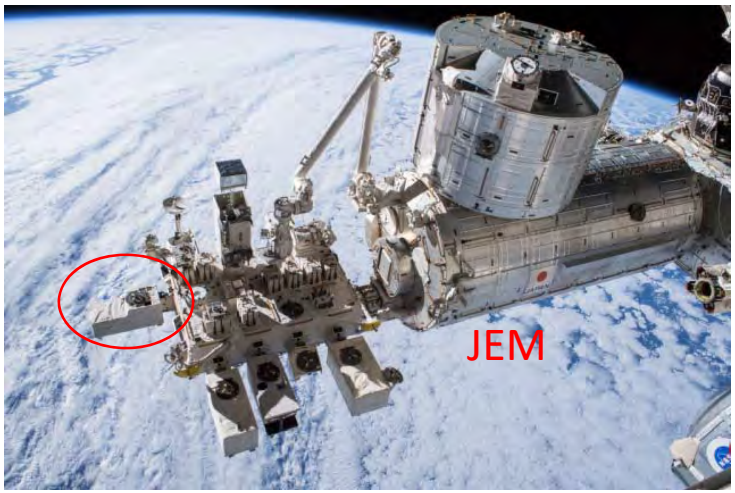

GAD5c

High-Energy Gamma-ray Observations Using the CALorimetric Electron Telescope (CALET) on the ISS

Masaki Mori, *Ritsumeikan University*

Yoichi Asaoka, *Waseda University*

For the CALET collaboration

36th International Cosmic Ray Conference, Madison, USA, July 29, 2019

The CALET collaboration

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9) JAXA, Japan
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12) KEK, Japan
13) Louisiana State University, USA
14) Nagoya University, Japan
15) NASA/GSFC, USA
16) National Inst. of Radiological Sciences, Japan
17) National Institute of Polar Research, Japan
18) Nihon University, Japan
19) Osaka City University, Japan
20) Ritsumeikan University, Japan
21) Saitama University, Japan
22) Shibaura Institute of Technology, Japan
23) Shinshu University, Japan
24) University of Denver, USA
25) University of Florence, IFAC (CNR) and INFN, Italy
26) University of Padova and INFN, Italy
27) University of Pisa and INFN, Italy
28) University of Rome Tor Vergata and INFN, Italy
29) University of Siena and INFN, Italy
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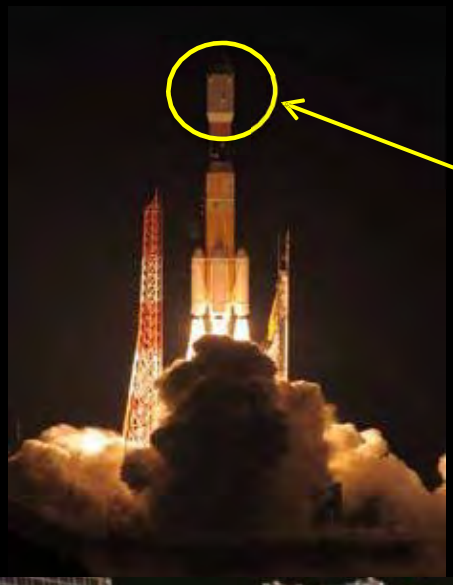
31) Waseda University, Japan
32) Washington University-St. Louis, USA
33) Yokohama National University, Japan
34) Yukawa Institute for Theoretical Physics, Kyoto University, Japan

