Statistical analysis into the drivers behind relativistic electron precipitation events observed by CALET on the International Space Station

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Abstract: The Calorimetric Electron Telescope (CALET), launched to the International Space Station in 2015, provides more than 7 years of continuous observation of the radiation environment at low earth orbit. Using this dataset, we present a method for the detection and categorization of MeV relativistic electron precipitation (REP) events. From this catalog we identify a subset of a few hundred REP events observed at times where CALET is in magnetic conjunction with the Van Allen probes. These conjugate measurements enable studies of associated plasma wave data from RBSPA/B and potential drivers for MeV electron precipitation. We show that roughly 10 percent of the observed REP events are associated with enhanced electromagnetic ion cyclotron wave activity, suggesting that waves can play a significant role in driving MeV electron precipitation.

The CALorimetric Electron Telescope (CALET)[1]

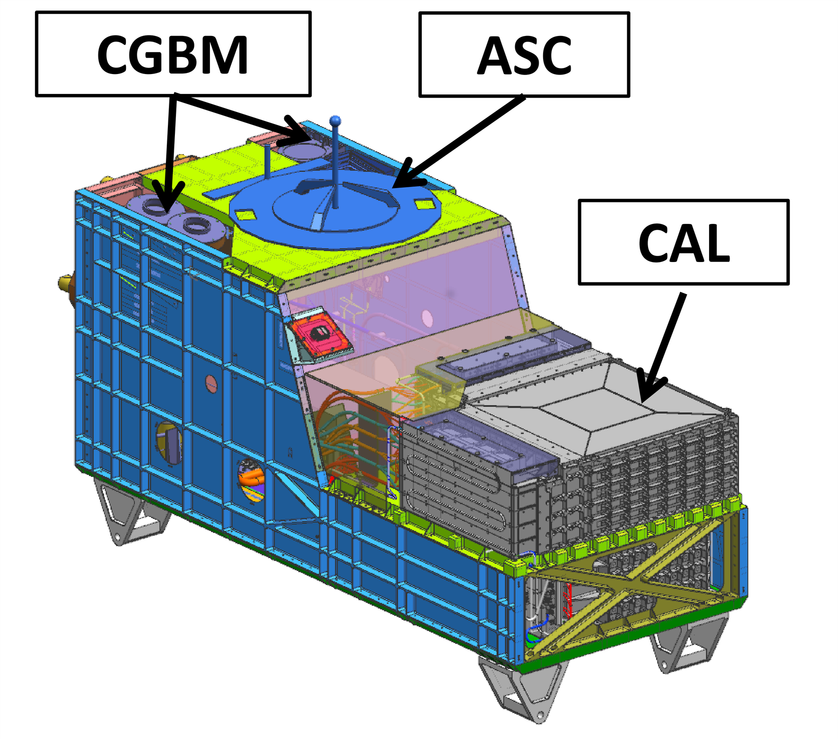

Figure 1: CALET structure indicating the CALET Gamma-ray Burst Monitor (CGBM), Advanced Stellar Compass (ASC), and CALET Calorimeter (CAL).

CHD	• Plastic scintillating paddles • 14 paddles x 2 layers (X, Y) = 28 paddles • Each paddle: 32 x 10 x 450 mm^3	Charge Measurement
IMC	• Plastic scintillating fibers & tungsten plates • 448 fibers x 16 layers (8X, 8Y) = 7168 fibers • Each fiber: 1 x 1 x 448 mm^3 • 7 W layers: (5 x 0.2 X_0) + (2 x 1 X_0) = 3 X_0	Particle Tracking
TASC	• Lead tungstate ($PbWO_4$; PWO) logs • 16 logs x 12 layers (6X, 6Y) = 192 logs • Each log: 19 x 20 x 326 mm^3 • Total thickness: 27 X_0, ~1.2 λ_I	Energy reconstruction

- Although the primary scientific goal of CALET is the observation of cosmic rays from a few GeV up to 1 PeV, early observations showed that the top two layers of the detector were sensitive to lower energy radiation events, namely relativistic electron precipitation (REP) events[2][13].

