

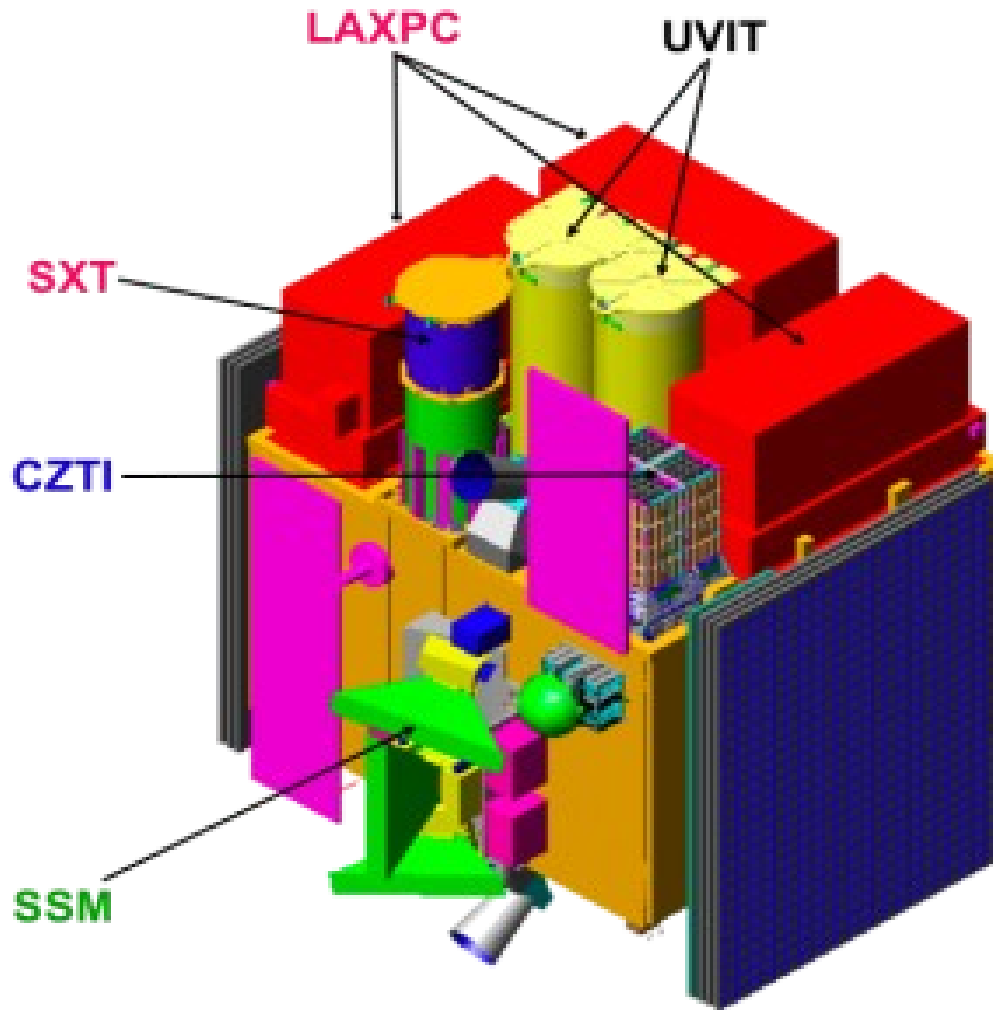
Polarization Measurements of Astronomical X-ray sources with CZTI onboard AstroSat

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Pennsylvania State University, USA**

On behalf of AstroSat-CZTI team

12th IACHEC Meet, 27th March, 2017, USA

Astrosat



India's first
dedicated satellite

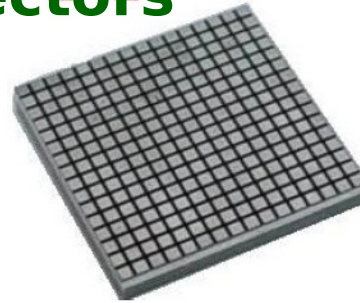
for **Multi wavelength
Astronomy**

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



Hard X-ray Polarimetry with Astrosat - CZT-Imager

pixelated CZT detectors

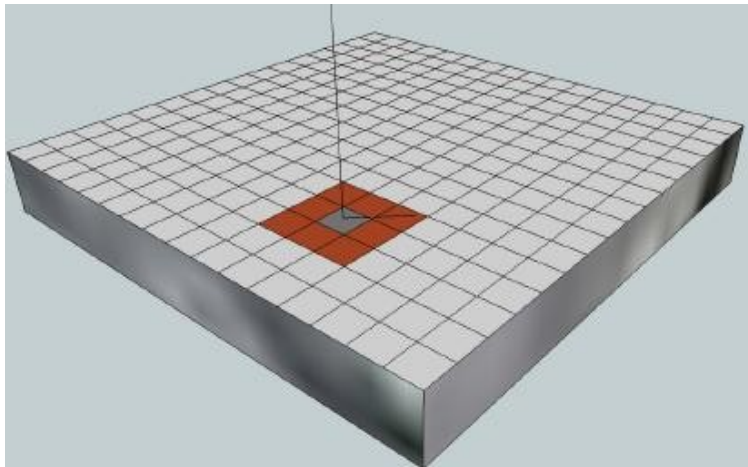


Orbotech CZT modules

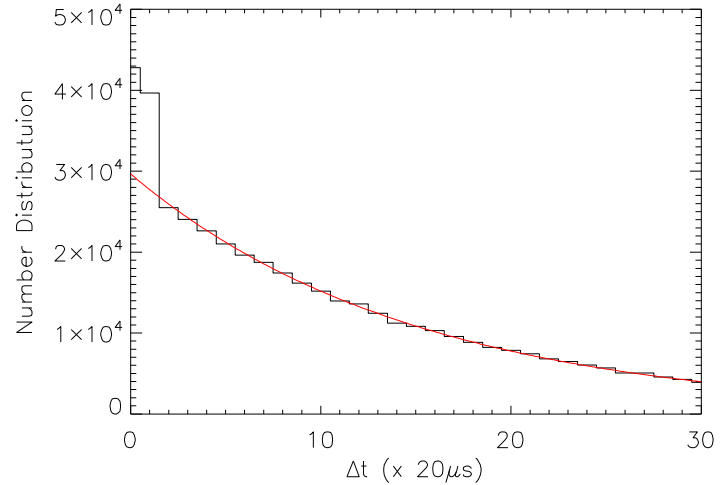
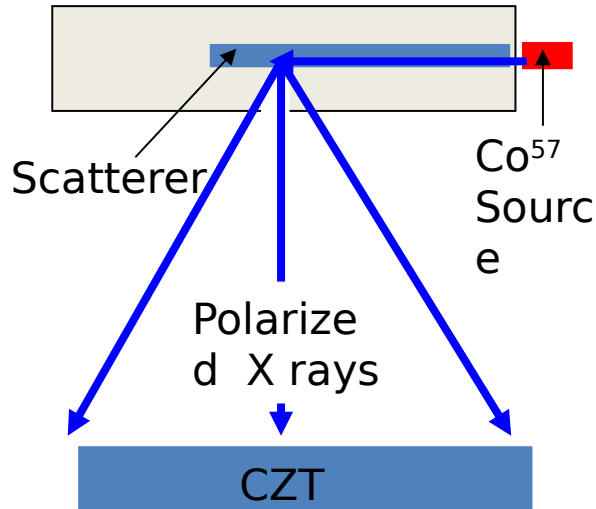
- 4 x 4 cm² (16 x 16 pixel)
- 5 mm thick
- Total 64 modules (16 in 4 quadrants)