See Highlight talk H7 (Asaoka et al.) for the summary of CALET results

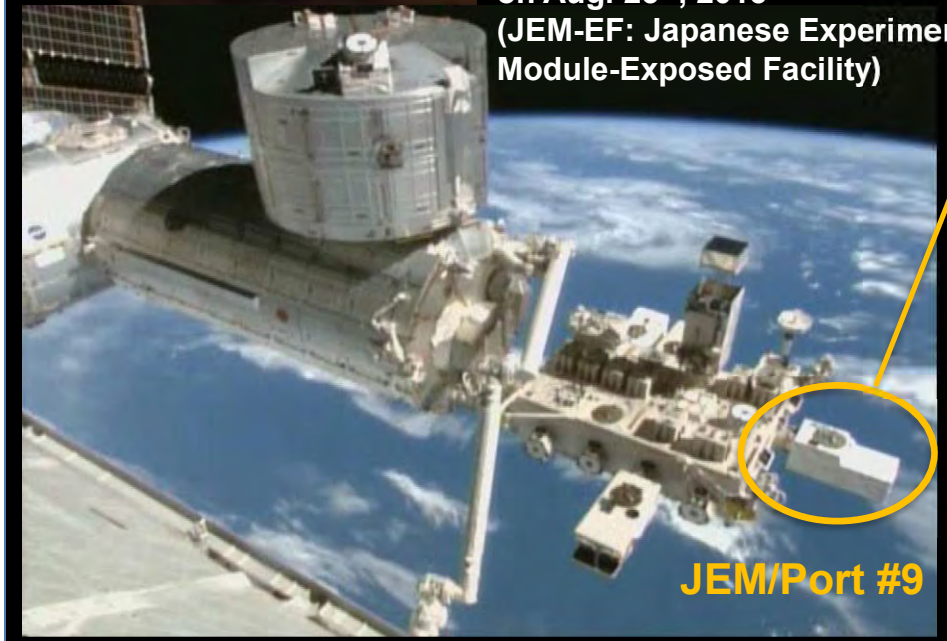
CALET Payload

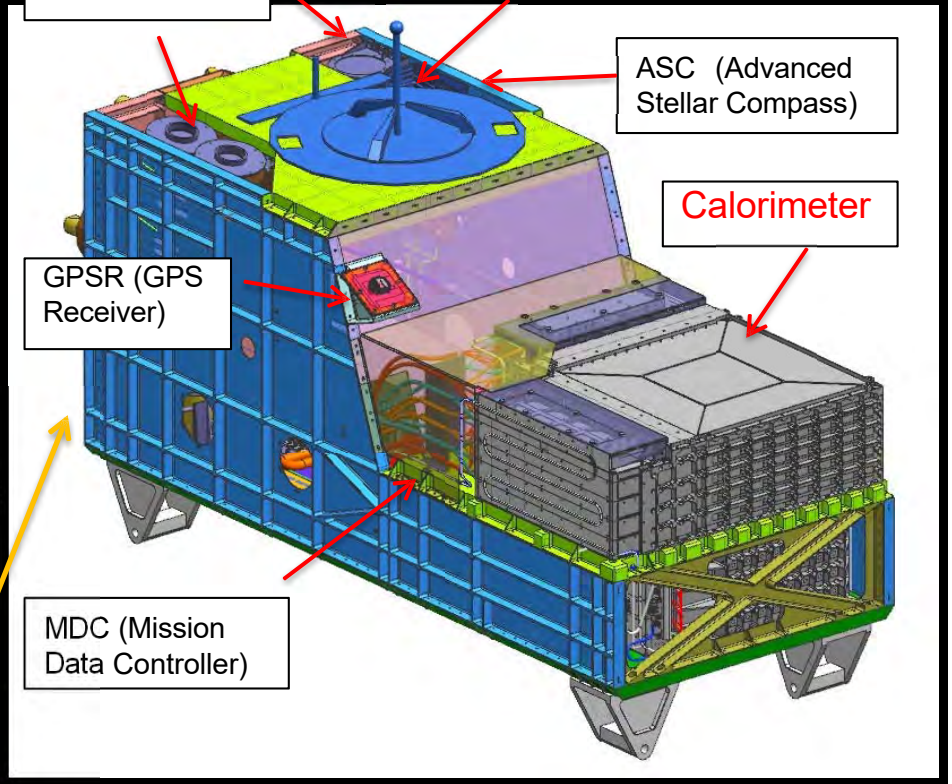


Kounotori (HTV) 5

Launched on Aug. 19th, 2015 by the Japanese H2-B rocket

Emplaced on JEM-EF port #9 on Aug. 25th, 2015 (JEM-EF: Japanese Experiment Module-Exposed Facility)

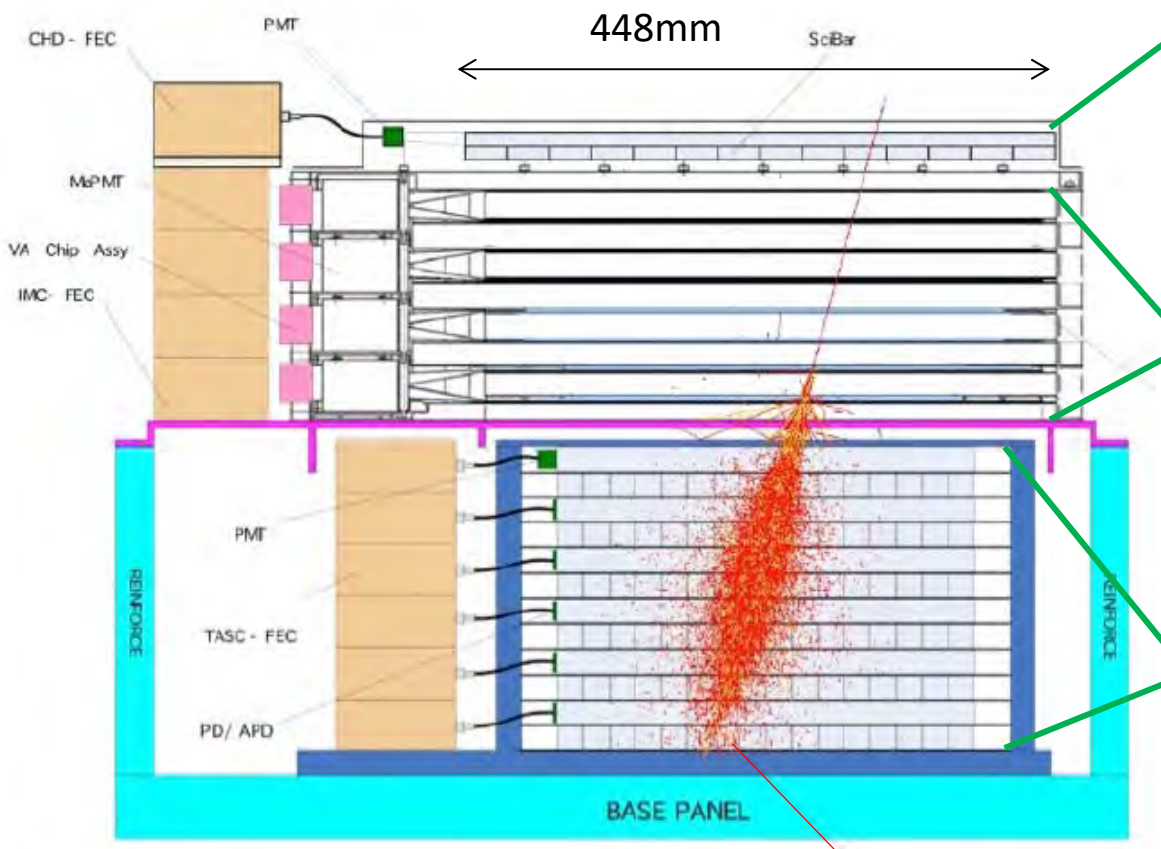




- **Mass: 612.8 kg**
- **JEM Standard Payload Size: 1850mm(L) × 800mm(W) × 1000mm(H)**
- **Power Consumption: 507 W（max）**
- **Telemetry: Medium 600 kbps (6.5GB/day) / Low 50 kbps**

CALET/CAL Detector

Fully active thick calorimeter ($30X_0$) optimized for electron spectrum measurements well into TeV region



1TeV electron shower is fully contained in TASC

Charge Detector **CHD**

plastic scintillator hodoscope, absolute charge measurement (including charge zero)

Imaging Calorimeter **IMC**

SciFi + tungsten plate ($3X_0$), reconstruction of arrival direction and initial shower development

Total Absorption Calorimeter **TASC**

PWO hodoscope ($27X_0$), energy measurements and particle identification

See poster PS1-249 (Kawakubo et al.) for CALET/CGBM results

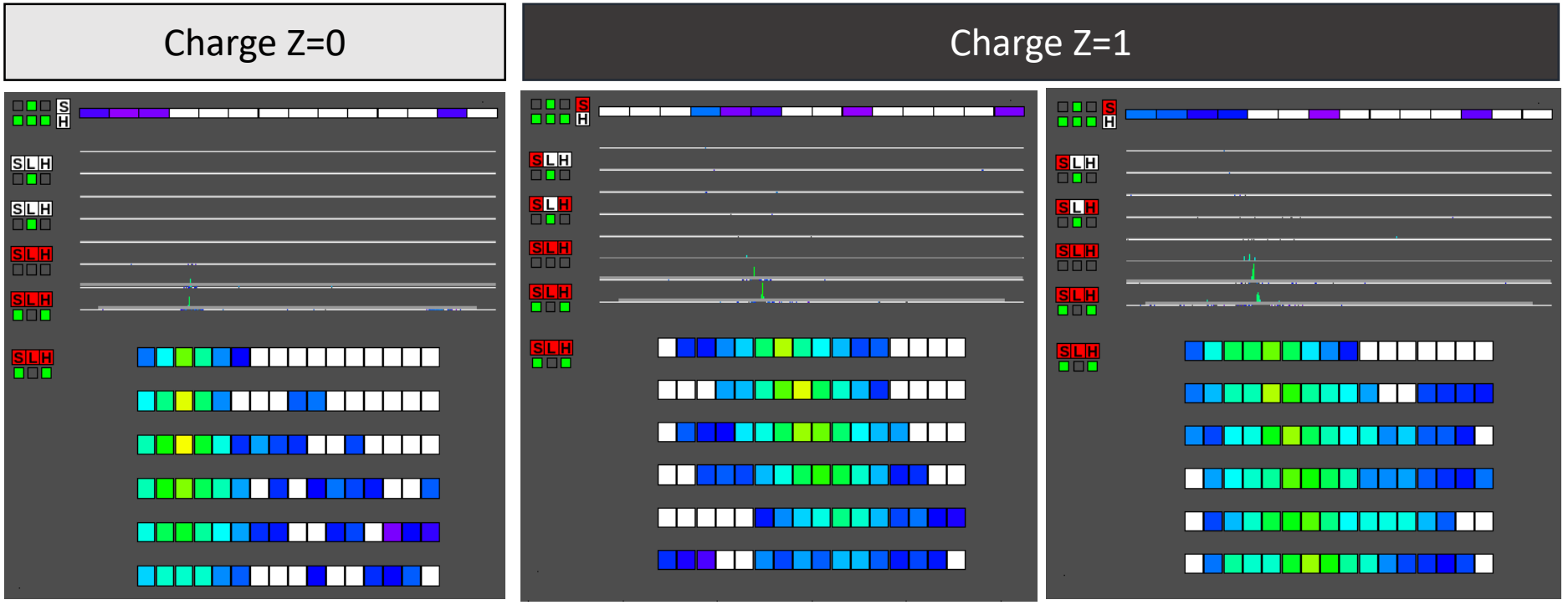
Cannady et al., ApJS 238:5 (2018)

