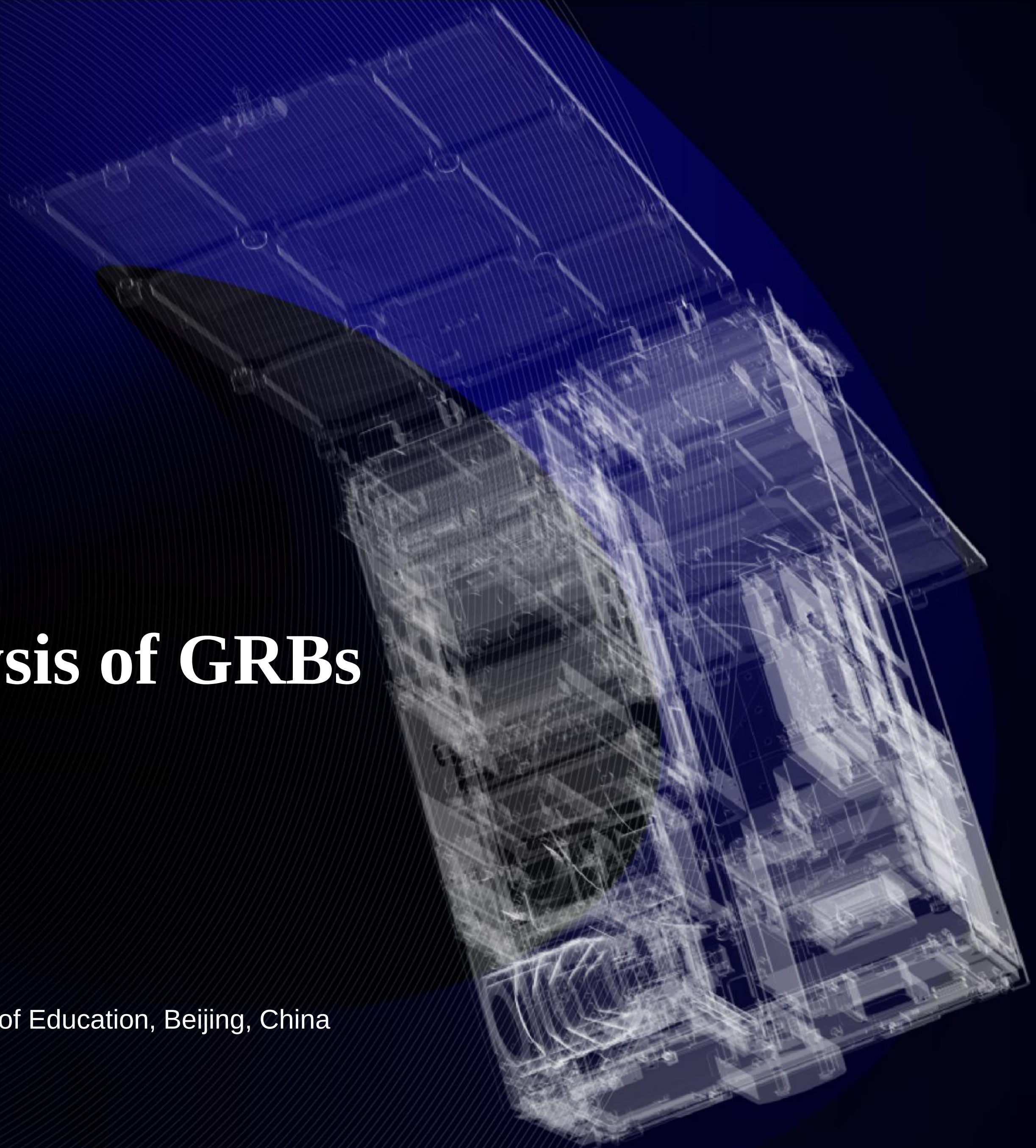
THU Gamma Ray Integrated Detectors

Cross-Calibration of GRID via Correlative Spectral Analysis of GRBs



Zirui Yang[1,2], Xiaofan Pan[1,2] and Ming Zeng[1,2]

On behalf of the GRID collaboration

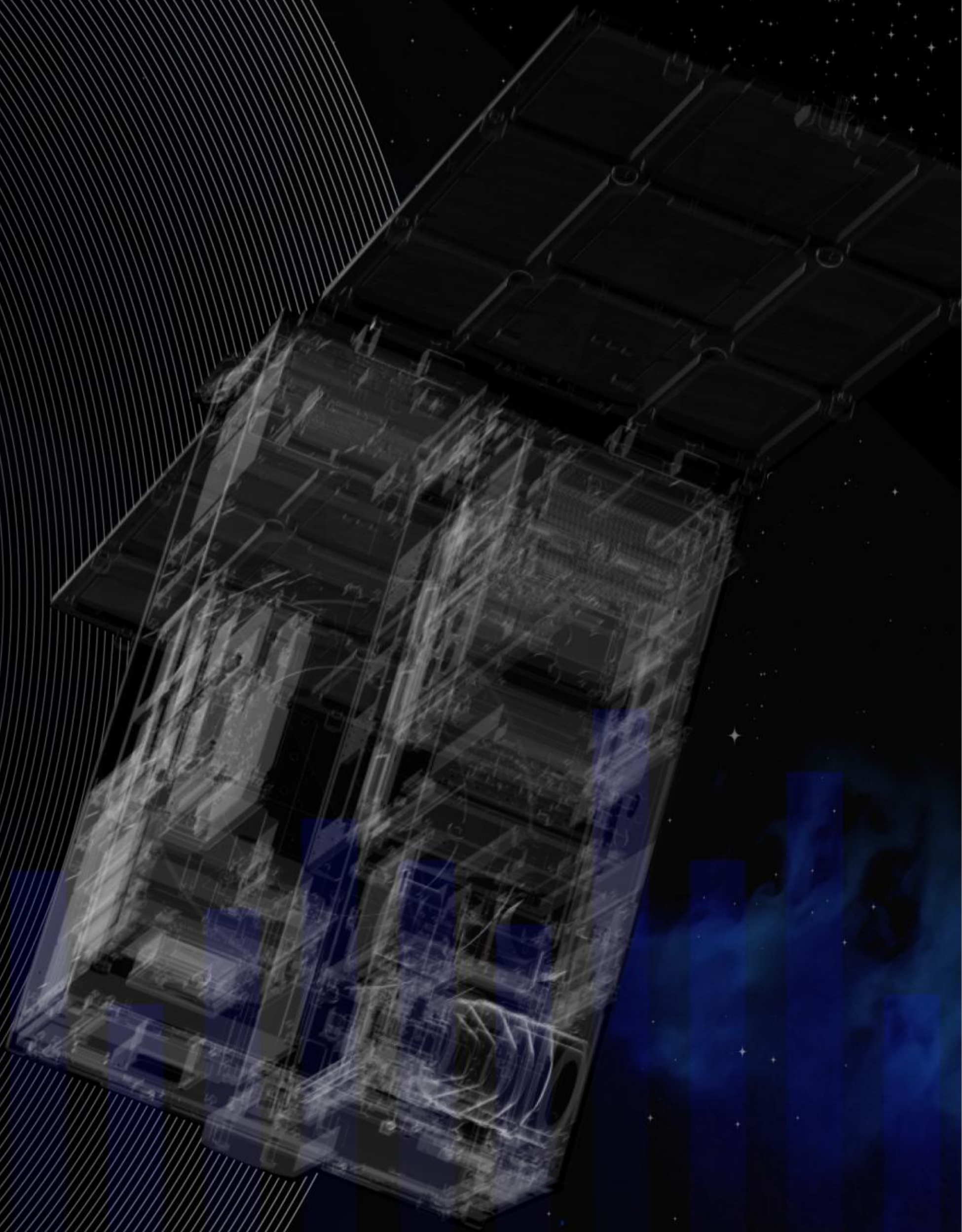
[1]Department of Engineering Physics, Tsinghua University, Beijing, China

[2]Key Laboratory of Particle and Radiation Imaging (Tsinghua University), Ministry of Education, Beijing, China

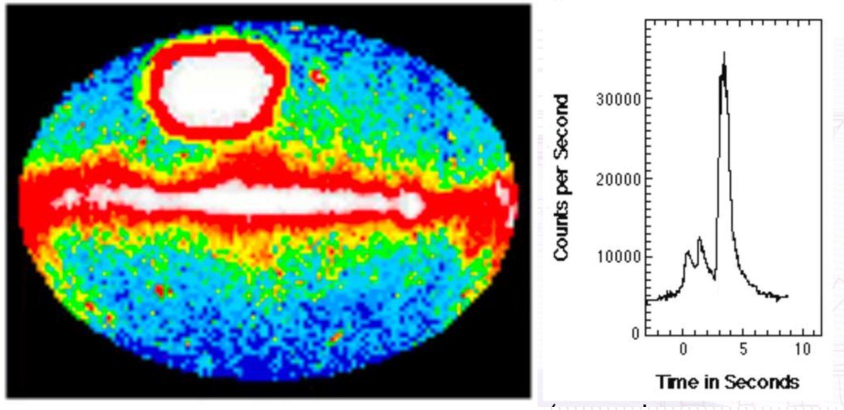
2025.05.12 @ 17th IACHEC meeting

yzr23@mails.tsinghua.edu.cn pxf21@mails.tsinghua.edu.cn zengming@tsinghua.edu.cn

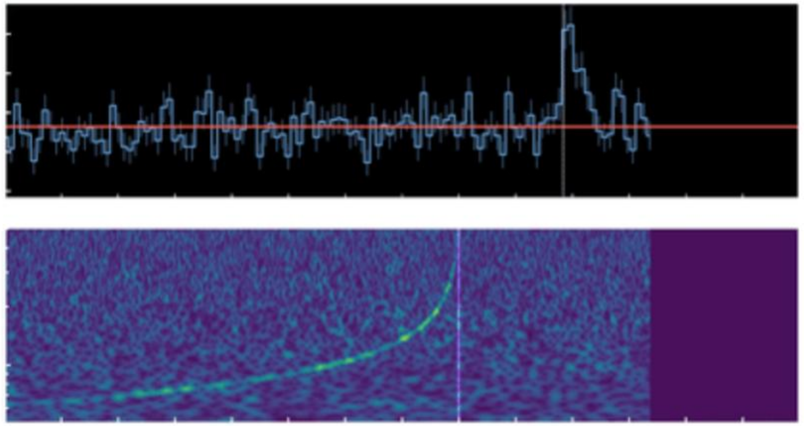
Introduction



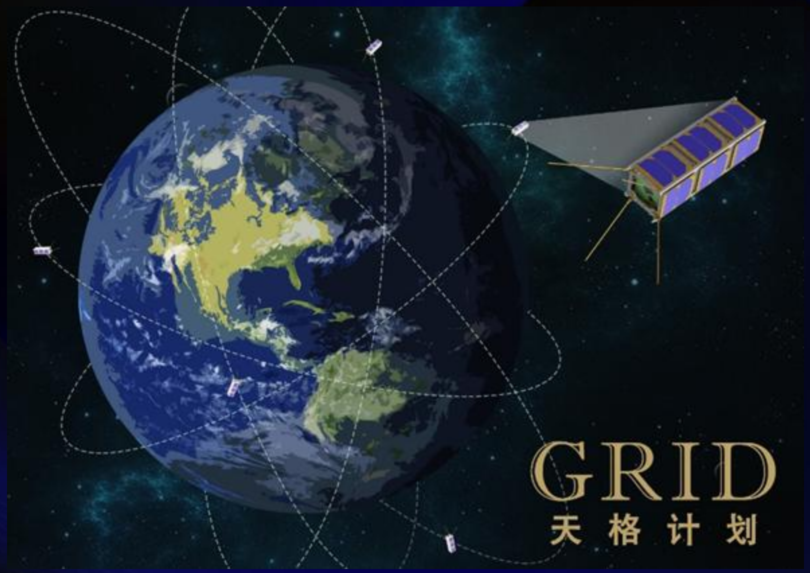
Gamma Ray Integrated Detectors (GRID)



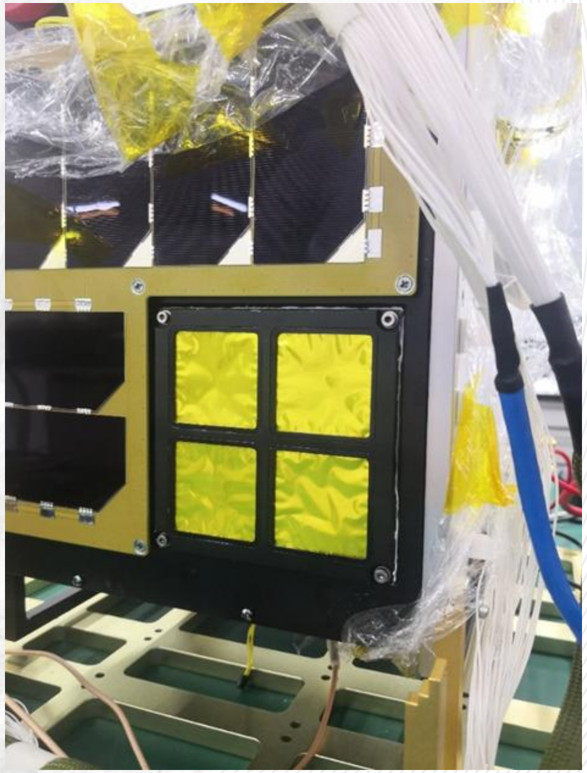
NASA: Gamma-Ray Burst(GRB) and its lightcurve



Joint, multi-messenger detection of GW170817 and GRB 170817A[1]



- **Scientific Objective**: To search for GRBs associated with gravitational waves or Fast Radio Bursts (FRBs).
- **Technical Approach**: Using compact space gamma-ray detectors onboard nanosatellites and multi-satellite networking for constellation [2].