Pixelated detectors can measure polarization

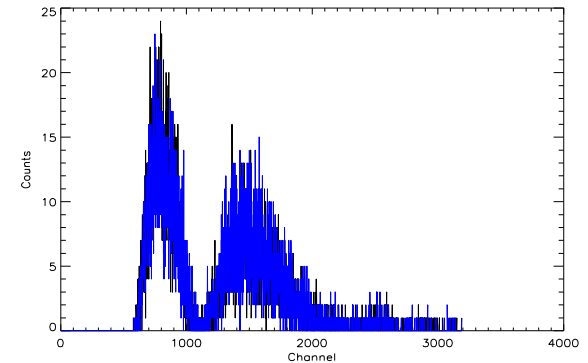
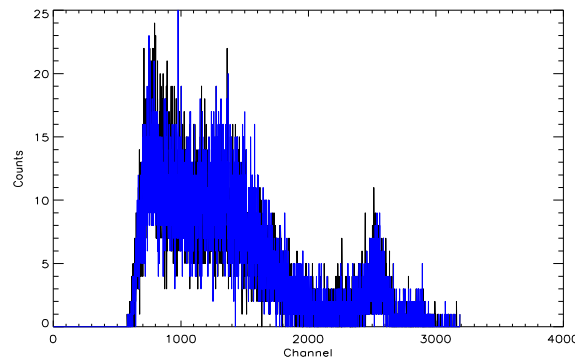
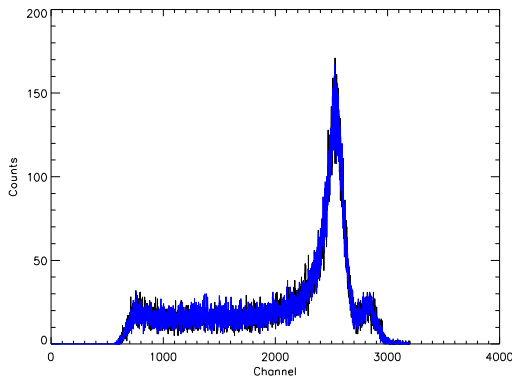
Compton scattering in one pixel and absorption of the scattered photon in another pixel constitute the azimuthal angle histogram



Proof-of-Concept Experiment

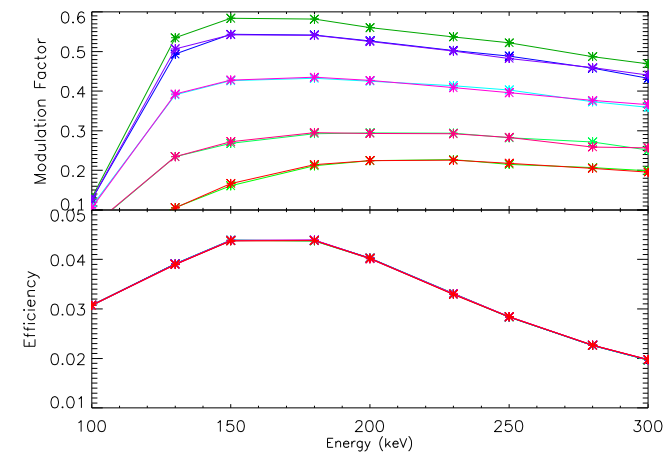
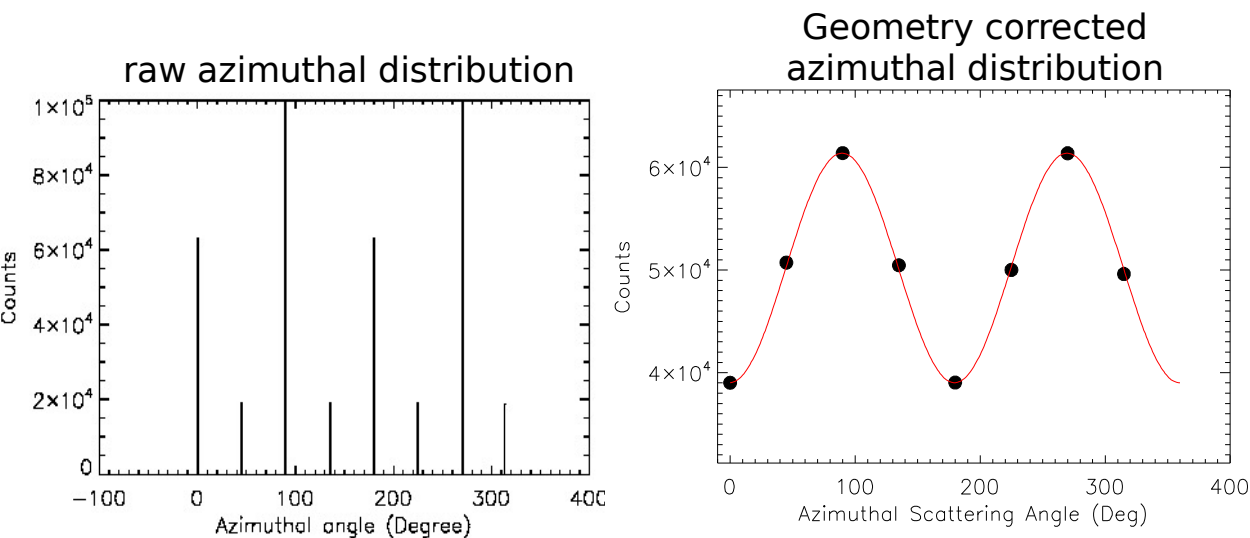


- All the double/triple/four/five pixel events were distinguished within 20/40 μs time
- Spectra of the double pixel events
- Only the neighboring pixel events are considered
- Ratio of deposited energies in two pixels is greater than 2



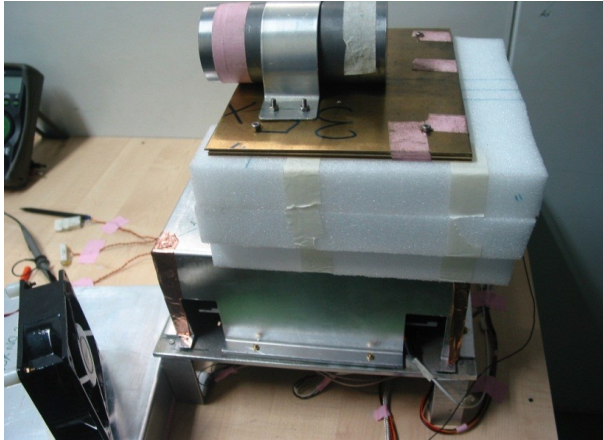
Data 'cleaning' and analysis

- Double pixel events are dominated by escape events
 - Only way to reject these events is to increase lower energy threshold to 35 keV
 - Effective polarimetric energy range is 150 - 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



