Tenth International Fermi Symposium
9th-15th October 2022

Probing into emission mechanisms of GRBs using time-resolved spectra and polarization studies (GRB 190530A)

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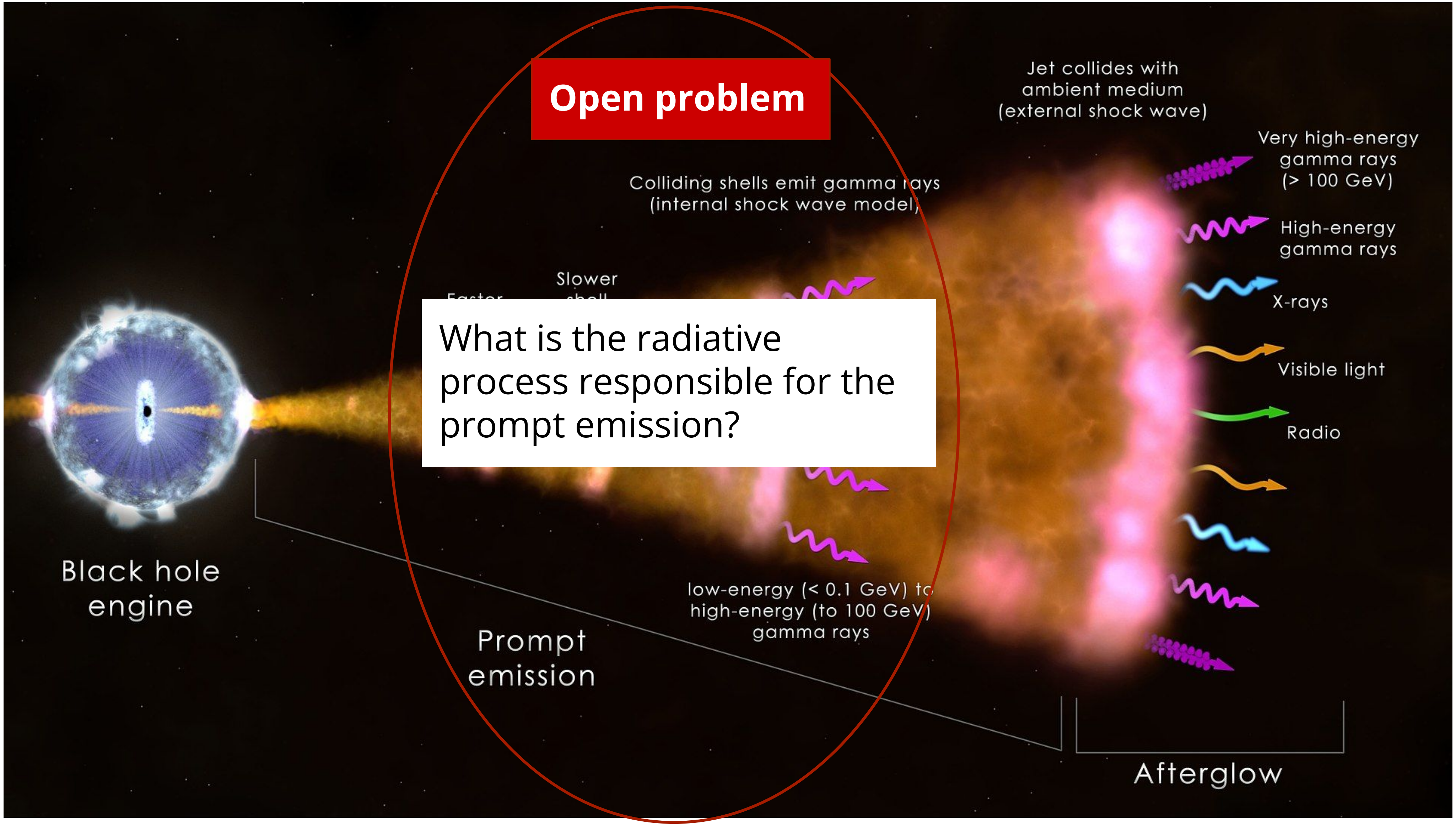
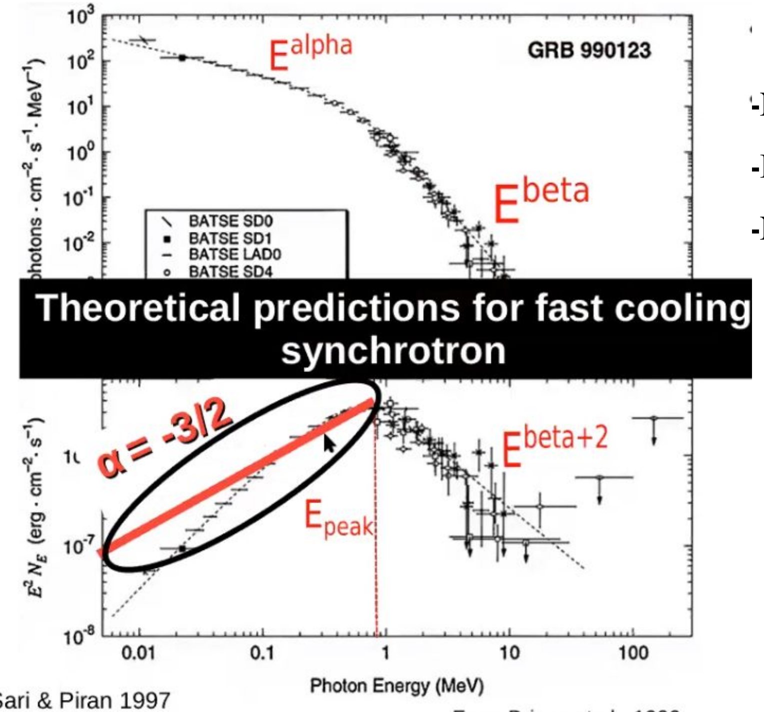
Gamma-Ray Burst: standard model



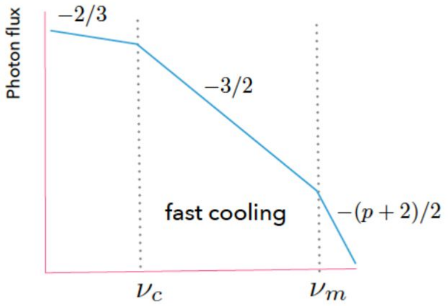
Typical observed GRB prompt emission spectrum

Konus* Wind, *BATSE, Integral , Swift, Fermi, AstroSat



Sari & Piran 1997
Preece 1998
Ghisellini 2000

From Briggs et al., 1999



-Non-thermal spectrum

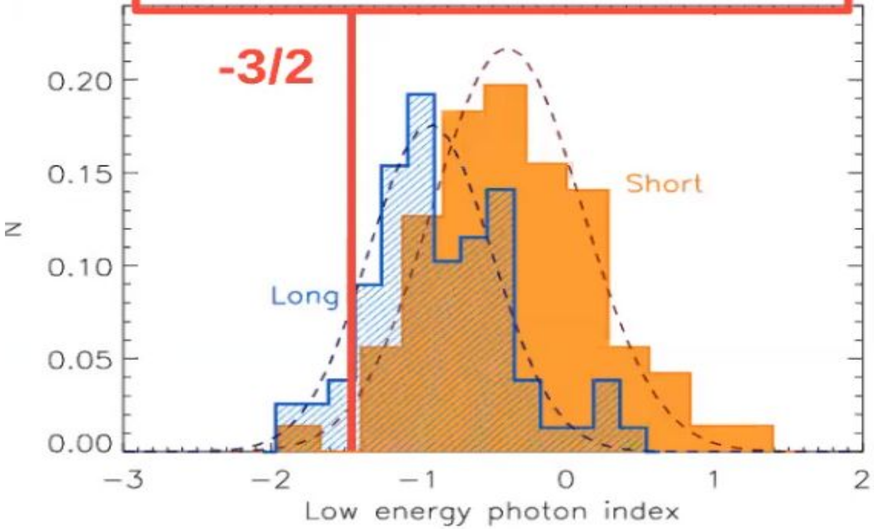
-Band function (Band et al., 1993)

-No physical meaning

David Louis Band (Jan. 9, 1957 – Mar. 16, 2009)

Observed slopes

LONG GRBs: <α> ~ -1
SHORT GRBs: <α> ~ -0.4



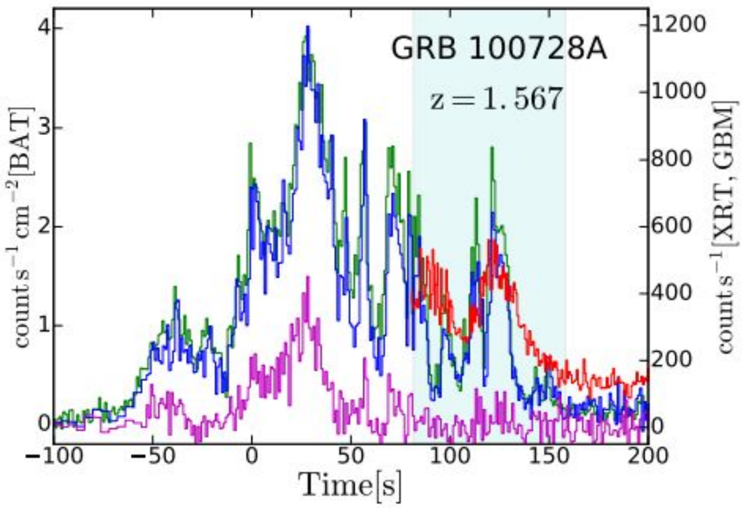
From Ghirlanda et al., 2009
(see also Preece 1998, Kaneko 2006, Nava 2011, Goldstein 2012, Gruber 2014)

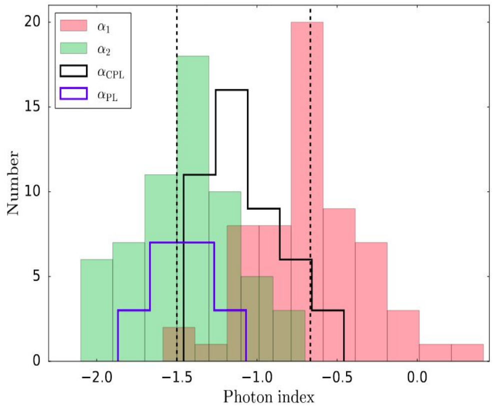
A large fraction is inconsistent with synchrotron emission.

Recent developments

Gor Oganesyan et al. 2017, 2018.

The prompt emission of 34 GRBs observed simultaneously with XRT and BAT





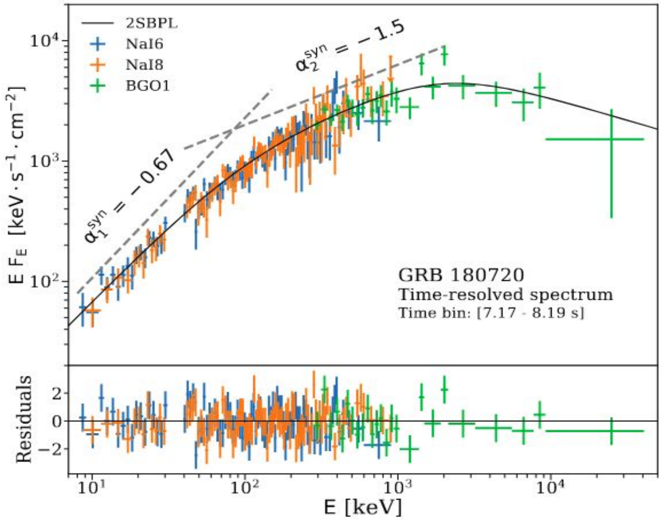
- 62% of the prompt spectra display a **break** between 2 and 30 keV
- the spectral indices are $<\alpha_1> = -0.66 \pm 0.35$ and $<\alpha_2> = -1.46 \pm 0.31$

Consistent with synchrotron prediction!

Thanks to *Swift* XRT (0.3-10 keV)

Ravasio et al. 2019

Ten brightest short and long GRBs observed by Fermi.

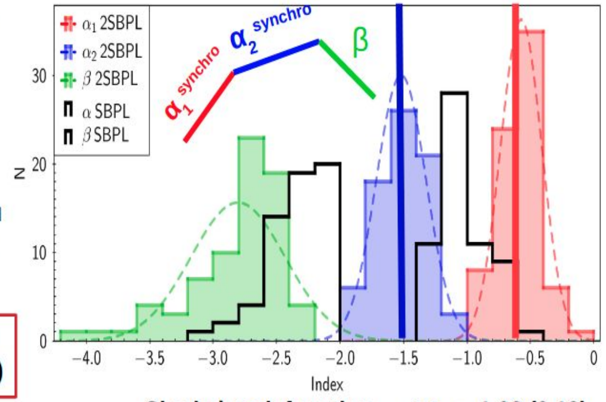


10 LONG GRBs

BREAK FOUND IN 8/10 GRBs

In most of the time resolved spectra (139/199, ~ **70%**) the best fit model is the 2SBPL function

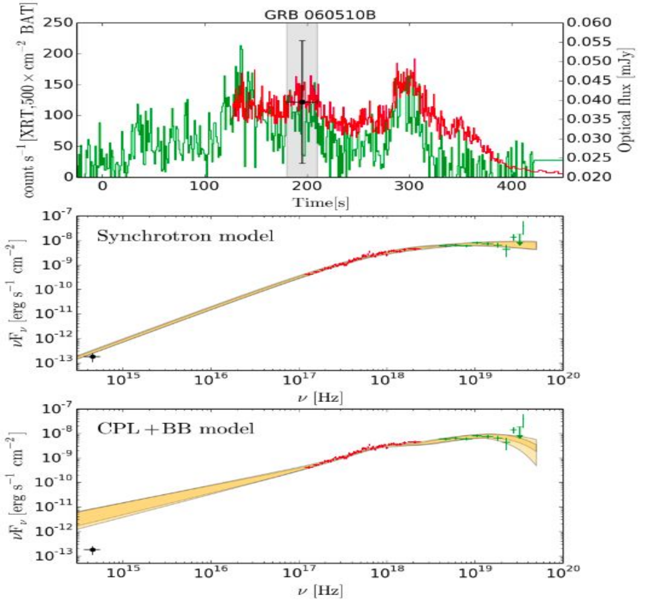
$<\alpha_1> = -0.58\ (0.16)$
$<\alpha_2> = -1.52\ (0.20)$

