Gamma-ray burst observation & gravitational wave event follow-up with CALET on the International Space Station

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Gamma-ray burst observation with CALET

Gamma-ray bursts (GRBs) are getting attention as electromagnetic (EM) counterparts of binary neutron star mergers[1,2,3]. **CALorimetric Electron Telescope (CALET) on the International Space Station (ISS) also has monitored GRBs in keV-MeV and GeV-TeV energy ranges.**

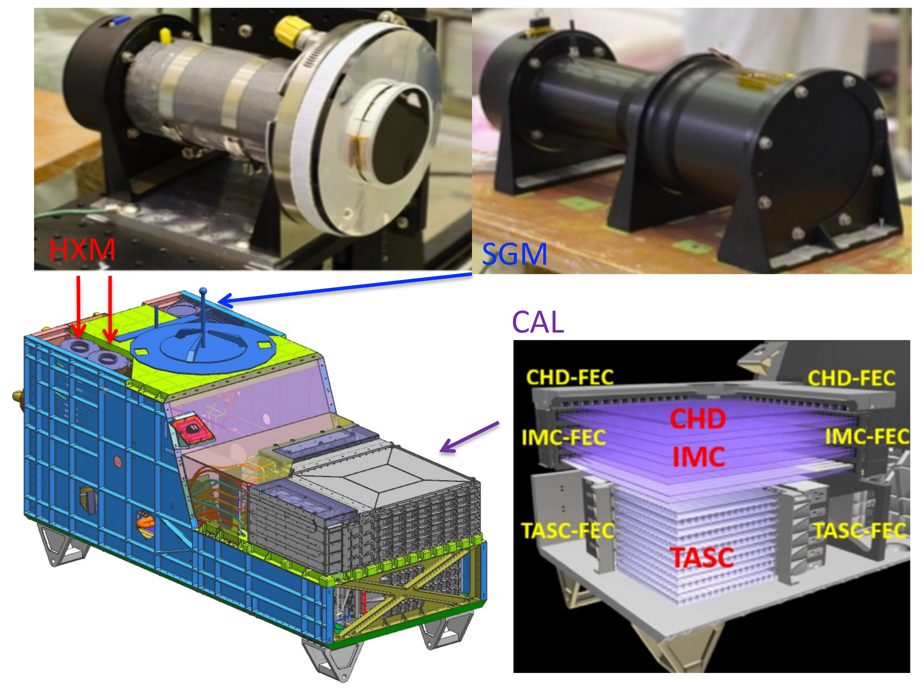

Figure 1. Schematic images of CALET and CAL and pictures of CGBM flight detectors.

Calorimeter (CAL)

Electrons: 1 GeV – 20 TeV
Gamma-rays: 10 GeV – 10 TeV
Protons & nuclei : 100 GeV - 1 PeV

CAL has collected gamma-ray data in the high-energy trigger (HE; > 10 GeV) mode and the low energy gamma-ray (LEG; > 1 GeV) mode. While the HE mode is on continuously except while collecting pedestal data, the LEG mode is only enabled at low latitudes and when a CGBM trigger occurs. Further information is available in [4][5][6] and two further CALET gamma-ray presentations in ICRC 2021 [7][8].

CALET Gamma-ray Burst Monitor (CGBM)

Hard X-ray Monitor (HXM) 7 keV – 1 MeV
Soft Gamma-ray Monitor (SGM) 40 keV – 20 MeV

CGBM consists of two HXMs and one SGM [9][10]. The crystal of HXM and SGM are $LaBr_3(Ce)$ and BGO, respectively. CGBM collects Time History data (TH; 1/8s, 8 ch) and Pulse height data (PH; 4 s, 512 ch). The CGBM onboard trigger system calculates signal-to-noise ratio (SNR) every 1/4 s. If the SNR exceeds the trigger threshold, CGBM captures event data, and GCN notice will be sent from the ground analysis server [11].