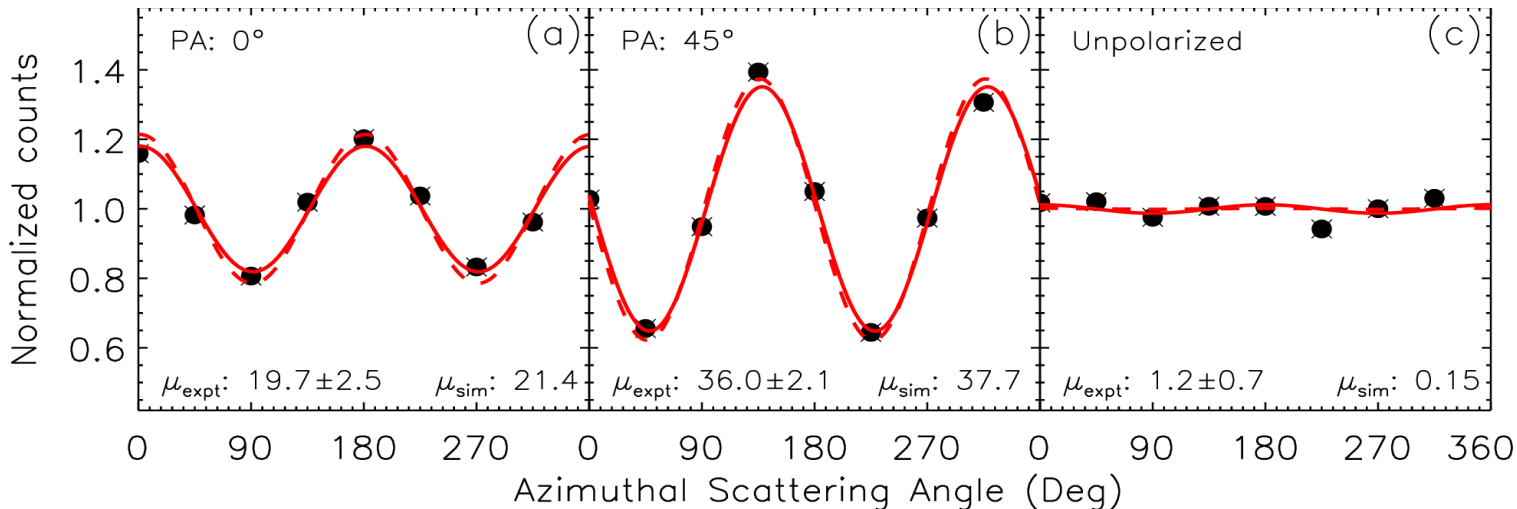
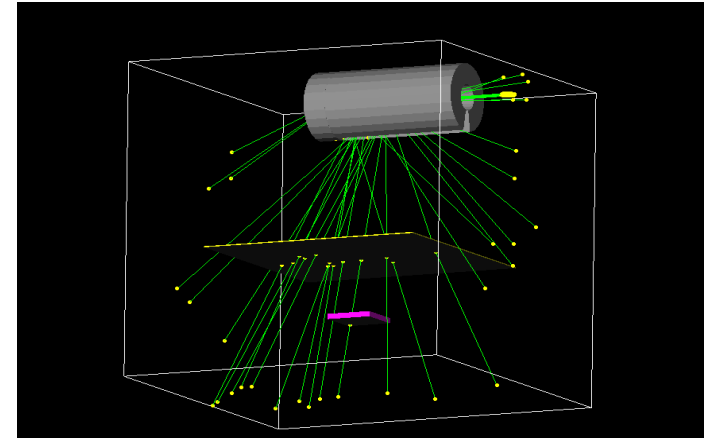
Hard X-ray Polarimetry with CZTI

Observed Modulation for Polarized Beam



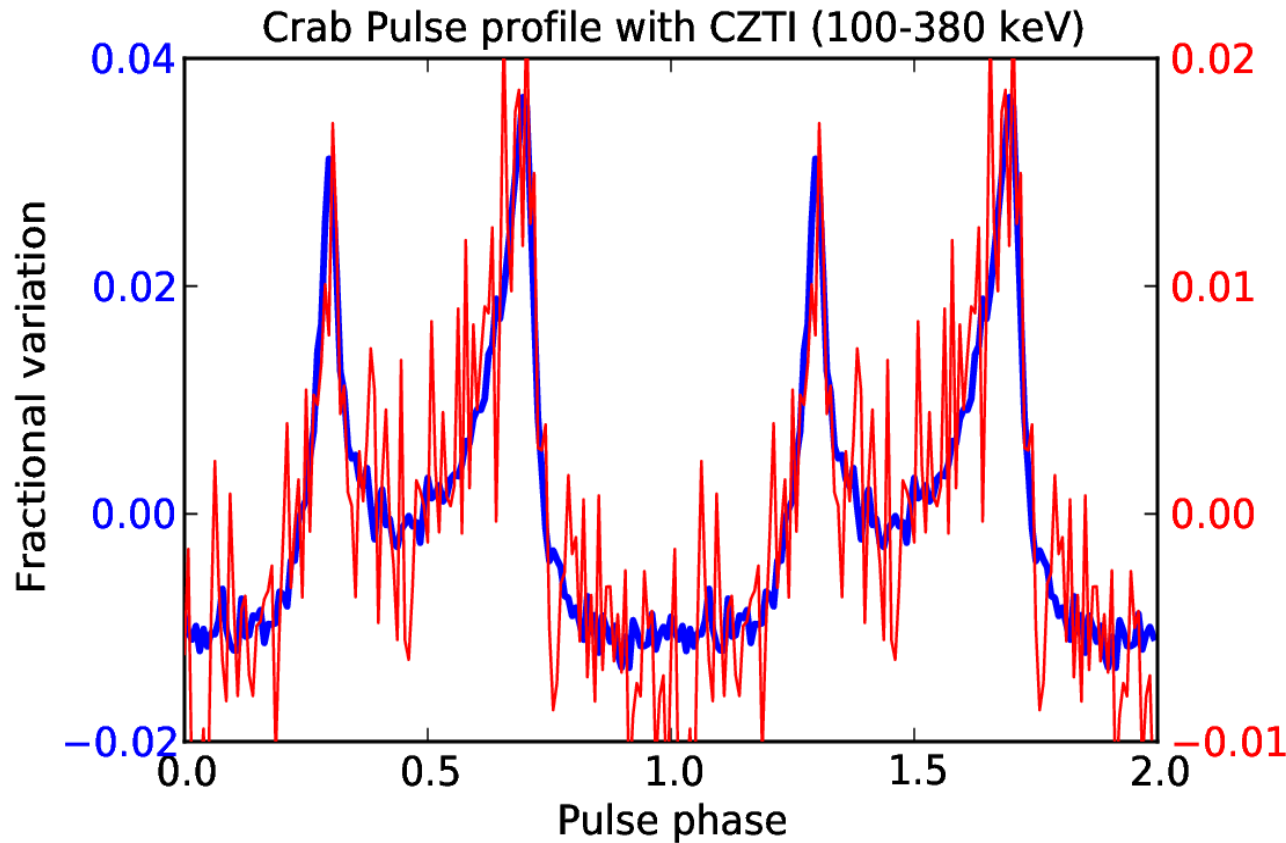
Polarization expt with CZTI using Ba133 (356 keV) source

