Fermi-GBM Observations of Recent Extraordinarily Bright Gamma-ray Bursts:

GRB 221009A, GRB 230307A, and GRB 230812B

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on behalf of the *Fermi*-GBM team

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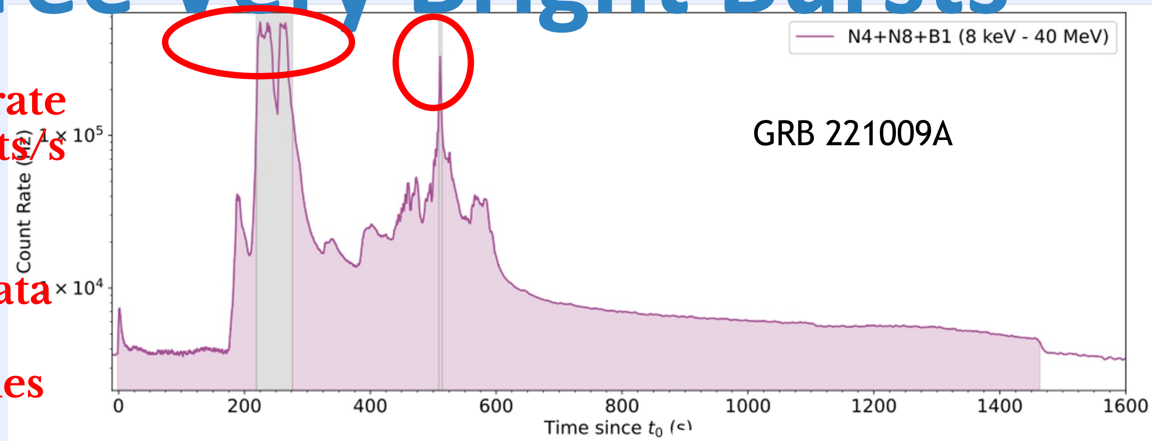
Fermi Gamma-ray Space Telescope

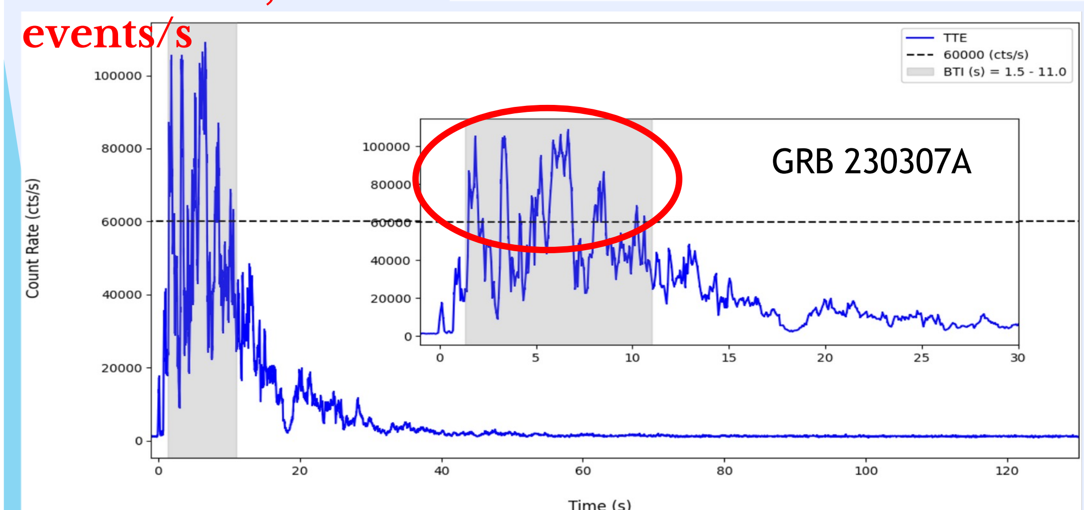
Three Very Bright Bursts

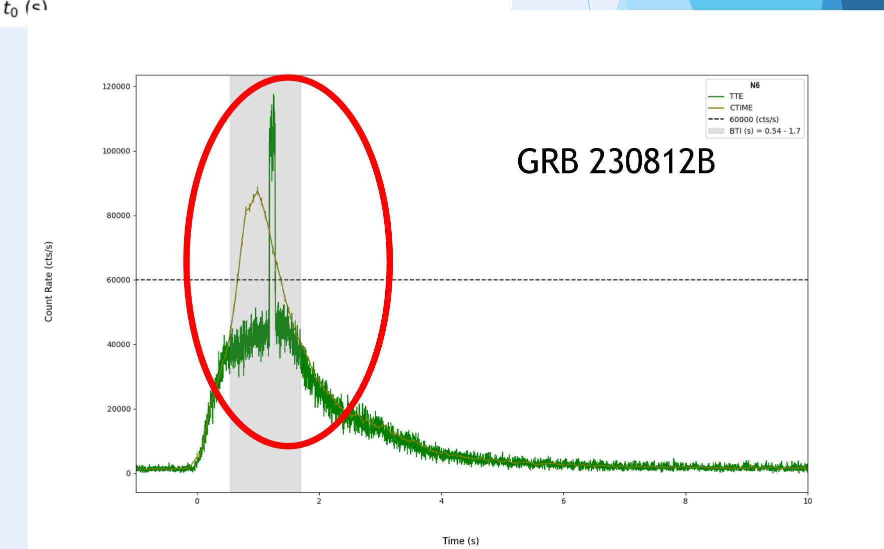
Pulse Pile-Up (PPU) occurs when count rate exceeds ~60,000 cnts/s

Affects CSPEC, CTIME, and TTE Data

TTE bandwidth issues above ~ 375, 000 events/s







Pulse Pile-Up (PPU)

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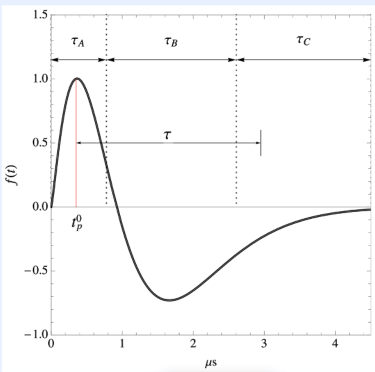
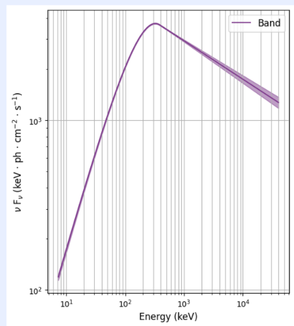
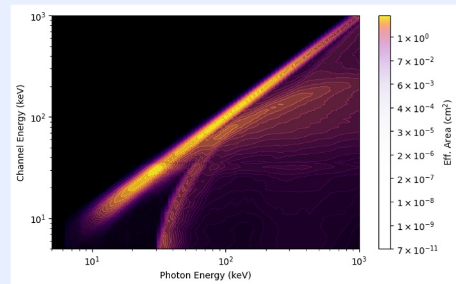
Standard Pulse



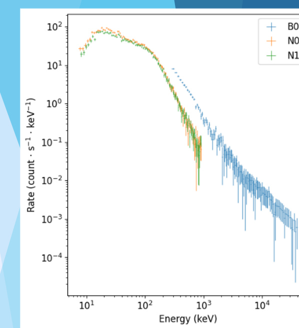
Photon Spectrum



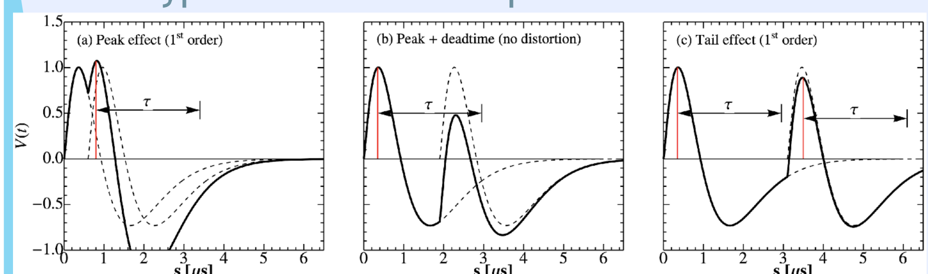
Detector Response



Counts Spectrum

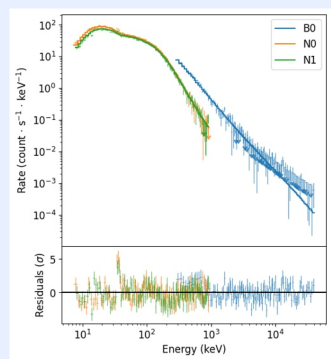


Types of Pulse Pile-up

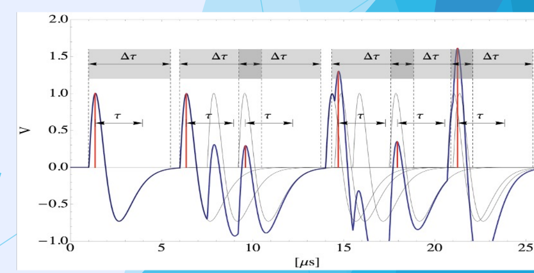


Chaplin et al. (2013)

Compare



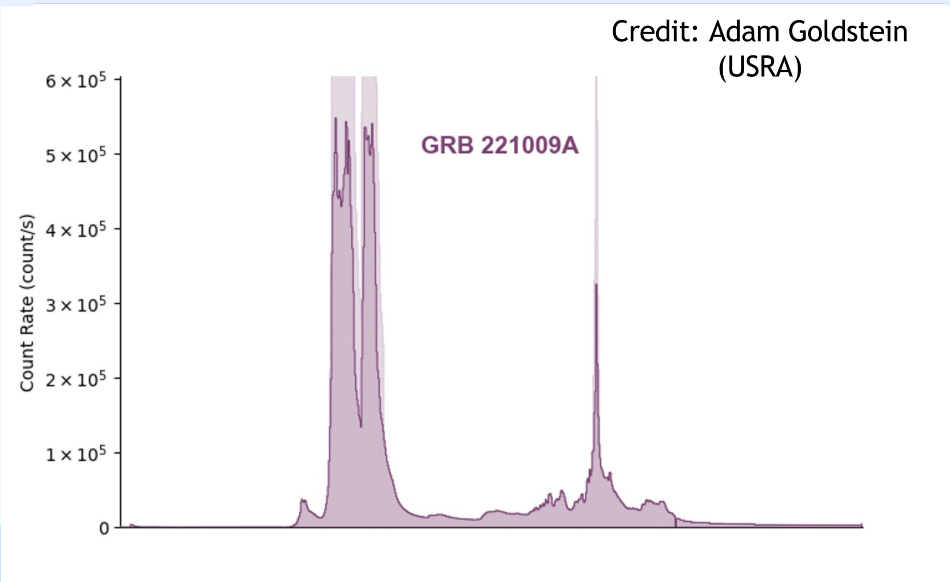
PPU-Distortion



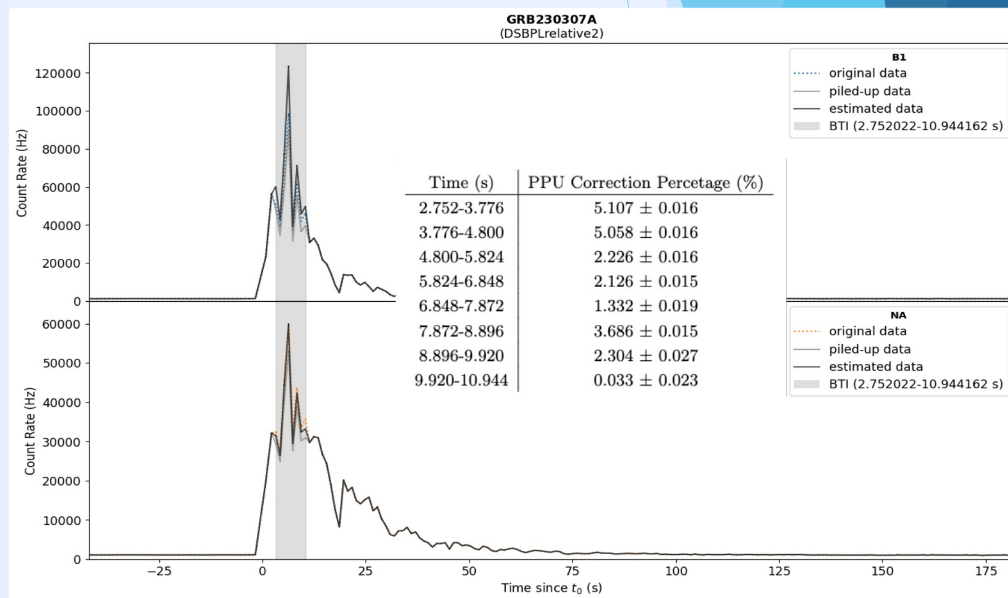
For more detailed PPU process see Lesage et al. (2023)