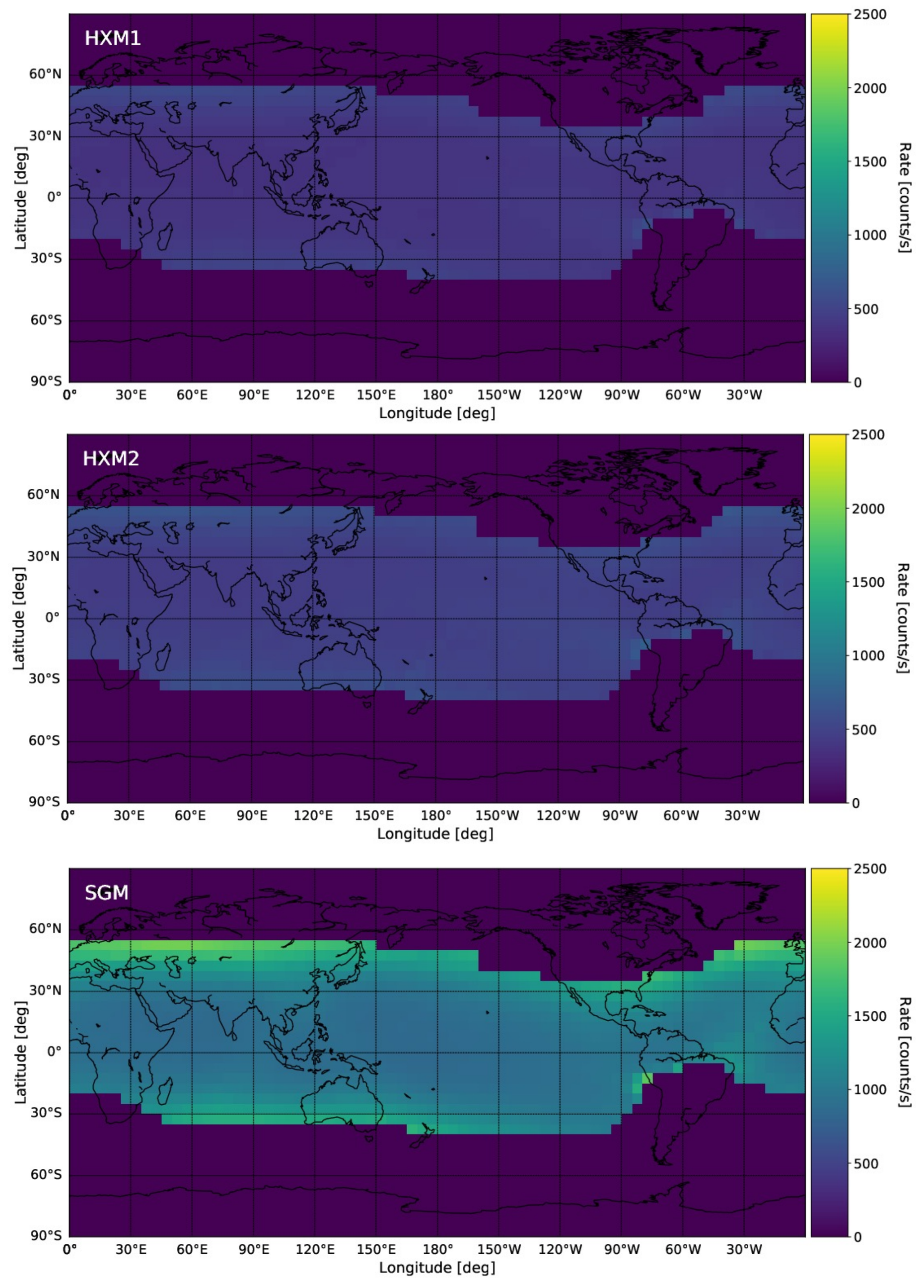

Figure 2. Averaged background count rate for each geographic position. PH data for September 2020 were used for making these plots.