Radiation Belt Science Probes (RBSP)

- For the observation of electromagnetic ion cyclotron (EMIC) wave events, we used data from the Electric and Magnetic Field Instrument Suite and Integrated Science (EMFISIS) aboard both RBSP-A and RBSP-B.
- The EMFISIS instrument[10] measures electric and magnetic field wave data covering frequencies from 1Hz to 400kHz and its data includes calculated power spectrum density that can be used to identify several different types of plasma wave activity.

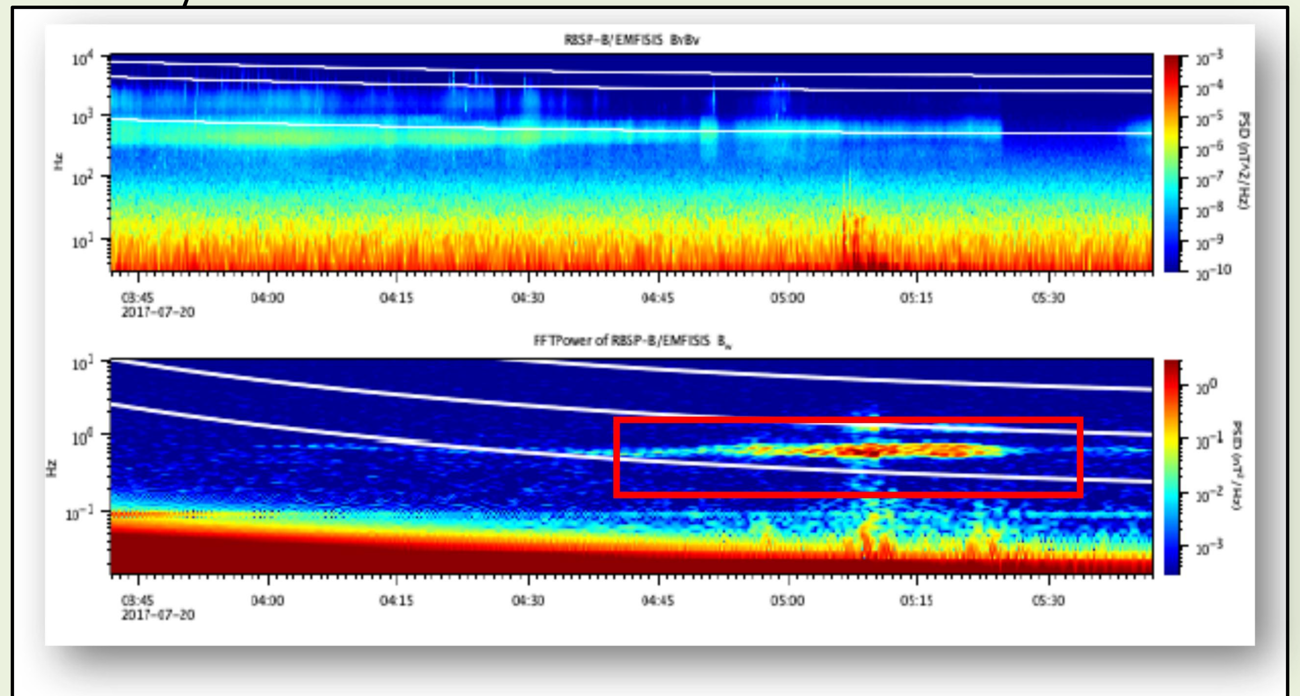

Figure 2: Magnetic field waveform measured by RBSP for a period with enhanced EMIC wave activity ,shown in the red box.

REP Event Catalog

- To identify relativistic electron precipitation in the CALET dataset an algorithm was developed which use self organizing maps (SOM), an unsupervised machine learning technique, to both detect and categorize potential REP events[6].
- Events are sorted by the SOM based on the spectral shape of their power spectral density and identified as either rapid precipitation, smooth precipitation, or background noise.
- For a period from October 2015 to October 2021 this method found a total of 1448 rapid REP events and 21301 smooth profile events.