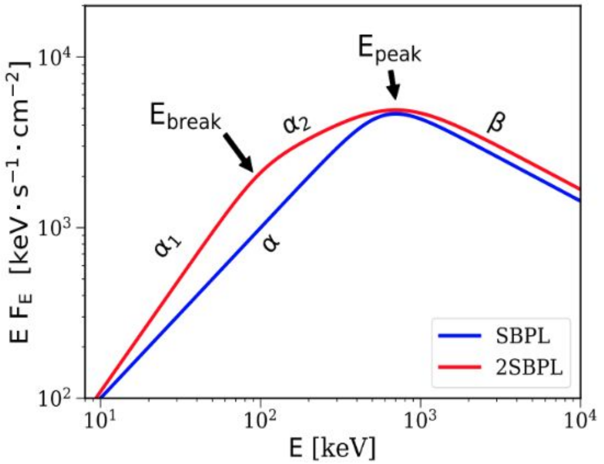


Single break function → $<\alpha> = -1.02\ (0.19)$

Gor Oganesyan et al. 2019

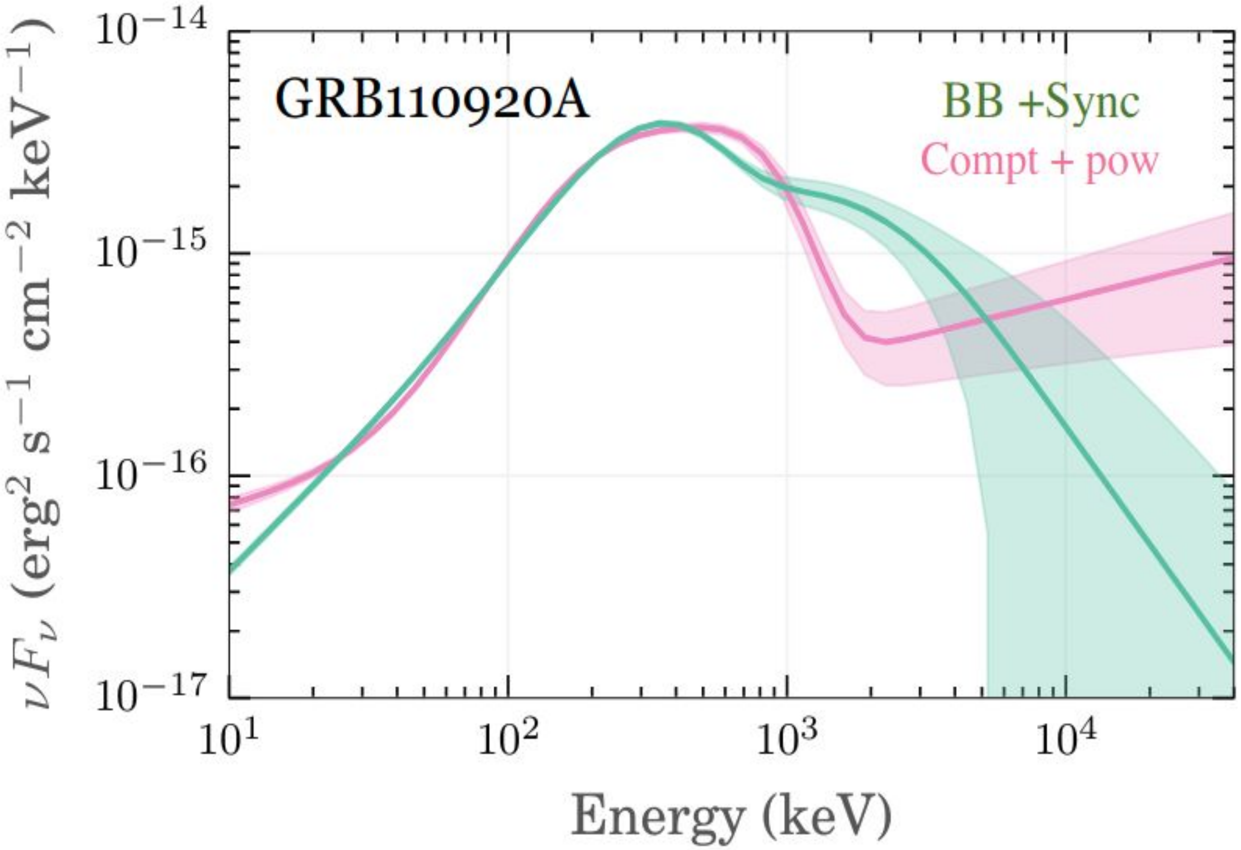
Extend the range down to the optical band

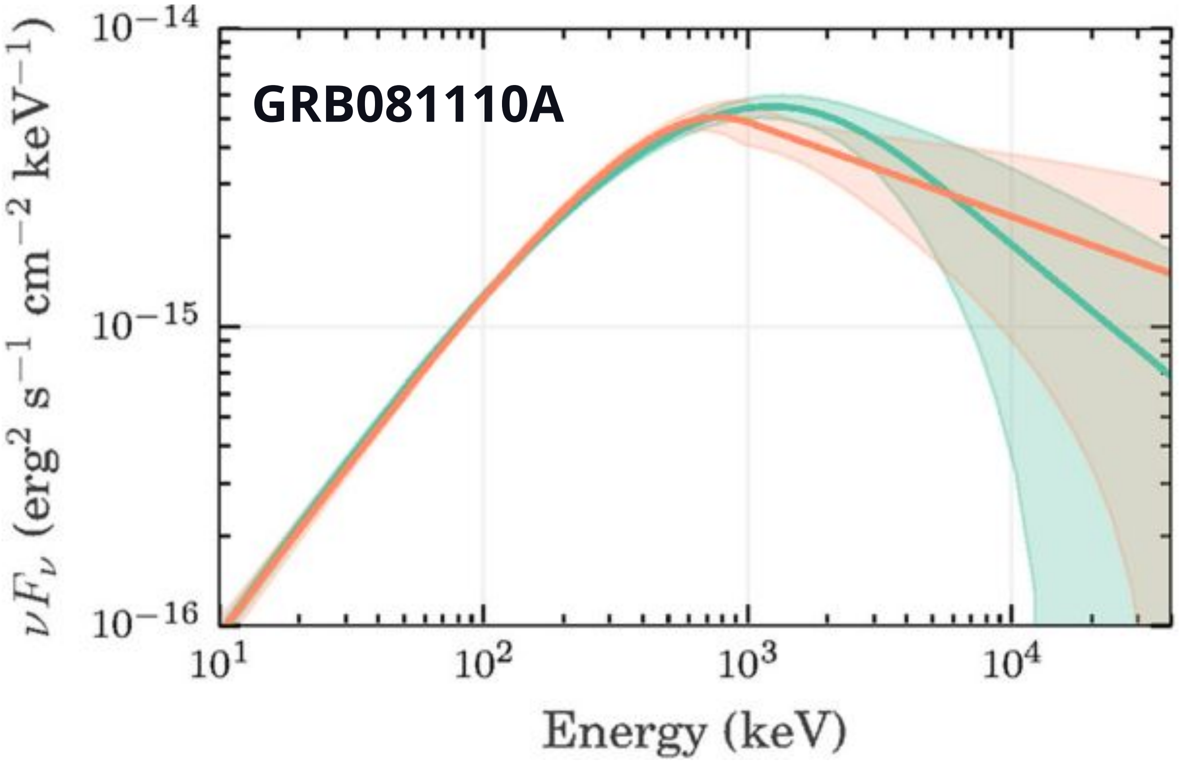




Synchrotron emission in marginally fast cooling regime

Limitation: Degeneracy between spectral models



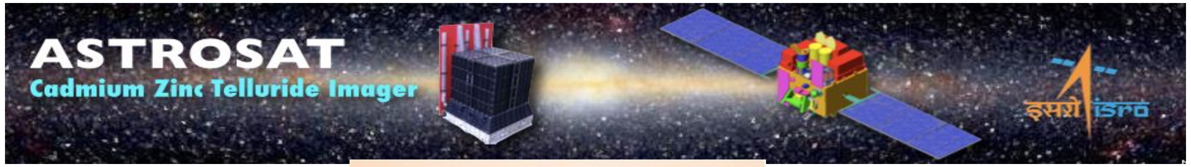


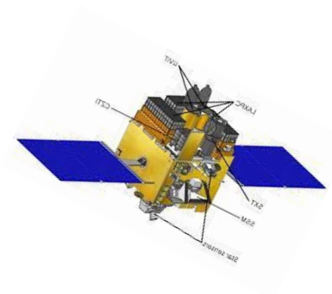
Two Models: Two completely different spectral shape

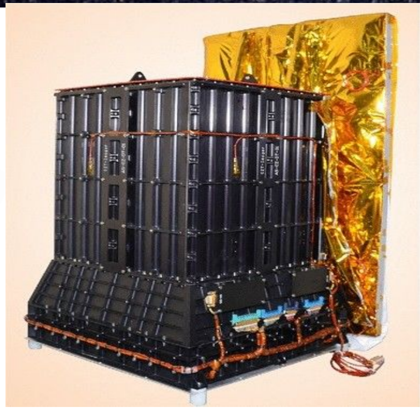
Narrow spectral width: Does not mean synchrotron emission is inconsistent with data

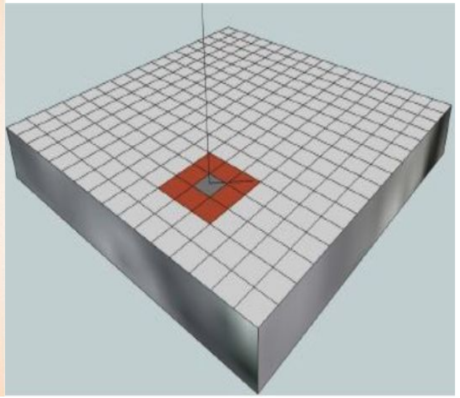
Iyyani et al. 2016, 2018

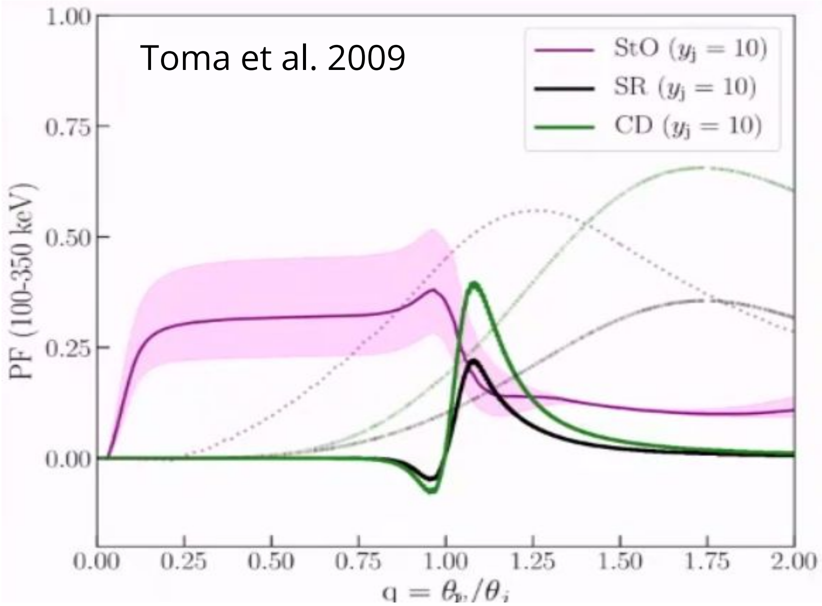
Constraining Observables: GRB polarimetry





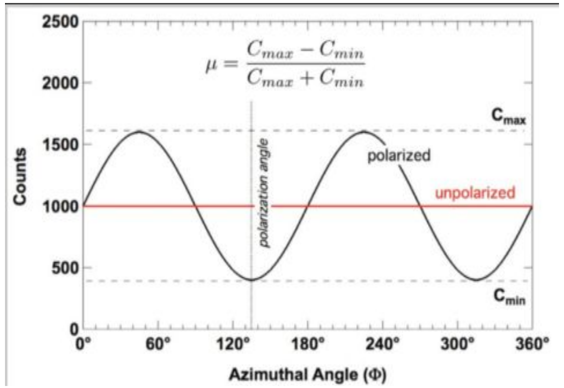


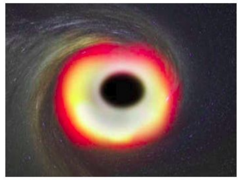




Compton scattering in one pixel and absorption of the scattered photon in another pixel constitute the **8 bin azimuthal angle distribution.**

Aim: To measure the azimuthal distribution of scatter angles about the incident photon direction.





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THE TIMES OF INDIA

India's AstroSat witnesses black hole birth for the 500th time

TNN | May 24, 2022, 04.33 AM IST

India's first dedicated multi wavelength space observatory, Astrosat, has detected the birth of a black hole for the 500th time, a key milestone that Indian scientists have called a "remarkable achievement".

Elaborating on the research, Pune-based Inter-University Centre for Astronomy and Astrophysics (IUCAA), in a recent statement, said, "One of the instruments in Astrosat is the Cadmium Zinc Telluride Imager (CZTI) — which has just witnessed the birth of a black hole for the five hundredth time." "The wealth of data obtained by CZTI on Gamma Ray Bursts is making a big impact worldwide," Prof Dipankar Bhattacharya of Ashoka University and IUCAA, who is the current principal investigator of CZTI, said.

AstroSat, launched by Isro in space in September 2015, is one of the most sensitive space telescopes in the world as it has five instruments that can simultaneously study the universe in ultraviolet, optical and X-ray radiation.

Credit: CZTI team

Polarisation depends on the jet viewing geometry:

On axis viewing

High Polarisation fraction:
Synchrotron emission in ordered magnetic field.

Nearly, null Polarisation fraction:
Synchrotron emission in random magnetic field.
Photospheric emission: Compton scattering

Polarization measurement for a large sample of GRBs might be useful to understand the prompt emission mechanism.

Polarization measurement before *AstroSat* -

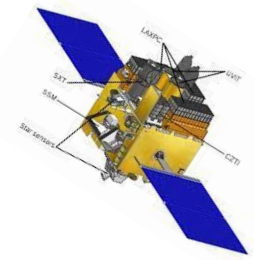
RHESSI 1 GRB
INTEGRAL ~2 GRBs
GAP 3 GRBs
POLAR 14 GRBs
Total 20 GRBs

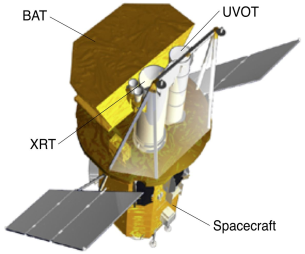
Multiwavelength Observations of GRB 190530A

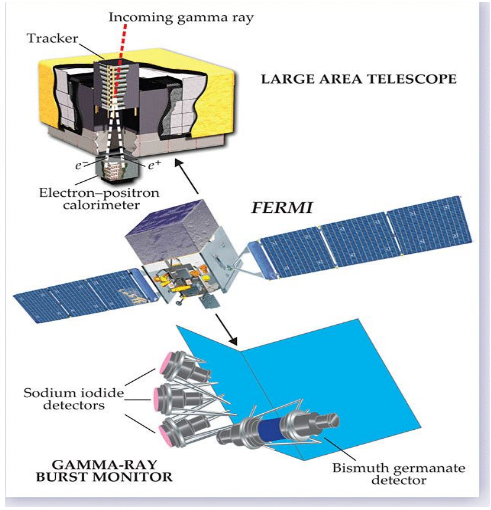
Prompt Observations :

Detected by *Fermi* GBM and LAT on 30 May 2019 at 10:19:08 UT. (GCNs 24676, 24679)

Also detected by *AstroSAT* CZTI, KW, and AGILE. (GCNs 24694, 24678)







Afterglow Observations :

The XRT observed GRB from ~ 33.8 ks after the trigger time. (GCN 24689)

MASTER detected the afterglow ~ 8 hrs after the trigger. (GCN 24703)

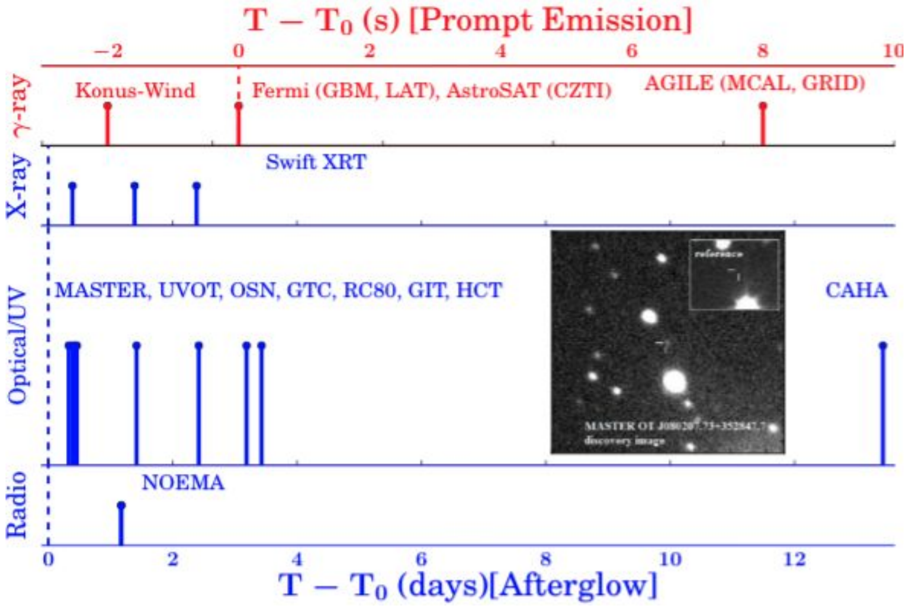
The UVOT detected a optical afterglow in U, B, V, UVW1, UVW1, and UVM2 filters.

