High Energy Telescope (HET) on the Solar Orbiter Mission: Overview and First Data

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Abstract

As part of the Energetic Particle Detector (EPD) suite onboard Solar Orbiter, the High Energy Telescope was launched on its mission to the Sun on February 10, 2020, and has been measuring energetic particles since it was first switched on about two weeks after launch. Using their double-ended telescopes, the two HET units provide measurements of ions above 7 MeV/nuc and electrons above 300 keV in four viewing directions. Since commissioning, HET has observed several Solar Energetic Particle (SEPs) events. For instance, a large SEP event was observed on November 29, 2020, which accelerated particles up to 100 MeV.[3] Apart from SEP events HET can be used to observe the Galactic cosmic rays (GCR) and their temporal variation. The GCR measurements can be also utilized for the validation of the energy response of HET. The overall spectra observed by HET are as expected, except for calibration issues in some specific energy bins that we are still investigating. Finally, the HET also observed several Forbush Decreases (FD), i.e., cosmic ray decreases caused by coronal mass ejections(CME) and their embedded magnetic field. Here, the capabilities and data products of HET, as well as first measurements of SEPs, GCR and FDs are presented.

Instrument and Measurement Principle

Solar Orbiter carries two double-sided HET telescopes, providing four viewing directions (sunward, antisunward, north and south), where the sunward viewing direction is aligned with the expected orbit-averaged Parker spiral direction (35°) during nominal operations. As shown in Fig. 1, Each telescope consists of four silicon solid-state detectors A1, B1, B2, A2. A1 and A2 are at the two ends, B1 and B2 sandwich a BGO($Bi_4Ge_3O_{12}$) scintillator, also called C, in the center. Combining these detectors, HET is able to measure protons and heavy ions in the energy range from $\sim$7 MeV to a few hundred MeV/nuc(species dependent) and electrons between 0.3 - 30 MeV.

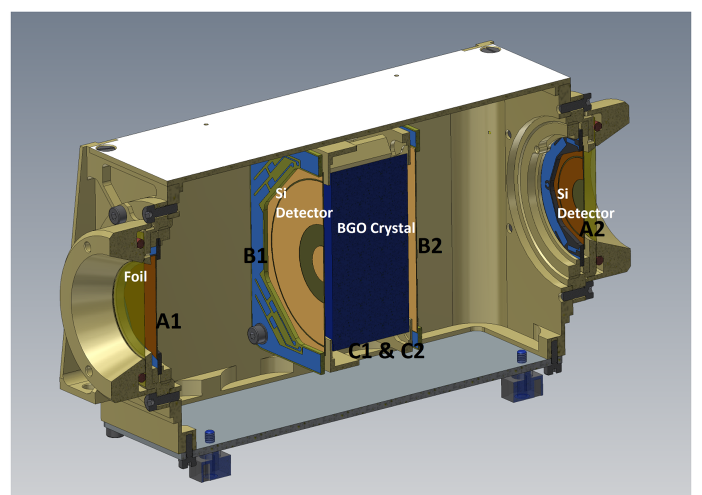

Figure 1. Cross-section of HET sensor head[5]

HET uses the $\mathrm{d}E/\mathrm{d}x$ vs total E measurement principle to discriminate different particle species. The 2D histograms of relevant particle species stopping in the B and C detectors as well as penetrating particles are shown in the left and middle panels as well as the right-hand panel of Fig. 2. Those histogram are based on the Pulse-height analysis (PHA) data after HET switched on in Feb, 2020. Only a part of the PHA data are downloaded due to limited buffer size. The green boxes in the histogram show how we set the energy channels for high time resolution data products. Different particle species are clearly separated in the 2D histogram.