Gamma Ray Event Selection

= 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

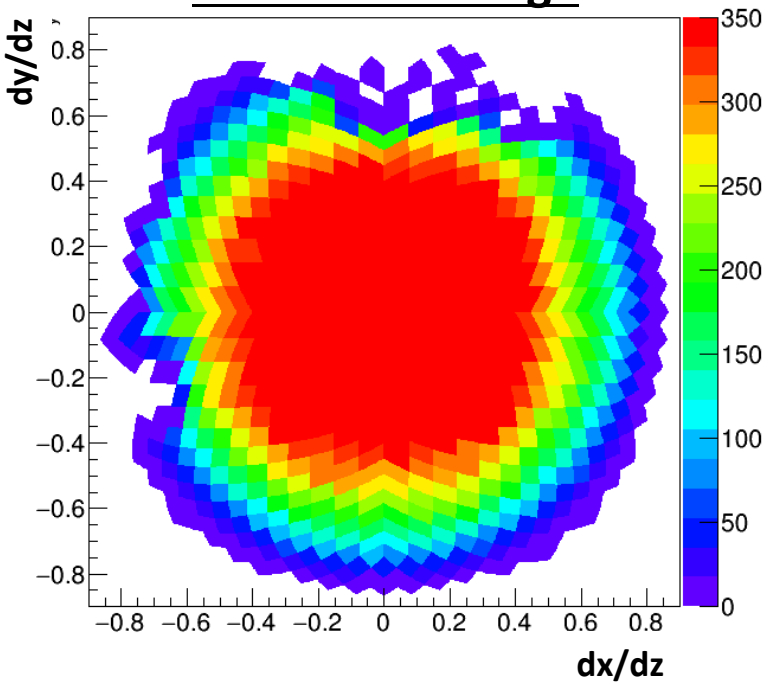
Effective Area and Sensitivity

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

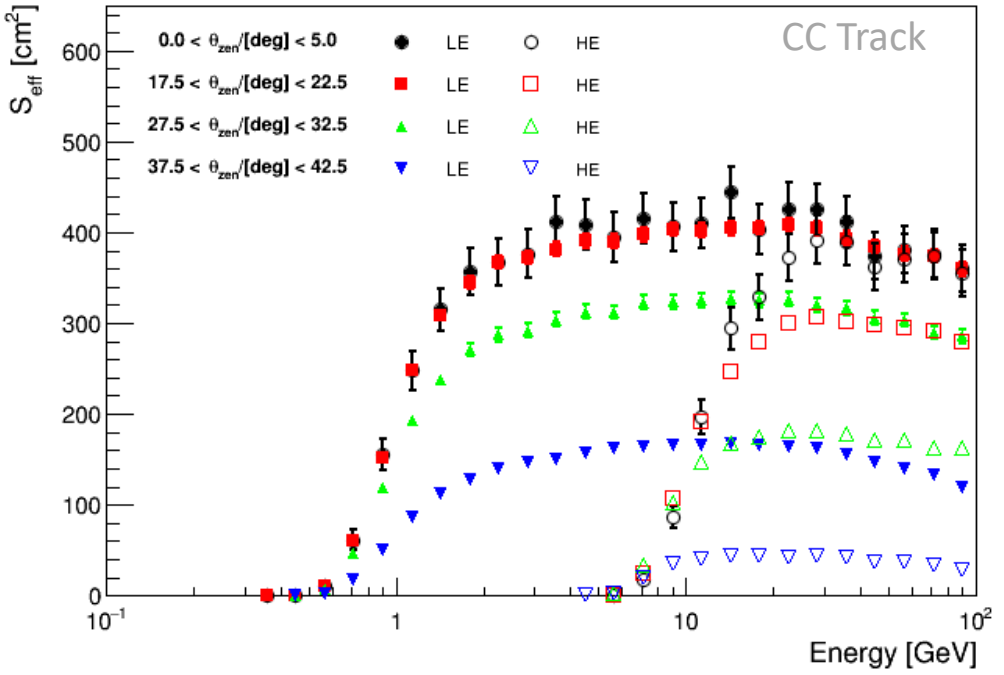
Effective area is estimated as a function of incident angle (dx/dz, dy/dz) and energy. Maximum effective area is achieved at around 5 GeV, but lower energy is more important for steep spectrum like E^{-2}.

LE-γ trigger: > 1 GeV
HE trigger: > 10 GeV

3-10GeV average



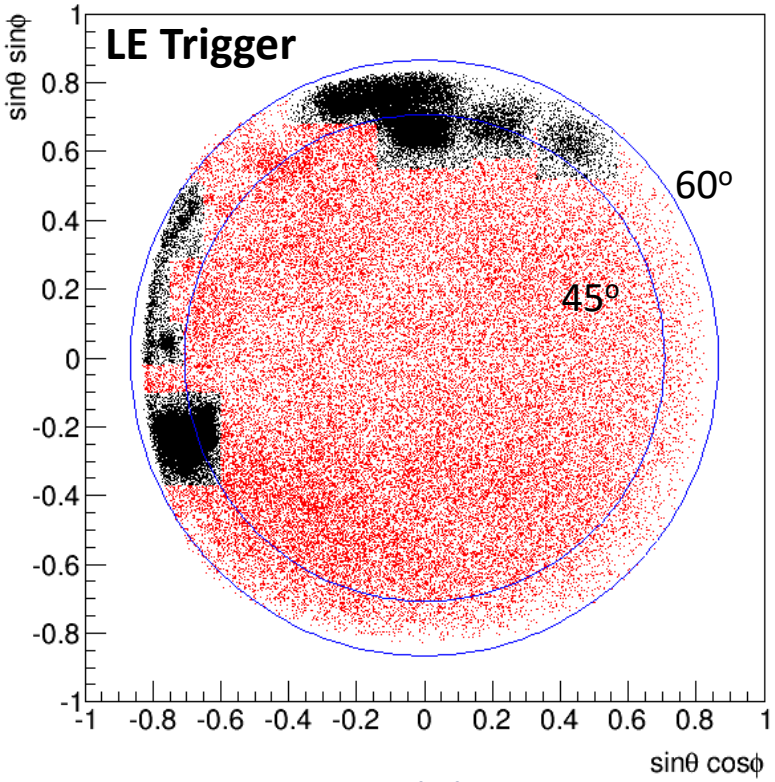
Mostly axially symmetric except for FOV cut



Effective area as a function of energy. Four representing zenith angle ranges are shown.