Several Optical/ NIR telescopes performed the follow-up observations. (https://gcn.gsfc.nasa.gov/other/190530A.gcn3)

Afterglow spectroscopy using 10.4m GTC : on 31st May 2019, and measured the redshift of the burst.

Millimeter observations using NOEMA

Ground Based Telescopes



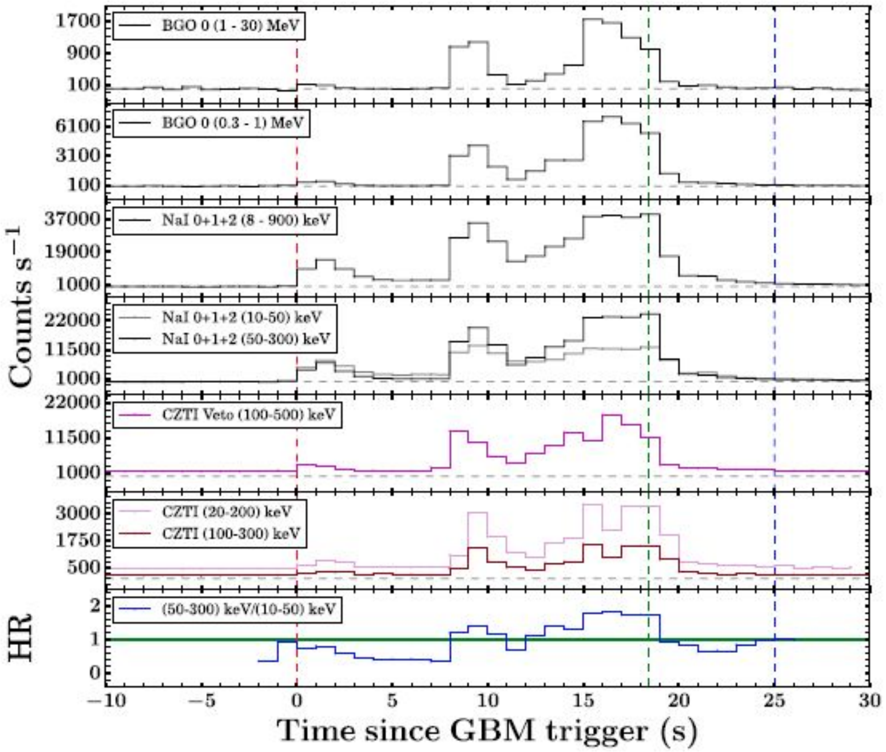
Host Observations :

Host photometric observations (UBVRI) using 3.6m DOT.

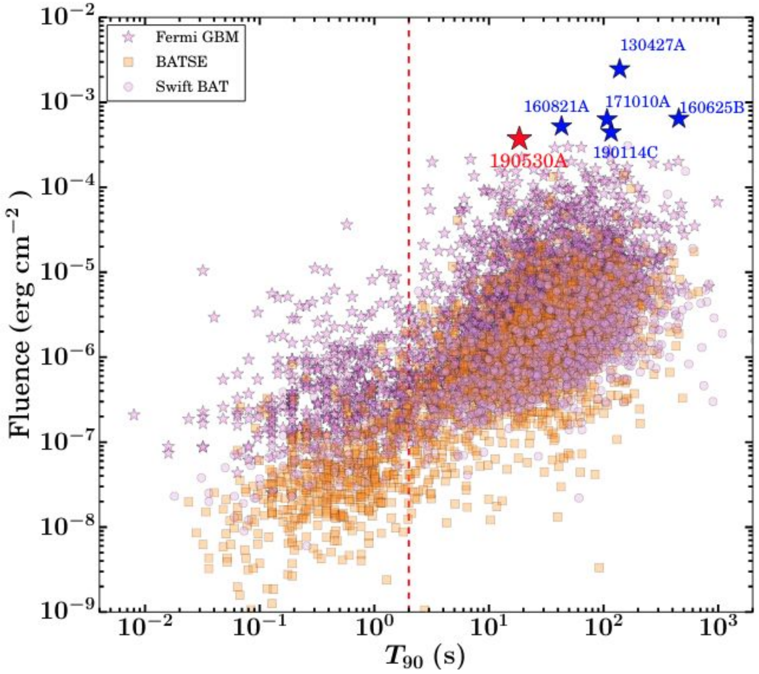
Deep observations using 10.4m GTC.

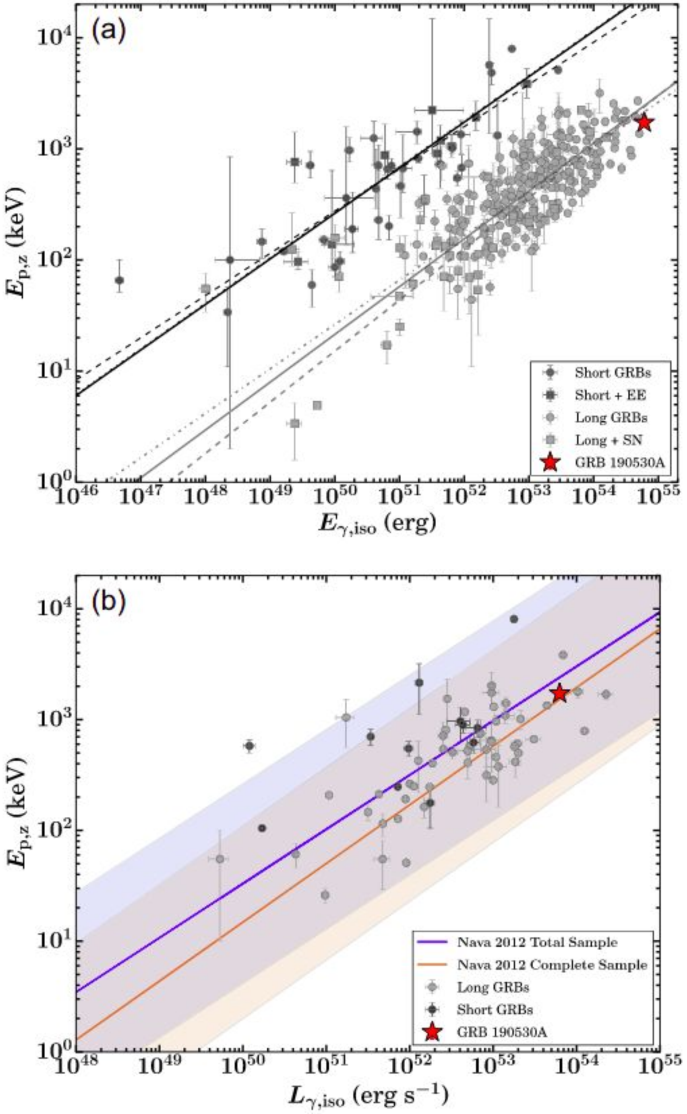
Prompt emission properties of GRB 190530A

Energy-resolved prompt emission LC



Prompt properties	GRB 190530A	Detector
T_{90} (s)	18.43 ± 0.36	GBM
$t_{\rm mvts}$ (s)	~ 0.50	GBM
HR	1.35	GBM
$E_{\rm p}$ (keV)	$888.36^{+12.71}_{-11.94}$	GBM + LAT
$F_{\rm p}$	135.38	GBM
$E_{\gamma,\rm iso}$ (erg)	6.05×10^{54}	–
$L_{\rm p,iso}$ (erg s^{-1})	6.26×10^{53}	–
Redshift z	0.9386	GTC

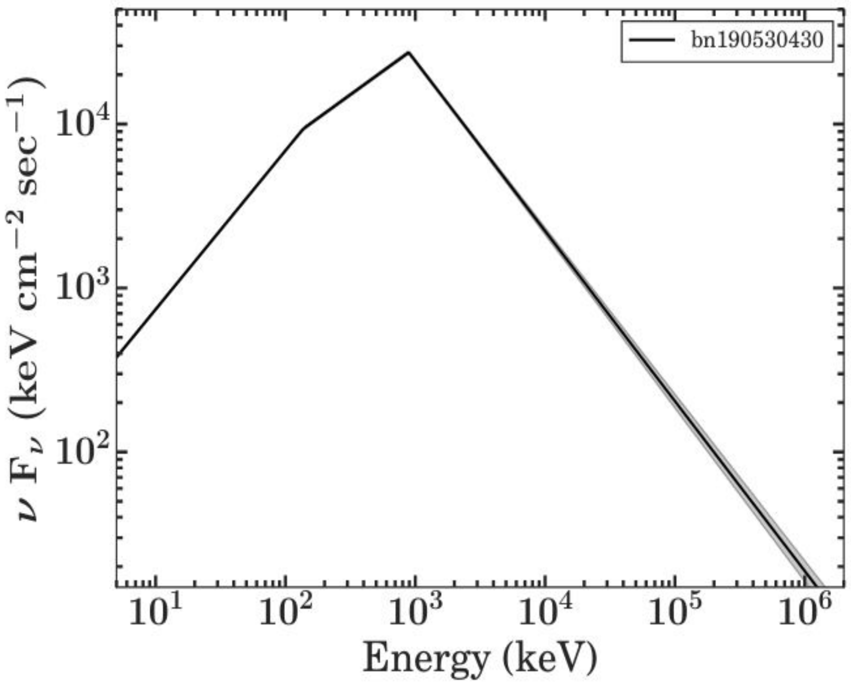




Gupta et al 2022, MNRAS

Prompt emission Spectral Properties

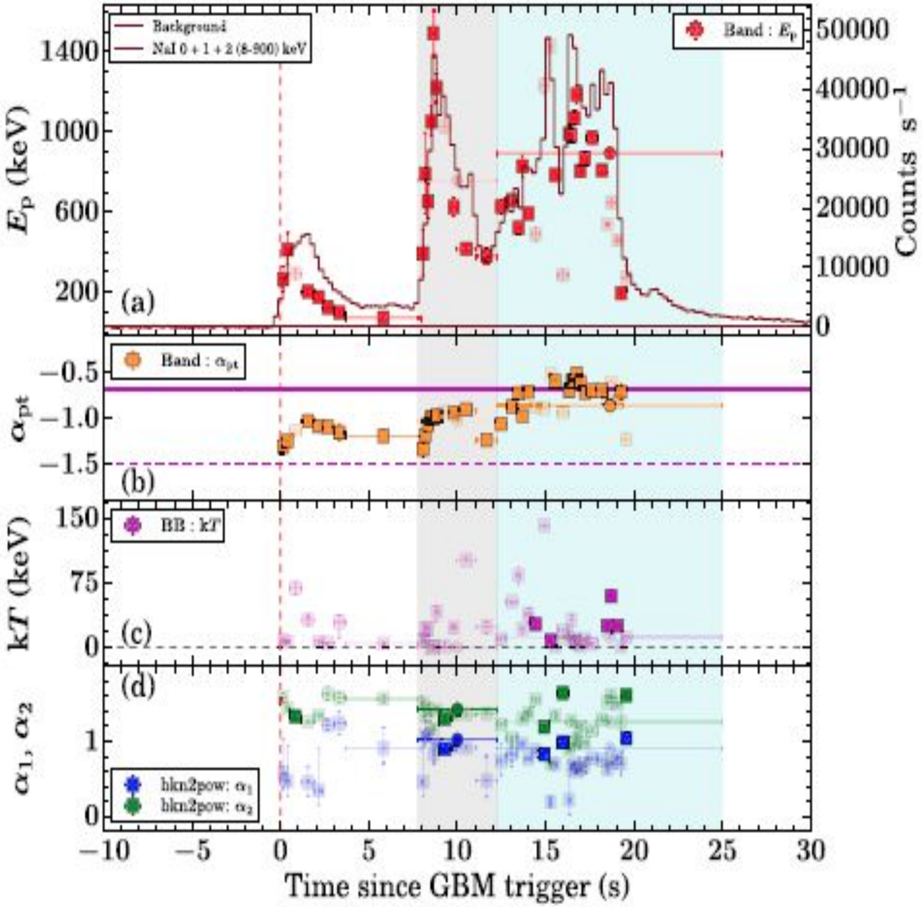
The time-integrated best fit energy spectrum in model space.



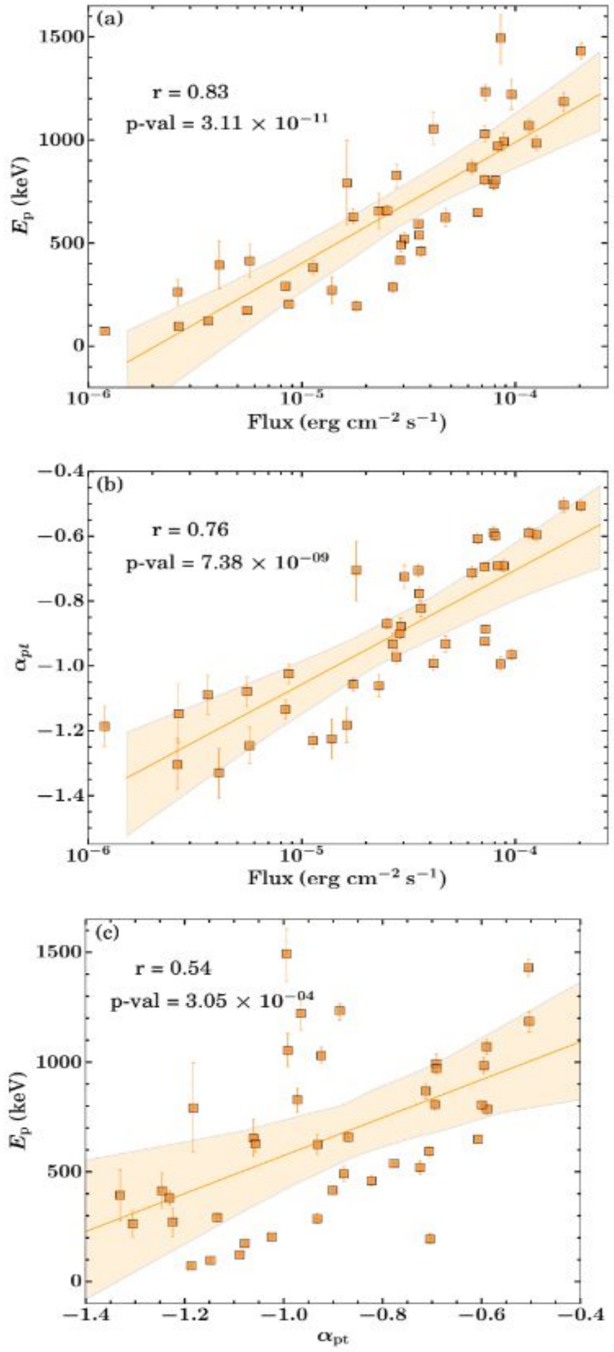
$\langle\alpha_1\rangle = 0.77 \pm 0.06$

$\langle\alpha_2\rangle = 1.43 \pm 0.05$

Evolution of spectral parameters



Double tracking Characteristic !



