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Ultra-low-L sub-MeV electron microbursts during the May 2024 superstorm

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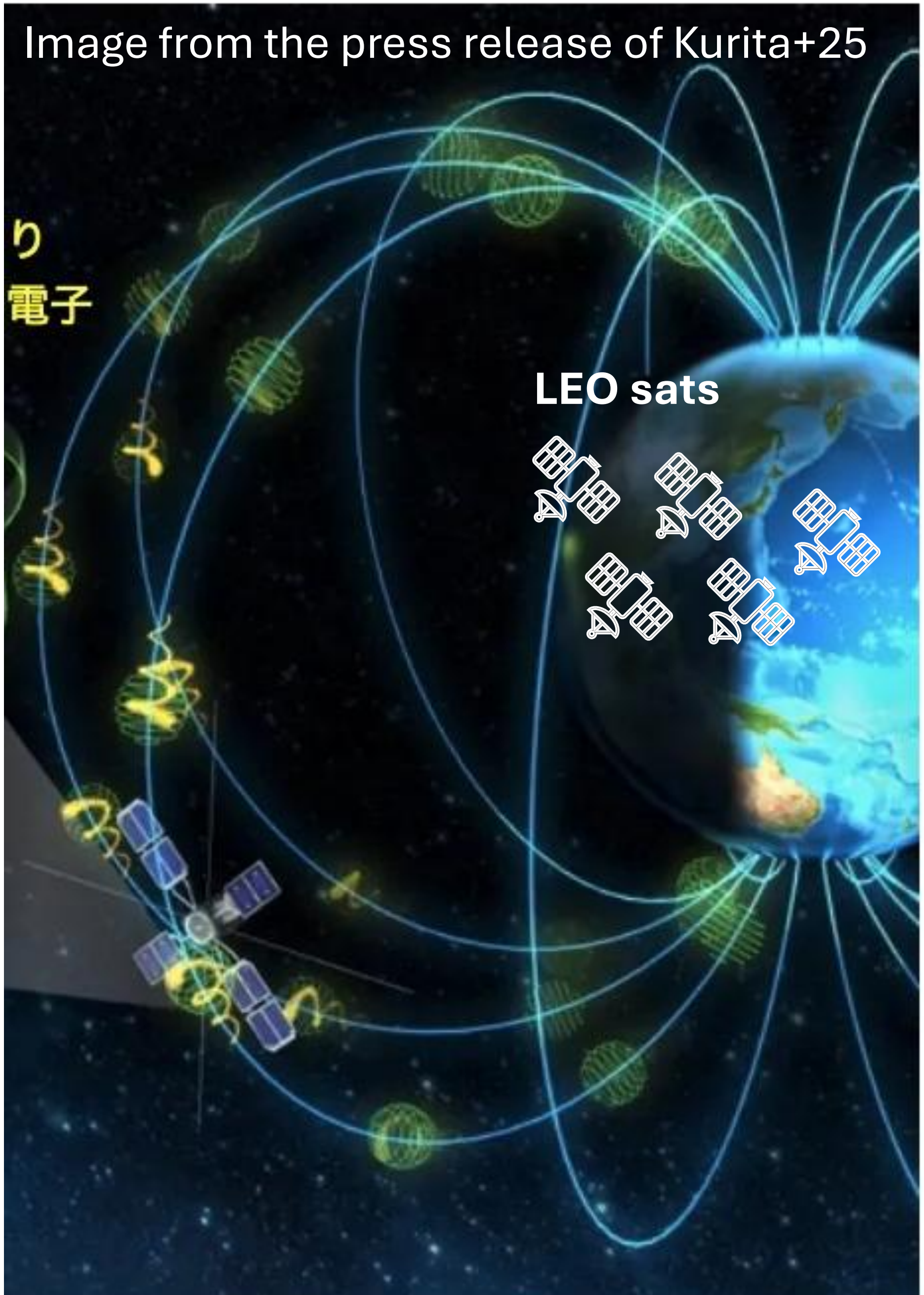
Main Results

