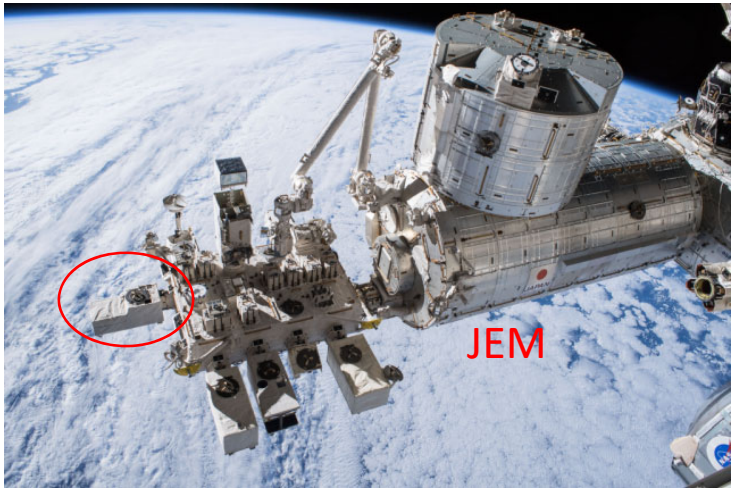
GAD5c



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

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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
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16) National Inst. of Radiological Sciences, Japan
17) National Institute of Polar Research, Japan
18) Nihon University, Japan
19) Osaka City University, Japan
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34) Yukawa Institute for Theoretical Physics, Kyoto University, Japan

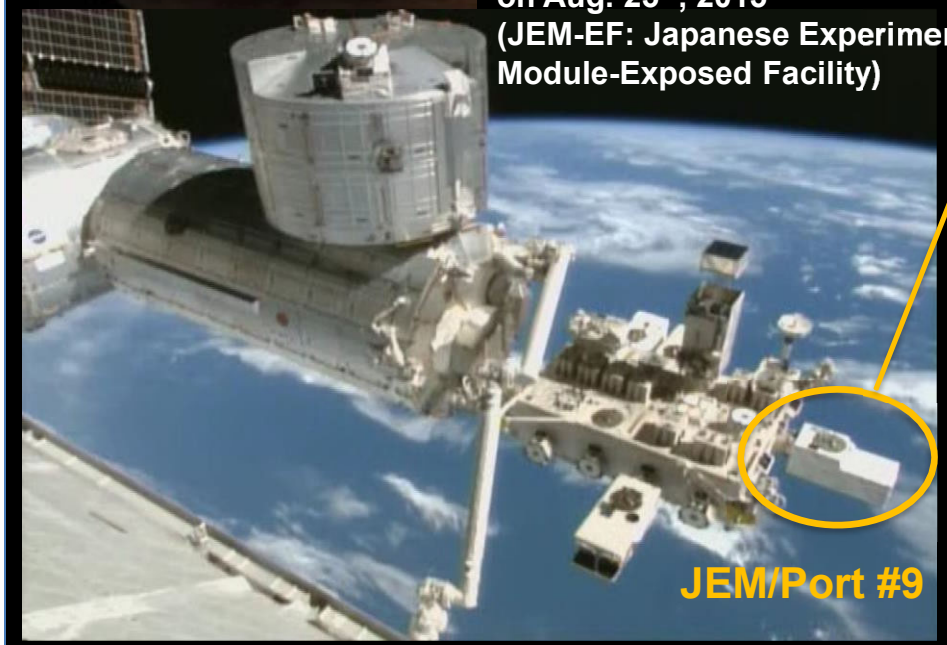
See Highlight talk H7 (Asaoka et al.) for the summary of CALET results

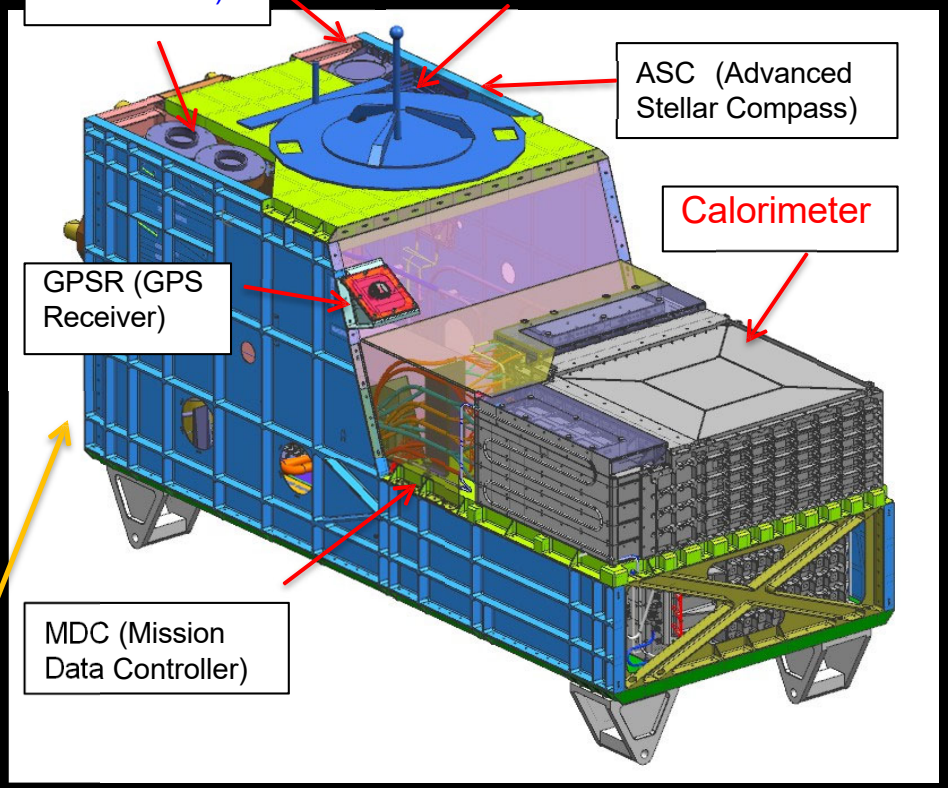
CALET Payload

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)