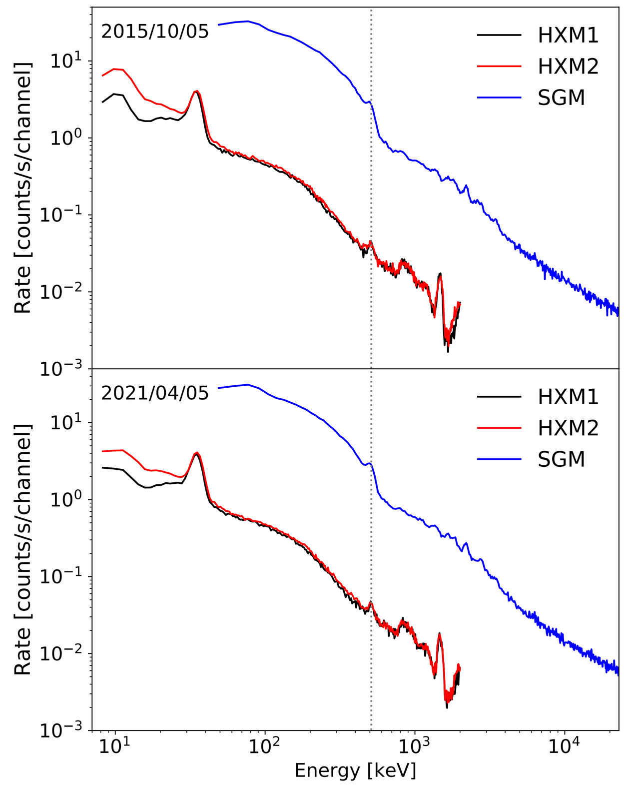

Figure 3. Averaged background spectra of each CGBM detector. Gray dotted lines show 511 keV.

Figure 2 shows CGBM count rates increase at high latitude and around the South Atlantic Anomaly (SAA). We turn off CGBM at high latitudes and around the SAA to avoid false alerts due to charged particles. As a result, the duty cycle of CGBM is ~60%. However, charged particle rates vary depending on time, and CGBM is still sometimes triggered by charged particles.

Figure 3. shows the background spectra of each CGBM detector. There is no big difference between the spectra for October 5 in 2015 and April 5 in 2021. All detectors of CGBM have remained in good condition for more than five years since October 2015.

Five years of GRB observation with CALET

At the end of May 2021, **CGBM has detected 254 GRBs, including 31 short GRBs,** thanks to the onboard trigger system. We also found two possible gamma-ray events from GRBs in CAL data.

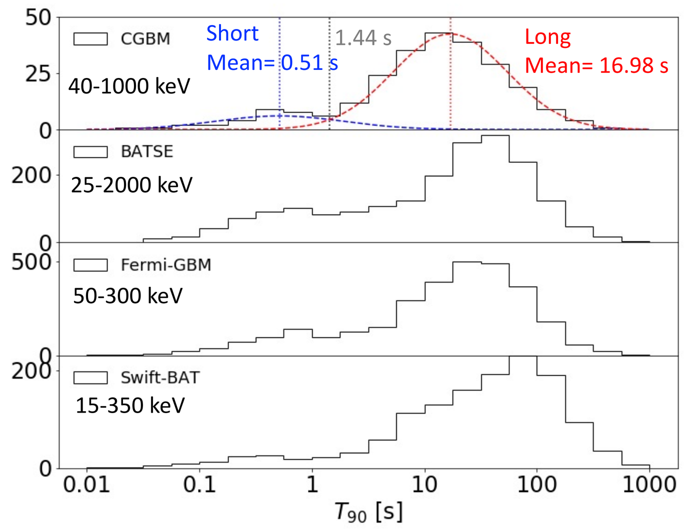

Figure 4. T_{90} distribution of CGBM GRBs. Distributions derived by other instruments are also shown[12][13][14][15][16].

