AstroSat CZTI
&
Future Indian Missions

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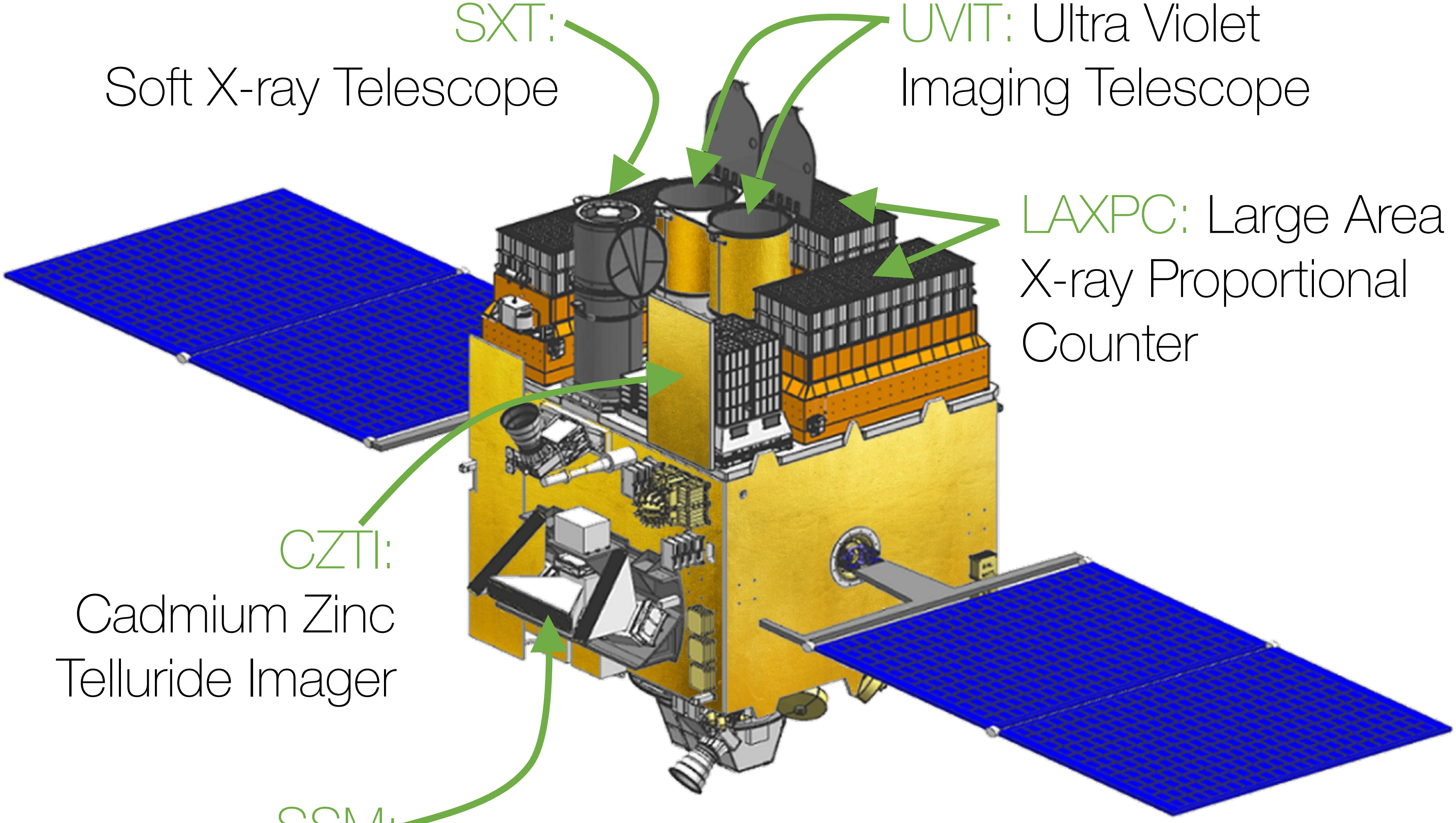
Astrosat



http://astrosat.iucaa.in

AstroSat results

- 5 years since launch
- 100+ papers published, several theses

- AO-11: October 2021 to September 2022
  - » Last date – 25th March 2021
  - » 20% time open for international observers

What's next?

- LAXPC: Continuing legacy of Ginga, RXTE/PCA
  - » Direct successor is not being planned in India
  - » Community will be happy to get involved with eXTP

- UVIT: Highly successful UV telescope
  - » Proposed successor: INSIST (separate UV mission)

- SXT, SSM, CZTI: Amalgamated into two proposed missions
  - » Daksha and Broad-band X-ray polarimetry mission

Cadmium Zinc Telluride Imager

AstroSat CZTI

CZTI at a glance

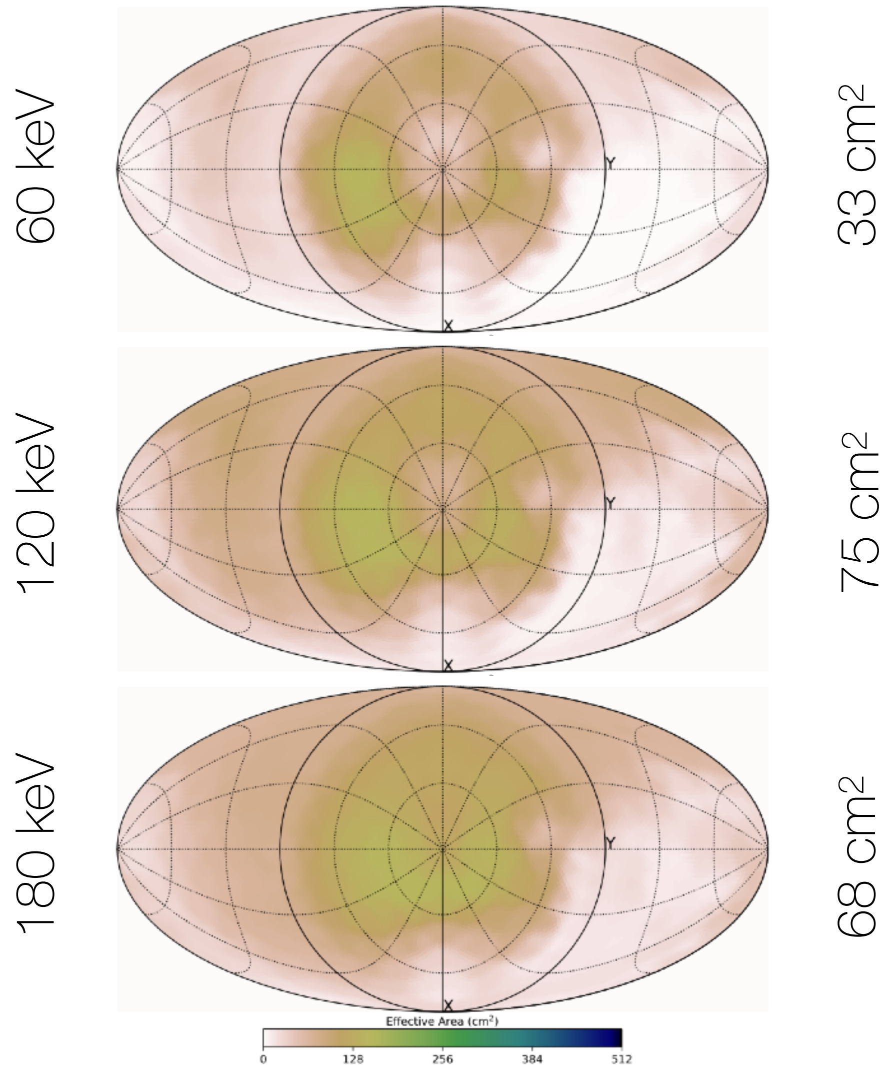
- 5 mm thick CZT detectors
- 976 cm^2 area
- 2.46 × 2.46 mm pixels
- 64 modules, 16384 pixels

- Nominal energy range: 20-200 keV

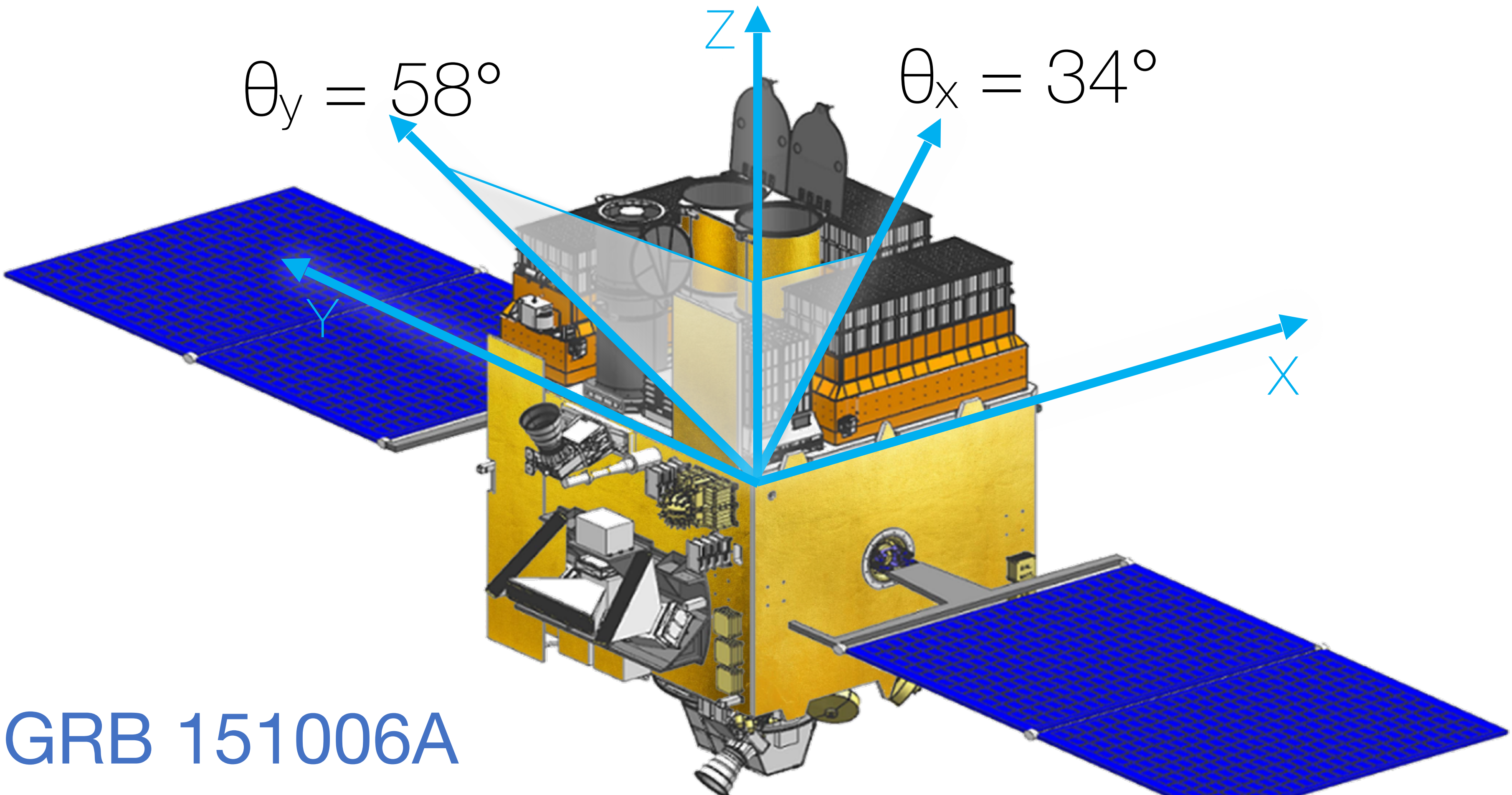
CZTI for off-axis transients

- Collimators opaque up to ~100 keV
  - » “Open” at higher energies!
- Detectors sensitive to ~400 keV

- Off-axis transients
- Polarisation



AstroSat's first science result!