- Microburst-type relativistic electron precipitation (REP) events were observed by CGBM during the main phase of the May 2024 super geomagnetic storm.
    - $L \sim 2$ & MLT just after midnight
    - Simultaneous responses were detected by CALET/CHD & MAXI/RBM → indicating precipitation of hundreds of keV to MeV electrons
- On the magnetospheric side, Arase observed enhanced chorus waves.
    - At $L^* \sim 2$ and morning MLT.
- Physical Interpretation: Relativistic electrons in the inner magnetosphere were pitch-angle scattered by chorus waves (Arase) and precipitated into the atmosphere (CGBM).
    - First observational evidence at $L \sim 2$ (despite imperfect magnetic conjunction)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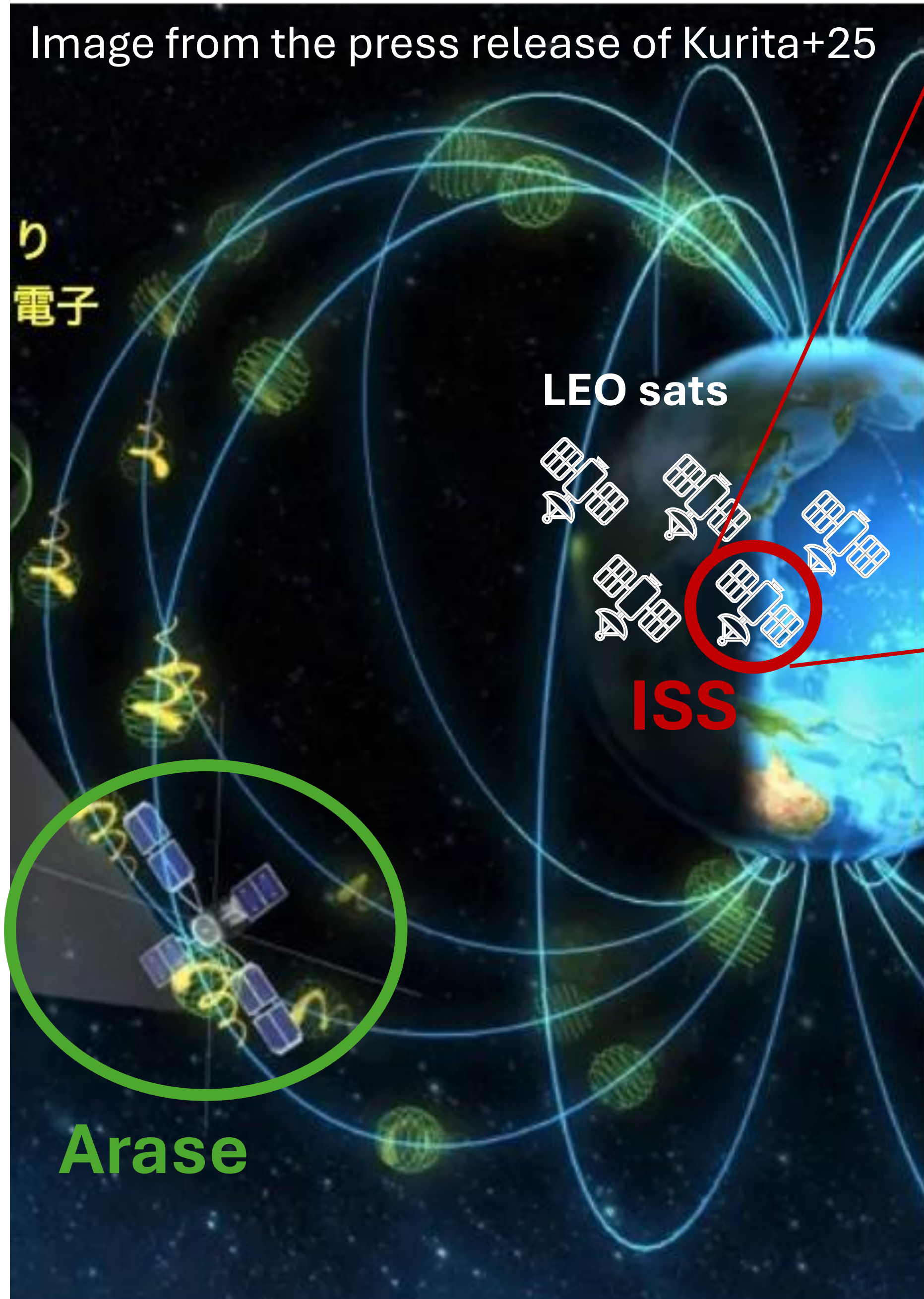
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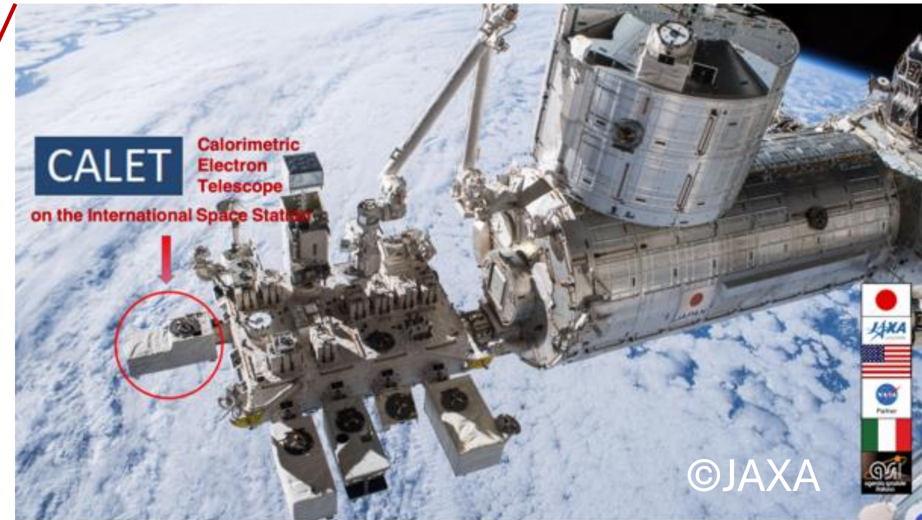
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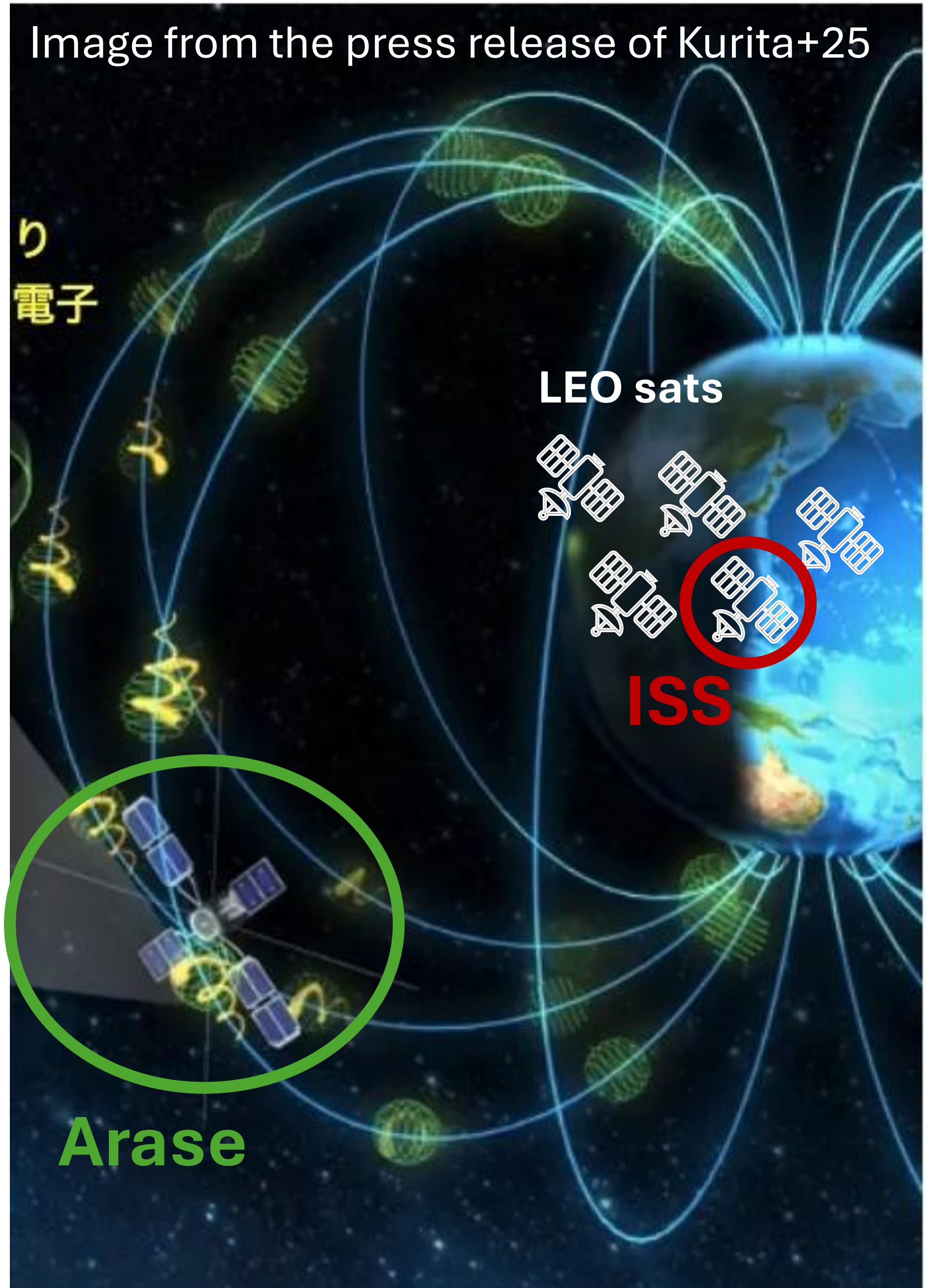
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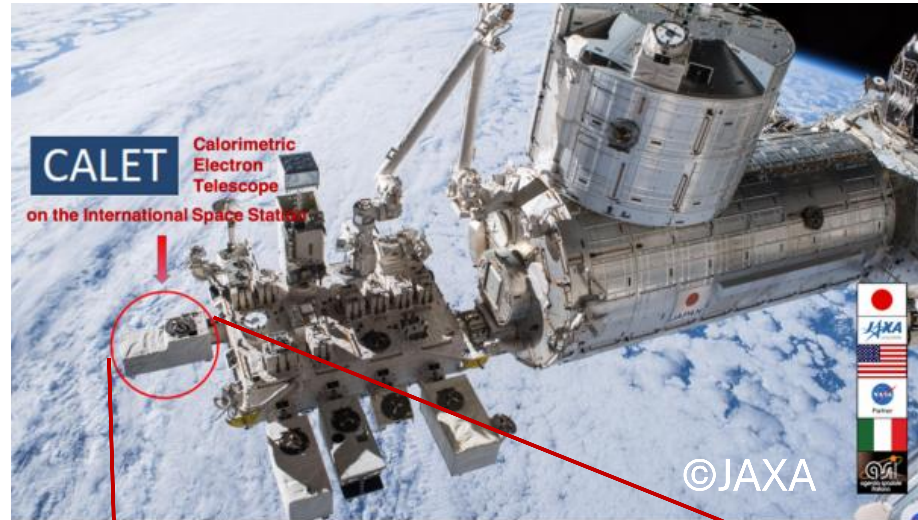
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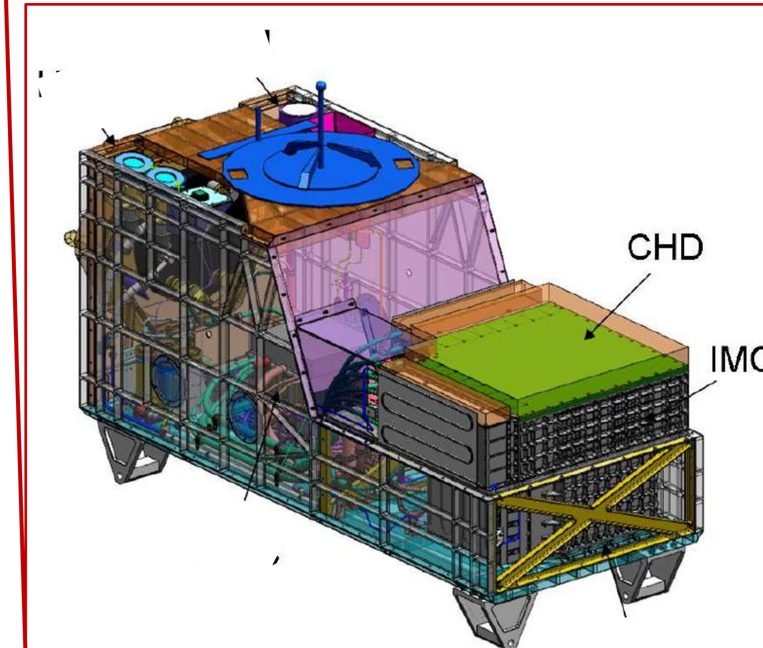
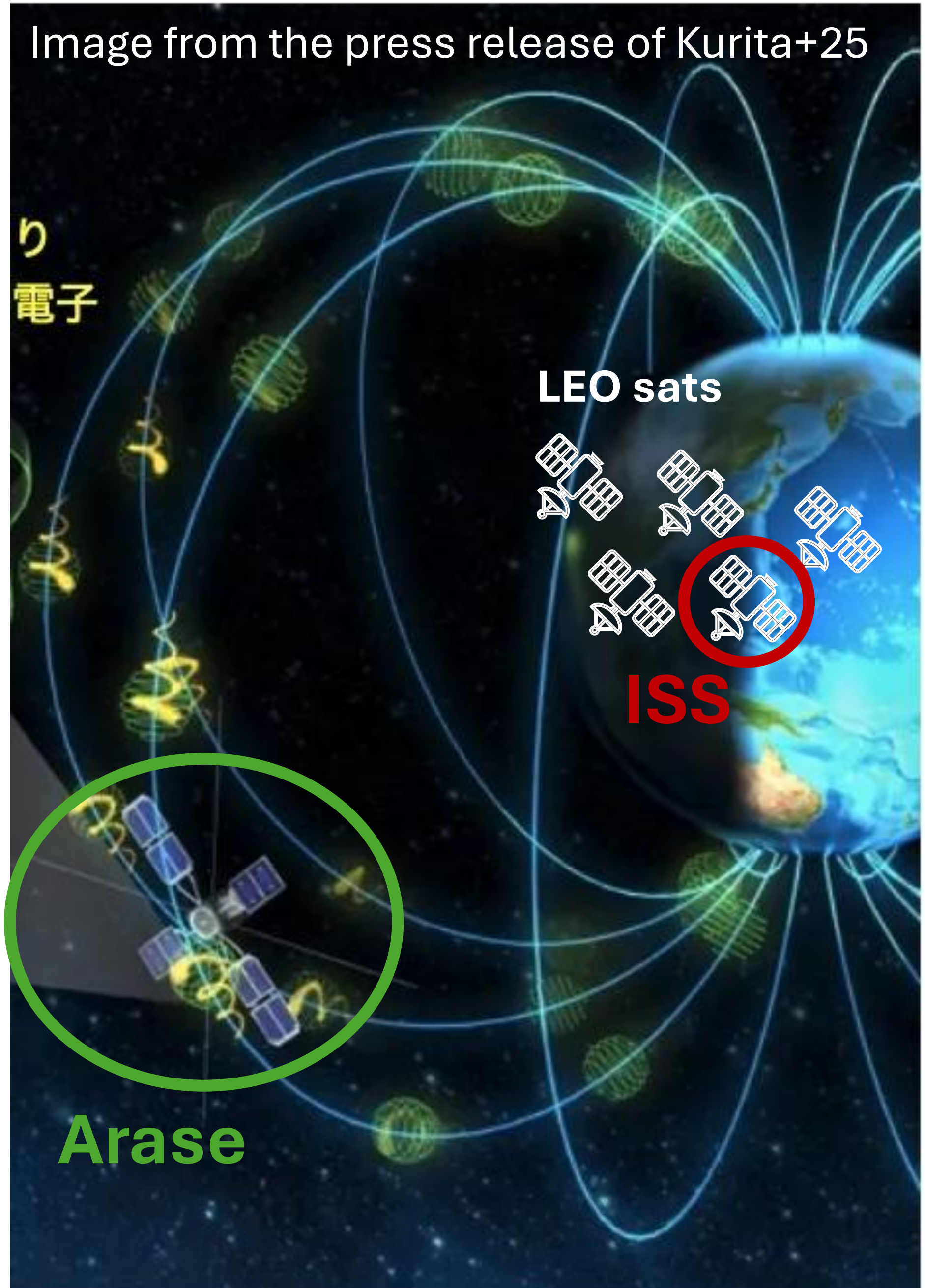