GRID-02 installed on the NanoSat

[1] B. P. Abbott et al. 2017 [2] J. Wen et al. 2019

The need for Cross-calibration of GRID

- **GRID Constellation's Milestone[3]**
  - 12 detectors deployed across nanosatellites
  - Enables continuous, all-sky GRB monitoring

GRID-ID	Launch Date	Ownership	Spacetrack catalog No.
GRID-01	2018/10/29	THU	43663
GRID-02	2020/11/06	THU	46838
GRID-03B	2022/03/11	THU	51830
GRID-04	2022/03/11	THU	51830
GRID-05B	2023/01/15	THU	55254
GRID-06B	2023/01/15	NJU&SCU	55252
GRID-07	2023/01/15	BNU	55261
GRID-08B	2023/01/15	NJU&SCU	55261
GRID-10B	2024/06/22	THU&SCU	60088
GRID-11B	2024/11/11	THU&SCU	61897
GRID-12B	2024/11/27	THU	62112
GRID-13B	2024/11/27	THU	62111

THU: Tsinghua University
NJU: Nanjing University
SCU: Sichuan University
BNU: Beijing Normal University

[3] Z. Yang and L. Li et al. 2024

The need for Cross-calibration of GRID

- **GRID Constellation's Milestone[3]**
  - 12 detectors deployed across nanosatellites
  - Enables continuous, all-sky GRB monitoring
- **Why Cross-Calibration Matters**
  - Ensures detector uniformity for reliable multi-detector data fusion
  - Validates overall constellation performance
- **Essential for GRB Localization**
  - Methods like flux modulation and arrival-time triangulation rely on calibration accuracy
  - Misalignment in detector responses will reduce localization precision

GRID-ID	Launch Date	Ownership	Spacetrack catalog No.
GRID-01	2018/10/29	THU	43663
GRID-02	2020/11/06	THU	46838
GRID-03B	2022/03/11	THU	51830
GRID-04	2022/03/11	THU	51830
GRID-05B	2023/01/15	THU	55254
GRID-06B	2023/01/15	NJU&SCU	55252
GRID-07	2023/01/15	BNU	55261
GRID-08B	2023/01/15	NJU&SCU	55261
GRID-10B	2024/06/22	THU&SCU	60088
GRID-11B	2024/11/11	THU&SCU	61897
GRID-12B	2024/11/27	THU	62112
GRID-13B	2024/11/27	THU	62111

THU: Tsinghua University
NJU: Nanjing University
SCU: Sichuan University
BNU: Beijing Normal University

[3] Z. Yang and L. Li et al. 2024

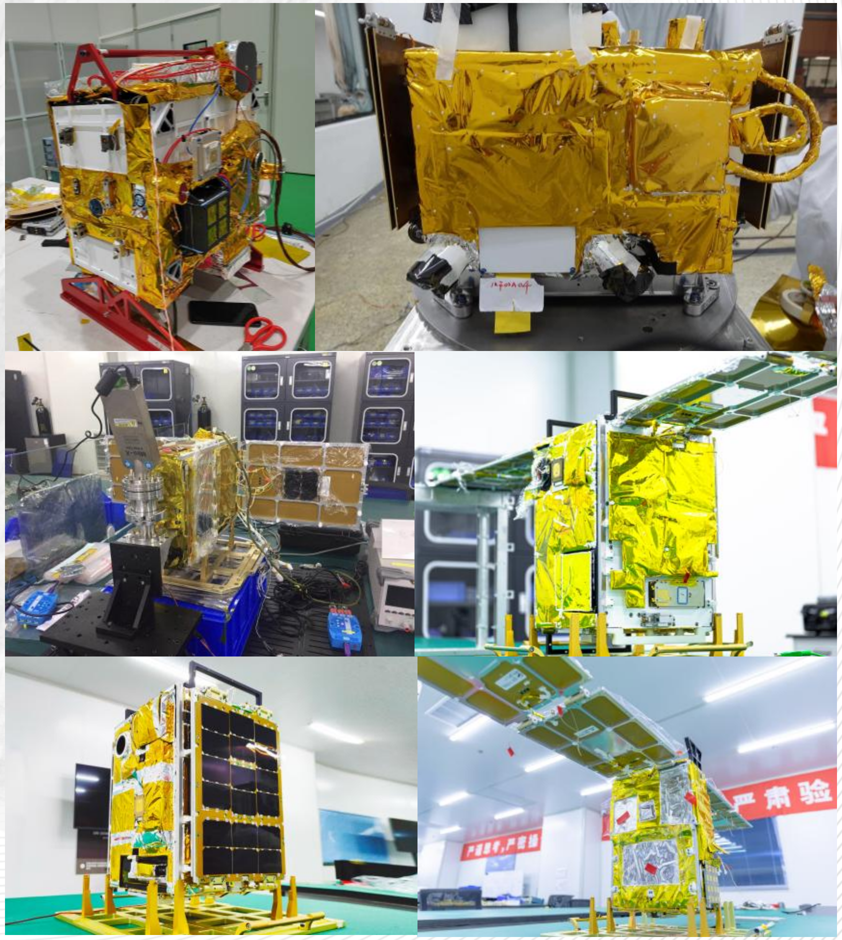
Unique Challenges in Constellation Missions

- **Phased Development and Deployment over 6 Years (2018–2024)**

  introduce variations in:

  - Design and build processes
  - Personnel and calibration teams
  - Material and electronics differences

- **Platform Differences**
  - Satellite structures can affect detector response matrix (DRM)



Parts of GRID payloads onboard nanosatellites

[4] X. Zheng et al. 2022

Unique Challenges in Constellation Missions

- **Phased Development and Deployment over 6 Years (2018–2024)**

  introduce variations in:

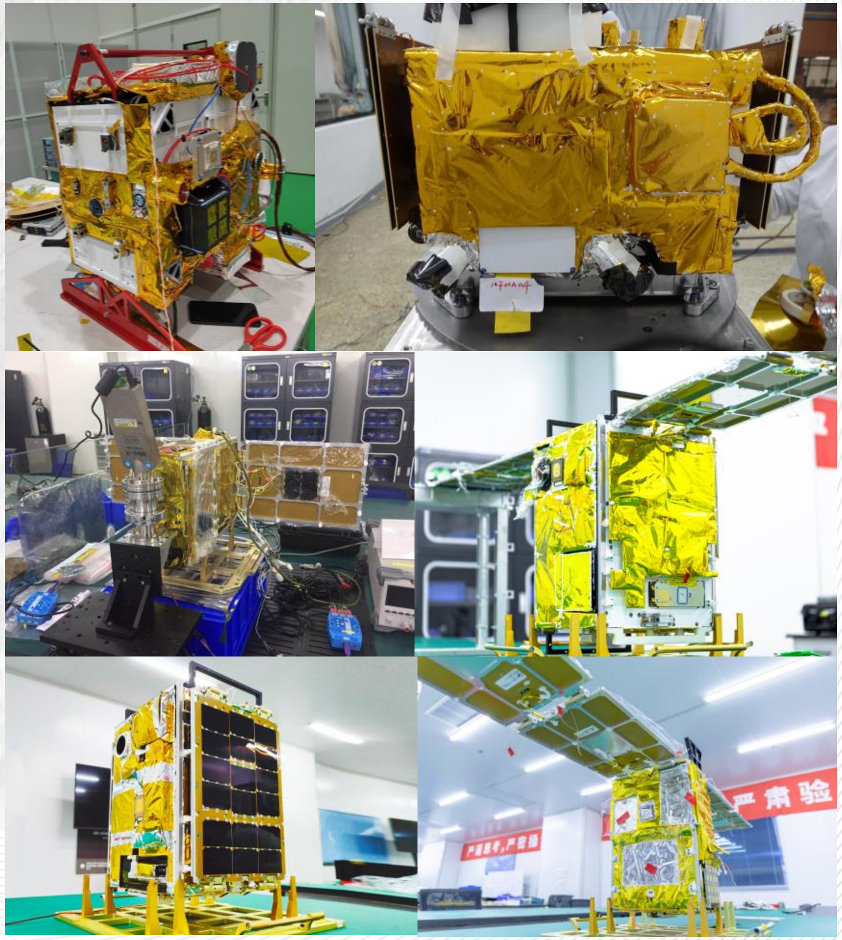
  - Design and build processes
  - Personnel and calibration teams
  - Material and electronics differences

- **Platform Differences**

  - Satellite structures can affect detector response matrix (DRM)

- **Effects of Radiation Damage on SiPMs[4]**

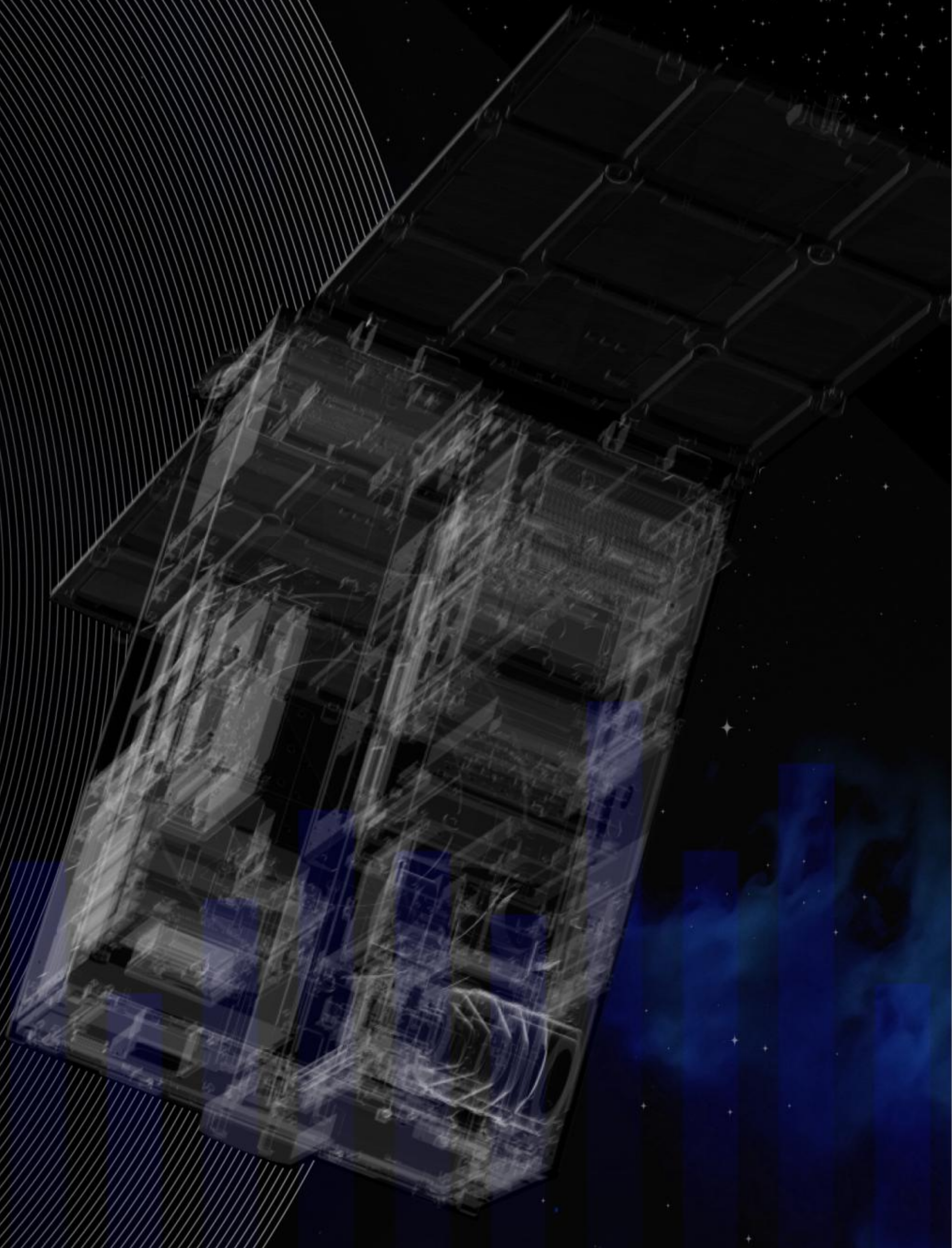
  - Varying damage across payloads
  - Increase in dark count rate and impact on energy threshold
  - Effect on the DRM needs to be tracked and corrected



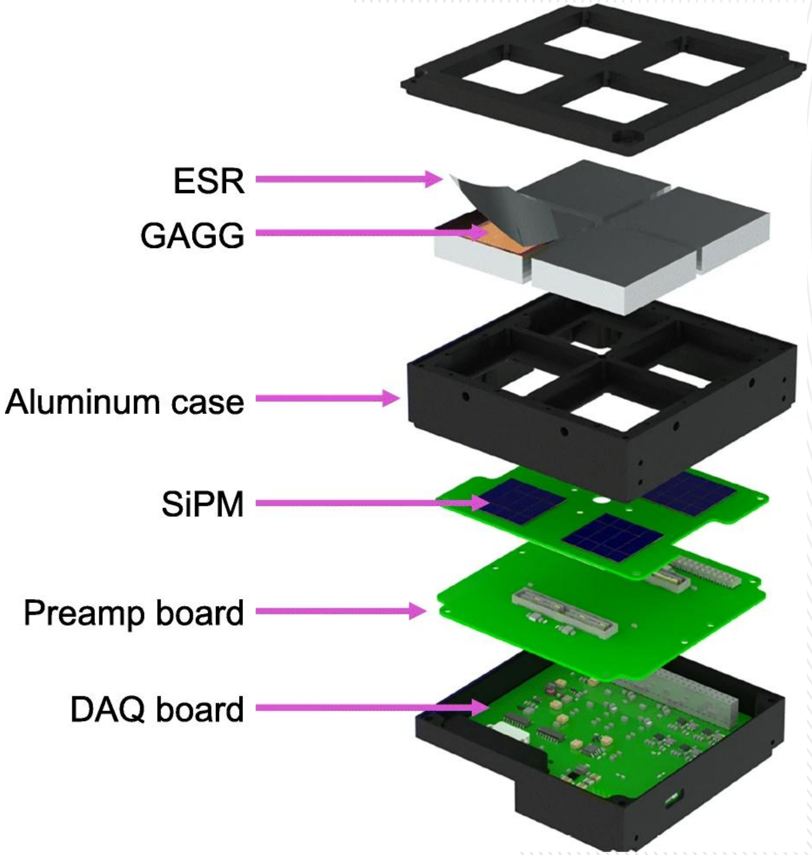
Parts of GRID payloads onboard nanosatellites