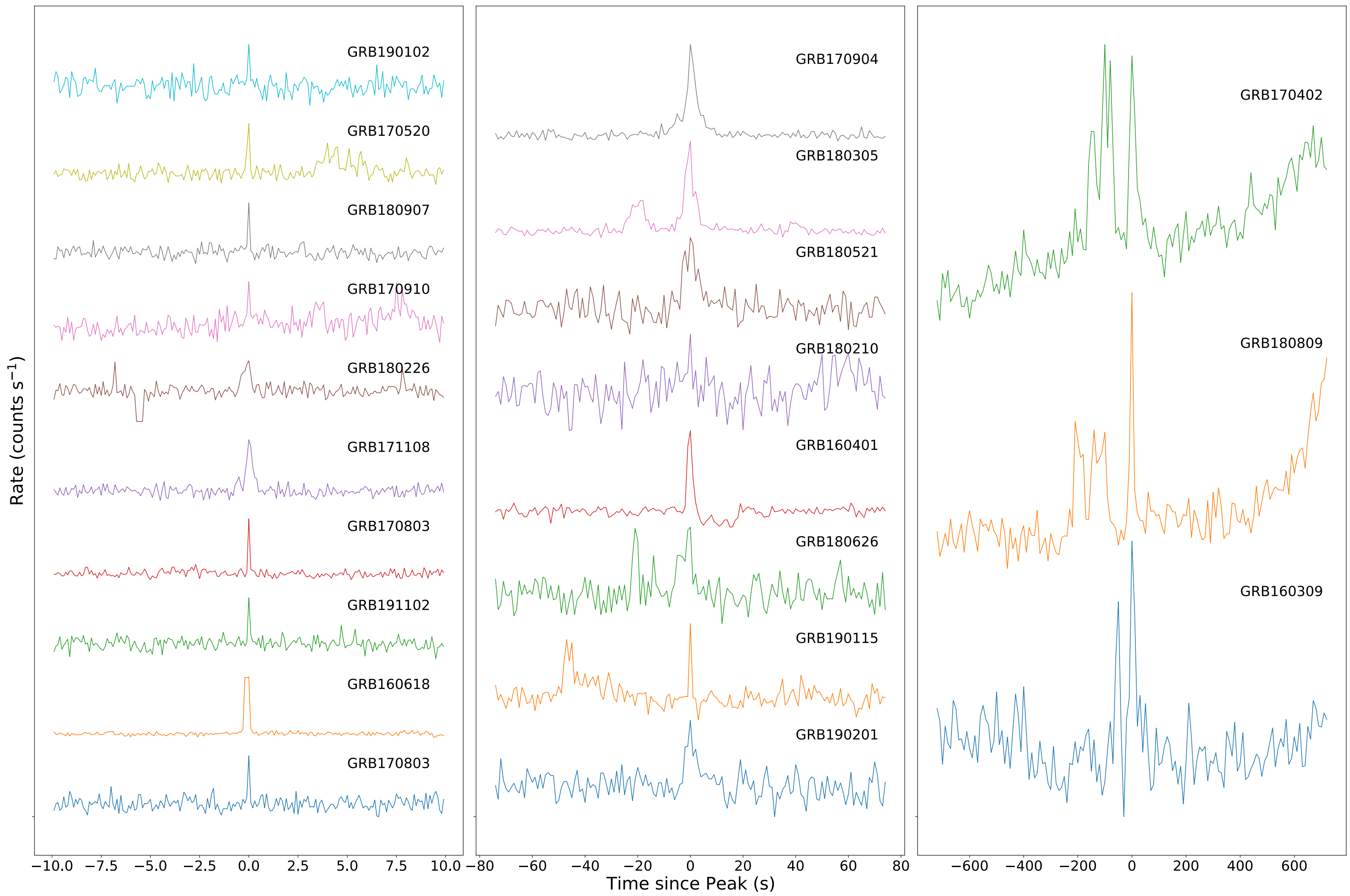


GRB 151006A

Detected 60.7° off axis

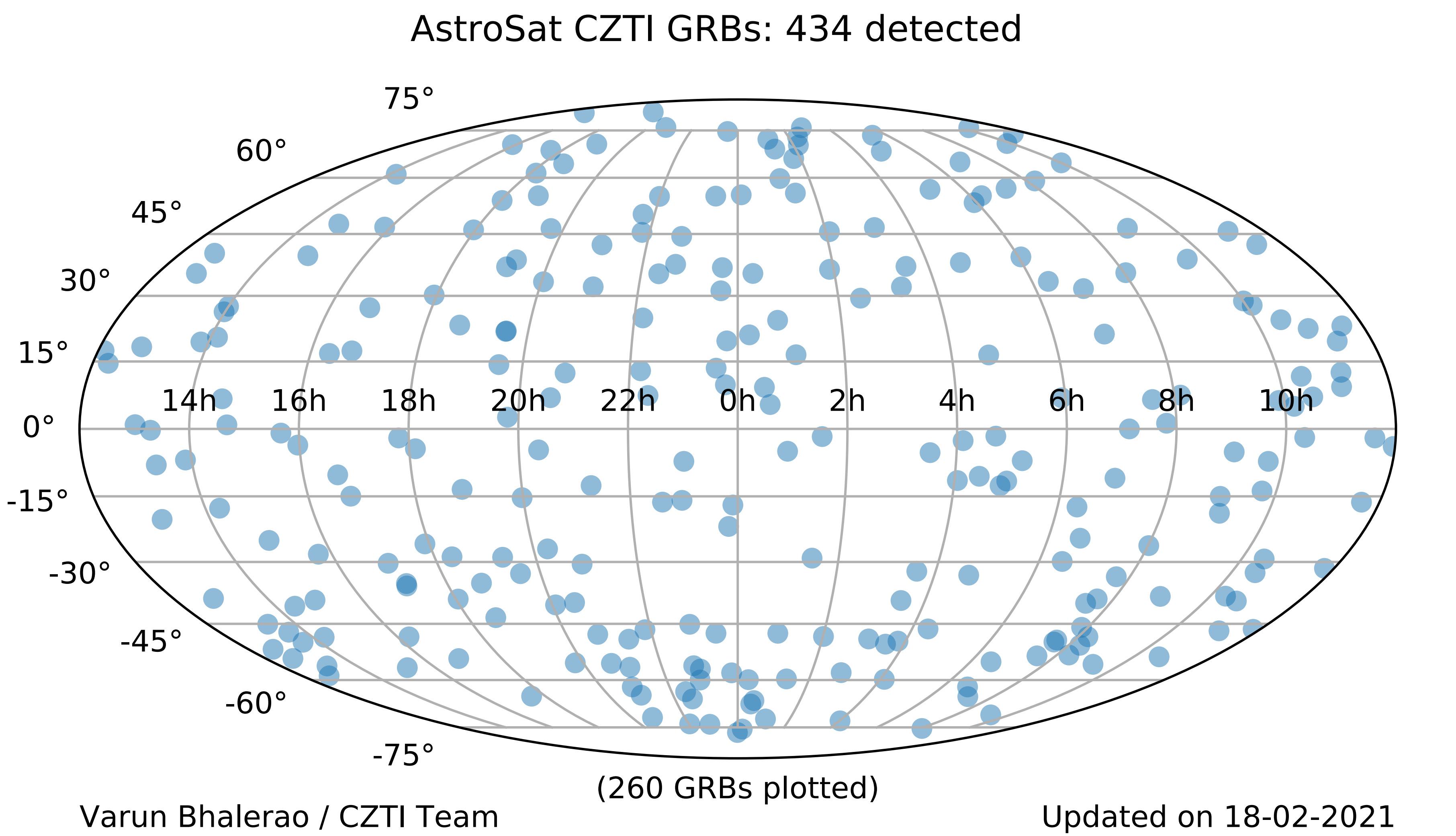
Bhalerao et al., 2015, GCN 18422

Transient search



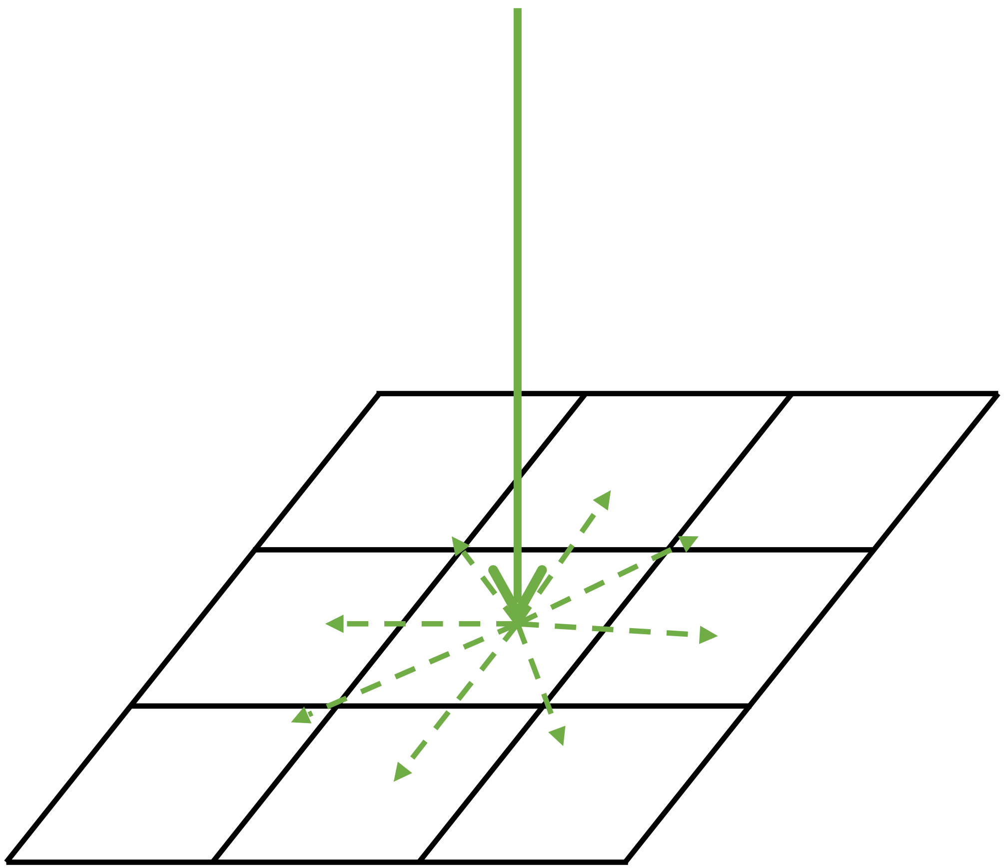
Credit: CIFT Team (AstroSat CZTI, IIT Bombay)