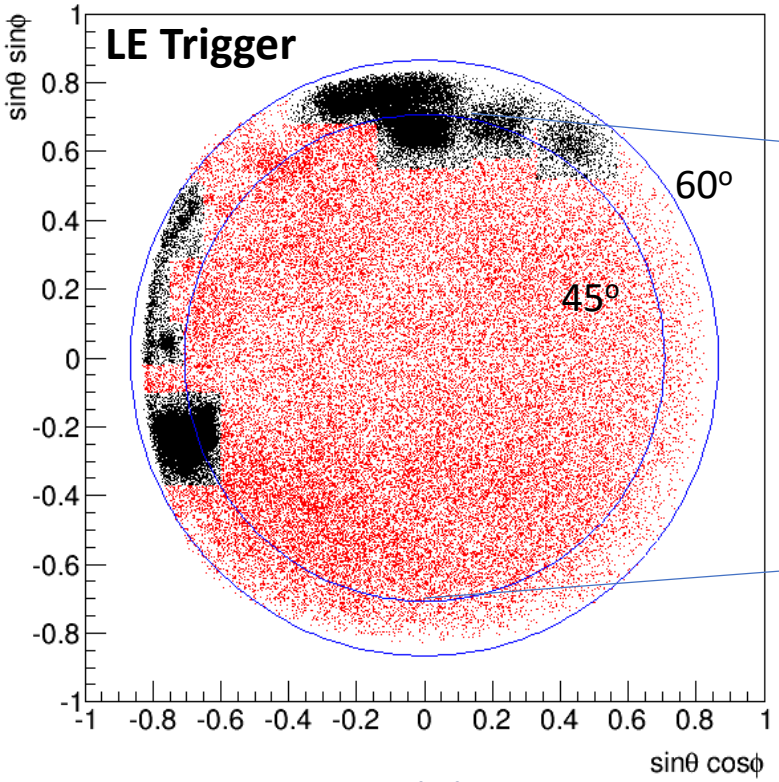
* LE-γ mode is activated when the geomagnetic latitude is below 20° and following a CALET Gamma-ray Burst Monitor (CGBM) burst trigger

Gamma-ray candidates in CALET FOV

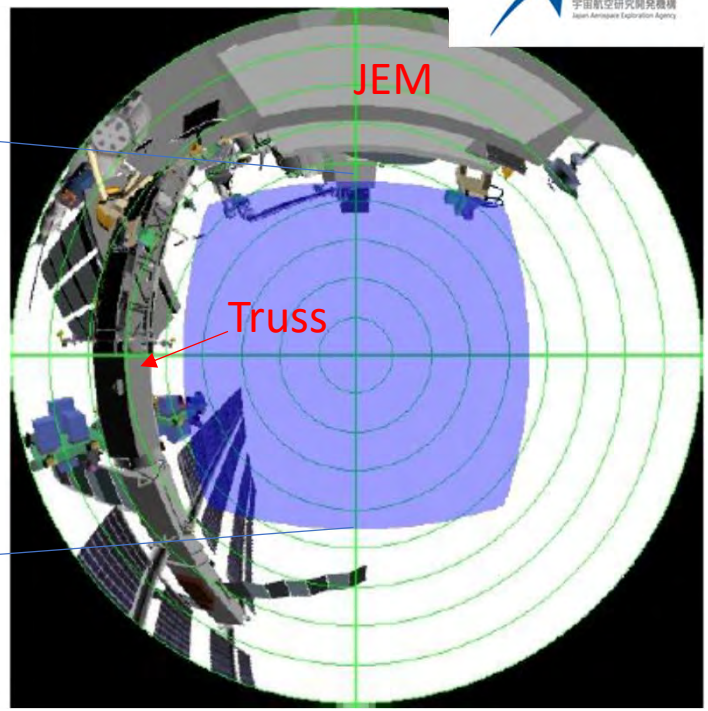


Gamma-ray candidates
in CALET FOV

Gamma-ray candidates in CALET FOV



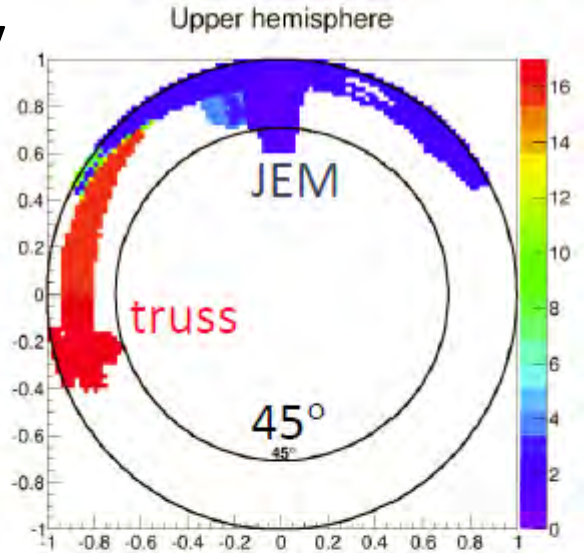
Gamma-ray candidates in CALET FOV

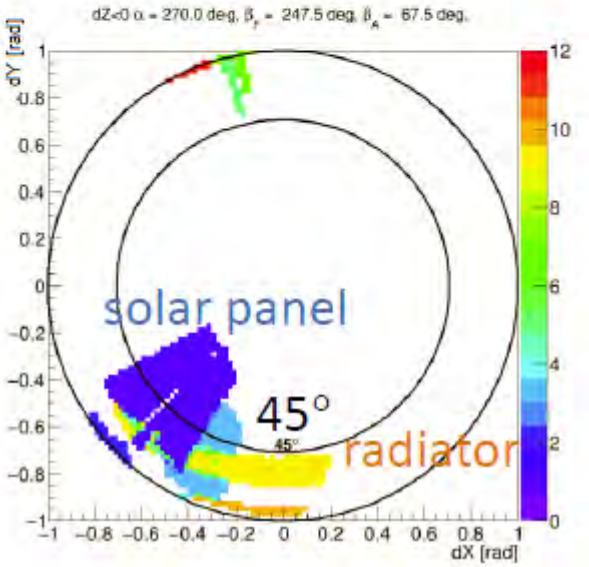


Fish-eye view of CALET FOV

ISS structures in CALET FOV

- Fixed structures (ISS truss, JEM pressurized sect.)
  - Model calculation
- Robot arms (SSRMS, JEMRMS)
  - Check gamma-ray data monthly
- Solar panels, radiators
  - Rotation in 90min period
    - Model calculation in each period