CGBM has detected 254 GRBs by the end of May 2021 (2066 days, 44.9 GRB / yr). SGM measured T_{90} in the 40 ~ 1000 keV energy range. The CGBM distribution was well fitted with two logarithmic normal distributions. If we classify the GRBs by the intersection of two distributions, the number of long and short GRBs were 218 and 31, respectively. In addition, there were five long GRBs for which SGM cannot measure T_{90}.

GRB positions in Figure 5 were based on reported GRB positions by other instruments. Although most bursts came from clear directions, some bursts came from directions blocked by the fixed ISS structures. We are still investigating the effect of the ISS structures on CGBM observations.

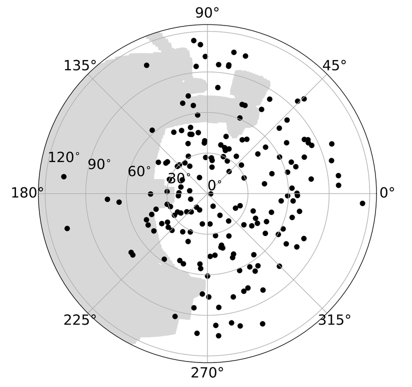

Figure 5. Incident angle distribution in the SGM coordinate. 182 GRBs well localized by other instruments were plotted. Gray shaded region was shadows of the fixed ISS structures.

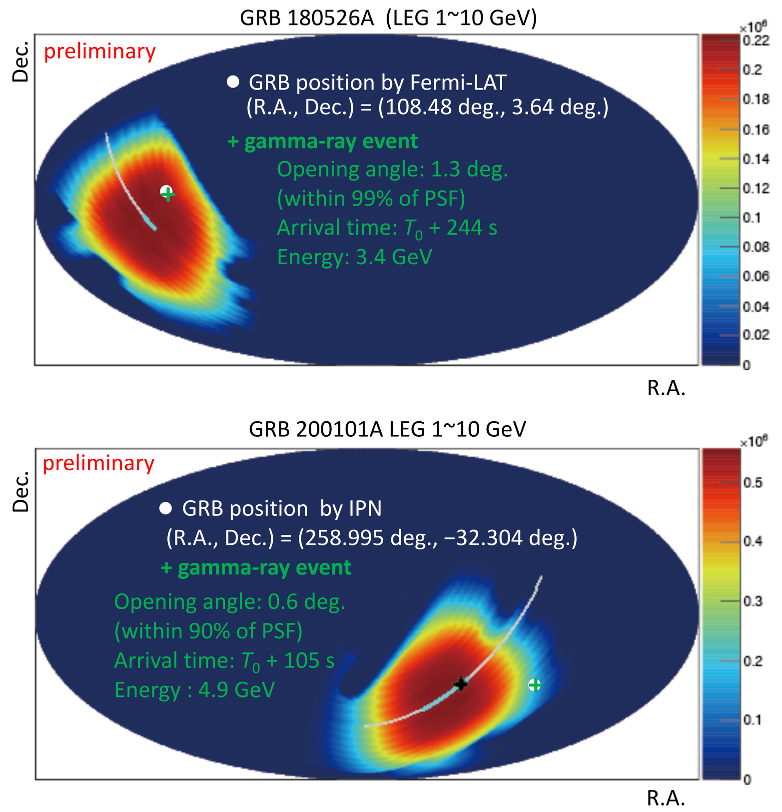

Figure 6. Exposure maps (LEG) for GRB 180526A and GRB 200101A with gamma-ray events and GRB positions [17][11](#26635).