Slide Courtesy of S. Lesage

PPU Correction

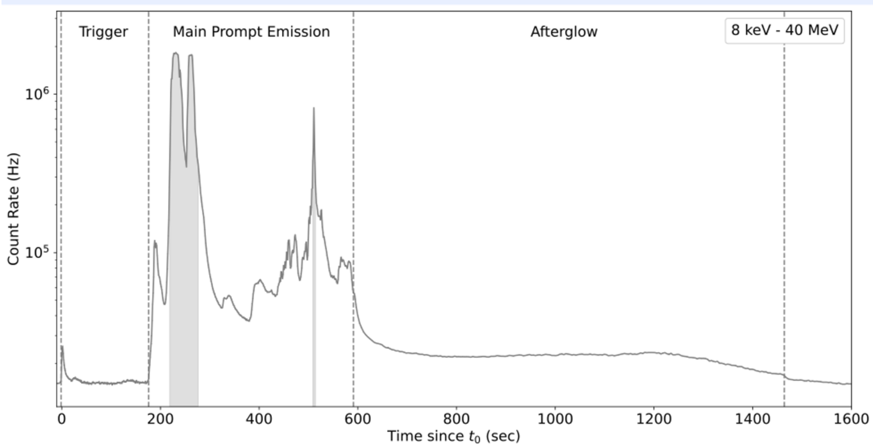


Credit: Adam Goldstein (USRA)

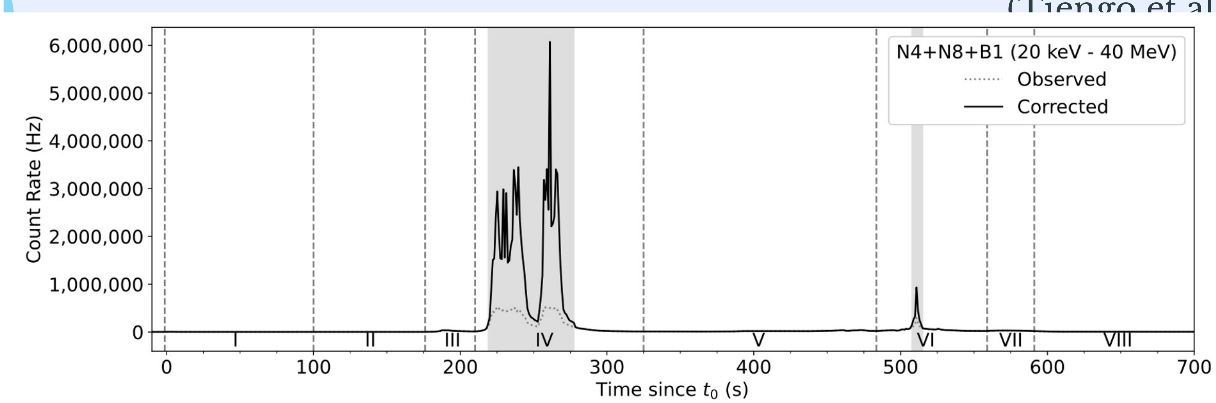


Time (s)	PPU Correction Percetage (%)
2.752-3.776	5.107 ± 0.016
3.776-4.800	5.058 ± 0.016
4.800-5.824	2.226 ± 0.016
5.824-6.848	2.126 ± 0.015
6.848-7.872	1.332 ± 0.019
7.872-8.896	3.686 ± 0.015
8.896-9.920	2.304 ± 0.027
9.920-10.944	0.033 ± 0.023

GRB 220109A: The “BOAT”



- Triggered at 13:16:59.99 UTC 9th of October, 2022
- T90: 289s
- One in 10,000 year event
- Over 100 follow-up notices including:
  - The first detection of TeV-energy photons during the prompt emission by LHAASO (up to 18TeV; Huang et al. 2022).
  - A redshift of z=0.151 reported by the Very Large Telescope (VLT; de Ugarte Postigo et al. 2022).
  - The identification of rings from dust echoes by Swift- XRT (Tiengo et al. 2022).
  - Polarization observations from IXPE (Negro et al. 2022).
  - Unsaturated observations from a Solar instrument (STIX; Xiao et al. 2022)
  - Measurable disturbances in Earth’s ionosphere (Guha & Nicholson 2022; Schnoor et al. 2022).

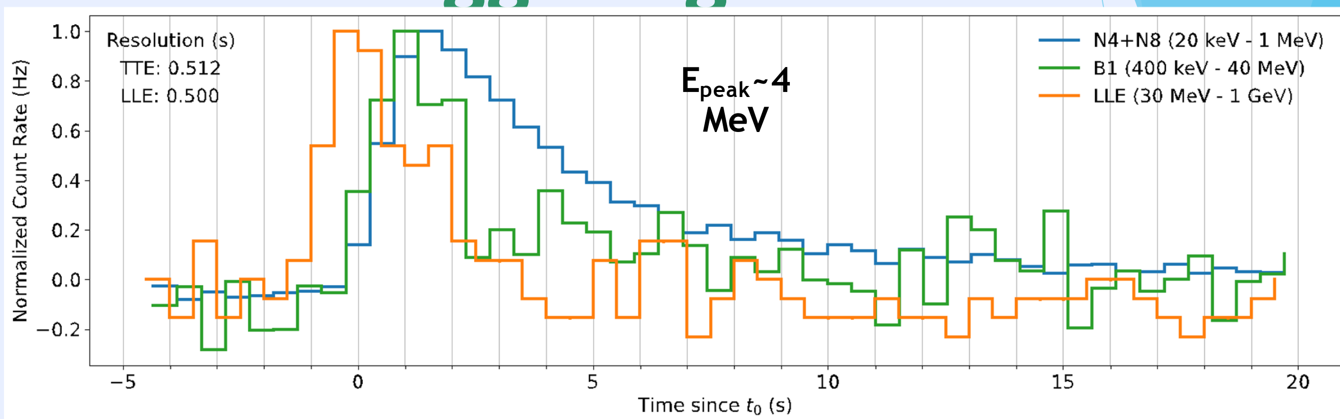


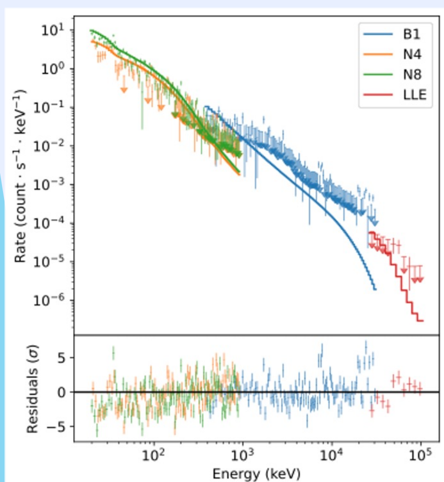
GRB 220109A: Triggering Pulse

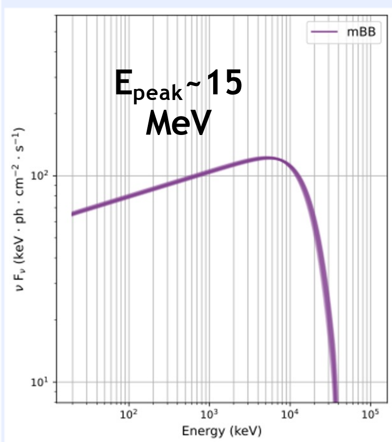
Same as GRB 130427A

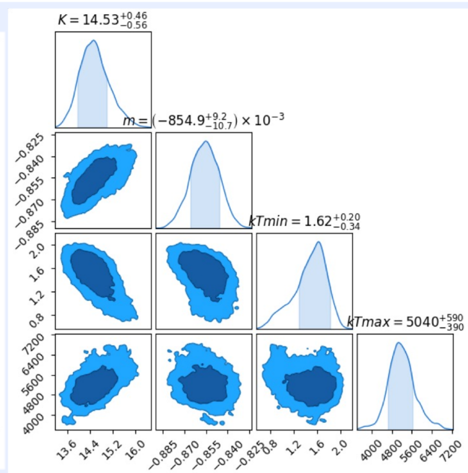
$\Gamma_{\text{trigger, SB}}$ = 300-1000

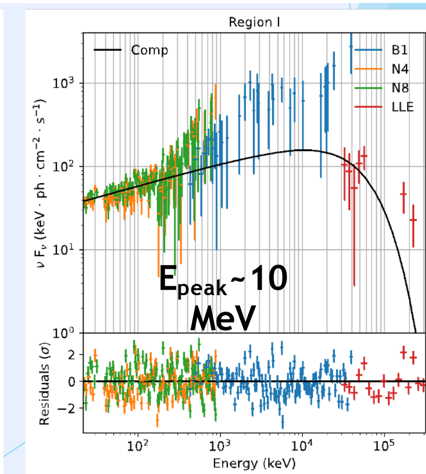
$\Gamma_{\text{trigger, OT}} \gtrsim 188$