Polarisation measurement using *AstroSat* CZTI

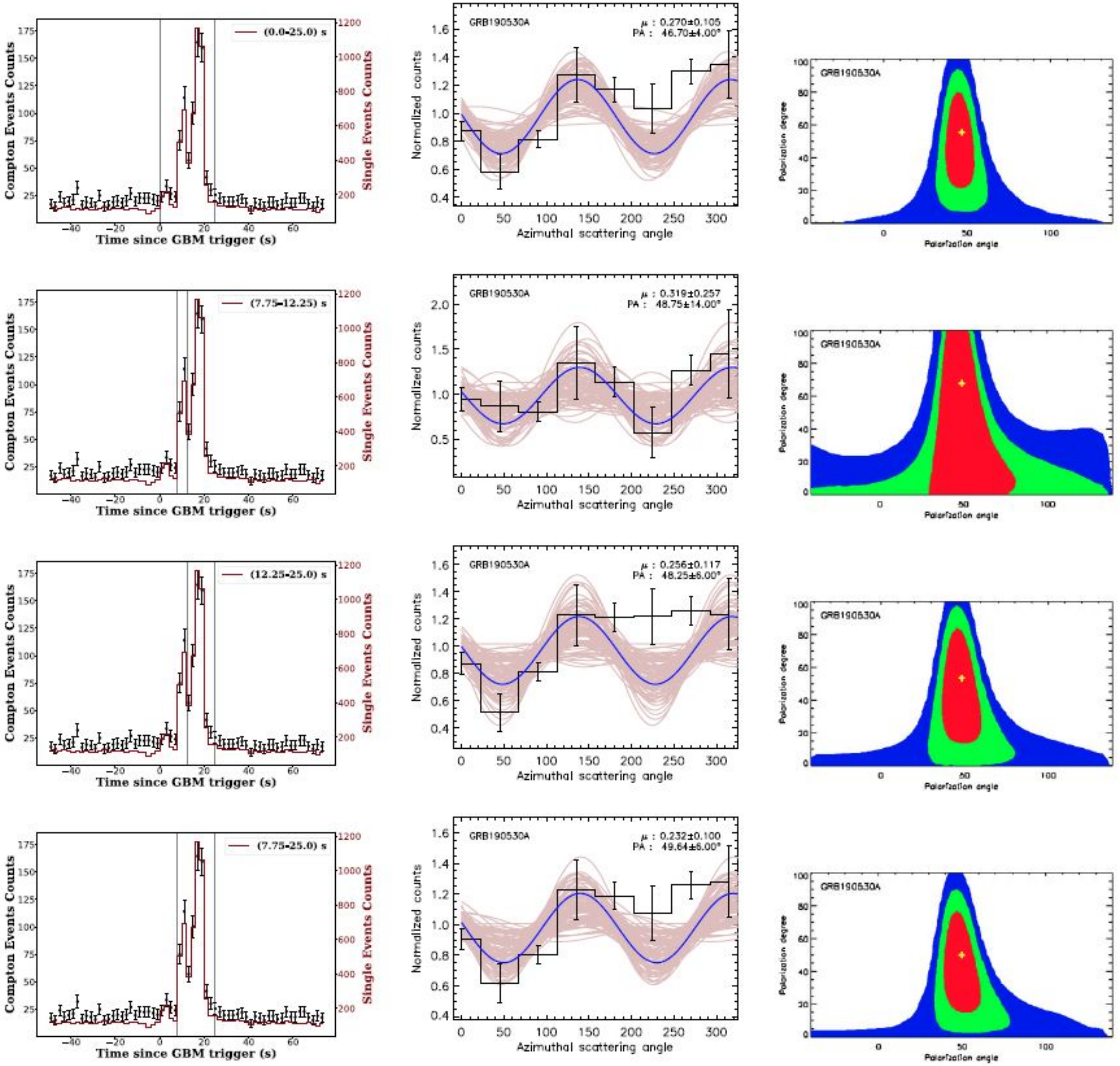
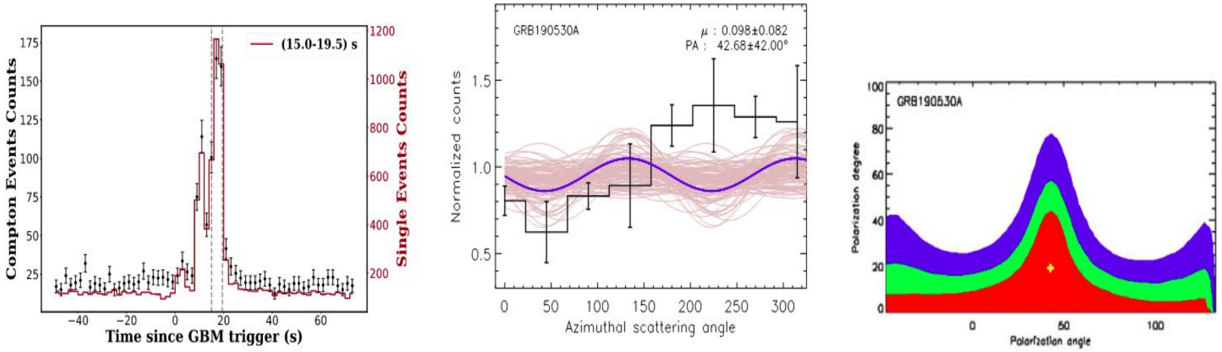


Table 3. The *AstroSat*-CZTI polarimetry results of GRB 190530A in the time-integrated and time-resolved temporal window in the 100–300 keV energy range.

Burst interval (s)	Energy (keV)	No. of Compton events	Modulation amplitude (μ)	Polarization angle (°)	Bayes factor	Polarization fraction
0.0–25.0	100–300	1246	0.27 ± 0.10	46.74 ± 4.0	3.51	55.43 per cent ± 21.30 per cent
7.75–12.25	100–300	319	0.32 ± 0.26	–	1.08	<64.40 per cent (95 per cent)
12.25–25.0	100–300	870	0.26 ± 0.12	48.17 ± 6.0	2.11	53.95 per cent ± 24.13 per cent
7.75–25.0	100–300	1189	0.23 ± 0.10	49.61 ± 6.0	2.52	49.99 per cent ± 21.80 per cent
15.0–19.5	100–300	577	0.09 ± 0.08	–	0.71	<65.29 per cent (95 per cent)



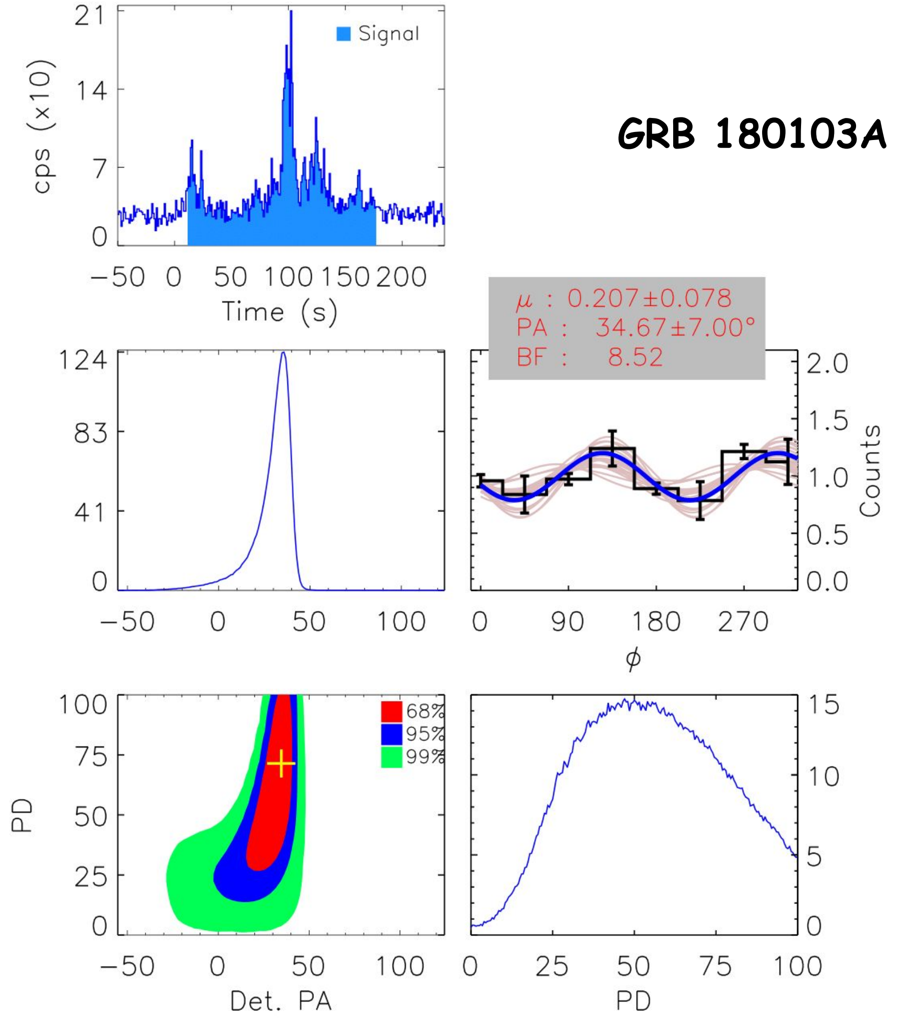
Synchrotron emission in ordered magnetic field.

Gupta et al 2022, MNRAS

GRB polarization for a 5 year sample

shortlisted **20 GRBs** for polarization analysis

- bright
- localized (simulation for the same direction and spectra)
- <60 degree from detector normal

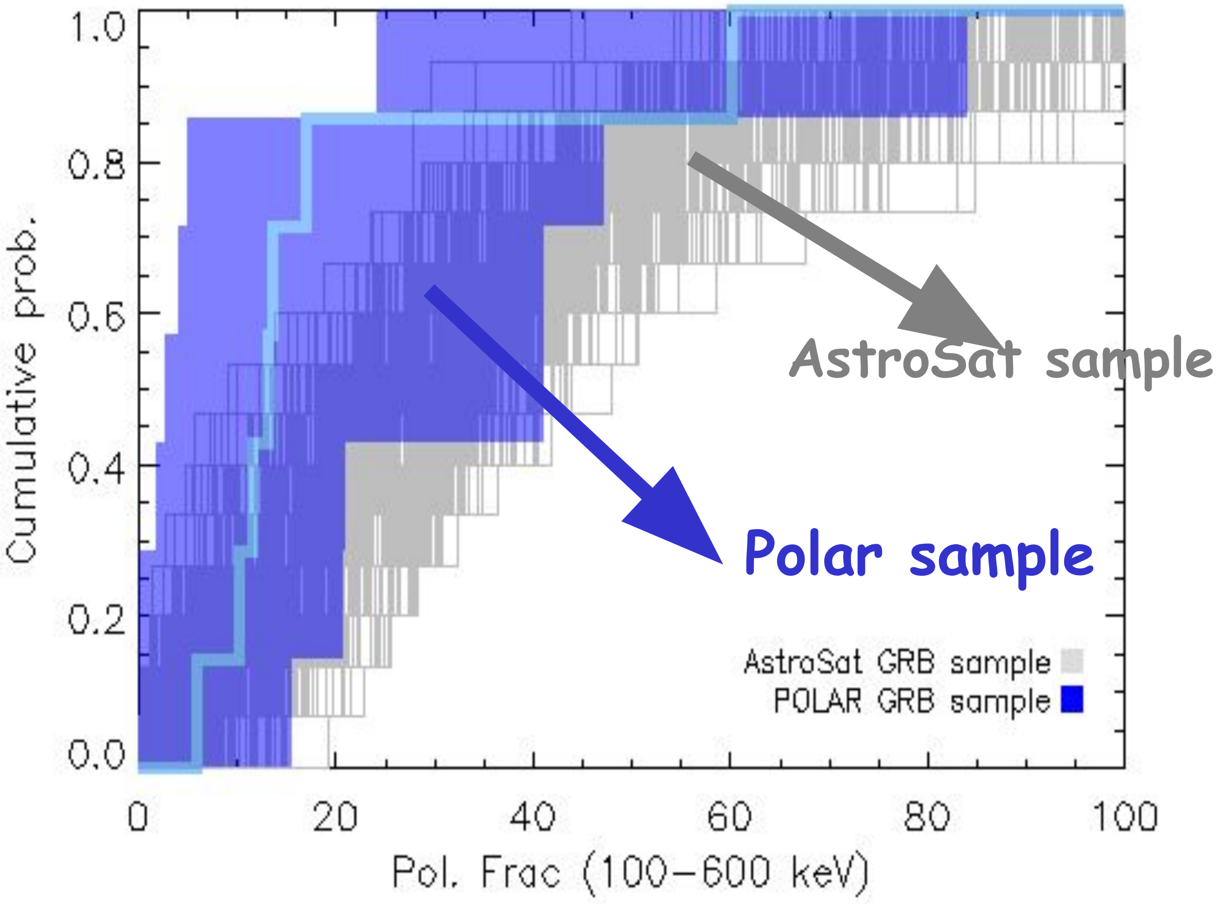


Results (100-600 keV, full burst)

1. **25 % of the sample polarized (50 - 70 %)**
2. Most GRBs are unpolarized in the full burst
3. the total sample size is now 40

Chattopadhyay et al 2022, ApJ

GRB polarization for a 5 year sample



Slightly higher polarization (around 20%) in *Astrosat* sample

Changing PA across the burst

PA changing in the prompt emission (already seen in some GRBs)

- seen in GRB100826A, GRB160821A etc

narrower sampling region at the higher energies (>100 keV) in case of *AstroSat*, less chance of mixing

Chattopadhyay et al 2022, ApJ

Summary

GRB 190530A

- Sixth most GBM fluent burst in *Fermi.*
- Time-averaged spectrum has a peculiar low-energy break in addition to the typical peak energy break. Such breaks are also present in time-resolved spectrum with the mean value of photon indices equal $<\alpha_1>= 0.77 \pm 0.06$ and $<\alpha_2>= 1.43 \pm 0.05$ before and after the break, consistent with the power-law indices expected by synchrotron emission in a marginally fast cooling spectral regime.
- We measured a high polarization fraction based on our CZTI observations in 100-300 keV, and a synchrotron model could explain such high polarization fraction with an ordered magnetic field. Based on our detailed spectro-polarimetric analysis, we suggest that GRB 190530A has a synchrotron origin.

5 years *AstroSat* CZTI sample

- **20 GRBs polarization measurements in 2015-2020**
  - Most GRBs are unpolarized in the full burst
  - Possibly because of changing polarization angle during the burst
  - More samples are needed
  - **Time resolved spectro-polarimetry for the bright GRBs are very useful**

    (Chand et al. 2018, 2019, Sharma et al. 2019, 2020, Gupta et al. 2022)
- ***AstroSat* will be the only GRB polarimeter till 2025 at least**
  - Another 20 GRB polarization measurement expected
  - after localization of the GRBs, the number may go to total 50 GRBs (20+20+10)

Tenth International Fermi Symposium

9th-15th October 2022

fermi

Thank you for your attention!