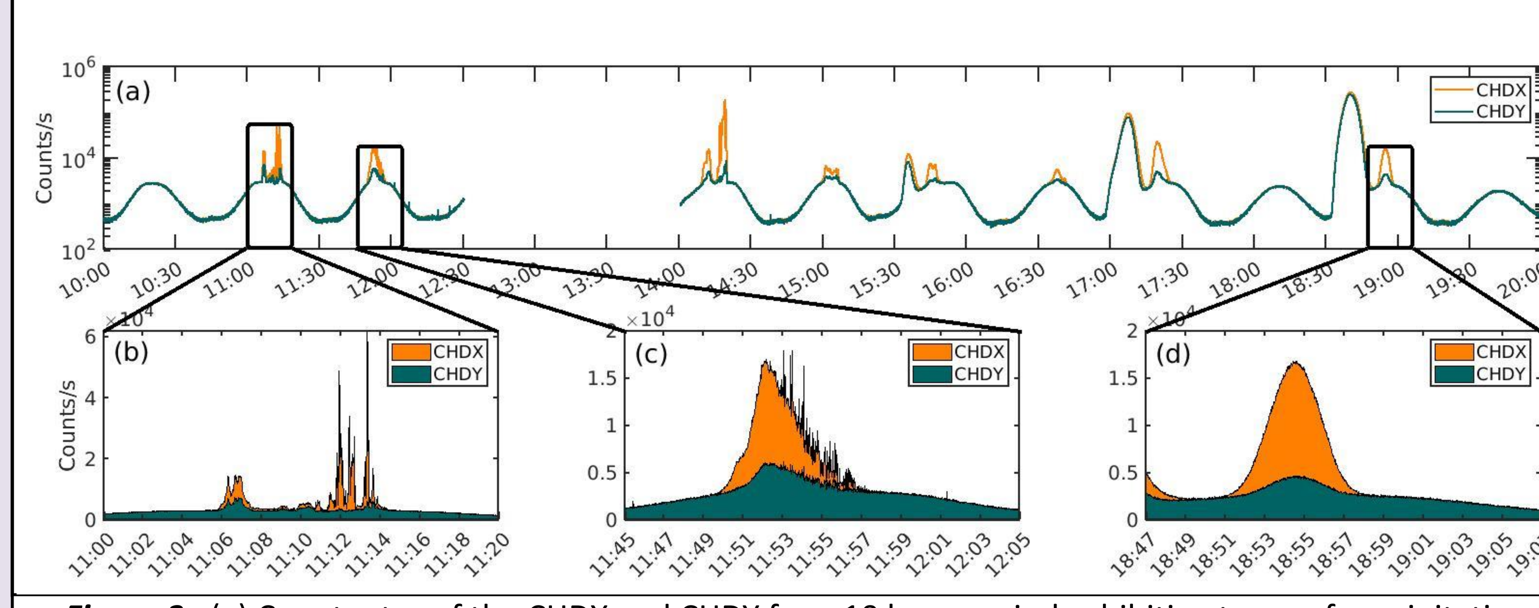

Figure 3: (a) Count rates of the CHDX and CHDY for a 10 hour period exhibiting types of precipitation observations. (b) An example of an event classified by the SOM as rapid precipitation. (c) An example of an event classified as a mixed between rapid and smooth precipitation. (d) An example of an event classified as smooth precipitation..

EMIC Wave Event Catalog

- The EMIC wave events used in this work were pulled form a catalog of events produced B. Reyma et al. (2023)[7] which used an automatic wave detection algorithm developed by Bortnik (2006)[9].
- The algorithm selects events based on their spectral peak and requires the peak to be one order higher than the calculated background for a one hour period surrounding the potential event.
- In total, 664 events were identified in RBSP-A data and 443 events for RBSP-B, an example of which is shown in figure 2.