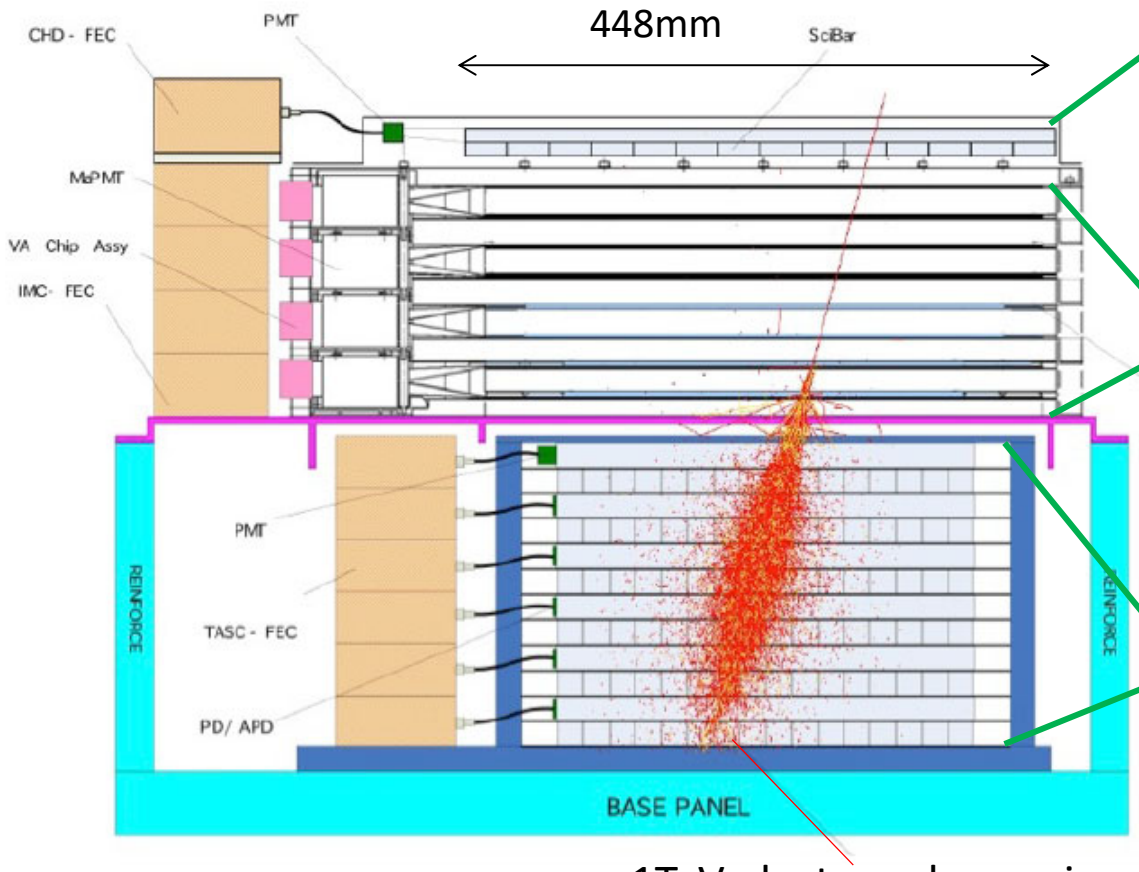




- **Mass: 612.8 kg**
- **JEM Standard Payload Size: 1850mm(L) × 800mm(W) × 1000mm(H)**
- **Power Consumption: 507 W（max）**
- **Telemetry: Medium 600 kbps (6.5GB/day) / Low 50 kbps**

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)