CHD
IMC
Yamaoka+13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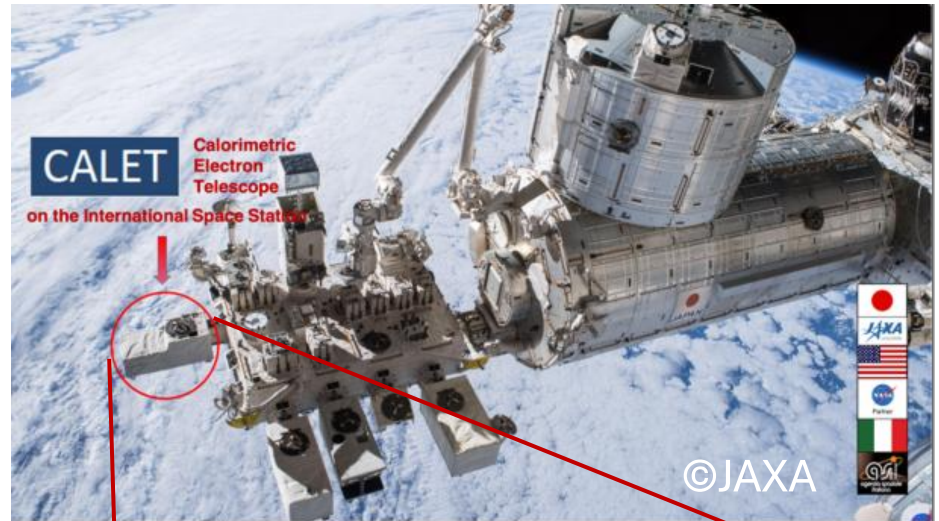
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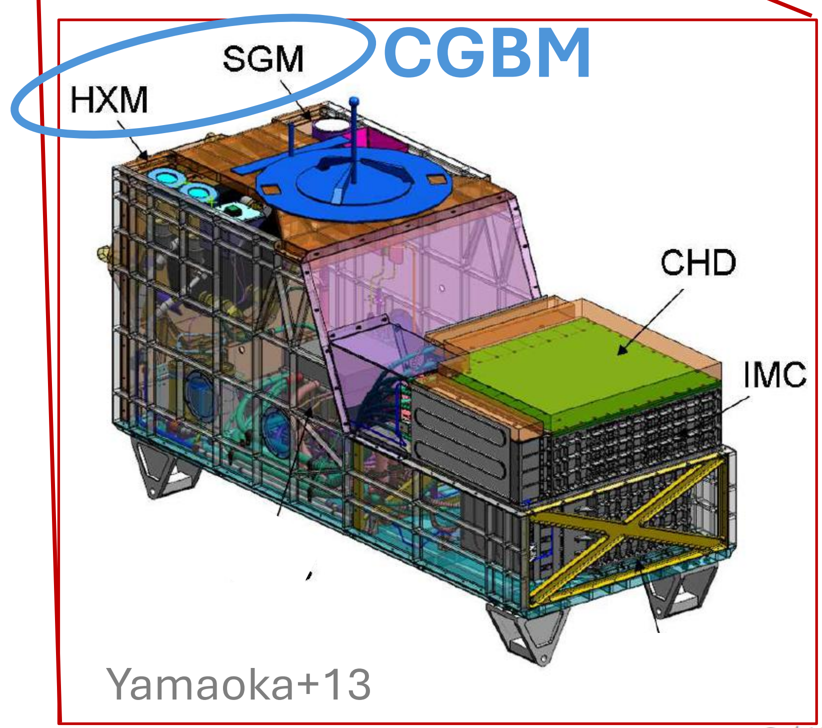