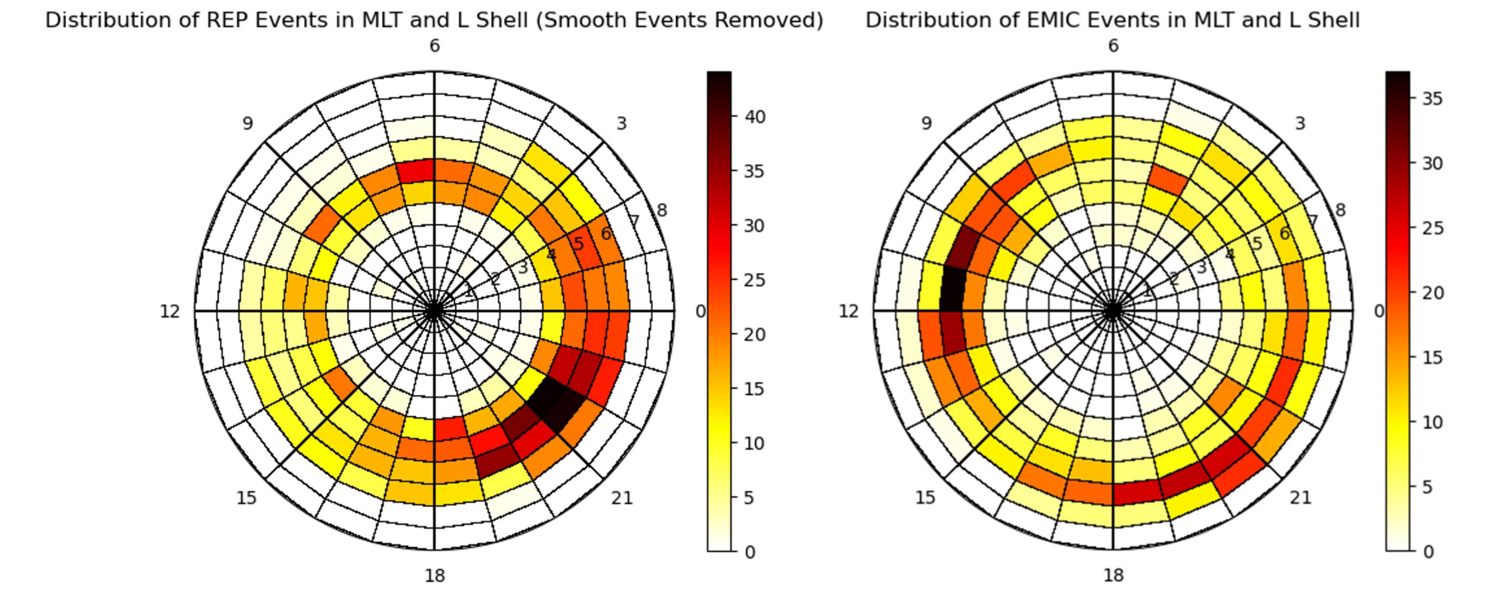

Figure 4: Spatial distribution in terms of magnetic local time (MLT) and L shell for observed REP events (left) and observed EMIC wave events (right).

Checking for Coincidence

- On an event-by-event basis, events were checked for coincidence in time, as well as spatially using their geomagnetic location in MLT and L shell. The initial criteria for coincidence were as follows:
  - $L_{CAL\text{-}min} - 0.5\ Re < L_{rbsp} < L_{CAL\text{-}max} + 0.5\ Re$
  - $MLT_{CAL\text{-}min} - 1h < MLT_{rbsp} < MLT_{CAL\text{-}max} + 1h$
  - $T_{CAL\text{-}start}$ -10min < T_{rbsp} < $T_{CAL\text{-}stop}$ + 10min
- Results:
  - Out of 1448 REP events, 78 events happened at times where CALET was spatially coincident with either RBSPA or RBSPB.
  - Out of these, 8 events were also coincident with EMIC wave activity, which is ~10 percent of the total events.
- To view how dependent on MLT and L shell these statistics are, the analysis was repeated for a grid of MLT and L shell criteria up to +/- 5 hours in MLT and +/- 5 in L shell, but with the same +/- 10-minute window in time.
- The results, shown in Figure 6, show how the number of coincident events change as the criteria is relaxed in either MLT or L shell. The number of coincident events shows a stronger dependence on the criteria applied to MLT, which could be beneficial since recent work suggests that EMIC wave events can be wider in MLT than the initial coincidence criteria implies[11].