Geometry used in simulation



CZTI does have polarization measurement capability

Crab Polarimetry with CZTI



**Total
Exposure :
550 ks**

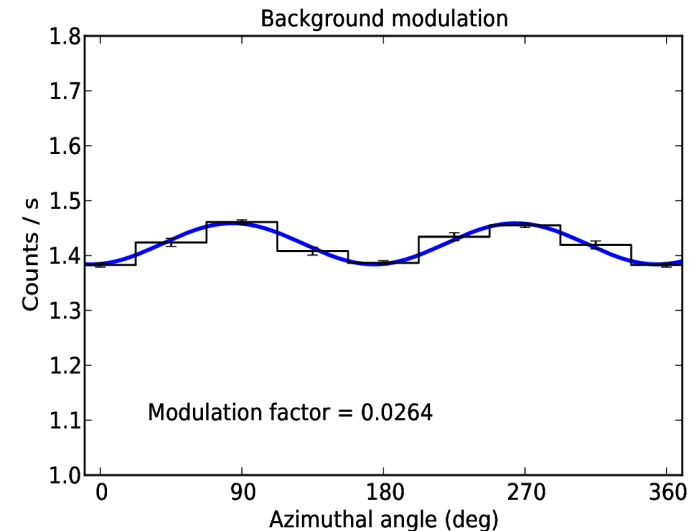
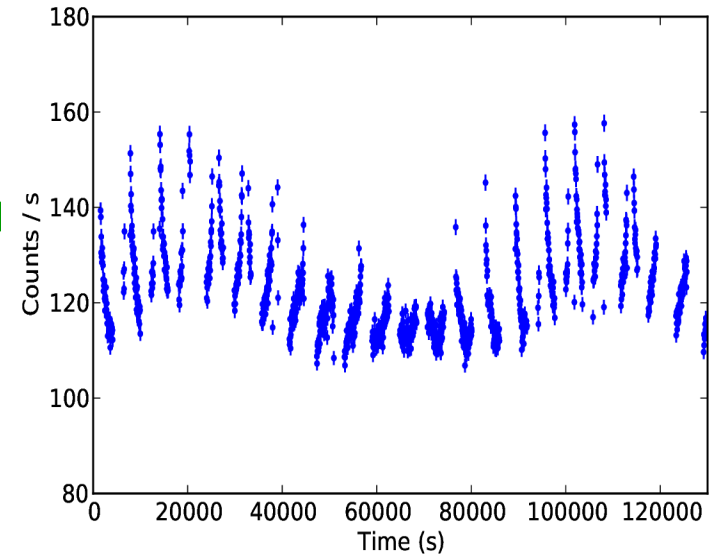
RED : Pulse
profile in
Compton events
(adjacent double
pixel events
satisfying
Compton
criteria)

BLUE : Pulse
profile in Single
pixel events

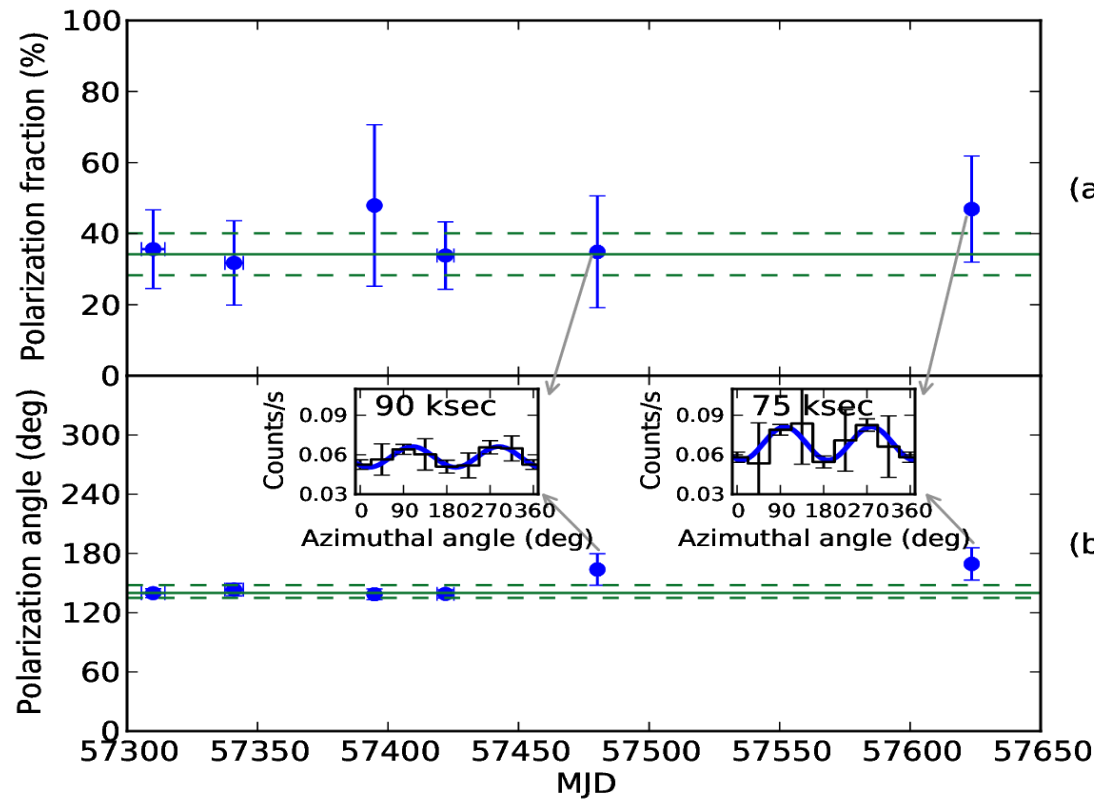
Validation of the Event selection

Background analysis

- Background pattern changes with DEC
- Need to select blank sky observation with same DEC as Crab
- Both Crab and Cygnus X-1 should be more than 80° away
- Background rate varies with ground track
- Selecting only similar tracks result in significant reduction in exposure
- Manually optimize back ground regions and correct for exposure



Crab Polarimetry with CZTI



(a)

(b)