FOV used for celestial gamma ray analysis is enhanced, taking account of angular resolution (3° from structures)

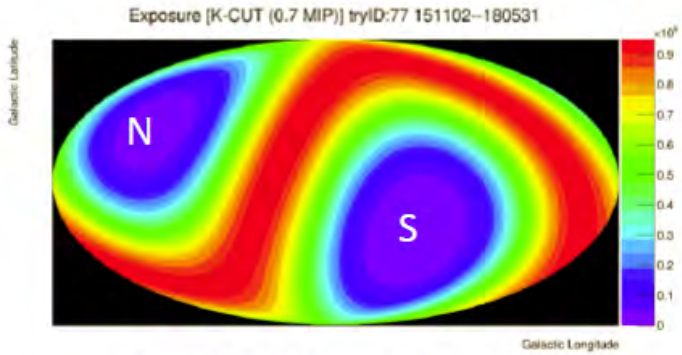
Improvements in exposures

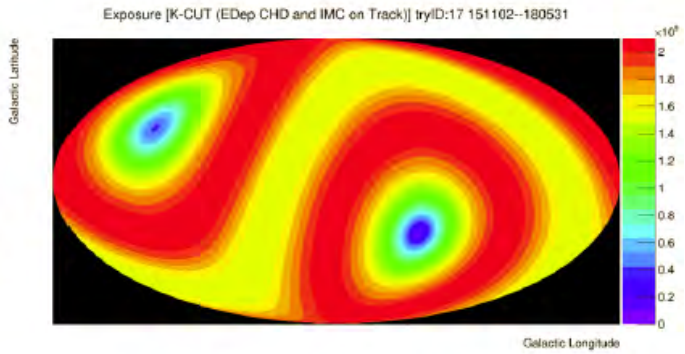
Low-Energy Region (2.5~3.2GeV)

High-Energy Region (25~32GeV)

No cut on moving structures

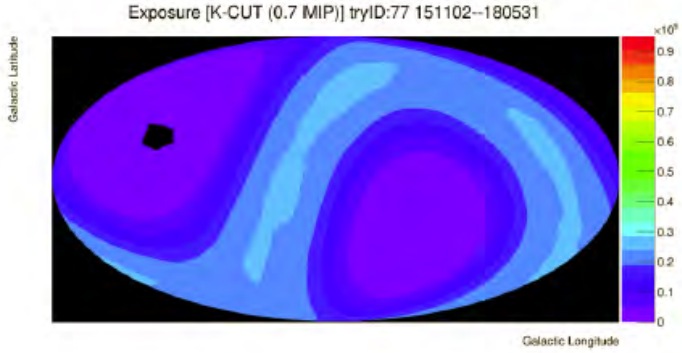
(A)

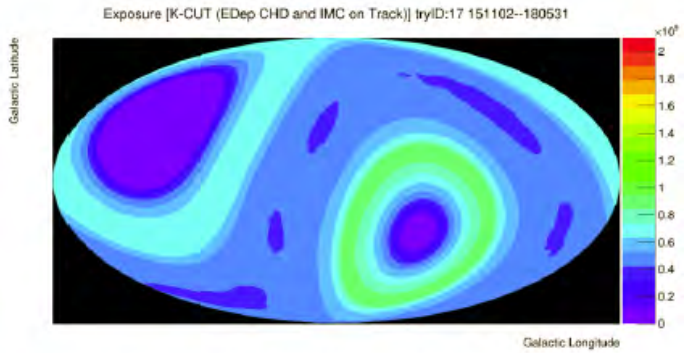




ApJS 238(2018)5 w/ upper right region only in FOV

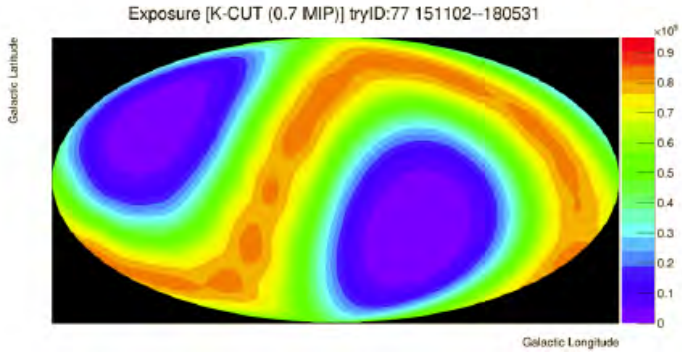
(B)