GRB detections

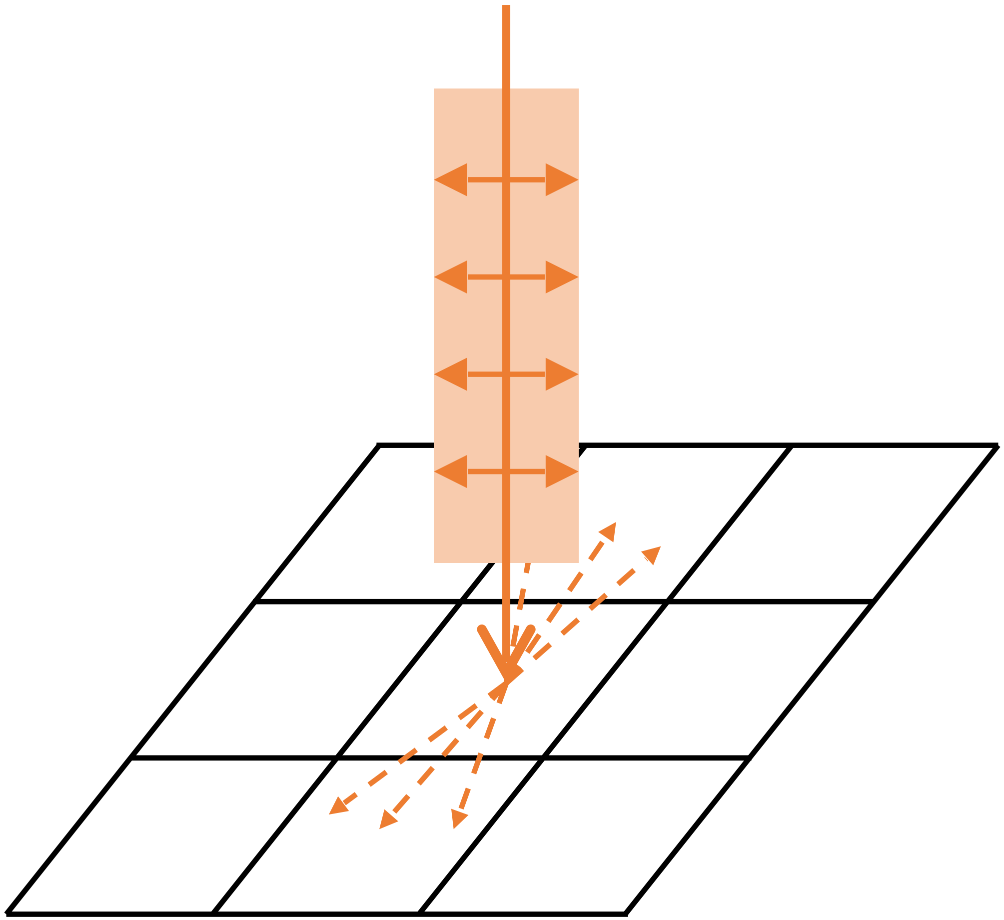


CZTI + Polarisation

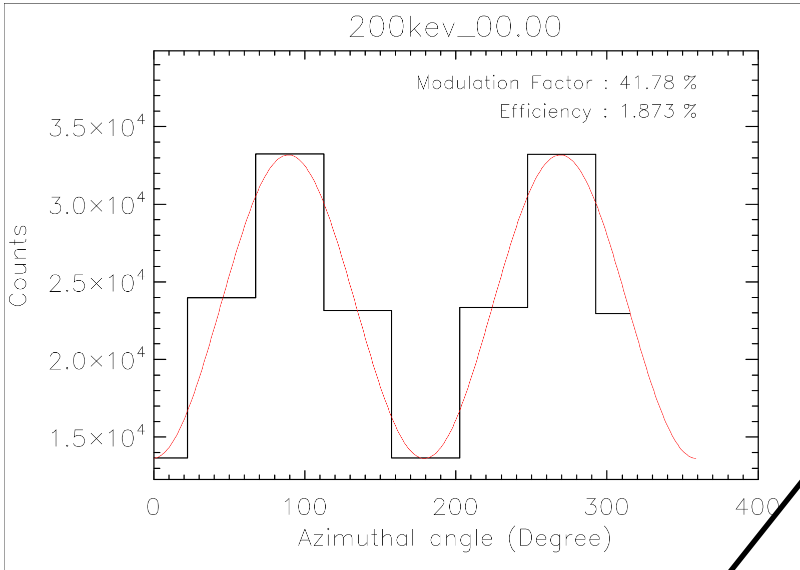
Polarisation & Scattering

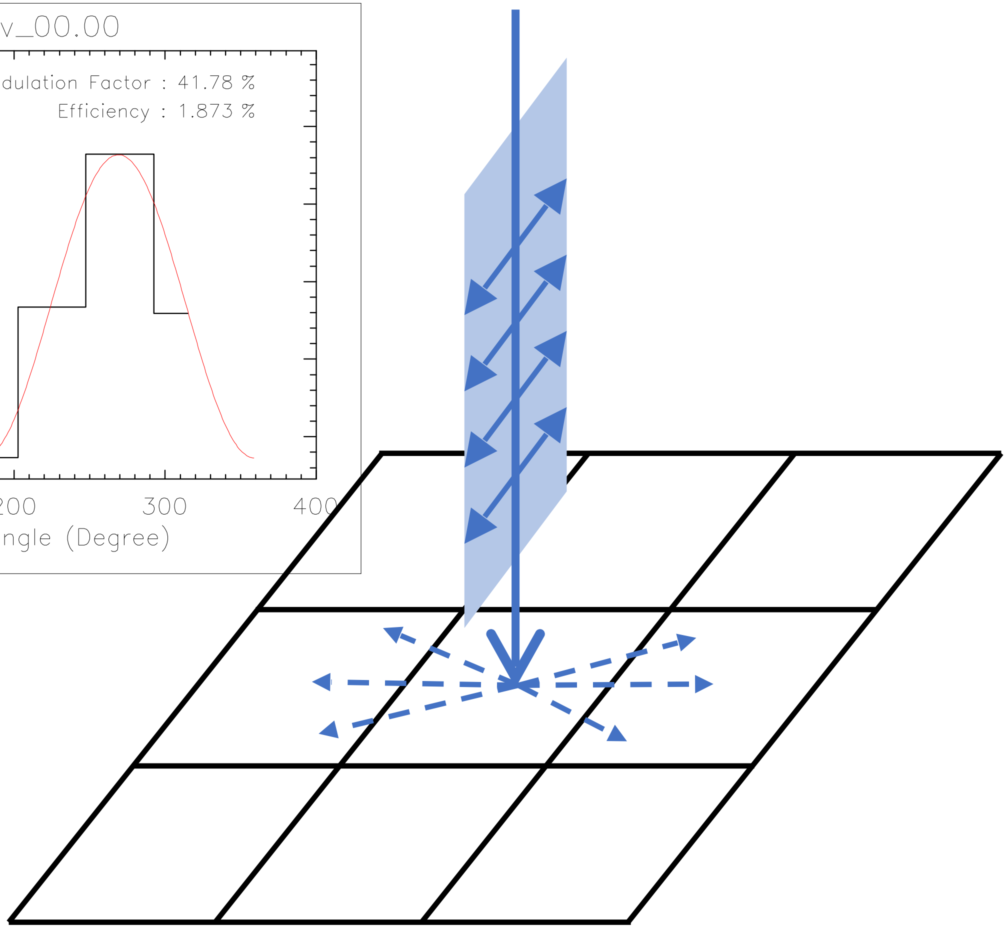


Polarisation & Scattering



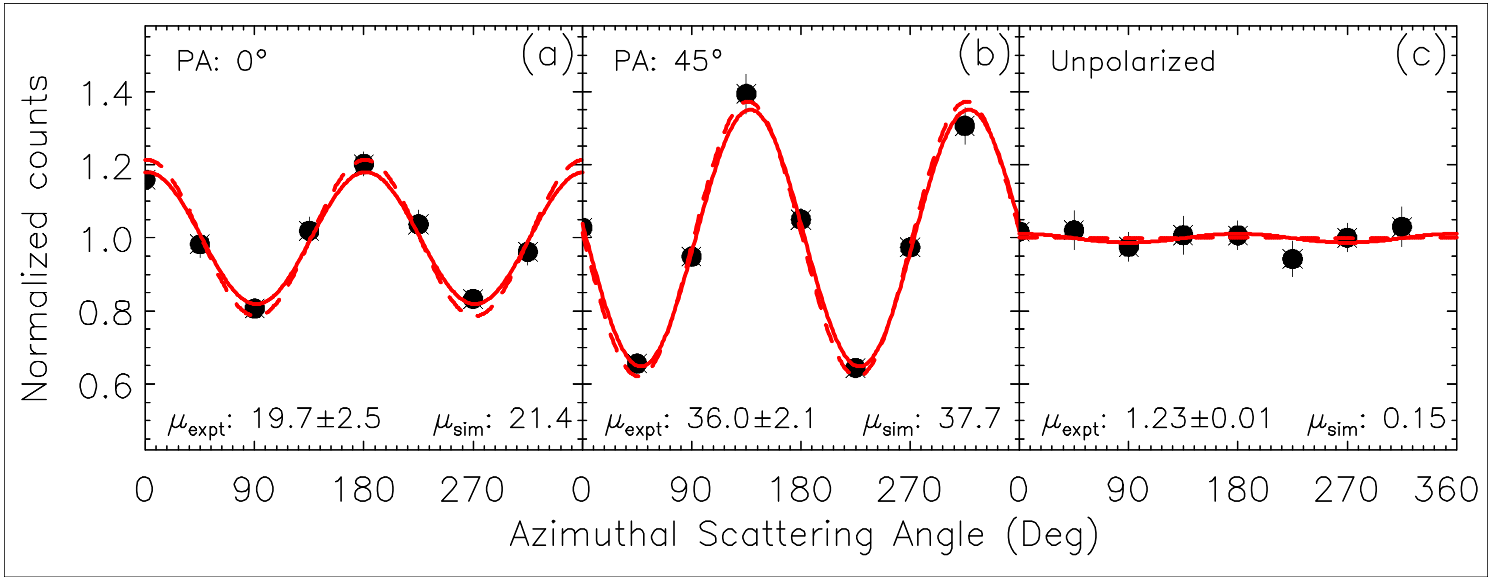
Polarisation & Scattering





CZTI and polarisation

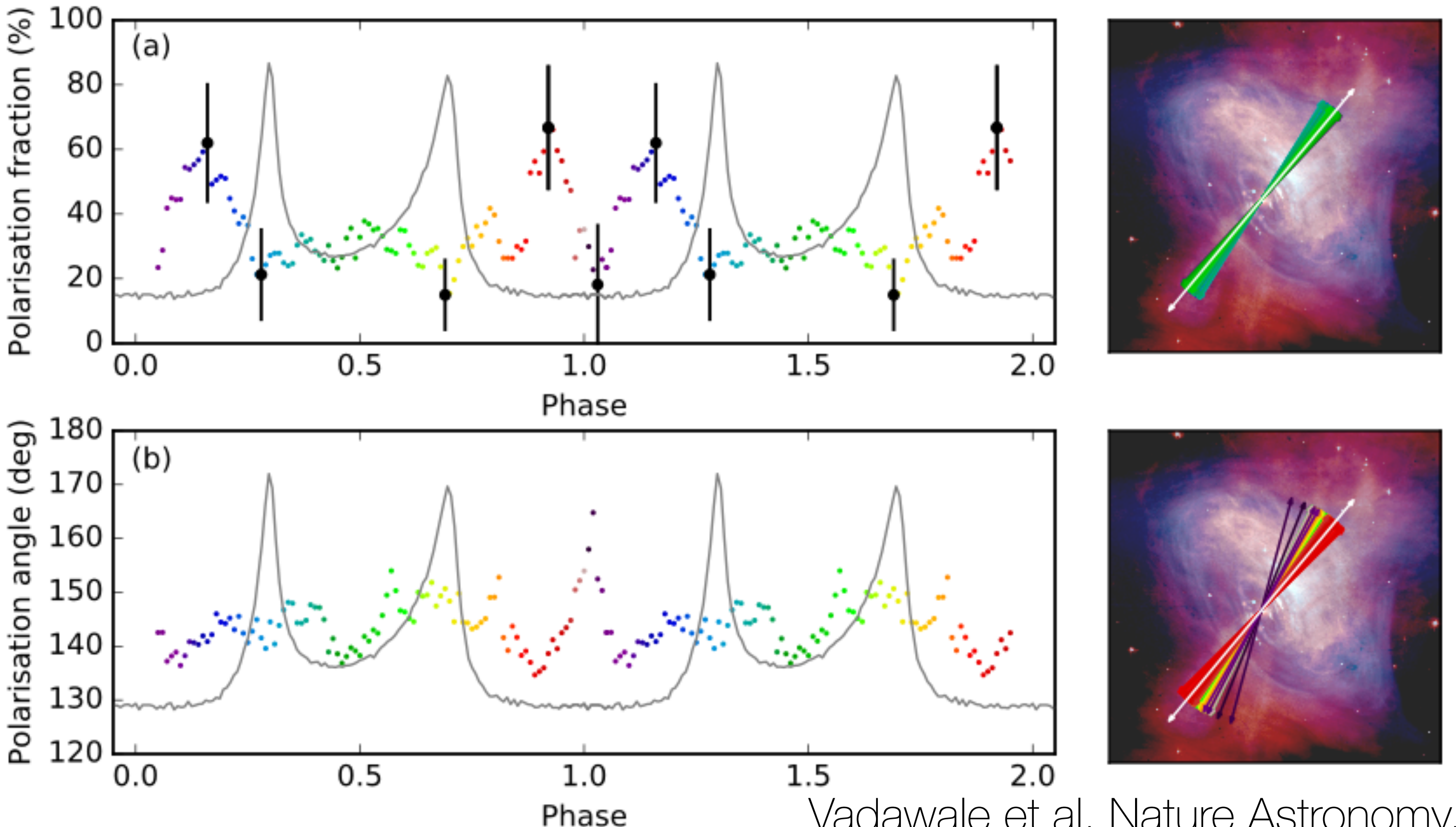
- Experimentally tested before launch
- 100 – 380 keV range
- Limited to very bright sources