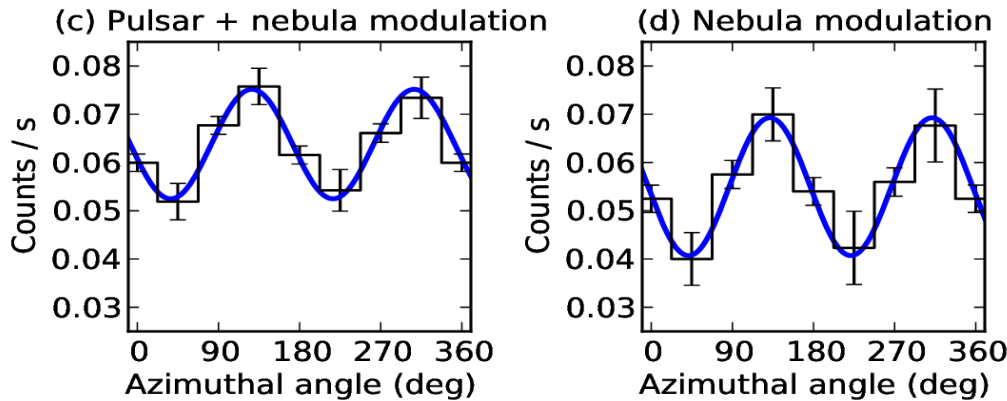
Total Exposure : 550 ks

**Full Crab Polarization :
35 % +/- 6% at angle 140
deg (North-East)**

**Nebula Polarization :
48 % +/- 10 % at angle
135 deg (North-East)**

**Good agreement with
the published results
(Dean 08, Forot 08)**

**Upcoming obs : ~ 160 ks
from April**

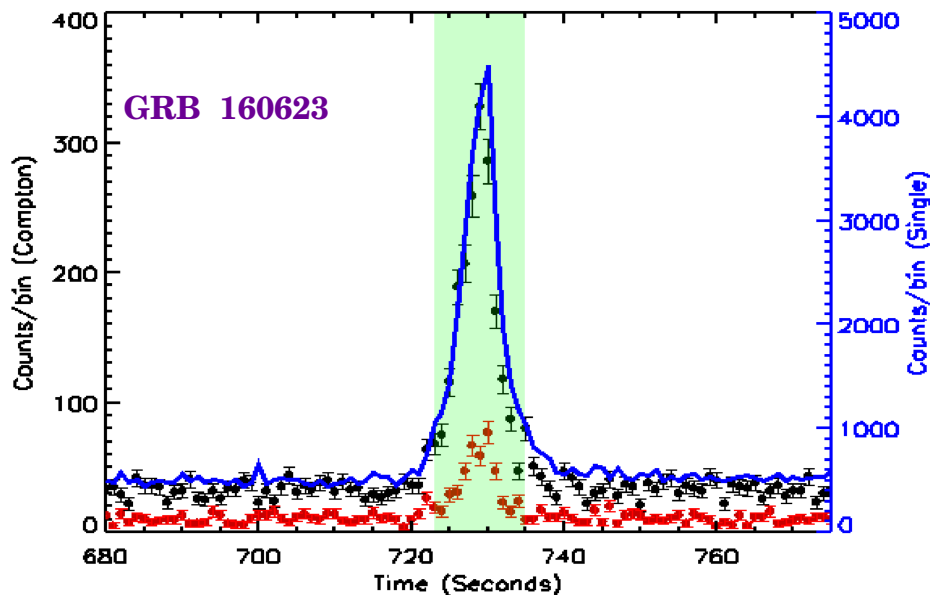
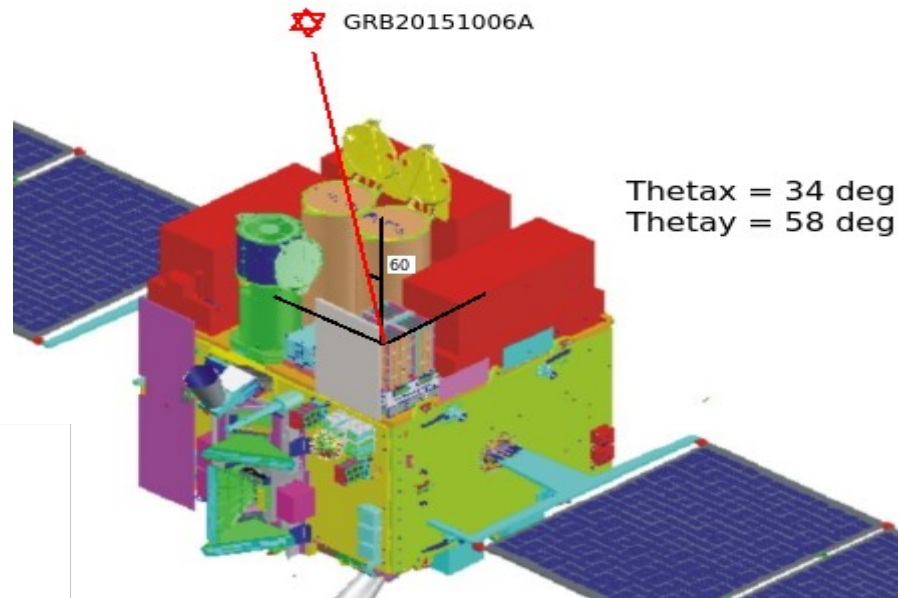


**Vadawale, Chattopadhyay et al, 2017
(communicated to Nature Astronomy)**

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 transient sources and GRBs



GRB search triggered by BAT / Fermi detection

GRB position from BAT

Automated GRB search engine under development

GRB Polarization

CZTI had detected more than 50 GRBs during first year

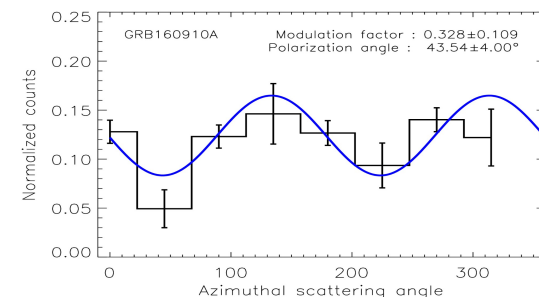
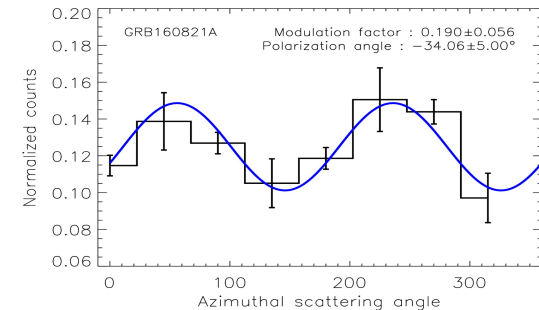
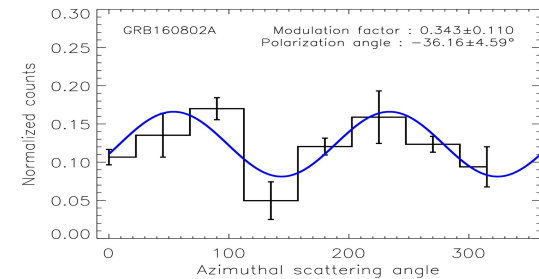
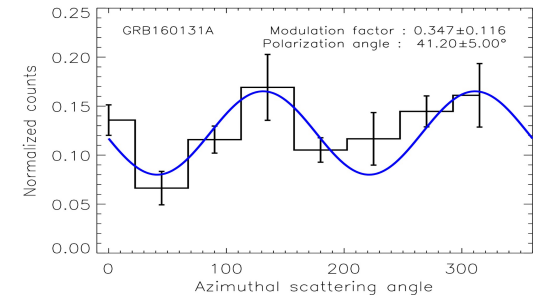
- 11 are suitable for polarization analysis
- Selected based on number of Compton events (> 350)

