



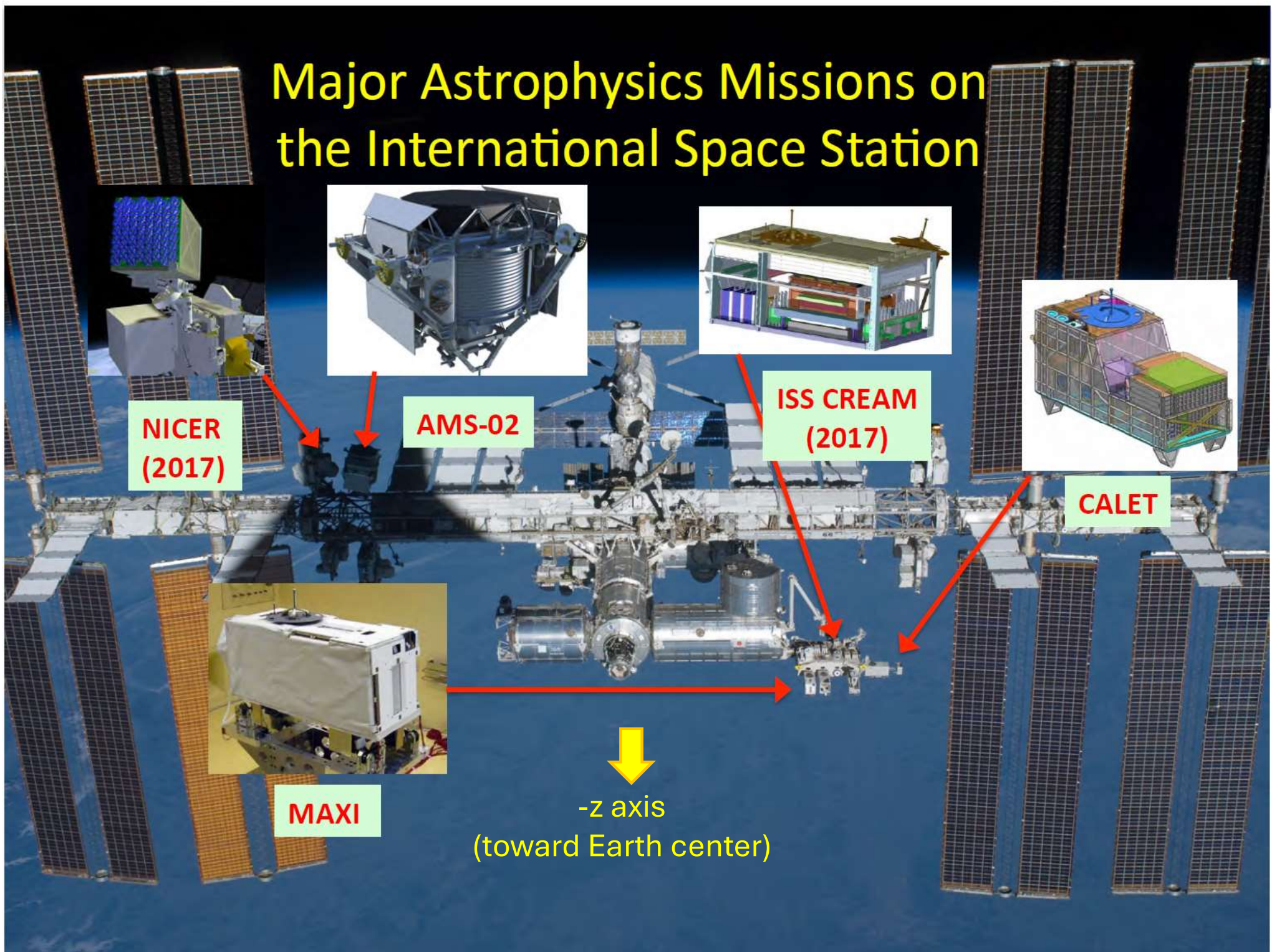
# CALET Alert System

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Ritsumeikan University

II “Synergies at New Frontiers”, Kashiwa Library, Univ. Tokyo, 25-26 March, 2024

# Major Astrophysics Missions on the International Space Station



**NICER  
(2017)**

**AMS-02**

**ISS CREAM  
(2017)**

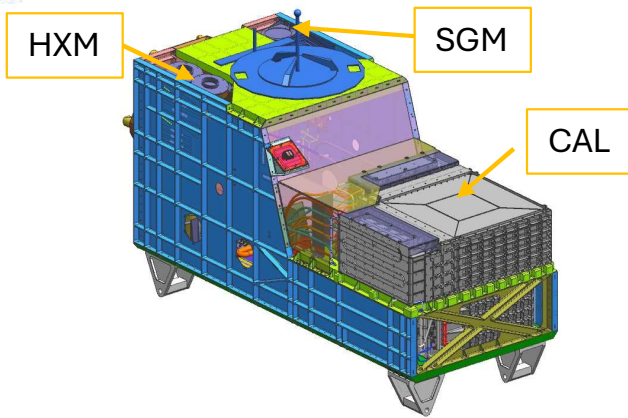
**CALET**

**MAXI**

**-z axis  
(toward Earth center)**



# CALET (CALorimetric Electron Telescope)



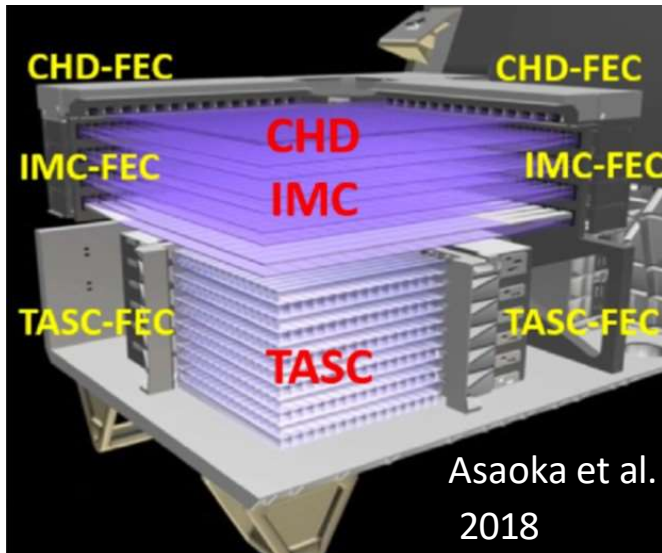
- In operation on the Japanese Experiment Module (JEM) `Kibo'-Exposed Facility of the International Space Station since 2015
- Japan-USA-Italy collaboration

## Calorimeter (CAL)

Electrons: 1 GeV - 20 TeV

Gamma rays: 1 GeV – 10 TeV

Protons and nuclei: 10 GeV – 1 PeV



### CHD

- charge

### IMC

- tracking  
- particle ID

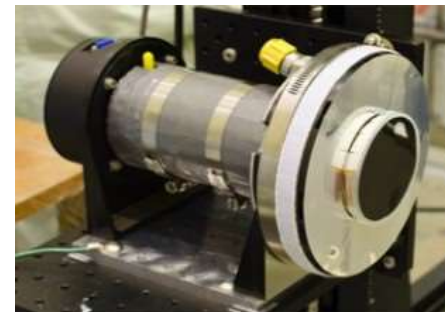
### TASC

- energy  
- particle ID

High-energy gamma rays

## CALET Gamma Ray Burst Monitor (CGBM)

### • Hard X-ray Monitor (HXM)



7 - 1000 keV  
LaBr<sub>3</sub>(Ce) + PMT  
(2 sets)

### • Soft Gamma-ray Monitor (SGM)



0.04 – 20 MeV  
BGO + PMT  
(1 set)

Prompt emission from transients



# Performance of CAL and CGBM

CAL	
Energy resolution	~3 % @ 10 GeV
Energy range	1 GeV – 10 TeV
Field of view	~ 2 sr
Angular resolution	~0.5 deg. @ 10 GeV

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

	CGBM	
	HXM	SGM
Crystal	LaBr <sub>3</sub> (Ce)	BGO
Number of detectors	2	1
Diameter [mm]	66.1 (small) 78.7 (large)	102
Thickness [mm]	12.7	76
Energy range [keV]	7-1000	40-20000
Field of view	~3 sr	~8 sr

Yamaoka et al., Proc. 7th Huntsville Gamma-Ray Burst Symposium, 41, C1304143, 2013



# Gamma Ray Event Selection (CAL)

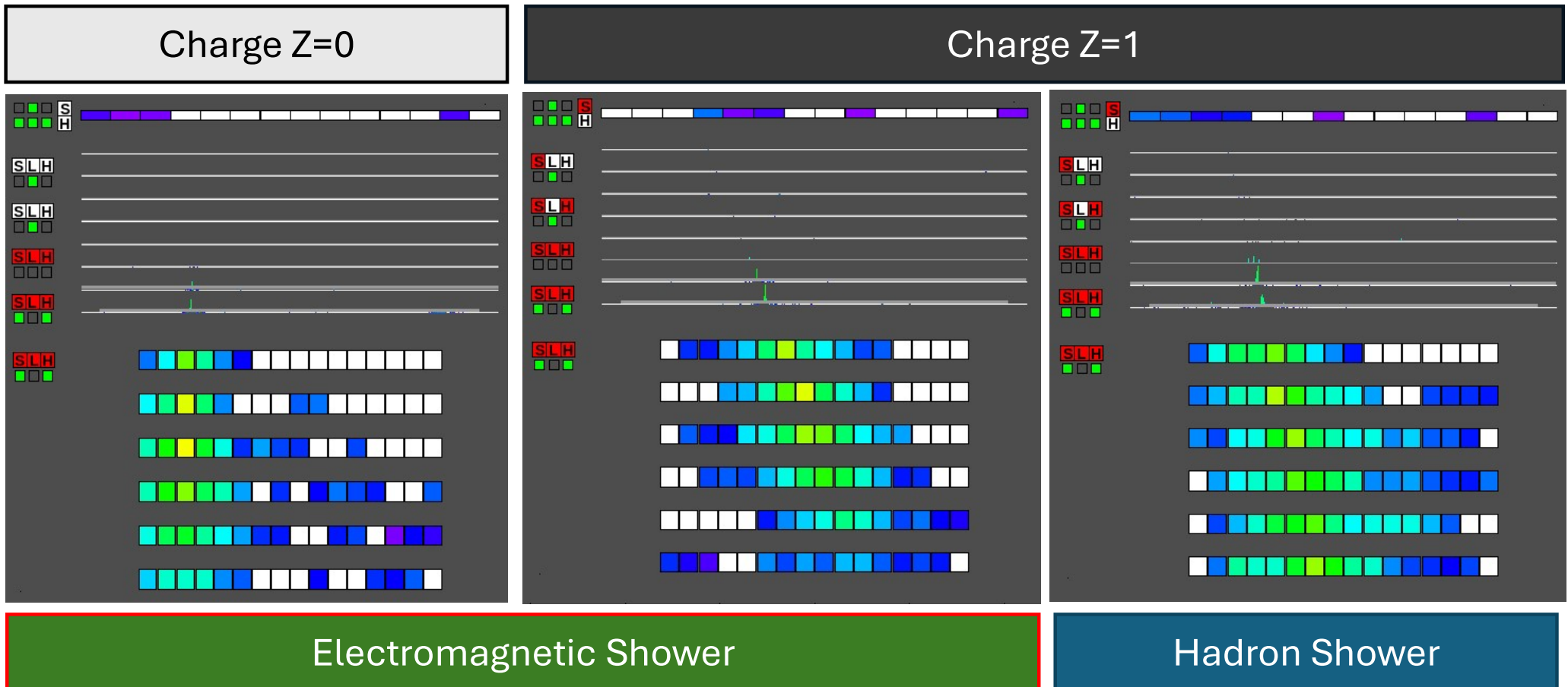
= Electron Selection Cut + Gamma-ray ID Cut w/ Lower Energy Extension