CGBM
SGM
HXM
CHD
IMC
Yamaoka+13

Microburst-type REP

- Overview
  - **Electron microbursts** are **sub-second** bursts of precipitating electrons with soft and relativistic populations (Johnston and Anderson, 2010).
  - Known as a key process during magnetic storms for the rapid depletion and generation of energetic electrons in the radiation belt.
    → Space Weather hazards (e.g., **Baker et al.**; **1987**)

- Previous studies
  - Extensive observations by two LEO missions with $\lesssim 1$ s time resolution: **SAMPEX** (1996–2007) and **FIREBIRD-II** (2015–2019)
    (e.g., J. Blake et al., 1996; Nakamura et al., 2000; A. B. Crew et al., 2016; Breneman et al., 2017; Miyoshi et al., 2020; Colpitts et al., 2020; Chen et al., 2022)
  - The origin is primarily attributed to interactions with whistler-mode chorus waves (e.g., Rosenberg et al., 1990) **for the outer belt $L \gtrsim 3$ in nominal storms**.

Microburst-type REP in low L ?

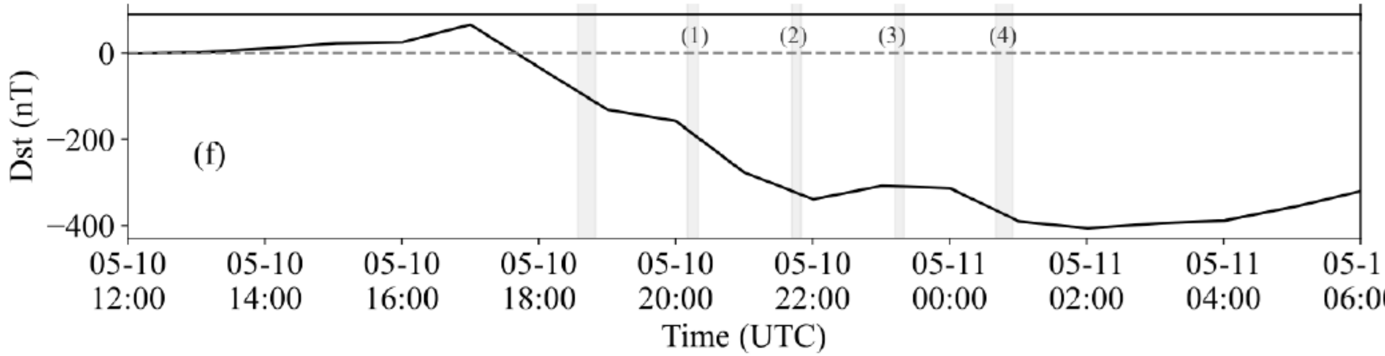
- Questions:
  - **Similar microburst occurs at $L \sim 2$ during super storms?**
    - During super storms, the inner boundary of the outer belt can penetrate deep into the inner magnetosphere, reaching $L \sim 2$–3.
  - **If so, the same origin as $L \gtrsim 3$?**
    i.e., whistler-mode chorus wave interaction?
- The only observational evidence to date was reported for the **March 2001 superstorms (Johnston and Anderson, 2010)**.
  - SAMPEX detected microbursts in low-Earth orbit (LEO) down to $L \sim 2.3$ for > 1 MeV electrons.
  - However, **no corresponding magnetospheric observation** was able to be performed to identify its origin.
- This study investigates the recent Mother's Day super storm in 2024, the most intense geomagnetic storm in the past 20 years.
  - The extreme contraction of the plasmapause to $L^* \sim 1.5$ was confirmed (Shinbori et al., 2025)

Unique combination of instruments

- For the Mother's Mother's Day super storm in 2024, **Arase** (2016–) is available for magnetospheric observation!
  - Wave observations with PWE/OFA (Matsuda et al., 2018), HFA (Kumamoto et al., 2018)
- However, without SAMPEX and FIREBIRD-II, the time resolution of current LEO instruments was very limited.
- In this study, we demonstrate a new application of the CALET Gamma-ray Burst Monitor (**CGBM**; Yamaoka et al. 2013), originally designed as an astrophysical instrument.
  - **CALET** (Torii, 2016) is a Japan-led high-energy astrophysics mission conducted in collaboration with Italy and the US.
  - Its instruments, **CHD** and **IMC**, played an important role in geospace research (e.g., Kataoka et al., 2016; Ficklin et al., 2026), utilizing its altitude of ~ 400 km with an orbital inclination of $\sim 51^\circ$

Observations during the main phase

Dst



ISS instruments in LEO: - for precipitating electrons

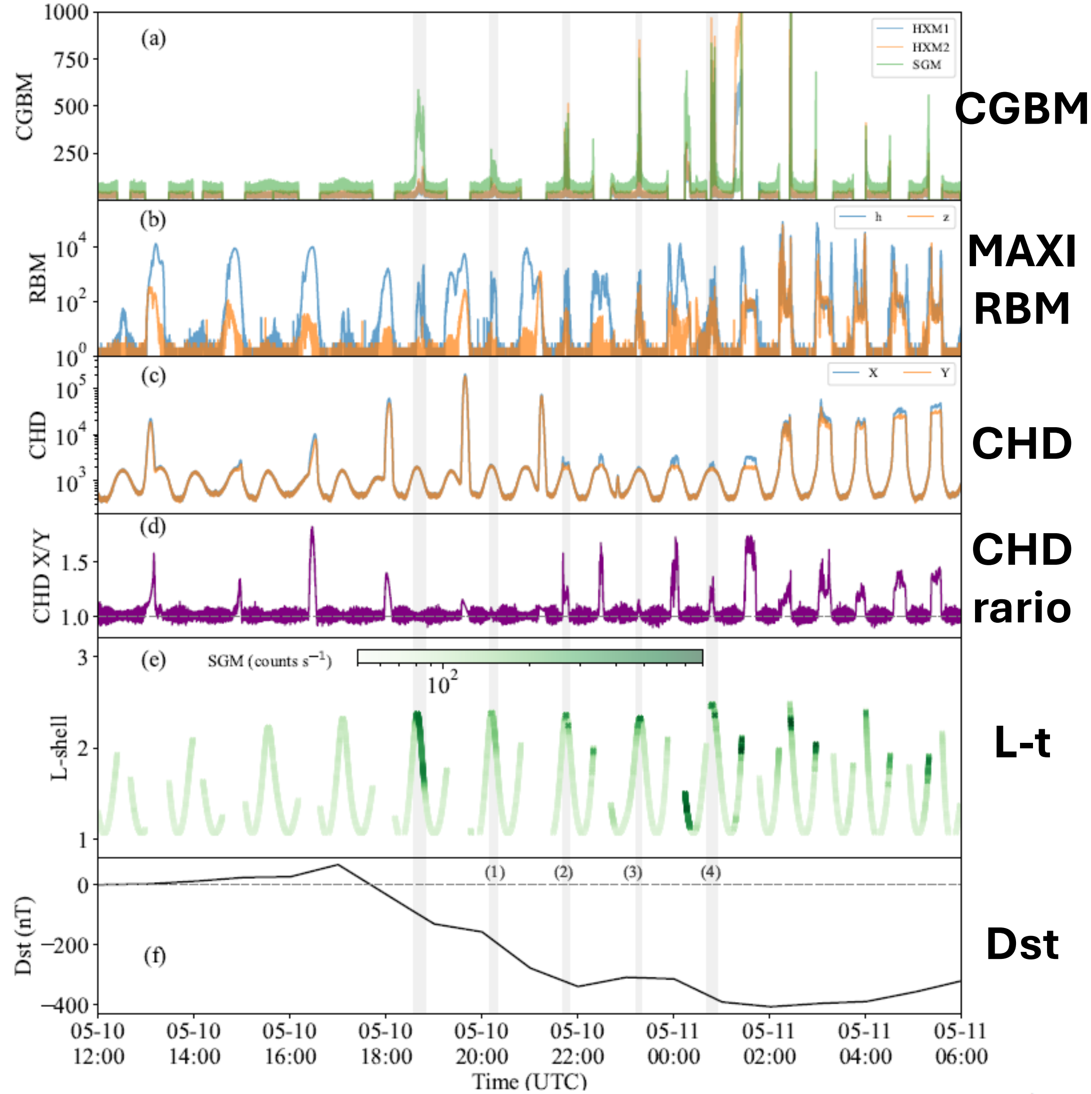
- **CGBM**: **1/8 s** count-rate monitor for $\gtrsim 0.3$ **MeV** on ISS.
- CALET/CHD: **1 s MeV** electron indicator.
- MAXI/RBM: **1 s** charged-particle monitor for $\gtrsim$ **0.15 MeV**.

