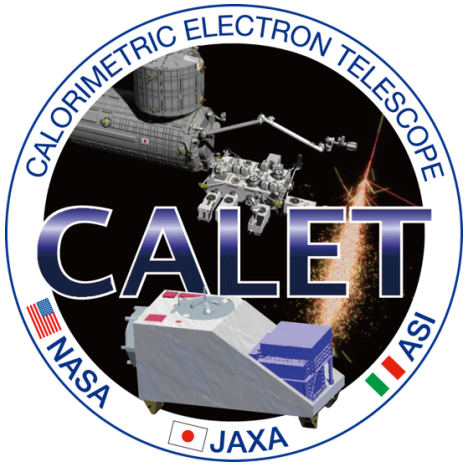
GRB observations & Search for EM counterparts of GW events with CALET



Yuta Kawakubo

Louisiana State University

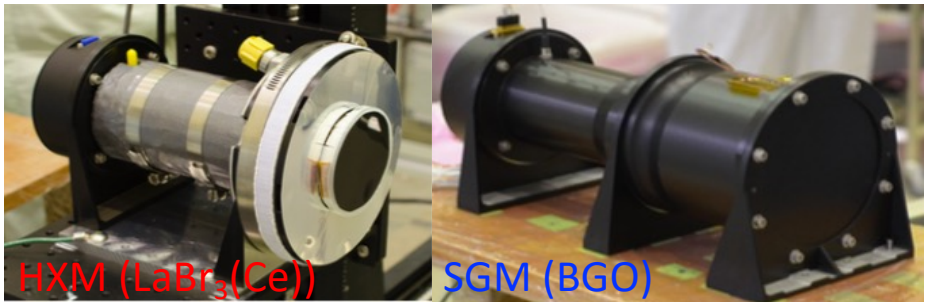
for the CALET collaboration

CALorimetric Electron Telescope

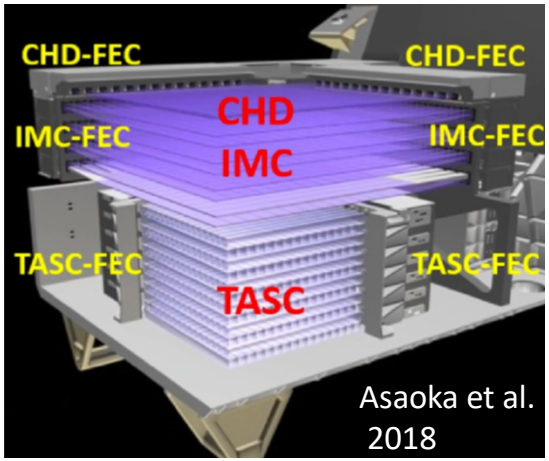
CALET Gamma-ray burst Monitor (CGBM)

Hard X-ray Monitor (HXM)

Soft Gamma-ray Monitor (SGM)



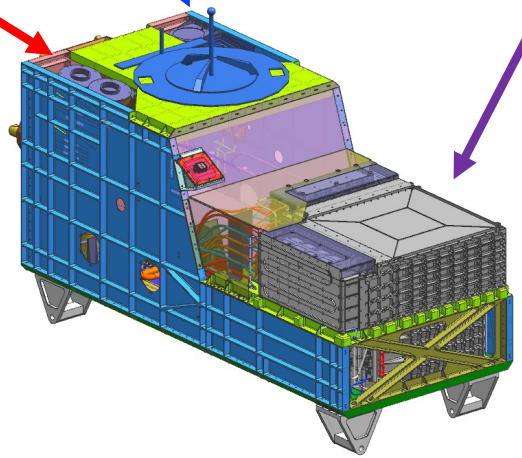
CALorimeter (CAL)

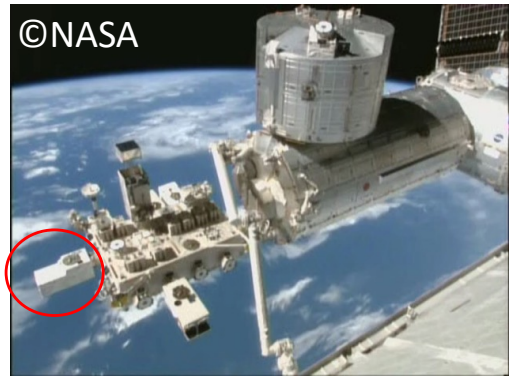


CHD
- Charge measurement

IMC
- Direction measurement
- Particle identification

TASC
- Energy measurement
- Particle identification

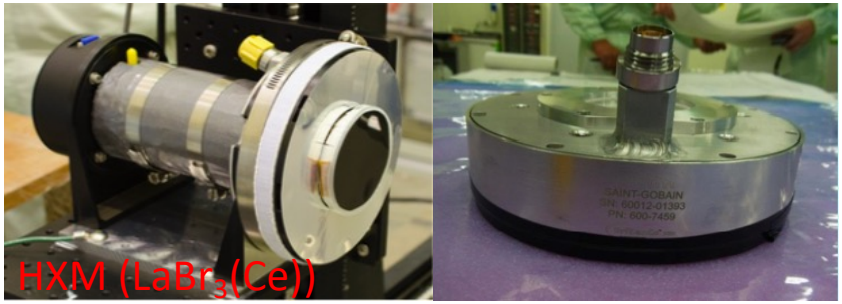




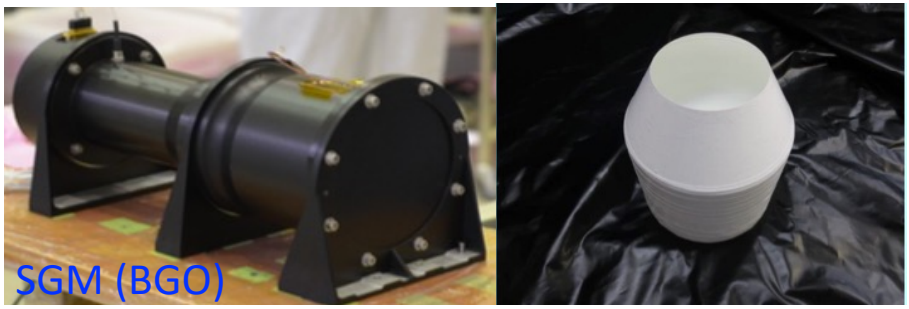
CALorimetric Electron Telescope (CALET) is a payload for observing high-energy cosmic rays and gamma-rays on the International Space Station (ISS).

CALET Gamma-ray burst monitor

Hard X-ray Monitor (HXM)



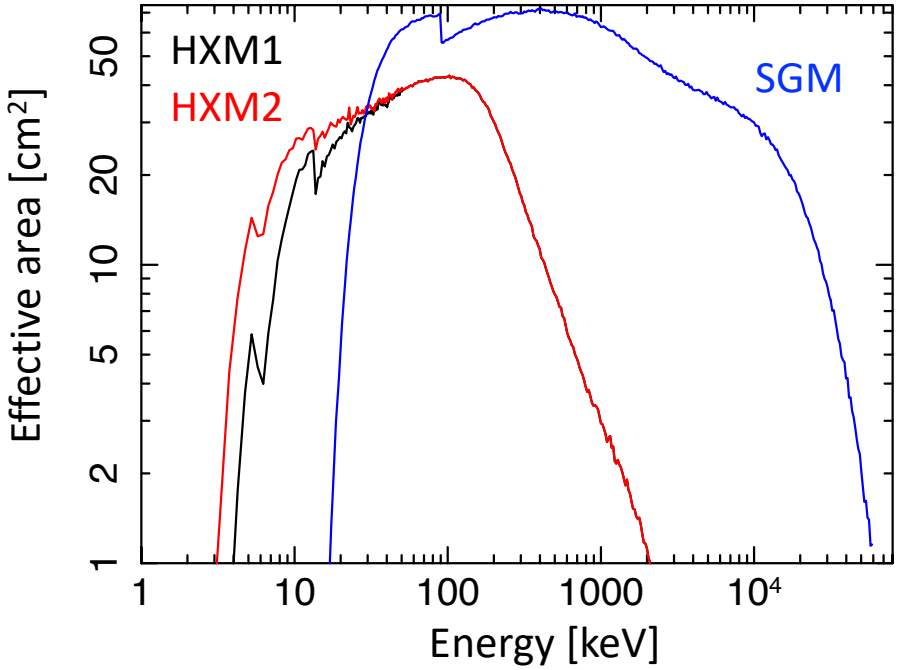
Soft Gamma-ray Monitor (SGM)