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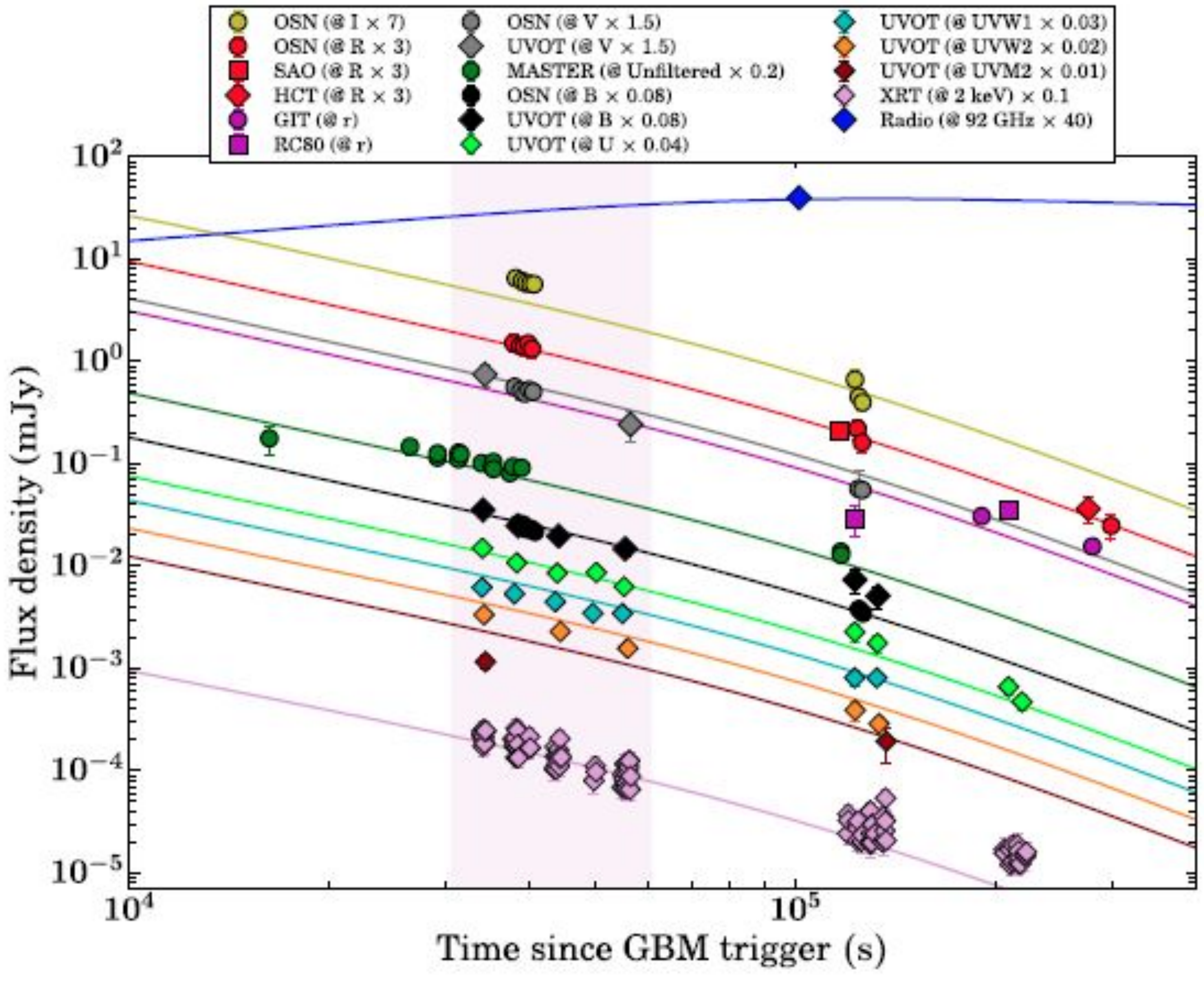
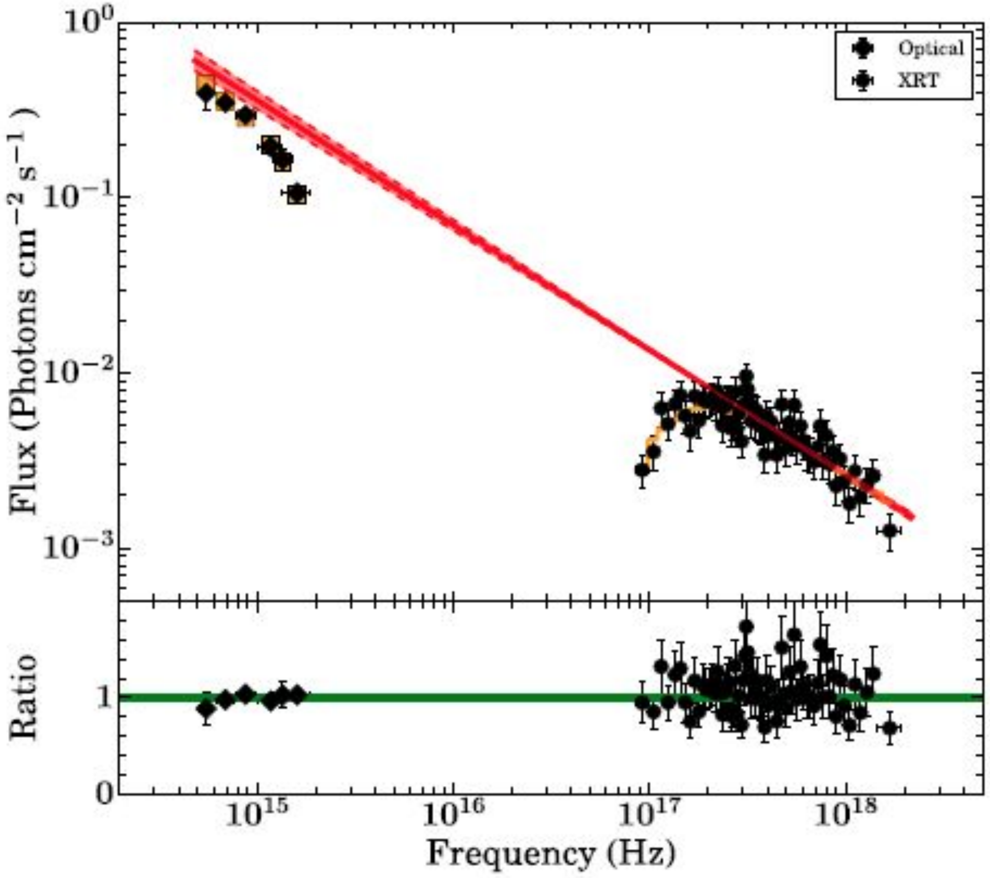
Backup Slides

Afterglow properties of GRB 190530A

Multiwavelength light curve
Forward shock !!



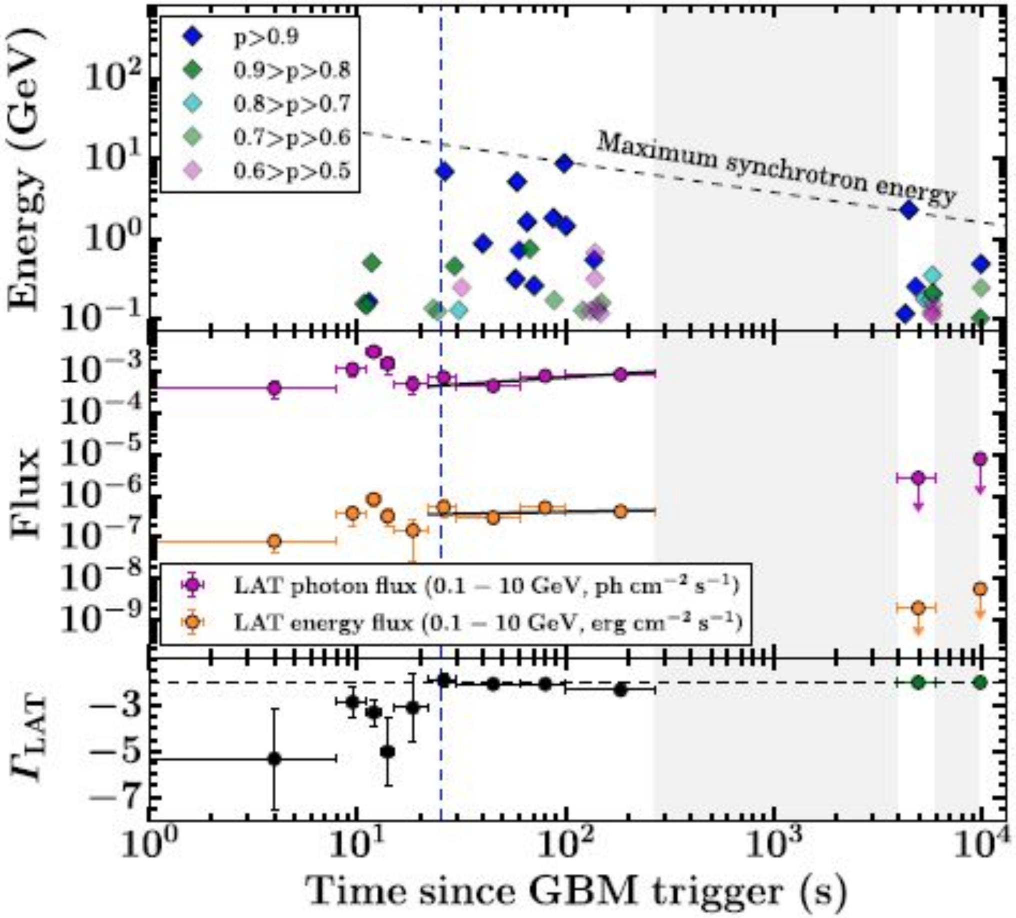
Spectral Energy Distribution



De Pasquale et al. 2007

Fermi-LAT Observations of GRB 190530A

We extracted the LAT data within a temporal window extending 10,000 s after T_0 using gtburst.



The probability of association of the photons with GRB 190530A is calculated using the gtsrcprob tool.

We calculated the maximum photon energy radiated by the synchrotron process (Piran & Nakar 2010).

We noticed that some of the late time photons lie above the maximum synchrotron energy, which indicates that these photons could have Synchrotron Self-Compton (SSC) origin, observed in the recent TeV detected GRBs.

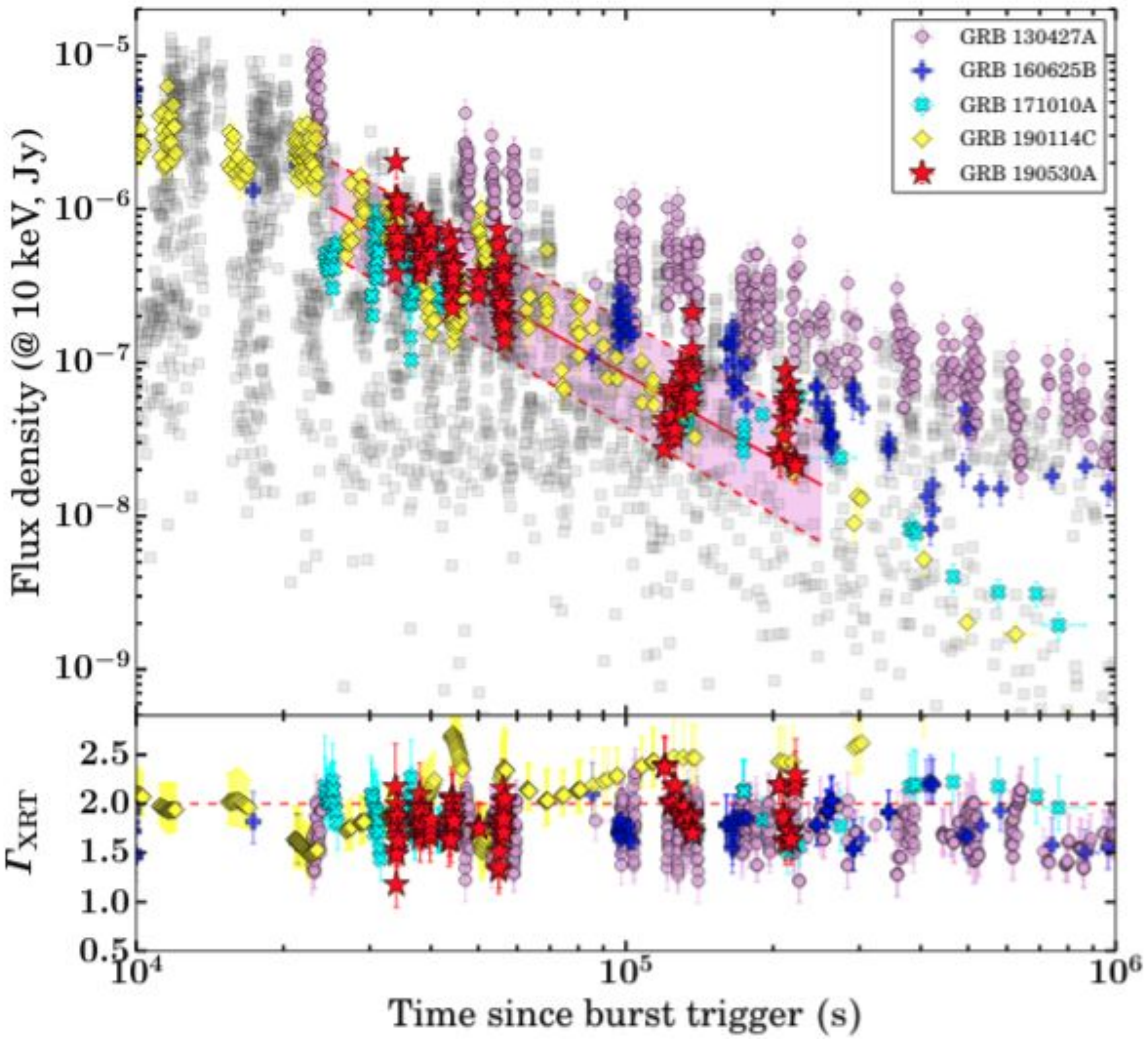
The late time LAT high energy data have afterglow origin and formed in an external forward shock?

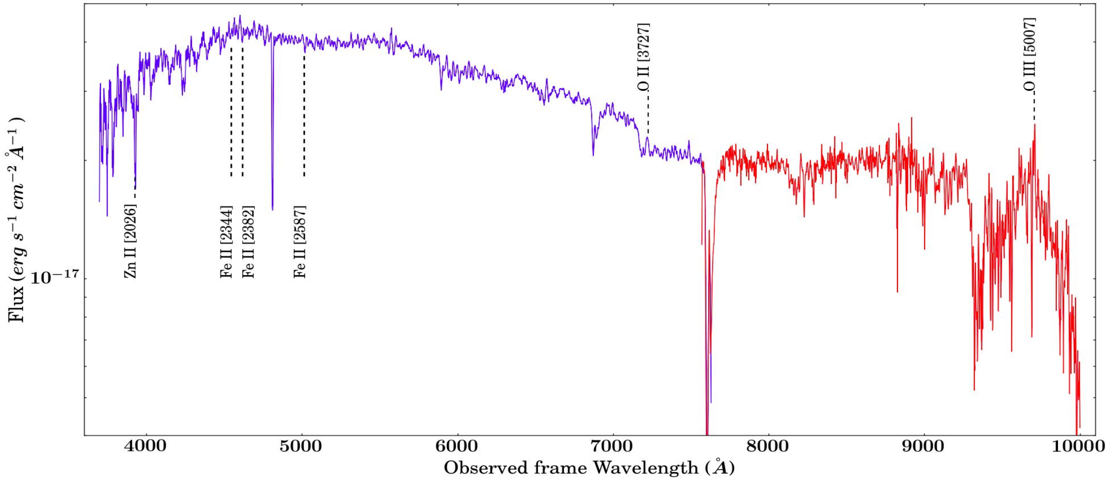
Soft (FV) to hard (SV) change:

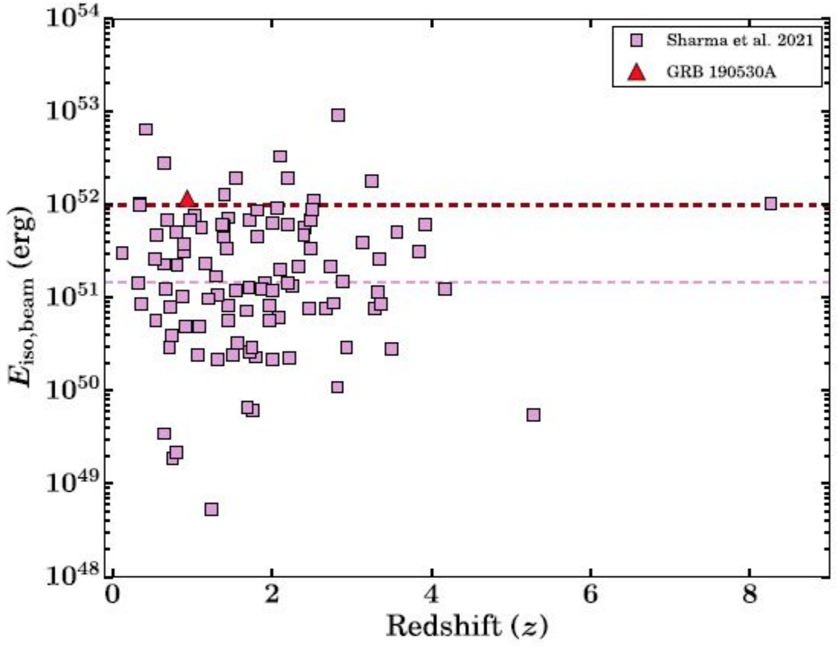
Prompt → Afterglow

GRB 190530A: Central Engine ?