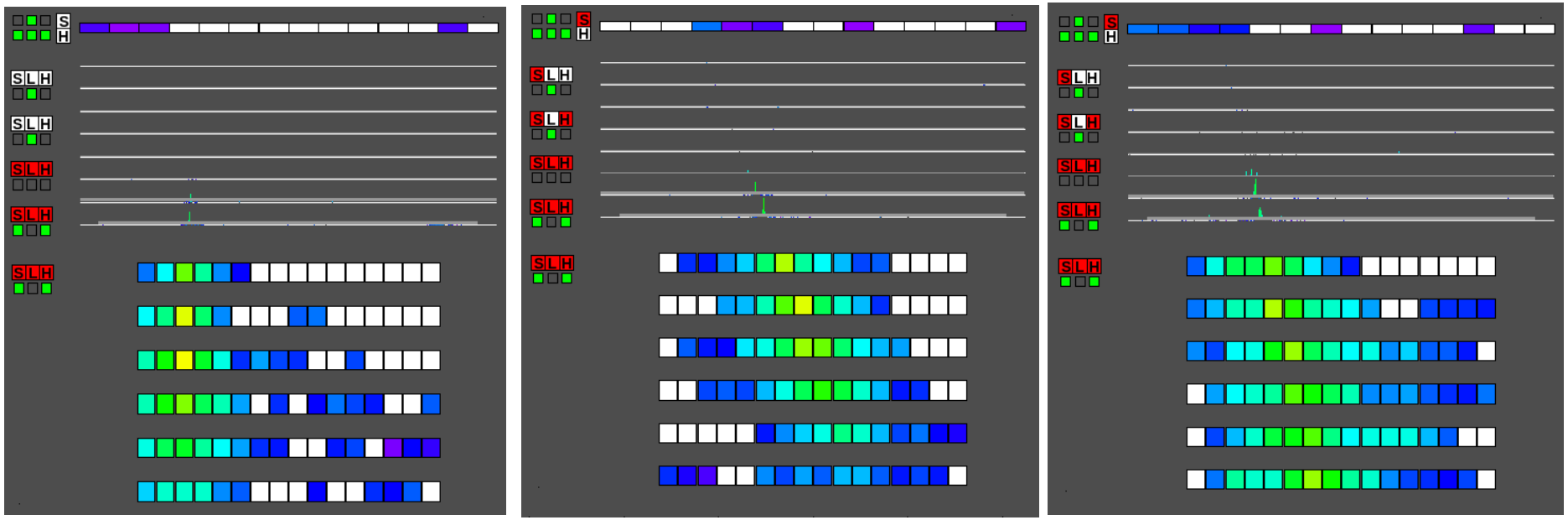
Gamma Ray Event Selection

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

100 GeV Event Examples

gamma-ray | electron | proton

Charge Z=0 | Charge Z=1



Electromagnetic Shower | Hadron Shower

well contained, constant shower development | larger spread

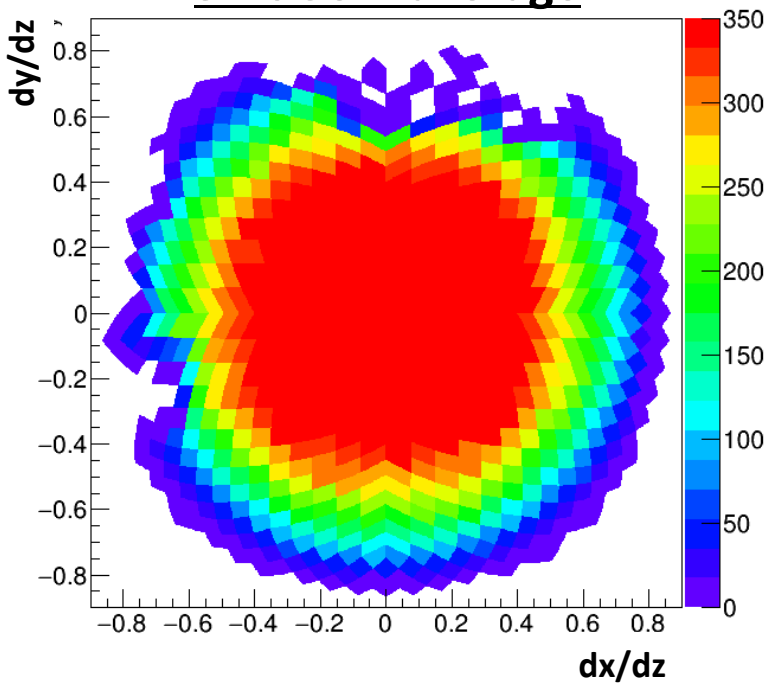
Effective Area and Sensitivity

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

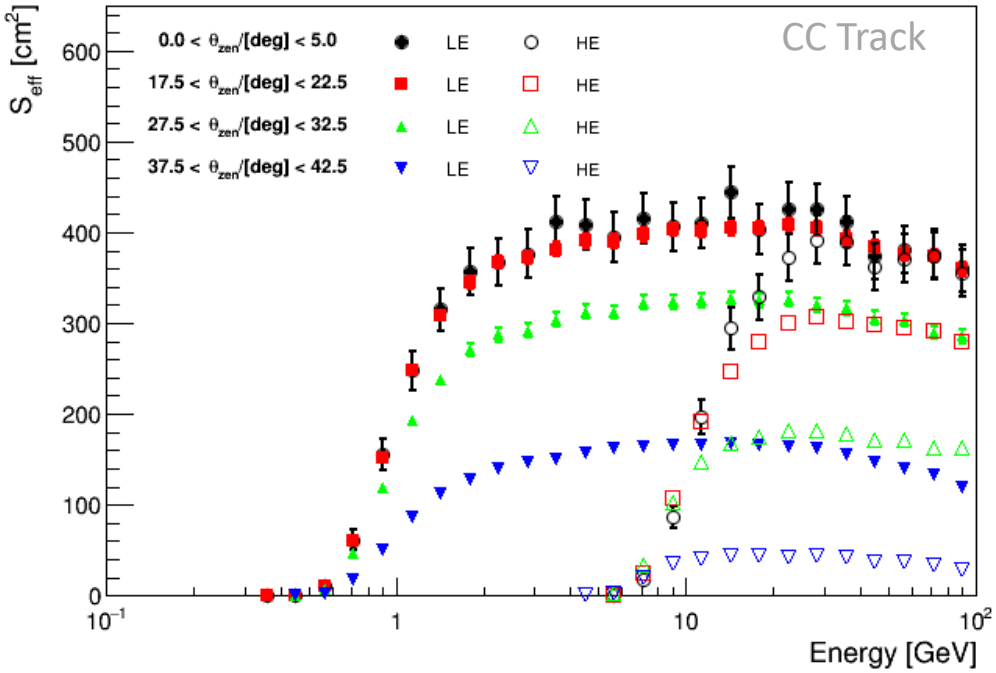
Effective area is estimated as a function of incident angle (dx/dz, dy/dz) and energy. Maximum effective area is achieved at around 5 GeV, but lower energy is more important for steep spectrum like E^{-2}.

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

3-10GeV average



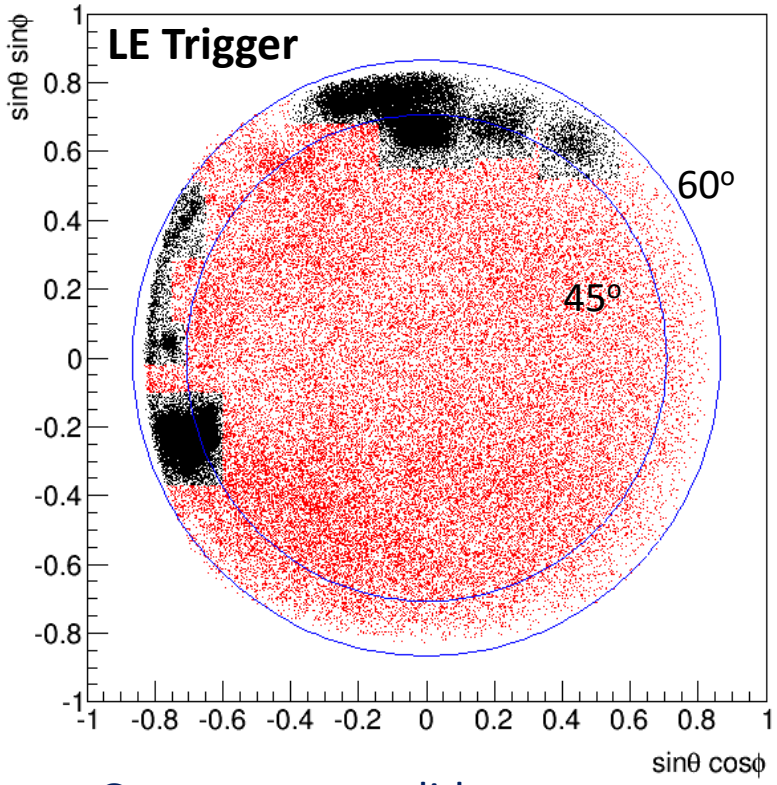
Mostly axially symmetric except for FOV cut