[4] X. Zheng et al. 2022

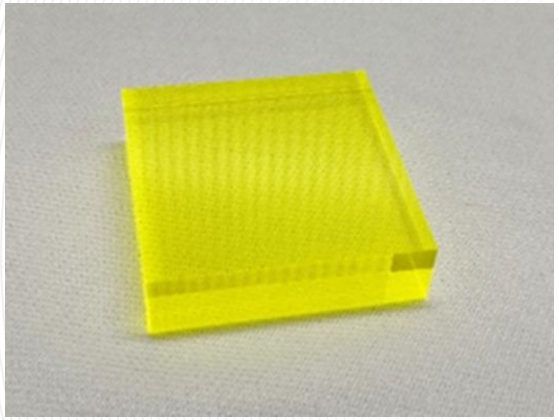
Instrument and DRMs



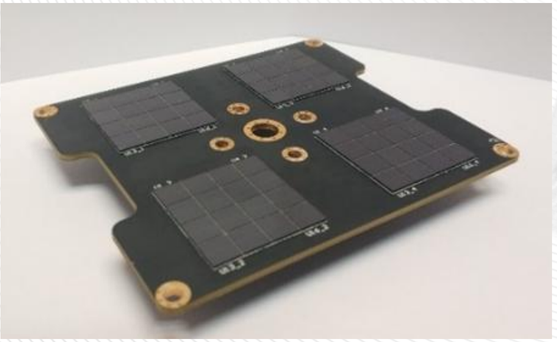
Compact Detector Design



GRID type-A detector design[3]



GAGG:Ce* scintillator
*Ce-doped $Gd_3(Al, Ga)_5O_{12}$



GRID SiPM* array board
*Silicon photomultiplier
SensL MicroFJ-60035

General Specifications of GRID detectors

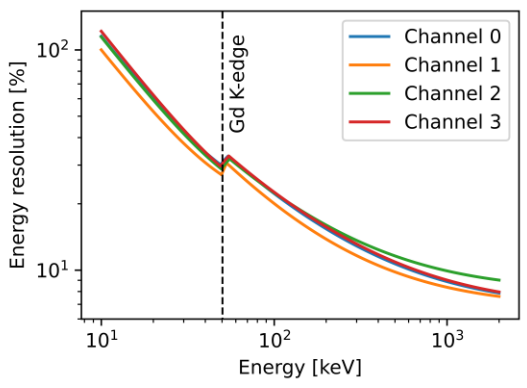
items	value
Size	< 0.5U ($9.4 \times 9.4 \times 5$ cm^3)
Weight	~ 780 g
GAGG unit	$3.8 \times 3.8 \times 1$ cm^3
Detection area	~ 58 cm^2
Field of view	2π
Energy range	10 keV to 2 MeV

DRM Construction Workflow

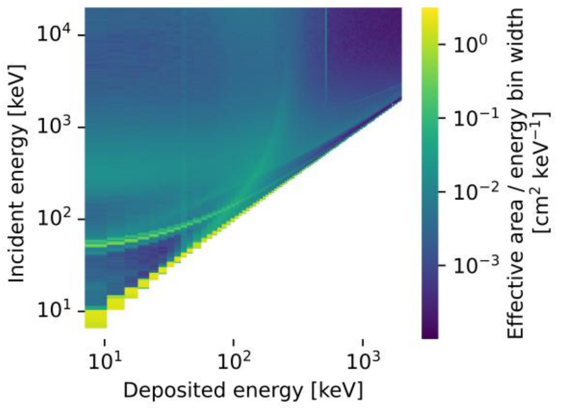
The DRM links **true photon energy** to **detected signal**.

It's a matrix: each element shows the chance that a photon of energy *i* is recorded in channel *j*.

Ground calibration[6] using radioactive sources and X-ray beam tests to measure **gain, energy resolution** and angular response



Geant4 simulations[7] to model **energy deposition** at various incident directions & energies

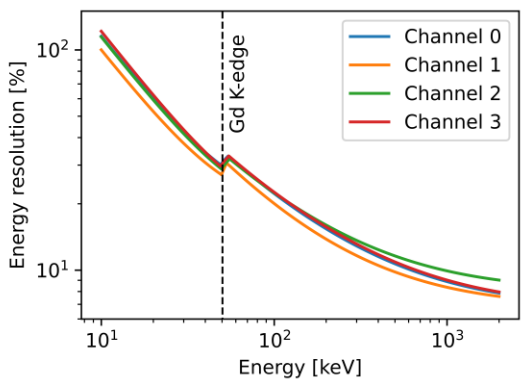


DRM Construction Workflow

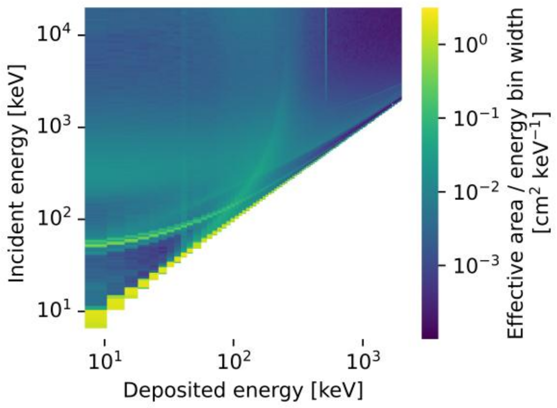
The DRM links **true photon energy** to **detected signal**.

It's a matrix: each element shows the chance that a photon of energy *i* is recorded in channel *j*.

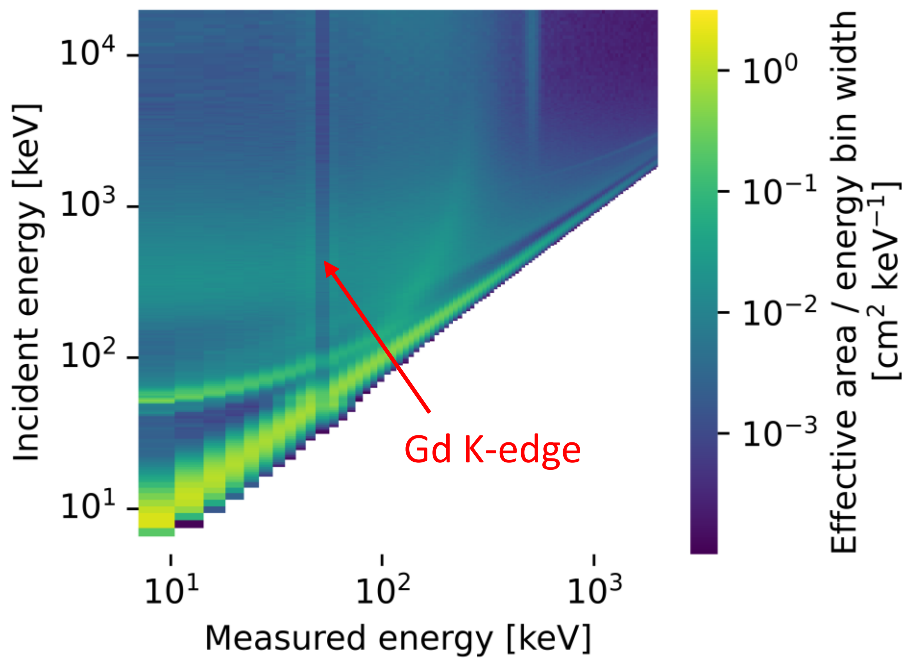
Ground calibration[6] using radioactive sources and X-ray beam tests to measure **gain, energy resolution** and angular response



Geant4 simulations[7] to model **energy deposition** at various incident directions & energies



Simulation refinement using measured energy resolution



Evolution of DRMs due to SiPM Radiation Damage

SiPM radiation damage

↓

Increased dark count noise

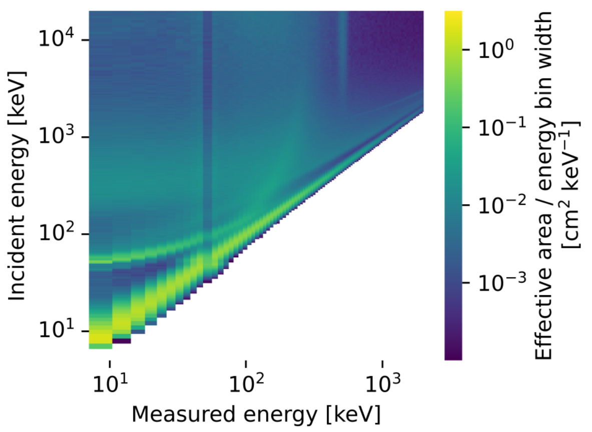
↓

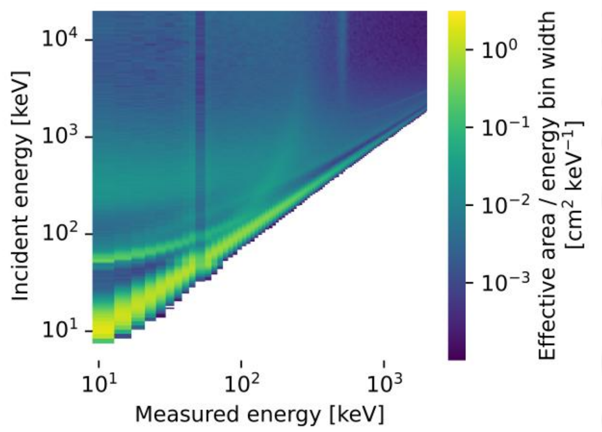
Deteriorated energy resolution

↓

Evolution of DRM

Before radiation damage:

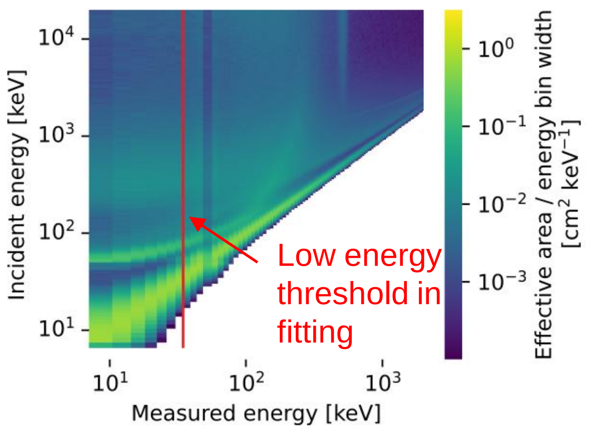


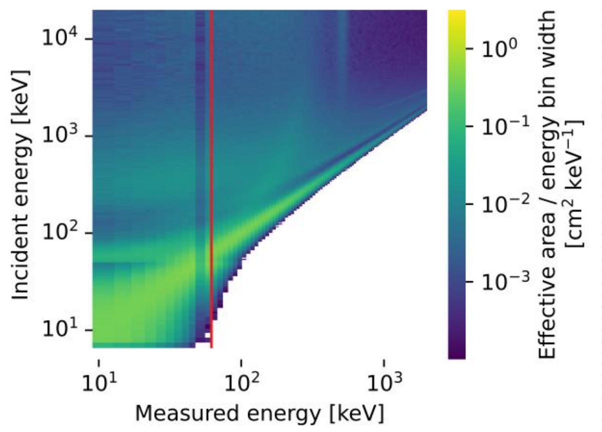


GRID-02 detected GRB 210121A after being in orbit for **2 months**

GRID-04 detected GRB 240229A after being in orbit for **23 months**

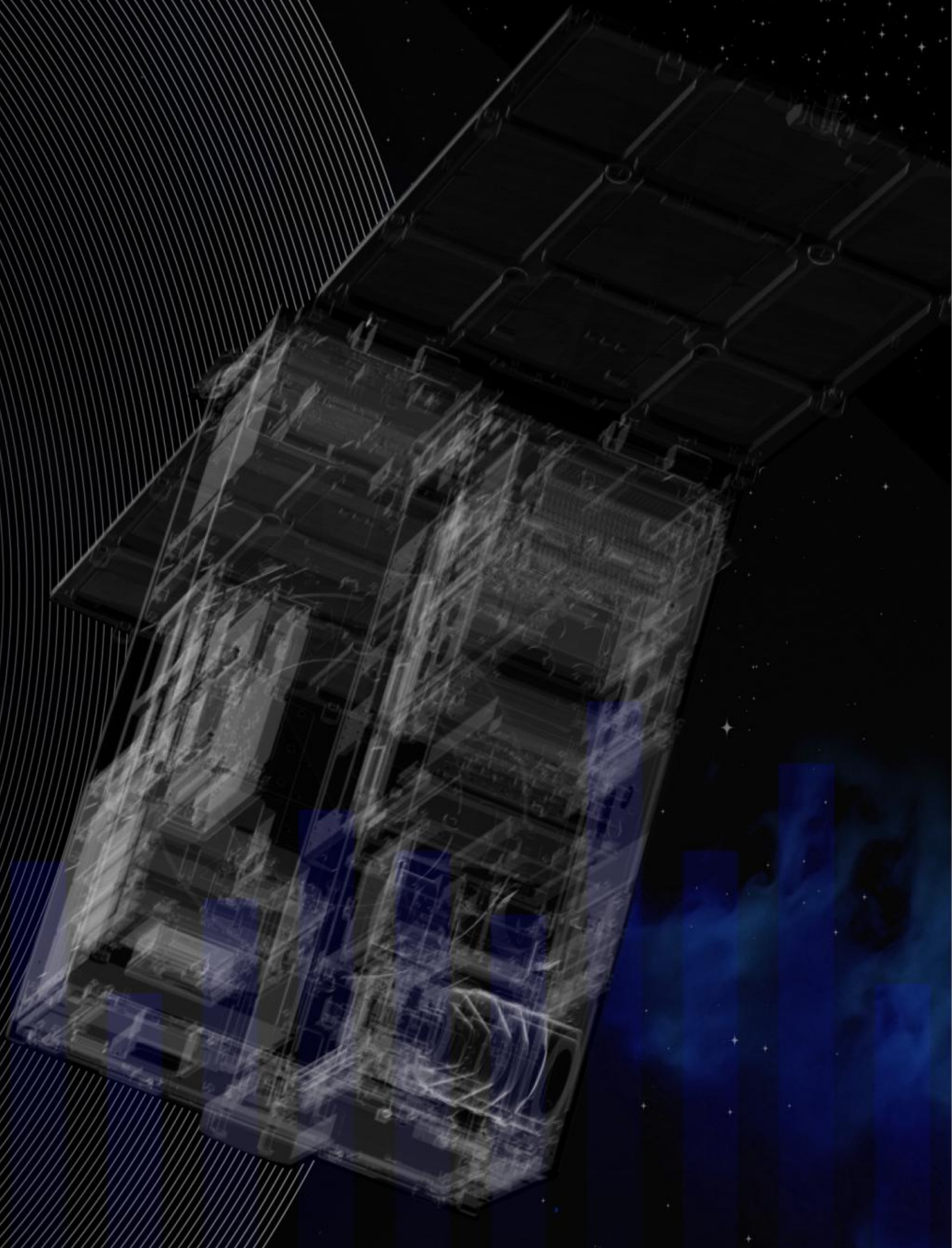
After radiation damage:



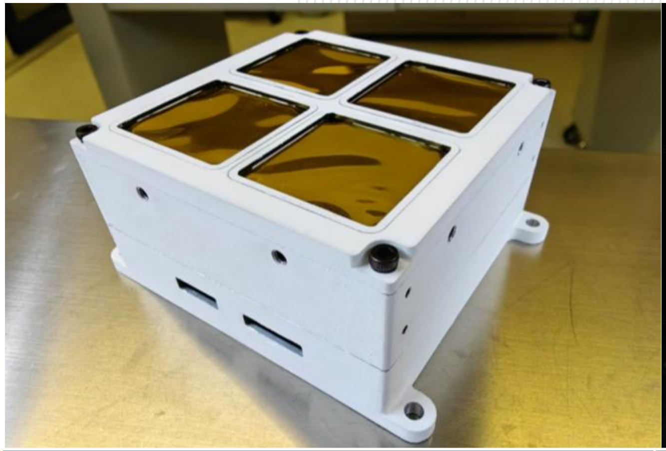


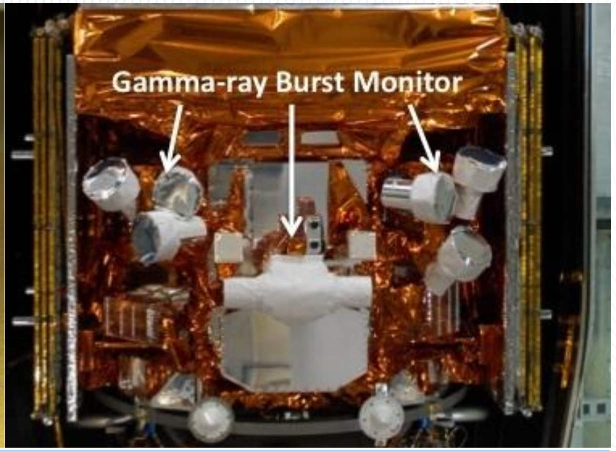
In this work, Using DRMs with or without radiation damage accounted has **insignificant influence** on fitting results (1σ uncertainty)

Methodology of Cross-calibration

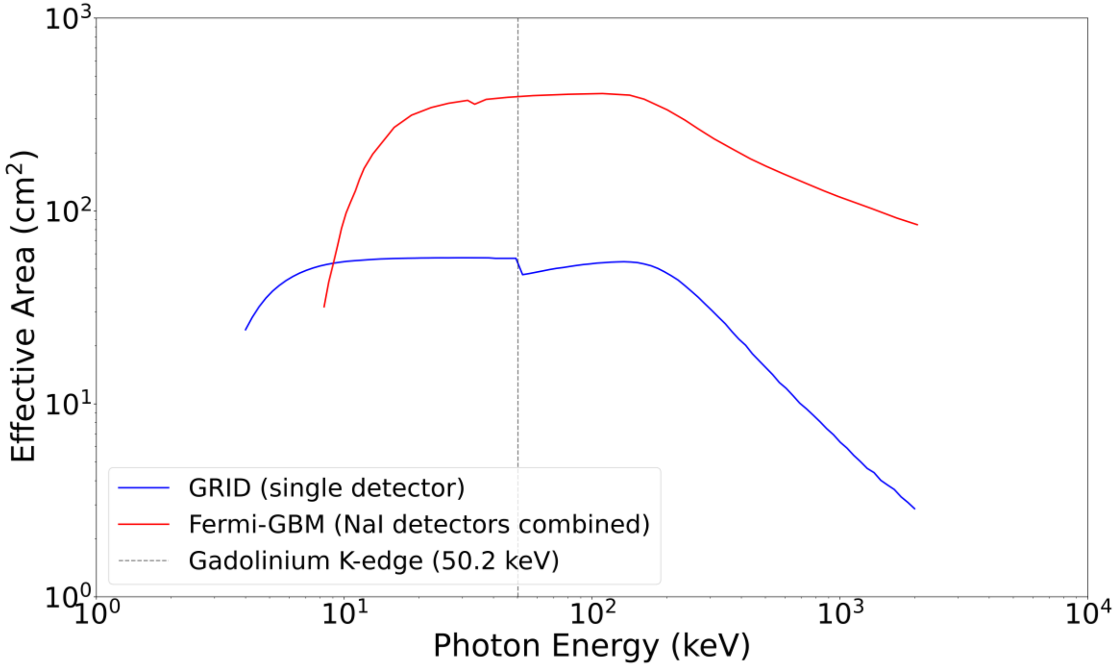


GRID and Fermi-GBM





Single GRID payload	Fermi-GBM[8]
GAGG: 30 keV - 1.2 MeV	NaI: 8 keV -1 MeV (BGO: 200 keV-40 MeV)
Overlapping energy range enables calibration	
high energy	low energy

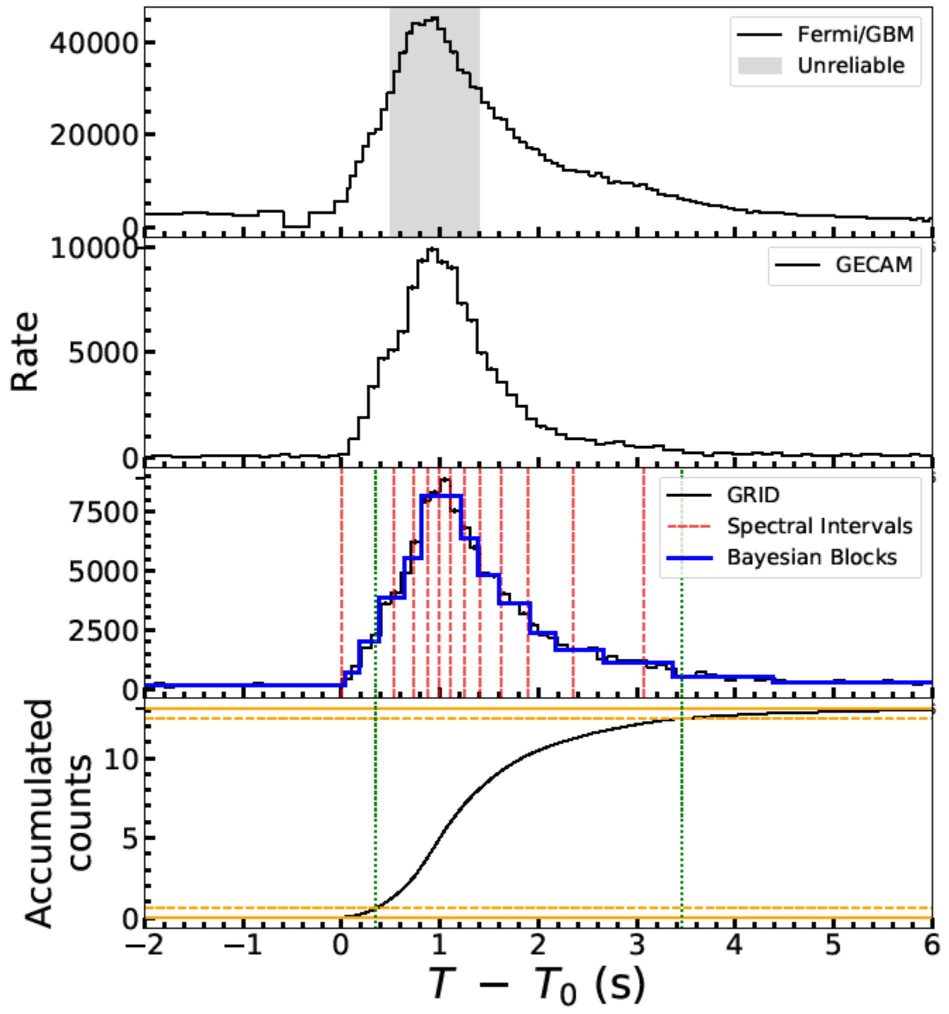


Effective areas of GRID and Fermi-GBM.
Blue: single GRID detector.
Red: GBM- 12 NaI combined on-axis.

Data Preprocessing

- GRID Data Tools and XSPEC Version 12.13.0c
- Unified file formats, units, metadata
- **Background subtraction:**
  - Polynomial fit (smooth changes)
  - Bayesian blocks (abrupt changes)

- T_{90} : Time window for 5%–95% of total fluence
- Captures core emission of the GRB
- **Extract time and energy info within T_{90}**

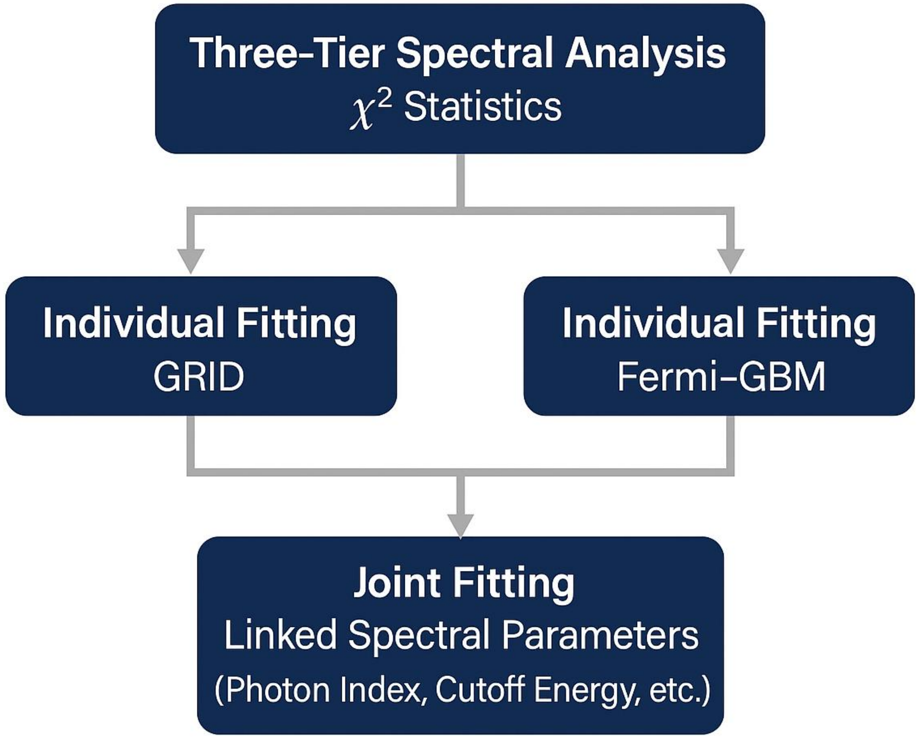


Data Preprocessing for GRB 230812B[9]

Fitting Strategy

- Individual fits: GRID & GBM
- Joint fit: **shared shape**, separate normalizations
- **Forward-folding** used instead of direct unfolding

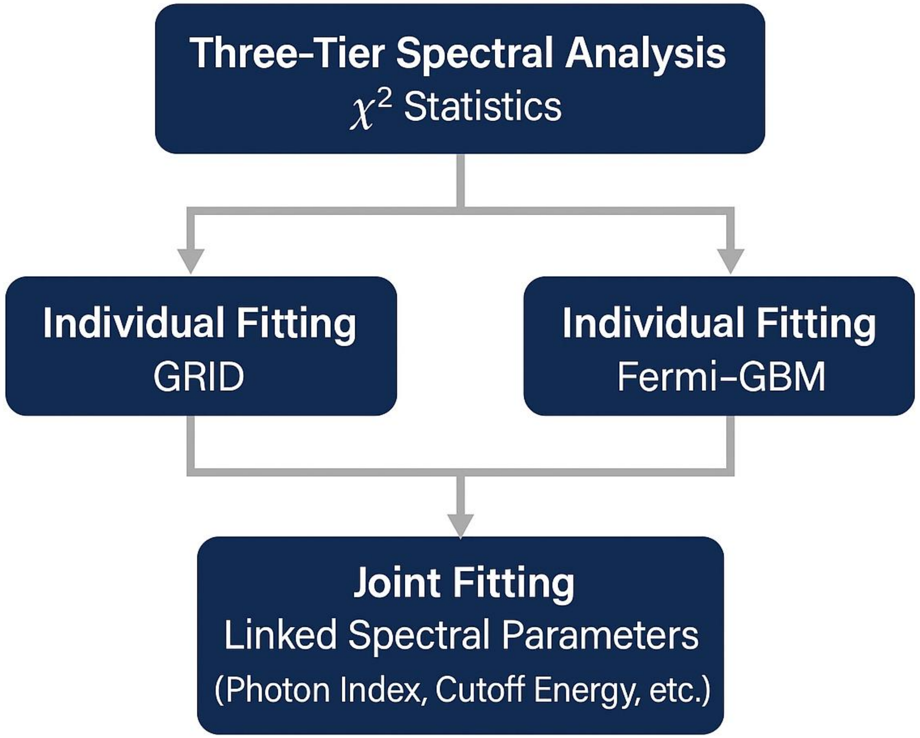
$$N_{\mathrm{det}}(E_{\mathrm{obs}}) = \sum_i R(E_{\mathrm{obs}}, E_i) \cdot N_{\mathrm{true}}(E_i)$$