Redshift = 0.9386
(using 10.4m GTC spectrum)

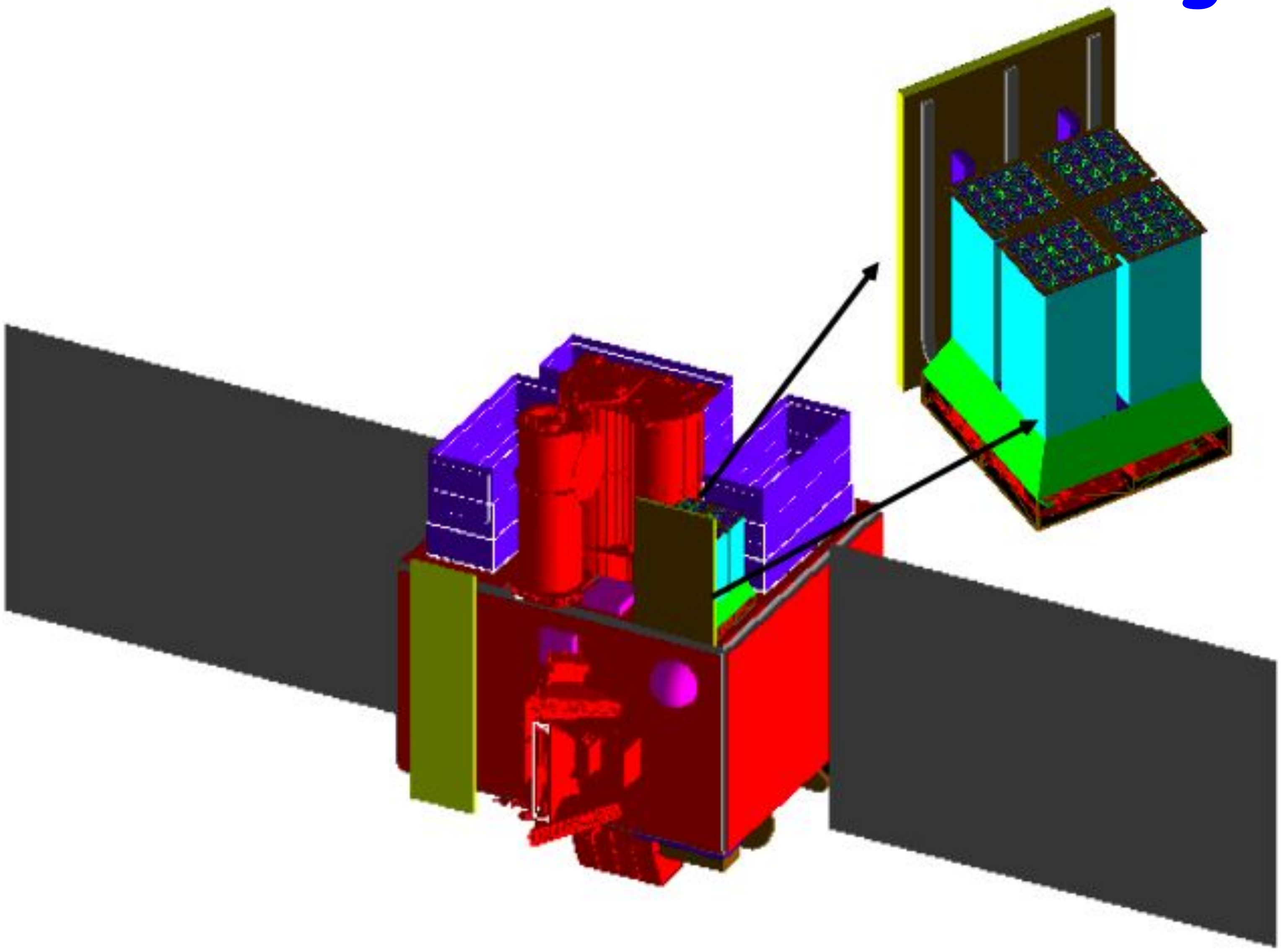


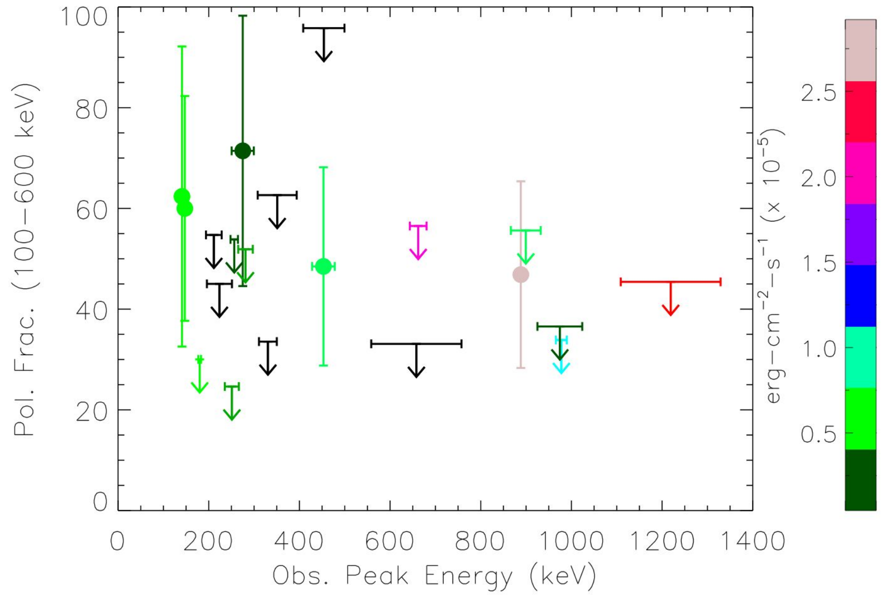




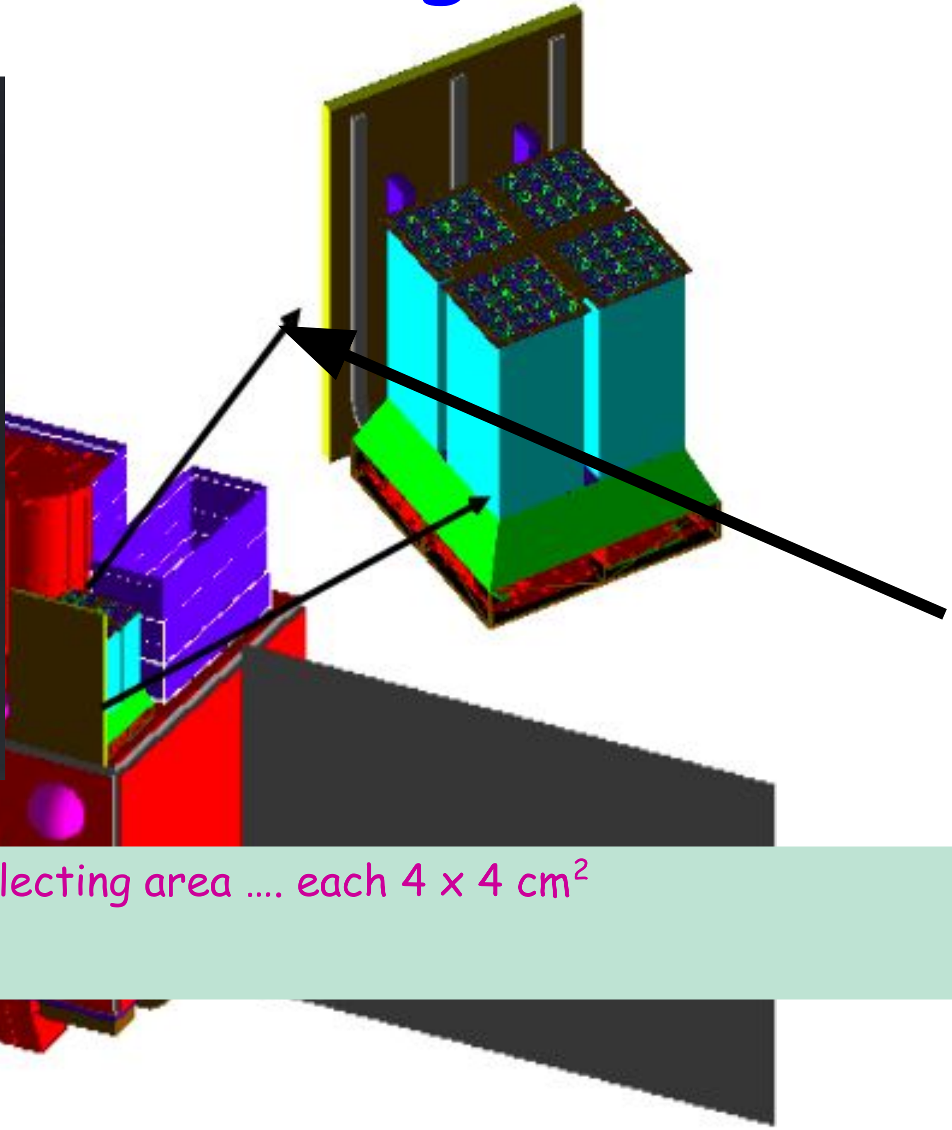
Black Hole

AstroSat and X-ray Polarimetry with CZT-Imager





AstroSat and X-ray Polarimetry with CZT-Imager



Orbotech CZT modules

- Total 64 modules … ~1000 cm^2 collecting area …. each 4 x 4 cm^2
- 5 mm thick

AstroSat and X-ray Polarimetry with CZT-Imager

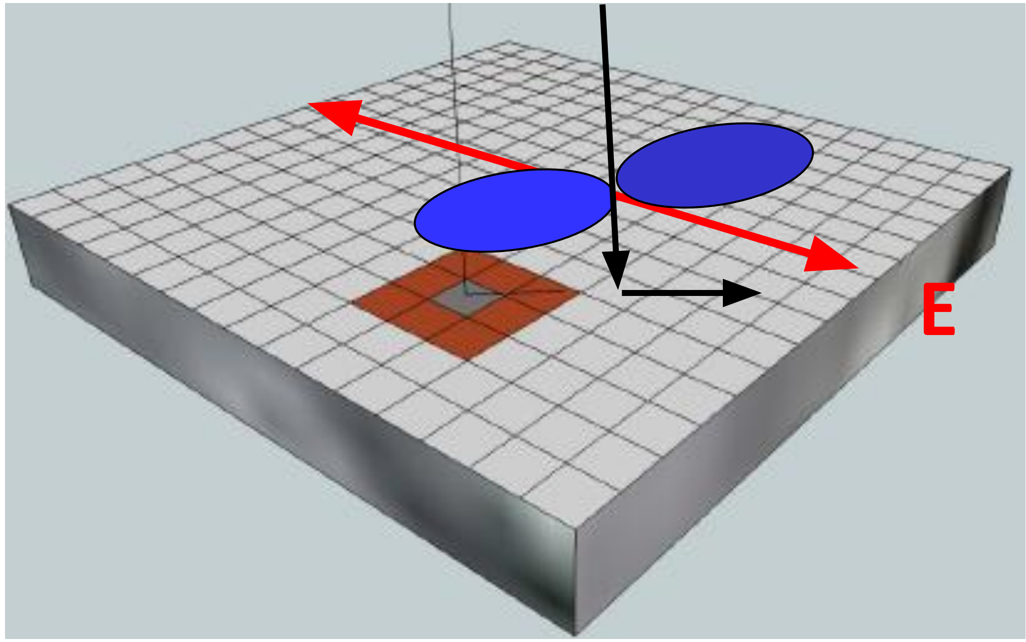
Each Module is pixelated in 16 x 16 pixel ~ pixel size of 2.5 mm

Timing resolution ~ 20 us

Orbotech CZT modules

- Total 64 modules … ~1000 cm^2 collecting area …. each 4 x 4 cm^2
- 5 mm thick

AstroSat and X-ray Polarimetry with CZT-Imager

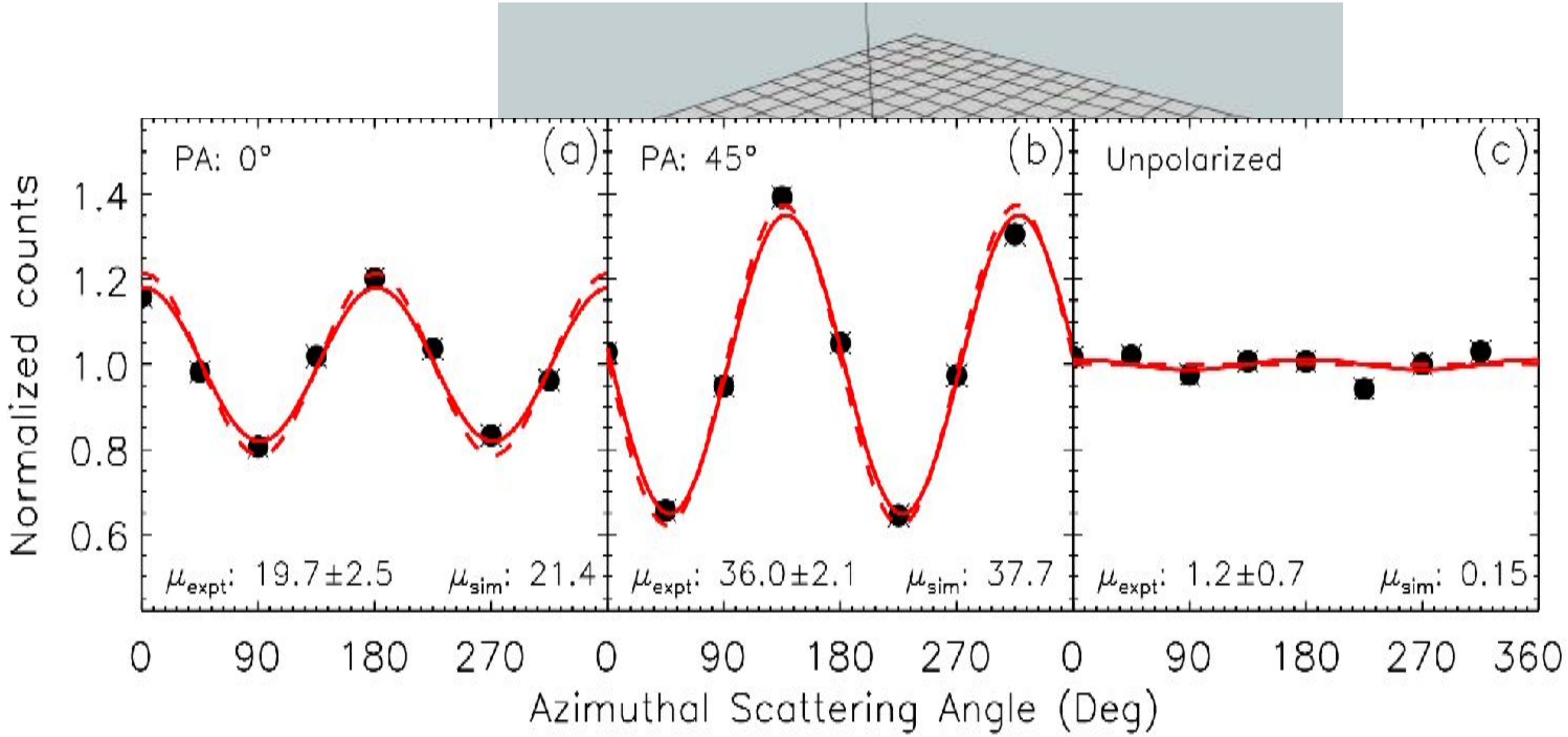


5 mm CZT has ~10 % Compton scattering probability > 100 keV

Photons are preferentially Compton scattered at angles perpendicular to the polarization direction – asymmetry in the azimuthal angle distribution