7 – 1000 keV

40 keV – 20 MeV

	HXM	SGM
Sensor	$LaBr_3(Ce)$ + PMT	BGO + PMT
Number of detectors	2	1
Diameter [mm]	61	102
Thickness [mm]	12.7	76
Energy resolution	8 % @ 511 keV	11 % @ 511 keV
Field of View	~3 sr	~8 sr

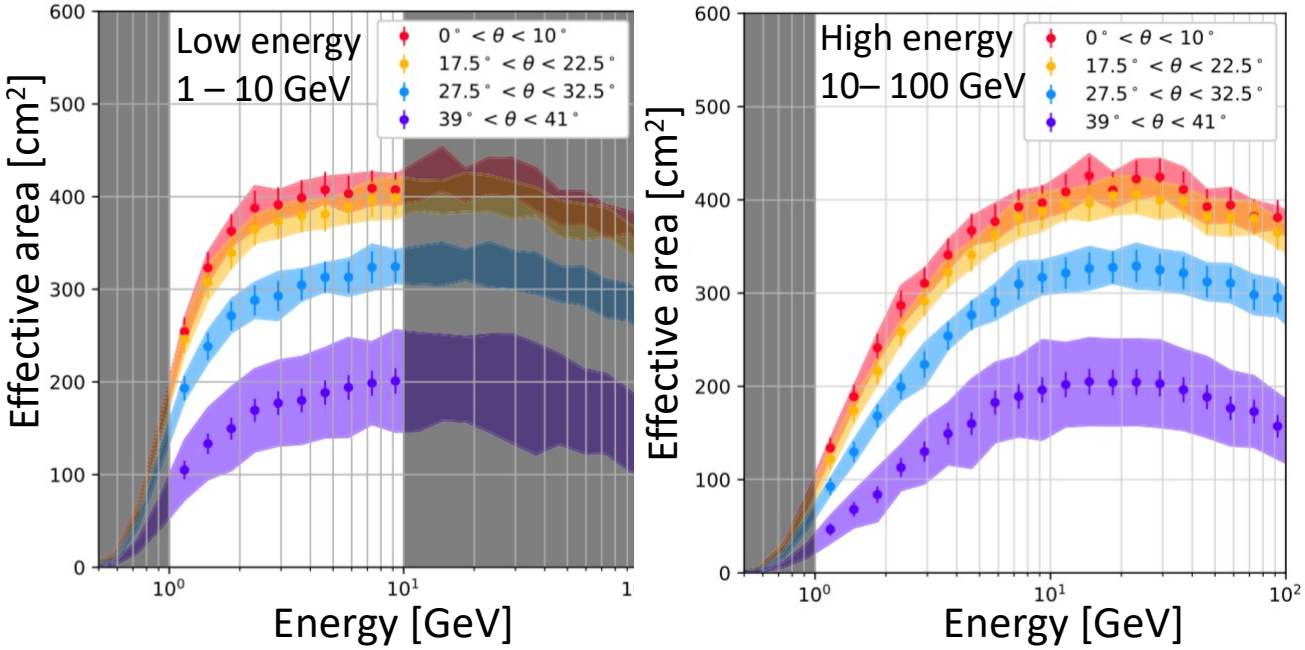


CGBM covers the typical energy range of GRB prompt emissions.

Specification for CAL gamma-ray observations

	CAL
Energy resolution	~3 % @ 10 GeV
Energy range	1 GeV - 10 TeV
Field of view	~2 sr
Angular resolution	~0.5° @ 10 GeV

Cannady et al. 2018, ApJS, 238:5, 2018



High energy trigger mode (HE)

- > 10 GeV
- Always on

Low energy gamma-ray mode (LEG)

- > 1 GeV
- Only Low latitude
- Short interval after CGBM triggers

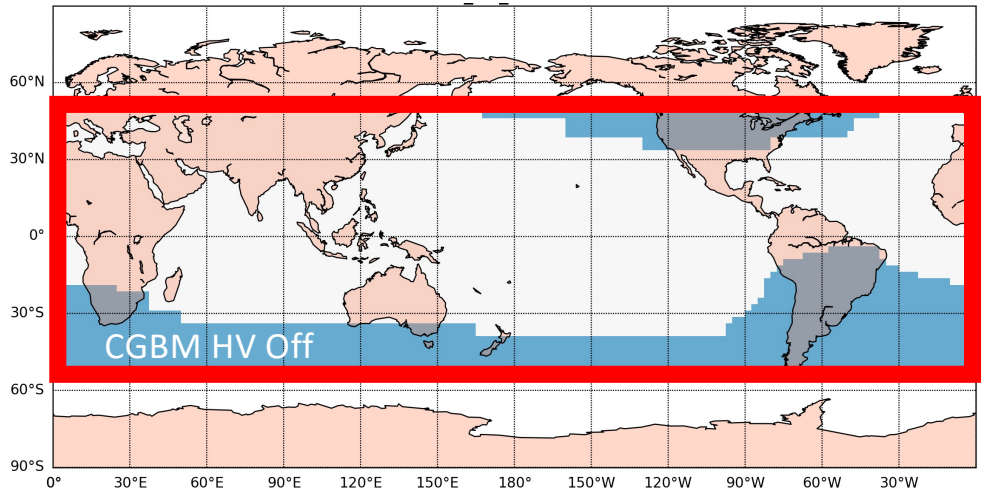
- **CAL has collected gamma-ray data above 1 GeV.**
  Mori et al. in this workshop, Cannady et al. 2018
- **CAL has a possibility of detecting the high-energy gamma-ray from GRBs.**

GRB observation with CALET

Flight operation of CGBM

CGBM has been in operation for more than six years since October 5, 2015.

- Collecting monitor data
  - Time History (TH) data
    1/8s, 4 / 4 ch
  - Pulse Height (PH) data
    4s, 102 + 510 ch
  - High voltages are off at high latitude
    and around SAA



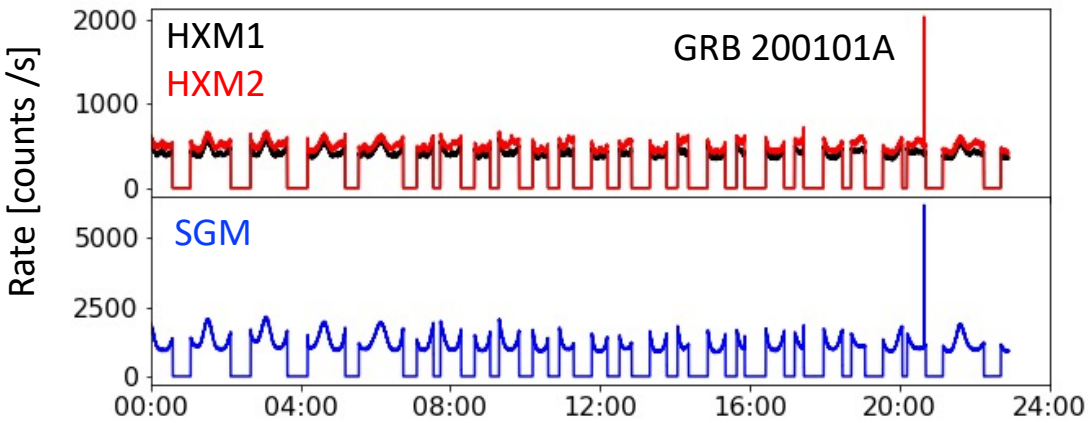
- Onboard trigger & Capturing Event data
  - Calculating signal-to-noise ratio (SNR)
    every 0.25 s
  - Event data capture
    62.5 us, 4096 ch x 2
    When SNR exceeds thresholds
  - Event data downlink (3 times/week)

Trigger settings	HXM	SGM
Threshold	8.5 σ	7.0 σ
Energy range	25 - 100 keV	50 – 300 keV