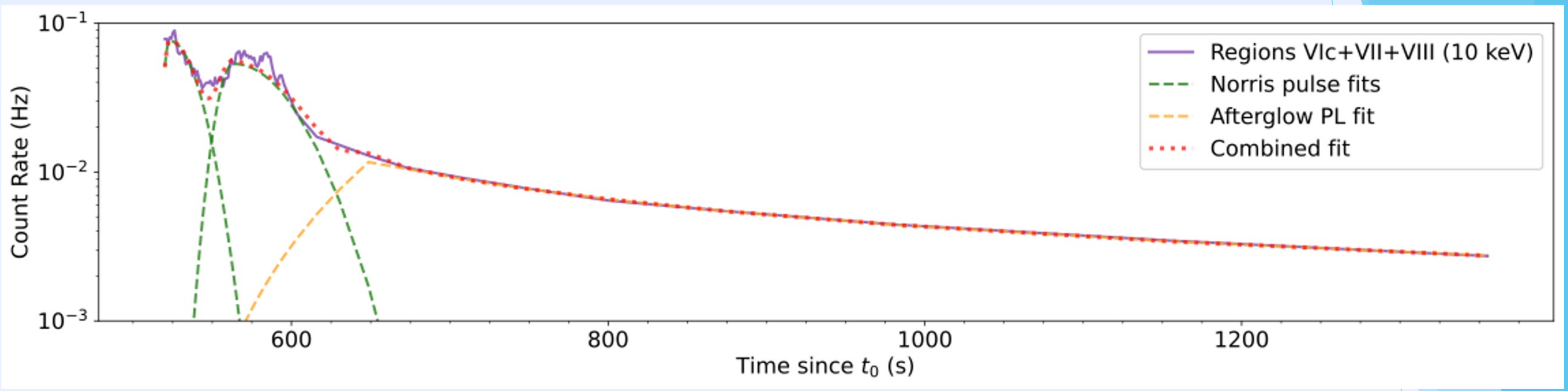


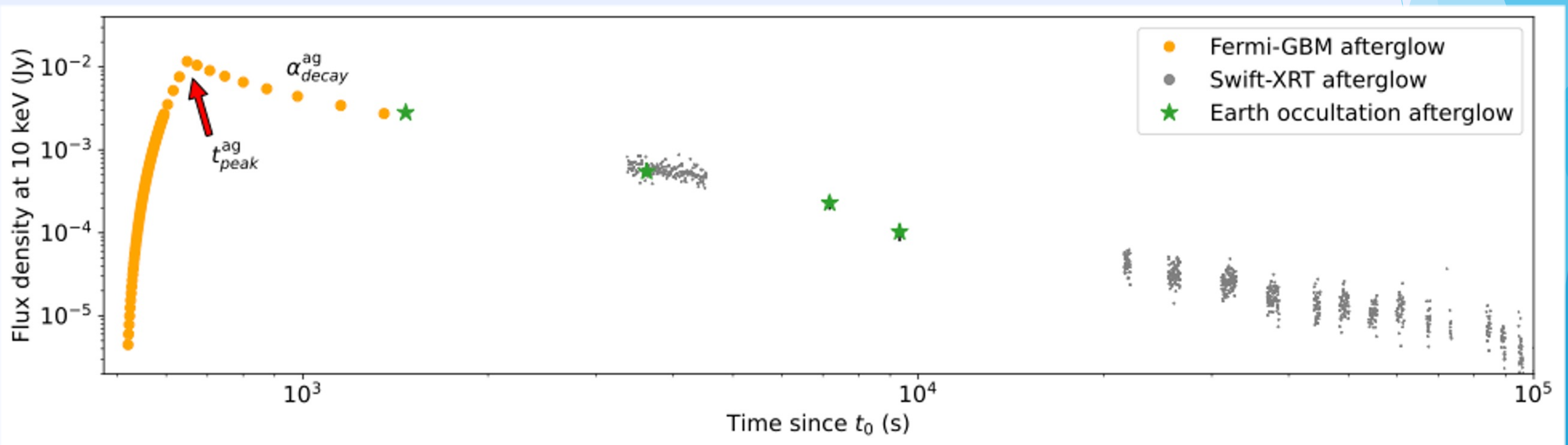




Slide Courtesy of S. Lesage

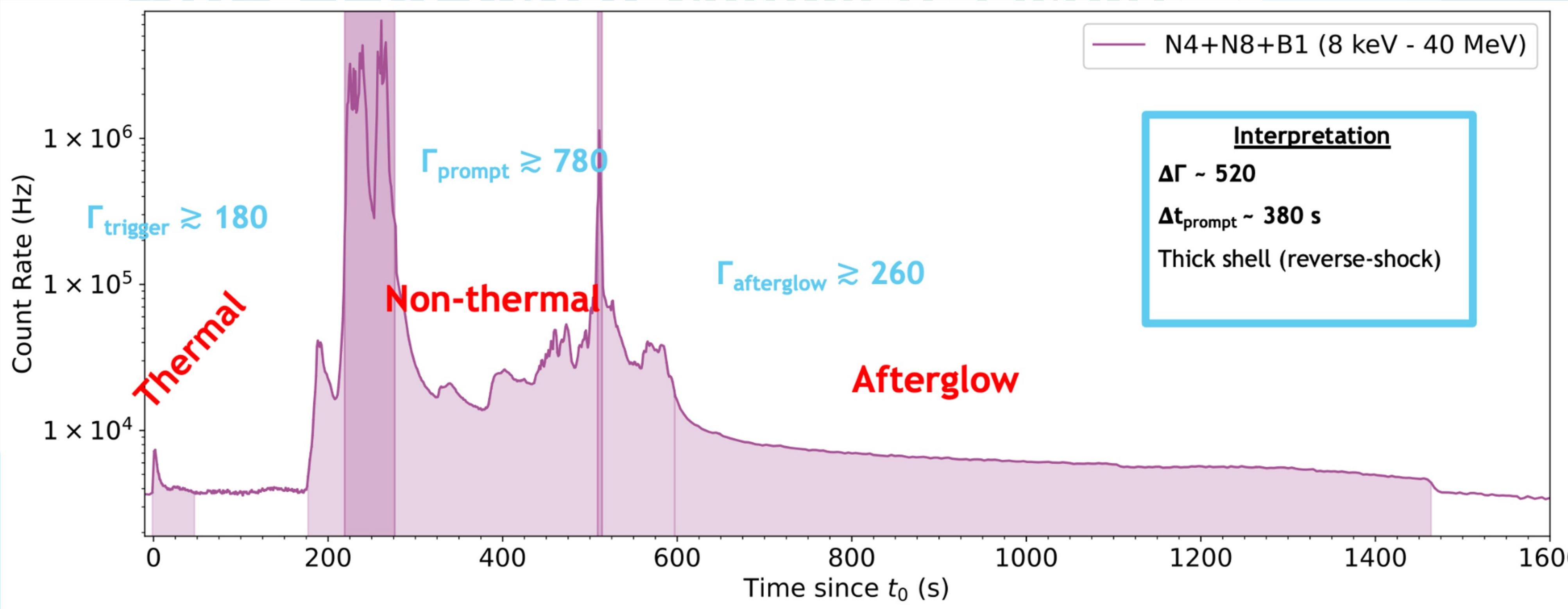
GRB 220109A: Afterglow





Slide Courtesy of S. Lesage

GRB 220109A: Complete Picture



Slide Courtesy of S. Lesage

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Fermi Gamma-ray Space Telescope

GRB 230307A

- Triggered at 15:44:07 UTC on 7th of March 2023
- T90: 34.56s
- Occulted at 128s
- Only useable detectors N10 & B1
- Fine-time spectral analysis with variable binning

- Over 30 follow-up detections including:
  - Late time X-ray afterglow by Chandra (Rouco Escorial et al. 2023)
  - A redshift of 0.065 (Gillanders et al. 2023)
  - Two rounds of observations by the James Webb Space Telescope, confirming an associated kilonova and favoring the nearby distance of the event (Levan et al. 2023)

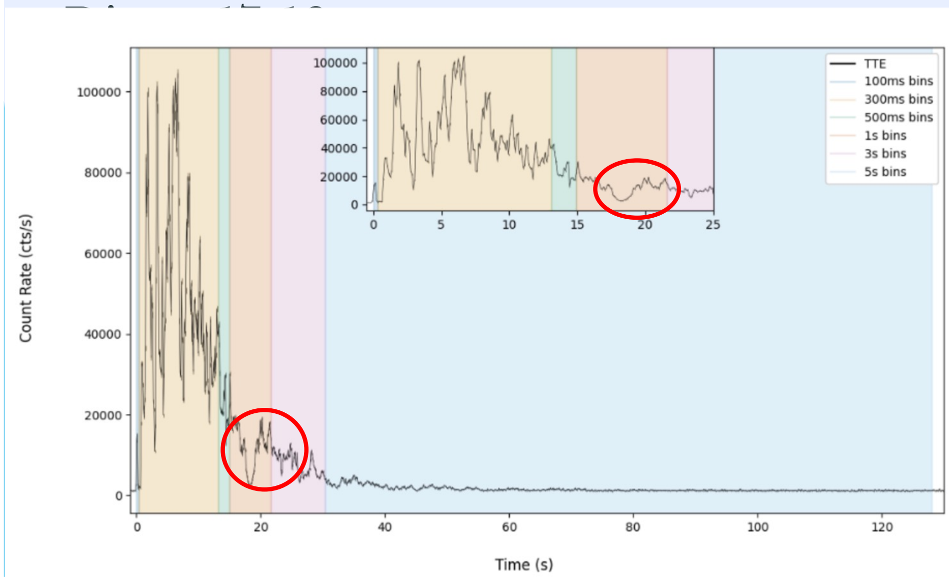
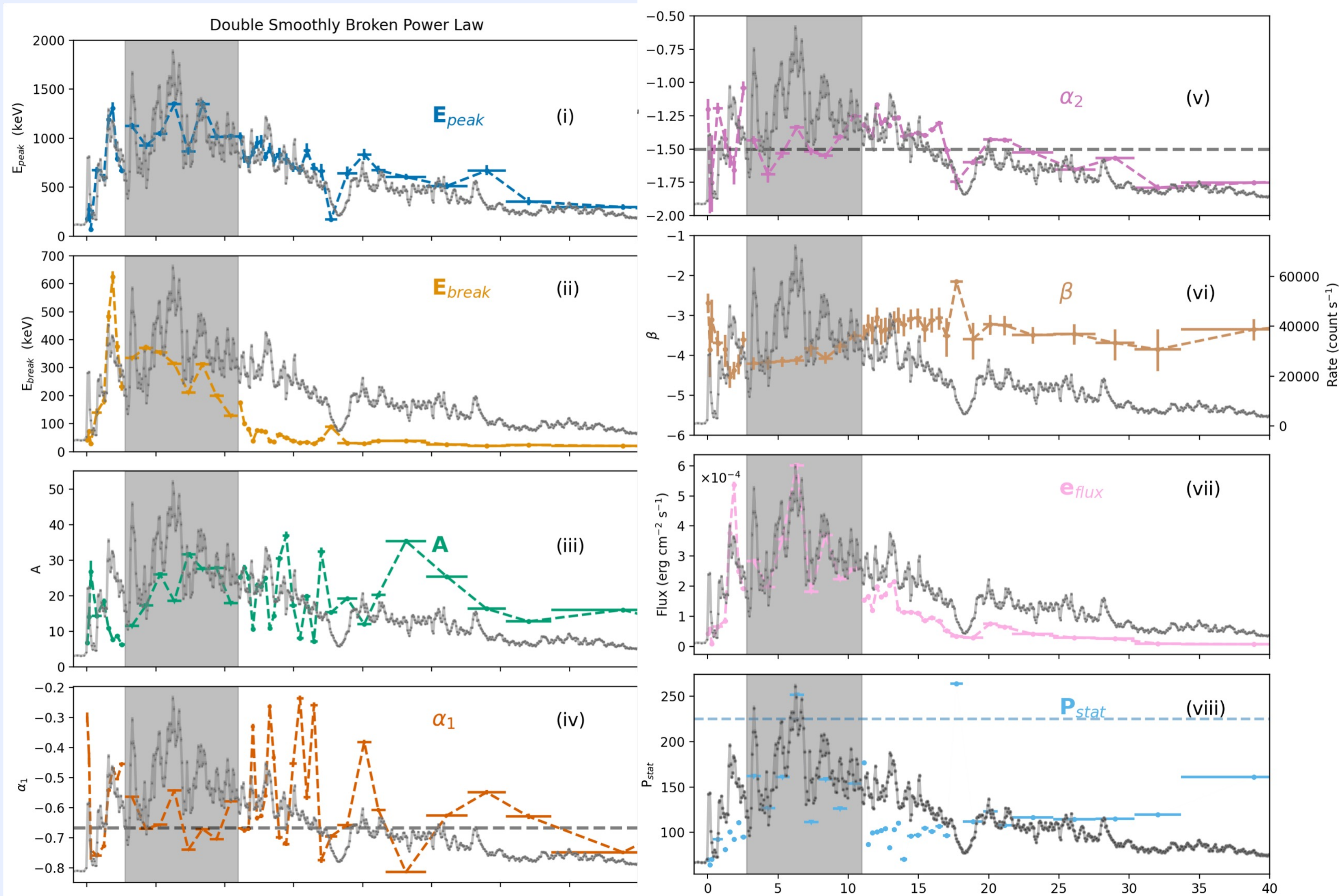


Image: NASA, ESA, CSA, STScI, A. Levan (Radboud University and University of Warw[illegible]k)

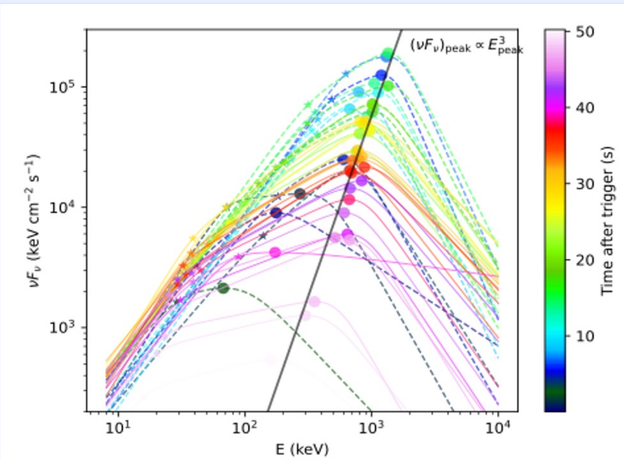
- 47 time bins ranging from 100ms - 5s
- Fit using DSBPL (Ravassio et al. 2018)