Polarization - 100 - 380 keV

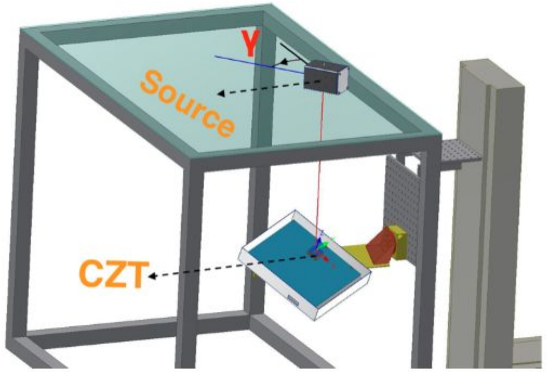
AstroSat and X-ray Polarimetry with CZT-Imager



- asymmetry in the azimuthal

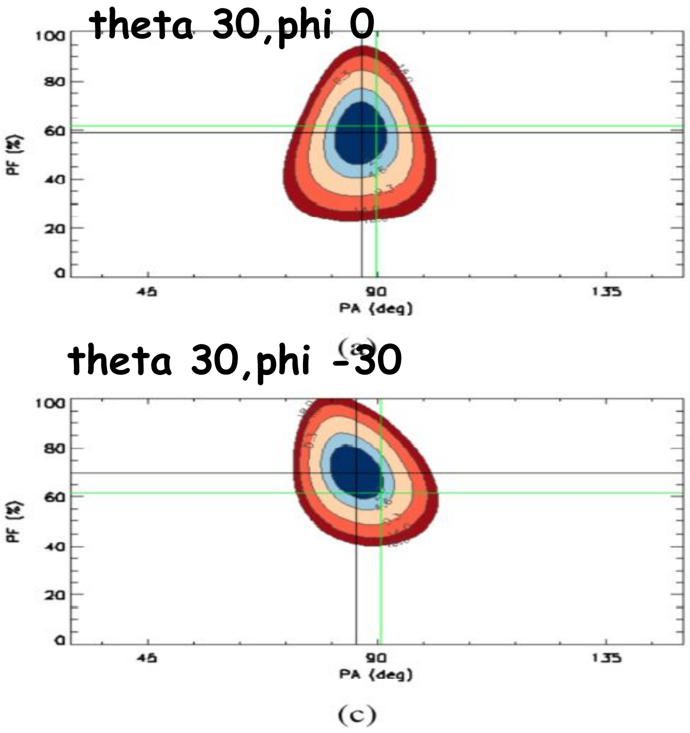
Pre-flight calibration using on-axis laboratory sources

Also recently characterized CZTI detectors for off-axis polarization in lab …



A Ba133 radioactive source to make polarized radiation.

Expt done at multiple off-axis angles - 30,45, 60 degree



Main results:

1. experimental and simulation results match within error
2. **>60 degree angles, the MDP is less and prone to systematics**

Vaishnava et al 2022, JATIS

CZTI also works as Open Detector in Hard X-rays - ~80 GRB detections/ year

transparent spacecraft, CZTI supporting structures at > 100 keV

Regular detection of GRBs ~ 80 GRBs / year

Prompt emission polarization of GRBs?

- can detect the GRBs in Compton events
- Simultaneous background is available,
- Better signal to noise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THIS STORY IS FROM MAY 24, 2022

India's AstroSat witnesses black hole birth for the 500th time

SURENDRA SINGH / TNN / May 24, 2022, 04:33 IST

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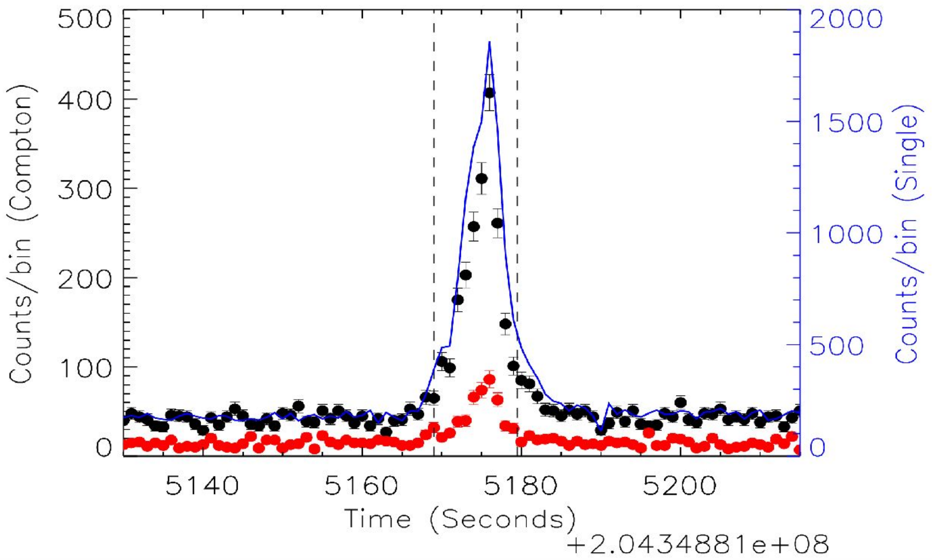
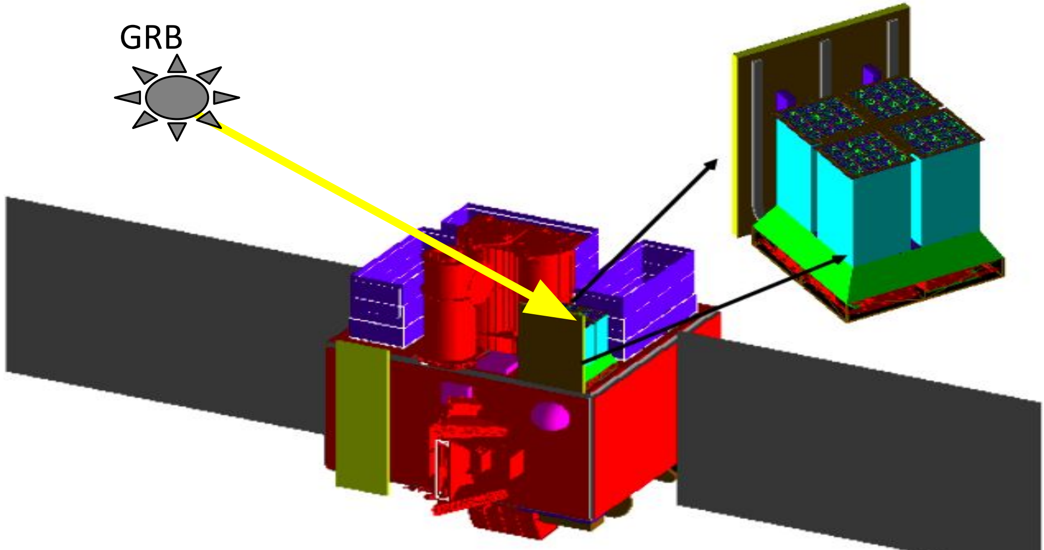


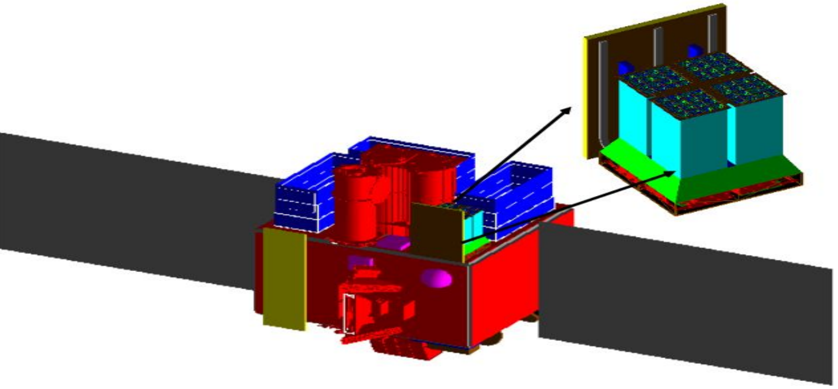
Chattopadhyay et al 2019, ApJ

well … GRB polarization is difficult…

1. Interaction of photons with the satellite structure - how accurate is the mass model?
2. charge sharing between CZTI pixels - how to include charge sharing in the Geant4 simulation?
3. Low gain pixels to increase the energy range to 600 keV?



We validated the AstroSat mass model …

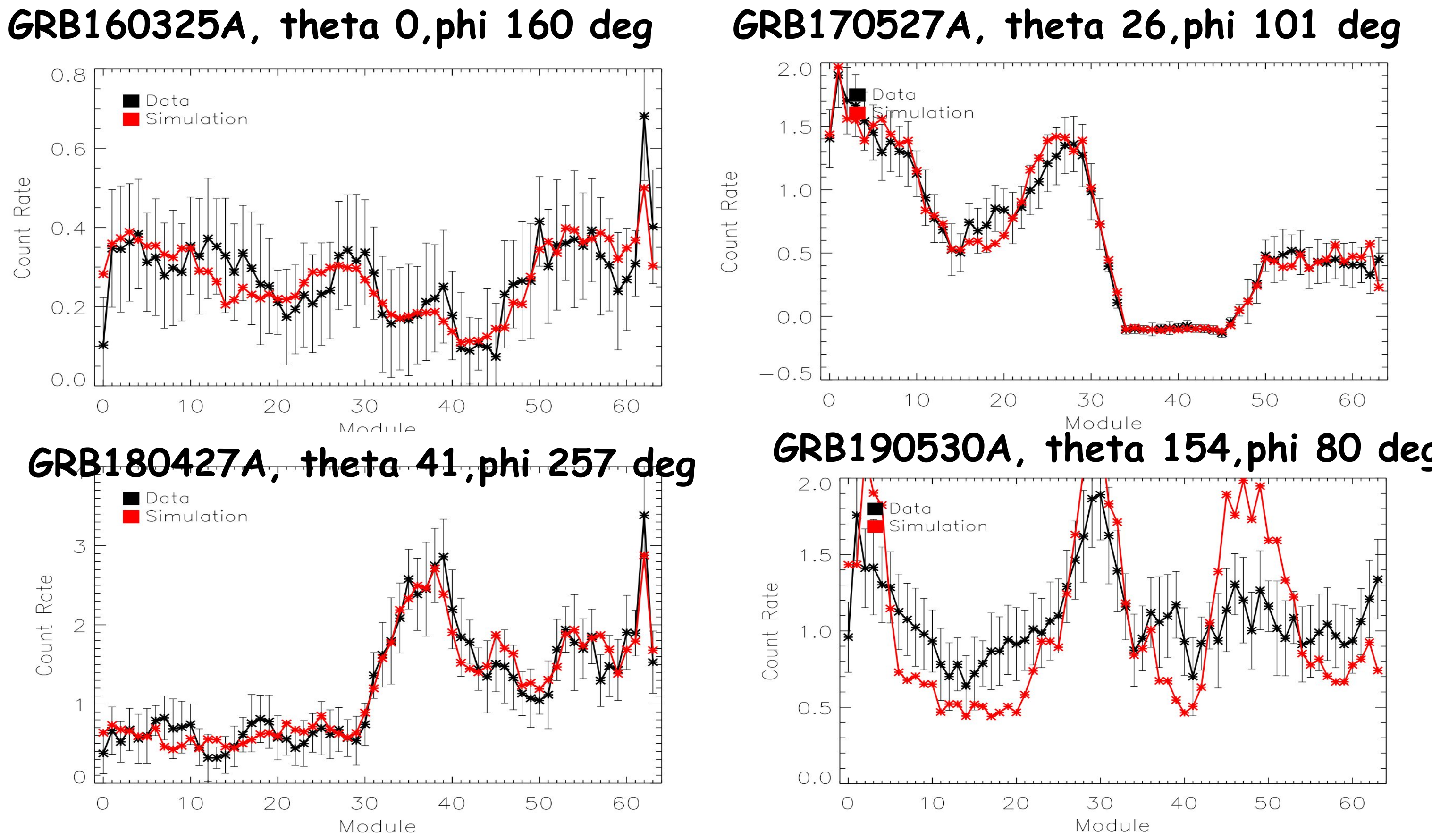


Mate et al 2021

- A mass model including all instruments, spacecraft in Geant4.
- Some parts hard coded
- Some parts in Cadmesh

Validation:

- the collimators, mask, supporting structures, veto cast shadow on the CZTI modules
- compared the simulated and observed DPH
- matching reasonable well!