Vadawale et al 2015

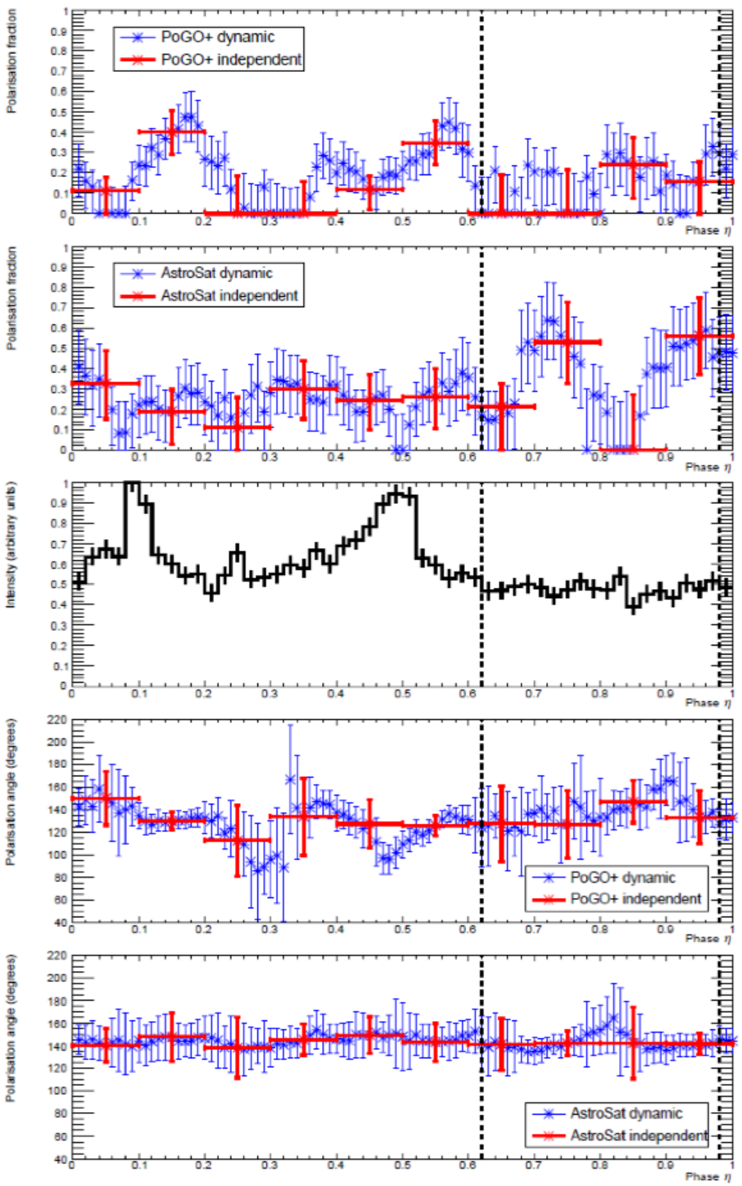
Crab polarisation

- 6σ result (800 ks), 8σ with 1.8 Ms
- Significant off-pulse variation challenges models!

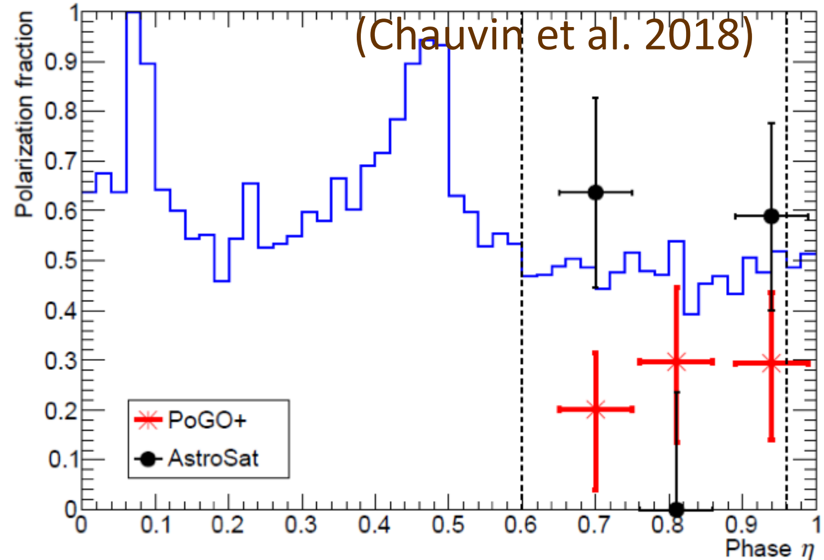


Vadawale et al, Nature Astronomy, 2017

POGO+ Results



Reanalysis (18 – 160 keV)



Suggests strong energy dependence

More data is needed

Finer independent phase bins

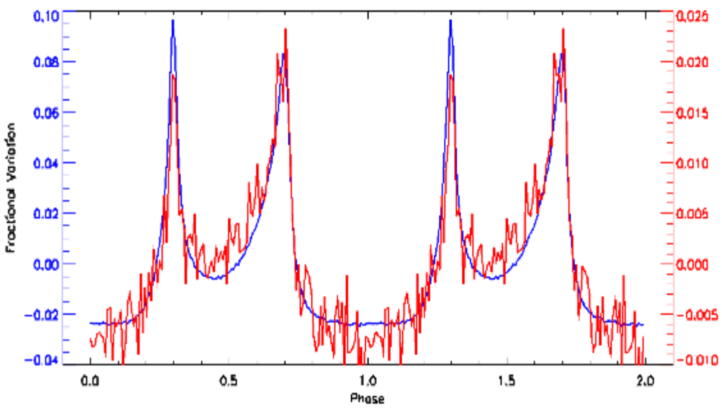
Validation of dynamic phase resolved analysis

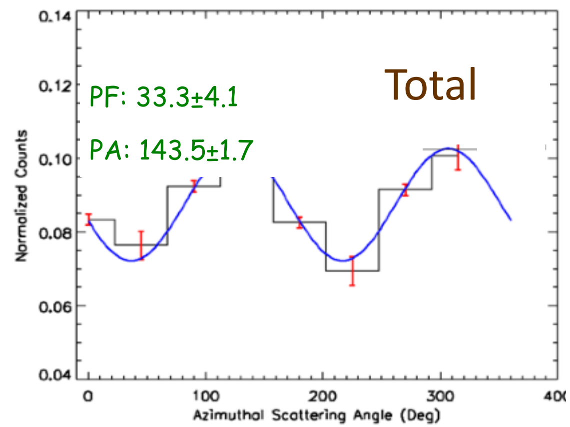
Working on both, but delayed due to pandemic

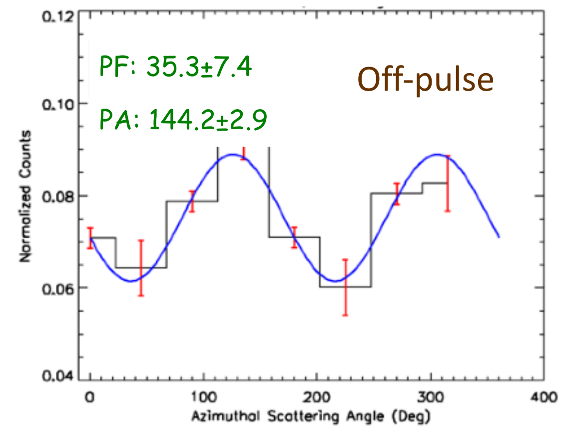
Expect paper in few months

Crab New Observations

1 Ms new data, total 1.8 Ms analysed (500 ks more observed in Sep.20)



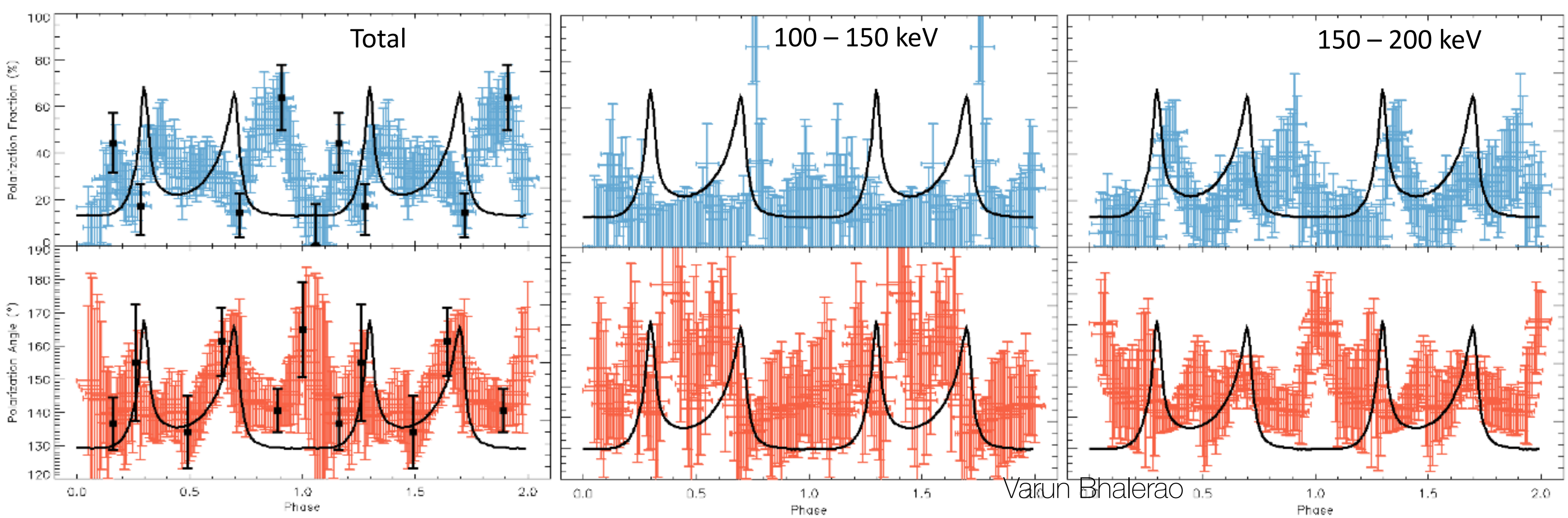




X-ray polarimetry is challenging!