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

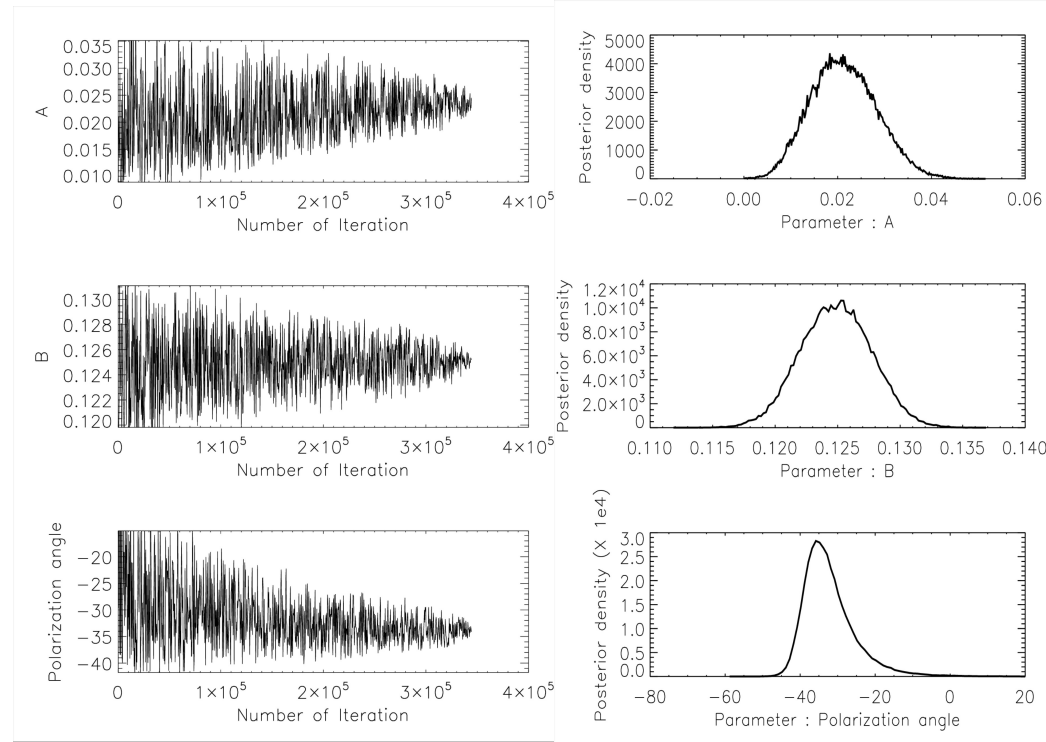
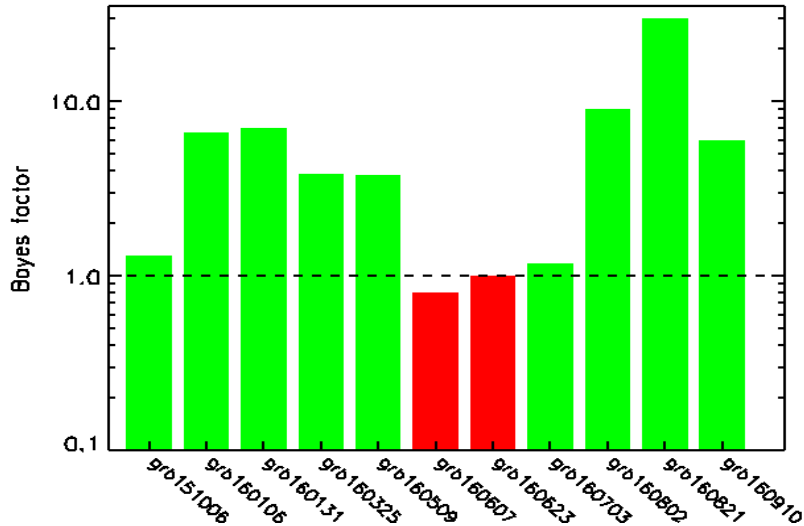
- Requires modulation curves for both 100% and completely unpolarized X-rays from the location of GRB
- Obtained by extensive Geant4 simulations with the mass model of full spacecraft
- Require extensive computing effort



GRB Polarization

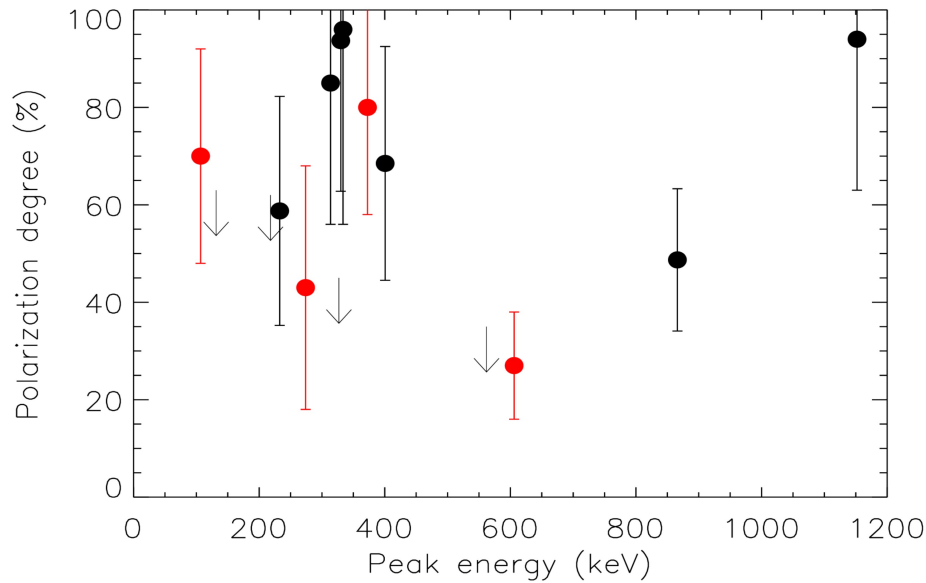
Error estimation on modulation factor and polarization angle based on Bayesian statistics

Firm confirmation of polarization detection - Bayes factor !!