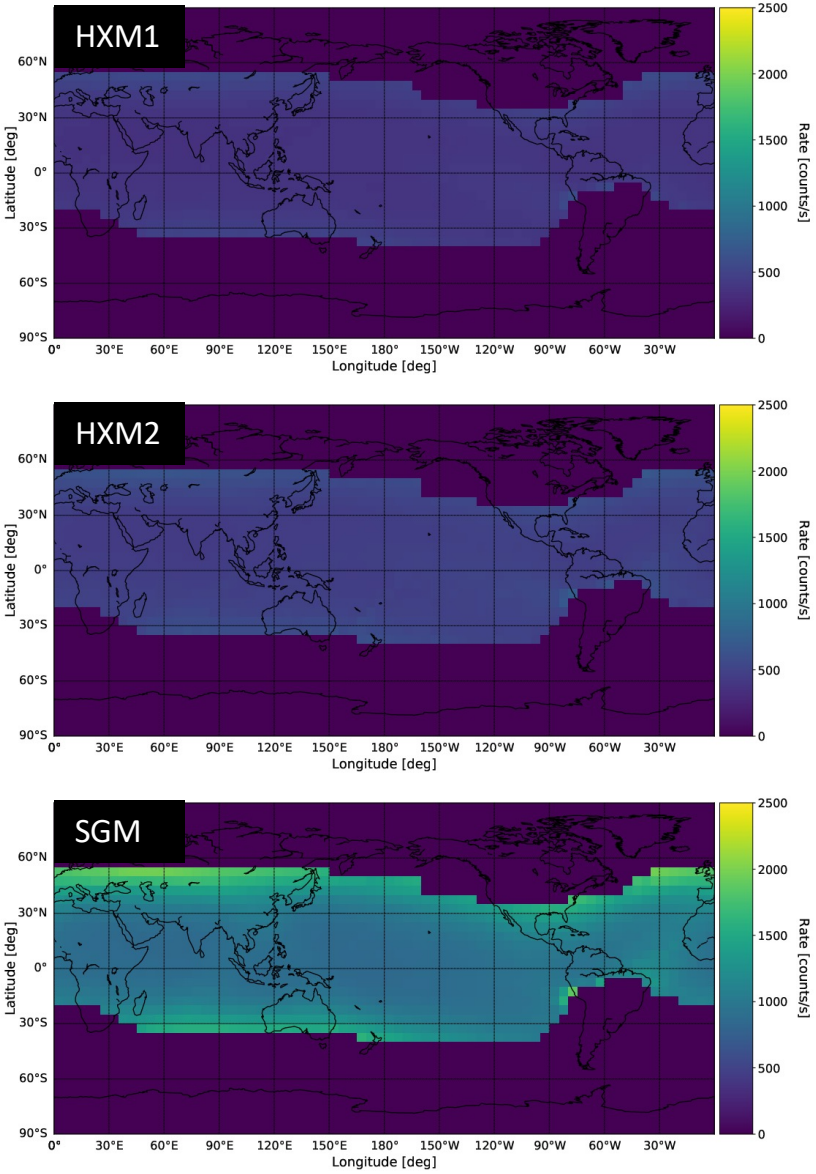
- GCN alert
  - Automatic GCN notice based on real-time TH data (~ 1min)
    Light curves are available on the GCN web page
    (https://gcn.gsfc.nasa.gov/calet_triggers.html)
  - GCN circulars for remarkable events (~ several days)

On-orbit background of CGBM

The Daily count rate of CGBM (2020/01/01)



Averaged background count rate (2020/09)

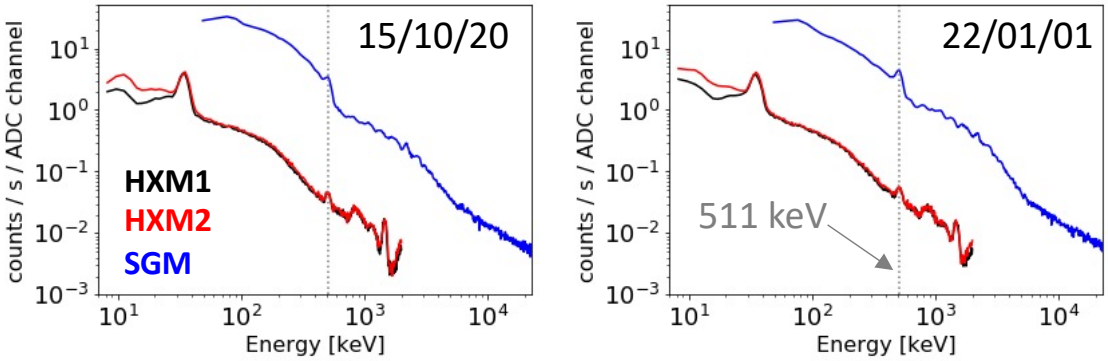


Since we turn CGBM high voltages off at high-count rate regions, duty cycle is ~ 60 %.

Typical count rates (at the low latitude)

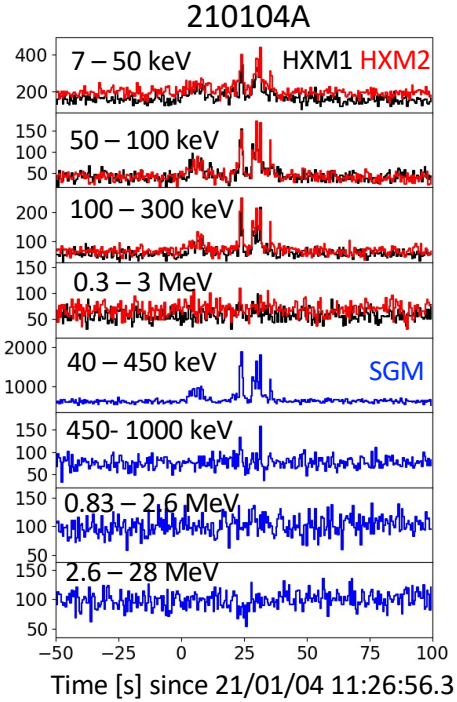
HXM: ~ 500 counts / s

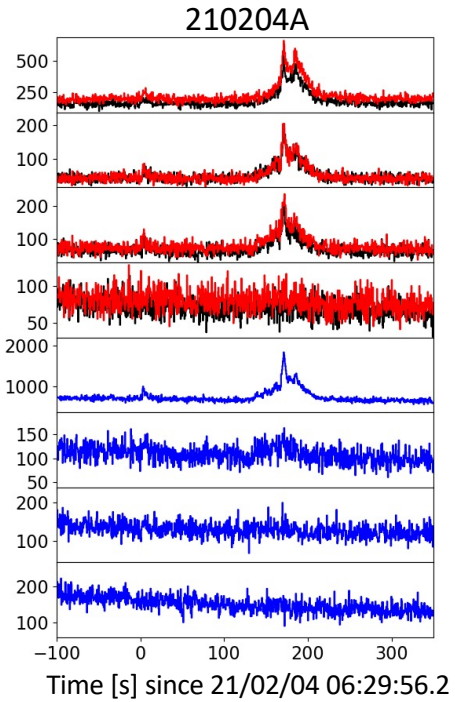
SGM: ~ 1000 counts / s

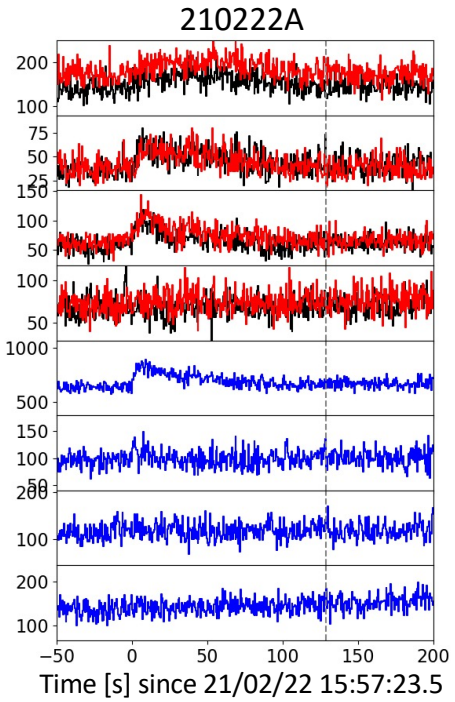


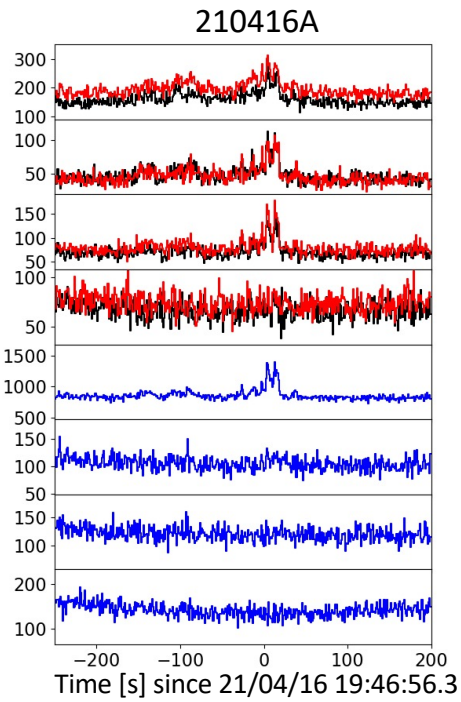
CGBM has continued stable data collection since the observation started.