## 100 GeV Event Examples

gamma-ray

electron

proton



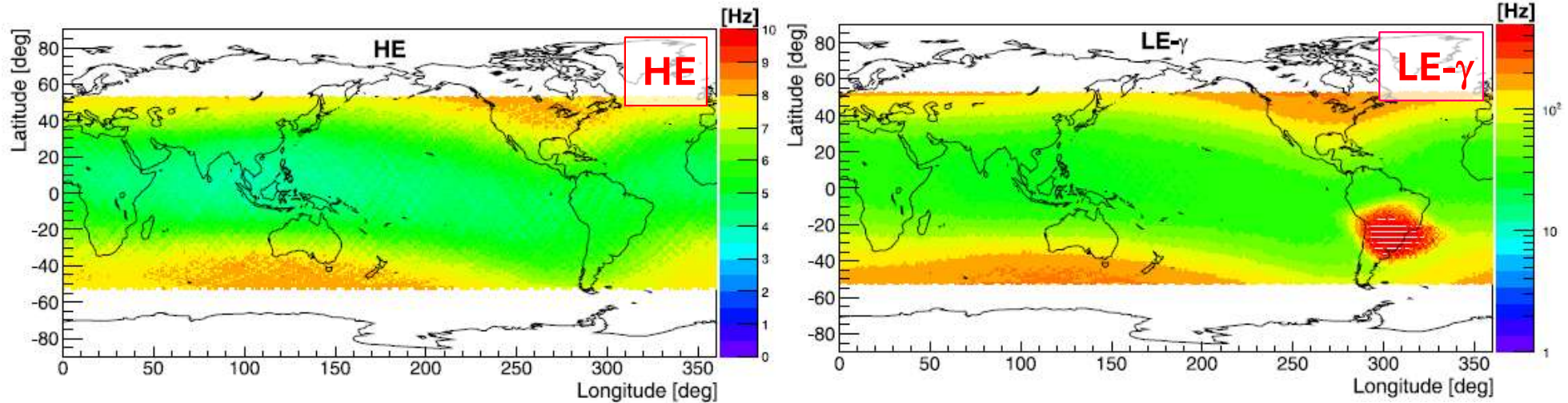
well contained, constant shower development

larger spread<sub>5</sub>



# CALET triggers and gamma-ray observation

Trigger rate vs ISS location Asaoka et al., Astropart.Phys. 100, 29 (2018)



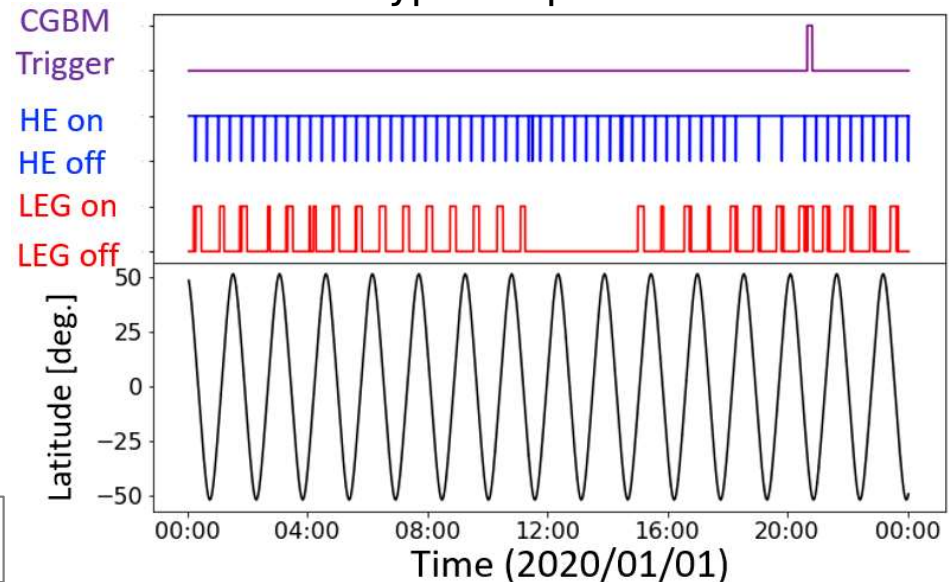
HE trigger:  $E_\gamma > 10 \text{ GeV}$

LE- $\gamma$  trigger:  $E_\gamma > 1 \text{ GeV}$

- HE trigger mode: always ON
- LE- $\gamma$  mode: ON when geomag.lat.  $< 20^\circ$  or CALET Gamma-ray Burst Monitor (CGBM) is triggered

ISS orbit: altitude  $\sim 400 \text{ km}$ , incl.  $51.6^\circ$

## Typical operation

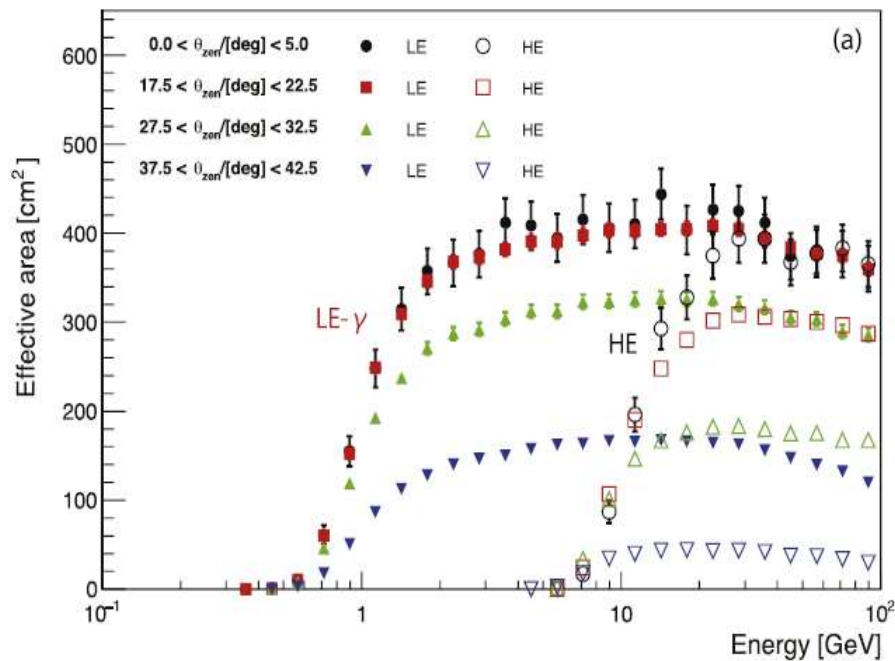




# Effective area for gamma rays

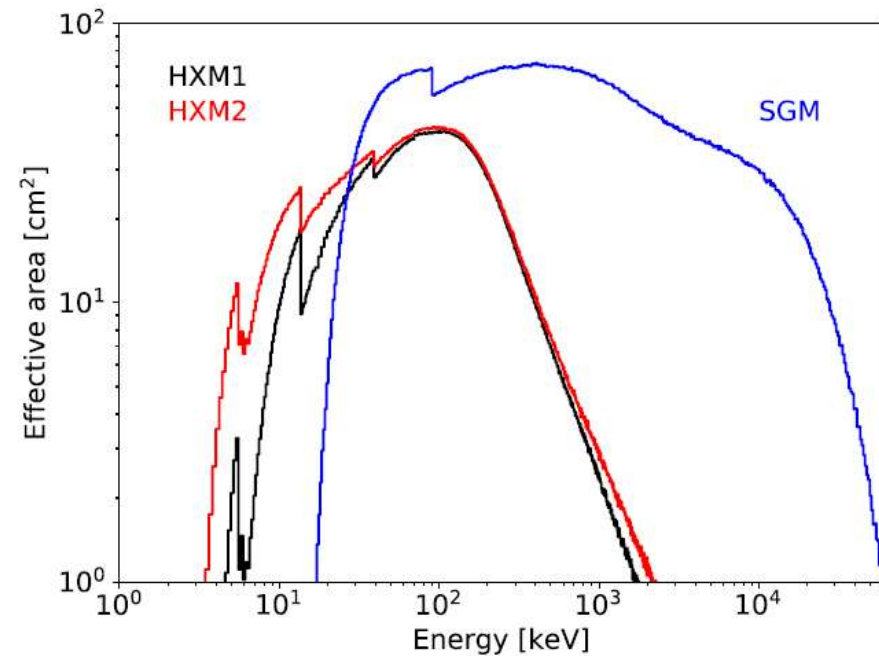
Adriani et al., ApJ 933, 85 (2022)

## CAL



**Figure 6.** (a) CAL effective area for gamma rays as a function of energy in four zenith angle ranges for both the LEG (CC Track, solid symbols) and HE (EM Track, open symbols) trigger configurations, from Adriani et al. (2018).