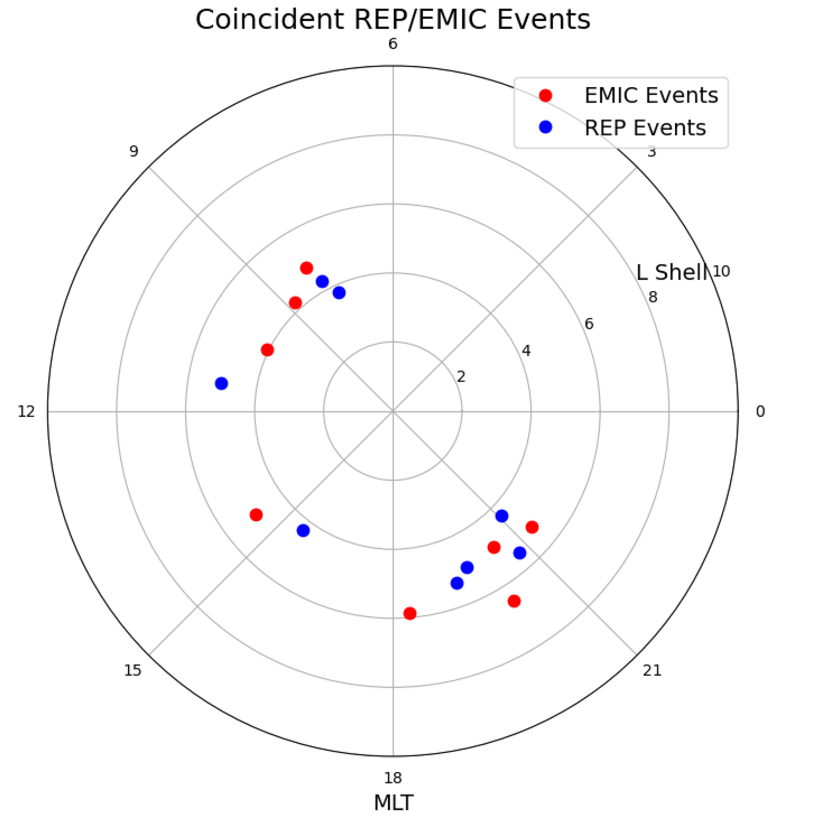

Figure 5: Spatial distribution of coincident REP/EMIC wave events in MLT and L.

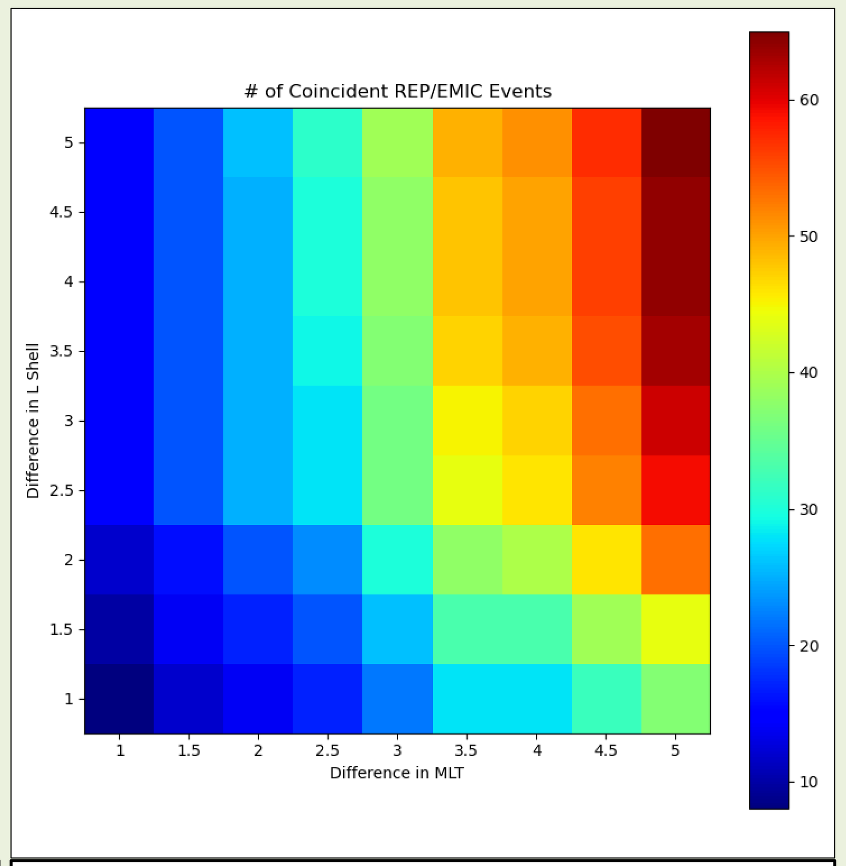

Figure 6: Number of coincident REP/EMIC wave events as a function of MLT and L shell.

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