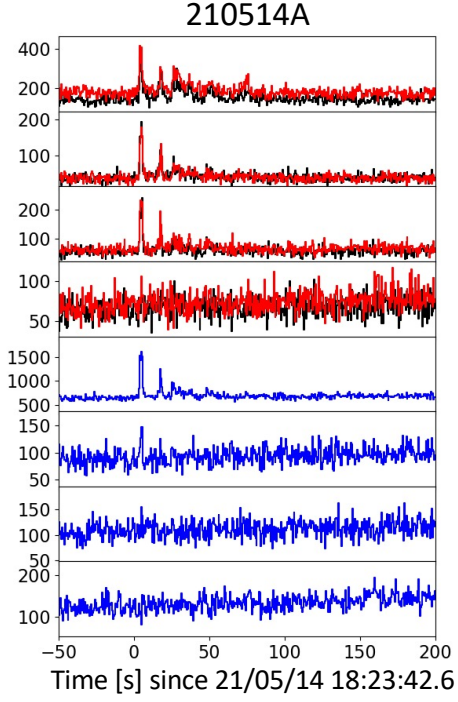
CGBM GRB light curves

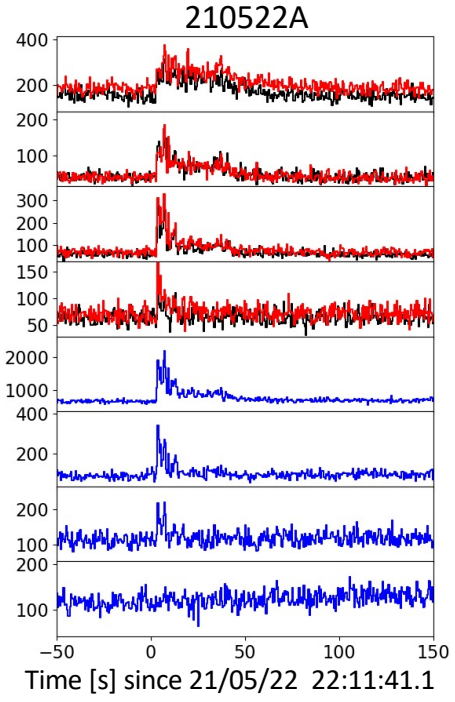


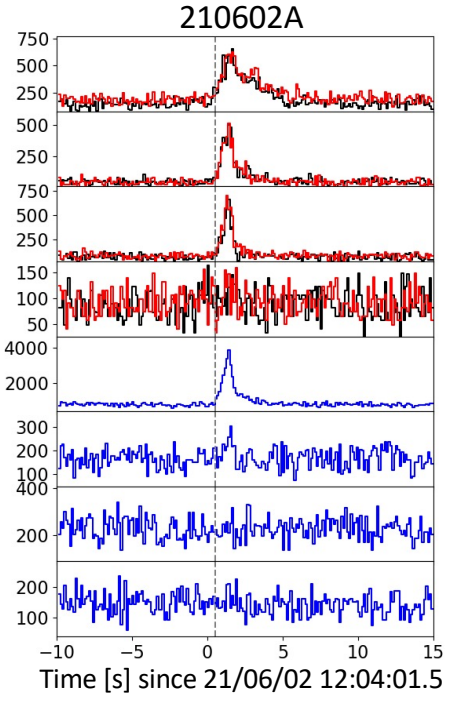


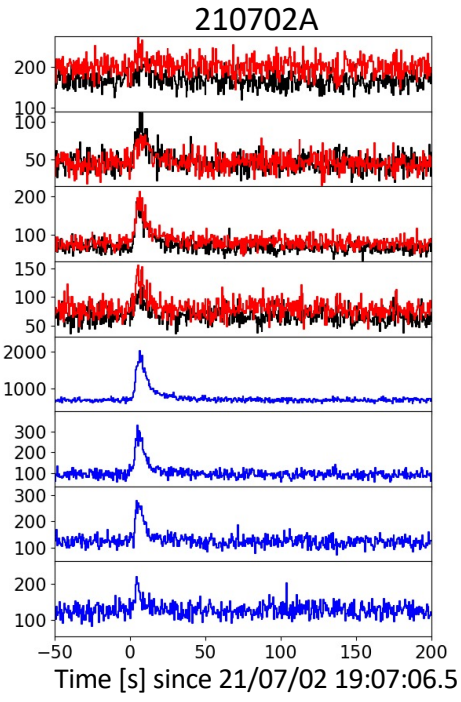












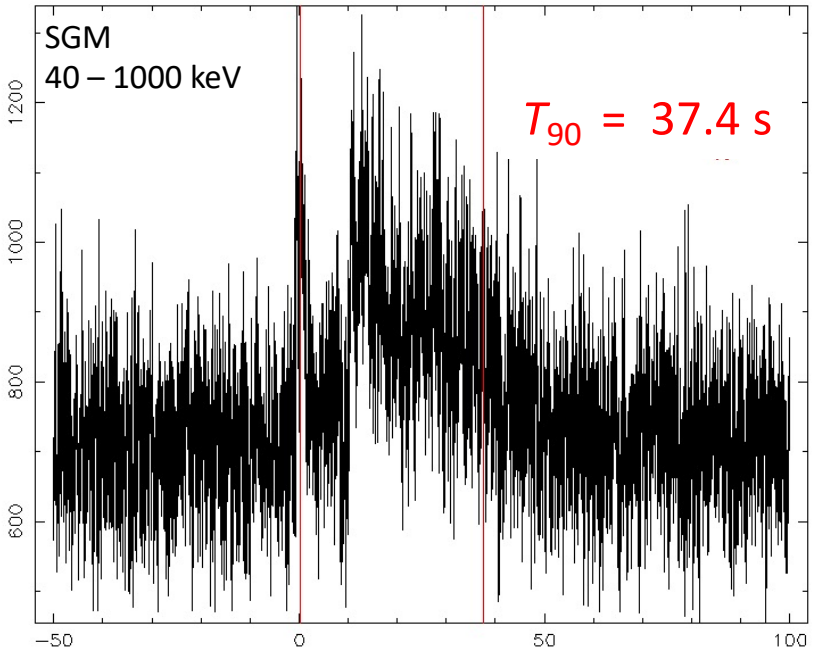
Duration distribution

CGBM has detected 280 GRBs by the onboard trigger .

280 GRBs (2021/10/05 ~ 2022/01/31)

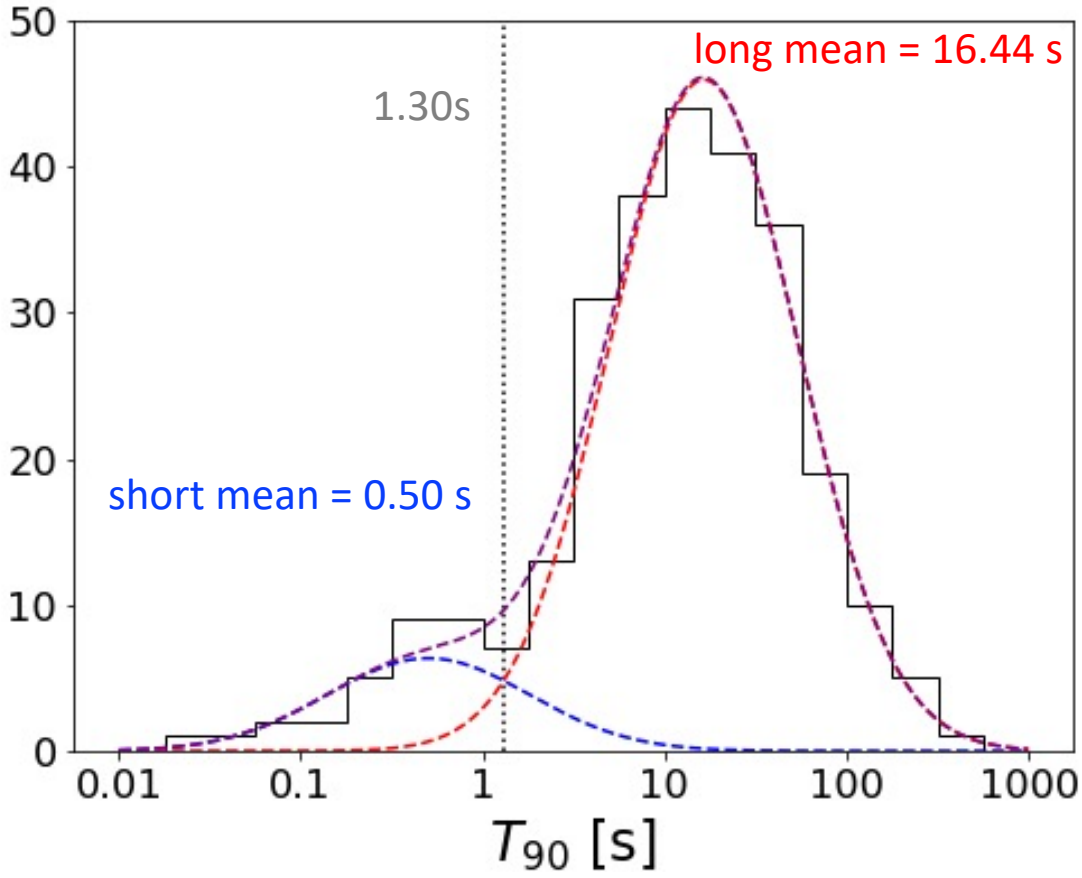
T_{90} < 1.30s : 33 T90 >= 1.30s : 242 (+ 5)