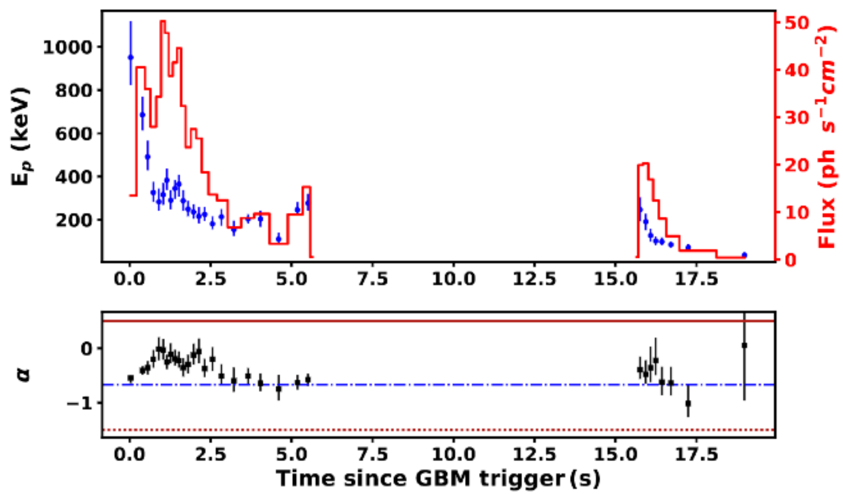
Must have more data, better instruments

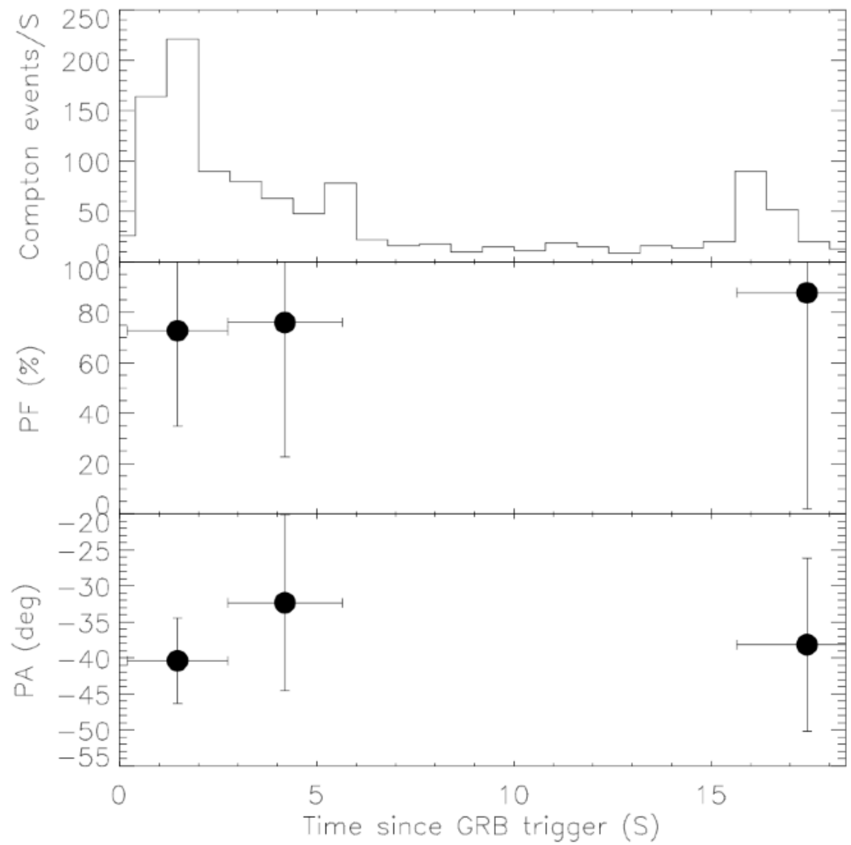
Preliminary results



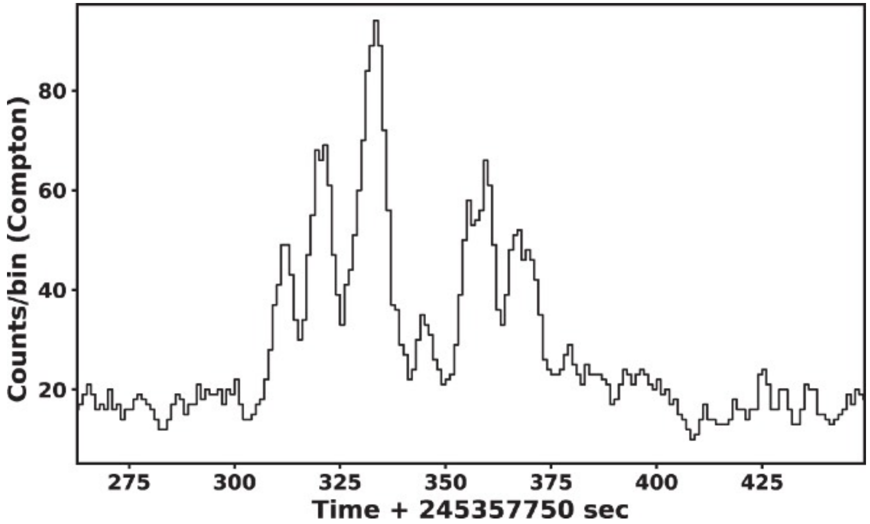
GRB 160821A

- Violation of synchrotron line of death by the highly polarised GRB 160821A
- Chand et al., 2018, ApJ, 862, 154



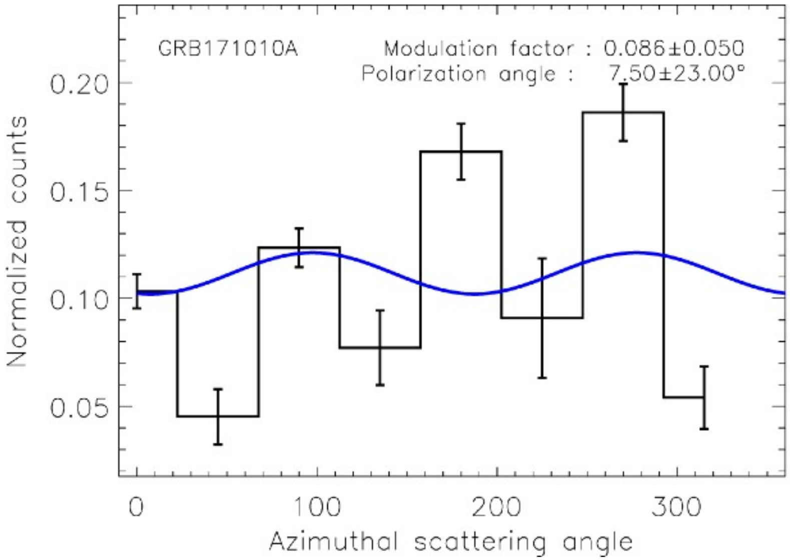


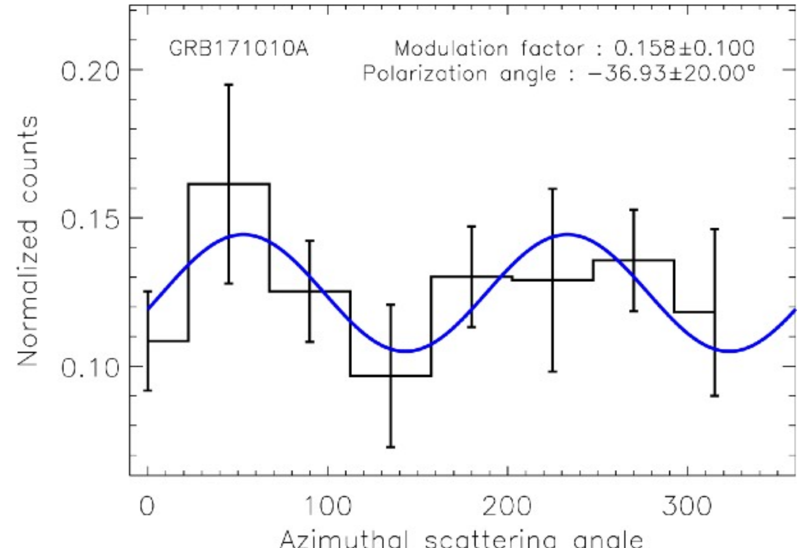
GRB171010A



100 – 300 keV
Compton event lightcurve

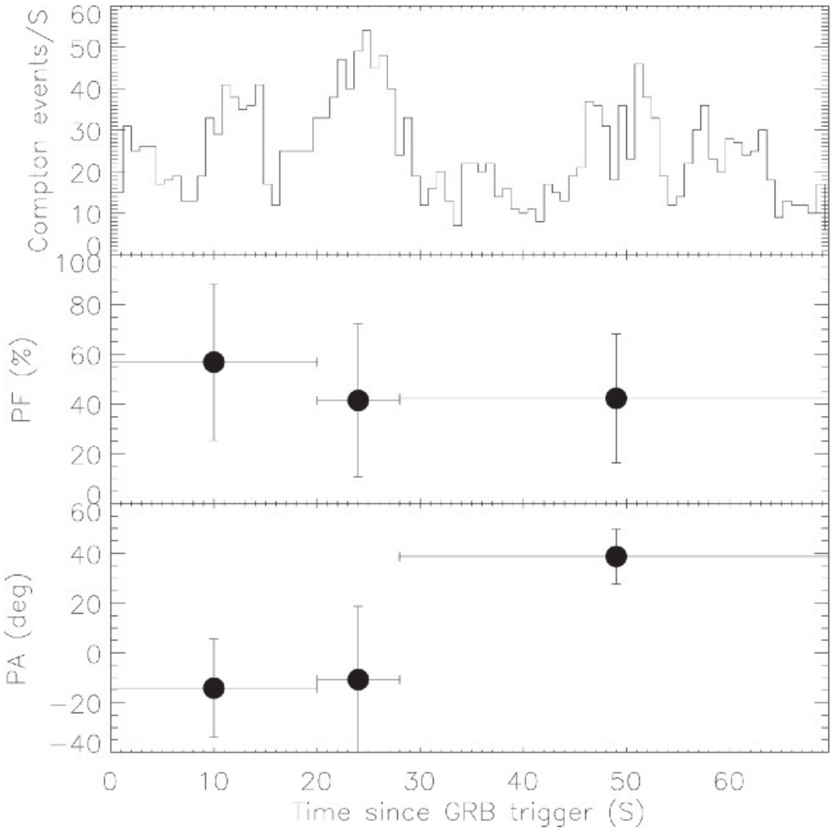
↓ Total GRB:



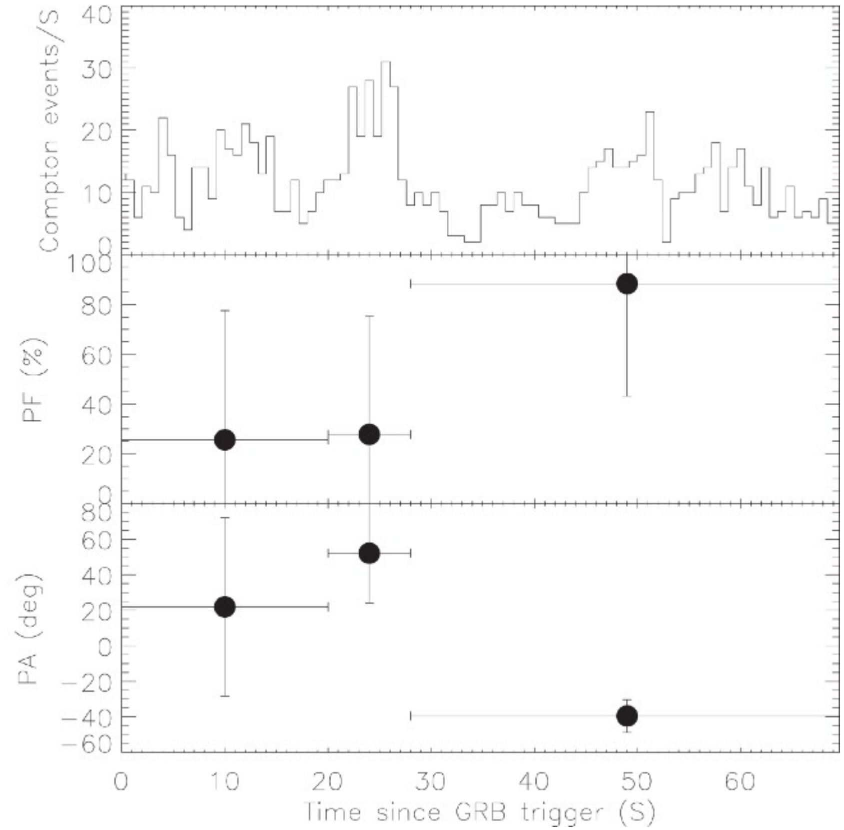


100 – 200 keV: unpolarised | 200 – 300 keV: polarised

GRB171010A



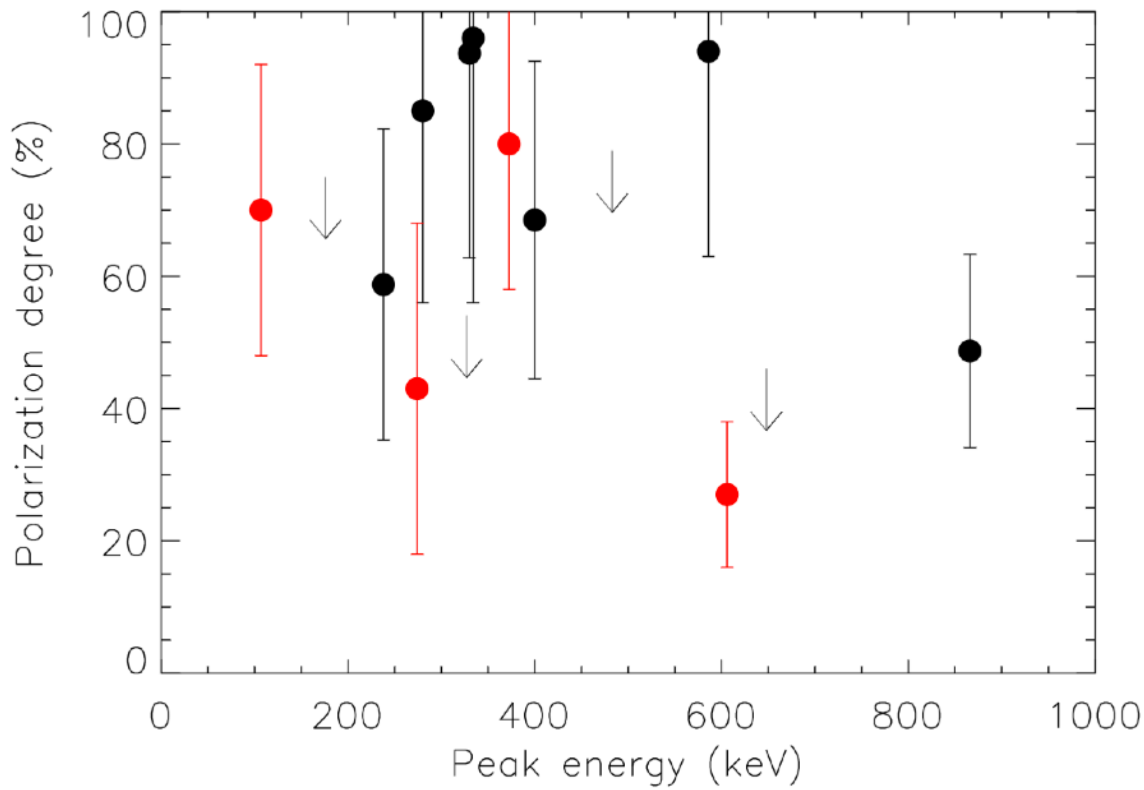
100 – 200 keV



200 – 300 keV

GRB Polarisation: sample study

- Prompt emission polarimetry for 11 GRBs
  - » Chattopadhyay et al., 2019, ApJ, 884, 123
- 5-year, 22 GRB paper in prep