- E_{peak} ~1350 keV
- E_{break} ~625 keV

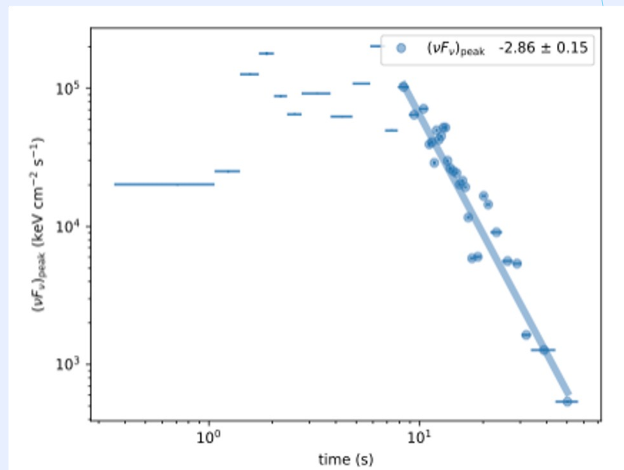
- $\alpha_1 \sim -0.57$
- $\alpha_2 \sim -1.46$
- $\beta \sim 3.51$



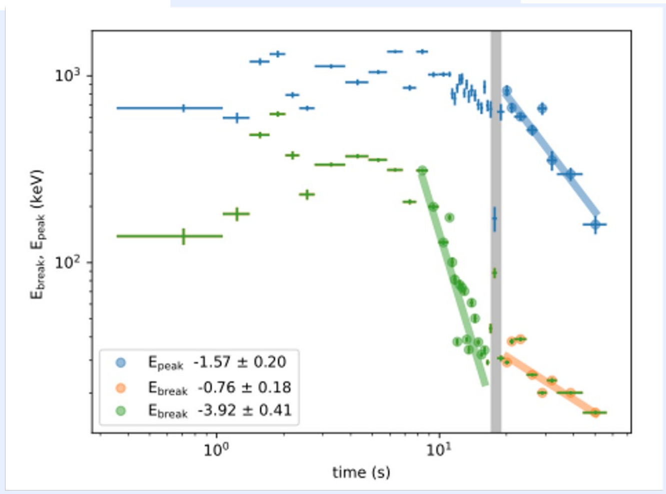
GRB 230307A: Parameter Evolution



•Combinded νF_ν spectra for each time bins
•Deviation at early time bins

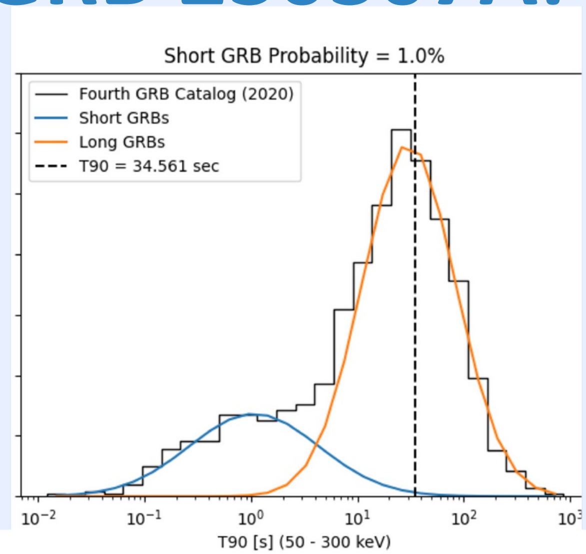


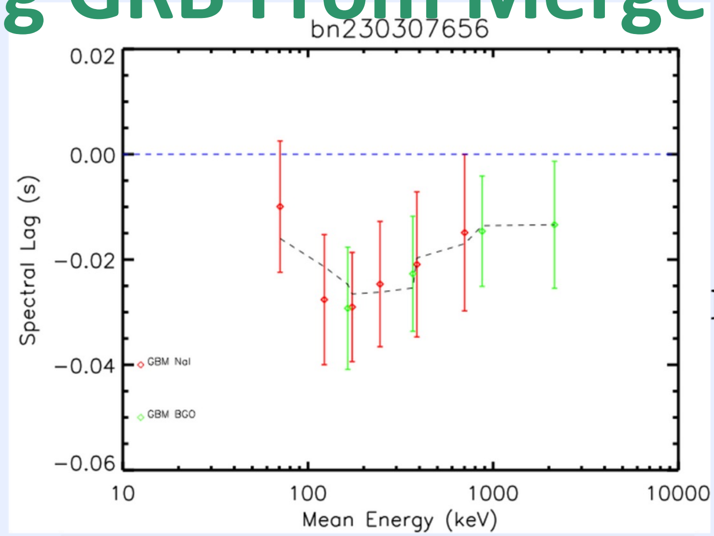
• Late time steep decrease in flux reminiscent of High Latitude Emission (HLE) seen in X-ray observation of GRBs.



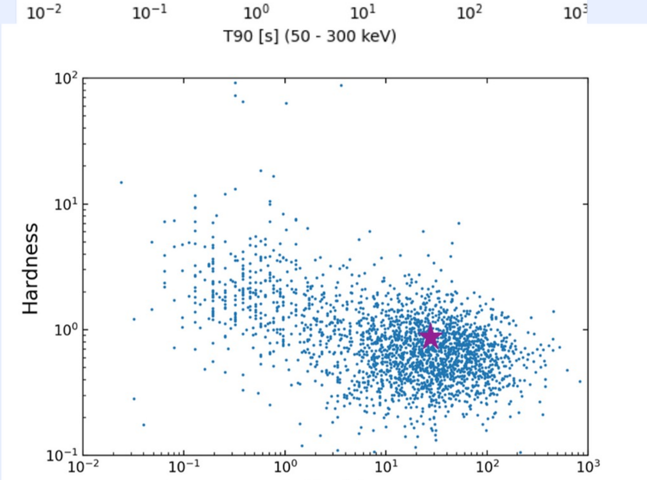
•E_{break} is cooling frequency ν_c
•E_{peak} is typical frequency ν_m
•Post dip phase corresponds to afterglow
•Average Lorentz Factor $\Gamma \approx 1500$ for brightest bins

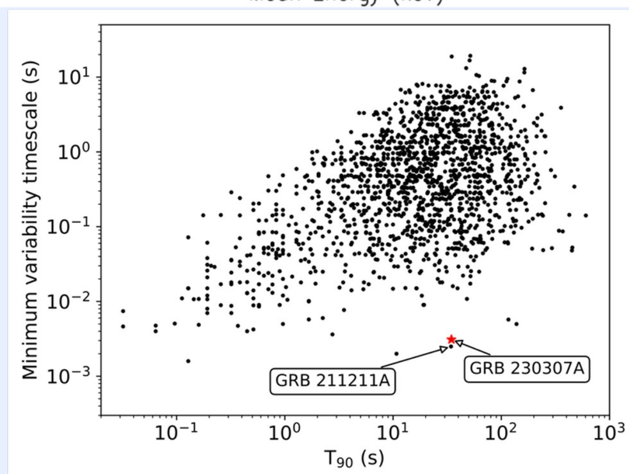
GRB 230307A: Long GRB From Merger





$$\mathrm{lag} = -0.0164 \pm 0.0196\ \mathrm{s}$$

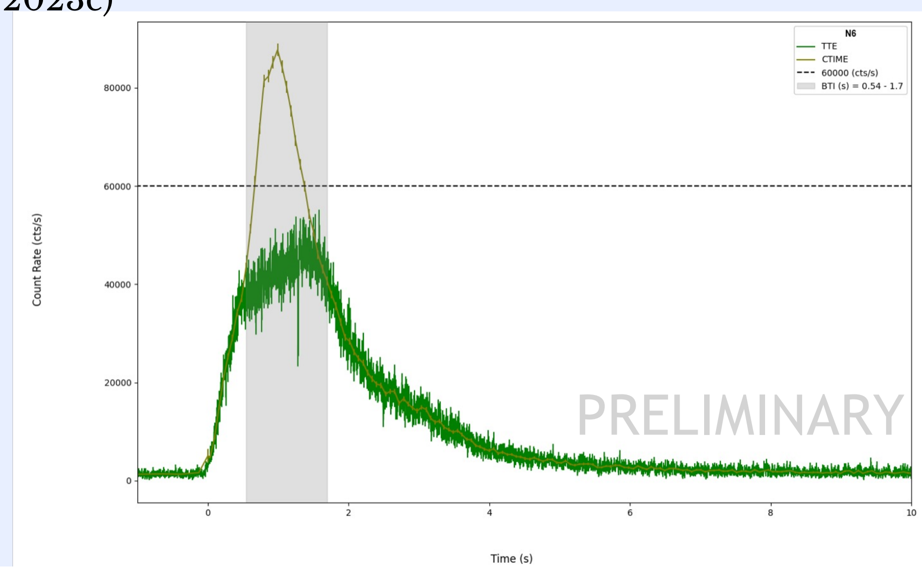


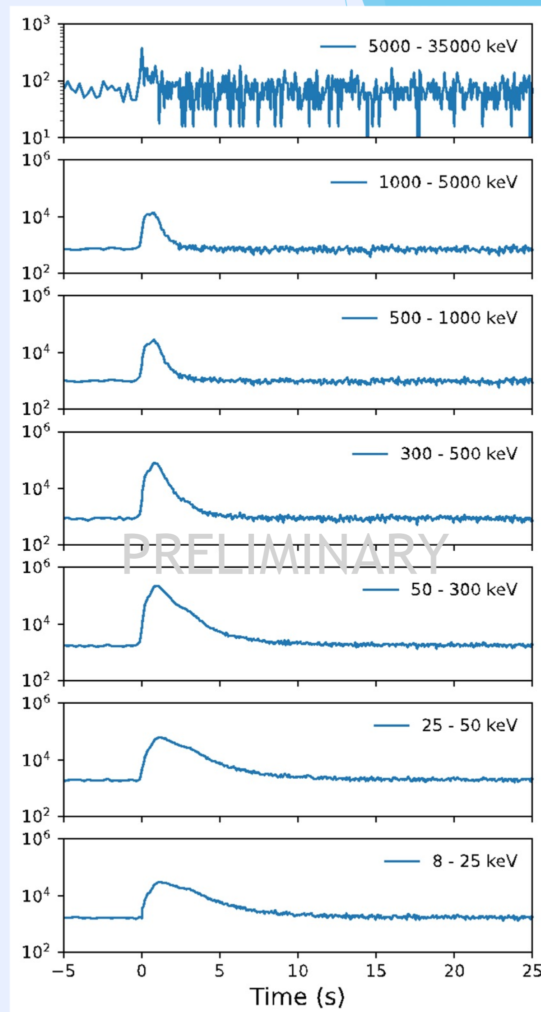


$$\mathrm{MVT} = 3.17 \pm 0.07\mathrm{ms}$$

GRB 230812B

- Triggered 12th of August, 2023 at 18:58:12.05 UTC
- RA,δ=249.1°,47.8°, Elliptical host galaxy
- T90: 3.26s
- Follow-up observations include:
  - Redshift of 0.36 from GTC (de Ugarte Postigo et al. 2023a,b)
  - Type Ic Supernova confirmation (Srinivasaragavan et al. 2024)
  - Late Chandra detection confirms afterglow decay
  - Detection in the mm-band by NOEMA (de Ugarte Postigo et al. 2023c)