## CGBM



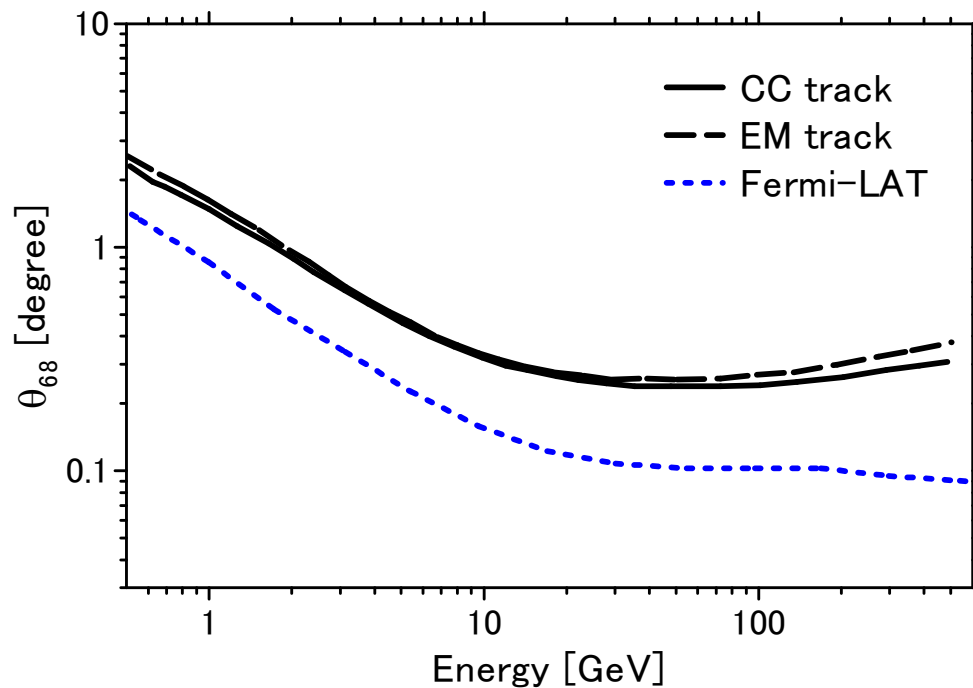
**Figure 2.** CGBM effective areas vs. gamma-ray energy for the individual HXM1 and HXM2 detectors and for SGM at vertical incidence.



# CALET/CAL performance

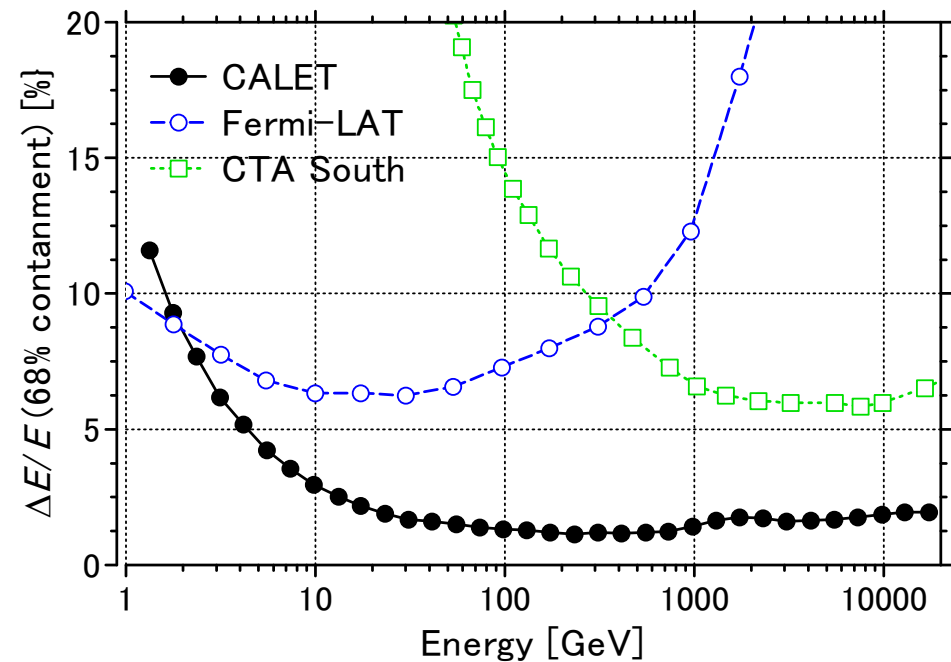
- **HE trigger ( $>10$  GeV)** is always active in normal observations
- **LE- $\gamma$  trigger ( $>1$  GeV)** mode is activated when the geomagnetic latitude is below  $20^\circ$  or following a CALET Gamma-ray Burst Monitor (CGBM) burst trigger

## Angular resolution



Cannady et al., ApJS 238, 5 (2018)

## Energy resolution



Asaoka et al, Astropart. Phys. 91, 1 (2017)

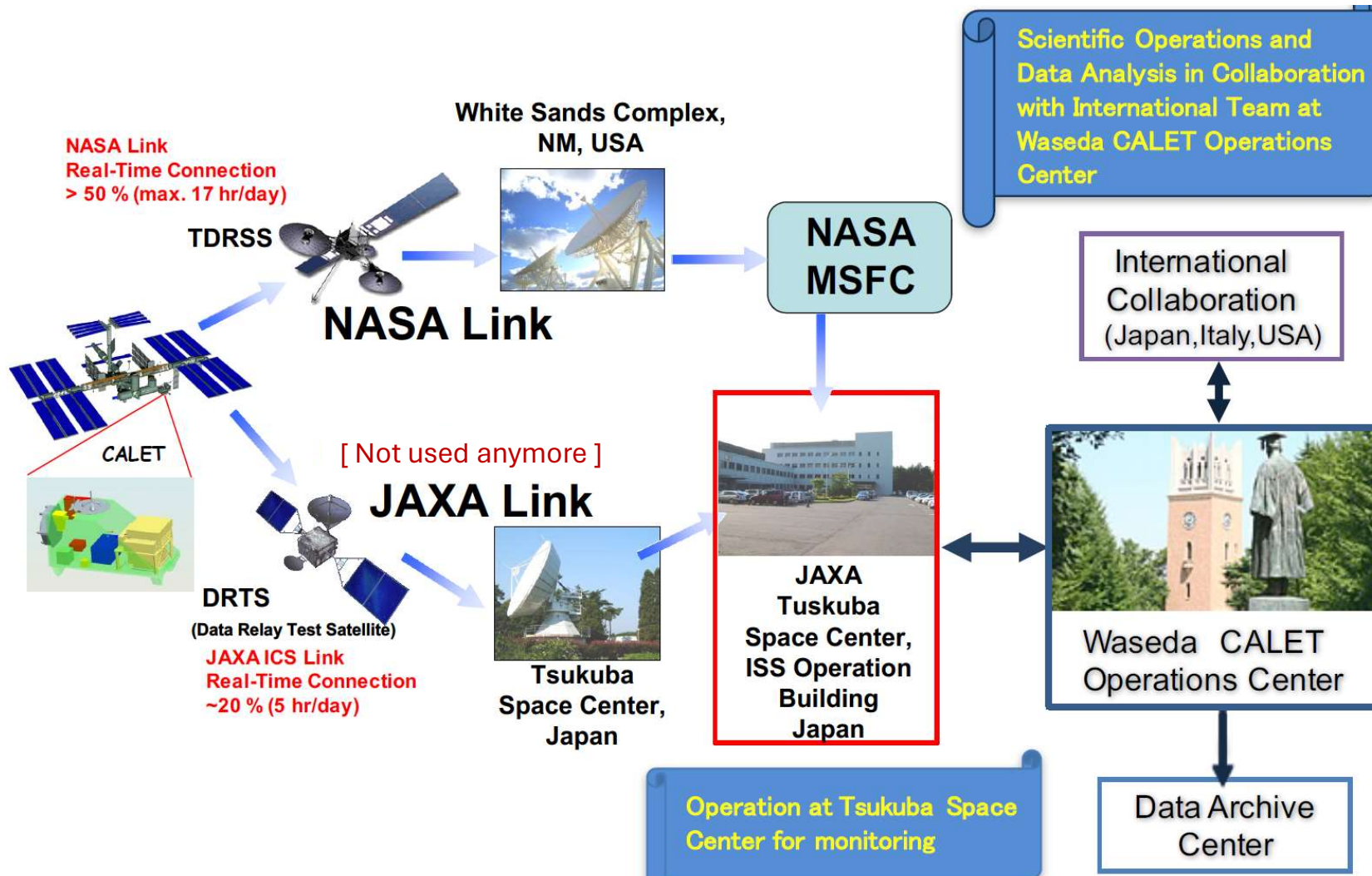
- Good energy resolution at high energies thanks to the thick calorimeter!





