CALET results after three years on the International Space Station

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Abstract. The CALET (CALorimetric Electron Telescope) space experiment, which is currently conducting direct cosmic-ray observations onboard the International Space Station (ISS), is an all-calorimetric instrument optimized for cosmic-ray electron measurements with capability to measure hadrons and gamma-rays. Since the start of observation in October 2015, smooth and continuous operations have taken place. In this paper, we will give a brief summary of the CALET observations ranging from charged cosmic rays, gamma-rays, to space weather, while focusing on the energy spectra of electrons and protons.

1. Introduction

During the space era of the cosmic-ray direct measurements, the International Space Station (ISS) has become an important cosmic-ray observatory by hosting three instruments on orbit, i.e., AMS-02 (Alpha Magnetic Spectrometer), CALET (CALorimetric Electron Telescope), and ISS-CREAM (Cosmic Ray Energetics And Mass). Among them, CALET uses an all-calorimetric instrument with total vertical thickness of 30 radiation lengths and fine imaging capability [1]. The instrument is optimized for cosmic-ray electron measurements by achieving large proton rejection and excellent energy resolution well into the TeV energy region [2]. In addition, very wide dynamic range of energy measurements [2] and absolute charge identification capability (0.1–0.3e from proton to above iron) [3] of the instrument enable us to measure proton and nuclei spectra as well as electron and gamma-ray spectra. The CALET mission goals include the investigation of acceleration and propagation of galactic cosmic rays, of possible nearby sources, and of potential signature of dark matter. During a mission life of five years (or more), CALET will measure the flux of cosmic-ray electrons ($e^- + e^+$) to 20 TeV, gamma-rays to 10 TeV and nuclei with Z=1 to 40 up to 1,000 TeV for the more abundant elements. Since the start of on-orbit observation in October 2015, smooth and continuous operations have taken place [4].

2. Results

All-Electron Spectrum: High-energy cosmic-ray electrons provide a unique probe of nearby cosmic accelerators due to their radiative energy losses during propagation in the Galaxy. Using the dedicated instrument for direct measurements of all-electrons (electrons+positrons), CALET collaboration published its first result [5] up to 3 TeV in 2017. Subsequently, DAMPE (DArk Matter Particle Explorer) collaboration published their all-electron spectrum [6] up to 4.6 TeV.

In order to better compare with DAMPE's result, an updated version of the CALET all-electron spectrum based on ∼2 times more statistics has recently been published up to 4.8 TeV [7] as shown in Fig. 1. Detailed description of the analysis procedure, systematic uncertainties, and discussions about the obtained spectrum are given in the paper and its supplemental material. In addition to them, it is noteworthy that the consistency between CALET and AMS-02 became even better by just updating AMS-02 results with more statistics [8]. In the low-energy region, the difference in solar modulation effects is mitigated because of overlap in the observation period, while statistics must be a crucial factor in the high-energy region.

Five years or more observations will give us 3 times more statistics and reduction of systematic errors based on the better understanding of the data. Since the possibility of new discoveries dwells in fine structures of the all-electron spectrum, the further precision in the sub-TeV region will allow us to investigate the origin of positron excess. By extending the energy reach and combining it with the anisotropy study, moreover, CALET's all-electron spectrum in the TeV region might identify a local cosmic-ray accelerator by taking advantage of its localness.

Proton Spectrum: As the most abundant species in cosmic rays, protons are extensively studied in the wide energy region to understand the high-energy radiation in the universe. In particular, the spectral hardening observed in the spectra of cosmic-ray protons and various nuclei triggered many attempts to theoretically interpret these unexpected phenomena. The current experimental approaches to direct measurements of the proton spectrum, however, are based on magnetic spectrometers (calorimeters) at lower (higher) energies, leaving a room for systematic errors between two types of experiments.

In 2019, progressive hardening of the cosmic-ray proton spectrum in the TeV region has been revealed [9] with CALET by a wide dynamic range measurement from 50 GeV to 10 TeV with a single instrument in space. As shown in Fig. 2, the observed spectrum is consistent with accurate magnet spectrometers in the low energy region but extends to nearly an order of magnitude higher energy, providing an important anchor for the interpretation of the proton spectrum. Again, detailed description of analysis and further discussions about the obtained

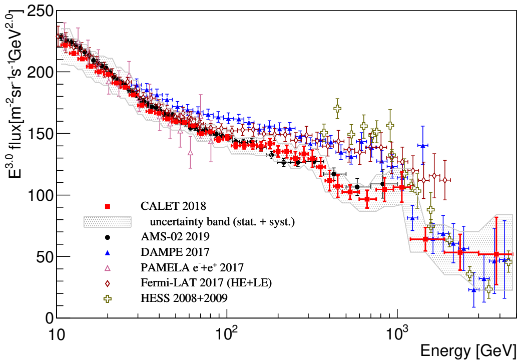

Figure 1. Cosmic-ray all-electron spectrum measured by CALET (red points) from 10.6 GeV to 4.75 TeV [7]. Also plotted are direct measurements in space and from ground-based experiments (see [7] for references), including the updated AMS-02 results [8].

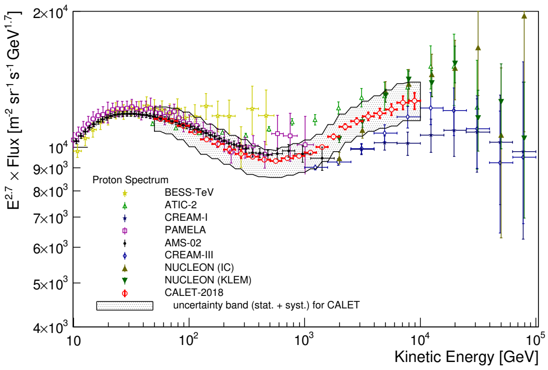

Figure 2. Cosmic-ray proton spectrum measured by CALET (red points) from 50 GeV to 10 TeV [9]. Also plotted are recent direct measurements (see [9] for references). Recently published DAMPE results [10] are not included in the plot.

spectrum are given in the paper and its supplemental material.

The future main objective is to verify the charge-dependent acceleration limit of supernovae by precisely measuring the spectra of protons and helium up to the 100 TeV region, which might affect the interpretation of "knee" indirectly measured by ground-based detectors.

3. Summary and Prospects

Since October 2015, CALET continues very stable observation for more than 4 years. We have published all-electron spectrum [5, 7] and proton spectrum [9] including the detailed assessment of systematic errors. There are many more results such as heavy nuclei spectra [11, 12], gamma-ray observations including GW counterpart searches [13, 14, 15], and space weather [16]. The so far excellent performance of CALET and the outstanding quality of the data [17] suggest that a 5-year (or more) observation period is likely to provide a wealth of new interesting results.

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