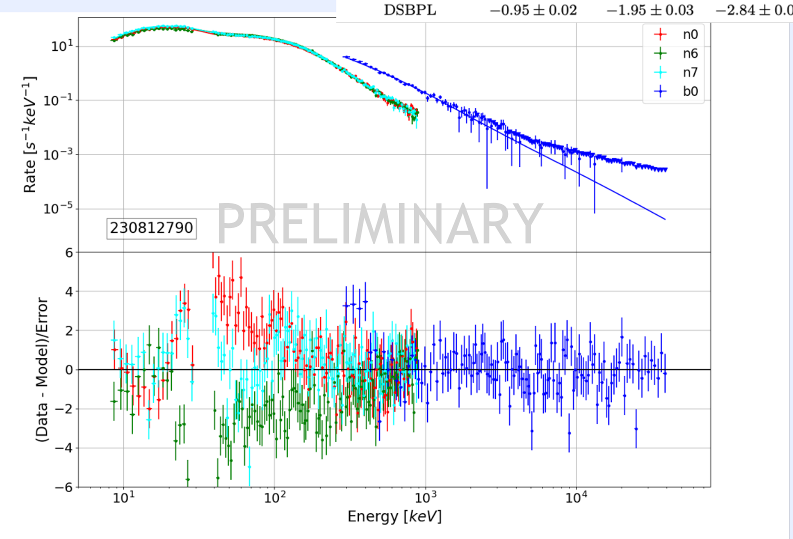


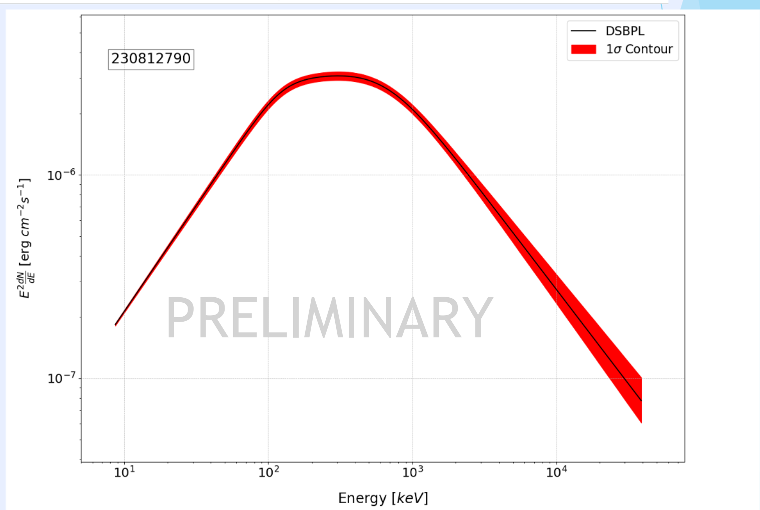
GRB 230812B: Spectral Analysis

Table 1. *Fermi*-GBM Time-Integrated Spectral Fitting

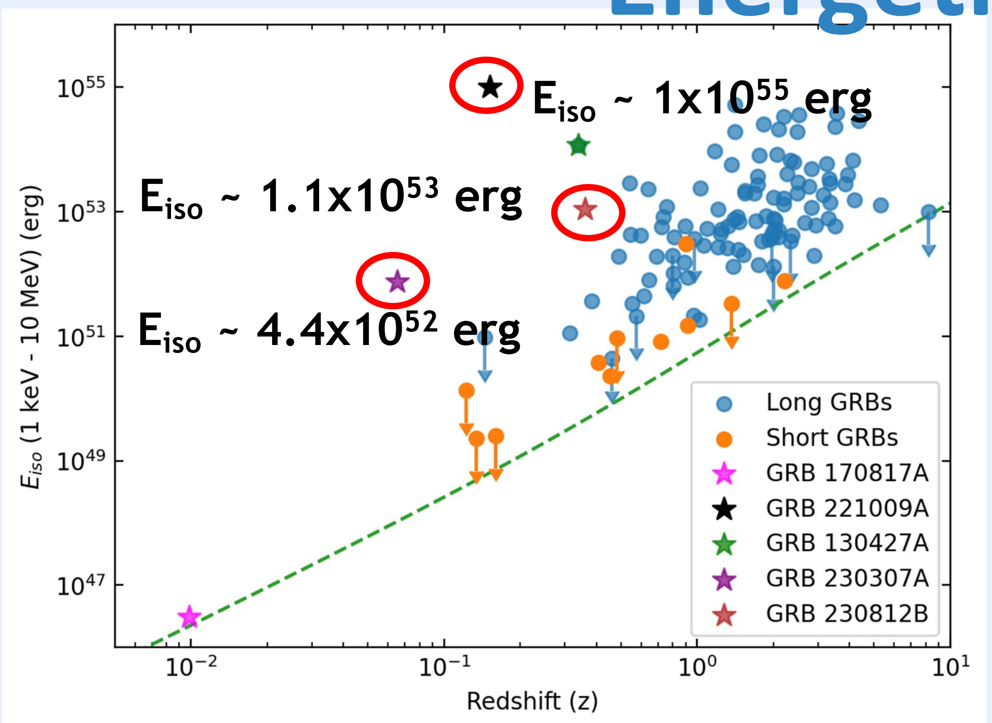
Model	α	α_2	β	E_p (keV)	E_{break} (keV)	kT (keV)	index	PG-Stat/DoF	Energy Flux ($\times 10^{-5}$erg s^{-1} cm^{-2})	Fluence ($\times 10^{-4}$erg cm^{-2})
GBM (CSPEC, 4096 ms)										
PL	$-1.52^{+0.0003}_{-0.0003}$	-	-	-	-	-	-	14117/466	0.692 ± 0.001	1.991 ± 0.004
COMP	$-0.95^{+0.006}_{-0.006}$	-	-	$306.6^{+2.8}_{-2.8}$	-	-	-	1102/465	0.685 ± 0.002	2.029 ± 0.007
Band	$-0.84^{+0.007}_{-0.007}$	-	$-2.32^{+0.03}_{-0.03}$	$234.5^{+2.0}_{-2.0}$	-	-	-	1135/464	0.675 ± 0.002	2.009 ± 0.008
SBPL	$-0.94^{+0.009}_{-0.009}$	-	$-2.45^{+0.02}_{-0.02}$	-	$162.7^{+2.7}_{-2.7}$	-	-	732/463	0.668 ± 0.003	1.995 ± 0.008
DSBPL	-0.99 ± 0.002	-1.92 ± 0.001	-3.17 ± 0.08	299.6 ± 0.8	119.24 ± 3.3	-	-	814/462	0.685 ± 0.003	2.040 ± 0.010
Band+BB	-1.04 ± 0.01	-	-2.73 ± 0.2	417.4 ± 6.6	-	34.5 ± 0.3	-	1059/462	0.671 ± 0.001	1.996 ± 0.004
GBM (CSPEC) + LLE										
PL	-1.793 ± 0.001							114058/498		
COMP	-0.87 ± 0.01			317.4 ± 2.5				2940/497		
Band	-0.80 ± 0.01		-2.66 ± 0.01	275.5 ± 2.7				1801/496		
SBPL	-0.96 ± 0.01		-2.63 ± 0.01		196.6 ± 2.3			1763/496		
DSBPL	-0.95 ± 0.02	-1.95 ± 0.03	-2.84 ± 0.02	215.6 ± 39.3	125.4 ± 2.4			1482/494		

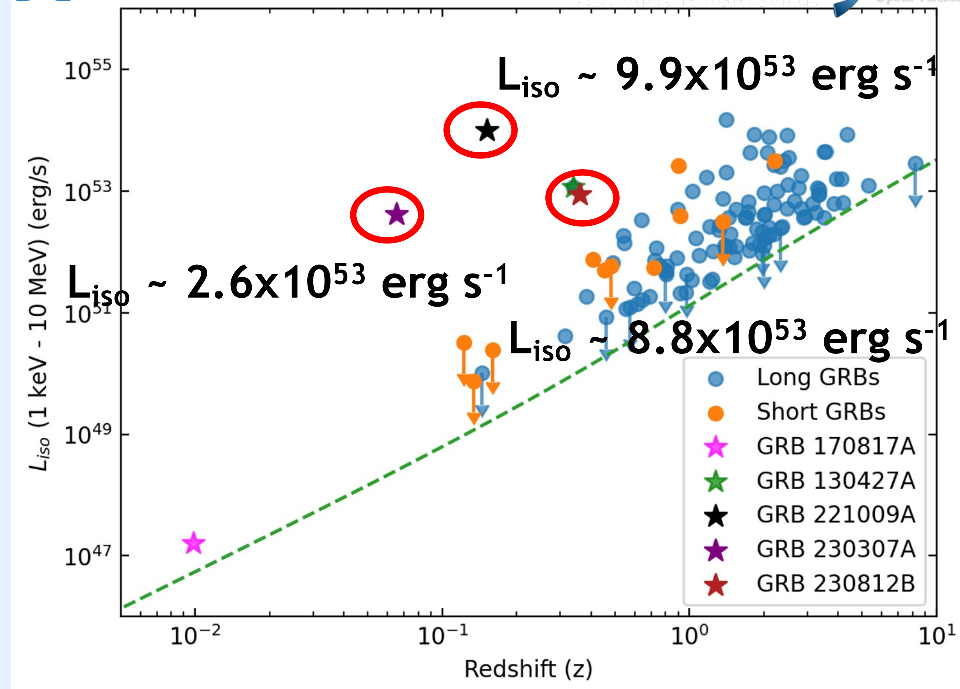
PRELIMINARY





Energetics





1st	GRB 221009A	$\text{Fluence} = 0.20 \text{ erg cm}^{-2}$
2nd	GRB 230307A	$\text{Fluence} = 5.70 \times 10^{-3} \text{erg cm}^{-2}$
Outside of top 20	GRB 230812B	$\text{Fluence} = 2.69 \times 10^{-4} \text{erg cm}^{-2}$

Summary

- We are in an unprecedented time of extraordinarily bright GRBs
- PPU correction process tested and validated for cases of extreme and mild pulse pile-up.
- GRB 221009A: The BOAT
  - Brightest GRB in 3 out of 4 common metrics (E_{iso}, Fluence, Peak Flux) and 3rd in fourth (L_{iso}), unrivaled probe into the continuously active central engine, tracks the evolution of the bulk Lorentz factor through to the afterglow phase
  - Lesage et al. 2023 ***ApJL* 952, L42**
- GRB 230307A: Long burst with associated kilonova
  - Fine time DSBPL spectral fitting consistent with synchrotron radiation, afterglow flux seen after the dip, MVT and spectral lag consistent with merger origin bursts
  - Dalessi et al. (to be submitted)
- GRB 230812B: Bright, relatively nearby burst
  - Bright single pulse GRB, preliminary spectral fits of GBM and LAT data using DSBPL, associated type Ic supernova
  - Roberts and Scotton et al. (to be submitted)

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Fermi Gamma-ray Space Telescope

Back Up Slides

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Fermi Gamma-ray Space Telescope