GRB 211227A



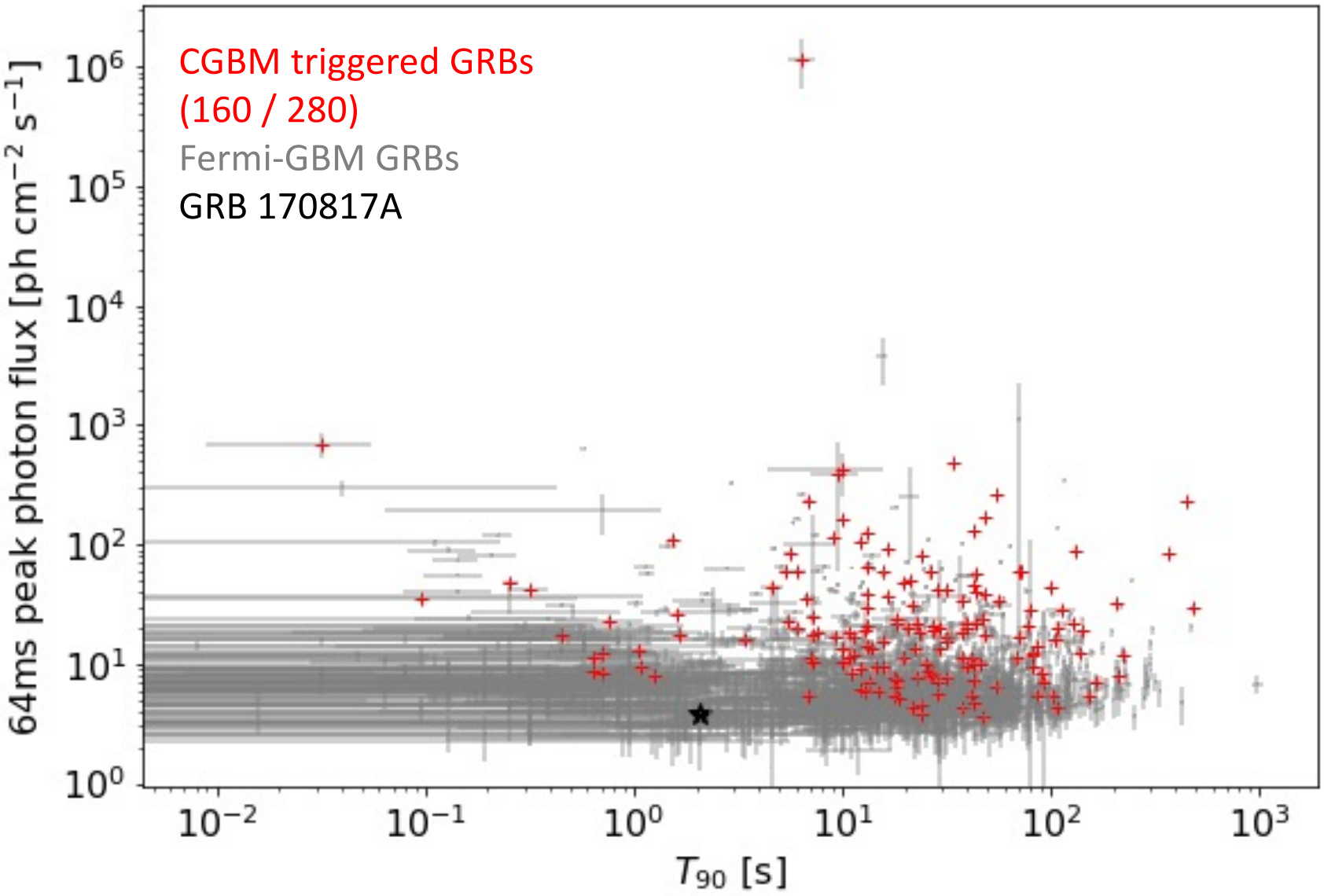
Time [s] since 2021/12/27 23:32:07.5

T_{90} was measured by SGM in the 40 – 1000 keV energy range.



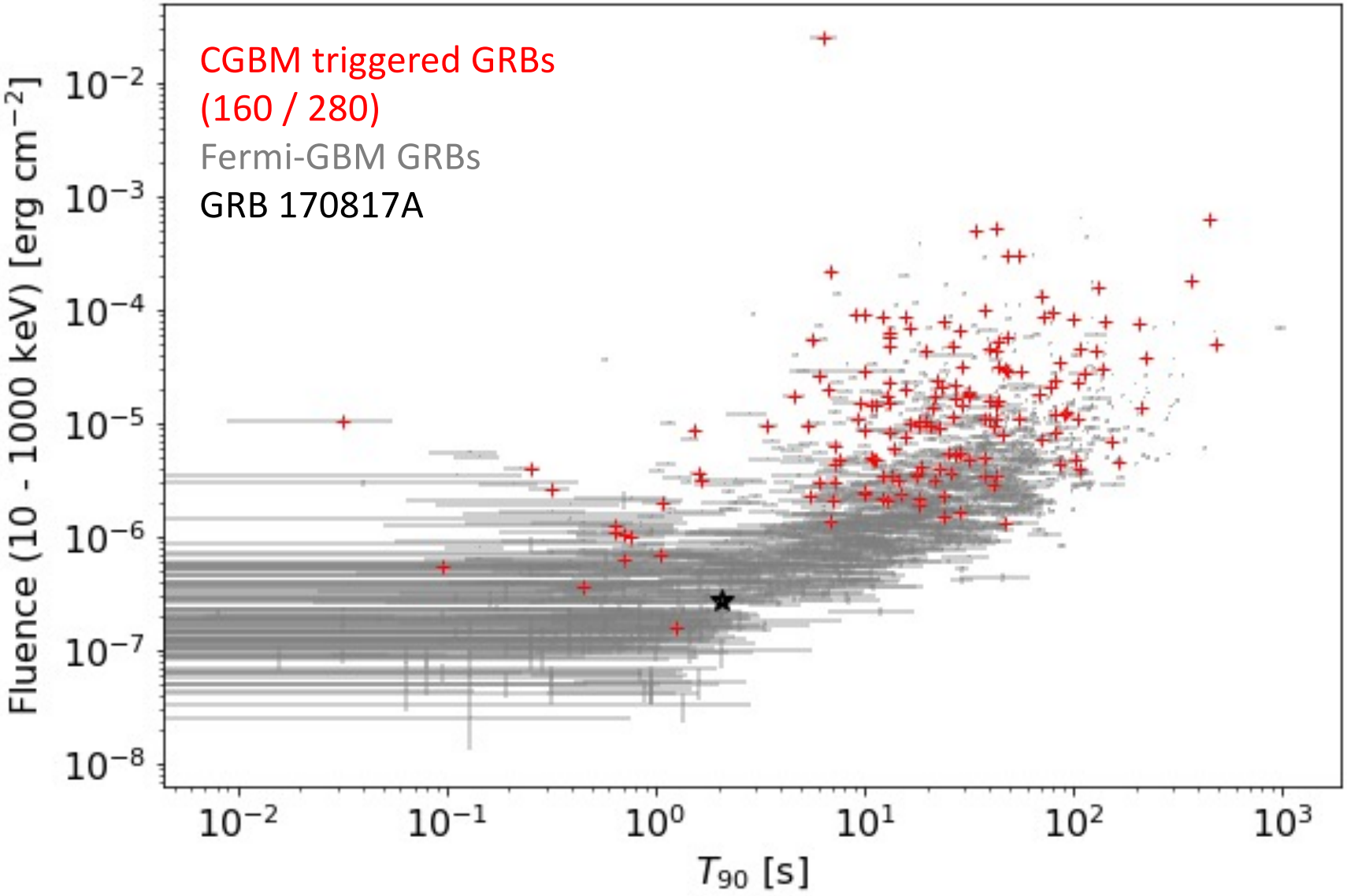
CGBM observed both long and short GRBs.
12 % of CGBM GRBs were classified as short GRBs.