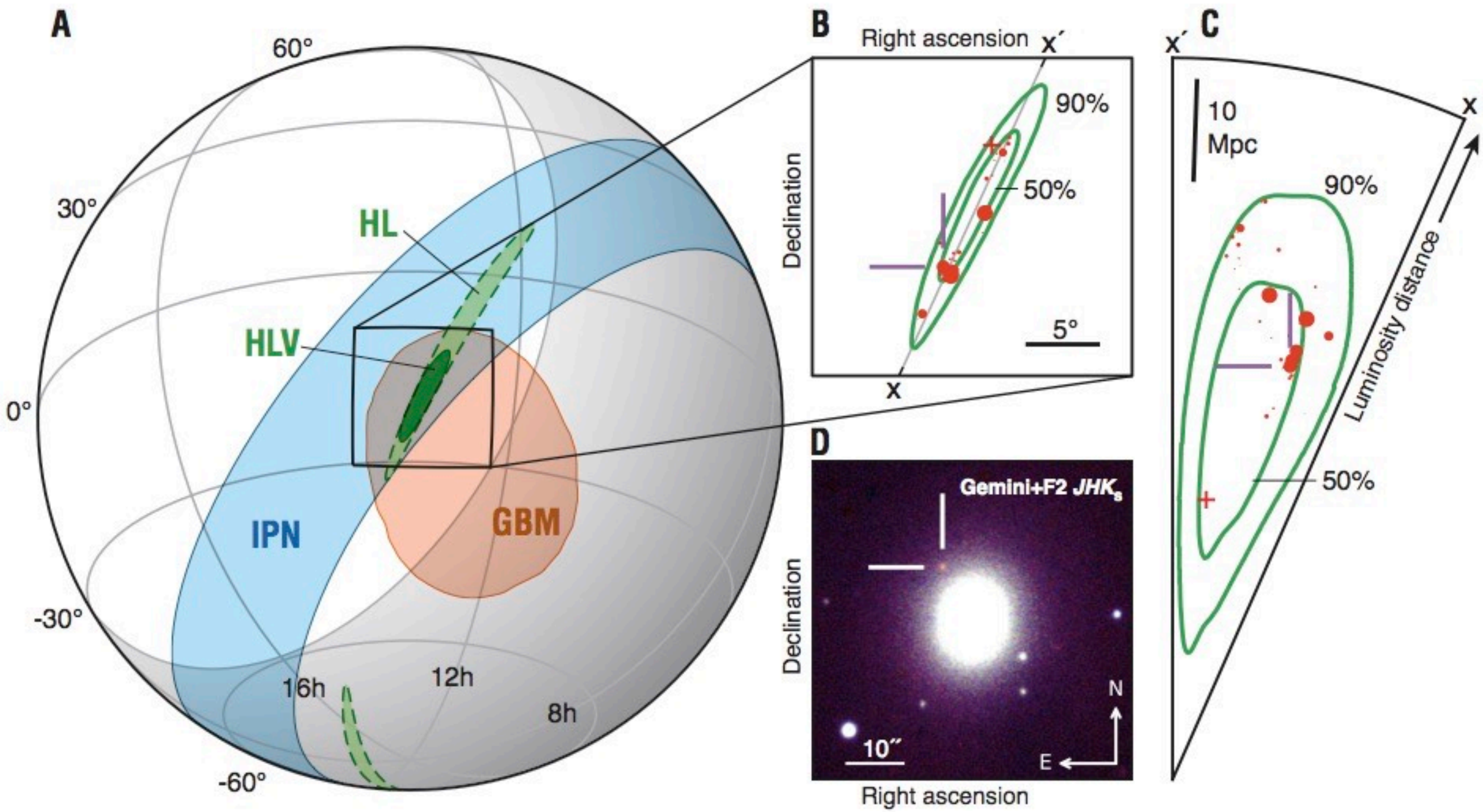
Other transients with CZTI

Fast Radio Bursts

Continuous event mode data

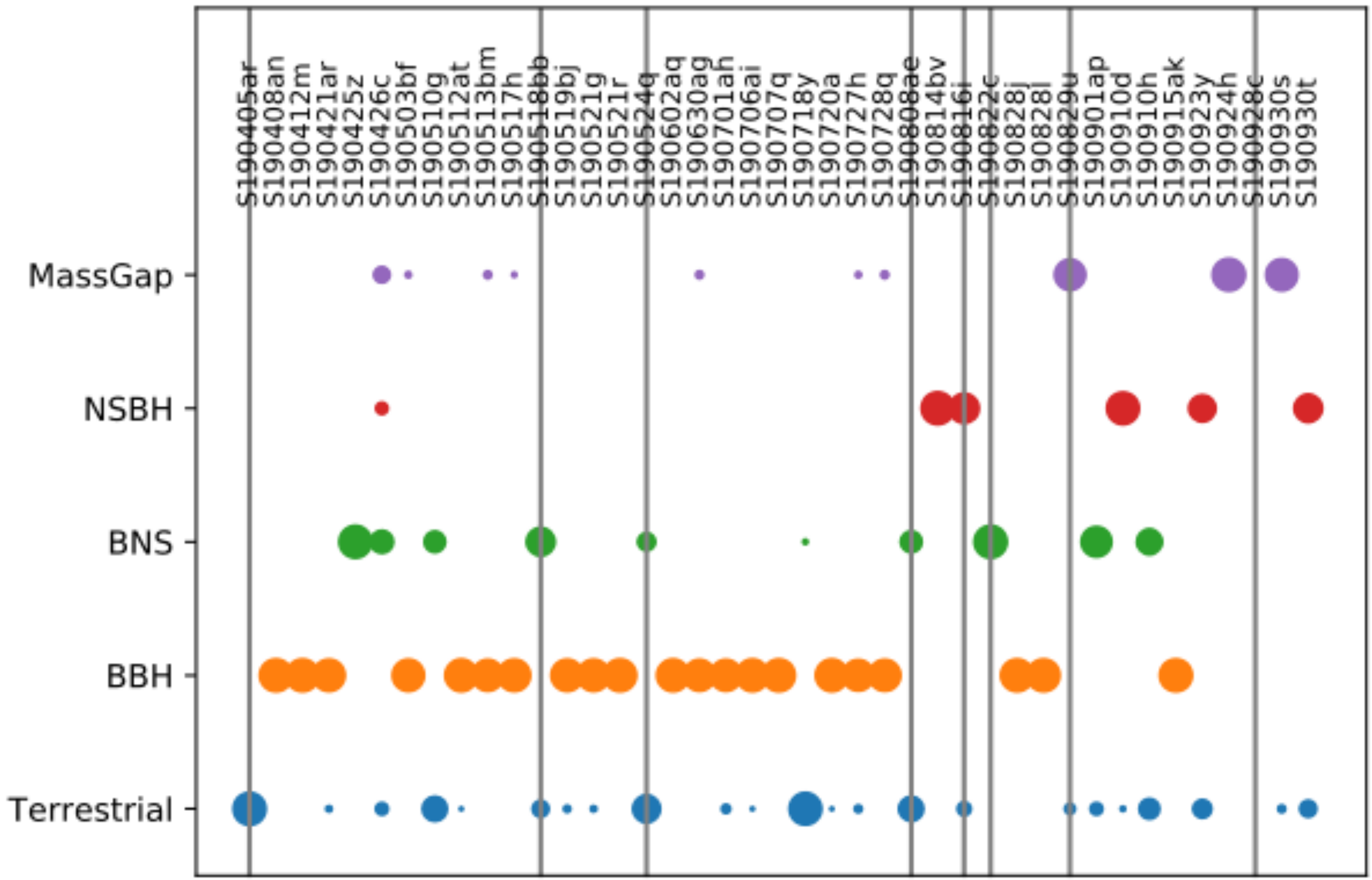
- Strong limits on FRB X-ray emission
  - » Anumarlapudi et al., 2020, ApJ, 888, 40
- Detection of bursts from SGR 1935+2154
  - » Raman et al., in prep
- "Deeper, Wider, Faster" survey
  - » Coordinated observations with ~20 telescopes

GW170817: AstroSat



Kasliwal et al., including VB, 2017, Science, 358, 1559

O3a candidates



https://gracedb.ligo.org/superevents/public/O3/

O3 NS candidates

Name	Type	Distance (Mpc)	90% area (sq deg)	Counter-part
S190425z	99% BNS	156 ± 41	7461	No
S190426c	49% BNS, 13% NSBH, 24% Gap, 14% Ter	377 ± 100	1131	No
S190510g	42% BNS, 58% Ter	227 ± 92	1166	No
S190718y	2% BNS, 98% Ter	227 ± 165	7246	No
S190814bv	100% NSBH	267 ± 52	23	No
S190901ap	86% BNS, 14% Ter	242 ± 81	14753	No
S190910d	98% NSBH, 2% Ter	606 ± 197	2482	No
S190910h	61% BNS, 39% Ter	241 ± 89	24264	No
S190923y	68% NSBH, 32% Ter	438 ± 133	2107	No
S190930t	74% NSBH, 26% Ter	108 ± 38	24220	No
GW170817	100% BNS	41	31	Yes

GW170817-like scaling

Name	Type	Distance (Mpc)	X-ray flux
S190425z	99% BNS	156 ± 41	5e-8
S190426c	49% BNS, 13% NSBH, 24% Gap, 14% Ter	377 ± 100	8e-9
S190510g	42% BNS, 58% Ter	227 ± 92	2e-8
S190718y	2% BNS, 98% Ter	227 ± 165	2e-8
S190814bv	100% NSBH	267 ± 52	2e-8
S190901ap	86% BNS, 14% Ter	242 ± 81	2e-8
S190910d	98% NSBH, 2% Ter	606 ± 197	3e-9
S190910h	61% BNS, 39% Ter	241 ± 89	2e-8
S190923y	68% NSBH, 32% Ter	438 ± 133	6e-9
S190930t	74% NSBH, 26% Ter	108 ± 38	1e-7
GW170817	100% BNS	41	7e-7

Typical X-ray / Gamma ray sensitivity: ~ few e-7 erg/cm^2/s

Requirements

Order of magnitude higher sensitivity

(Large area, lower noise, background rejection)