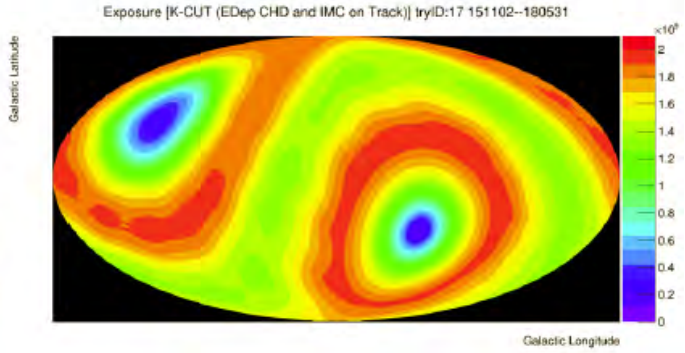




w/ moving structure cut

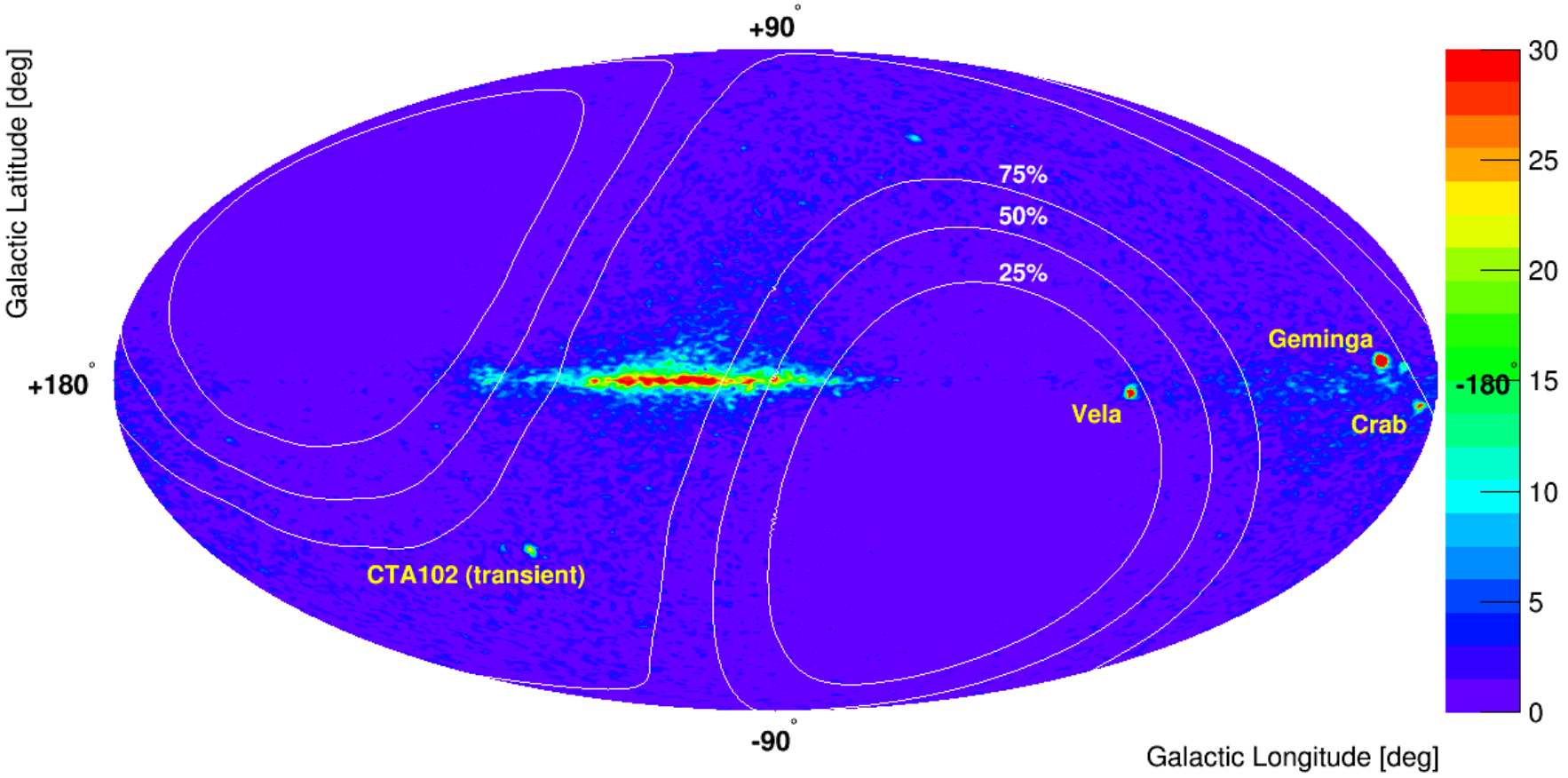
(C)





(Gamma-ray candidates after the improved cut) > 3*(candidates after the old cut)

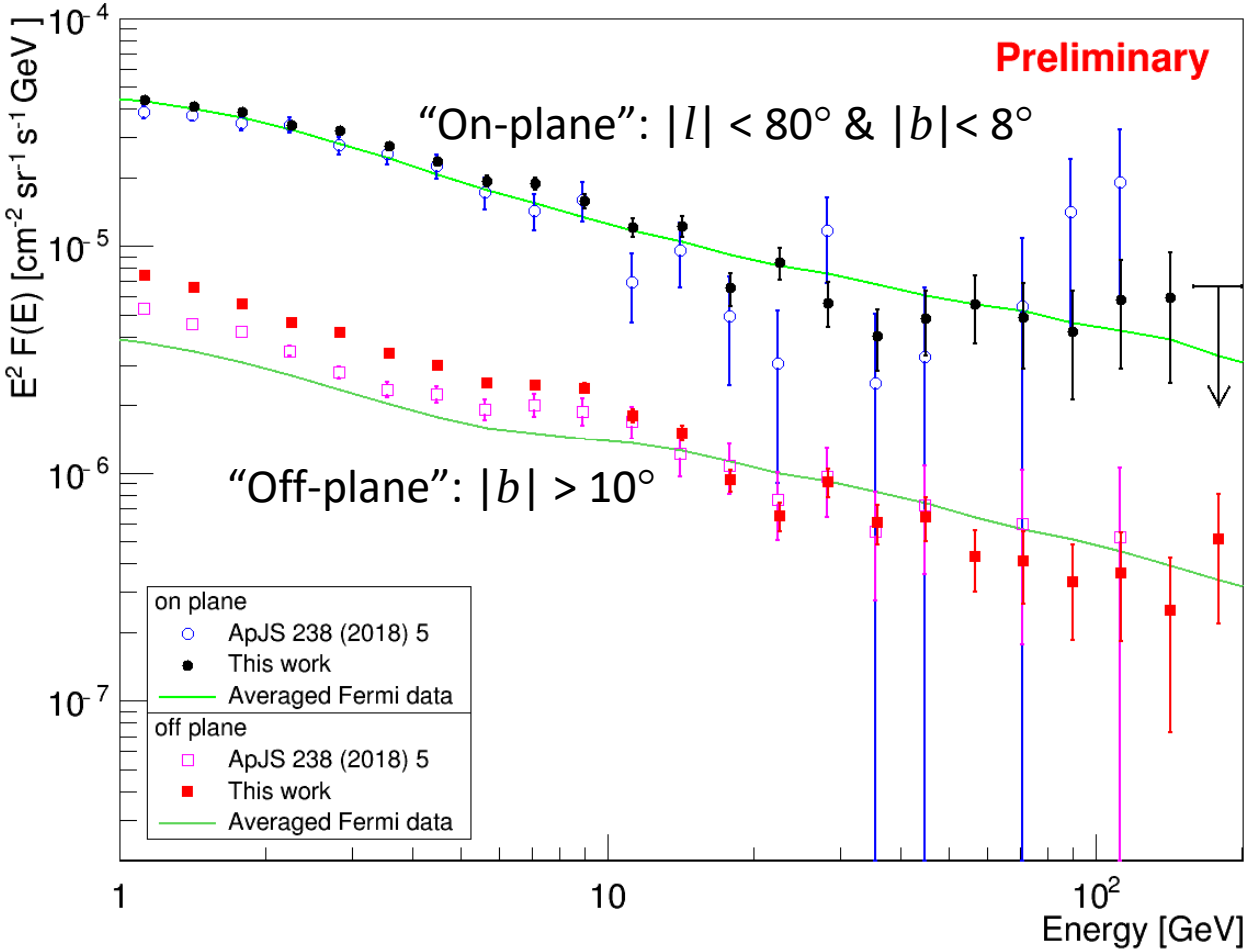
Gamma-ray skymap



LE-γ mode, from 2015 November to 2018 May
(Contours show relative exposures)

