Relativistic Electron Precipitation Detections with CALET on the International Space Station

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ABSTRACT

The CALET (Calorimetric Electron Telescope) is a high-energy astroparticle physics experiment installed on the International Space Station, and taking data since October 2015. While designed for studying the origin and properties of galactic cosmic rays, CALET is also able to provide a continuous monitoring of space-weather phenomena affecting the near-Earth environment, including solar energetic particles and relativistic electron precipitation (REP) events. In this work we present preliminary results of the REP observations made over a four-year acquisition time (2015-2019), investigating their correlations with the interplanetary and geomagnetic conditions. We also take advantage of a multi-spacecraft study using two Van Allen Probes measurements to complement CALET detections in low-Earth orbit, enabling a more complete picture of the global precipitation rates and drivers.

The CALET experiment

The CALET experiment is the result of an international collaboration involving Italy, Japan and USA [1]. It is a large-area high-performance instrument installed on the International Space Station (ISS) on Aug 2015, aimed to investigate the interplay between various cosmic ray and solar electromagnetic wave mechanisms, and their impact on the Earth’s radiation belts, magnetosphere and magnetosheath. CALET is also able to provide a continuous monitoring of the space weather phenomena affecting the near-Earth environment. The instrument consists of 3 sub-detector systems: two-layered hodoscope of plastic scintillators (CHD) providing charge measurements (Z=1 to ~40); a finely-segmented imaging calorimeter (IMC) used to determine the incoming-particle trajectory; an homogenous liquid absorption calorimeter (RDC) providing energy measurements and identification discrimination.

Data analysis

CALET REP observations are based on the count-rate information of the two CHD ingridial layers, CHDX and CHDY, with a detection threshold corresponding to ~1.5 MeV Electron Equivalent (Eeq). The present study is based on the dataset collected between October 2015 to May 2020, during the extended solar minimum phase between solar cycles 24 and 25. The selected sample includes data collected at relatively high geomagnetic latitudes (McIlwain’s L>7.9), excluding periods of high-energy solar flare events (e.g.). During early September 2019, four REP events were recognized as spikes in the CHD count rates. Displayed data do not include observations made in the SAA (0.05 < Bz < 0.61). Specifically, REP events were recognized by requiring a count-rate ratio R = CHDX/CHDY > 1.5, where u is the statistical uncertainty on R. Overall, 775 REP events were selected. However, as discussed below, the dataset includes a significant background component associated with the loss-cone electron population beneath the outer radiation belt, mostly detected in the geographic region South of the SAA. The bottom-right figure reports a sample REP interval observed by CALET. The top panel shows the temporal profiles of the CHDX (red) and CHDY (blue) count rates, while the bottom panel is a count-rate ratio (magenta), which can be used to provide an estimate of the REP event spectral hardness. The two green curves indicate, respectively, the Li62 (top) and Li61 (bottom) energy bands of the CALET collaboration Geomagnetic Reference Field-13 [2] and the Nagoya and Shinozaki 2007 [3] models for the description of the internal and external geomagnetic field, respectively.

REP event spatial distribution

To have a clearer view of the detected REP events, we compared CALET observations (top two panels) to outer-radiation belt electron measurements (third panel) and other contextual data, including interplanetary and geomagnetic parameters (last four panels). This figure shows the different observations as a function of the spatial-temporal coordinates of the REP events, selecting only those events with the black markers making the corresponding CALET REP detections. We can essentially subdivide the REP CALET sample into three categories. The first corresponds to a population of events with high count-rate enhancements (orange ovals). The second comprises events detected during intervals of outer belt depletions (orange ovals), typically following the arrival of a new magnetic field sector. The third situation includes ordinary loss-cone events, mostly detected in the geographic region South of the SAA, with relatively low latitudes around L-3.5 Re (plume region). This precipitation is not necessary linked to local acceleration mechanisms, and constitutes a background component to REP events.

Summary and future work

The CALET experiment on the ISS is able to provide a continuous monitoring of space-weather phenomena affecting the near-Earth environment, including solar energetic particles and relativistic electron precipitation. The observed in situ data can be used to complement those of the Van Allen Probes in the magnetosheath region. We are currently investigating a coordinated study between the two missions to identify the wave populations generated near the magnetic equator which are potentially responsible for the precipitation detected observed on the ISS. In the future, we plan to perform a statistical investigation of the detected REP events, in order to sort REP events by wave-driven and precipitation mechanisms (space-weather, solar wind etc.), enabling a more complete picture of the global precipitation origin and rate.

CALET REP observations and contextual data

References


Relativistic Electron Precipitation: a space-weather phenomenon commonly observed at high latitudes, in which energetic electrons trapped in the geomagnetic field are lost into the upper atmosphere. It plays an important role in the magnetosphere dynamics, in particular during depletion intervals of the outer belt, and it has also a significant impact on the electrodynamics and chemical structure of the atmosphere. REP events are thought to be predominantly originated by pitch-angle scattering into the loss cone by plasmas waves, In the shallow plasmas wave, they occur more frequently during the declining phase of the solar cycle, mostly in association with high-speed streams (HSSs) and under active geomagnetic conditions.