Fitting Strategy

- Individual fits: GRID & GBM
- Joint fit: **shared shape**, separate normalizations
- **Forward-folding** used instead of direct unfolding

$$N_{\rm det}\left(E_{\rm obs}\right) = \sum_i R\left(E_{\rm obs}, E_i\right) \cdot N_{\rm true}\left(E_i\right)$$



Spectral models used in this work:

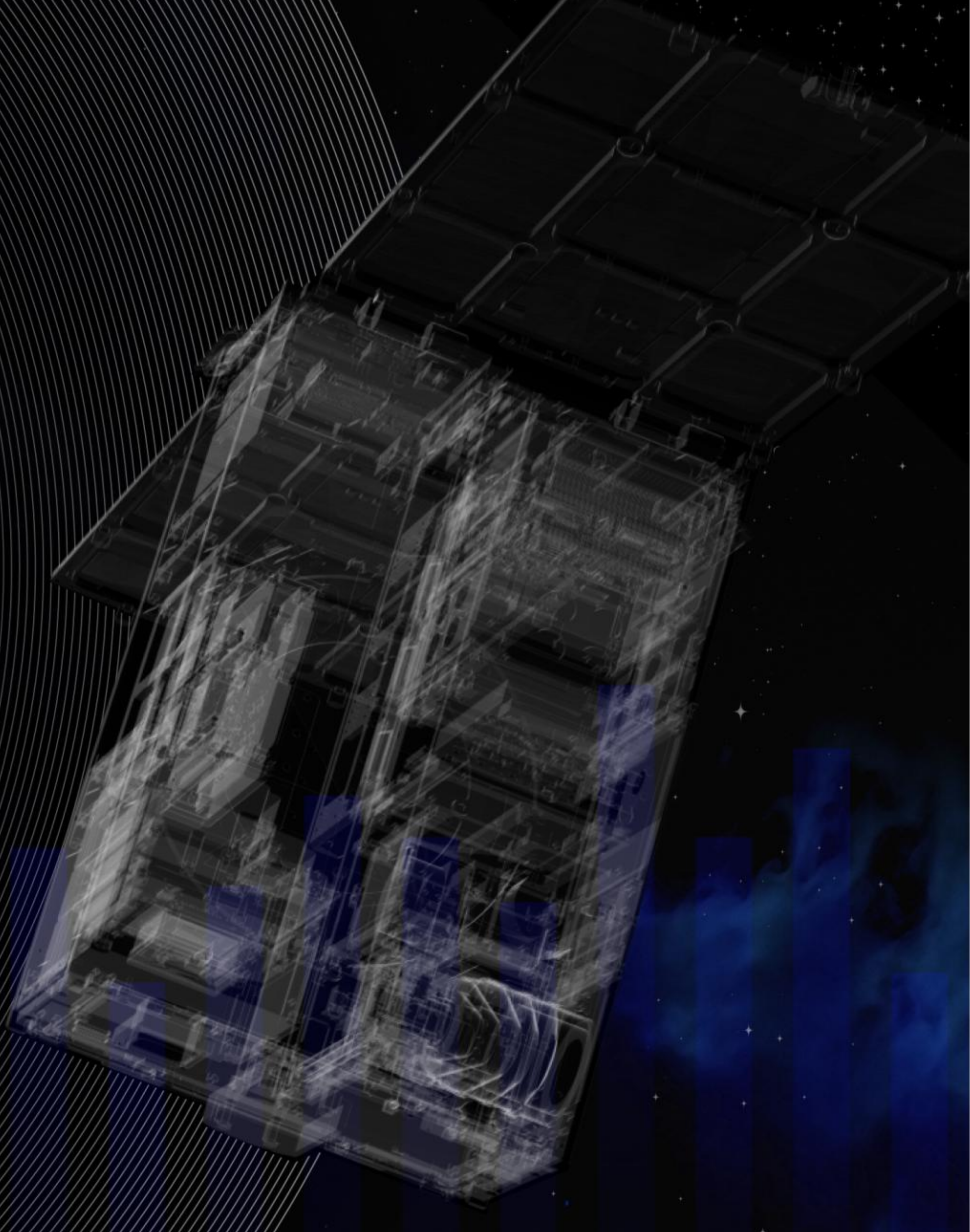
Power Law: $N(E) = K \cdot E^{-\alpha}$

Band Function:

$$N(E) = \begin{cases} K \cdot E^{\alpha} \cdot e^{-\frac{E}{E_0}}, & E \le E_{\rm peak} \\ K \cdot \left(E_{\rm peak}\right)^{\alpha-\beta} \cdot E^{\beta} \cdot e^{(\beta-\alpha)\cdot\frac{E_{\rm peak}}{E_0}}, & E > E_{\rm peak} \end{cases}$$

Cut-Off Power Law: $N(E) = K \cdot E^{-\alpha} \cdot e^{-\frac{E}{E_{\rm cut}}}$

GRB analysis and result



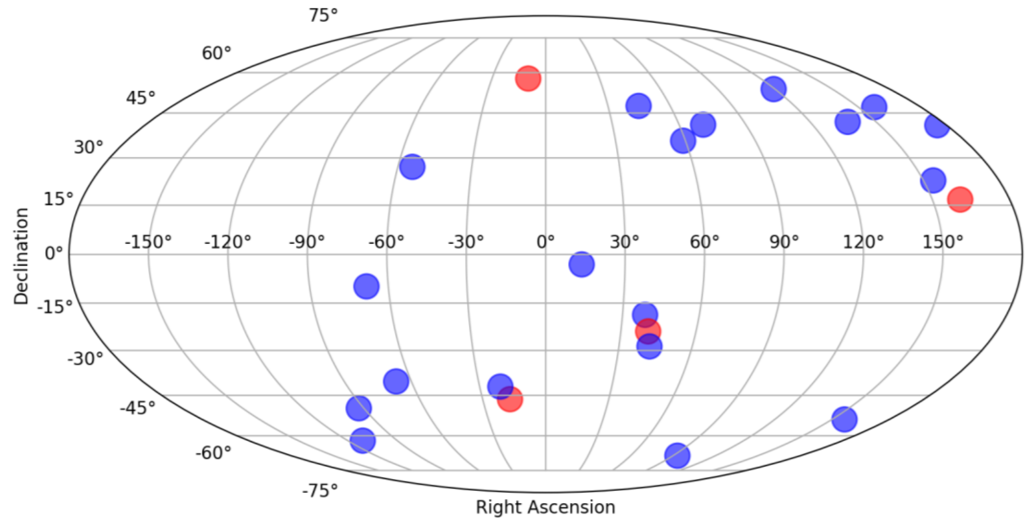
Data Selection & Processing

•Event Selection:

- GRID: Prioritize high-flux events with small incident angles
- For Fermi-GBM: Select 2 NaI detectors per event Choose based on smallest angular offset and unobstructed view

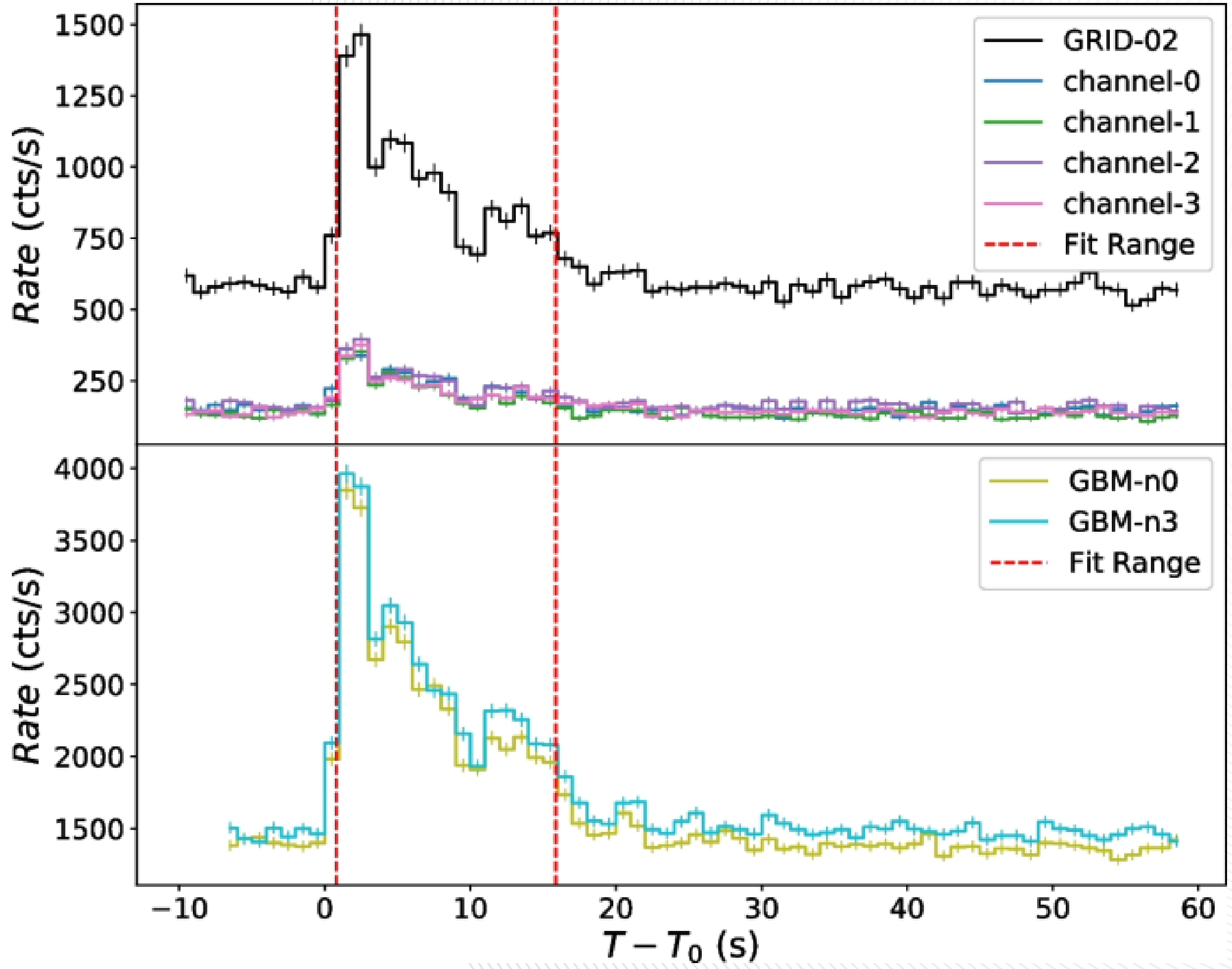
• GRBs for Joint Analysis[10]:

- GRB 210121A, GRB 230827A, GRB 231215A, GRB 240229A
- Spectral analysis over GRID's T_{90} intervals (30–1200 keV)

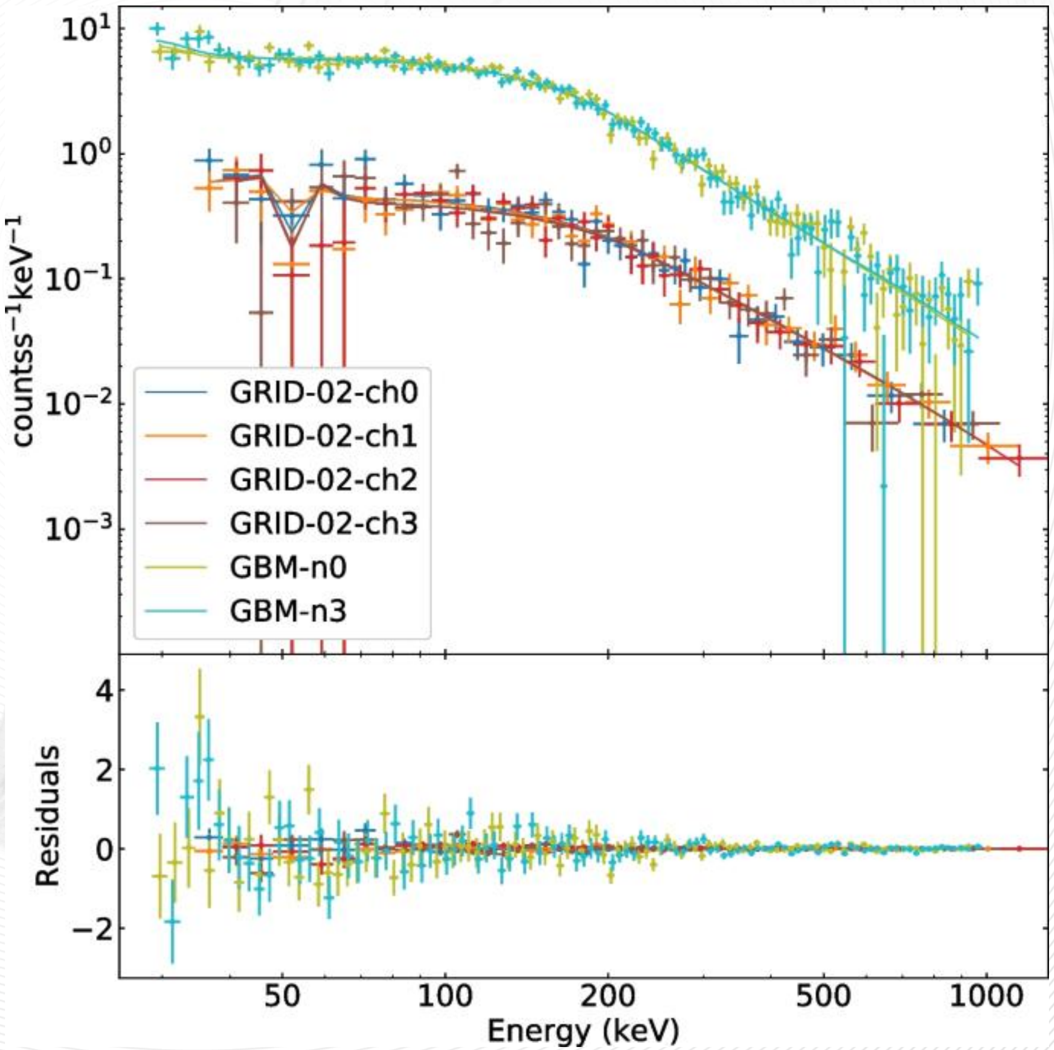


23 GRBs from 500 hours observation of GRID-02, 03B, 04, 07, and 08B

Analysis Result: GRB 210121A



GRID-02 and Fermi-GBM light curves for **GRB 210121A**, with T0 = 18:41:49.0 UT.
The vertical red dashed lines indicate **the joint fit interval**.