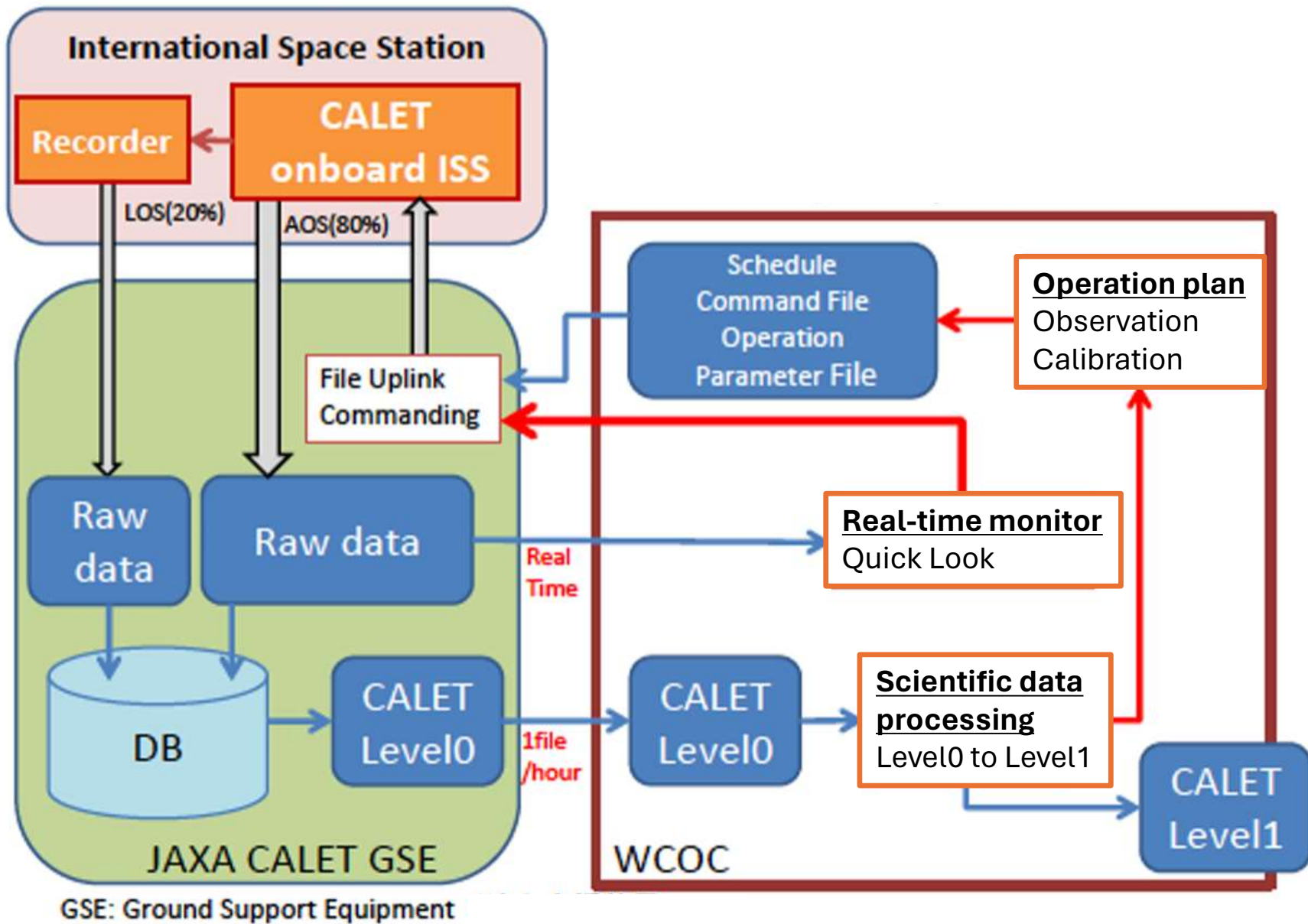
# CALET data downlink scheme

Low speed link (50 kbps, almost **real time**): house keeping data etc.  
Medium speed link (600 kbps, **every hour**): raw data (“level 0”)





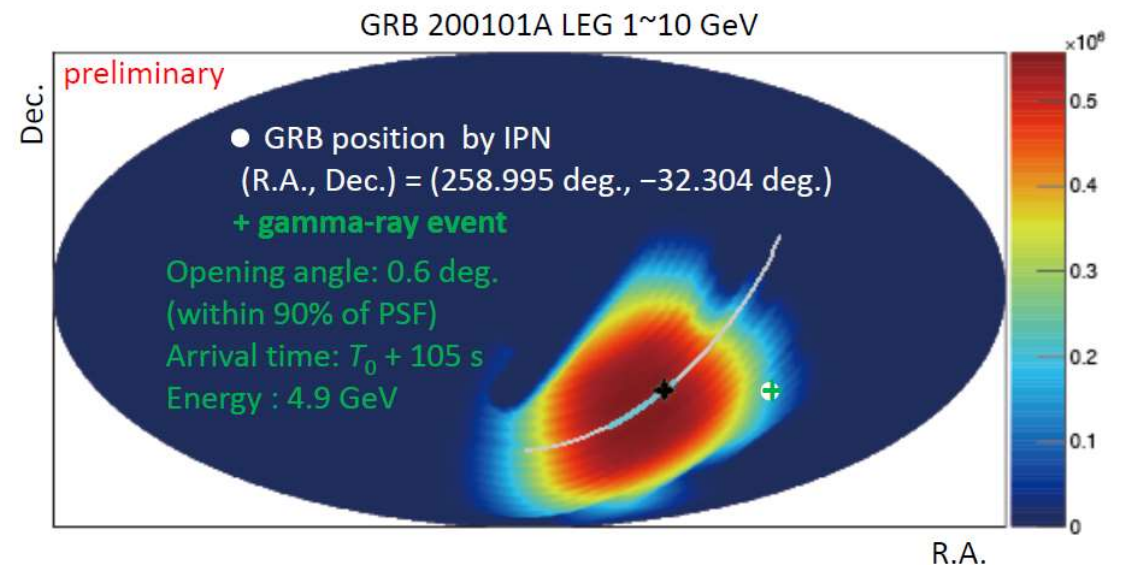
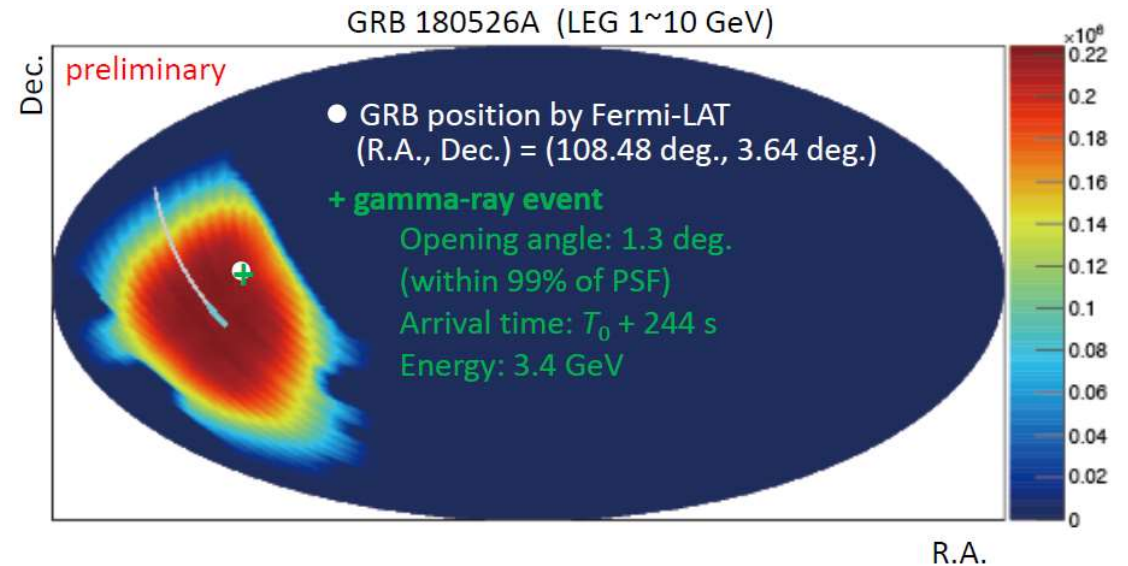
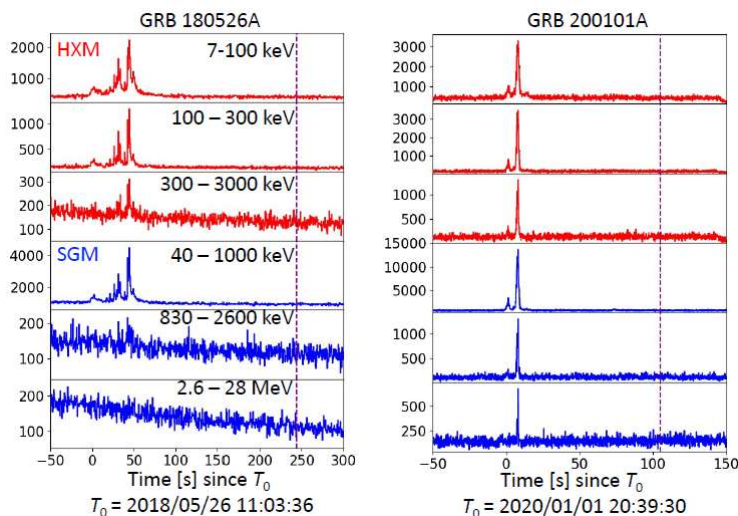
# CALET ground system – data flow





# CAL gamma-ray search for CGBM-detected events

- 99 GRBs detected by CGBM
- Looked LE- $\gamma$  data in [ $T_0$ -60s,  $T_0$ +60s] within 2 deg from the central position
- 37 GRBs: no LE- $\gamma$  data
- 59 GRBs: no LE- $\gamma$  events
- 3 GRBs with LE- $\gamma$  events
  - GRB 180526A
  - GRB 200101A
  - GRB 200613A – likely secondary

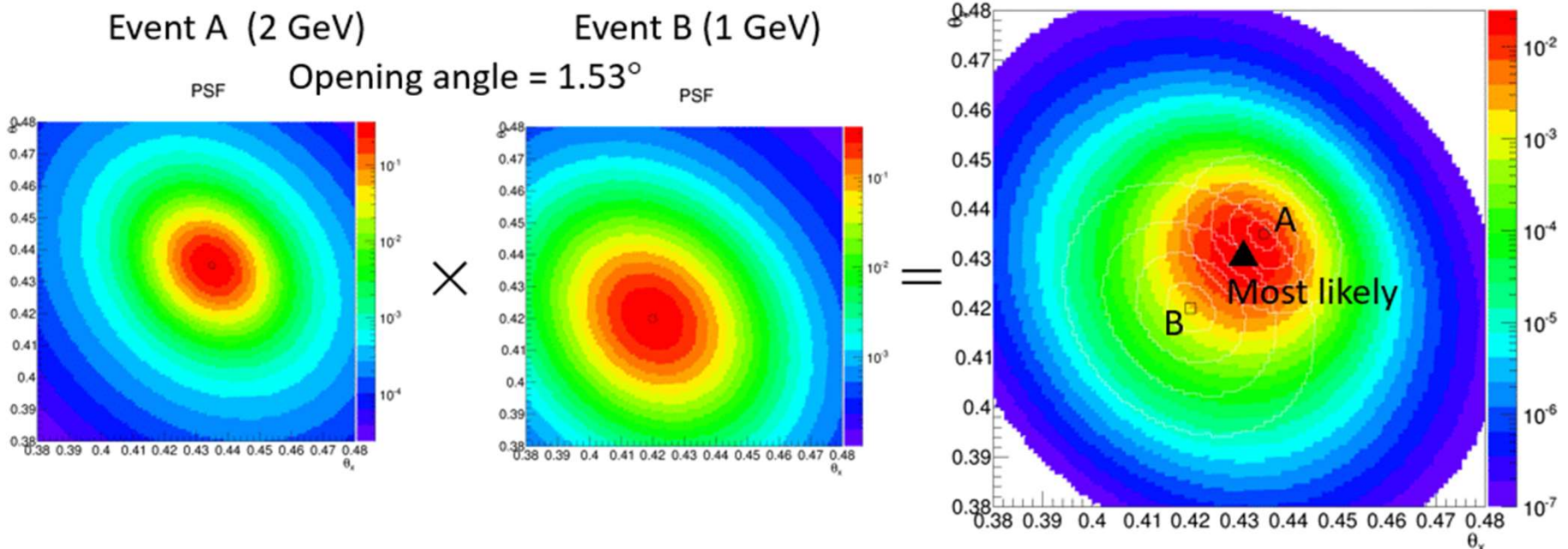




# Searching transient events with CAL

- Gamma ray bursts, AGN flares, EM counterparts of GW, ...
- We define a ‘transient event’ as a gamma-ray pair coming from the same direction (within our angular resolution) in a 120-s time window.