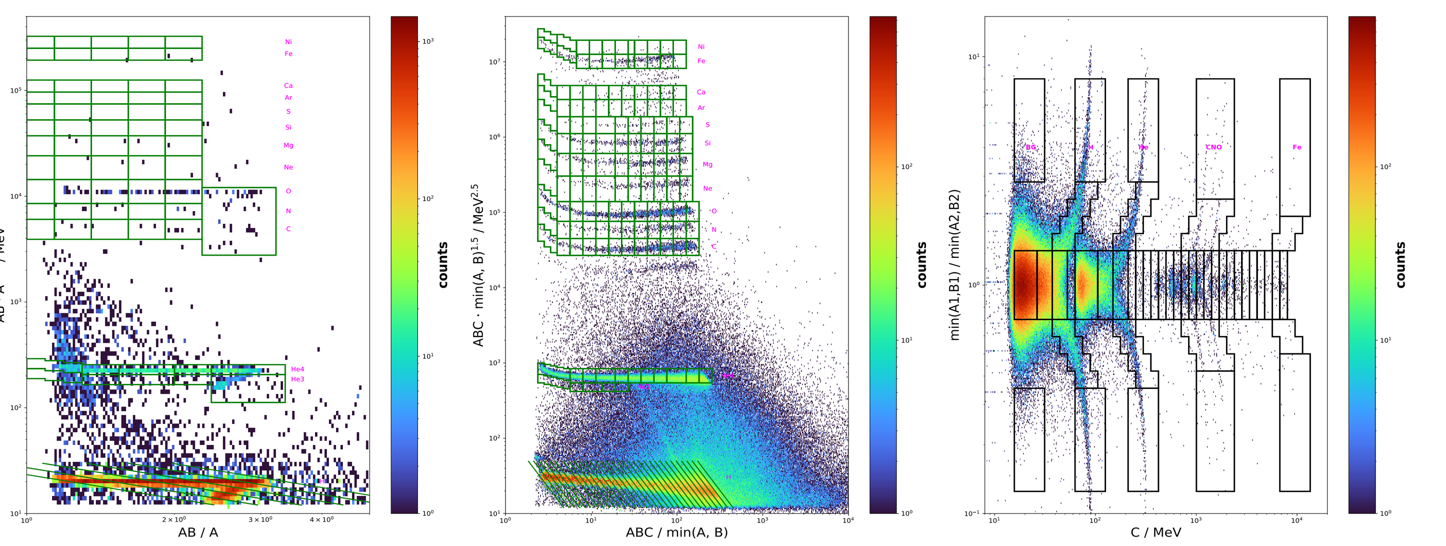

Figure 2. The 2D histograms of HET,which are based on the PHA data, for particles stopping in B (left), particles stopping in C (middle) and particles penetrating all the detectors (right)

HET measurements of the first widespread SEP observed by Solar Orbiter on November 29, 2020

The widespread SEP which occured on Nov 29, 2020 was detected at multiple view points. This gradual event generated up to $\sim$100 MeV protons which perfectly cover the channels of the C detector and up to $\sim$10 MeV electrons triggering all the HET electron channels. The intensity profiles of protons (top left) and electrons (bottom left) of different energy channels measured by HET are given in Fig.3. The vertical red line marked out the time period that we use to plot the integral protons spectra shown in the right panel. Here, both EPT ions (mostly protons in blue) and HET protons stopping in B (orange) and C (green) are given. The pre-event background has been subtracted. The overall spectra have a very nice power-law, especially in EPT and HET-C. While EPT measures ions, the HET spectrum is given for protons, which contributes to the spectral break below 10 MeV. The obvious discrepancy around 10 MeV is currently not fully understood and we are working on developing a GEANT4 model to explain it. The cross calibrations between the EPD suite, SIS, STEP, EPT and HET for another SEP event are given in the first year's EPD observation paper [6]. For more detailed analysis on this widespread SEP combined the in-situ and remote-sensing observation in different view directions, please see [3].