Energy spectrum fitting with residuals

Analysis Result: GRB 210121A

GRID 天格计划

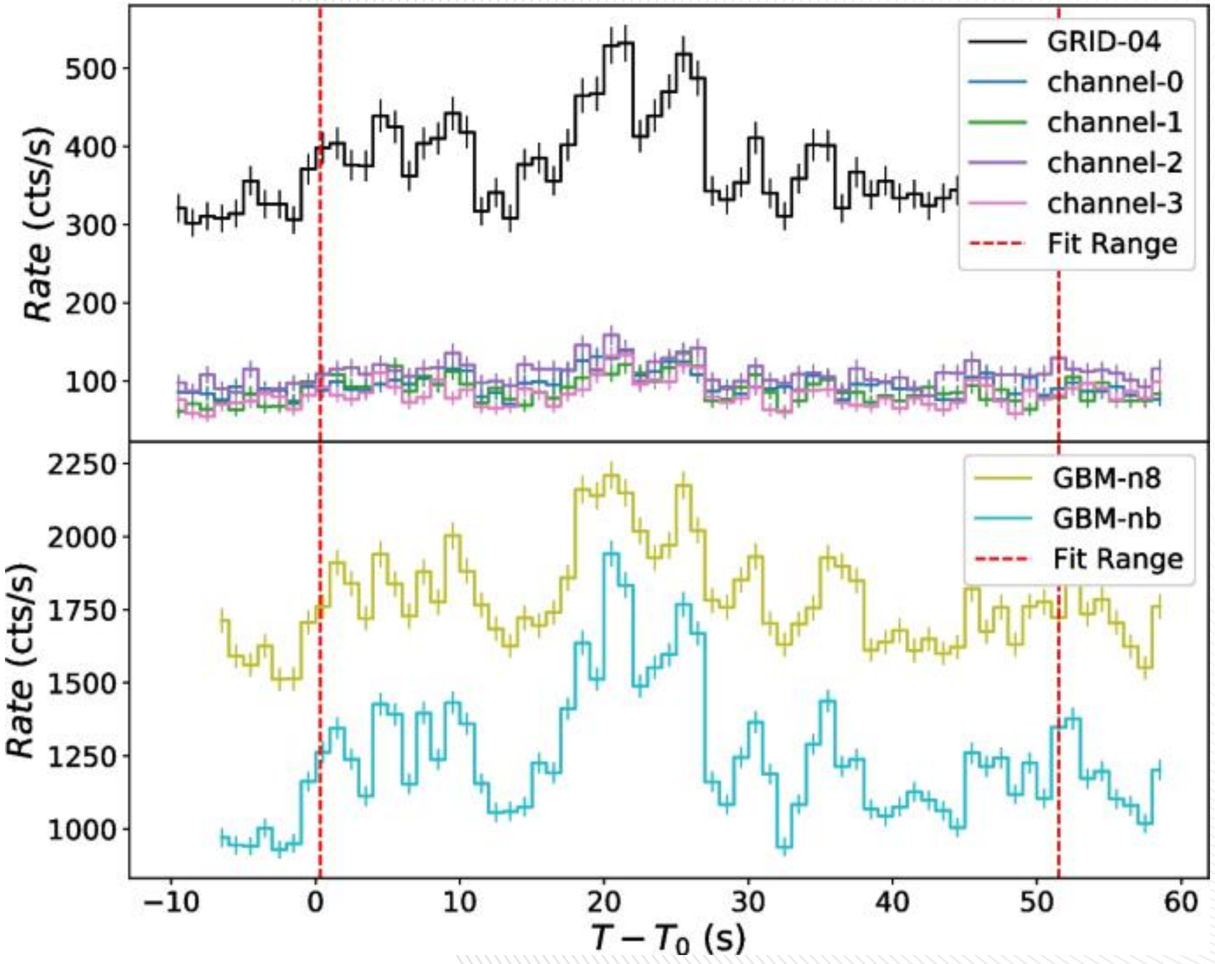
Fitting parameters for GRB 210121A (1σ uncertainty)

$$\mathrm{BIC} = \mathrm{fitsta} + \log d.o.f.$$

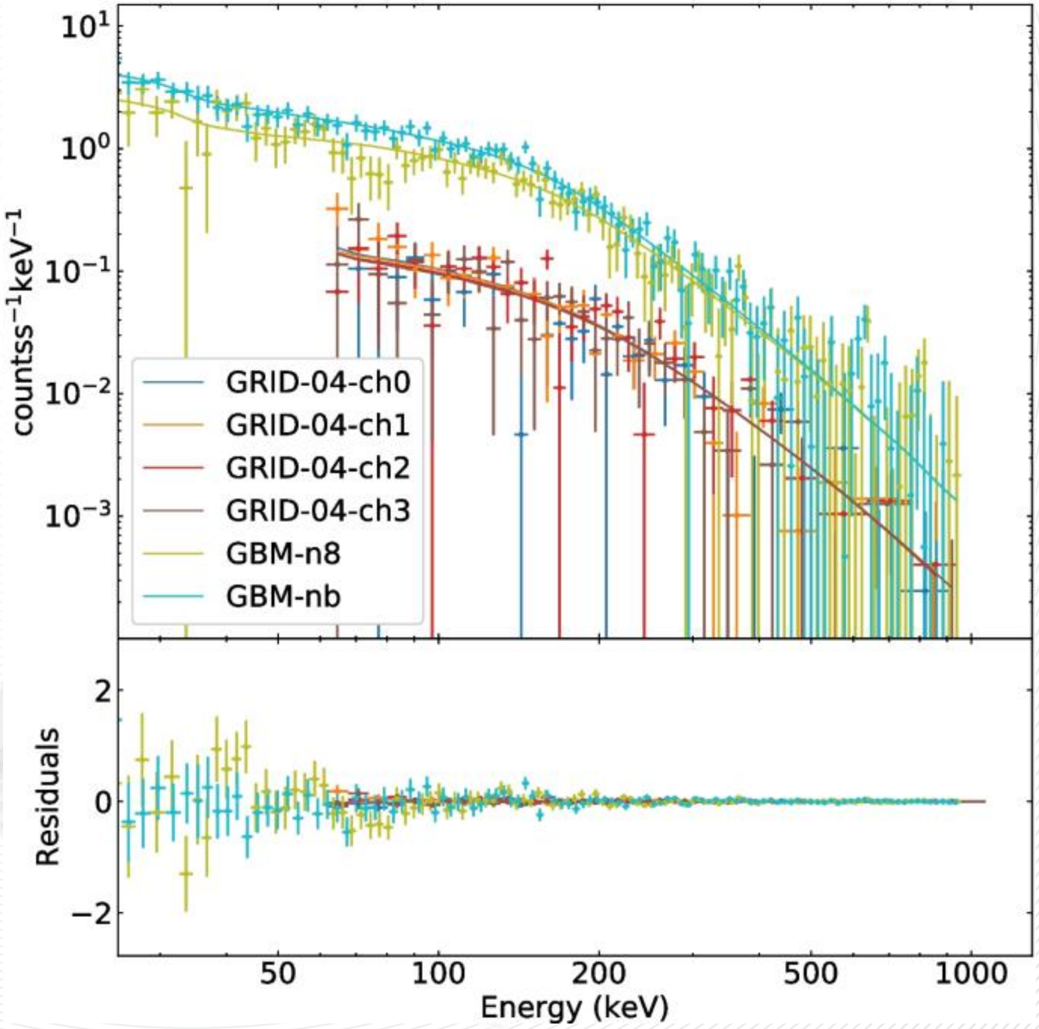
Model	Detector	Index(α)	Index(β)	E_{cut} (E_{peak} for Band)	$\frac{\chi^2}{d.o.f.}$	BIC
PL	Combined	$1.00^{+0.01}_{-0.01}$	\	\	$\frac{597.09}{364} = 1.640$	620.68
	GRID-02	$1.08^{+0.03}_{-0.03}$	\	\	$\frac{211.86}{155} = 1.367$	221.95
	GBM n0, n3	$0.99^{+0.01}_{-0.01}$	\	\	$\frac{369.34}{208} = 1.776$	385.35
CPL	Combined	$0.56^{+0.03}_{-0.03}$	\	$743.6^{+80.3}_{-68.4}$	$\frac{433.88}{363} = 1.195$	**463.35**
	GRID-02	$0.58^{+0.08}_{-0.09}$	\	$716.2^{+166.5}_{-120.5}$	$\frac{165.31}{156} = 1.060$	180.45
	GBM n0, n3	$0.58^{+0.04}_{-0.04}$	\	$787.9^{+111.1}_{-90.3}$	$\frac{272.39}{207} = 1.316$	299.06
BAND	Combined	$-0.53^{+0.04}_{-0.04}$	$-1.58^{+0.13}_{-0.25}$	$578.4^{+98.4}_{-84.1}$	$\frac{435.78}{362} = 1.204$	471.13
	GRID-02	$-0.46^{+0.18}_{-0.12}$	$-1.59^{+0.19}_{-0.41}$	$468.2^{+185.0}_{-164.0}$	$\frac{163.50}{153} = 1.069$	183.62
	GBM n0, n3	$-0.56^{+0.05}_{-0.05}$	$-1.57^{+0.17}_{-0.51}$	$636.1^{+143.1}_{-118.1}$	$\frac{270.66}{206} = 1.314$	297.30

Boldface indicates the BIC value of the best joint fitting among all used models

Analysis Result: GRB 230827A



GRID-04 and Fermi-GBM light curves for **GRB 230827A**, with T0 = 18:17:53.0 UT.
The vertical red dashed lines indicate **the joint fit interval**.



Energy spectrum fitting with residuals

Analysis Result: GRB 230827A

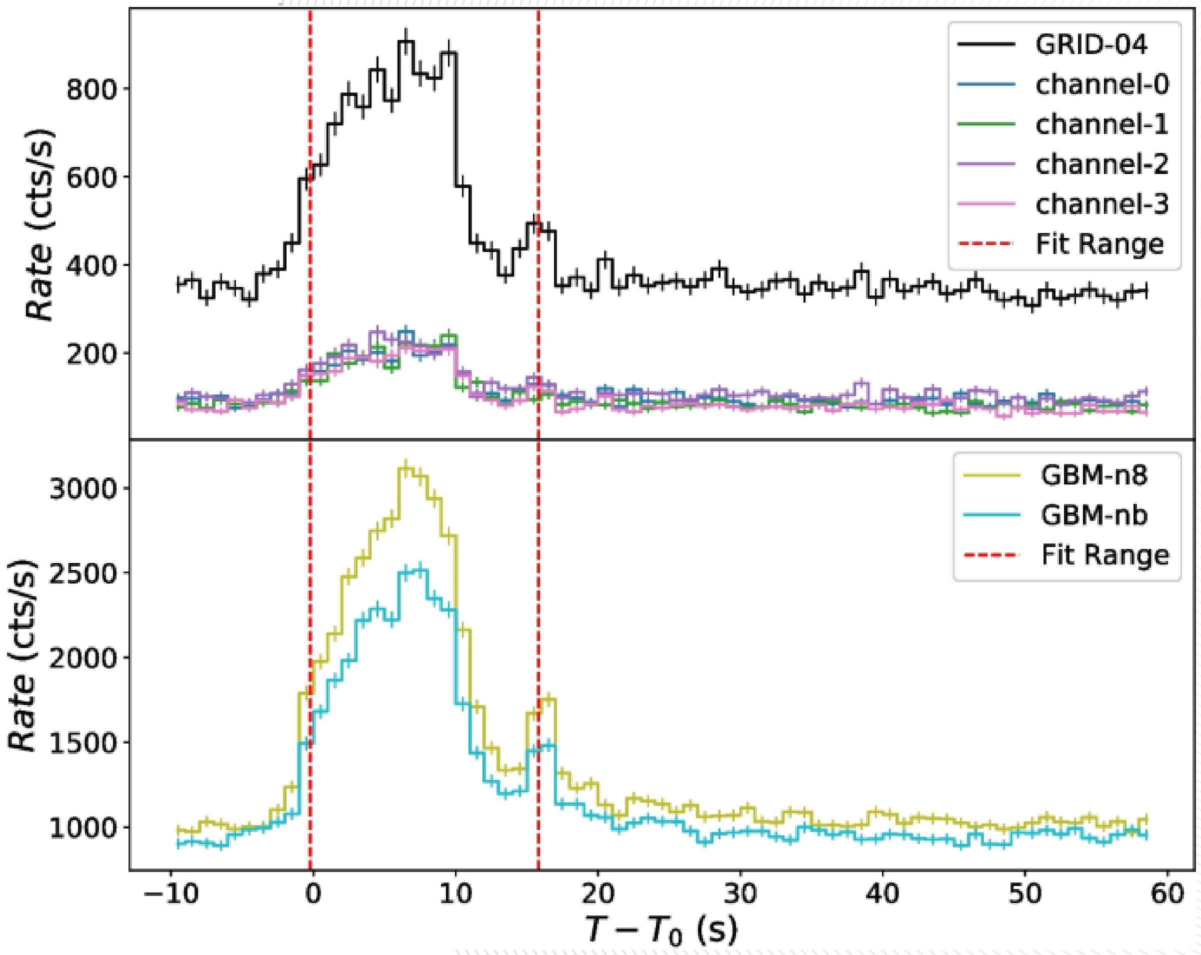
Fitting parameters for GRB 230827A (1σ uncertainty)