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

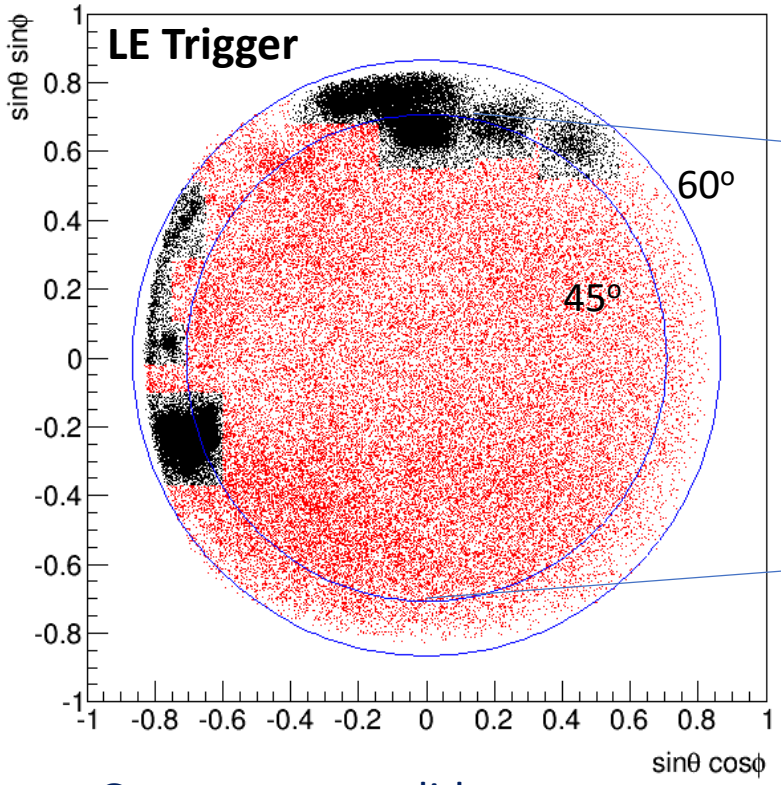
Gamma-ray candidates in CALET FOV



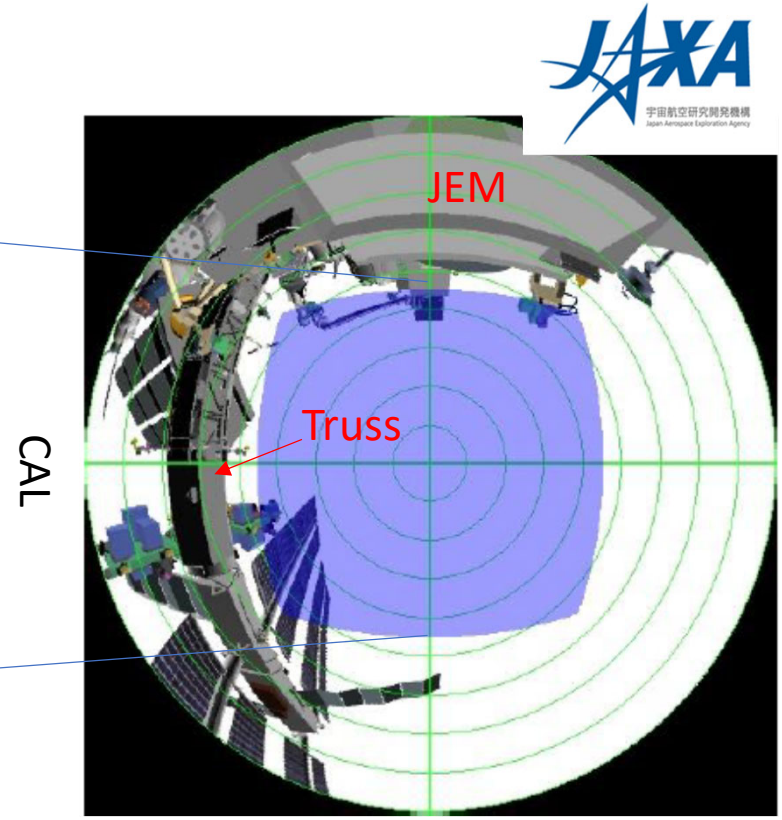
Gamma-ray candidates
in CALET FOV

* Secondary production is seen only in gamma-rays
because of extended field of view and very-low flux.