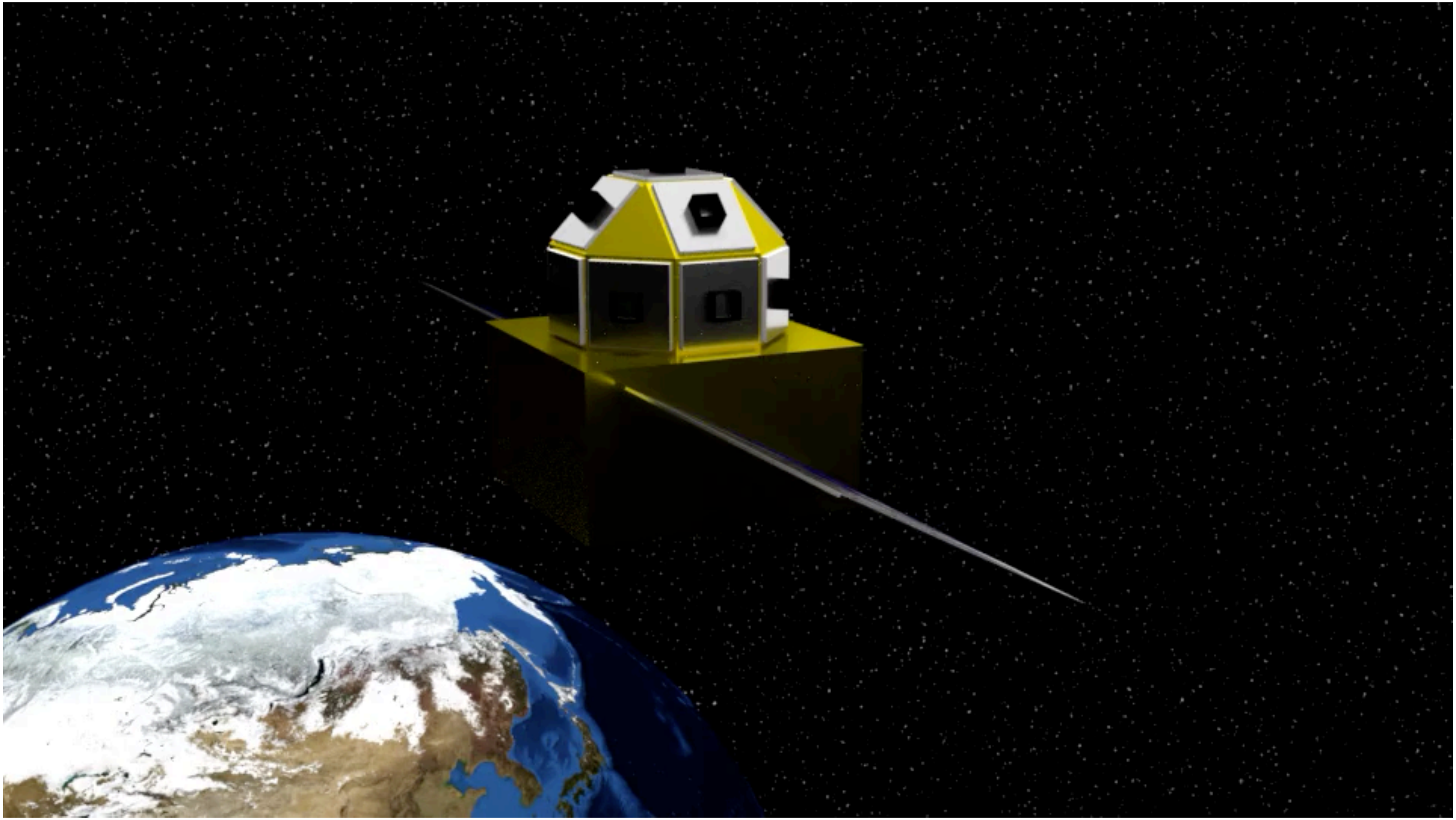
Wide spectral band

(1 keV to >1 MeV)

Continuous all-sky coverage

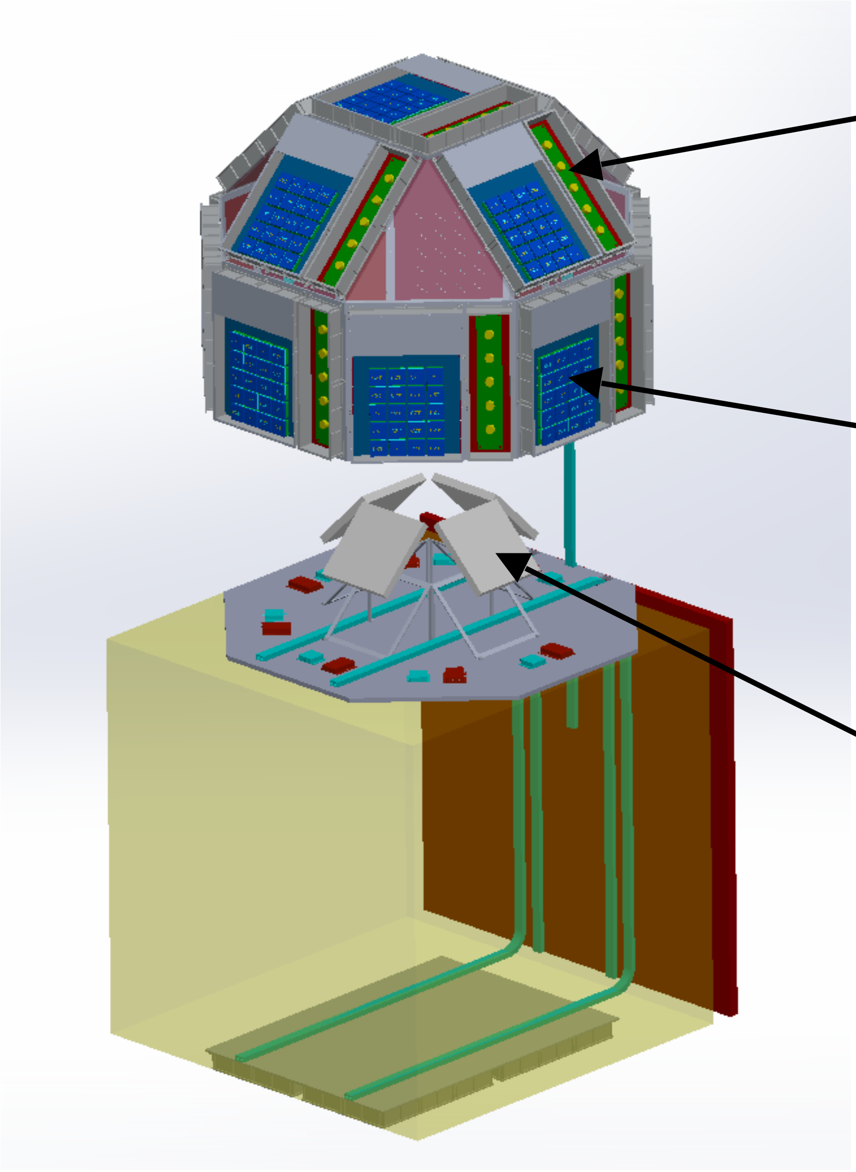
(Two satellites)

Daksha



On alert for high energy transients

Daksha



Low Energy: SDDs
1-25 keV

Medium Energy: CZT
20-200 keV

High Energy: Scintillator
100-1000 keV

Two satellites

Advantage Daksha

- Effective area (2 satellites): 1700 cm^2
  - » Fermi: ~100 cm^2 individual, ~300 cm^2 total
- Sky coverage:
  - » 71% individual, ~100% two satellites
  - » BAT: ~11%, GECAM ~100%
- Energy range: 1 keV to > 1 MeV
  - » BAT 15 – 150 keV, Fermi GBM > 8 keV

Daksha results

- Detect dozens of BNS mergers per year
  - » Also ~1000 on-axis GRBs per year
- Localisation:
  - » ~10° on board, ~5° ground processing
- Broadband prompt spectra
  - » Only mission to give prompt soft spectra
- Alert GW network with time, location
  - » Lower FAR, 2× – 3× more detections!
- Huge discovery space!

Daksha: Polarisation

- 15 – 20 times CZTI effective area
- No collimators
  - » Simpler modelling of polarisation signal
- Each burst sees 6-8 faces
  - » Different angles
  - » Eliminate systematics

- High significance GRB polarisation studies!

Polarimetry Beyond Daksha

On behalf of Santosh Vadawale

What is the requirement?

- Hard X-ray focusing required for matching SXR sensitivity
- Many international proposals !
  - » XRISM, eXTP, Athena, Lynx…
- Community consensus:
  Broadband X-ray Polarimetry
- Development lead: SAG-URSC (ISRO), RRI, PRL
  - » Support several institutes (IUCAA, TIFR, IIT-B)

Possibility for collaboration with international groups

Proposed configuration

Soft Xray Concentrator + Polarimeter

- Optics energy: 1-10 keV
- 400 cm2 @ 2keV (100 cm2 @ 6 keV)
- Focal length: 3m
- Detector: GEM-TPC
- Energy: 2-10 keV
- Energy resolution: 15% @ 6keV
- MDP: 1% in 1 Ms for 5 mCrab

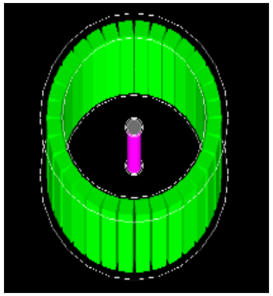
Medium Energy Polarimeter

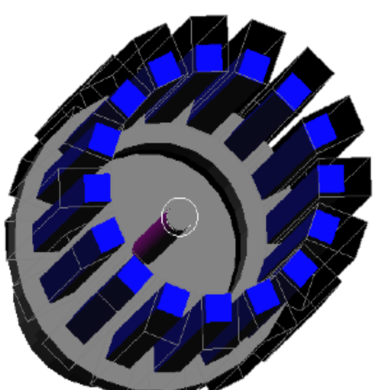
- Collimated Thomson Polarimeter
- Polix++
- 3-50 keV
- Effective area ~2000 cm2

Hard X-ray Concentrator + Polarimeter

- Optics energy: 1- 80 keV
- 400 cm2
- Focal length: 10m
- Detector: 20-80 keV
- Energy resolution: 10% @ 60 keV
- MDP: 1% in 100ks for 1 Crab