GRBs with Bayes factor < 2 - Upper limit on polarization

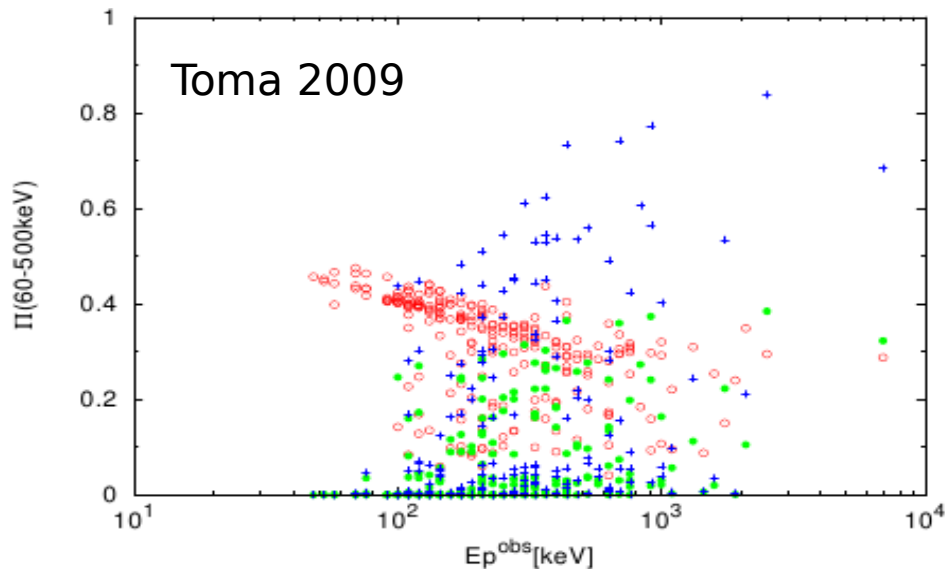
Polarization vs E_{peak}



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

CZTI is expected to provide a sample $>\sim 60$ GRBs in 5 years lifetime

Many more from POLAR



Cross-calibration by POLAR and CZTI – helpful for both the instruments

Chattopadhyay et al, 2017 (under prep)

SWIFT / XRT follow up

XRT follow up important for estimation of jet opening angle

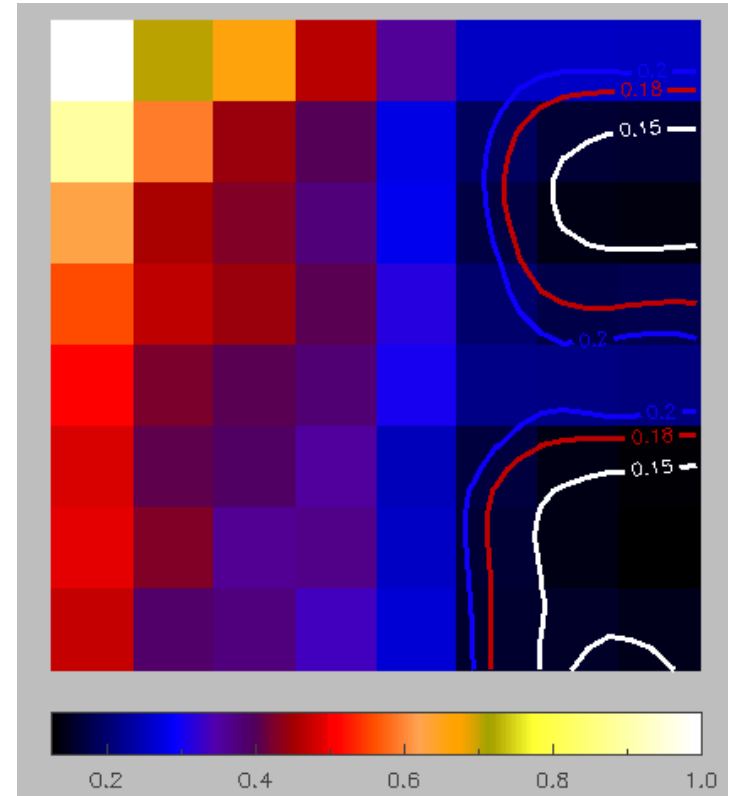
Detection of GRB in CZTI is possible in ~3 hrs

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%



Cyg X-1 obs of CZTI and spectral states

Nov	30 ks
Jan	40 ks
Apr	100 ks
Apr	58 ks
May	130 ks
May	82 ks
Jun	34 ks
Jul	32 ks
Jul	20 ks
Jul	8 ks
Jul	14 ks
Jul	7 ks