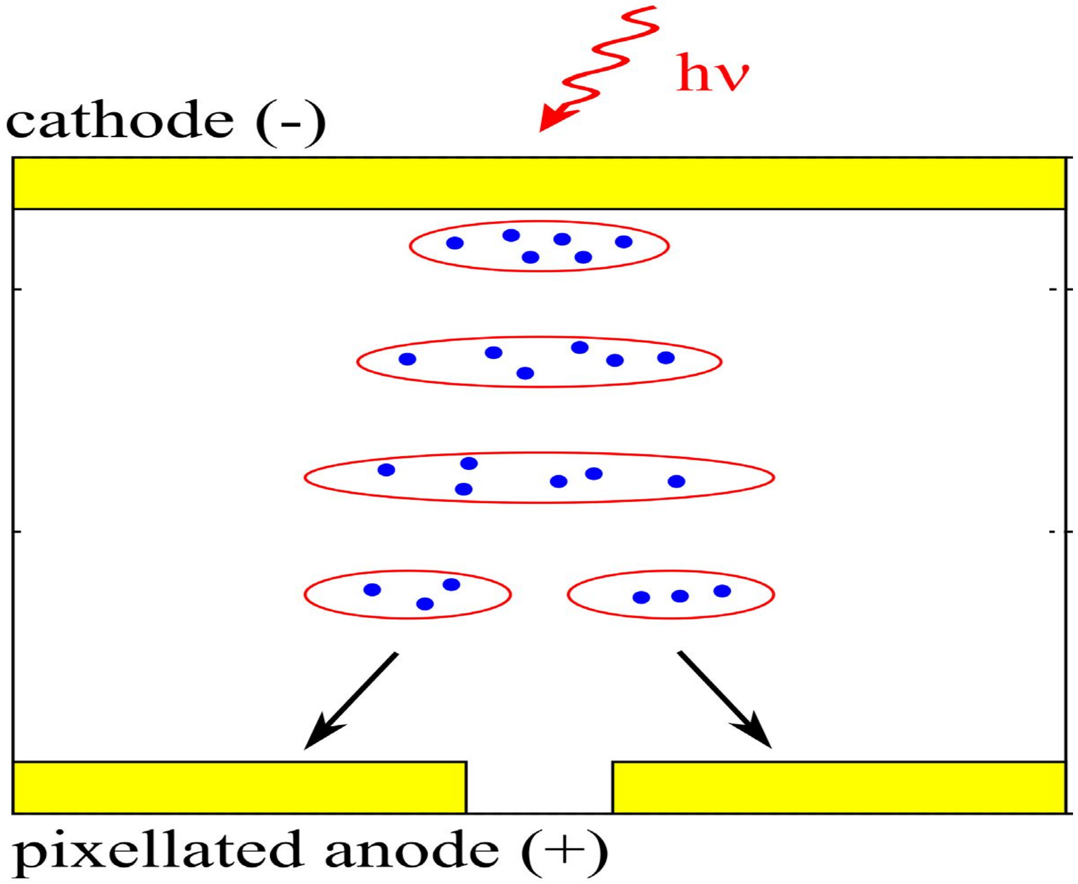
Chattopadhyay et al 2019, ApJ

Charge sharing in CZT pixels

- Charge sharing in any pixelated detector– f(thickness, temp, bias, energy)

- In large pixel size ~2.5 mm, charge sharing not significant in case of single pixel spectroscopy

- However, Compton events are a factor ~12 times lower. Therefore charge sharing events are significant in Compton polarimetry and spectroscopy



Evidence of charge sharing in case of GRBs

- **Expected single / Compton in CZT ~ 12**
- **Observed single / Compton ~ 6**

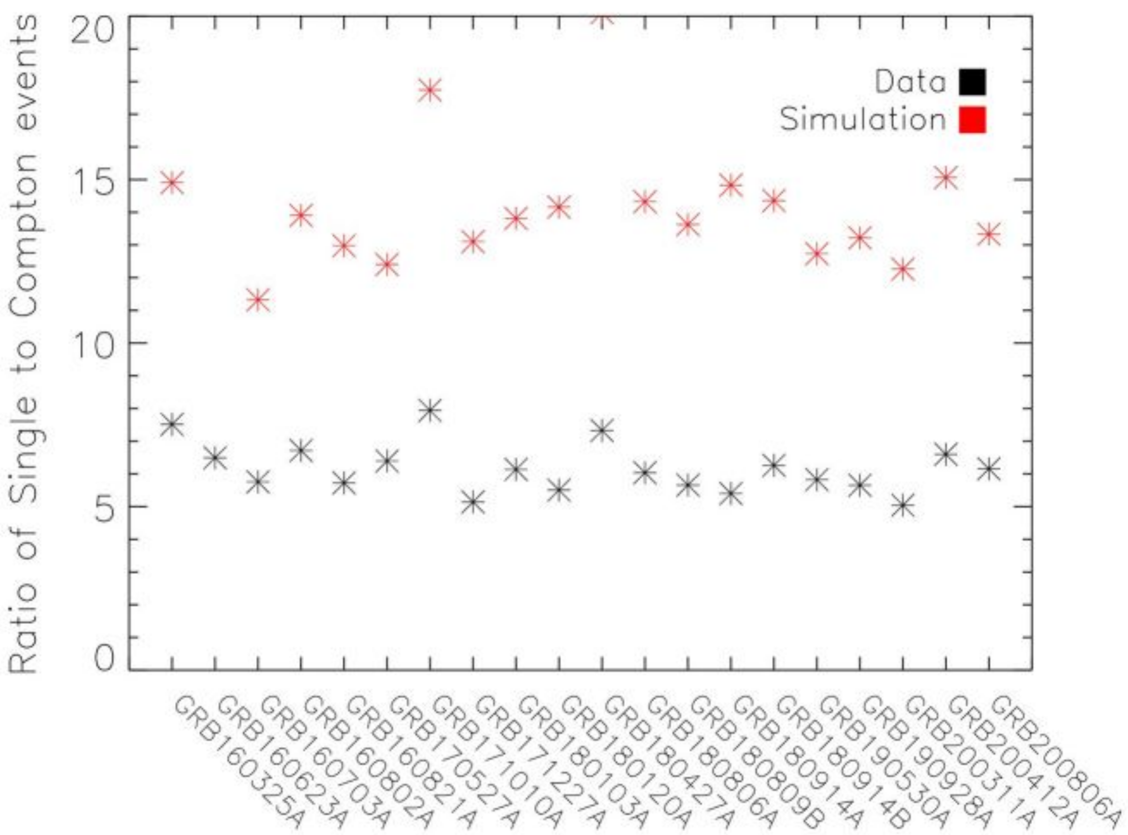
- **Why?**

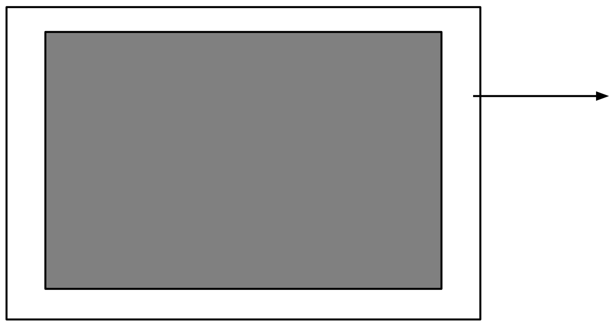
Obs Compton > Simulated Compton by charge sharing events

- **How to correct?**

Calculate the charge sharing region

Calculate the events in the charge sharing
> add it to the simulated Compton events
> subtract from the simulated single pixel events



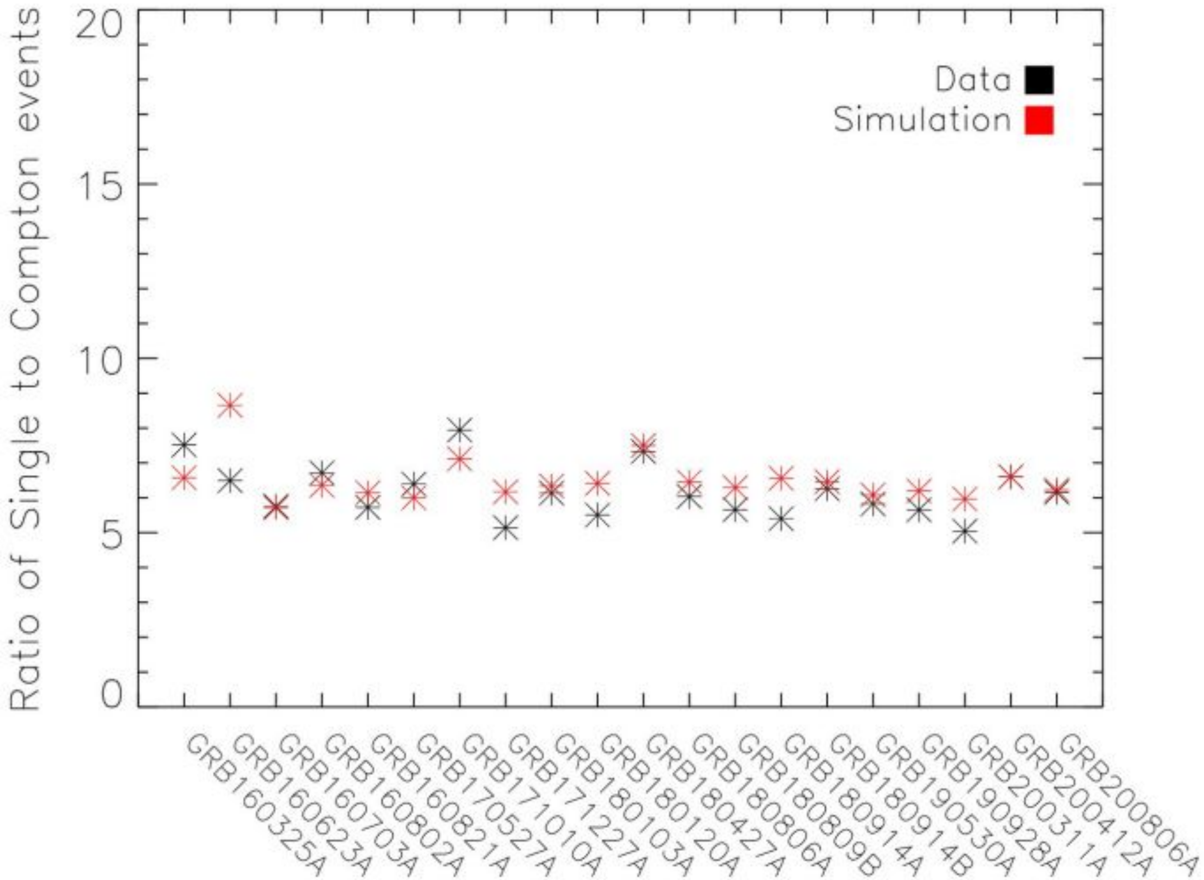


charge sharing region

Charge sharing corrected in CZT pixels

- We applied the charge sharing model to the simulated events and corrected them for charge sharing.

We also developed a semi-empirical model to correct the simulated azimuthal angle distributions. — next talk.



Chattopadhyay et al 2022, ApJ

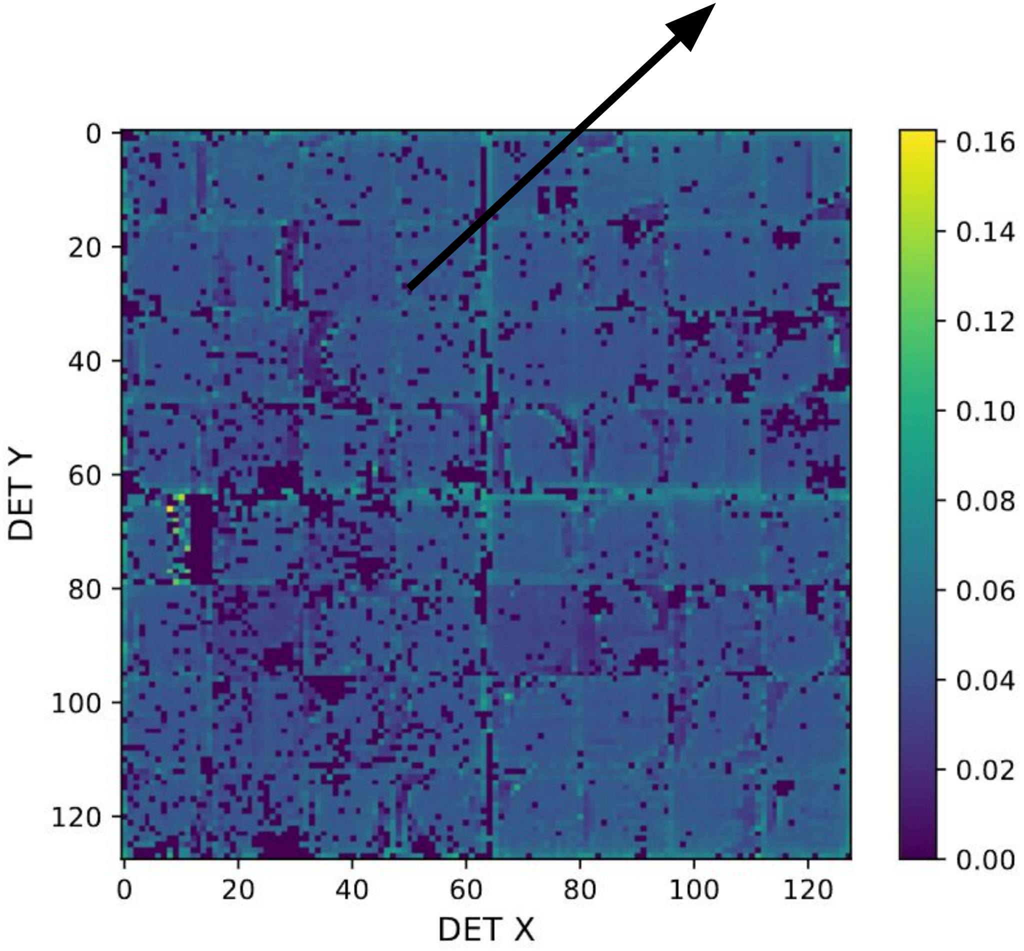
Extending the CZTI polarimetry energy to sub-MeVs

low gain pixels : post-launch
~20 % of the pixels in the CZTI plane found to have lower counts due to shift in the electronic gain

We have utilized the low gain pixels in CZTI to enhance the **polarimetric energy range to 600 kev** with 30-40 % increase in Compton counts.

> calibration of the low gain pixels were done using particle induced activation lines at 88 keV and ~150 keV

low gain pixels :



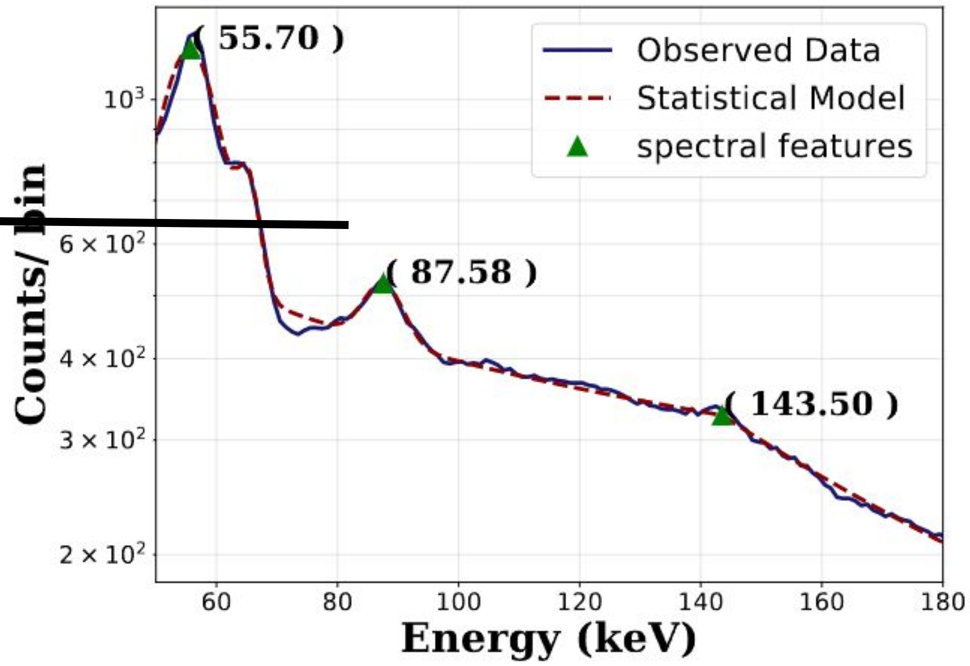
Chattopadhyay et al 2021, JAA

Low gain pixel calibration

spectrum of the good pixels in a detector module ~ 1 month of data July 2016

model -> **Gaussian 1 (54 keV** Tantalum kalpha + **Gaussian 2 (88 keV** proton induced Te activation) + **power law with break at 150 keV** due to break in CZTI detection efficiency)

Used this template model and compared the spectrum of each of the low gain pixels. The shift needed in the ground calibrated gain is the correction factor.



The polarimetric energy range is extended to 600 keV (otherwise it's limited to 380 keV). Above 600 keV, no intrinsic polarization analyzing power.

~ 20-30 % more Compton events.

Chattopadhyay et al 2021, JAA