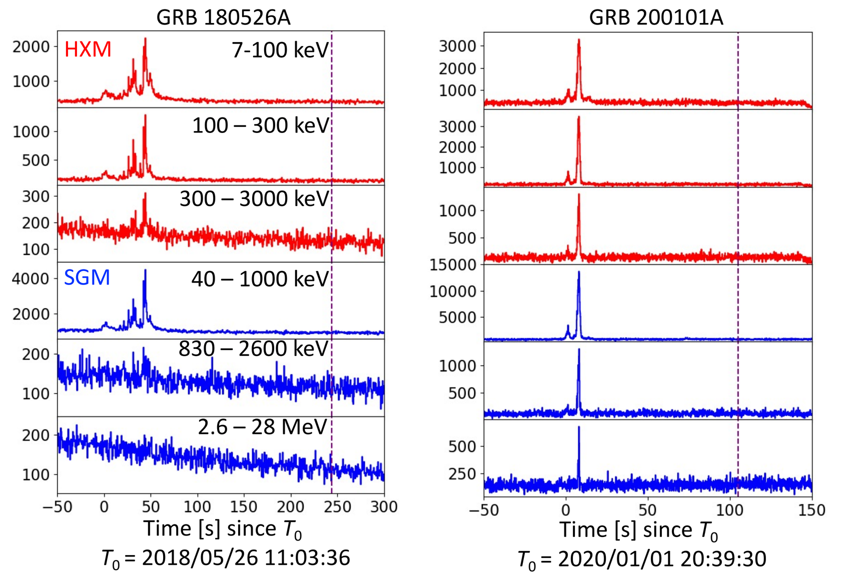

Figure 7. CGBM light curves for GRB 180526A and GRB 200101A The purple dotted line shows the arrival time of gamma-ray events.

We searched for high-energy gamma-rays from 99 GRBs detected by CGBM and well localized by other instruments. We used LEG data for T_0 – 60 s ~ T_0 + 7200 s to search for gamma-rays within 2 deg. from the reported central positions. For 37 of the GRBs checked, the LEG trigger was not active at the known time of detection. For 59 GRBs where the LEG trigger was active, there were no gamma-ray candidates near the GRB position, even for those in the CAL field of view. Gamma rays were found within 2 degrees of the remaining 3 GRBs: GRB 180526A, GRB 200101A, and GRB 200613A. The candidate of GRB 200613A was likely due to secondary gamma-rays from the ISS structures. Gamma rays near GRB 180526A and GRB 200101A are still possibly associated with the GRBs, even though there was no significant excess in CGBM data around the arrival time of the two candidates. However, further investigation is still underway.

Summary

CALET has monitored all-sky in the 7 keV – 20 MeV and 1 GeV – 10 TeV energy ranges. CGBM has detected **254 GRB prompt emissions, including 31 short GRBs**, by the end of May 2021. As a result of the high-energy gamma-ray search from GRBs, **two possible gamma-ray events were found in CAL data**. We have actively participated in the follow-up of EM counterparts of GW events. Although there was no candidate of EM counterparts of GW events in O3, we estimated **upper limits of gamma-ray flux for 26 events in O3**.

EM counterparts search for GW events in O3

CALET has participated in the follow-up observation of EM counterparts of gravitational wave (GW) since the observation start and contributed to increase the sky coverage in X-rays and gamma-rays [3, 10, 18-20]. Table 1 shows a summary of CALET observation for GW events in the LIGO/Virgo third observation run (O3).

There were 56 events reported by the LIGO/Virgo collaboration (LVC) and one sub-threshold event reported by LVC and Fermi-GBM team in O3 [21][11](#25406). No CGBM onboard trigger occurred around any GW events. No candidate of EM counterparts of GW events was found in CALET data for T_0–60 s ~ T_0+60 s [10][20].

If the summed localization probability in the CAL field of view is 5% or greater, we calculated 90 % upper limits of gamma-ray flux for each direction according to the method described in [19][20]. We derived the upper limits for 26 GW events in O3.