Arase in Magnetosphere: - for low-L chorus activity

- PWE/OFA:
  - E spectra in 10 Hz–100 kHz
  - B spectra in 10 Hz–20 kHz
- PWE/HFA:
  - E spectra in 10 kHz–10 MHz
- MGF: B field to calcurate local cyclotron-frequency context

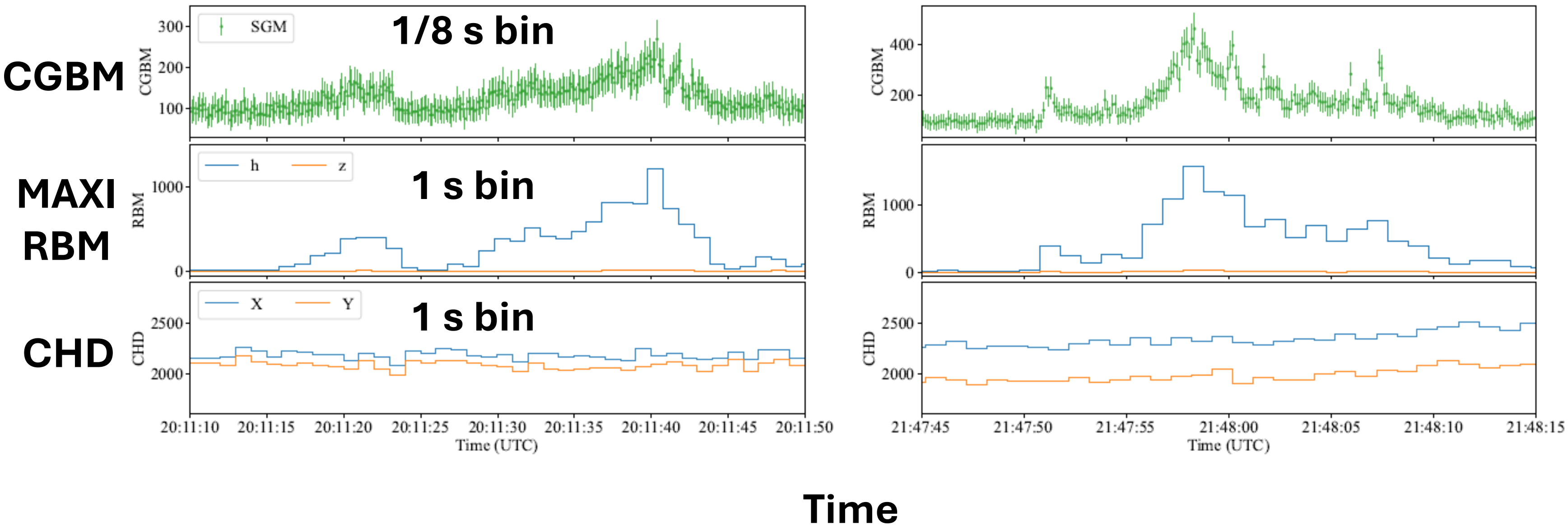
Overview of the LEO observations

- In (a), sudden flux increases are observed in the middle of the chunks (gray hushed).
- In (b), RBM also detected corresponding flux enhancements.
- In (e), shown that these flux enhancement occurs at $L \lesssim 2$.

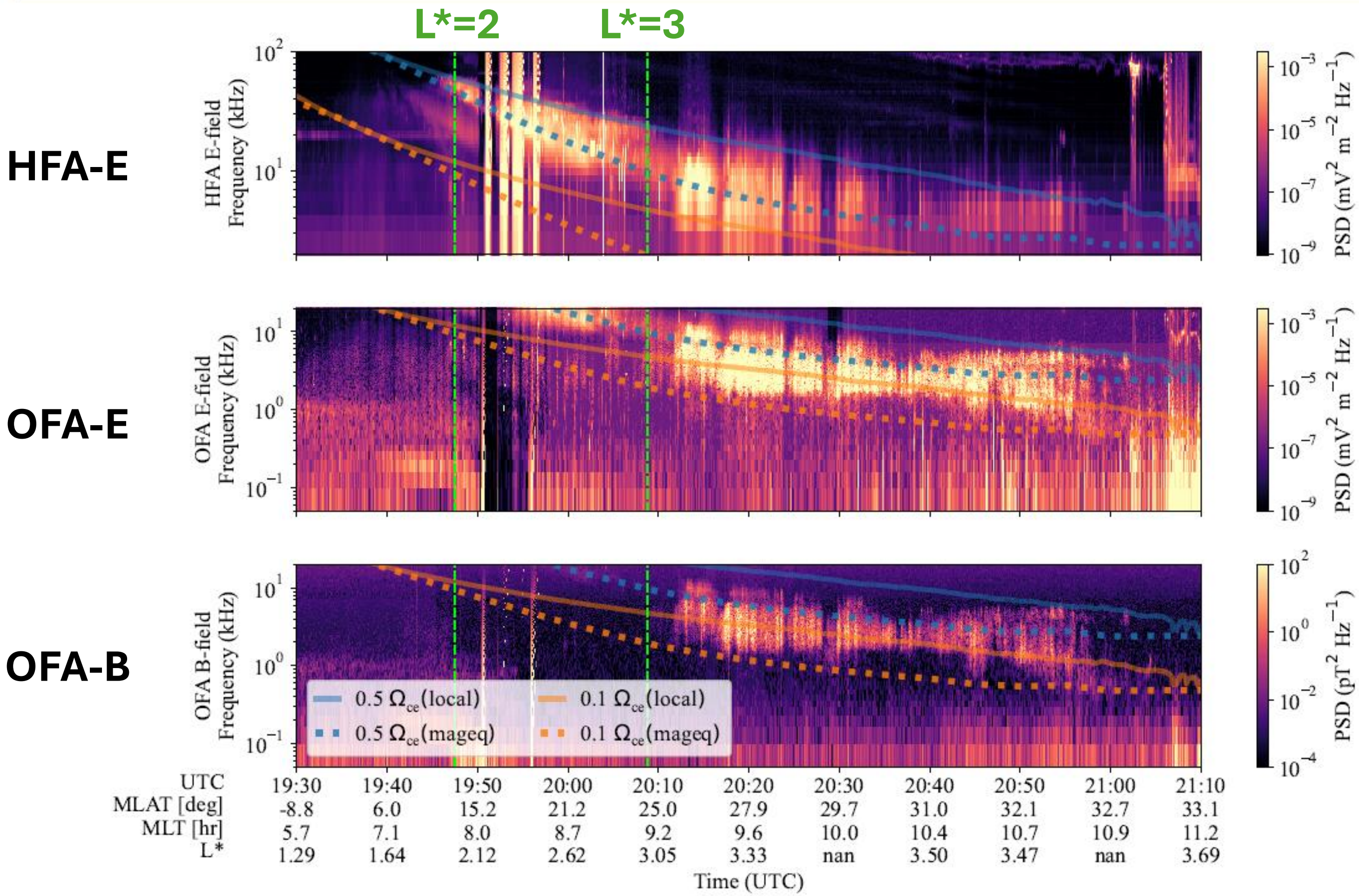


Sub-second variations at $L \sim 2$

- The four peaks (1)–(4) showed sub-second flux variations.
  - The approximate onset times:
    May 10 20:10 UT (just after midnight MLT), 21:40 UT, 23:10 UT, and May 11 00:40 UT, each lasting for $\lesssim 10$ minutes.



