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The High Energy Telescopes for the STEREO Mission

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Abstract: We describe the High Energy Telescopes (HETs), which are part of the IMPACT investigation for the STEREO mission (Principal Investigator: Janet Luhmann, University of California at Berkeley). The two STEREO spacecraft were launched from Cape Canaveral, FL on October 25, 2006. High energy electrons (~ 0.7 -6 MeV) and nuclei from hydrogen to iron (~ 13 – 200 MeV/nucleon) are detected by the HETs, one on each spacecraft. Observations from one pass through the Earth's magnetosphere and from four X-class solar events in December, 2006 are presented to illustrate the capabilities of the HETs. The HET observations are also compared with observations from other spacecraft. The event of December 13th was the first Ground Level Event in almost two years [This work was supported by NASA (at Caltech and JPL under contract NAS5-00133 and grant NAG5-12929)].

Introduction

The objective of the STEREO Mission is to study Coronal Mass Ejections (CMEs): their origins at the sun, their propagation from the sun to 1 A.U., the acceleration of energetic particles by CME-driven shocks, and the impact of CMEs on the Earth. To accomplish this objective, two STE-REO spacecraft were launched on a single rocket on October 25, 2006. Each spacecraft has a complement of optical telescopes capable of viewing the sun and viewing CMEs as they travel from the sun to 1 AU together with a variety of in situ instruments which include the Solar Energetic Particle (SEP) portion of the IMPACT investigation (Principal Investigator: Janet Luhmann, University of California at Berkeley). The SEP instruments detect particles from tens of keV to 100 Mev/nucleon and above. The High Energy Telescopes (HETs), which cover the top end of the SEP energy range, will be described in this paper; the Low Energy Telescopes are described in a separate paper at this conference [1].

Both STEREO spacecraft passed close to the moon on December 15, 2006, putting Ahead into

an orbit around the sun with an aphelion slightly less than 1 A.U. This corresponds to an orbital period somewhat less than one year so the Ahead spacecraft will drift ahead of the earth by 22.5 degrees per year. The Behind spacecraft passed near the moon a second time on January 21, 2007, putting it into an orbit around the sun with an orbital period slightly longer than one year, causing it to drift behind the earth by 22.5 degrees per year. This is the first time since the two Helios spacecraft were launched in the 1970's that we have been able to study the same solar event simultaneously from different solar longitudes.

The HET Telescope

A cross-section of the HET telescope is illustrated in Figure 1. The telescope is cylindrically symmetric about the central (vertical) axis. It consists of a passive aluminum housing which holds 9 parallel silicon solid-state detectors, each 1 mm thick. The first detector, denoted H1, is subdivided into an inner circular detector (H1inner, 0.8 cm in diameter) and a surrounding circular ring (H1outer, with outer diameter of 2 cm). Separate signals are taken from H1inner and H1outer.

During high rates the geometry factor for stopping electrons, protons, and He can be reduced by automatically raising the H1outer threshold. The second detector, denoted H2, is identical to the H1 detector but the two parts are summed into a single preamplifier. The remaining detectors are all 4 cm in diameter. The next six detectors are summed pair-wise into three preamplifiers (H3, H4, and H5). The final detector is denoted H6. Particles which stop in the telescope are those which have coincident signals from H1 and H2 but no signal from H6. The energy range of the HETs is extended by also analyzing penetrating particles, i.e particles which have an H1·H6 coincidence. Forwards and backwards moving protons and He have separate tracks up to 100 MeV/nucleon.
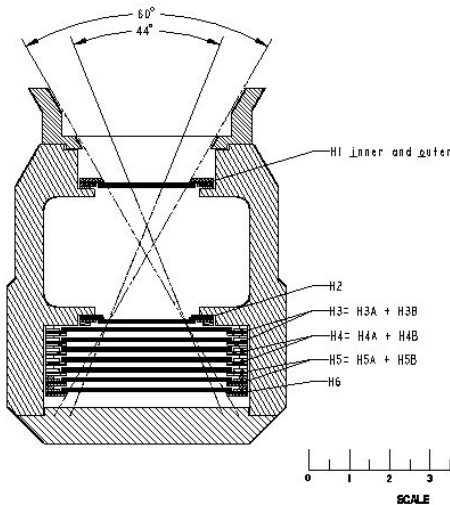

Figure 1: Cross-sectional view of the HET. For high rates the geometry factor for stopping particles is 0.61 cm2-sr.