CGBM GRB Properties: Photon flux vs. T_{90}



CGBM has detected high flux in GRBs detected by Fermi-GBM

CGBM GRB Properties: Energy fluence vs. T_{90}



CGBM has detected high flux and fluence in GRBs detected by Fermi-GBM

Transient search system for gamma-ray transient

The transient search system is running in the ground server.

Distribution of L0 data

- CALET data are distributed every hour.

Processing high-level data

Gamma-ray identification

Exposure calculation

- Hourly data are divided into 60 chunks and processed parallelly by 60 cores server.
- High-level data is used for further analysis.
  e.g., GRB, GW analysis
- Prompt gamma-ray identification
- Exposure calculation

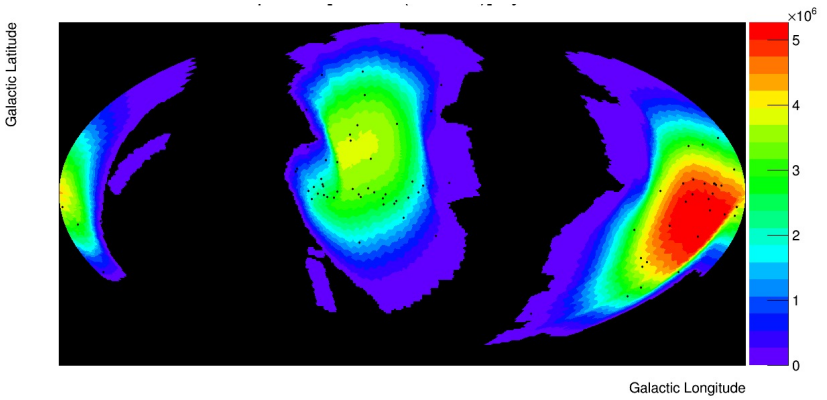
Targeted search for gamma-ray candidates in $T_0 \pm 60$ s

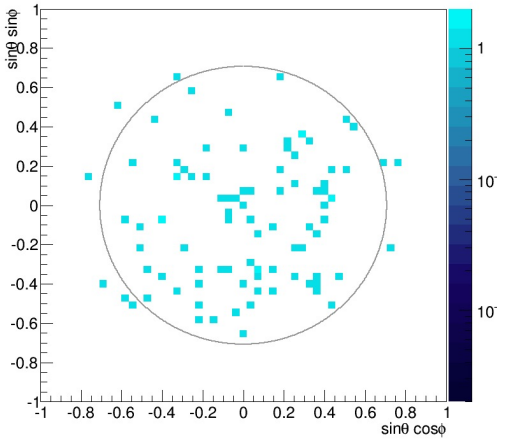
- If CGBM was triggered in the hourly data.
  T_0 is the trigger time of CGBM
- Gamma-ray candidates are listed on the internal web page

Search for pair gamma-rays from the same direction

- Search for high energy gamma-ray transients.
- Pair events are listed on the internal web page.

Making sky maps in detector coordinate and galactic coordinate.





High energy gamma-ray search with CAL

We searched for high-energy gamma-rays from GRBs detected by CGBM.

Method

- Searched for gamma-rays near the GRB positions reported by other instruments
  - Less than 2 degrees from the reported position
- 114 out of 280 GRBs were analyzed
- LEG data from T_0 - 60 s to T_0 + 7200 s

  T_0 is CGBM trigger time.

Results

- 40: No LEG data or outside of the CAL FOV
- 71: Inside of the CAL and No gamma-rays
- 3: A gamma-ray event was found

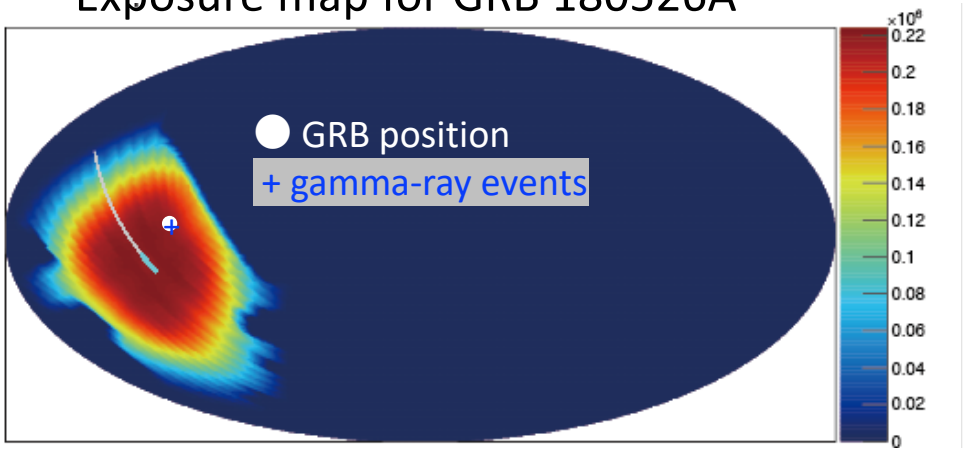
  GRB 180526A

  GRB 200101A

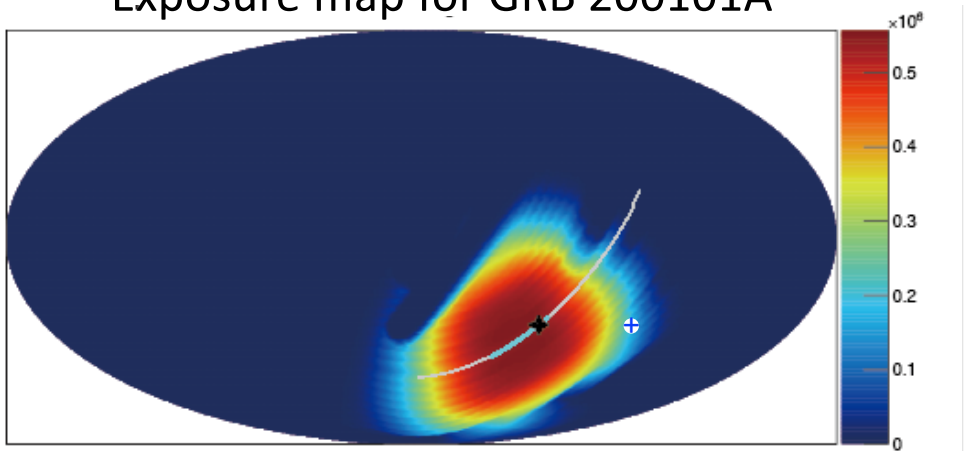
  GRB 200613A (likely to be secondary gamma-rays from ISS structures.)