Judging ‘pairs’ using PSF

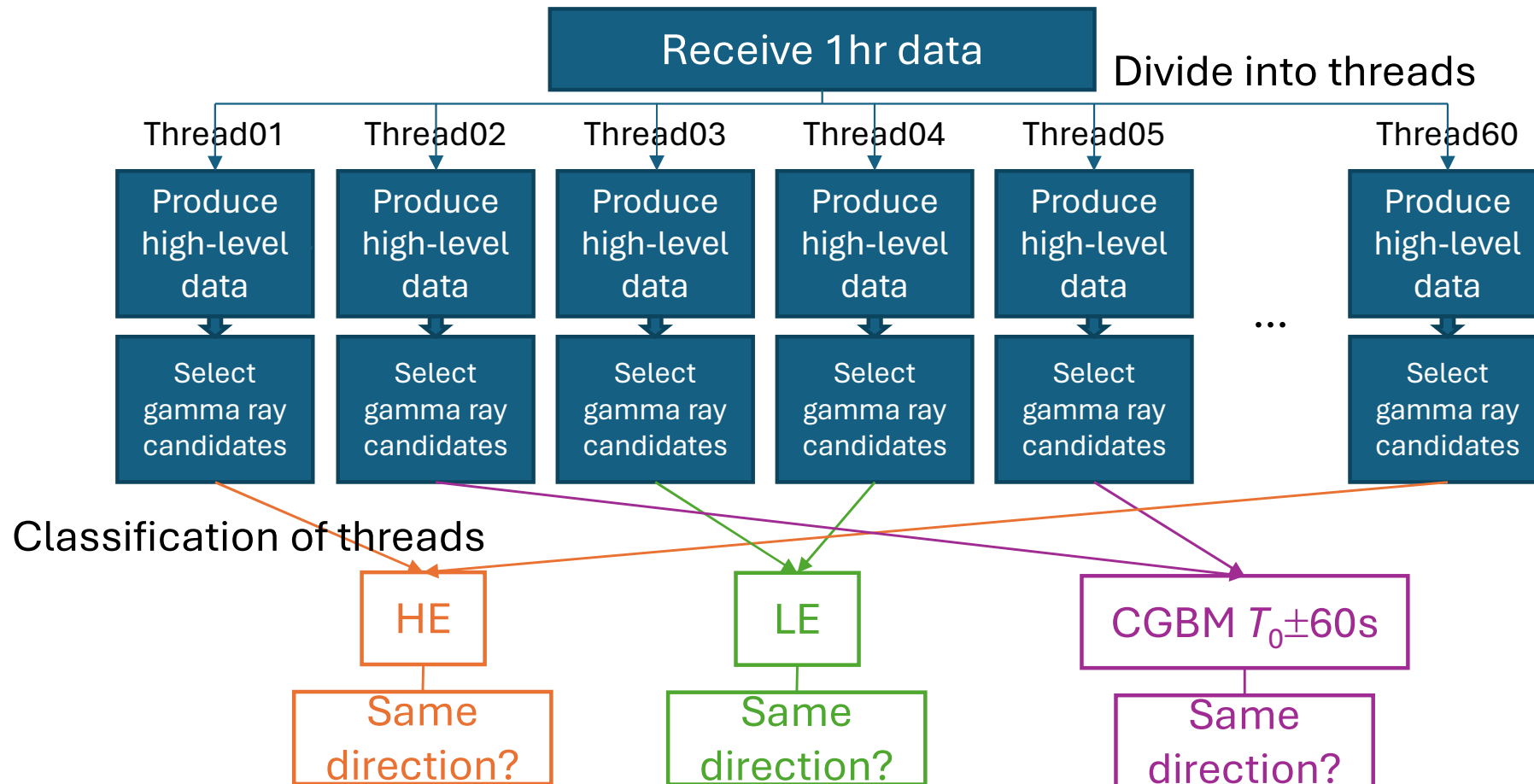


See also poster PS3-243 (Cannady et al.) for GRB search by CALET/CAL



# Transient gamma-ray monitor system

- Running since 2018/08/20 at WCOC
- Parallel processing (60 threads) – 40 min for 1hr data





# WCOC DQC "GAM\_PAIRS"

Monitor panel on Web checked by shift persons every day

CALET WCOC Web Tool QL DQC

[DAQ](#) [DSZ](#) [TMP](#) [TRG](#) [SPC](#) [GPS](#) [ASC](#) [L1C](#) [GAM](#) [GAM\\_PAIRS](#) [LEE](#) [FIL](#) [PED](#)  
 Prev Prev Week HOME Next week Next

fov\_info 2 | 181220T20:25 | TBD | JEMRMS Parked at Stowed

191229 GAM\_PAIRS

---

Pair event list

try77

EventID_1	EventID_2	Probability	(R.A, Dec) [degree]	Opening angle [degree]	MDCTIME [s]	UT [s]	Time difference [s]	Energy_1 [GeV]	Energy_2 [GeV]	(dir0_1, dir1_1)	(dir0_2, dir1_2)
31522	43347	0.136	(128.800, -45.093)	0.444	1261636038	2019/12/29 06:30:07.045266	289.191015	1.298	4.277	(-0.251, 0.561)	(-0.497, 0.543)

No pairs were found with try17.

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Event display

X-Z View

Y-Z View

Event display for EventID: 31522

X-Z View

Y-Z View

Event display for EventID: 43347

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[DAQ](#) [DSZ](#) [TMP](#) [TRG](#) [SPC](#) [GPS](#) [ASC](#) [L1C](#) [GAM](#) [GAM\\_PAIRS](#) [LEE](#) [FIL](#) [PED](#)  
 Prev Prev Week HOME Next week Next

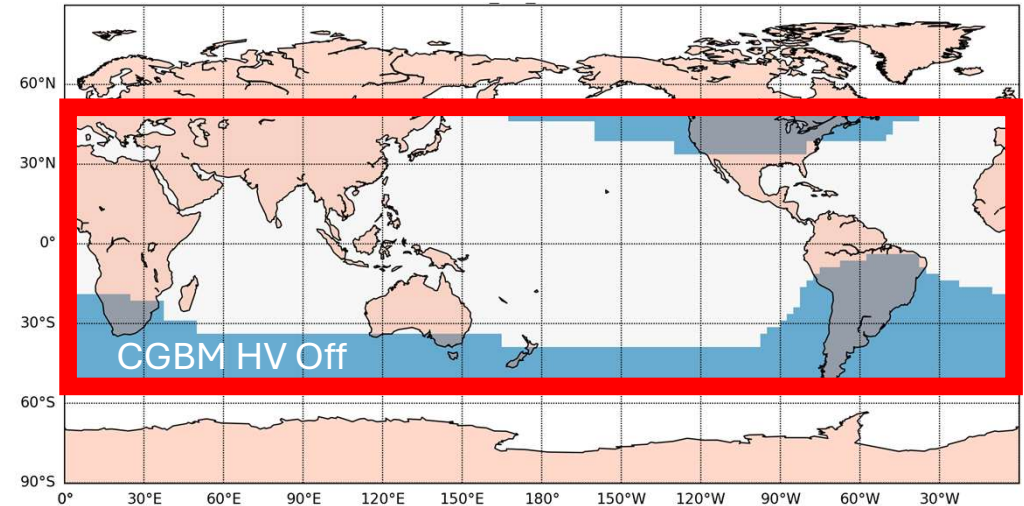
fov\_info 2 | 181220T20:25 | TBD | JEMRMS Parked at Stowed



# Flight operation of CGBM

**CGBM has collected monitor data, and captured event data & alerted onboard triggered events since the observation started in October 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  $\mu$ s, 4096 ch x 2  
When SNR exceeds thresholds
  - Event data downlink (3 times/week)
- GCN alert
  - Automatic GCN notice based on real-time TH data (~ 1min)  
TH Light curves are available on the GCN web page (~ 15 mins)  
[http://cgbm.calet.jp/cgbm\\_trigger/flight/](http://cgbm.calet.jp/cgbm_trigger/flight/)
  - GCN circulars and ground processed light curves for confirmed GRBs (~ several days)  
[http://cgbm.calet.jp/cgbm\\_trigger/ground/](http://cgbm.calet.jp/cgbm_trigger/ground/)