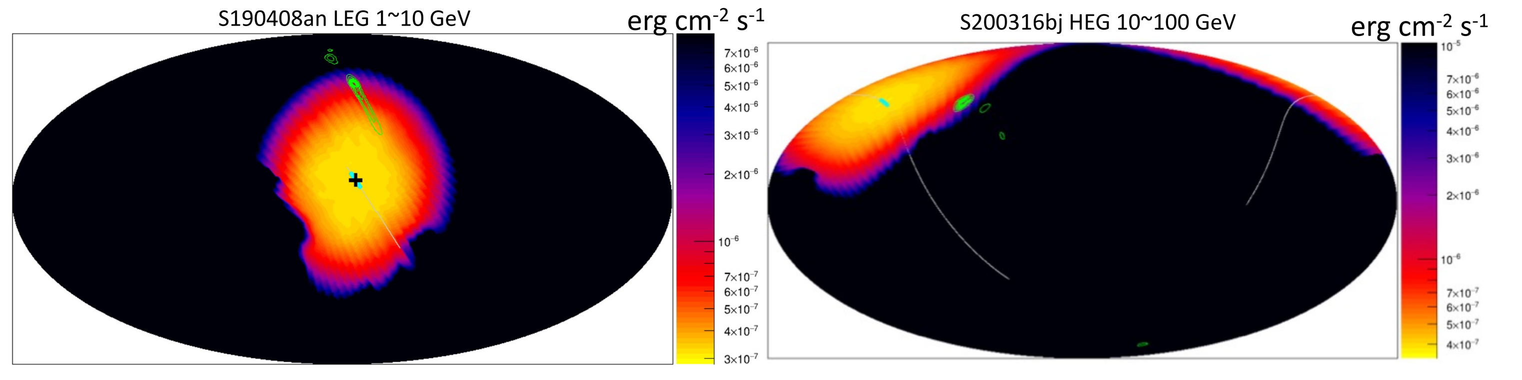

Figure 8. 90 % upper limit maps for S190408an and S200316bj. Green contours are LIGO/Virgo localization high probability region.