Arase PWE dynamic spectra



- Clear signatures of whistler-mode chorus waves!
  - From 19:50 UT to 21:00 UT down to $L^* \sim 2$

Discussion

- We successfully identified during the main phase of the super storm:
  1. Microberst events around $L \sim 2.0$ with CGBM in LEO
     - Not astrophysical photons ← MAXI/RBM scimultaneous detections
     - For the details of CGBM as a microburst detector, please refer to our paper's appendix
  2. Enhanced chorus wave activity around $L^* \sim 2$–4 with HFA and OFA in magnetosphere.
     - Our B conjunction between CGBM and Arase was imperfect, though multipoint observations have shown that chorus-associated microburst precipitation can occur over substantially broader spatial regions (Elliott et al., 2024)

  Suggesting that chorus-driven pitch-angle scattering can operate even at unusually low L-shells near the earthward-displaced inner edge of the outer radiation belt during extreme geomagnetic storms.

Discussion

Speculatively, this could contribute to **slot filling** after the super storm,,?

- Slot filling is known as the temporary population of the normally depleted slot region by energetic electrons, often after super storms (e.g., D. Baker et al., 2004), though the physical processes remains unclear.
- Also observed for the May 2024 super storm (Sun et al., 2026; X. Li et al., 2025; Ficklin et al., 2026).
- Our results suggest that chorus wave acceleration near the magnetic equator (Horne et al., 2005), which is commonly invoked for the outer radiation belt, may also contribute to slot filling in the low-L outer-belt boundary region during super storms.
  - Chorus-driven acceleration > microburst losses for MeV electrons in the October 2012 storm (Kurita et al., 2016)
  - For further discussion, though, evaluation of wave properties, plasma conditions, diffusion coefficients, and acceleration and loss timescales are required.

Summary and Future prospects

- Take-home messages:
  1. The 1/8 s time resolution of CALET Gamma-ray Burst Monitor (CGBM) onboard ISS can be used for Space weather studies of microburst events.
  2. Sub-second electron microbursts were detected at $L \sim 2$ during the May 2024 super storm.
  3. Arase observations show enhanced chorus waves near $L^* \sim 2 - 4$, supporting chorus-driven precipitation.

- Future prospects:
  1. Analyze other recent super storms and perform comparison

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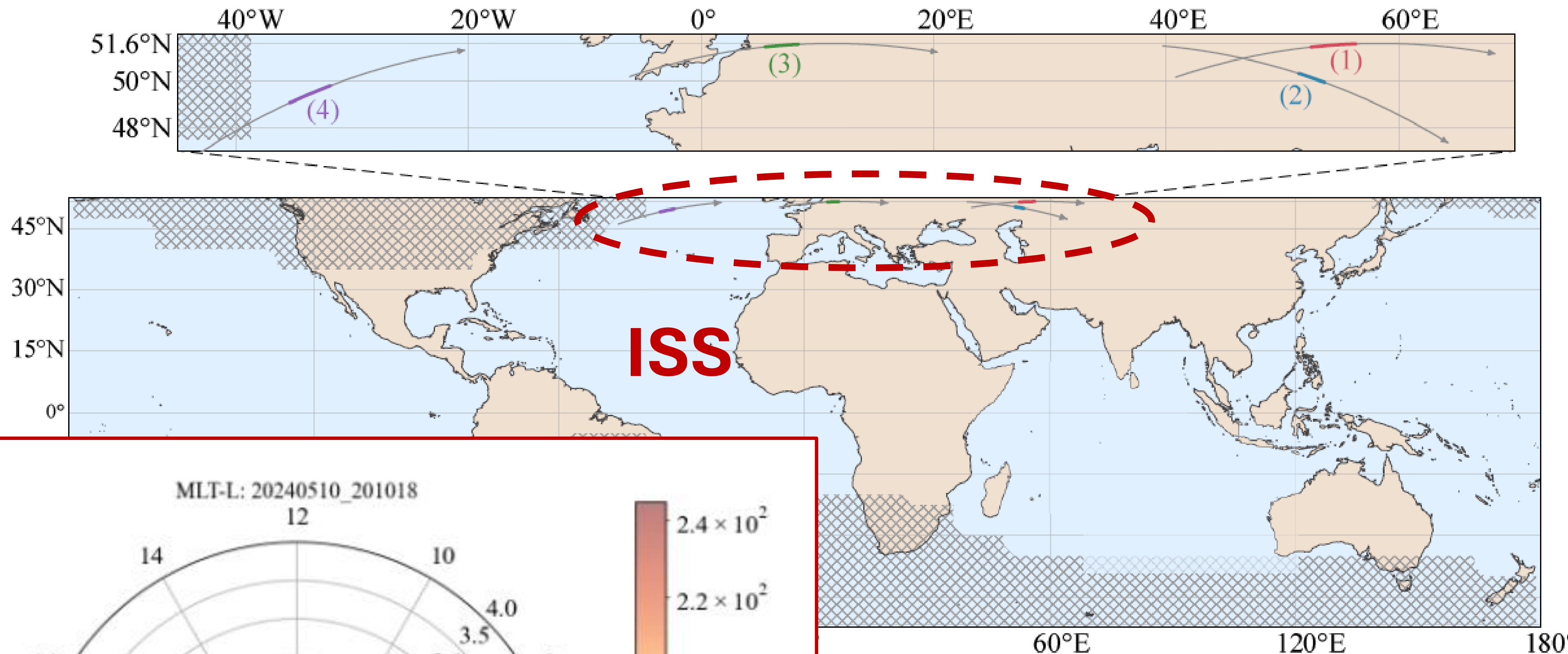
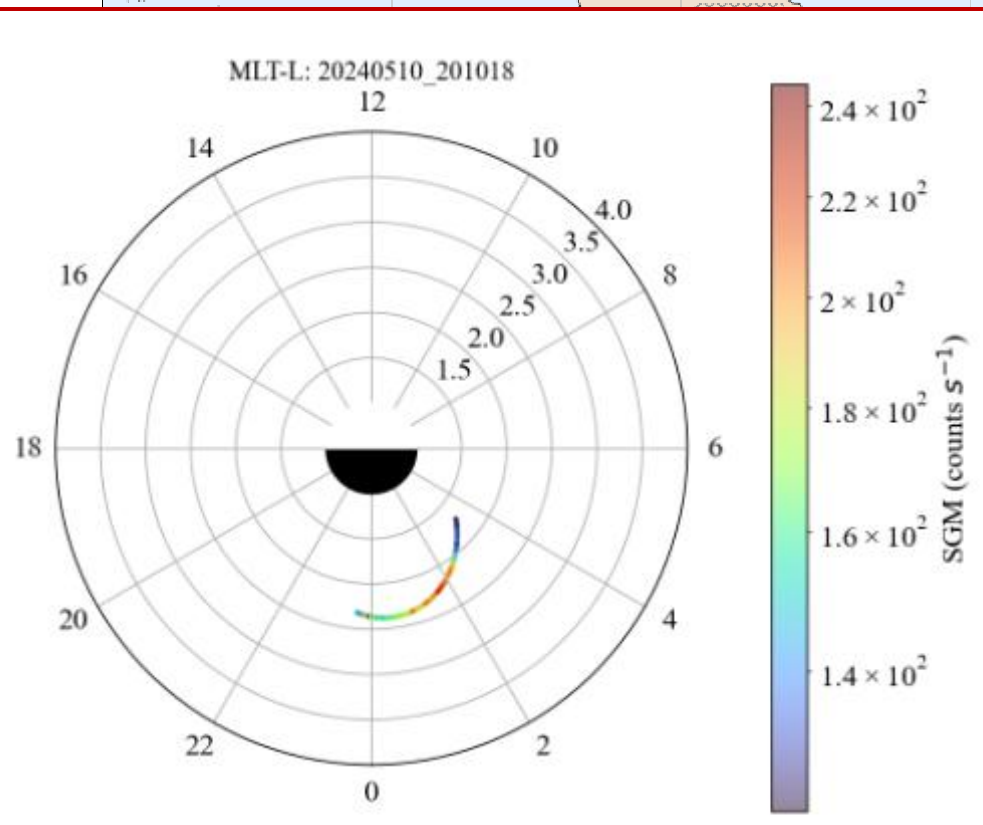