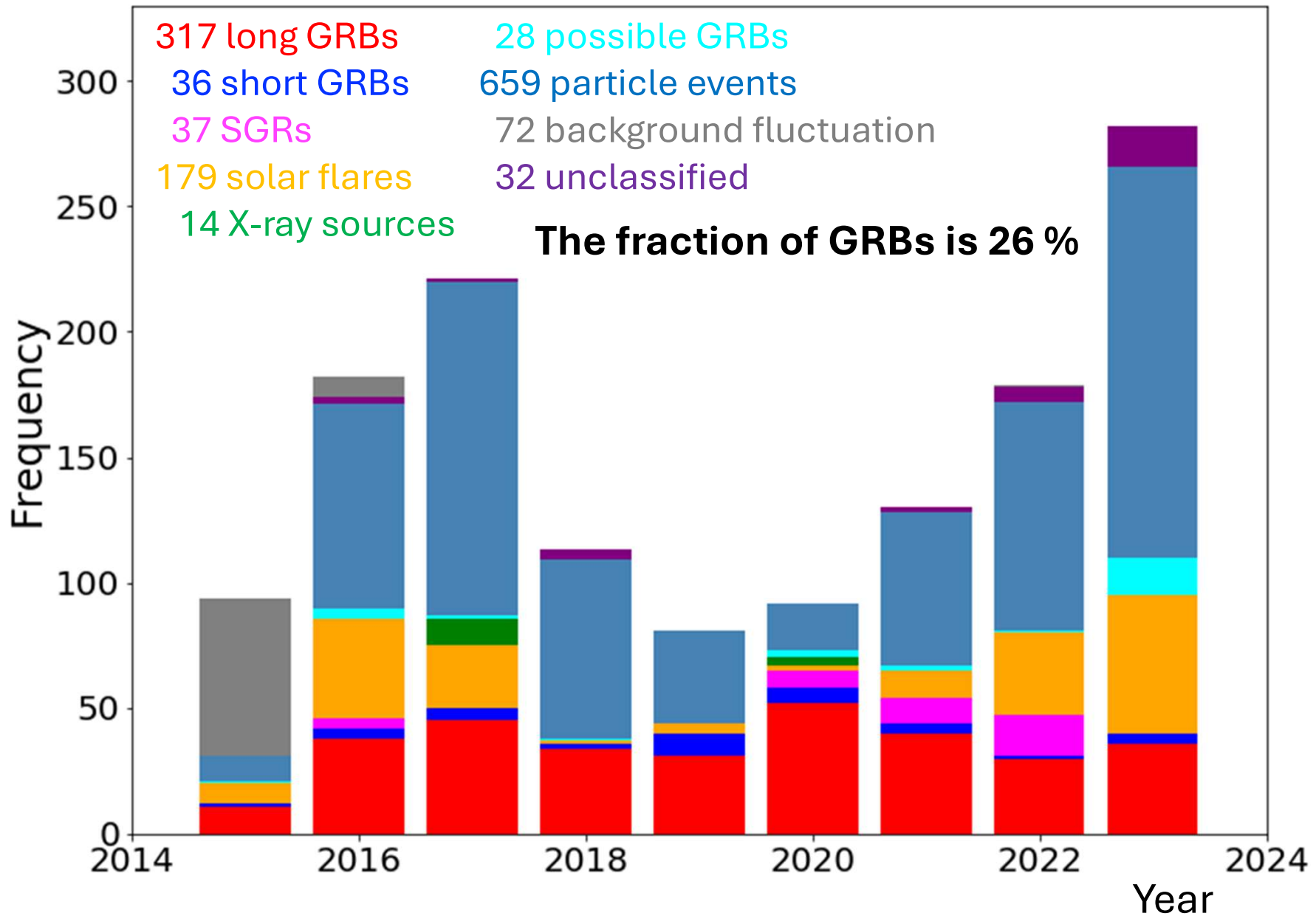
Trigger settings	HXM	SGM
Threshold	8.5 $\sigma$	7.0 $\sigma$
Energy range	25 - 100 keV	50 - 300 keV



# Onboard triggered events

**CGBM has been triggered 1374 times onboard by 2023/12/26**

**Real-time alerts have been distributed for about 2/3 of the total.**

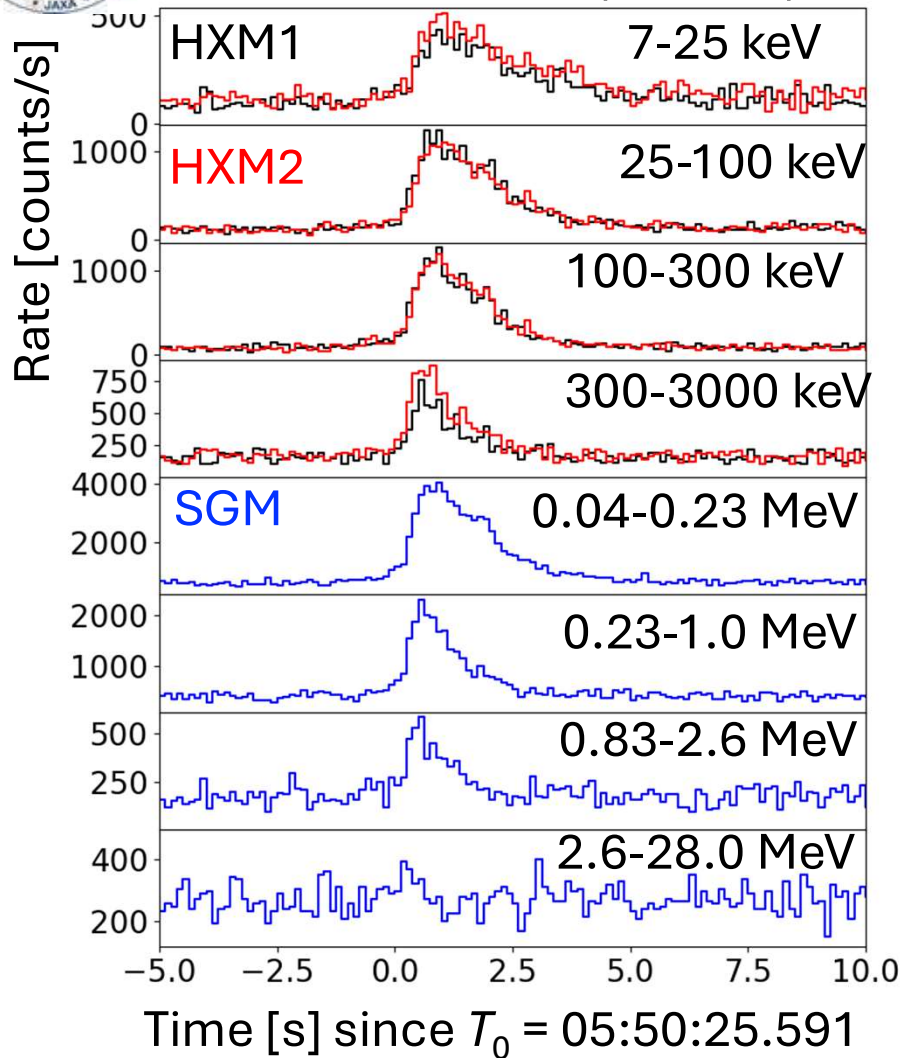




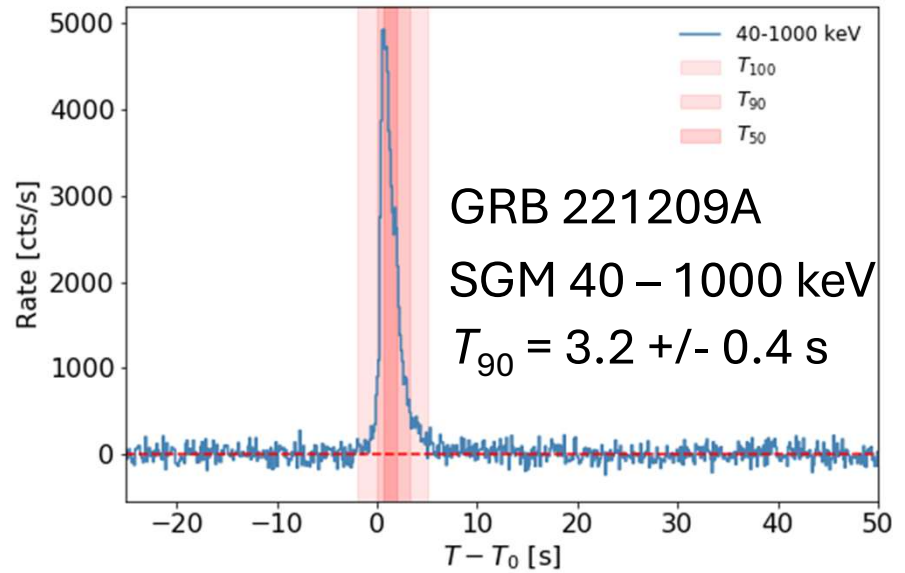


# GRB observations with CGBM

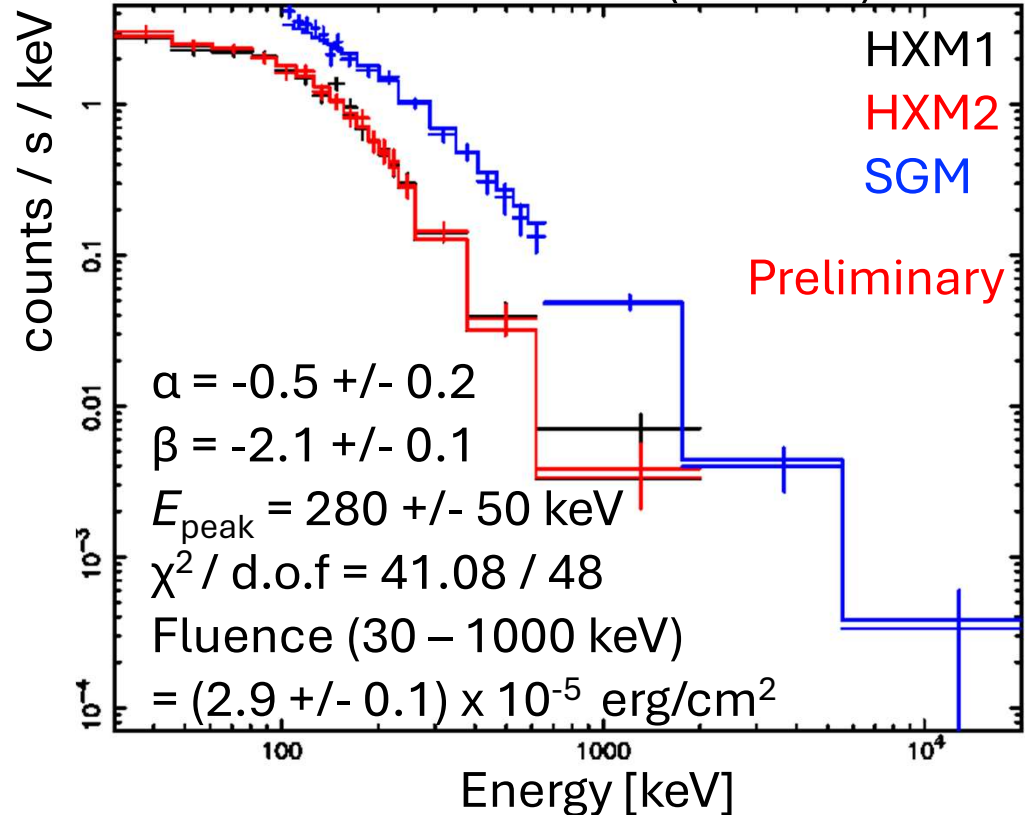
GRB 221209A (TH data)



**CGBM can observe GRB light curves and spectra in the broad energy bands. CGBM can measure durations and spectral parameters.**



GRB 221209A (PH data)





# Search for GW counterparts

- **CGBM:**

- No CGBM onboard trigger happened around any GW events during O3 (and O4 up to now).
- Ground search was performed for  $T_0 \pm 60$ s where summed probability ( $P_h$ ) above the horizon  $\geq 1\%$ , but no significant signals were found.