The HET Electronics

The HET electronics are very compact. Sixteen dual-range pulse height analyzers (PHAs) are contained in a single integrated circuit (referred to as a PHASIC chip). HET uses two such chips because of concerns about cross-talk between channels in the chip. The PHASIC is very flexible, including for example commandable gain range and threshold for each of the active PHAs; individual PHAs can be powered off. A GEANT simulation was used to determine the thresholds (0.2 MeV) for H1, H2, and H6 necessary to trig-

ger on minimum ionizing electrons. The two PHASIC gain ranges are separated by a factor of 20 and each range corresponds to 11 bits full scale. With a threshold at 0.2 MeV, Fe nuclei which pass through H1 and just enter H2 saturate the top end of the H1 pulse-height analyzer. This is acceptable because Fe dominates all nuclei which can produce such a saturated pulse height.

Another major component of the HET electronics is an ACTEL chip which contains the front-end electronics and a Minimal Instruction Set Computer (MISC). The MISC has 32 different instructions and uses 3-byte words. There are two different 3-byte quantities which can be read out of a PHASIC chip for each PHA: one is the number of times that the PHA threshold was triggered since the last reset pulse, and the other is the pulse height together with the chip number, the PHA number, and a bit signifying whether there are any more pulse heights to be read out. The purpose of the front-end electronics is to recognize valid coincidences and facilitate the transfer of data from the PHASICs to the MISC. The front-end electronics also measures the system live time.

Because of limited telemetry and potentially high counting rates, it is important to identify particle types on board and bin them according to kinetic energy interval. Particle identification for stopping particles is performed by the MISC using the standard dE/dx by residual E method. The H1 pulse height is converted to a logarithmic index (denoted logH1) from 0 to 255 and the sum of pulse heights from H2 to H5 is similarly mapped to a logarithmic index (denoted logH2_H5) from 0 to 127. The particle type is then given by the table element PrtclType[logH1][logH2_H5]. If the particle has entered detector H3, then a second determination of the particle type is given by the table element PrtclType[logH2][logH3_H5]. This provides a consistency check since the two values of the particle type should match. This helps to eliminate particles which went through the edges of H1inner and/or H1outer. Particle types include electrons, protons, ^{3}He, ^{4}He, C, O, Ne, Mg, Si, and Fe. The software counter bin number is obtained from a similar table lookup: SWCtr = SWCtrTbl[logH1][logH2_H5].

The table size is definitely sufficient for identifying particle types. Quantization of the residual E due to log conversion (logH2_H5) means that the energy intervals for each particle type are not quite as well matched as one might like. We are considering altering the on-board software to do this binning in linear space to improve this part of the HET performance.

Penetrating protons and He are analyzed similarly; i.e. a multidimensional pulse height space is reduced to two 2-dimensional spaces:

> logH1 vs logH6
> logH2 vs logH3_H5

Analysis above 100 MeV/nucleon is somewhat difficult for two reasons: (1) as mentioned earlier, the forwards and backwards particle tracks merge and (2) the merged energy intervals are not the same due to the extra material that the backwards particles encounter before entering H6 as compared to forwards particles entering H1.

Sample pulse height events are queued for readout in the following queues:

> stopping electrons and protons
> stopping He
> stopping Z >2
> penetrating protons
> penetrating He
> penetrating Z >2

These pulse height events are used to validate the on-board processing. They also make it possible to obtain spectra for other particle types than the ones for which there are specific software counters.

The MISC is able to process approximately 3,000 particles per second.

In addition to processing particles on board, the MISC has two other functions: it receives and processes commands (e.g. to configure the PHA-SICs) and it formats telemetry data for readout.

Data Examples

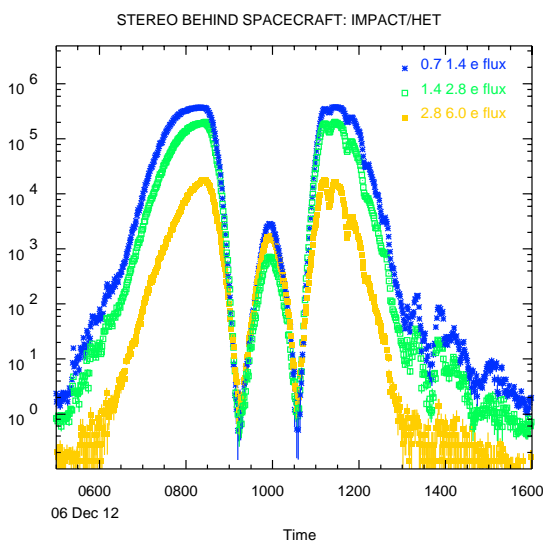The high-rate capabilities of the HET telescopes are illustrated in Figure 2.

