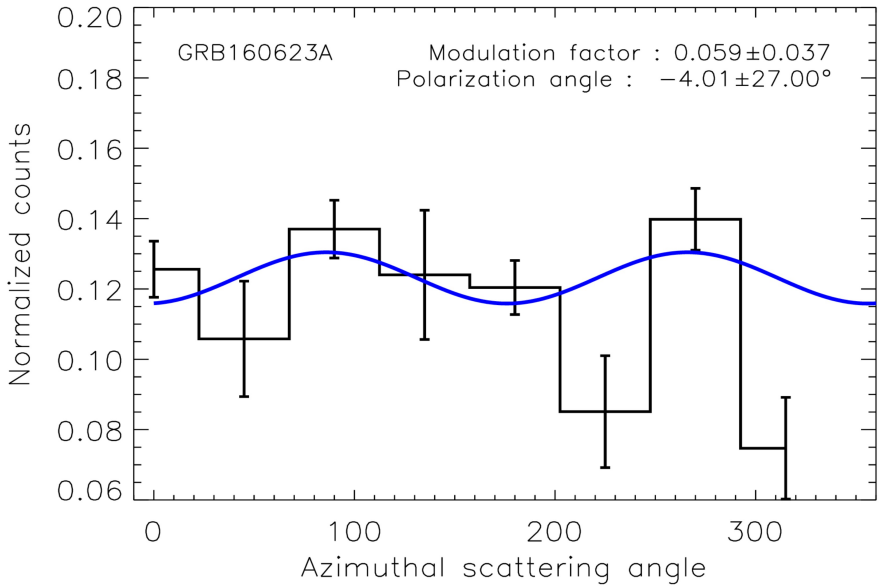
Chattopadhyay et al, 2017 (to be submitted)

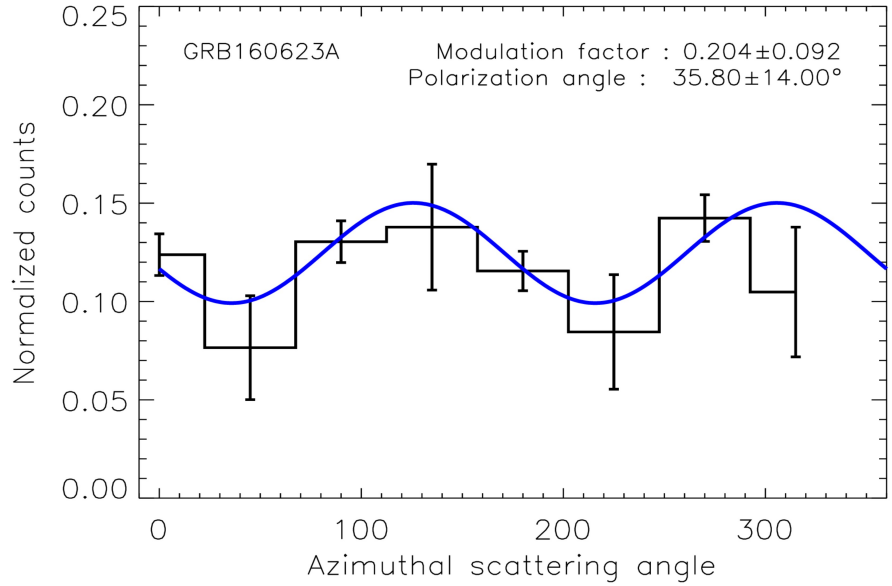
Bigger sample with the new GRBs

170329 A	
170311 B	
170304 A	Very bright
170228 A	Very bright
170209 A	
170208 A	
170207 A	
170127 C	Very bright
170126 A	
170121 B	
170115 B	
170105 A	
170101 B	
161218 B	Very bright
161203 A	
161023 A	
161015 A	Very bright

Promising results soon
Stay tuned !!!

Few interesting GRBs !!!





GRB 160623A

Z = .367

Unpolarized in 100 – 300 keV!!!

Polarized (50 %) in < 200 keV

Bayes factor ~ 2
Chance prob < 2%

Change in polarization characteristics at higher energies

Detailed spectro-polarimetric analysis under progress !!!