- **CAL:**

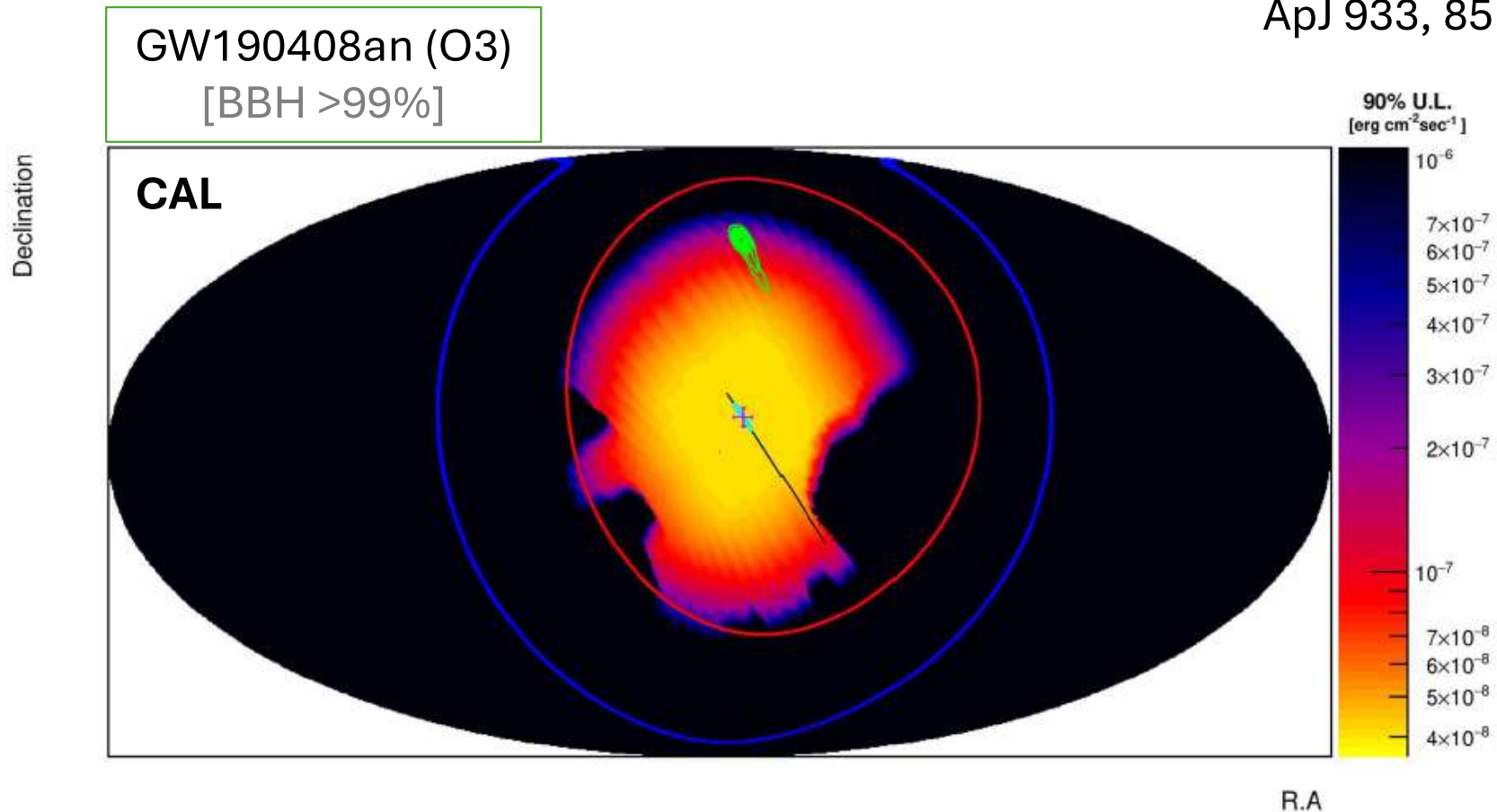
- Gamma-ray events within  $T_0 \pm 60$ s are searched for events selected in HE ( $>10$  GeV) and LE- $\gamma$  ( $>1$  GeV) modes in the case of “coverage” (fraction of CALET FOV covers LIGO/Virgo localization map)  $\geq 5\%$ ,
- No candidate was found during O3 (and O4 up to now). Upper limits on energy flux were calculated.

For O3, results are already reported: Adriani et al., ApJ 863, 160 (2018)/ApJ 933, 85 (2023).



# An example of upper limit maps

Adriani et al.,  
ApJ 933, 85 (2022)

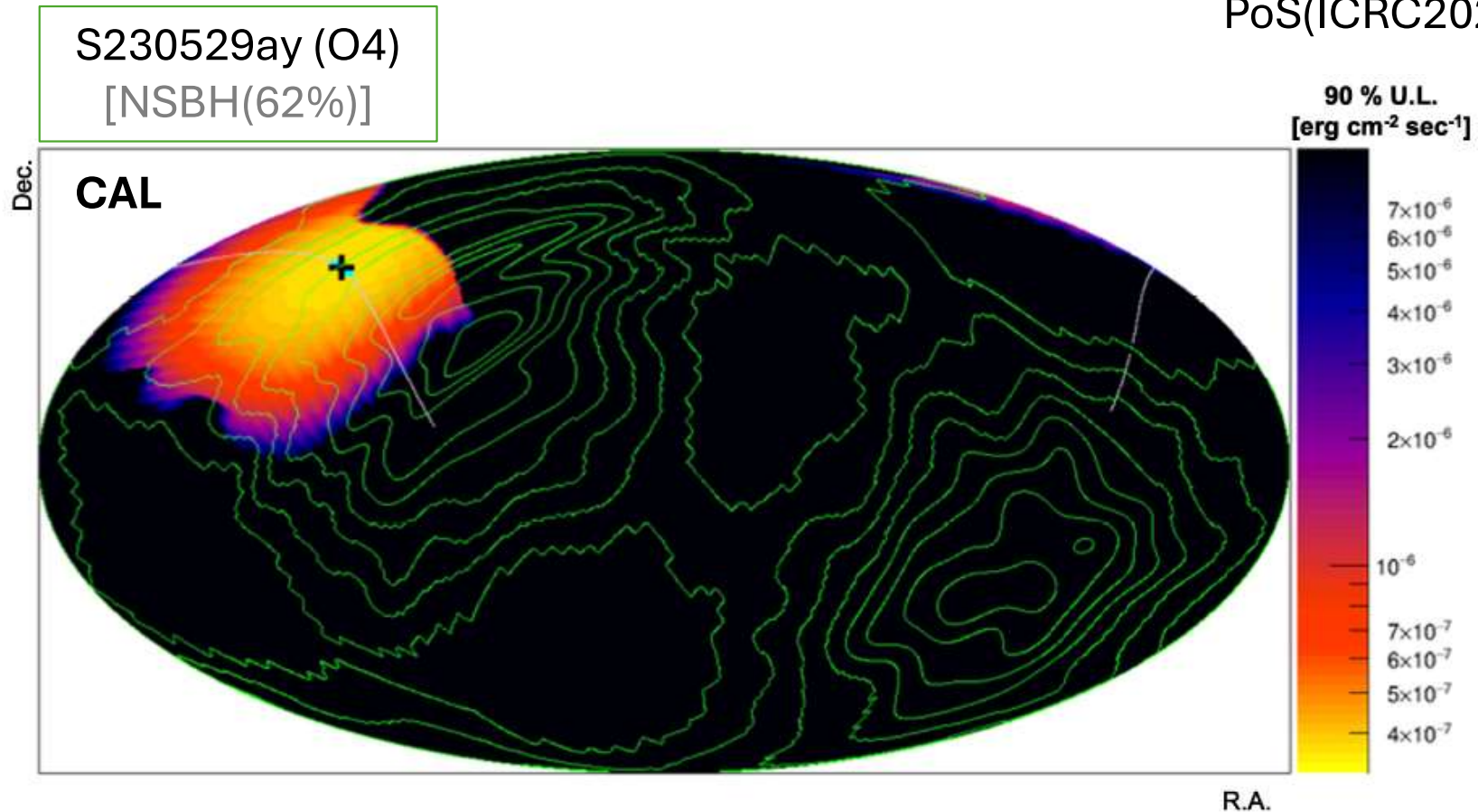


**Figure 10.** 90% confidence level upper limits observed by CAL in the energy range 1–10 GeV during the interval  $\pm 60$  s around the time of GW190408an reported by LIGO/Virgo. The intensity scale is given in units of  $\text{erg cm}^{-2} \text{s}^{-1}$ . Red and blue circles are the HXM and SGM fields of view, respectively.



# Another example of upper limit maps

Kawakubo et al.,  
PoS(ICRC2023)1517)



**Figure 4:** 90 % confidence level upper limits observed by CAL in the energy range 10 - 100 GeV during the interval  $\pm 60$  s around the time of S230529ay reported by LIGO/Virgo/KAGRA. The intensity scale is given in units of  $\text{ergs cm}^{-2} \text{s}^{-1}$ . Green contour is the LIGO/Virgo high probability region. Black cross marks the pointing direction of CAL at  $T_0$  and the track of the pointing direction is marked cyan broad line in the interval  $\pm 60$  s.