Gamma-ray candidates in CALET FOV



Gamma-ray candidates in CALET FOV

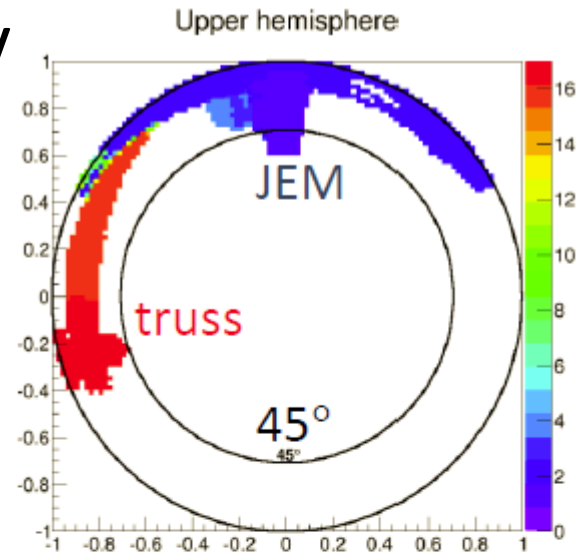


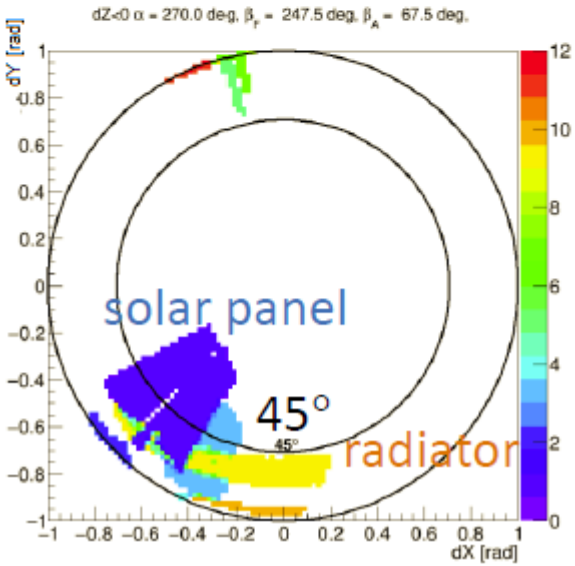
Fish-eye view of CALET FOV

* Secondary production is seen only in gamma-rays because of extended field of view and very-low flux.

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)

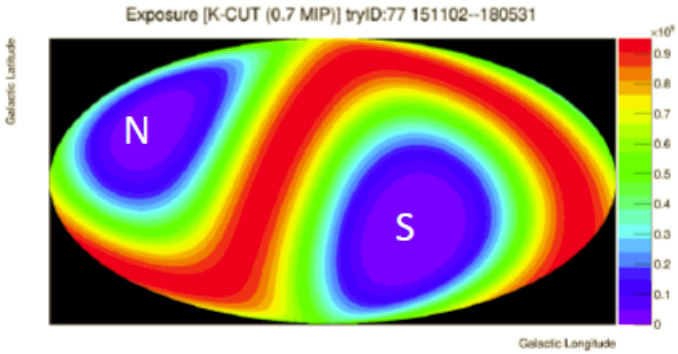
Improvements in exposures

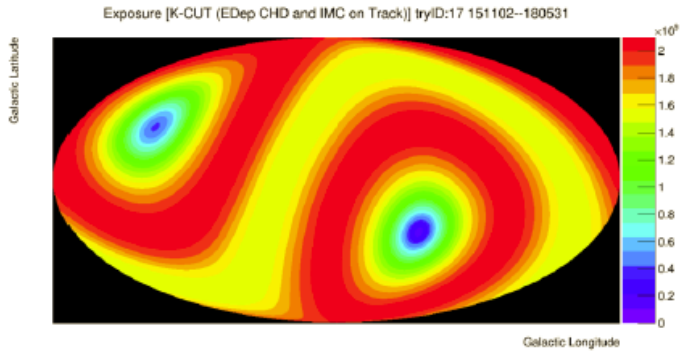
Low-Energy Region (2.5~3.2GeV)

High-Energy Region (25~32GeV)

No cut on moving structures

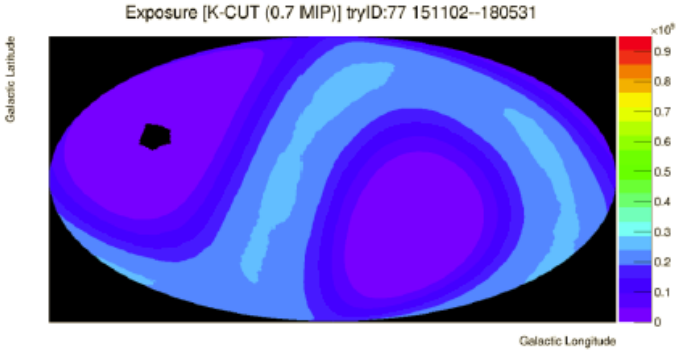
(A)

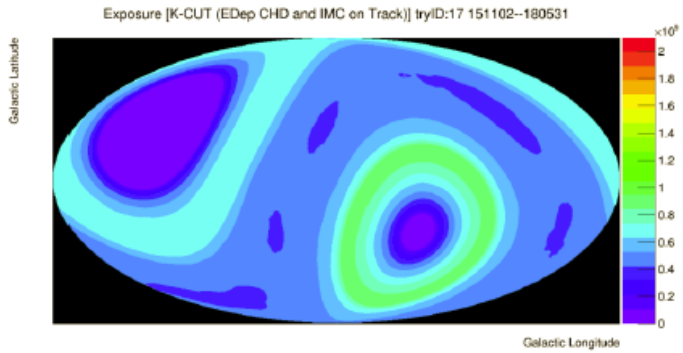




ApJS 238(2018)5 w/ upper right region only in FOV

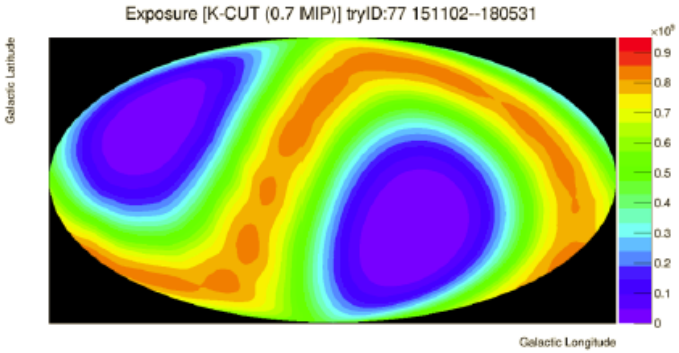
(B)

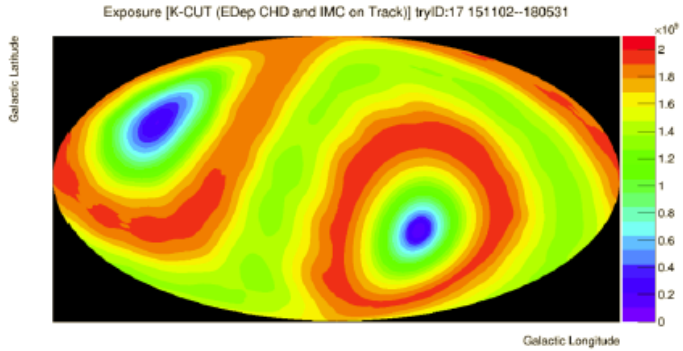




w/ moving structure cut (*)

(C)