$\mathrm{BIC} = \mathrm{fitsta} + \log d.o.f.$

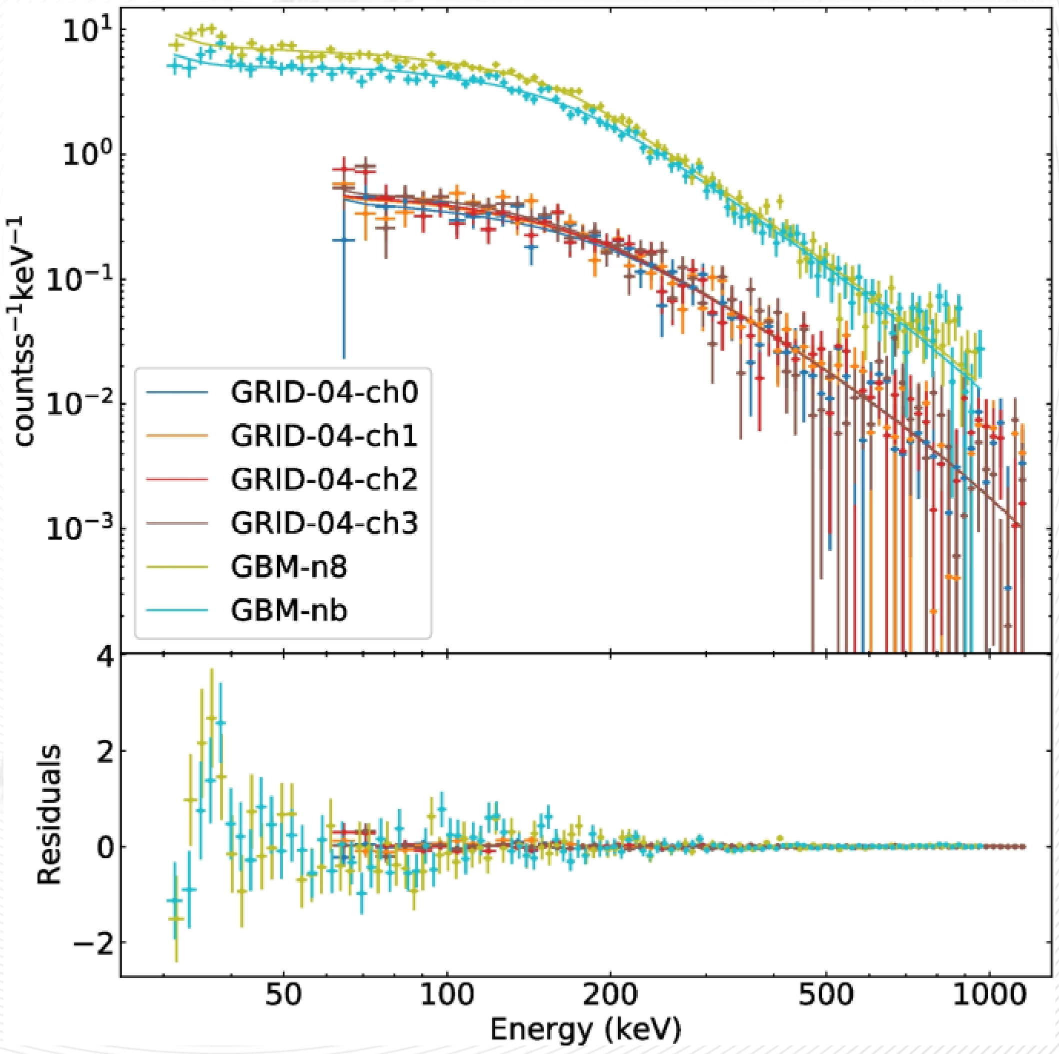
Model	Detector	Index(α)	Index(β)	$E_{\rm cut}$ ($E_{\rm peak}$ for Band)	$\frac{\chi^2}{d.o.f.}$	BIC
PL	Combined	$1.31^{+0.01}_{-0.01}$	\	\	$\frac{477.68}{365} = 1.309$	501.28
	GRID-04	$1.66^{+0.07}_{-0.07}$	\	\	$\frac{135.64}{127} = 1.068$	145.33
	GBM n8, nb	$1.30^{+0.02}_{-0.02}$	\	\	$\frac{309.94}{237} = 1.308$	326.34
CPL	Combined	$0.91^{+0.05}_{-0.05}$	\	$391.9^{+58.1}_{-47.6}$	$\frac{345.38}{364} = 0.949$	**374.87**
	GRID-04	$0.88^{+0.16}_{-0.36}$	\	$321.1^{+236.0}_{-112.4}$	$\frac{126.25}{126} = 1.002$	140.76
	GBM n8, nb	$0.93^{+0.05}_{-0.05}$	\	$428.8^{+78.4}_{-61.3}$	$\frac{217.74}{236} = 0.923$	239.60
BAND	Combined	\	\	\	\	\
	GRID-04	\	\	\	\	\
	GBM n8, nb	\	\	\	\	\

Boldface indicates the BIC value of the best joint fitting among all used models

Analysis Result: GRB 231215A



GRID-04 and Fermi-GBM light curves for **GRB 231215A**, with T0 = 9:47:19.0 UT.
The vertical red dashed lines indicate **the joint fit interval**.



Energy spectrum fitting with residuals

Analysis Result: GRB 231215A

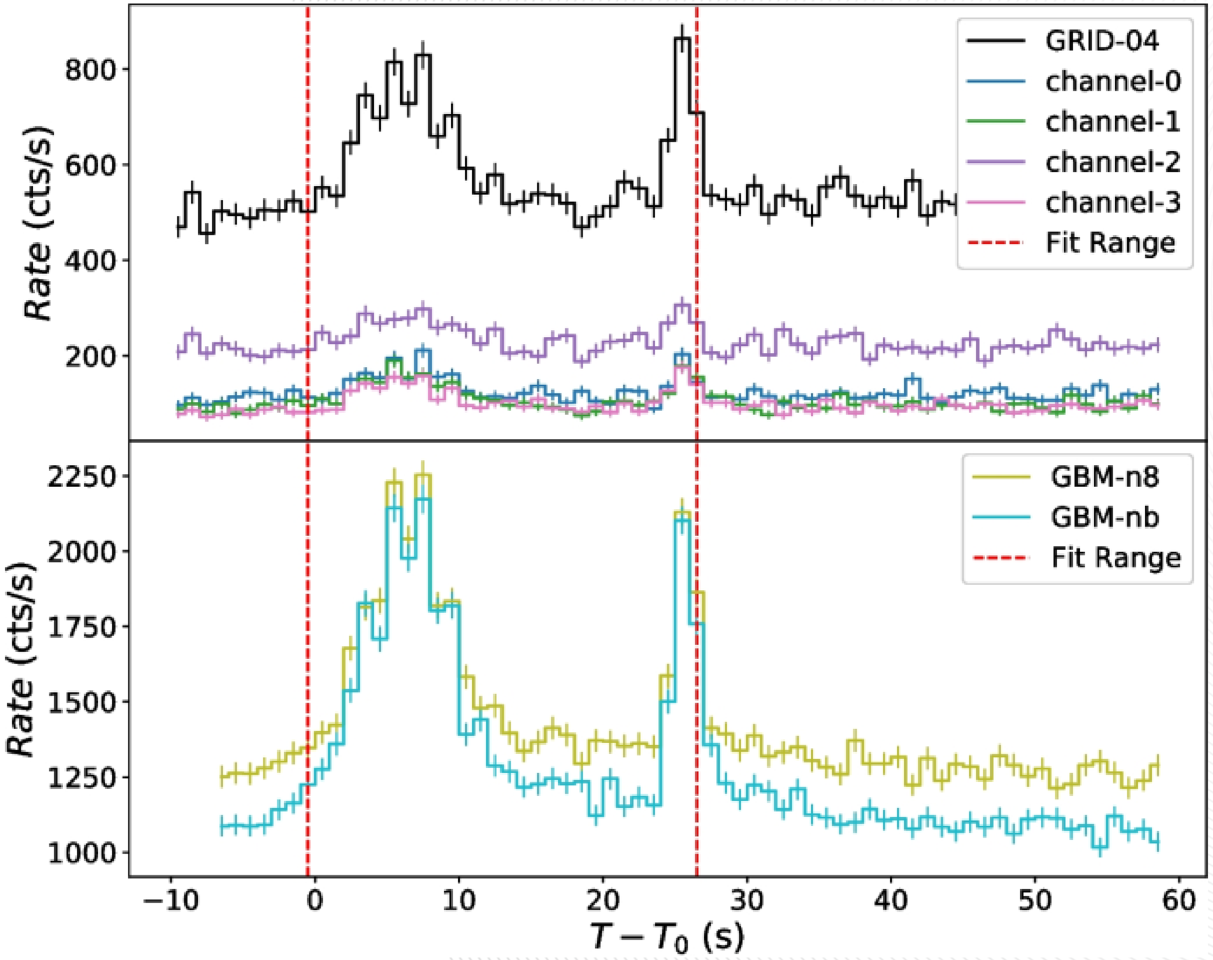
Fitting parameters for GRB 231215A (1σ uncertainty)

$\mathrm{BIC} = \mathrm{fitsta} + \log d.o.f.$

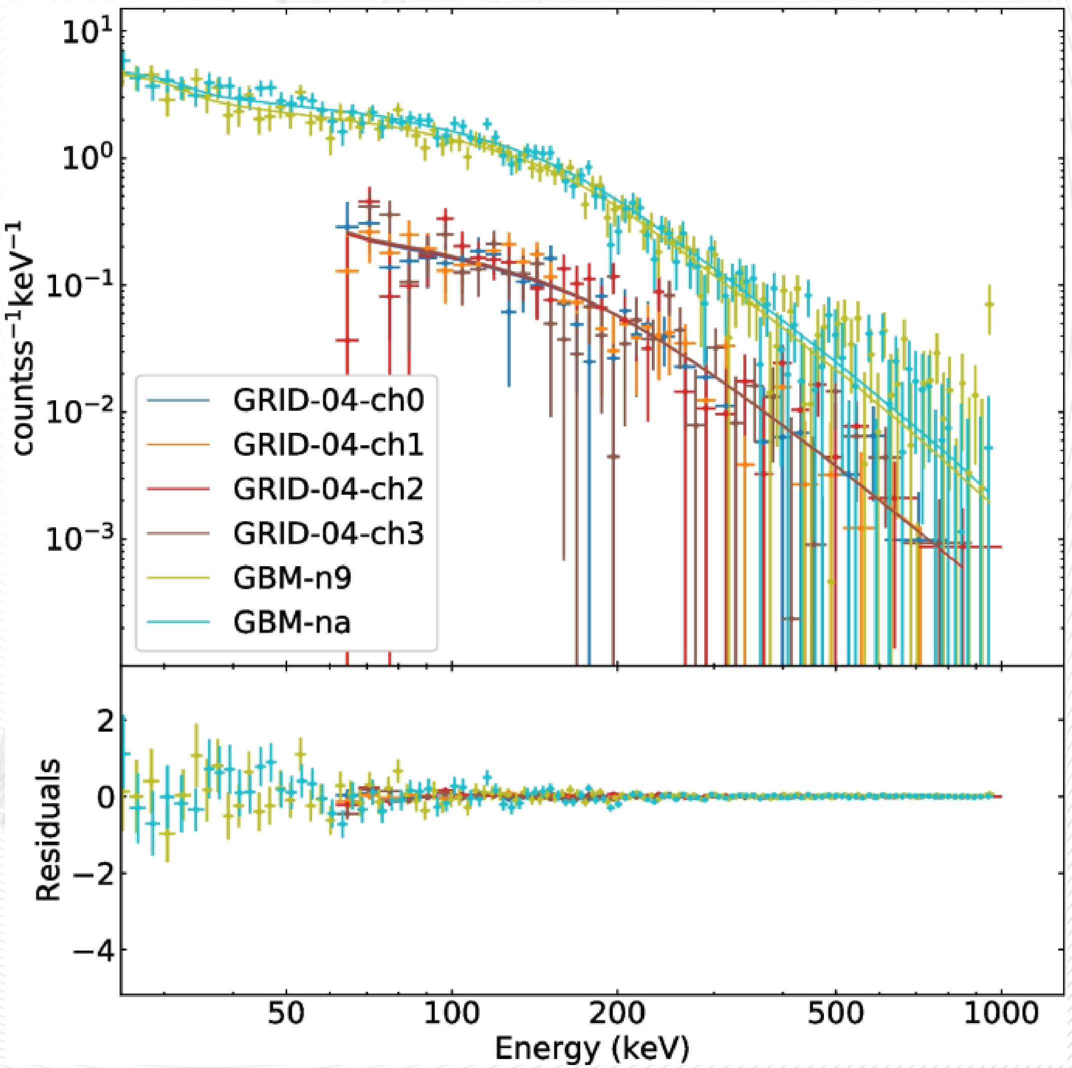
Model	Detector	Index(α)	Index(β)	E_{cut} (E_{peak} for Band)	$\frac{\chi^2}{d.o.f.}$	BIC
PL	Combined	$1.21^{+0.01}_{-0.01}$	\	\	$\frac{1140.91}{469} = 2.433$	1165.51
	GRID-04	$1.46^{+0.02}_{-0.02}$	\	\	$\frac{374.93}{262} = 1.431$	386.07
	GBM n8, nb	$1.18^{+0.01}_{-0.01}$	\	\	$\frac{622.54}{206} = 3.022$	638.52
CPL	Combined	$0.57^{+0.03}_{-0.03}$	\	$424.9^{+26.6}_{-24.5}$	$\frac{511.92}{468} = 1.094$	**542.66**
	GRID-04	$0.59^{+0.11}_{-0.11}$	\	$381.0^{+63.2}_{-51.6}$	$\frac{270.16}{261} = 1.035$	286.85
	GBM n8, nb	$0.60^{+0.04}_{-0.04}$	\	$467.3^{+111.1}_{-90.3}$	$\frac{233.76}{205} = 1.140$	255.05
BAND	Combined	\	\	\	\	\
	GRID-04	\	\	\	\	\
	GBM n8, nb	$-0.53^{+0.05}_{-0.05}$	$-1.94^{+0.13}_{-0.20}$	$364.1^{+45.6}_{-38.8}$	$\frac{256.44}{204} = 1.127$	229.85

Boldface indicates the BIC value of the best joint fitting among all used models

Analysis Result: GRB 240229A



GRID-04 and Fermi-GBM light curves for **GRB 240229A**, with T0 = 14:07:08.0 UT.
The vertical red dashed lines indicate **the joint fit interval**.