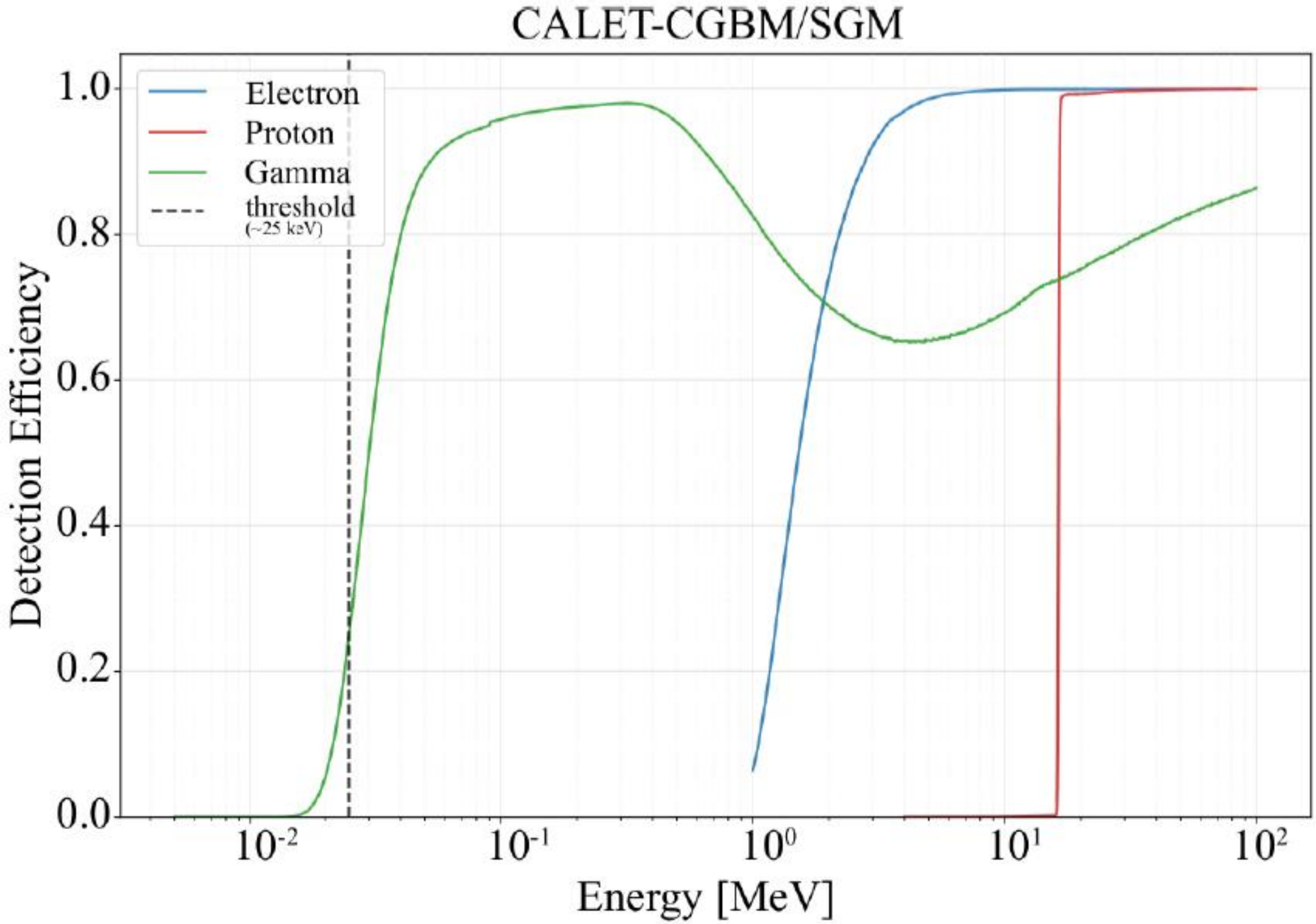


CGBM microburst:
- MLT ~ midnight

Arase:
- MLT ~ 7pm-10pm

Backup: CGBM

- CGBM consists of two scintillation detectors (Yamaoka et al., 2013):
  - Hard X-ray Monitors (HXMs)
  - Soft Gamma-ray Monitor (SGM)
- HXMs: two identical $LaBr_3(Ce)$ detectors
  - Coaxial cylinders with diameters of 66.0 and 78.7 mm
  - 410 $\mu\mathrm{m}$ Be window for low-energy X-ray detection
- SGM: BGO detector optimized for higher-energy photons
  - Diameter: 102 mm
  - Thickness: 76 mm
- CGBM is enclosed in a 3–5 mm-thick Al-alloy housing
  - Determines the minimum charged-particle energy needed to reach the crystals


CALET-CGBM/SGM
Electron
Proton
Gamma
threshold
(~25 keV)
Detection Efficiency
Energy [MeV]
1.0
0.8
0.6
0.4
0.2
0.0
10-2
10-1
10^0
10^1
10^2