Candidates of gamma-rays from GRBs (preliminary)

Exposure map for GRB 180526A

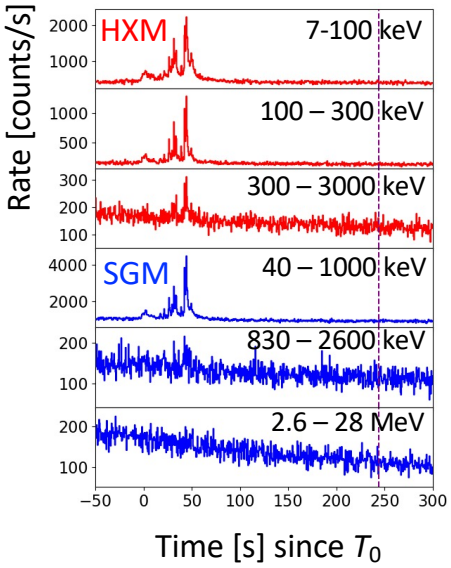


Exposure map for GRB 200101A



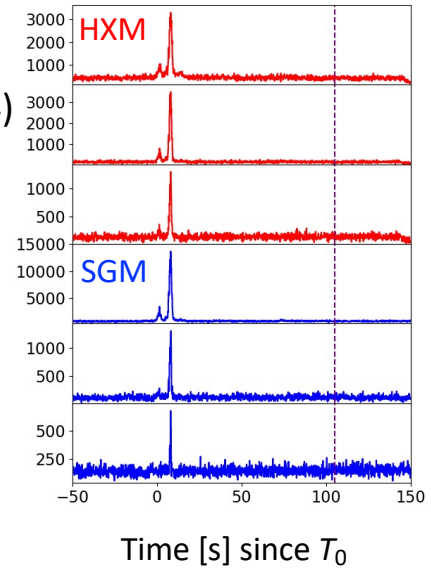
GRB 180526A
T_0 = 2018/05/26 11:03:36
(R.A, Dec.) = (108.48, 3.64)
(Fermi-LAT, Ajello, et al. 2019)

Candidate information
Opening angle: 1.34 deg.
(within 99% of PSF)
Arrival time: T_0 + 244 s
Energy: 3.46 GeV



GRB 200101A
T_0 = 2020/01/01 20:39:30.40
(R.A., Dec.) = (258.995, -32.304)
(IPN, GCN circular #26635)

Candidate information
Opening angle: 0.59 deg.
(within 90% of PSF)
Arrival time: T_0 + 105 s
Energy : 4.92 GeV



Although no decisive detection, two candidates from CGBM GRBs were found.

Search for electromagnetic (EM) counterparts of gravitational wave (GW) events

Follow-up for EM counterpart of GW events

CALET started the flight operation in October 2015 ,and CALET has actively participated in follow-up observation of EM counterparts of GW events since the middle of O1.

O1 & O2 (Adriani et al. 2016, Yamaoka et al. 2017, Adriani et al. 2018)

No candidate was found for any GW events in O1 & O2

- GW 150914 occurred before the operation start.
- GW 170817 & GRB 170817A (next slide)

O3 (Adriani et al. submitted to ApJ)

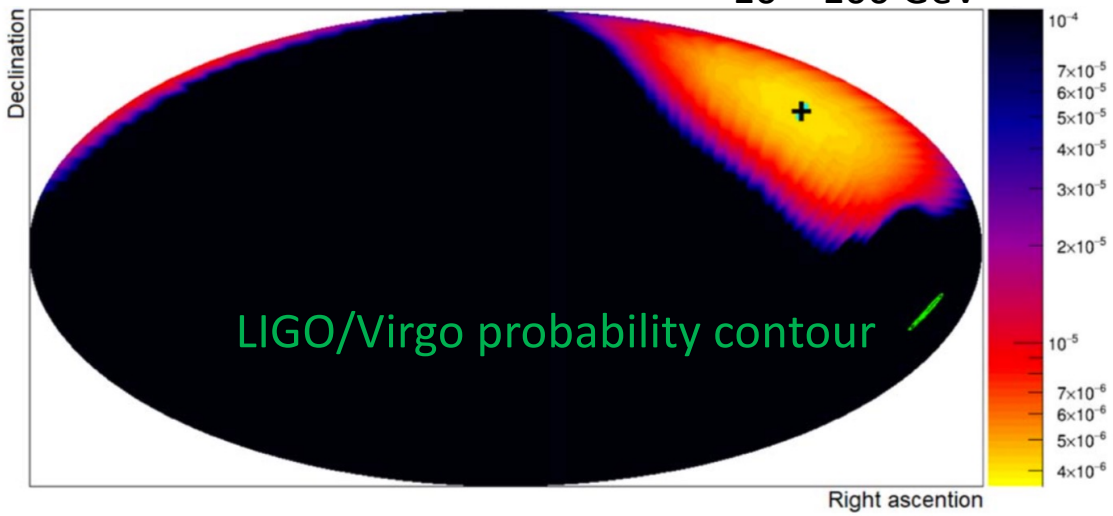
No candidate was found for any GW events in O3

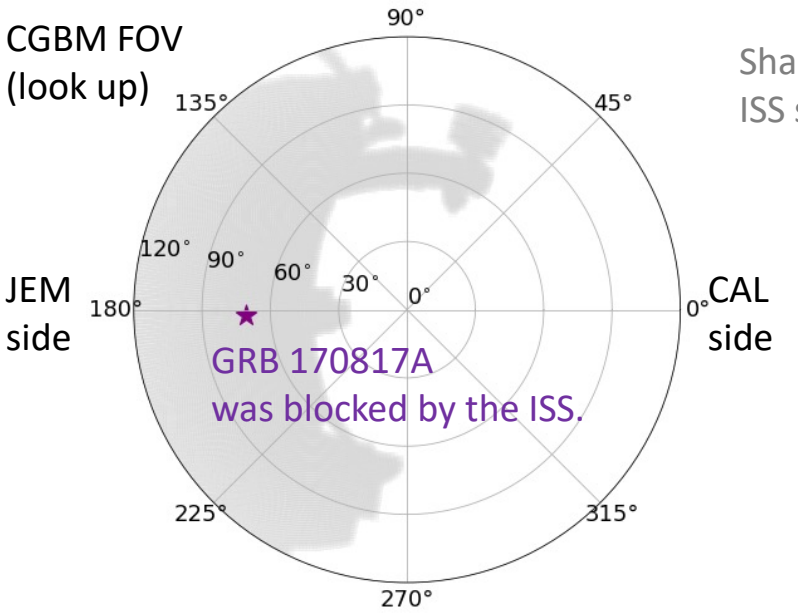
- CGBM observation & analysis
  - Signal search in TH data
  - $T_0 - 60$ s ~ $T_0 + 60$ s
  - Upper limit calculation
    - 1 s duration
    - Band function: $\alpha = -0.46$, $\beta = -2.98$, and $E_{peak} = 413$ keV (Poolakkil et al. 2021)
- CAL observation & analysis
  - Signal search with HE (> 10 GeV) or LEG (1 GeV) data
  - $T_0 - 60$ s ~ $T_0 + 60$ s
  - Upper limit calculation
    - Power-law with photon index -2

GW 170817 & GRB 170817A

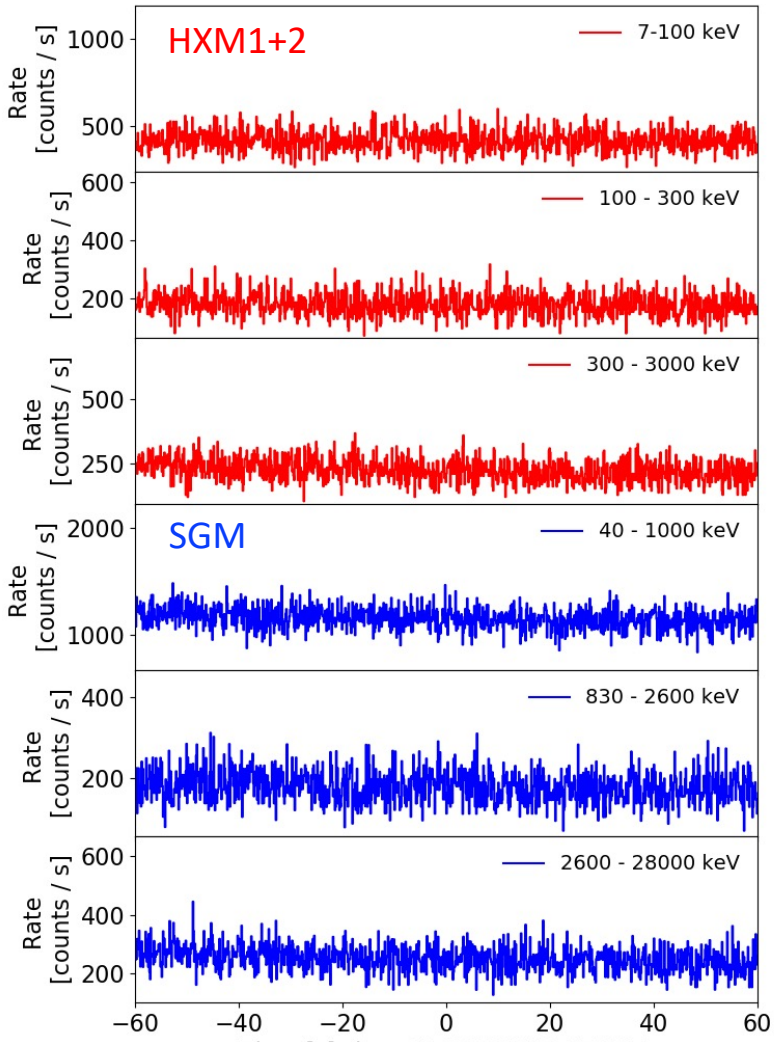
CAL and CGBM were observing at the trigger time of GW 170817A & GRB 170817A.