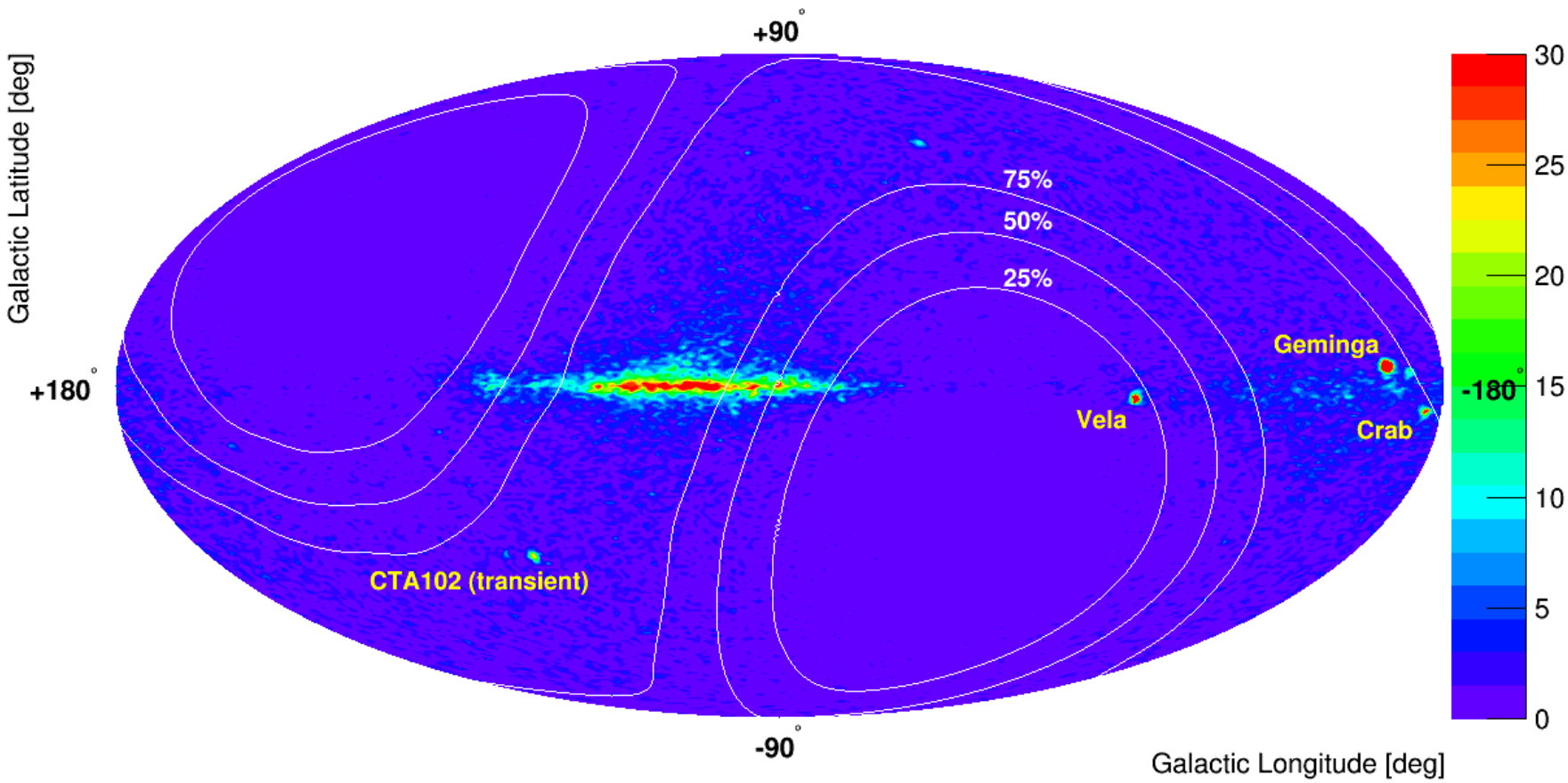




(*) only relevant in gamma-ray analysis. The effect of structures in electron analysis, for example, is completely negligible.