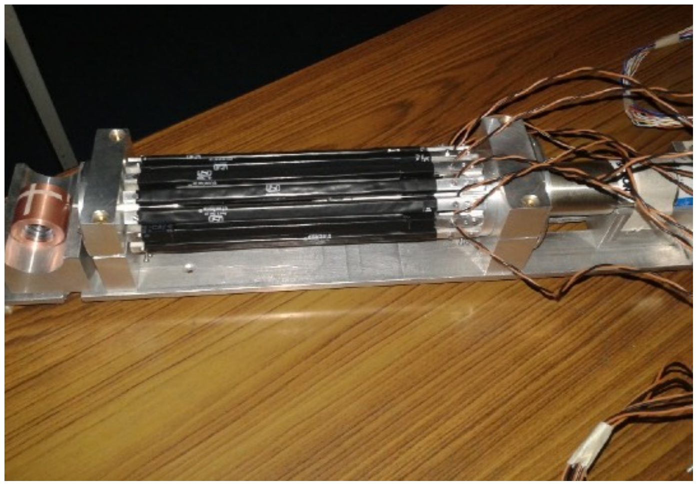
Focal Plane Compton X-ray Polarimeter

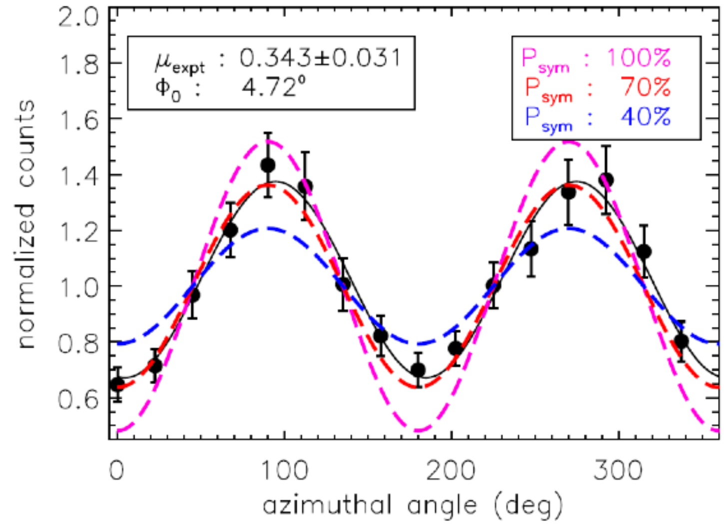


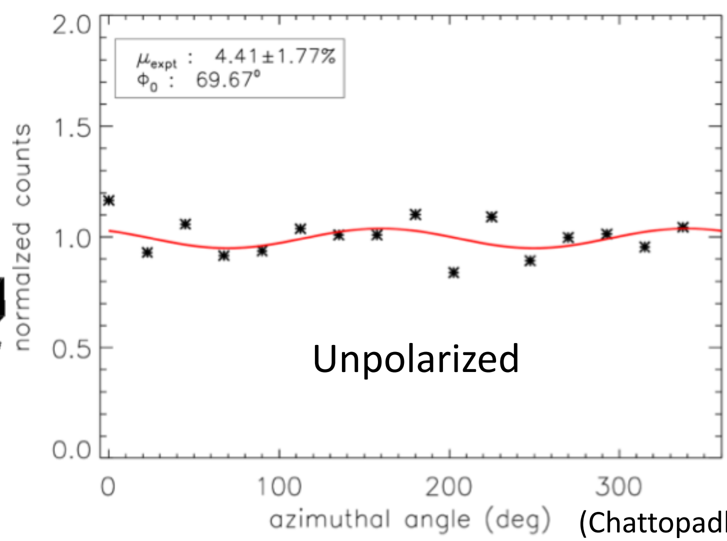


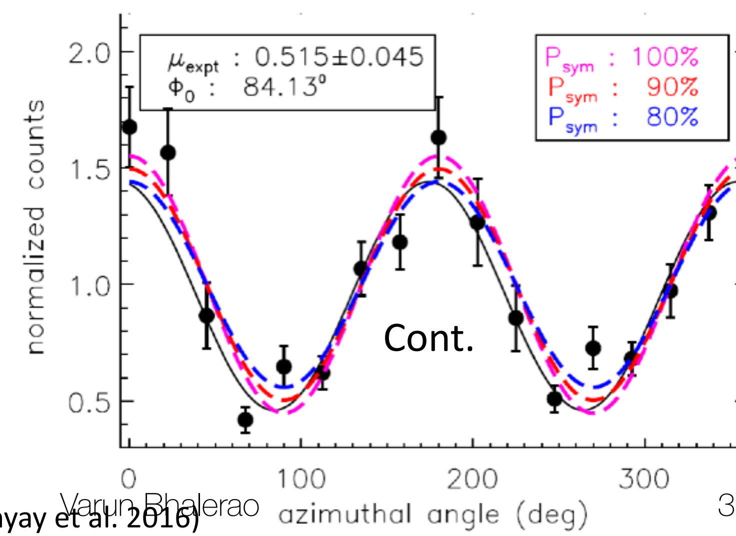
- Fully built and tested prototype
  - Active scatterer: Plastic scint.
  - Absorber: CsI+SiPM absorber

Lead Institute:
Physical Research Laboratory, Ahmedabad



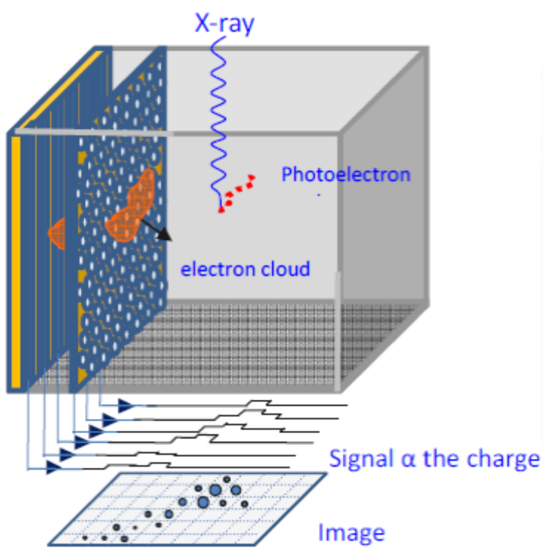






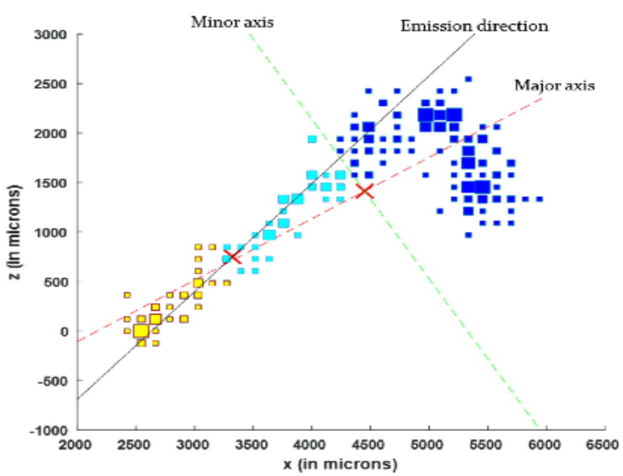
(Chattopadhyay et al. 2016)

GEM based TPC



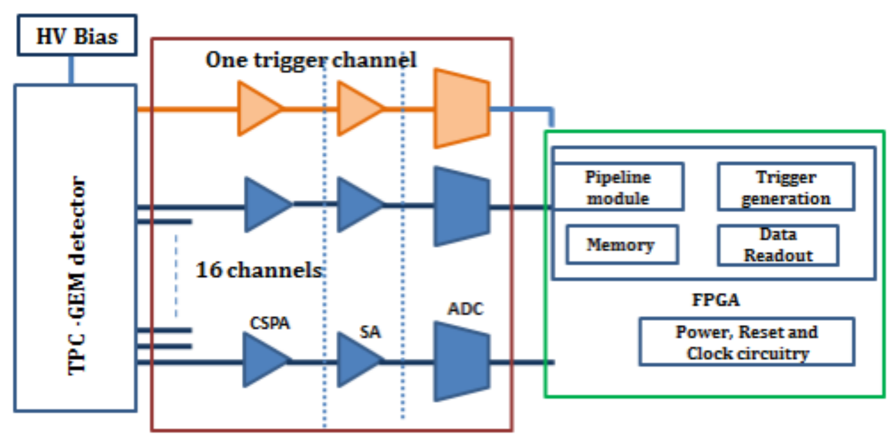
Lead Institute: Space Astronomy Group,
URSC (ISRO), Bangalore

- **GEM: 70 micron hole size, 120 micron pitch**
- **Detailed simulation of detector performance- U**sing ANSYS and GARFIELD - Insight into working and input to design and optimization of operating parameter.
- **Hardware realization in progress**– Discrete electronics based, multiple channels daisy chained.



The figure shows the 2D binned image of a photoelectron track of a 9keV photon in Ne/DME 50/50 gas mixture at 200 torr pressure.

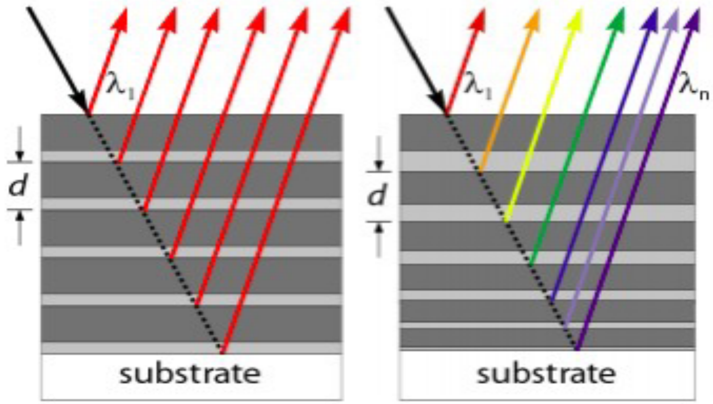
Looking for better GEM

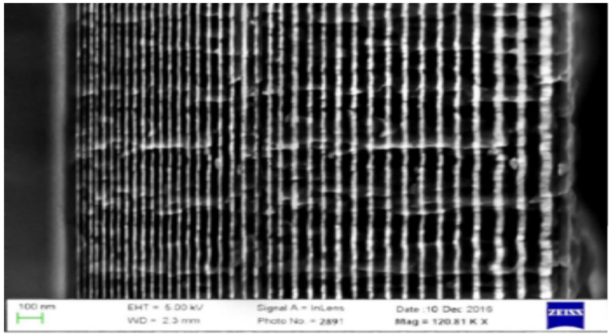


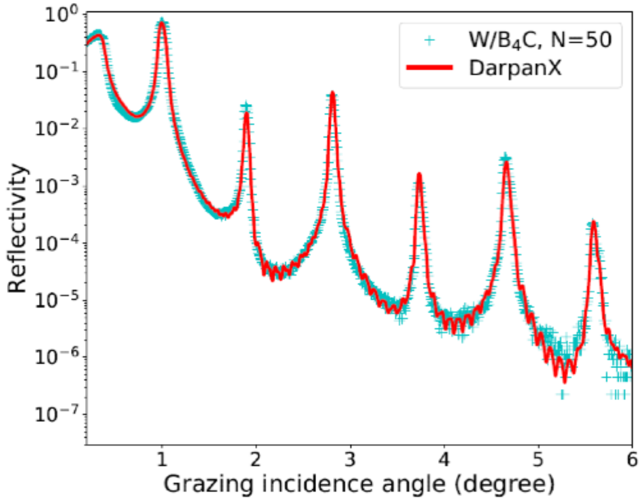
Hard X-ray Optics

Lead Institute:
PRL , Ahmedabad

- At hard X-rays, the critical angle ~ O(0.1) degree
  ➔ long focal length
- Depth graded multi-layer coating
  - Thickness: 20 Å to 200 Å
- RF Magnetron sputtering technique
  - Facility setup at PRL
- Multi-layer fabrication
  - Optimization under progress
- Developed a software package
  - Publicly available as open source





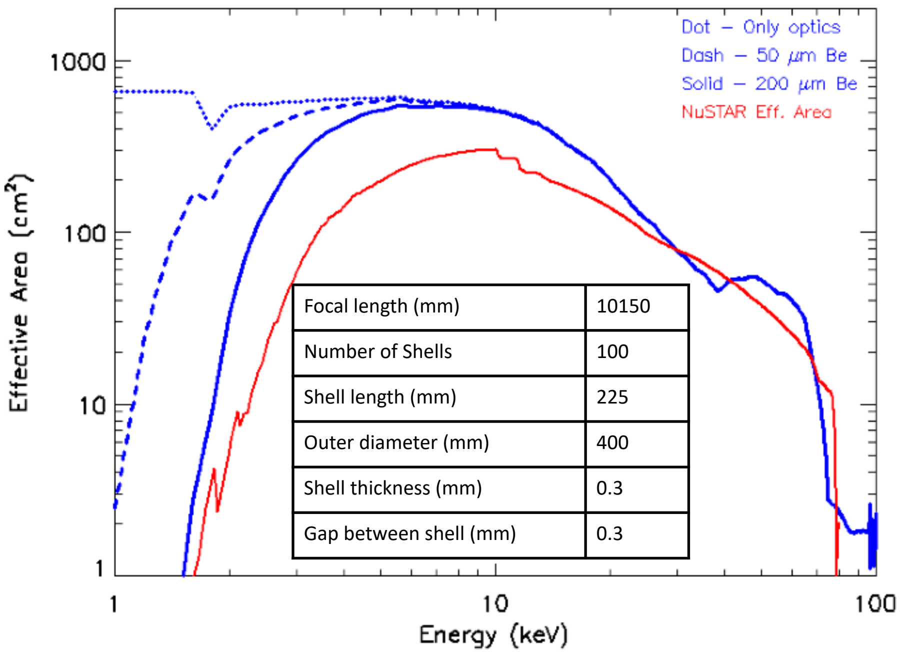


DarpanX:

- Python package for modelling X-ray Multilayer mirrors
- Usable as PyXSPEC model to fit XRR measurements

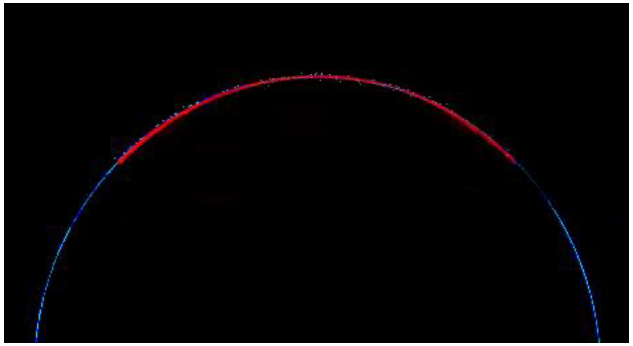
Mondal et al. 2021

Hard X-ray Optics



Focal length (mm)	10150
Number of Shells	100
Shell length (mm)	225
Outer diameter (mm)	400
Shell thickness (mm)	0.3
Gap between shell (mm)	0.3

- Mirror substrate is the key issue
- Present option → Slumped Glass Optics
  - Same as used in NuSTAR
  - Very low yield
  - Not scalable for larger area / multiple modules
- Need to explore alternatives
  - Ni-forming, Si-pore, Si-shell



- Precession assembly is another major challenge (currently at RRI)
- Deployment mast → Assuming ISRO support, commercial options available

Overall Significantly more work needed to realize hard X-ray optics

Thank you!