Gamma-ray spectra

LE-γ mode
from 2015 November to 2018 May

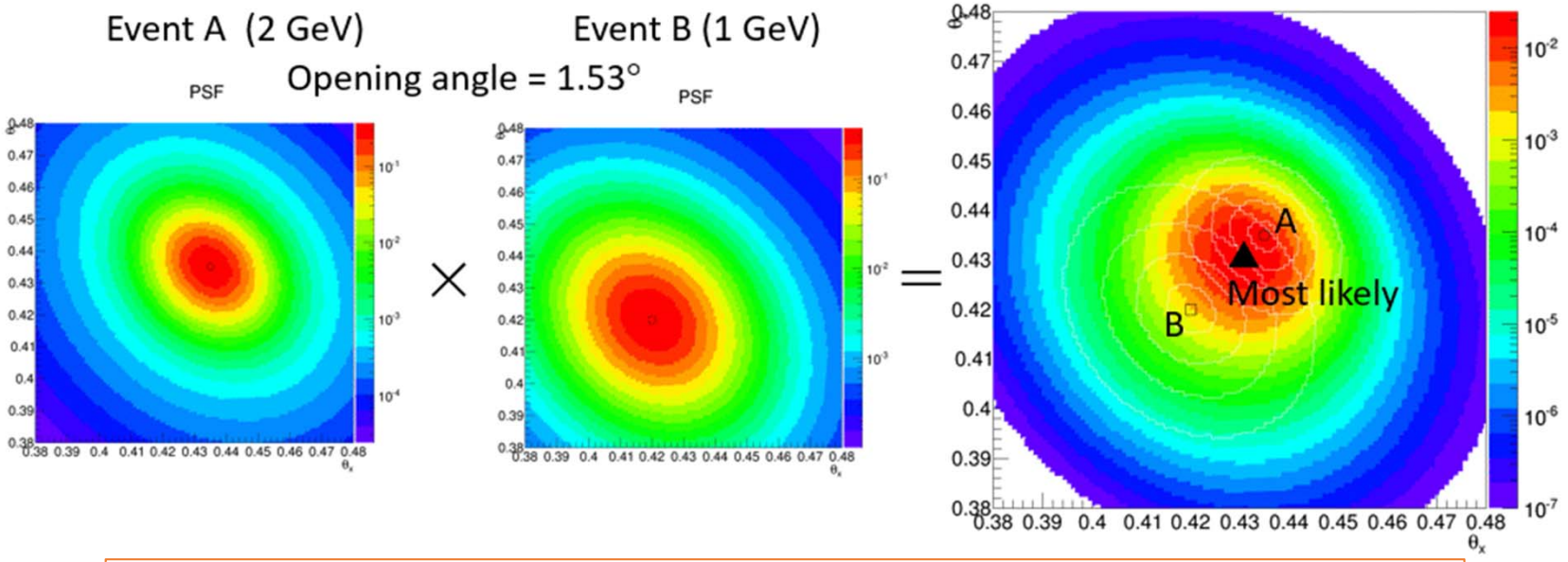


Some discrepancies with Fermi-LAT are seen, especially in the ``off-plane'' region, which may indicate remaining backgrounds and possible systematic errors, and should be studied further.

Searching transient events

- 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.