The "Dip" Across Missions

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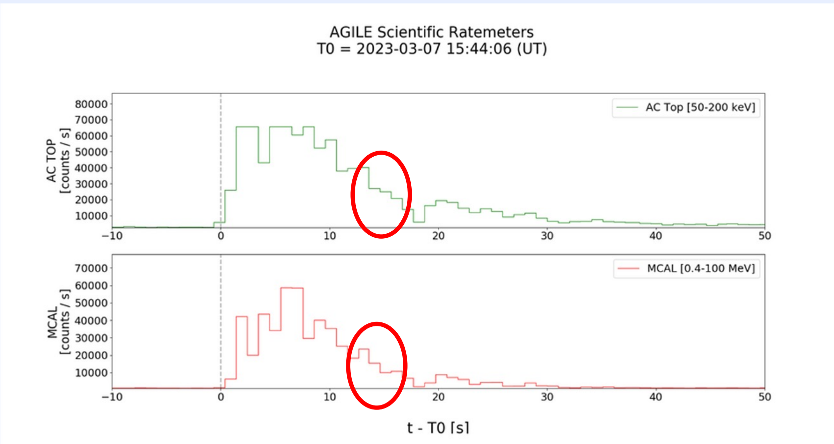
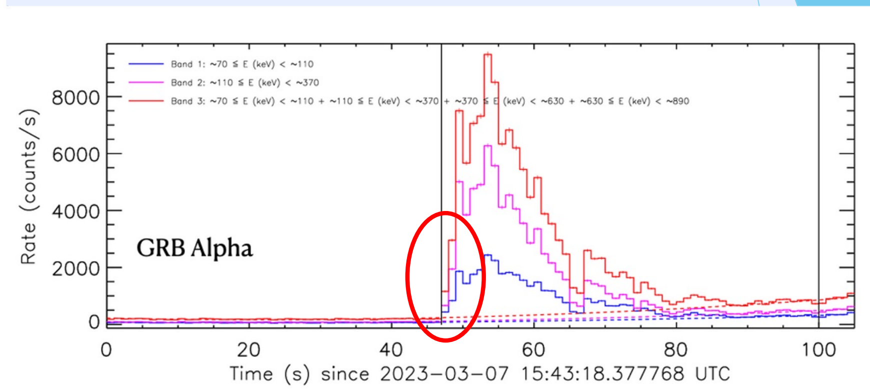
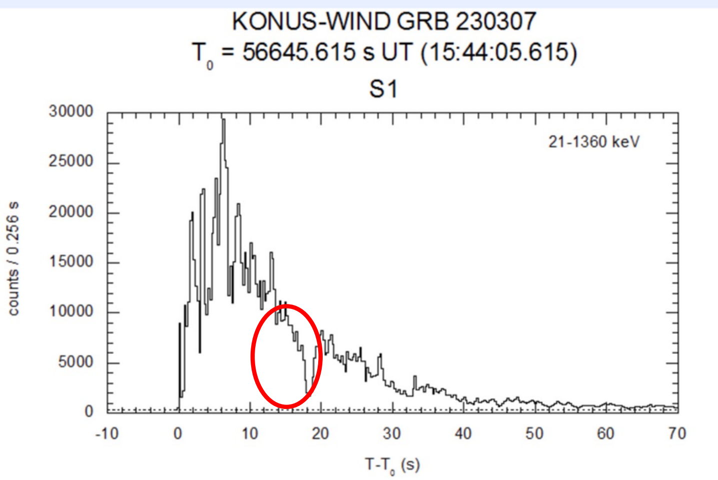
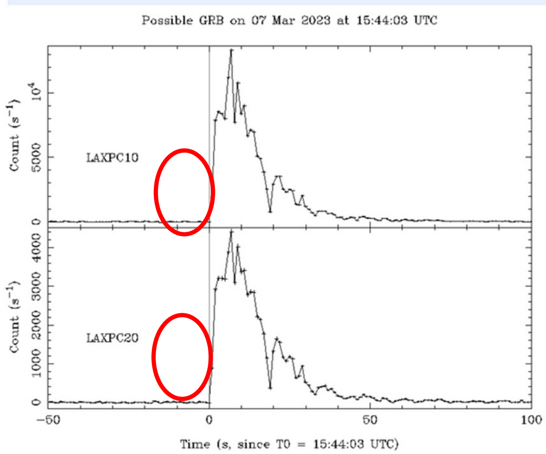
Fermi Gamma-ray Space Telescope

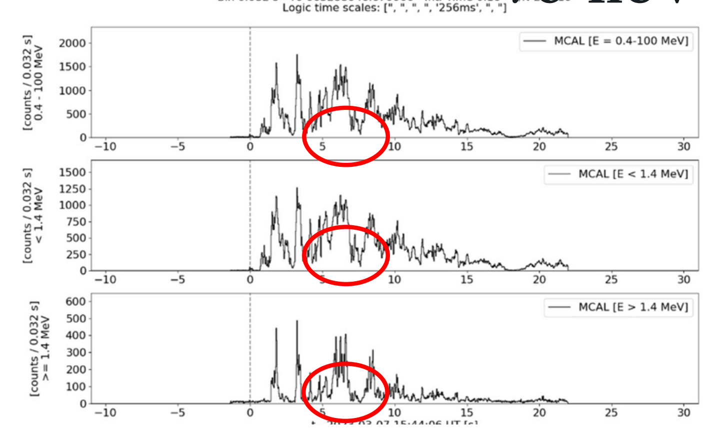




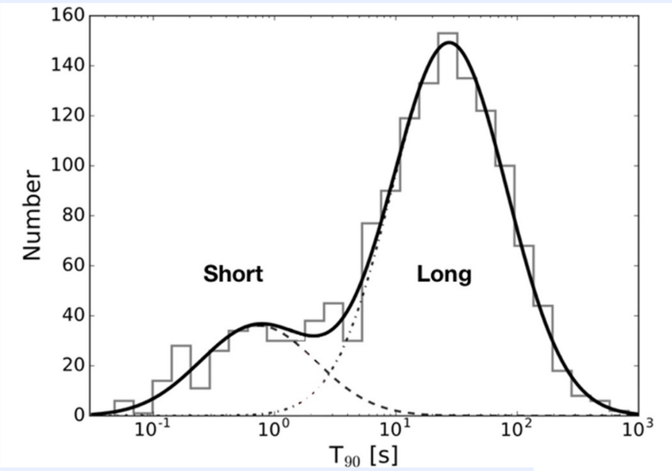
- Also NuSTAR which has sensitivity from 3 -79 keV