Gamma-ray skymap

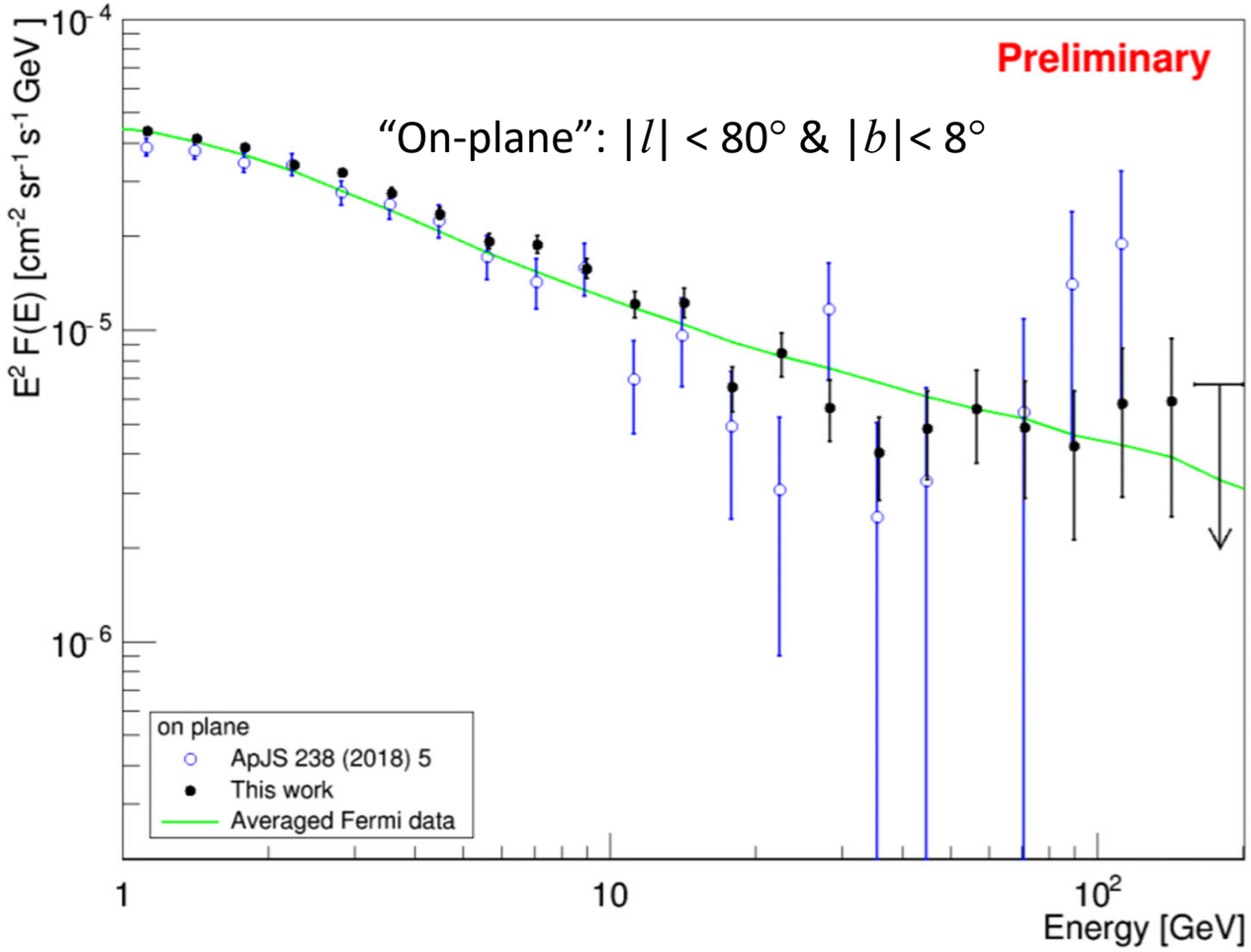
LE-γ trigger: > 1 GeV



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

Gamma-ray spectra

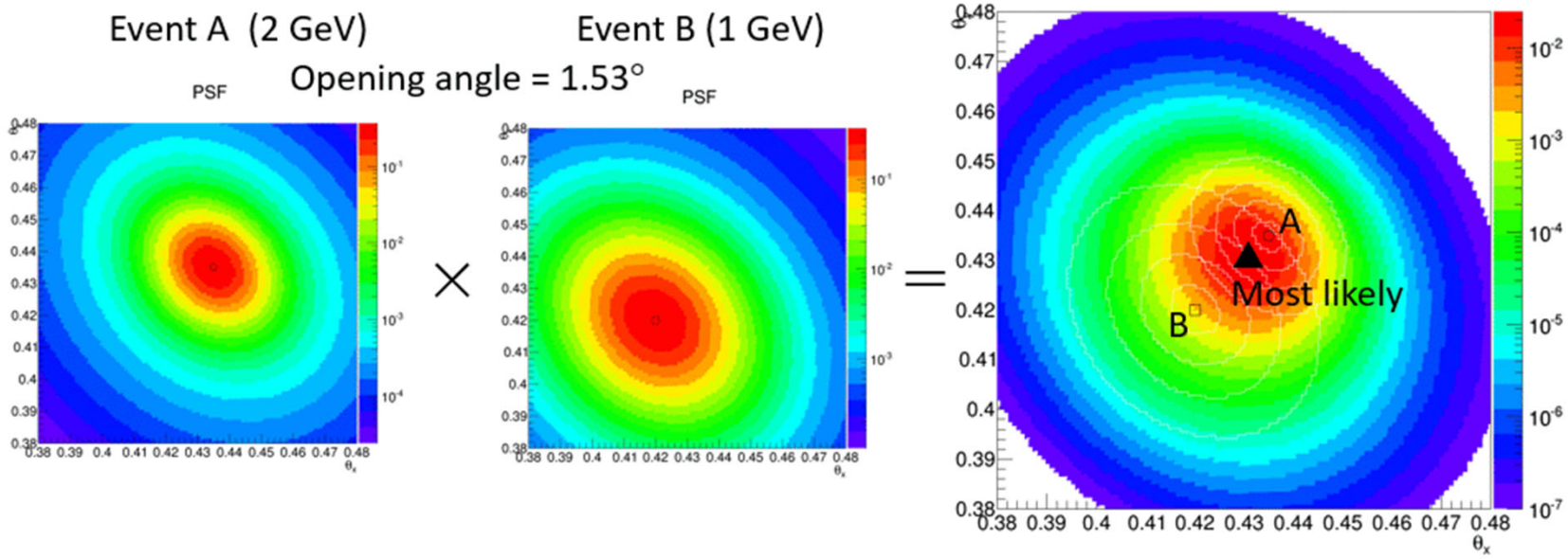
LE-γ mode
from 2015 November to 2018 May