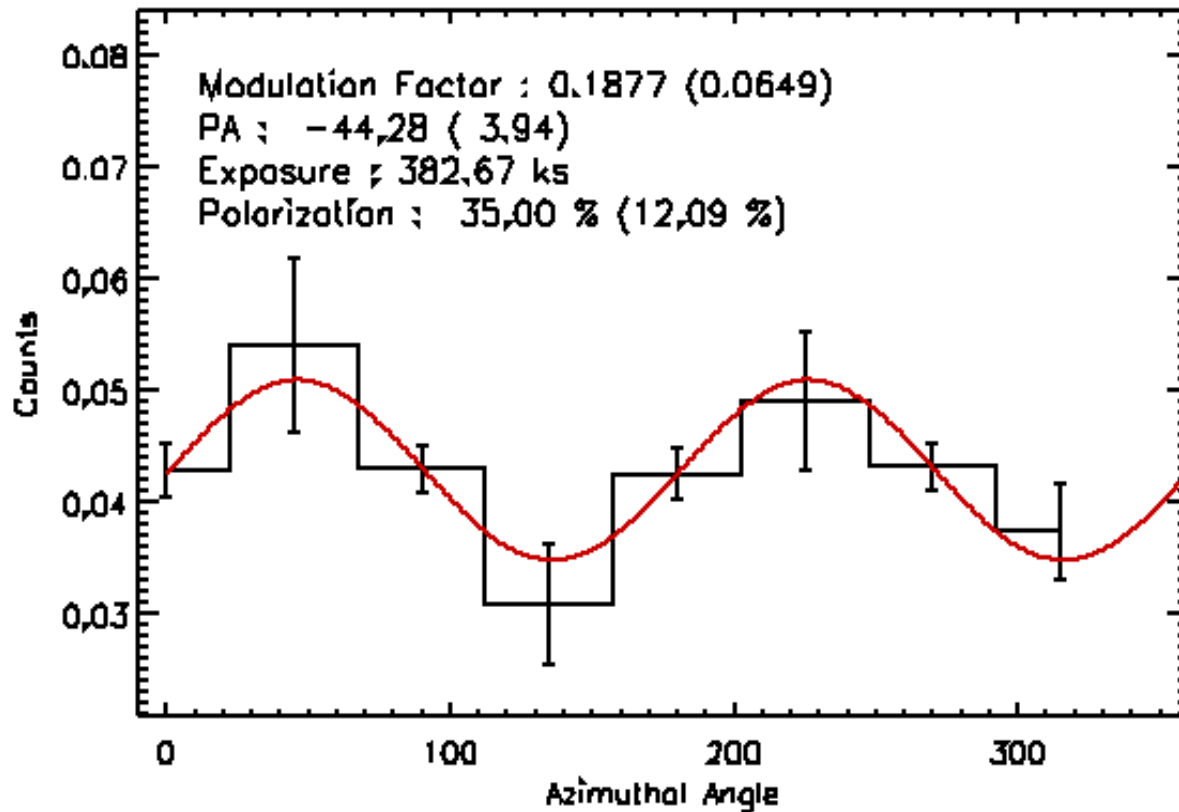
> Intermediate state

> hard state

Total Exposure ~ 500 ks

Modulation Curve : CygX1 Polarization

Hard State



**Polarization
angle in Sky:
224.3 deg**

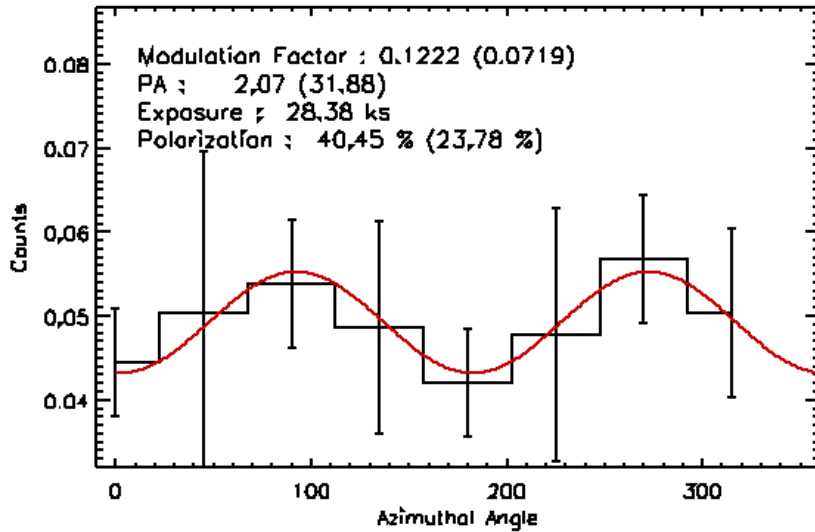
**Good
agreement with
Integral results**

Pol Degree : 35 %

**close agreement
with the optically
thin synchrotron
model predictions**

Modulation Curve : CygX1 Polarization

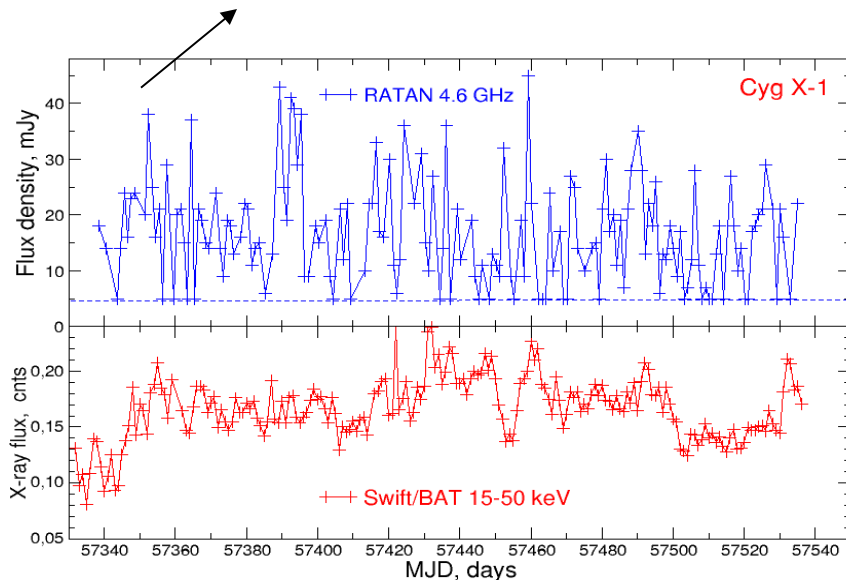
Intermediate state



**Polarization angle in Sky:
350 deg**

**Aligned with the radio
jet !!!**

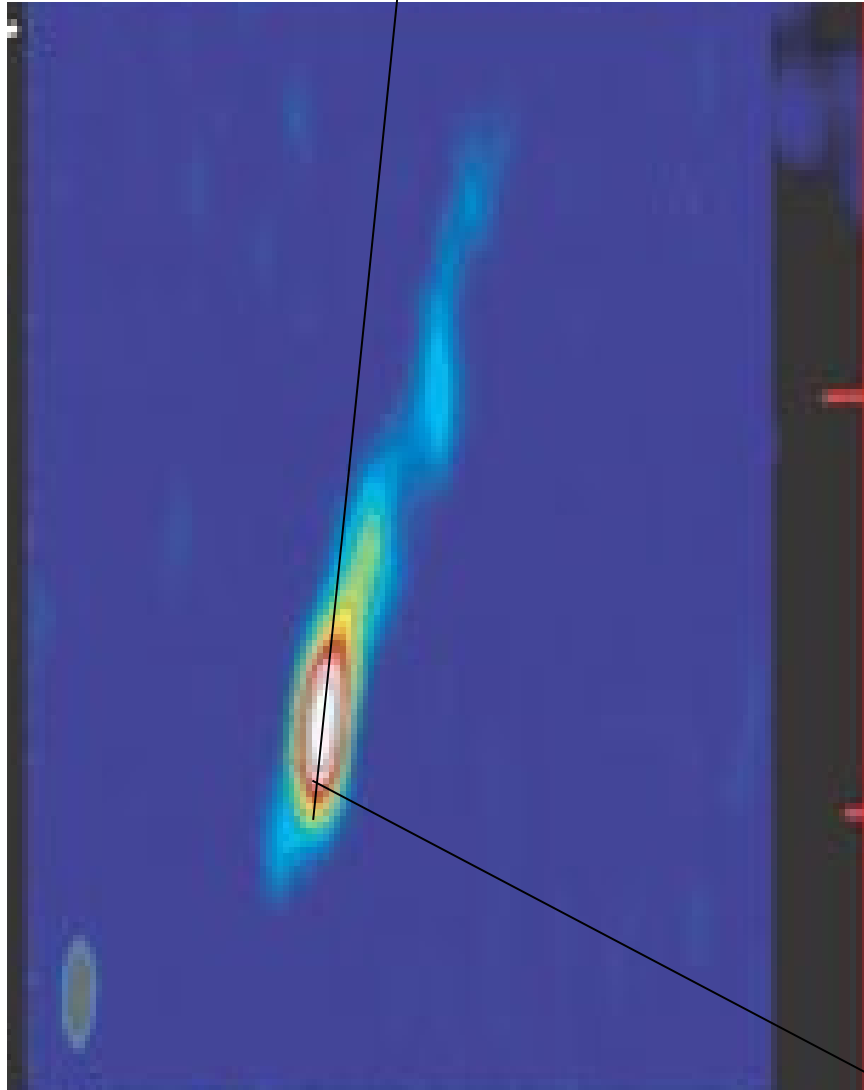
Pol Degree : 40 %



**Detection of radio flare
for the same obs--- atel
9087 !!!**

Cyg X-1 Polarization

Intermediate
state



Hard state

Work under progress !!!

Require multi-wavelength
spectro-polarimetric
modelling

More upcoming
observation : 100 ks (from
April)

Hint of state dependent
polarization: CZTI and
POLAR (and INTEGRAL)
simultaneous
observation !

Summary

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

Most accurate measurement of Crab hard X-ray polarization

First time possibility of phase resolved polarimetry of Crab
New challenges for the pulsar emission models

CZTI is also a prolific GRB detector and polarimeter

Detected more than 50 GRBs in first year
11 of them suitable for polarization analysis
Potential to constrain GRB models with bigger sample
Simultaneous detection of bright GRBs by CZTI and POLAR
would be extremely helpful

State dependent polarization of Cygnus X-1

Work under progress... but initial analysis show promising results
Simultaneous observation of CZTI and POLAR required

Thanks...