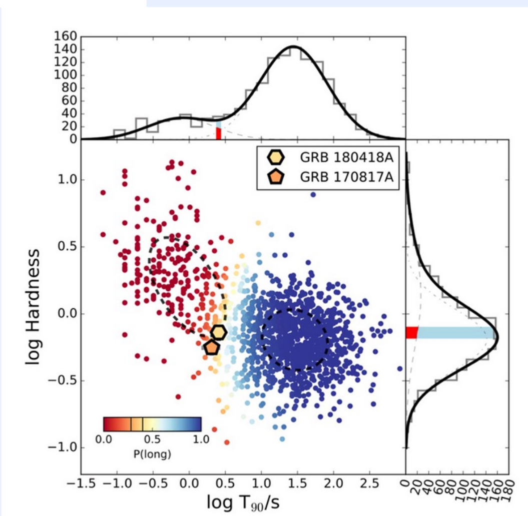


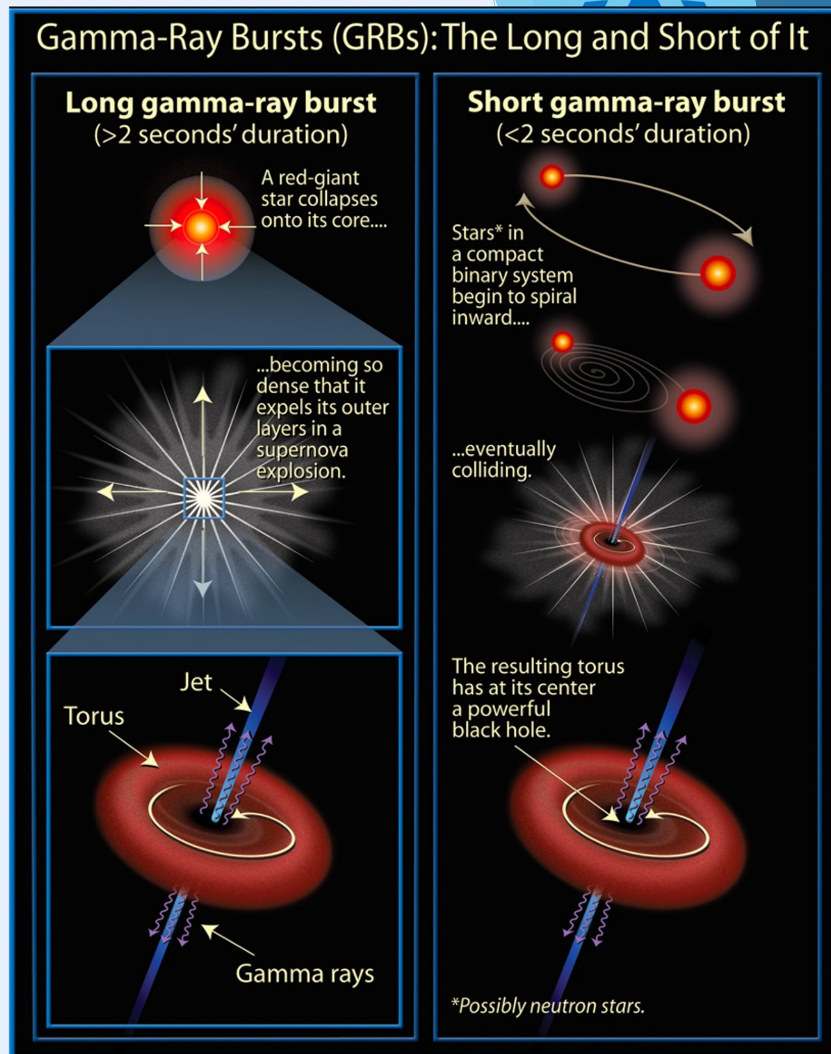




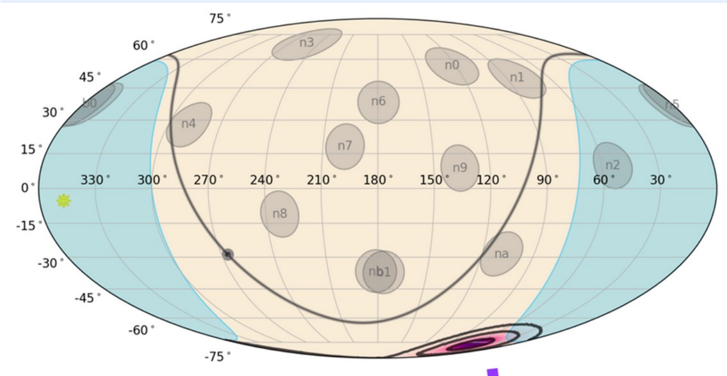
SHORT VS LONG

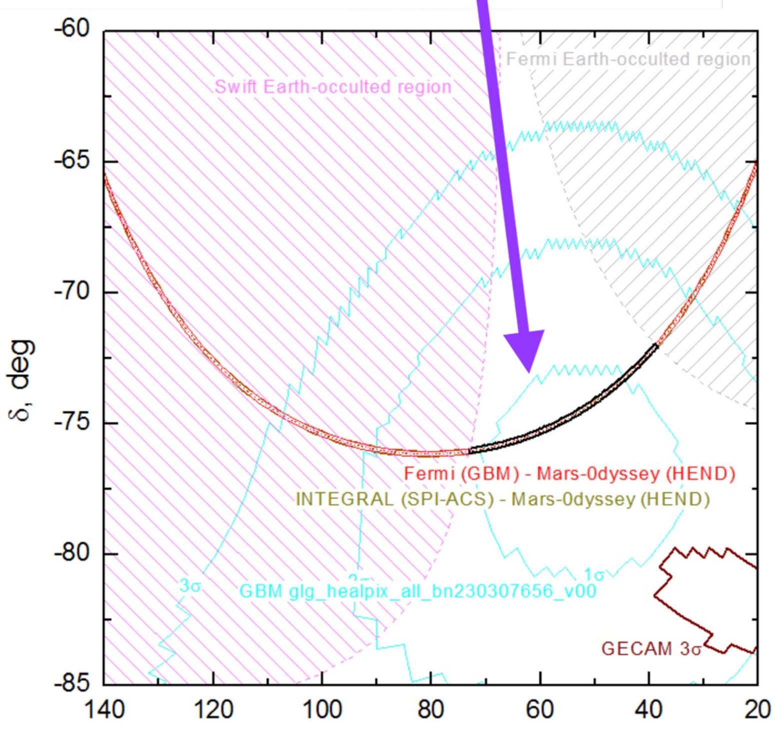


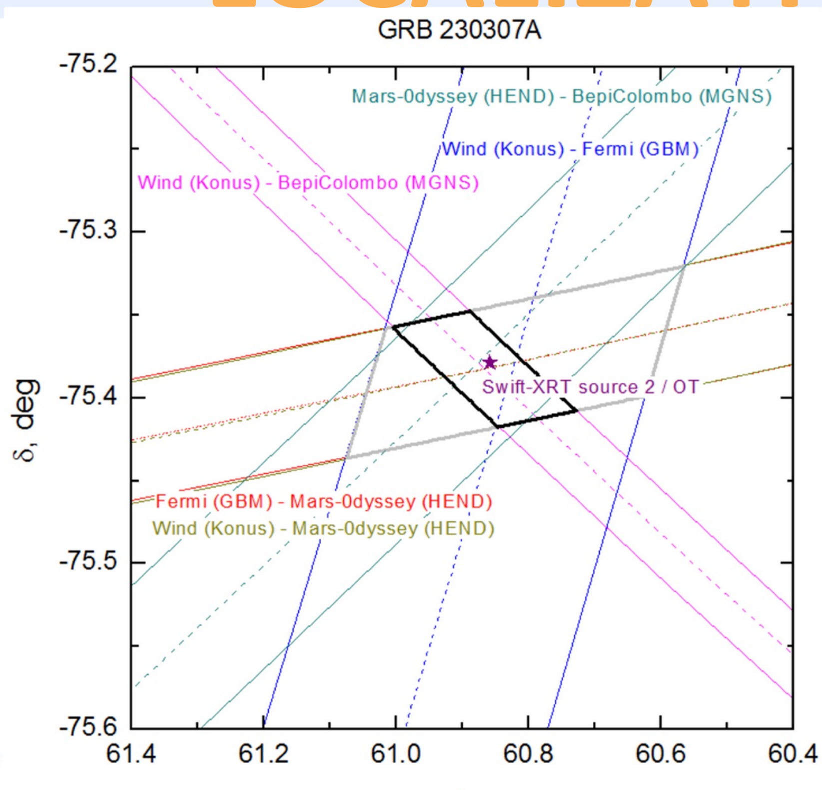




IPN LOCALIZATION





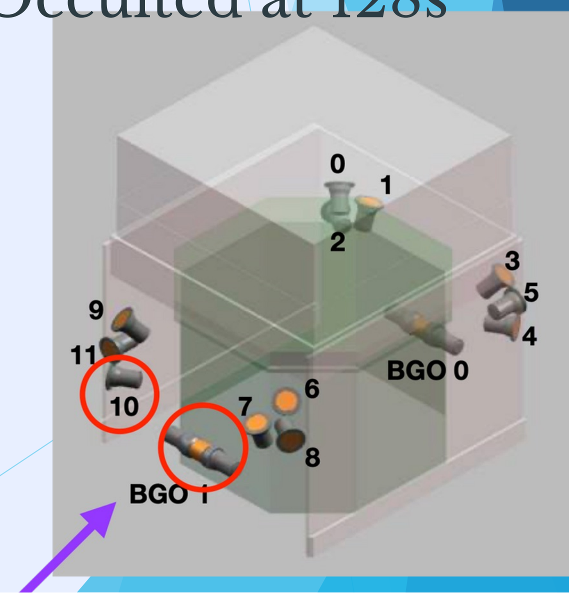


GBM Localizat
- RA: 54.06
- Dec:—76.61

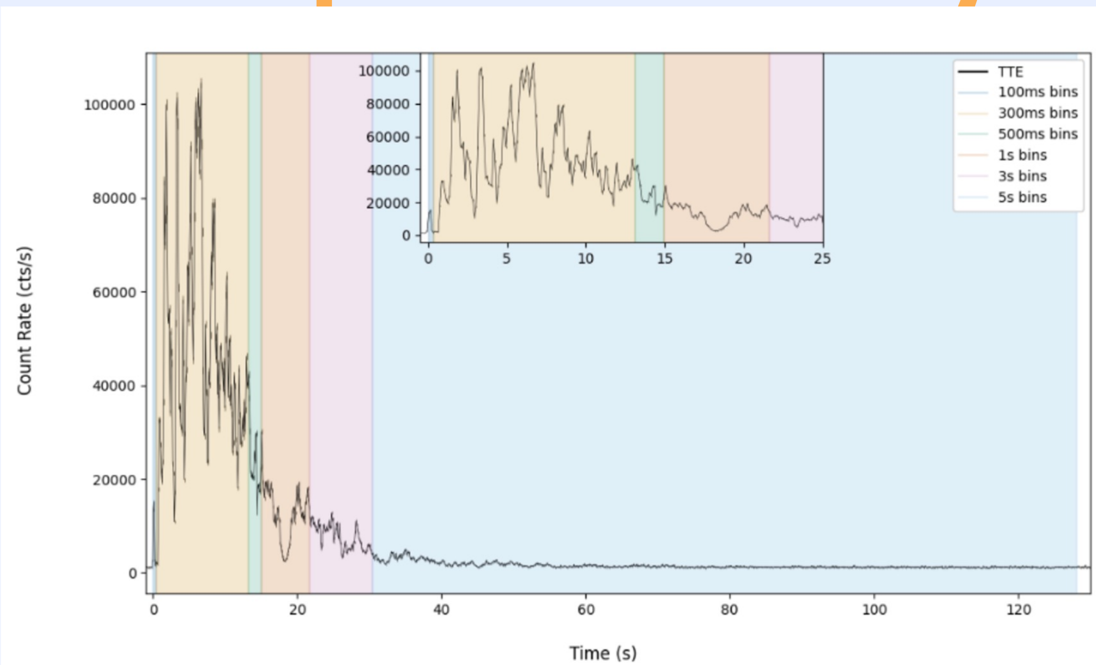
IPN Localizatio
RA: 60.867
Dec:-75.382

FERMI GBM Analysis

- Triggered at 15:44:07 UTC on March 7, 2023
- T90: 34.56s
- MVT: 3.1ms
- Occulted at 128s



Spectral Analysis



	Minimum bin duration	Time range (t_0 +s)
Triggering Pulse	100ms	0.0-0.355
Main Emission	300ms	0.355-1.5
	BTI	1.5-11.0
	300ms	11.0-13.712
	500ms	13.712-17.264
	1 s	17.264- 21.652
Secondary Emission	3s	21.652- 36.965
Tail	5s	36.965-128.0

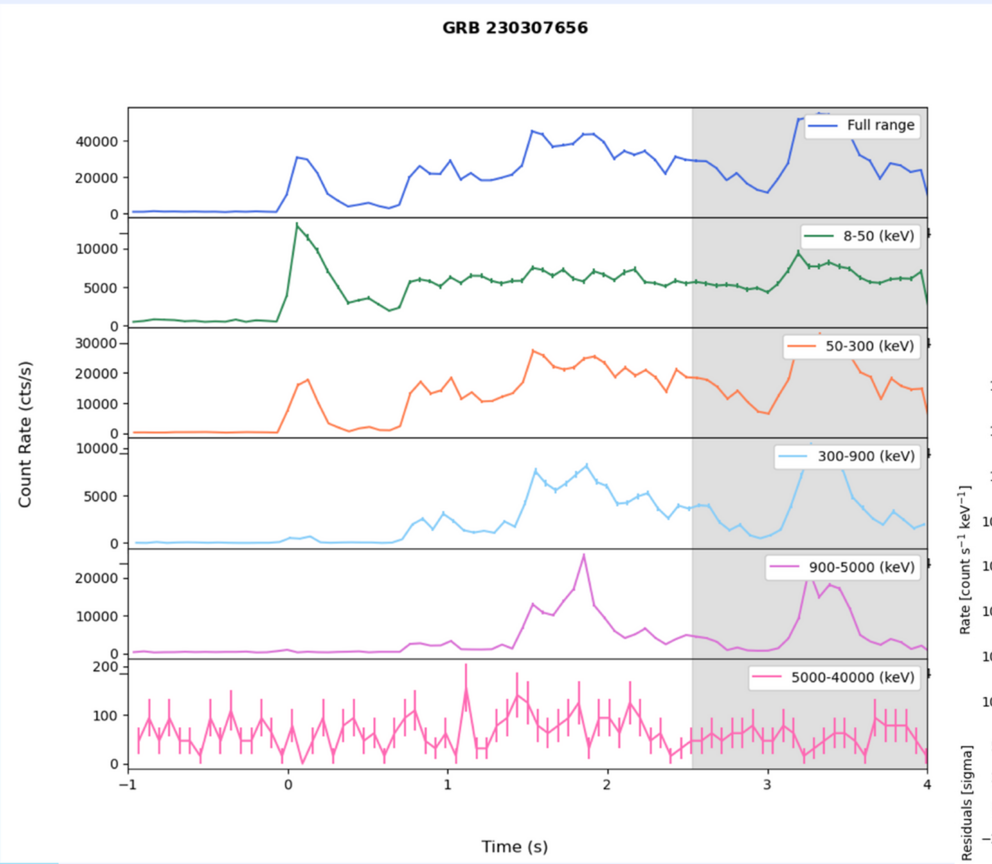
$$N_{\mathrm{E}}^{\mathrm{2SBPL}} = A\, E_{\mathrm{break}}^{\alpha_1} \left[\left[\left(\frac{E}{E_{\mathrm{break}}} \right)^{-\alpha_1 n_1} + \left(\frac{E}{E_{\mathrm{break}}} \right)^{-\alpha_2 n_1} \right]^{\frac{n_2}{n_1}} + \left(\frac{E}{E_{\mathrm{j}}} \right)^{-\beta n_2} \cdot \left[\left(\frac{E_{\mathrm{j}}}{E_{\mathrm{break}}} \right)^{-\alpha_1 n_1} + \left(\frac{E_{\mathrm{j}}}{E_{\mathrm{break}}} \right)^{-\alpha_2 n_1} \right]^{\frac{n_2}{n_1}} \right]^{-\frac{1}{n_2}}$$

where

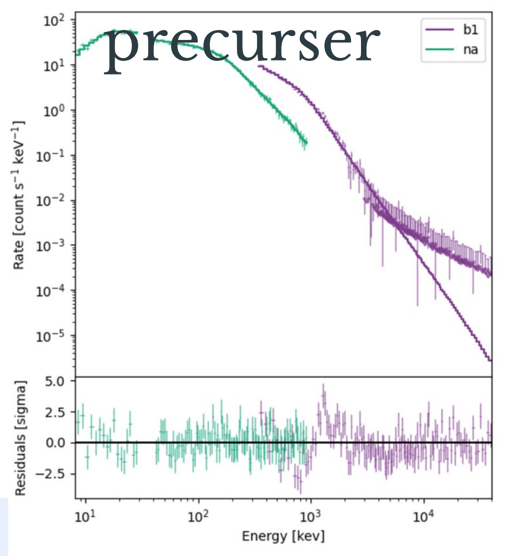
$$E_{\mathrm{j}} = E_{\mathrm{peak}} \cdot \left(-\frac{\alpha_2 + 2}{\beta + 2} \right)^{\frac{1}{(\beta-\alpha_2)\, n_2}}$$