Summary / Future works

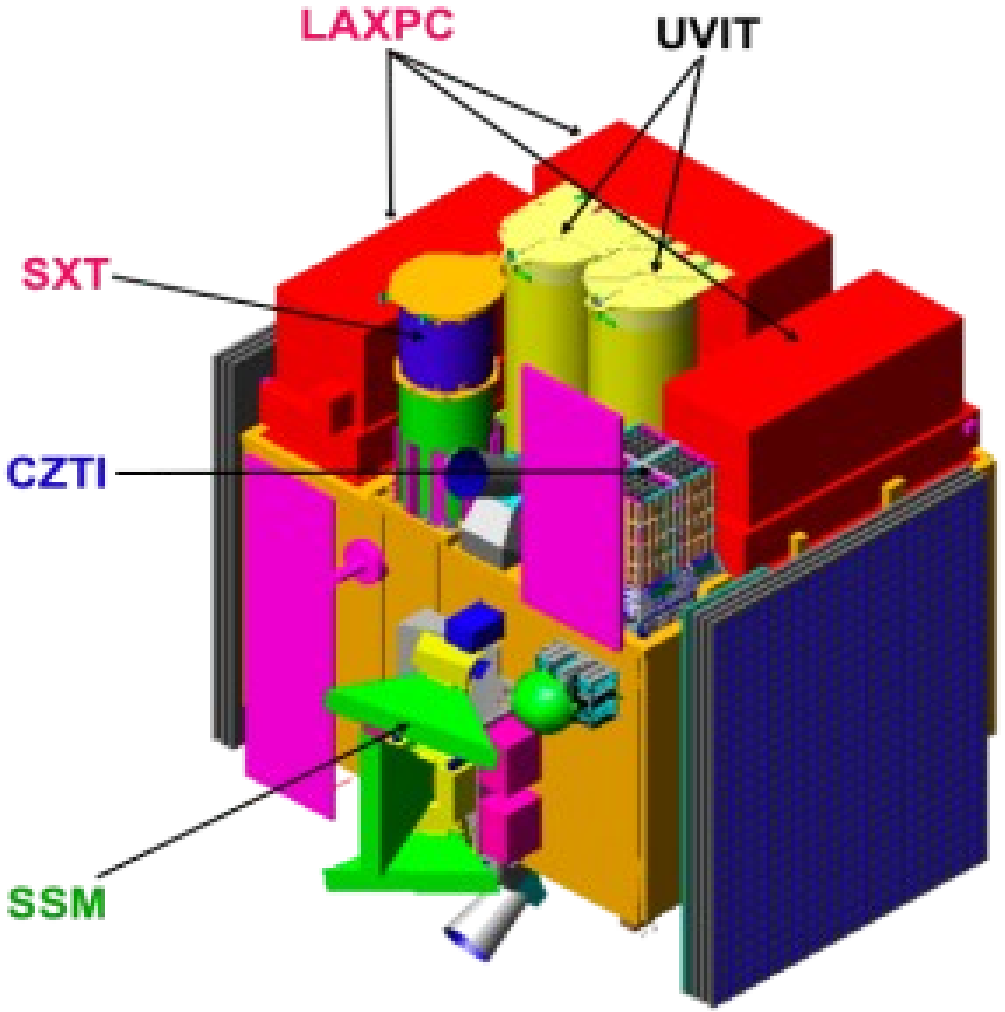
AstroSat-CZTI is proven to have good polarimetric capabilities in extended energy range of 100 – 300 keV

CZTI is also a prolific GRB detector and polarimeter

- Detected ~ 50 GRBs in first year
- 11 of them suitable for polarization analysis
- 4 GRBs > 3sigma polarization measurements, 3 ~ 2.5 sigma and upper limit for 4 GRBs
- Almost doubled the polarization sample
- A larger sample by the end of this year
- Potential to constrain GRB prompt emission models with a bigger sample

Thanks...

Astrosat



India's first dedicated satellite

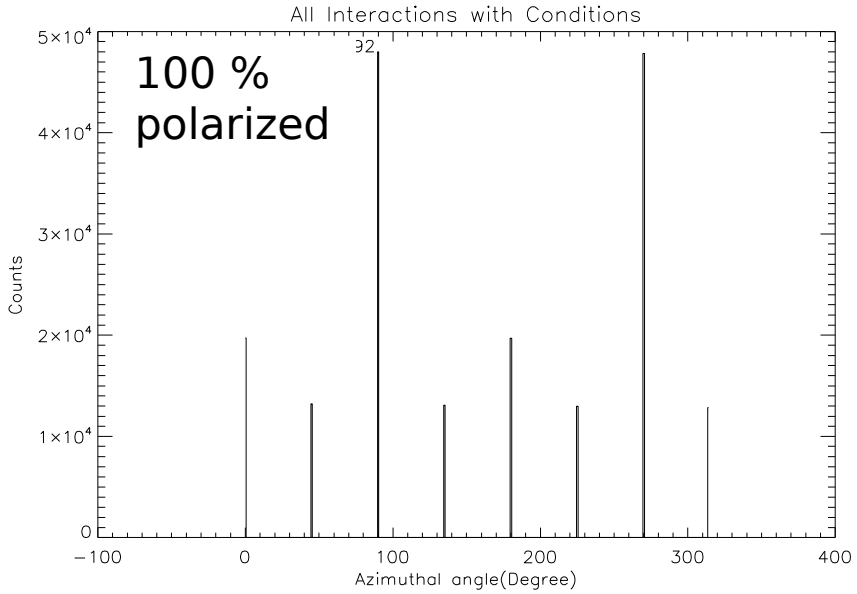
for Multi wavelength Astronomy

- near equatorial orbit, 650 km
- Launch by Indian PSLV in 2015 (October)