Energy spectrum fitting with residuals

Analysis Result: GRB 240229A

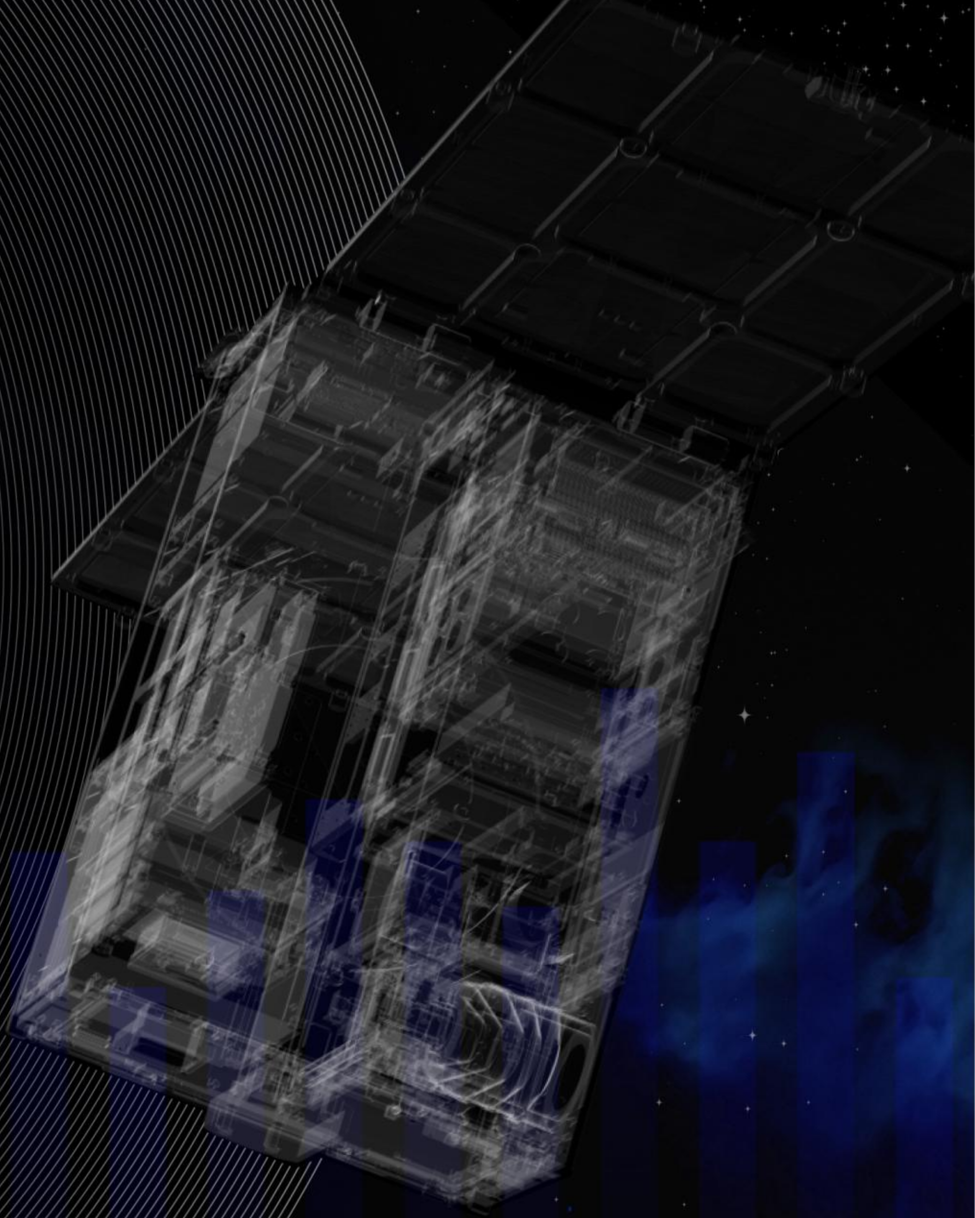
Fitting parameters for GRB 240229A (1σ uncertainty)

$$\mathrm{BIC} = \mathrm{fitsta} + \log d.o.f.$$

Model	Detector	Index(α)	Index(β)	$E_{\rm cut}$ ($E_{\rm peak}$ for Band)	$\frac{\chi^2}{d.o.f.}$	BIC
PL	Combined	$1.34^{+0.01}_{-0.01}$	\	\	$\frac{471.30}{370} = 1.274$	494.95
	GRID-04	$1.55^{+0.07}_{-0.07}$	\	\	$\frac{126.68}{133} = 0.952$	136.46
	GBM n9, na	$1.34^{+0.01}_{-0.01}$	\	\	$\frac{334.45}{236} = 1.417$	350.84
CPL	Combined	$0.97^{+0.05}_{-0.05}$	\	$445.0^{+75.0}_{-59.9}$	$\frac{366.86}{369} = 0.994$	**396.41**
	GRID-04	$0.97^{+0.29}_{-0.34}$	\	$413.0^{+499.8}_{-172.8}$	$\frac{121.16}{132} = 0.918$	135.81
	GBM n9, na	$0.98^{+0.02}_{-0.02}$	\	$455.3^{+84.8}_{-66.2}$	$\frac{245.54}{235} = 1.045$	267.38
BAND	Combined	\	\	\	\	\
	GRID-04	\	\	\	\	\
	GBM n9, na	$-0.83^{+0.09}_{-0.09}$	$-1.71^{+0.08}_{-0.17}$	$234.8^{+89.1}_{-54.2}$	$\frac{241.89}{234} = 1.034$	269.17

Boldface indicates the BIC value of the best joint fitting among all used models

Conclusion



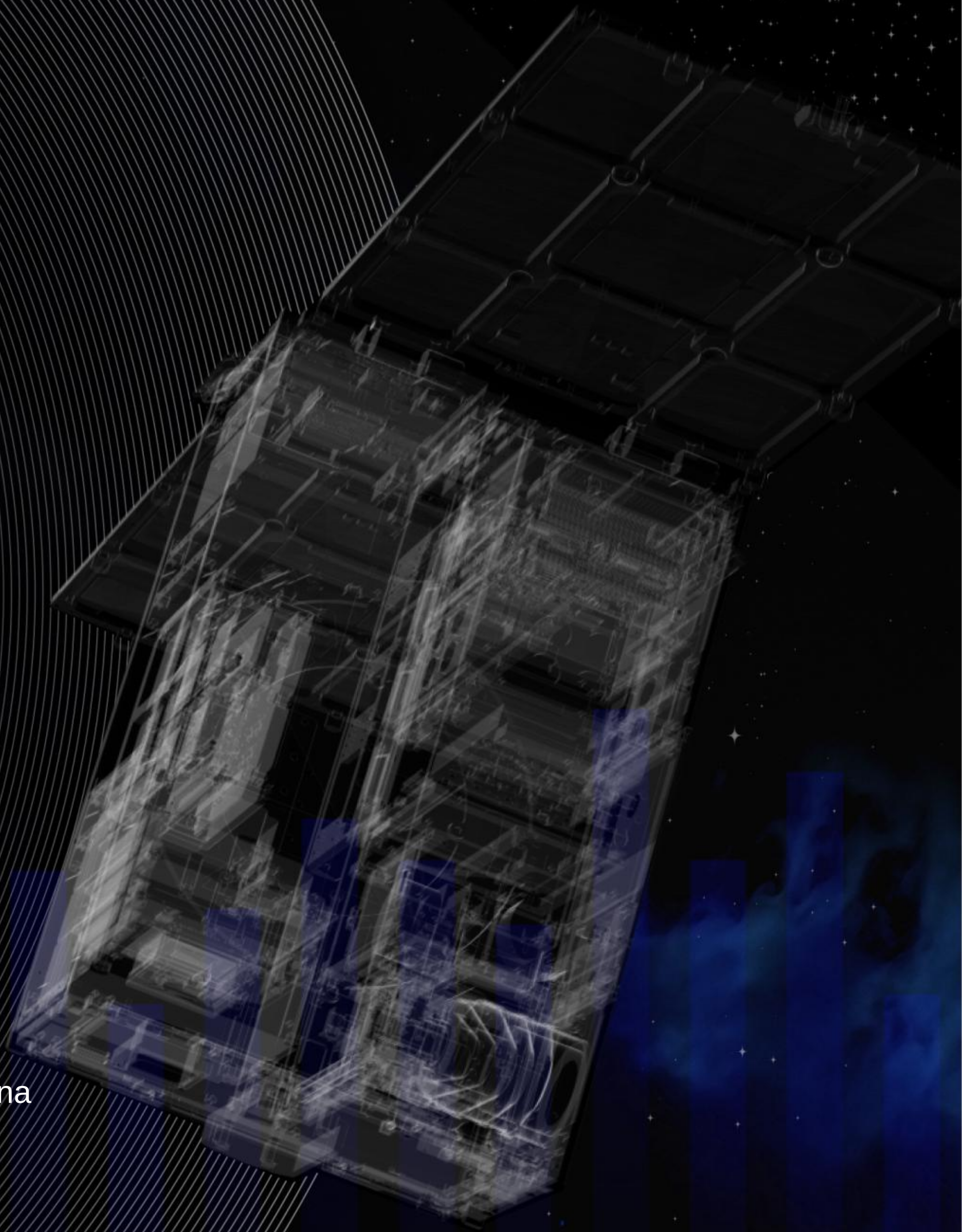
Conclusion & Outlook

- Cross-calibration between the GRID detectors and Fermi-GBM was performed through joint spectral analysis.
- The excellent agreement between the instruments validates the accuracy of GRID’s DRMs and the reliability of its scientific data.
- In our cross-calibration, the radiation damage of SiPM has insignificant influence on the DRM. However it is an in-orbit issue worthy of discussion.
- Accurate cross-calibration between detectors is particularly relevant in source localization methods
- For nanosatellite constellations like GRID, cross-calibration through orbital observations involving multiple distributed detector payloads is a crucial tool for ensuring uniformity and verifying overall performance of such systems.

References

[1] B. P. Abbott *et al.*, "Gravitational Waves and Gamma-Rays from a Binary Neutron Star Merger: GW170817 and GRB 170817A," *The Astrophysical Journal*, vol. 848, no. 2, p. L13, Oct. 2017, doi:10.3847/2041-8213/aa920c.
[2] J. Wen *et al.*, "GRID: a student project to monitor the transient gamma-ray sky in the multi-messenger astronomy era," *Experimental Astronomy*, vol. 48, no. 1, pp. 77–95, Aug. 2019, doi:10.1007/s10686-019-09636-w.
[3] Z. Yang, L. Li, X. Zheng, X. Pan, and M. Zeng, "Current status and recent scientific results of GRID: a student-driven NanoSat constellation for GRB observation," pp. 1–1, Sep. 2024, doi:10.1109/nss/mic/rtsd57108.2024.10655487.
[4] X. Zheng *et al.*, "In-orbit radiation damage characterization of SiPMs in the GRID-02 CubeSat detector," *Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment*, vol. 1044, p. 167510, Sep. 2022, doi:10.1016/j.nima.2022.167510.
[5] J.-X. Wen *et al.*, "Compact CubeSat Gamma-ray detector for GRID mission," *Nuclear Science and Techniques*, vol. 32, no. 9, Sep. 2021, doi:10.1007/s41365-021-00937-4.
[6] H. Gao *et al.*, "On-ground calibrations of the GRID-02 gamma-ray detector," *Experimental Astronomy*, vol. 53, no. 1, pp. 103–116, Dec. 2021, doi:10.1007/s10686-021-09819-4.
[7] Q. Liu *et al.*, "Monte Carlo simulation of angular response of GRID detectors for GRID mission," *Journal of Instrumentation*, vol. 20, no. 03, pp. P03017–P03017, Mar. 2025, doi:10.1088/1748-0221/20/03/p03017.
[8] C. Meegan *et al.*, "THE*FERMI*GAMMA-RAY BURST MONITOR," *The Astrophysical Journal*, vol. 702, no. 1, pp. 791–804, Aug. 2009, doi:10.1088/0004-637x/702/1/791.
[9] C.-Y. Wang *et al.*, "Bridging the Gap: GRB 230812B—A 3 s Supernova-associated Burst Detected by the GRID Mission," *The Astrophysical Journal*, vol. 980, no. 2, pp. 212–212, Feb. 2025, doi:10.3847/1538-4357/ada934.
[10] Z. Yang *et al.*, "Cross-calibration of GRID via correlative spectral analysis of GRBs," *Experimental Astronomy*, vol. 59, no. 3, May 2025, doi:10.1007/s10686-025-10002-2.

Thank you
for your attention!



Zirui Yang[1,2], Xiaofan Pan[1,2] and Ming Zeng[1,2]

On behalf of the GRID collaboration

[1]Department of Engineering Physics, Tsinghua University, Beijing, China

[2]Key Laboratory of Particle and Radiation Imaging (Tsinghua University), Ministry of Education, Beijing, China

2025.05.12 @ 17th IACHEC meeting

yzr23@mails.tsinghua.edu.cn pxf21@mails.tsinghua.edu.cn zengming@tsinghua.edu.cn