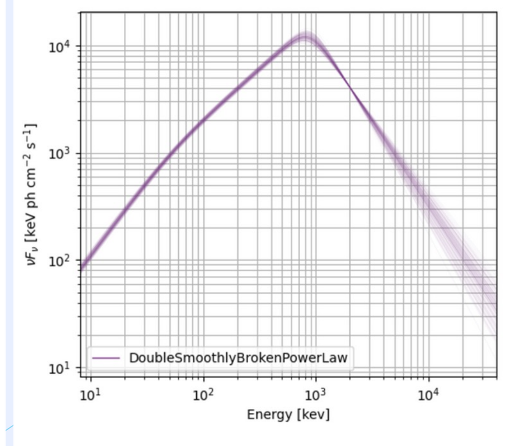
Ravassio et al. 2018

Triggering Pulse



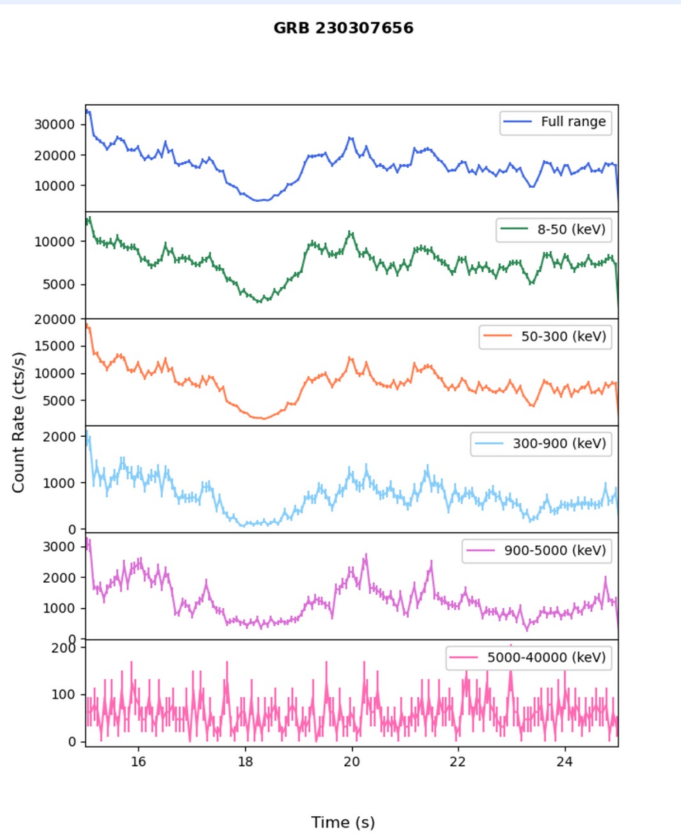
- -0.072 — 0.387s
- Prominent in the softer energy channels
- Dichara et al. 2023 found evidence of a non thermal precurser

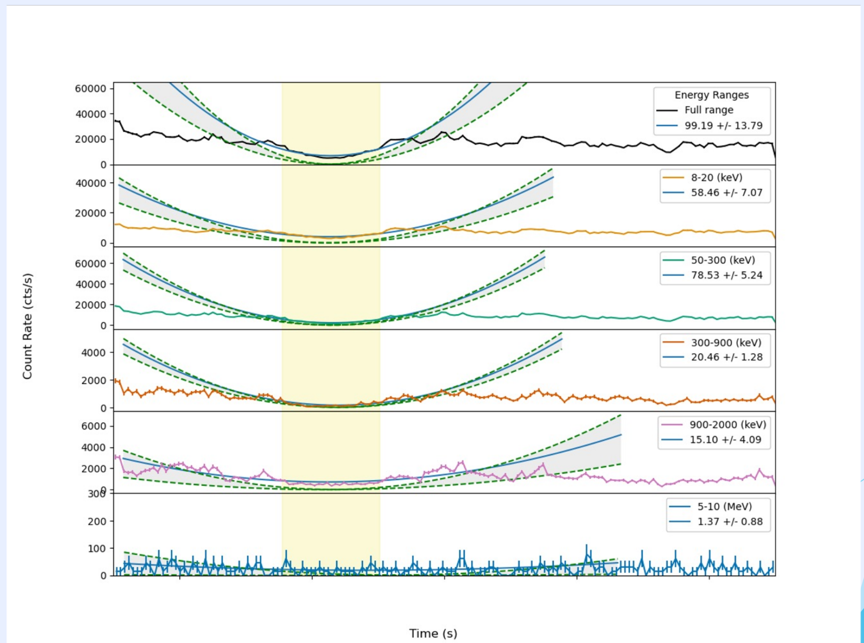




The “Dip”

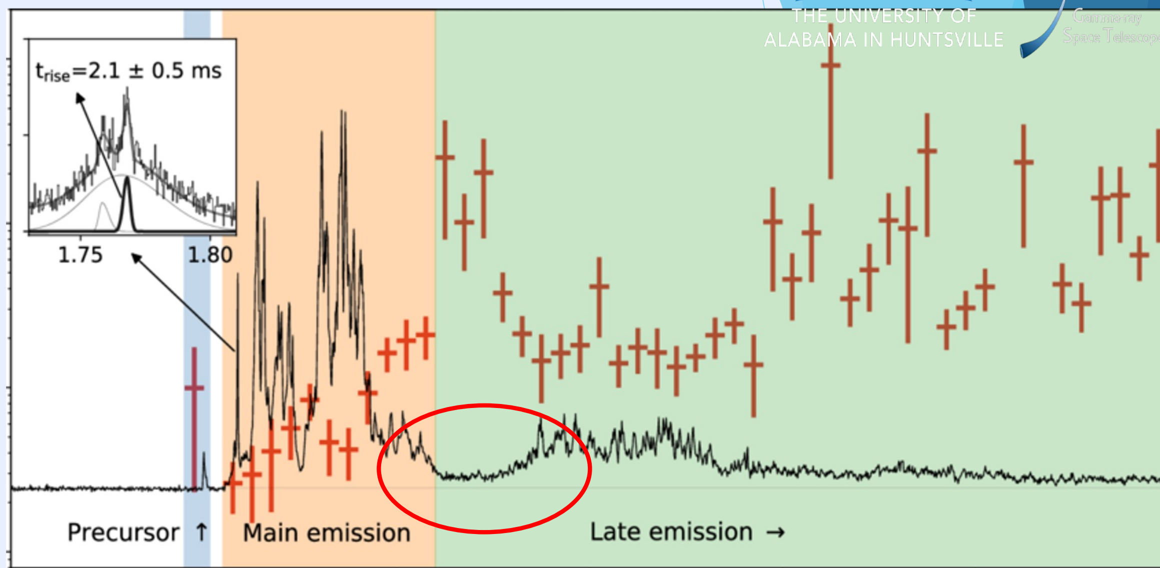
- 17.55 — 19.02s
- Independent of energy
- No temporal dependence

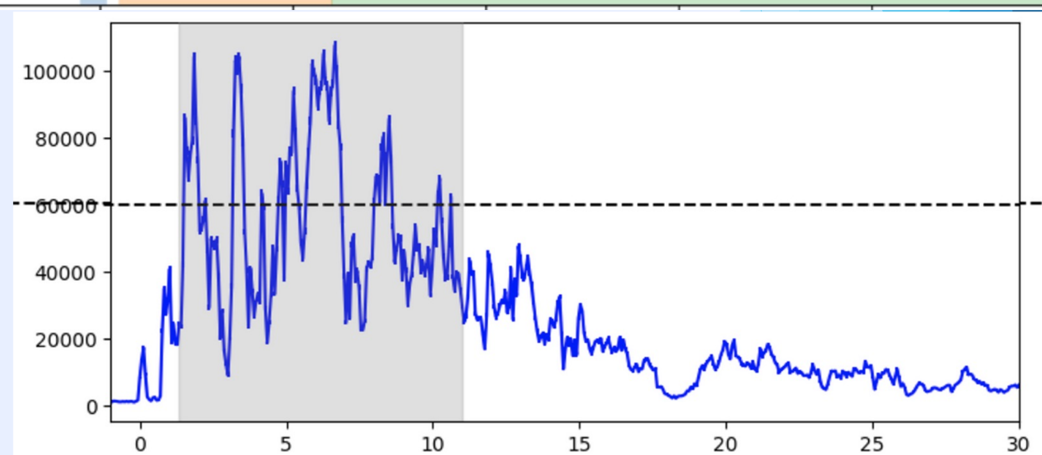




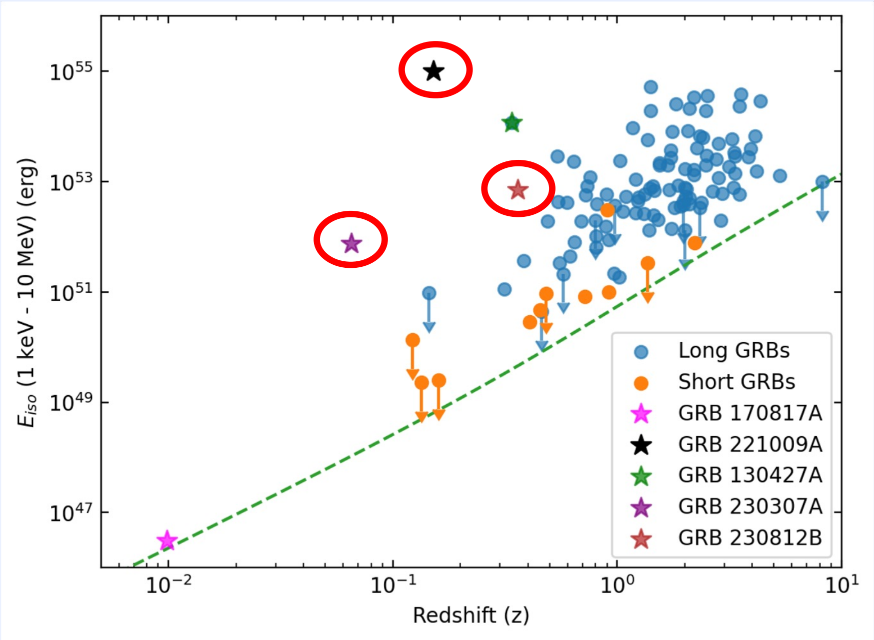
GRB 211211A

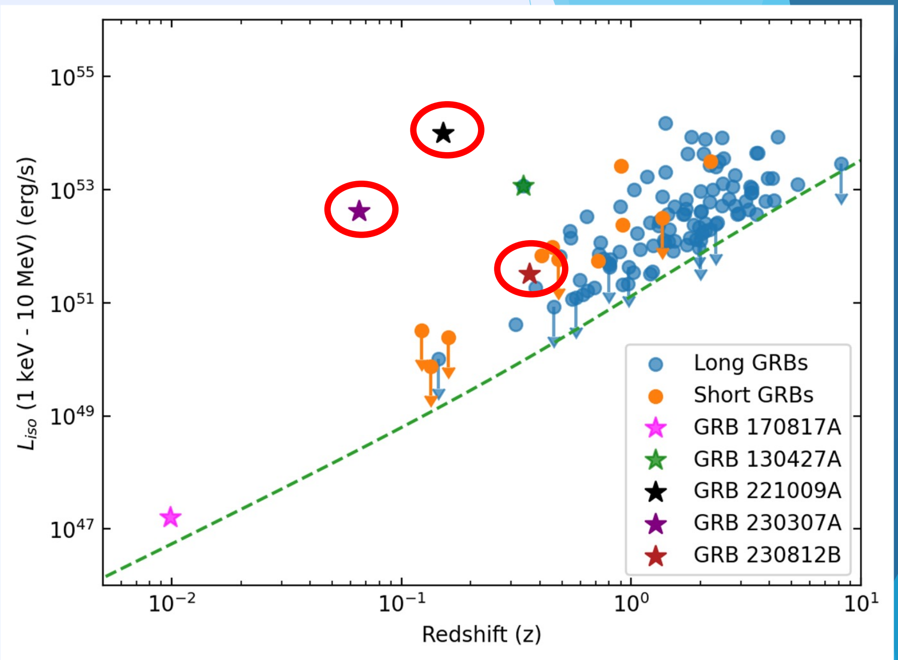
- Long GRB with associated kilonova
- Similar T90 value
- Suggested that some long GRBs be treated as possible counterparts for GW





Energetics





GRB 221009A $z = 0.151$ $E_{iso} = 1.0 \times 10^{55}\text{erg}$ $L_{iso} = 9.9{\times}10^{53}\text{erg s}^{-1}$

GRB 230307A $z = 0.065$ $E_{iso} = 4.4 \times 10^{52}\text{erg}$ $L_{iso} = 2.6{\times}10^{51}\text{erg s}^{-1}$

GRB 230812B $z = 0.360$ $E_{iso} = 7.0 \times 10^{52}\text{erg}$ $L_{iso} = 3.2{\times}10^{51}\text{erg s}^{-1}$