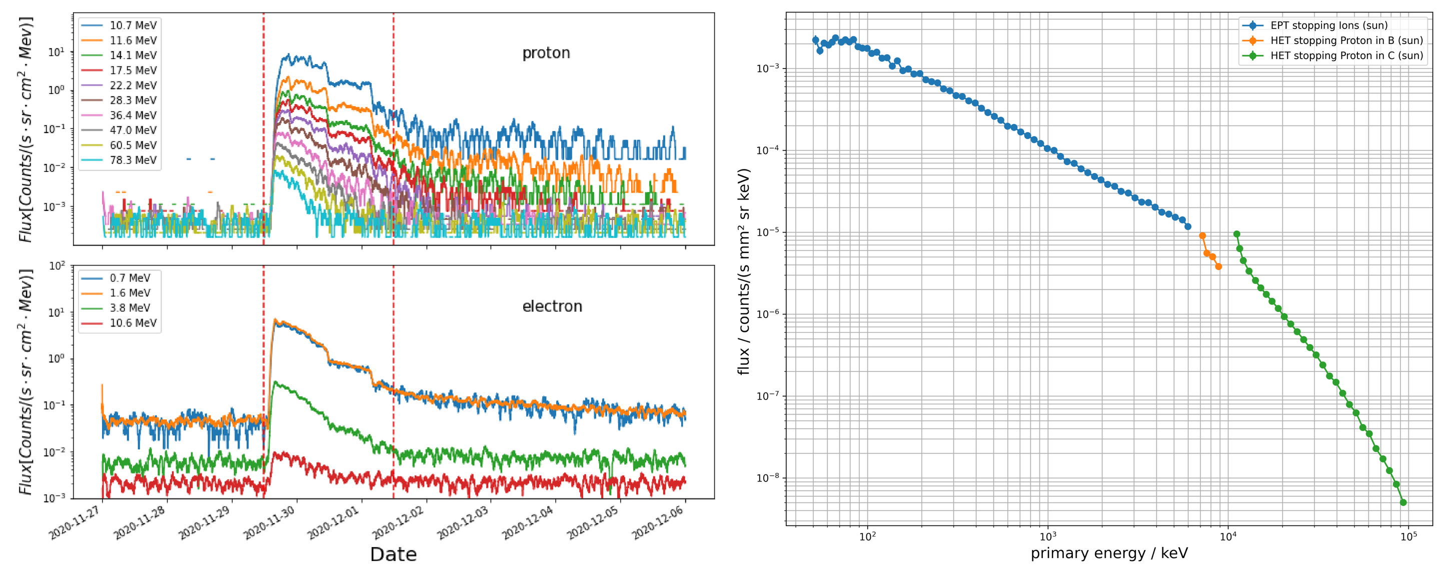

Figure 3. The temporal intensity profiles of protons and electrons during SEP on Nov 29, 2020 (left) and the event spectrum integrated between two vertical red lines (right).

The quiet-time spectrum

Due to the quiet Sun, HET mainly measured the GCR and ACR background since it was switched on on February 28, 2020. Here we compared quiet time spectra of H, He, carbon, nitrogen, oxygen, and iron, and with the CREME2009 model spectra at 1 AU. The main calibration issues are the higher proton count rates in HET-C (the middle part of blue points). In Fig.4, the proton flux of HET are a factor of 1.5-1.8 higher than the model and the comparison with the SOHO/EPHIN show similar results. The efforts to understand those issues are still ongoing. Despite of this, the HET measurements tend to agree with the models and other instruments. The HET spectra of $^4\mathrm{He}$ and heavier ions agree well with SIS and ACE/ULEIS at 1 au and Oxygen have a strong contribution from ACRs which is clearly visible. [4]

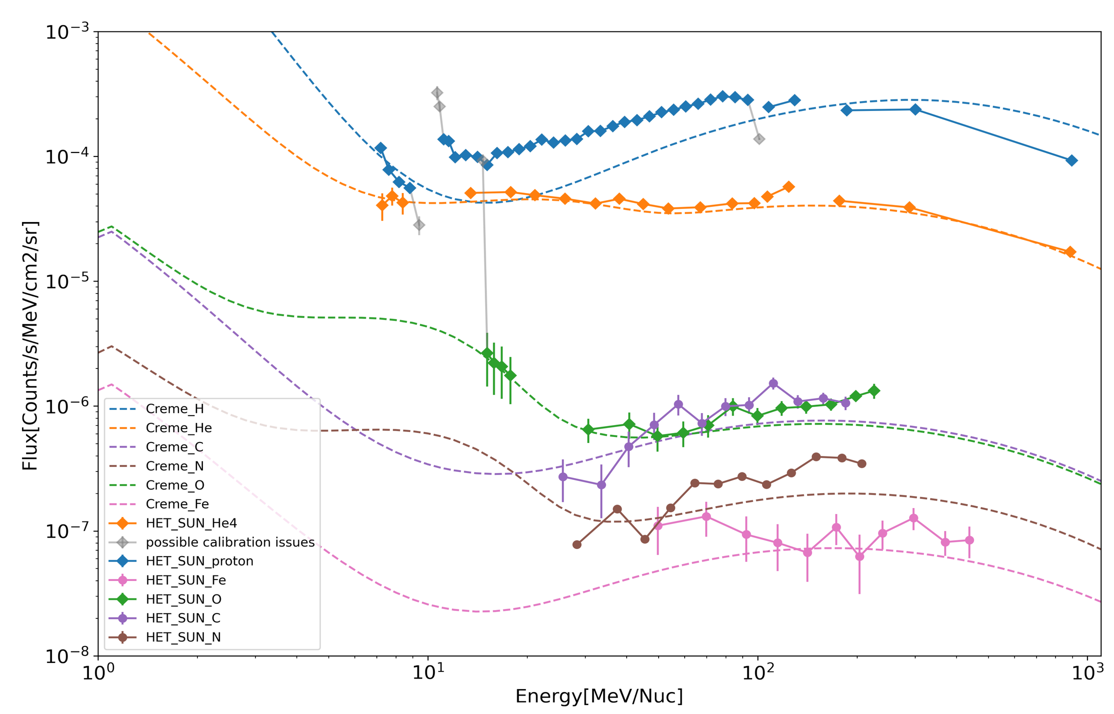

Figure 4. The protons and heavy ions quiet-time spectra and Creme model predicted spectra in 2020.