Table 1. Summary of CALET observation for GW events in O3

Event ID	Time (T_0)	Coverage	CAL upper limit [erg cm^{-2} s^{-1}]	CGBM status	GCN #
S200316bj	21:57:56.157	35 %	2.8 x 10^{-6} (10 - 100 GeV)	No detection	27405
S200311bg	11:58:53.398	0 %	Outside of the FOV	HV off	27372
S200302c	01:58:11.519	0 %	Outside of the FOV	No detection	27299
S200225q	06:04:21.397	0 %	Outside of the FOV	No detection	27232
S200224ca	22:22:34.406	95 %	5.0 x 10^{-7} (10 - 100 GeV)	HV off	27231
S200219ac	09:44:15.195	0 %	Outside of the FOV	No detection	27149
S200213t	04:10:40.328	0 %	Outside of the FOV	No detection	27084
S200208q	13:01:17.991	0 %	Outside of the FOV	HV off	27030
S200129m	06:54:58.435	5 %	5.7 x 10^{-5} (10 - 100 GeV)	HV off	26941
S200128d	02:20:11.903	10 %	4.6 x 10^{-6} (10 - 100 GeV)	No detection	26924
S200115j	04:23:09.742	20 %	1.7x10^{-6} (10 - 100 GeV)	HV off	26797
S200114f	02:08:18.239	80 %	4.7x10^{-6} (10 - 100 GeV)	HV off	26761
S200112r	15:58:38.094	5 %	1.1x10^{-6} (10 - 100 GeV)	No detection	26740
S200105ae	16:24:26.057	60 %	6.5x10^{-6} (10 - 100 GeV)	No detection	26664
S191222n	03:35:37.119	0 %	Outside of the FOV	No detection	26602
S191216ap	21:33:38.473	0 %	Outside of the FOV	No detection	26481
S191215w	22:30:52.333	0 %	Outside of the FOV	No detection	26465
S191213g	04:34:08.142	0 %	Outside of the FOV	No detection	26419
S191205ah	21:52:08.569	0 %	Outside of the FOV	HV off	26377
S191204r	17:15:26.092	0 %	Outside of the FOV	No detection	26358
S191129u	13:40:29.197	0 %	Outside of the FOV	No detection	26321
S191109d	01:07:17.221	0 %	Outside of the FOV	HV off	26236
S191105e	14:35:21.933	0 %	Outside of the FOV	HV off	26195
S190930t	14:34:07.685	5 %	1.7x10^{-5} (10 - 100 GeV)	No detection	25892
S190930s	13:35:41.247	5 %	3.5x10^{-5} (10 - 100 GeV)	No detection	25891
S190924h	02:18:46.847	0 %	Outside of the FOV	HV off	25844
S190923y	12:55:59.646	10 %	1.2x10^{-5} (10 - 100 GeV)	No detection	25830
S190915ak	23:57:02.691	0 %	Outside of the FOV	No detection	25770
S190910h	08:29:58.544	10 %	9.4x10^{-6} (1 - 10 GeV)	No detection	25735
S190910d	01:26:19.243	0 %	Outside of the FOV	No detection	25734
S190901ap	23:31:01.838	5 %	6.3x10^{-5} (1 - 10 GeV)	No detection	25647
S190828l	06:55:09.887	0 %	Outside of the FOV	No detection	25537
S190828j	06:34:05.756	0 %	Outside of the FOV	No detection	25536
GBM-180816	21:22:13.027	25 %	2.1x10^{-4} (10 - 100 GeV)	No detection	-
S190814bv	21:10:39.013	0 %	Outside of the FOV	HV off	25390
S190728q	06:45:10.529	0 %	Outside of the FOV	Outside of the FOV	25214
S190727h	06:03:33.986	0 %	Outside of the FOV	No detection	25184
S190720a	00:08:36.704	25 %	3.0x10^{-5} (10 - 100 GeV)	HV off	25134
S190718y	14:35:12.068	5 %	1.7x10^{-6} (1 - 10 GeV)	No detection	25099
S190707q	09:33:26.181	20 %	2.1x10^{-6} (1-10 GeV)	No detection	25033
S190706ai	22:26:41.345	0 %	Outside of the FOV	HV off	25027
S190701ah	20:33:06.578	0 %	Outside of the FOV	No detection	24970
S190630ag	18:52:05.180	25 %	1.2x10^{-5} (10-100 GeV)	HV off	24960
S190602aq	17:59:27.089	5 %	2.9x10^{-4} (10-100 GeV)	No detection	24735
S190521r	07:43:59.463	0 %	Outside of the FOV	HV off	24649
S190521g	03:02:29.447	30 %	6.0x10^{-6} (10-100 GeV)	HV off	24648
S190519bj	15:35:44.398	0 %	Outside of the FOV	No detection	24617
S190517h	05:51:01.831	0 %	Outside of the FOV	No detection	24593
S190513bm	20:54:28.747	5 %	6.0x10^{-5} (1-10 GeV)	No detection	24548
S190512at	18:07:14.422	10 %	1.9x10^{-5}(10-100 GeV)	No detection	24531
S190510g	02:59:39.292	0 %	Outside of the FOV	No detection	24495
S190503bf	18:54:04.294	10 %	4.2x10^{-5} (10-100 GeV)	HV off	24403
S190426c	15:21:55.337	10 %	2.5x10^{-5} (10-100 GeV)	HV off	24276
S190425z	08:18:05.017	5 %	1.0x10^{-4} (10-100 GeV)	HV off	24218
S190421ar	21:38:56.251	0 %	Outside of the FOV	Outside of the FOV	-
S190412m *	05:30:44.166	-	HV off	HV off	-
S190408an	18:18:02.288	80 %	2.3 x 10^{-6} (1-10 GeV)	No detection	24088

* CALET was off due to special activity on ISS when S190412m occurred.

Reference

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