Data ‘cleaning’ and analysis

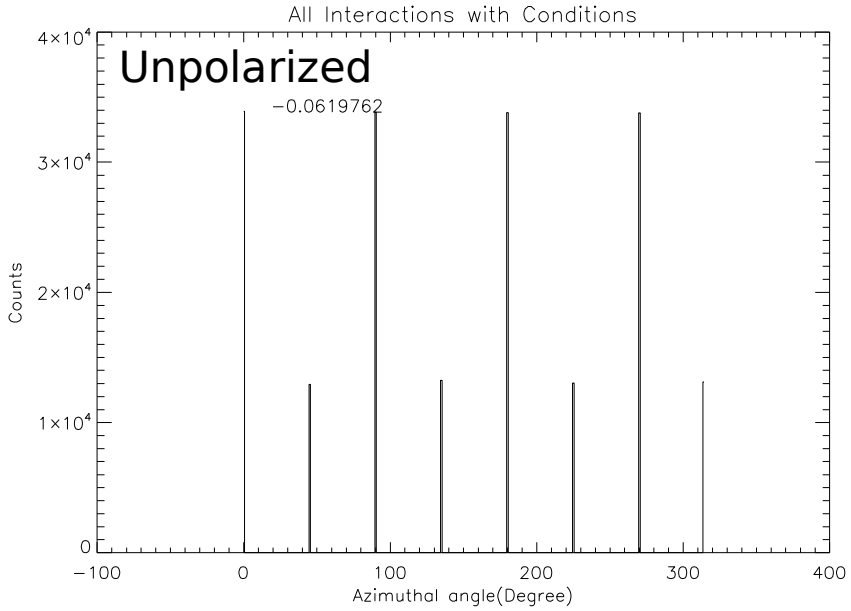
- Double pixel events are obtained for time window < 40 microsec
  - Effective polarimetric energy range is 100 – 300 keV
- Two more conditions are required based on preliminary experiments
  - Only adjacent pixel should be considered
  - Ratio of energy deposited in two pixels must be > 2
- Filter double pixel events with these conditions and Generate 8 angle azimuthal histogram with low energy pixel as scattering pixel

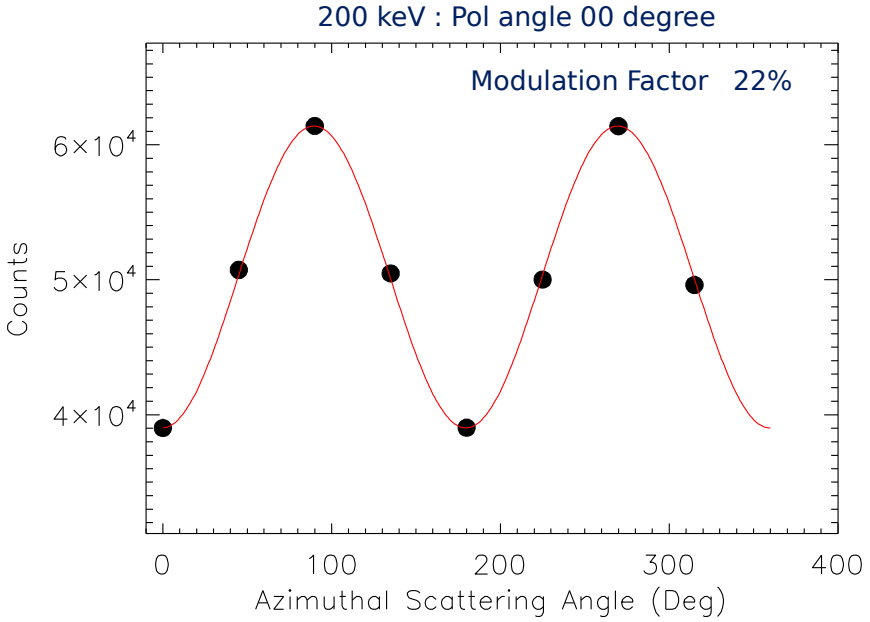
Modulation Curve Normalization



- Modulation curve has only 8 bins, which have non uniform angular coverage
- Has to be normalized with modulation curve for unpolarized beam

$$N_{i,nor} = \frac{\overline{M}_{unpol}}{M_{i,unpol}} N_{i,obs}$$ (Lei et al., 1997)





SWIFT / XRT follow up

XRT follow up important for estimation of jet opening angle

Detection of GRB in CZTI is possible in ~3 hrs

Localization ~ 1 day

Localization accuracy ~ 1 deg (still working)

XRT follow up possible when simultaneously detected by SWIFT/BAT

Probability of CZTI + BAT detection ~ 35%