Adriani et al. 2018





Shadow of the ISS structures

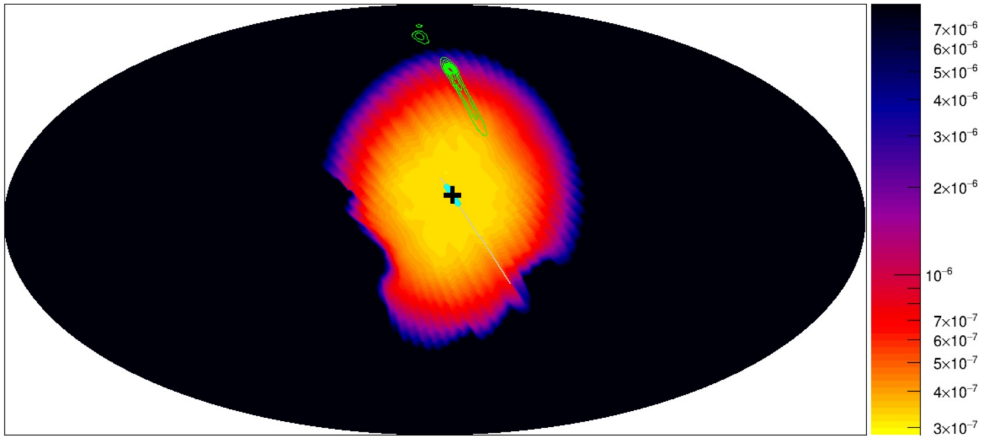


Unfortunately, the direction of GRB 170817A was blocked by ISS structures.

CALET observation in O3

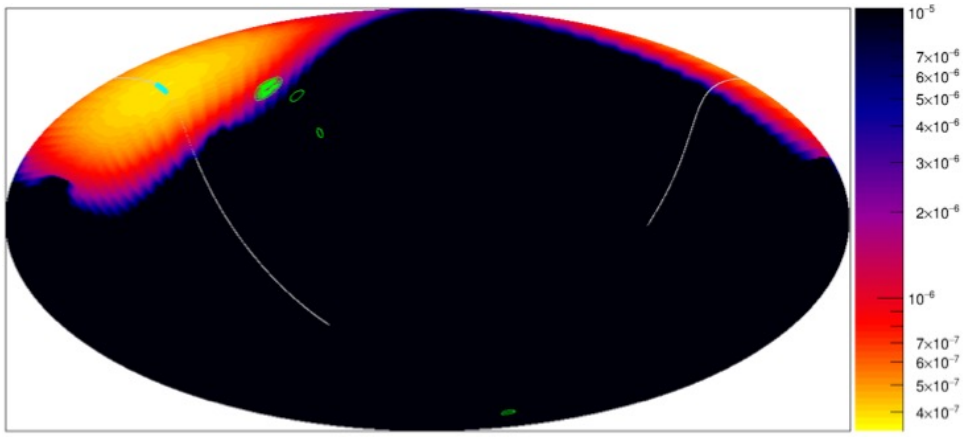
S190408an LEG 1~10 GeV

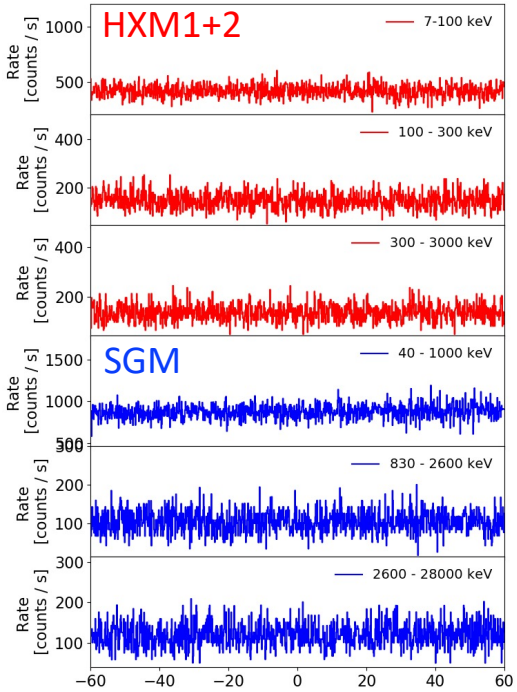
erg cm^{-2} s^{-1}



S200316bj HE 10~100 GeV

erg cm^{-2} s^{-1}





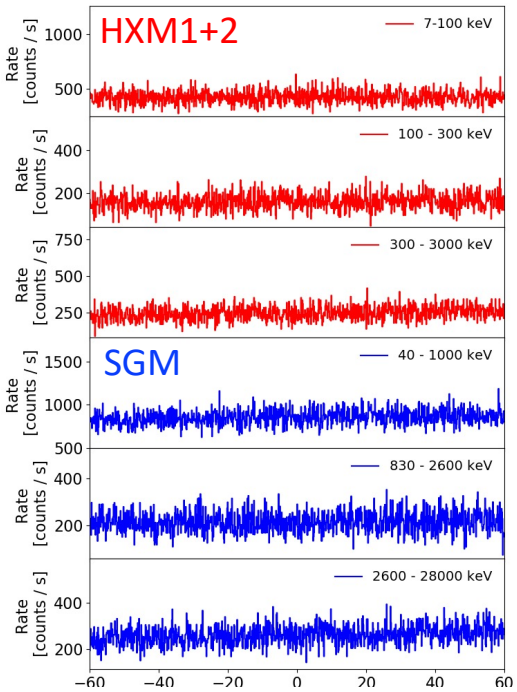
Time [s] since 19/04/08 18:18:02.3

7σ upper limit
(10 - 1000 keV)

HXM1
9.7×10^{-7} erg cm^{-2} s^{-1}

HXM2
1.2×10^{-6} erg cm^{-2} s^{-1}

SGM
8.2×10^{-7} erg cm^{-2} s^{-1}



Time [s] since 19/03/16 21:57:56.2

7σ upper limit
(10 - 1000 keV)

HXM1
1.0×10^{-6} erg cm^{-2} s^{-1}

HXM2
1.1×10^{-6} erg cm^{-2} s^{-1}

SGM
8.3×10^{-7} erg cm^{-2} s^{-1}

There was no candidate of EM counterparts of the GW events in CALET data.

Summary of O3

LIGO / Virgo collaboration (LVC) reported 56 GW events (except for retracted event).
LVC and Fermi-GBM team reported a sub-threshold event was reported.

* For safety during a special ISS activity

CGBM statistics

21 : HV off
4 : Outside of the FOV
32 : No detection

CAL statistics

37 : Outside of the FOV or HV off *
13 : No detection (HE)
7 : No detection (LEG)

Event ID	SGM summed probability	SGM upper limit (10 – 1000 keV) [erg cm^{-2} s^{-1}]	CAL summed probability	CAL 90 % upper limit [erg cm^{-2} s^{-1}]
S190408an	100 %	8.2×10^{-7}	95 %	3.0×10^{-7} (10 - 100 GeV)
S190412m	-	-	-	HV off*
S190421ar	0 %	-	0 %	Outside of the FOV
S190425z	-	-	10 %	8.5×10^{-5} (10 - 100 GeV)
S190426c	-	-	10 %	9.2×10^{-6} (10 - 100 GeV)
S190503bf	-	-	25 %	7.1×10^{-5} (10 - 100 GeV)
S190510g	4 %	1.2×10^{-6}	0 %	Outside of the FOV

The table continues. (Adriani et al. submitted to ApJ)

Summary

- CAL and CGBM have been continuing the flight operation for more than six years.
- As of the end of January 2022, CGBM has detected **280 GRBs, including 33 short GRBs**.
  - CGBM has detected high flux and fluence GRBs in GRBs detected by Fermi-GBM.
- High energy gamma-ray search from CGBM GRBs was performed, and **two candidates of the GRB gamma-rays** were found.
- CALET has performed the search for EM counterparts of GW events.
  - No candidate was found in O1, O2, O3.
- **CALET is currently approved to continue operating through 2024**. We will participate in follow-up observations in the upcoming O4.