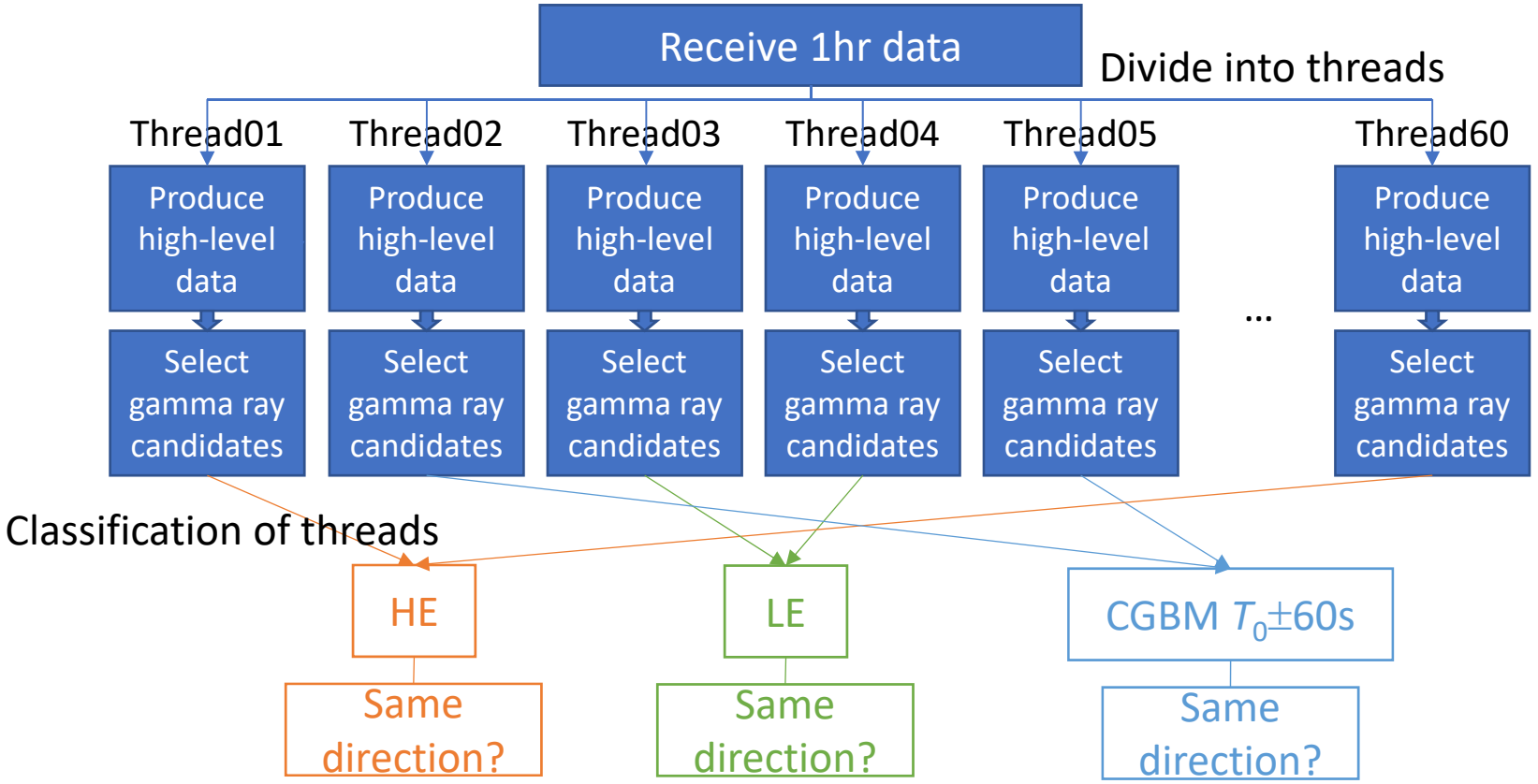
Judging ‘pairs’ using PSF



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



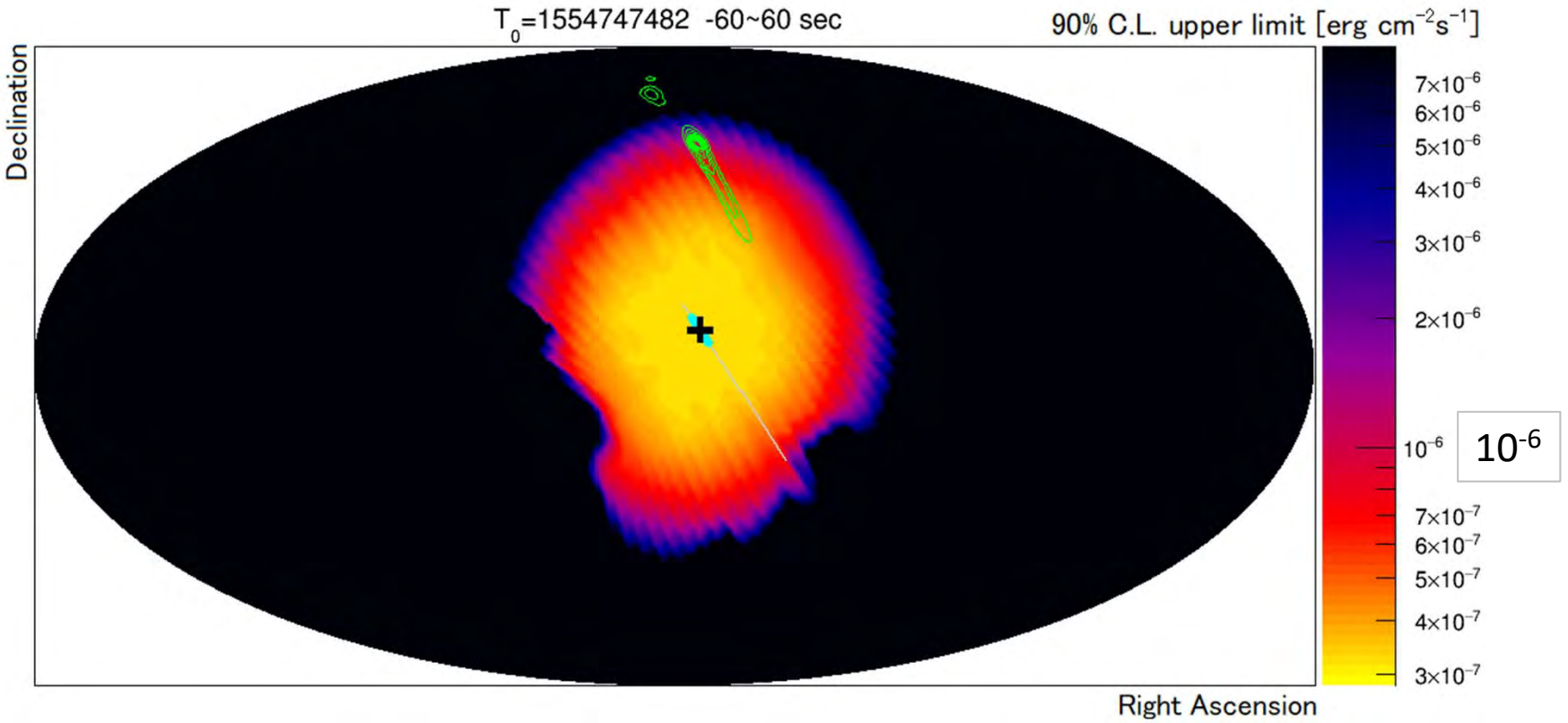
Limits on electromagnetic emission from gravitational wave events (LIGO/Virgo O3)

GCN No.	LIGO/Virgo trigger	Trigger time T_0 (2019)	Events $T_0 \pm 60$ s	90% C.L. U.L.	Summed probability	CAL α (°)	CAL δ (°)
24088	S190408an	04-08 18:18:02.288 UTC	0	2.3×10^{-6}†	80%	352.9	8.3
24218	S190425z	04-25 08:18:05.017 UTC	0	1.0×10^{-4}	5%	131.3	-43.6
24276	S190426c	04-26 15:21:55.337 UTC	0	2.5×10^{-5}	10%	183	-50.9
24403	S190503bf	05-03 18:54:04.294 UTC	0	4.2×10^{-5}	10%	169	-45.5
24495	S190510g	05-10 02:59:39.292 UT	0	–	No	295.7	50.8
24531	S190512at	05-12 18:07:14.422 UT	0	1.9×10^{-5}	10%	214.9	37.7
24548	S190513bm	05-13 20:54:28.747 UT	0	6.0×10^{-5}†	5%	348	4.4
24593	S190517h	05-17 05:51:01.831 UT	0	–	No	126.2	-31.9
24617	S190519bj	05-19 15:35:44.398 UT	0	–	No	243.1	51.1
24648	S190521g	05-21 03:02:29.447 UT	0	6.0×10^{-6}	30%	205.7	49.2
24649	S190521r	05-21 07:43:59.463 UT	0	–	No	225.3	51.4
24735	S190602aq	06-02 17:59:27.089 UT	0	2.9×10^{-4}	5%	127.5	45.1

Table 1: Summary of CALET/CAL gamma-ray observations on gravitational event candidates in the LIGO/Virgo third observing run reported in GCN circulars [10]. Upper limits (U.L.) are given in unit of erg cm^{-2}s^{-1} for the energy range 10–100 GeV except for those marked with † which are for 1–10 GeV, which corresponds to the HE and the LE-γ mode of the trigger condition of CAL around T_0. 'Summed probability' is the maximum probability in the overlap region of the CAL field-of-view at T_0 with the summed LIGO/Virgo probability map ('No' means there is no overlap). Also shown are the coordinates of the center of CAL field-of-view at T_0.

†: LE-γ

Energy flux limit map for S190408an



90% C.L. upper limit on S190408an energy flux in the energy region 1–10 GeV and time window [T_0-60s, T_0+60 s] shown in the equatorial coordinates. The thick cyan line shows the locus of the FOV center of CAL, and the plus symbol is that at T_0. Also shown by green contours is the localization significance map of S190408an reported by LIGO/Virgo.

Summary

- CALET cosmic ray detector onboard the ISS has been monitoring cosmic gamma-rays above 1 GeV since 2015 October.
- We have developed new cuts to reduce secondary gamma-ray background produced in the various ISS structures, which increase our event statistics significantly.
- A parallel-processing analysis server to search for gamma-ray pairs has been developed to reduce delay time from occurrence of transient events.
- Searches for electromagnetic counterparts of gravitational events upon triggers supplied by LIGO/Virgo interferometers during their third observing run yielded upper limits on gamma-ray emission.
- We continue observation at least until 2021, hoping for a further extension.