Single-detector counter as an indicator of GCR

The single-detector count rates of C detector are registered in the BGO scintillator crystal without any coincidence condition. This data product is dominated by penetrating GCR intensity when sun is quiet and the short-term disturbances such as passage of ICMES or planetary fly-bys could modulate it. This data product has large geometric factor of $\sim 100\,\mathrm{cm}^2$ sr ensuring high count rates, which make it possible to measure very small variation.

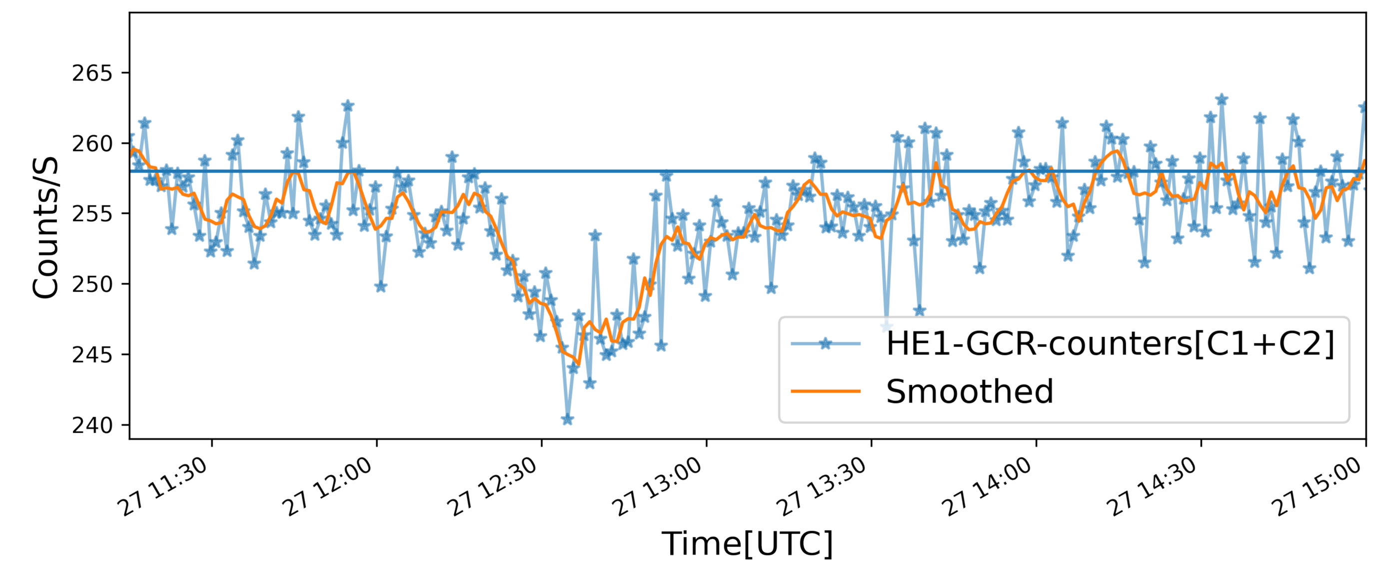

Figure 5. The count rates of C detector during the Venus fly-by. A 5% drop in count rates due to GCR shadow of venus is registered[1, 2].

Summary

The High-Energy Telescope (HET) was switched on about two weeks after the launch of Solar Orbiter and has since been operating continuously. The first year's GCR and SEP observations of HET look promising and the ACR components of oxygen are clearly seen. HET also observed the first widespread gradual SEP in Nov, 2020. At the same time, some calibration issues still need to be investigated. Here is a brief summary of the unsolved calibration issues of HET:

1. At energies around 10 MeV the results for particles "stopping" in the B detector and those triggering the C detector exhibit a substantial discrepancy which we are currently investigating.
2. The flux of protons measured with the HET C detector appear to be a factor 1.5 - 1.8 higher than those measured by SOHO/EPHIN.

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