# CALET summary for Observing Run 3

56 events in GraceDB + 1 sub-threshold event (Fermi GBM-190816)  
(5 are BNS candidates)

Adriani et al., ApJ 933, 85 (2022)  
Kawakubo et al., PoS(ICRC2023)1517

Event ID	Possible Source	Time ( $T_0$ )	Coverage	CAL upper limit [erg cm <sup>-2</sup> s <sup>-1</sup> ]	CGBM Observation	$P_h$
S200316bj	MassGap (>99 %)	21:57:56.157	0 %	Outside of the FOV	No detection	90%
S200311bg	BBH (>99 %)	11:58:53.398	0 %	Outside of the FOV	HV off	-
S200302c	BBH (89 %)	01:58:11.519	0 %	Outside of the FOV	No detection	81%
S200225q	BBH (96 %)	06:04:21.397	0 %	Outside of the FOV	HV off	-
S200224ca	BBH (>99 %)	22:22:34.406	95 %	9.0 x 10 <sup>-7</sup> (10 - 100 GeV)	HV off	-
S200219ac	BBH (96 %)	09:44:15.195	0 %	Outside of the FOV	No detection	71%
S200213t	BNS (63 %)	04:10:40.328	0 %	Outside of the FOV	No detection	18%
S200208q	BBH (>99 %)	13:01:17.991	0 %	Outside of the FOV	HV off	-
S200129m	BBH (>99 %)	06:54:58.435	5 %	4.8 x 10 <sup>-4</sup> (10 - 100 GeV)	HV off	-
S200128d	BBH (97 %)	02:20:11.903	5 %	4.5 x 10 <sup>-6</sup> (10 - 100 GeV)	No detection	60%
S200115j	MassGap (>99 %)	04:23:09.742	15 %	8.5 x 10 <sup>-5</sup> (10 - 100 GeV)	HV off	-
S200114f	-	02:08:18.239	85 %	1.2x10 <sup>-5</sup> (10 - 100 GeV)	HV off	-
S200112r	BBH (>99 %)	15:58:38.094	5 %	1.1x10 <sup>-6</sup> (10 - 100 GeV)	No detection	67%
S200105ae	Terrestrial (97 %)	16:24:26.057	45 %	3.1x10 <sup>-5</sup> (10 - 100 GeV)	No detection	67%
S191222n	BBH (>99 %)	03:35:37.119	0 %	Outside of the FOV	No detection	60%
S191216ap	BBH (>99 %)	21:33:38.473	0 %	Outside of the FOV	No detection	40%
S191215w	BBH (>99 %)	22:30:52.333	0 %	Outside of the FOV	No detection	83%
S191213g	BNS (77 %)	04:34:08.142	5 %	1.5x10 <sup>-5</sup> (1 - 10 GeV)	No detection	71%
S191205ah	NSBH (93 %)	21:52:08.569	0 %	Outside of the FOV	HV off	-
S191204r	BBH (>99 %)	17:15:26.092	0 %	Outside of the FOV	No detection	4%
S191129u	BBH (>99 %)	13:40:29.197	0 %	Outside of the FOV	No detection	70%
S191109d	BBH (>99 %)	01:07:17.221	0 %	Outside of the FOV	HV off	-
S191105e	BBH (95 %)	14:35:21.933	0 %	Outside of the FOV	HV off	-
S190930t	NSBH (74 %)	14:34:07.685	0 %	Outside of the FOV	No detection	74%
S190930s	MassGap (95 %)	13:35:41.247	5 %	4.5x10 <sup>-5</sup> (10 - 100 GeV)	No detection	100%
S190924h	MassGap (> 99 %)	02:18:46.847	0 %	Outside of the FOV	HV off	-
S190923y	NSBH (68 %)	12:55:59.646	0 %	Outside of the FOV	No detection	68%
S190915ak	BBH (>99 %)	23:57:02.691	0 %	Outside of the FOV	No detection	100%

Event ID	Possible Source	Time ( $T_0$ )	Coverage	CAL upper limit [erg cm <sup>-2</sup> s <sup>-1</sup> ]	CGBM Observation	$P_h$
S190910h	BNS (61 %)	08:29:58.544	10 %	5.3x10 <sup>-7</sup> (1 - 10 GeV)	No detection	78%
S190910d	NSBH (98 %)	01:26:19.243	0 %	Outside of the FOV	No detection	77%
S190901ap	BNS (86 %)	23:31:01.838	5 %	2.8 x 10 <sup>-5</sup> (1 - 10 GeV)	No detection	82%
S190828l	BBH (>99 %)	06:55:09.887	0 %	Outside of the FOV	No detection	79%
S190828j	BBH (>99 %)	06:34:05.756	0 %	Outside of the FOV	No detection	28%
GBM-180816	sub-threshold	21:22:13.027	25 %	2.8x10 <sup>-5</sup> (10 - 100 GeV)	No detection	66%
S190814bv	NSBH (>99 %)	21:10:39.013	0 %	Outside of the FOV	HV off	-
S190728q	MassGap (52 %)	06:45:10.529	0 %	Outside of the FOV	Outside of the FOV	0%
S190727h	BBH (92 %)	06:03:33.986	0 %	Outside of the FOV	No detection	14%
S190720a	BBH (99 %)	00:08:36.704	0 %	Outside of the FOV	HV off	-
S190718y	Terrestrial (98 %)	14:35:12.068	10 %	1.2x10 <sup>-5</sup> (1-10GeV)	No detection	22%
S190707q	BBH (>99 %)	09:33:26.181	25 %	3.8x10 <sup>-6</sup> (1-10 GeV)	No detection	76%
S190706ai	BBH (99 %)	22:26:41.345	0 %	Outside of the FOV	HV off	-
S190701ah	BBH (93 %)	20:33:06.578	0 %	Outside of the FOV	No detection	19%
S190630ag	BBH (94 %)	18:52:05.180	0 %	Outside of the FOV	HV off	-
S190602aq	BBH (>99 %)	17:59:27.089	0 %	Outside of the FOV	No detection	99%
S190521r	BBH (>99 %)	07:43:59.463	0 %	Outside of the FOV	HV off	-
S190521g	BBH (97 %)	03:02:29.447	30 %	7.4x10 <sup>-7</sup> (10-100 GeV)	HV off	-
S190519bj	BBH (96 %)	15:35:44.398	0 %	Outside of the FOV	No detection	100%
S190517h	BBH (98 %)	05:51:01.831	0 %	Outside of the FOV	No detection	86%
S190513bm	BBH (94 %)	20:54:28.747	15 %	4.5x10 <sup>-5</sup> (1-10 GeV)	No detection	100%
S190512at	BBH (99 %)	18:07:14.422	0 %	Outside of the FOV	No detection	100%
S190510g	Terrestrial (58 %)	02:59:39.292	0 %	Outside of the FOV	No detection	16%
S190503bf	BBH (96 %)	18:54:04.294	25 %	7.1 x 10 <sup>-5</sup> (10-100 GeV)	HV off	-
S190426c	Terrestrial (58 %)	15:21:55.337	10 %	9.2 x 10 <sup>-6</sup> (10-100 GeV)	HV off	-
S190425z	BNS (>99 %)	08:18:05.017	10 %	8.5 x 10 <sup>-5</sup> (10-100 GeV)	HV off	-
S190421ar	BBH (97 %)	21:38:56.251	0 %	Outside of the FOV	Outside of the FOV	0%
S190412m *	BBH (>99 %)	05:30:44.166	-	HV off	HV off	-
S190408an	BBH (>99 %)	18:18:02.288	95 %	3.0 x 10 <sup>-7</sup> (1-10 GeV)	No detection	100%



# Summary for CALET O4 follow-ups

15 events in GraceDB (no BNS candidate)

Kawakubo et al., PoS(ICRC2023)1517

Event ID	Possible Source	Time (T <sub>0</sub> )	Coverage	CAL upper limit [erg cm <sup>-2</sup> s <sup>-1</sup> ]	CGBM Observation	P <sub>h</sub>
S230630bq	BBH (97%)	23:45:32	10%	1.5 x 10 <sup>-3</sup> (10 – 100 GeV)	No detection	82%
S230630am	BBH (98%)	12:58:06	40%	3.3 x 10 <sup>-4</sup> (10 – 100 GeV)	HV off	-
S230628ax	BBH (>99%)	23:12:00	0%	-	HV off	-
S230627c	NSBH (49%)	01:53:37	0%	-	No detection	100%
S230624av	BBH (95%)	11:31:03	0%	-	HV off	-
S230609u	BBH (96%)	06:49:58	5%	4.2 x 10 <sup>-5</sup> (1 – 10 GeV)	No detection	87%
S230608as	BBH (>99%)	20:50:47	50%	5.0 x 10 <sup>-5</sup> (1 – 10 GeV)	No detection	100%
S230606d	BBH (>99%)	00:43:05	0%	-	No detection	100%
S230605o	BBH (99%)	06:53:43	0%	-	No detection	69%
S230601bf	BBH (>99%)	22:41:34	15%	1.6 x 10 <sup>-3</sup> (10 – 100 GeV)	HV off	-
S230529ay	NSBH (62%)	18:15:00	15%	6.5 x 10 <sup>-5</sup> (10 – 100 GeV)	HV off	-
S230522n	BBH (99%)	15:30:33	5%	1.5 x 10 <sup>-6</sup> (10 – 100 GeV)	HV off	-
S230522a	BBH (>99%)	09:38:05	-	-	HV off	-
S230520ae	BBH (>99%)	22:48:42	10%	1.5 x 10 <sup>-4</sup> (1 – 10 GeV)	No detection	61%
S230518h	NSBH (86%)	12:59:08	0%	-	No detection	62%



# Summary

- CALET CAL and CGBM are monitoring the gamma-ray sky continuously since 2015.
- CAL observes gamma rays above 1 GeV with  $\sim 2$  sr and CGBM detects photons above 7 keV and up to 20 MeV with  $\sim 8$  sr.
- Dedicated analysis system for transient events are working to alert within an hour.
- We are following up GW alerts during O3 and O4.
- Unfortunately, we have only upper limits up to now, but may have chances...
- CALET observation continues until March 2030!