Searching transient events

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

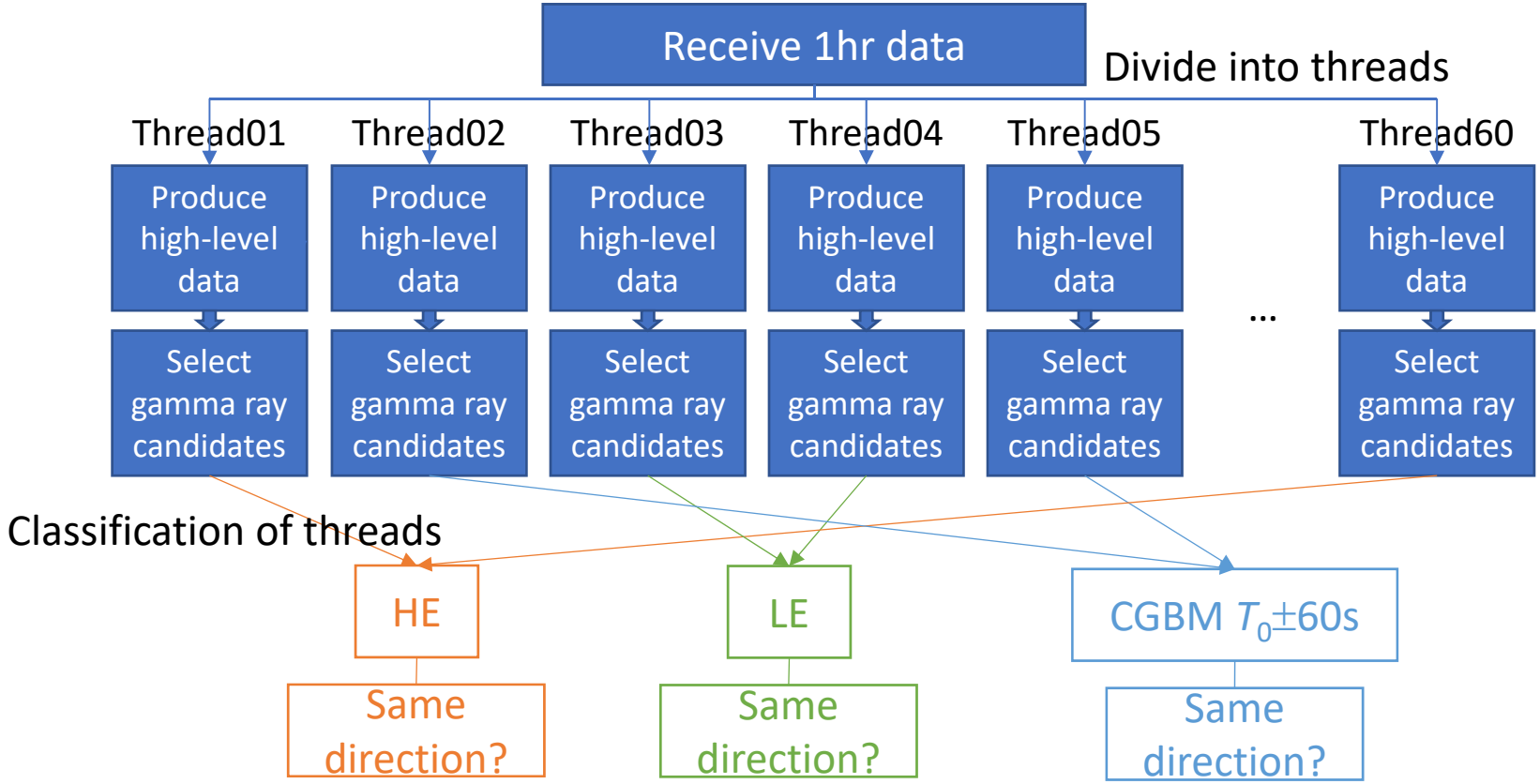
Judging 'pairs' using PSF



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



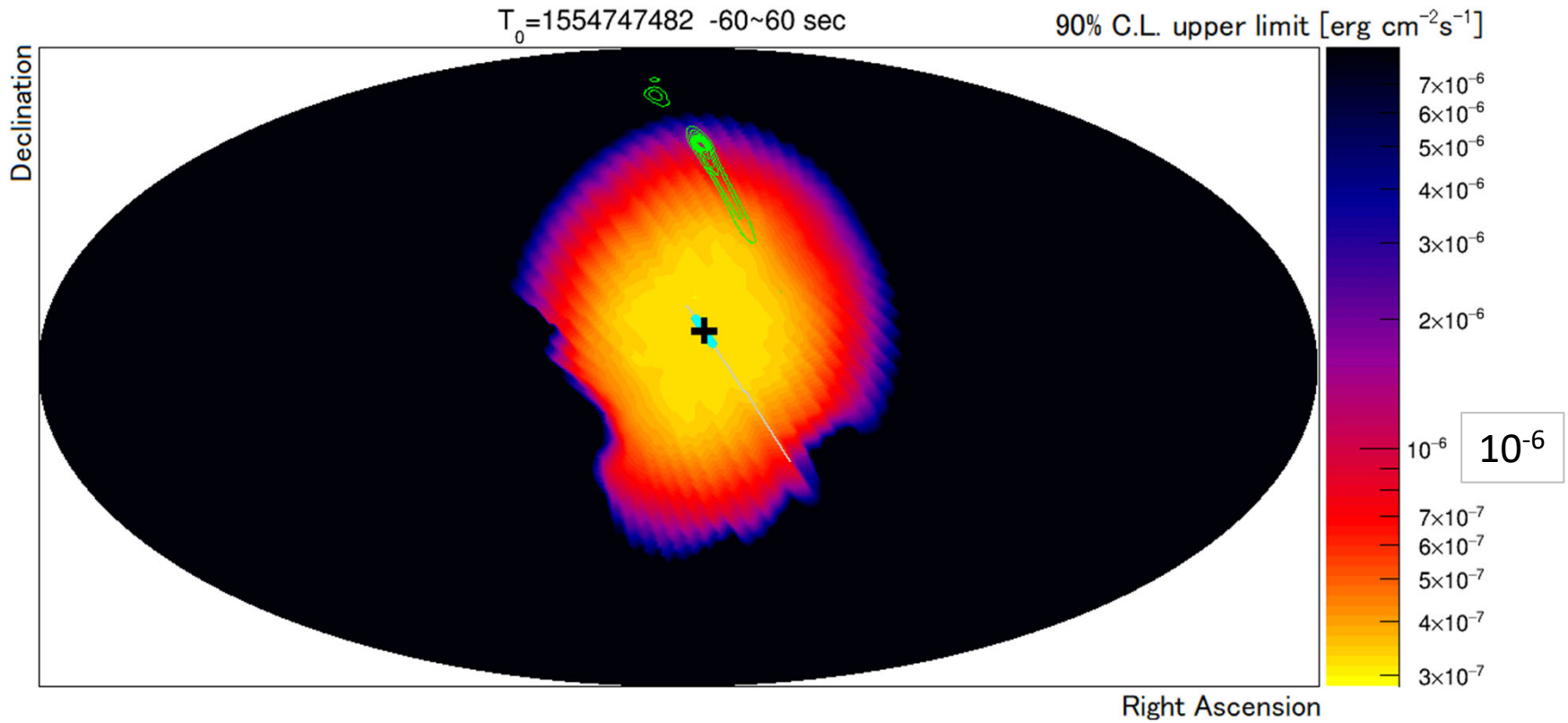
Limits on electromagnetic emission from gravitational wave events (LIGO/Virgo O3)

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 wave 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.