Figure 2: Electron intensities (electrons/cm^2-sr-sec-MeV) from the perigee passage of the Behind spacecraft of December 12, 2006.

Figures 3 and 5 show intensities observed for the four large solar events in December, 2006. The event of December 13th was a large Ground-Level Event, an unusual occurrence so close to solar minimum. The relative contributions of the first two events at the sun to the observed particle intensities near 1 AU are hard to determine. The close proximity of the peak particle intensities to the shock and the low Fe/O ratio (not shown; see [2]) indicate that these particles are shock accelerated.
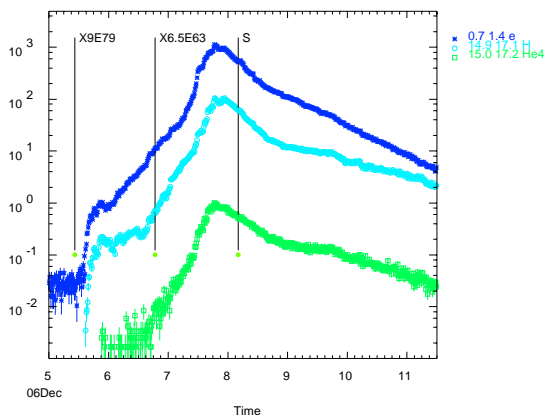
Figure 3: Shows electron, H, and He intensities observed by the Ahead HET for the first two events in December, 2006.
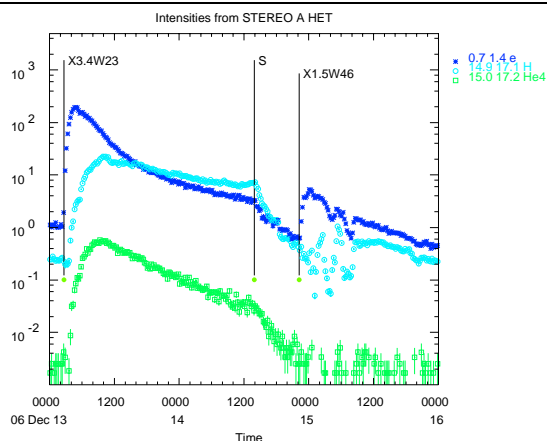

Figure 5: Showing intensities from the GLE event of December 13th and the subsequent event of December 14th.
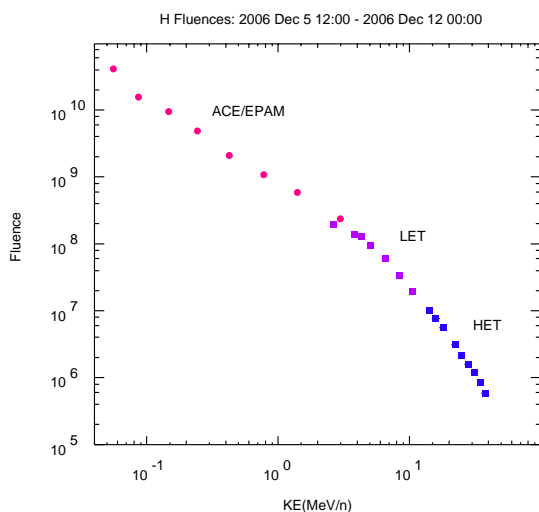

Figure 4: H fluence spectra from ACE/EPAM, LET, and HET for the events in Figure 3, showing good agreement amongst the three instruments.
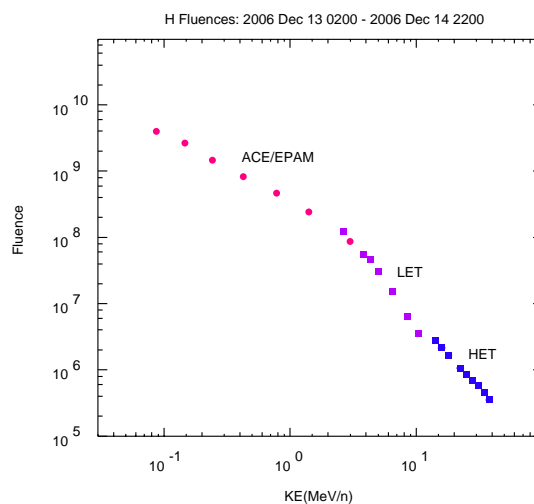
A paper providing a more complete description of the HETs has been submitted to Space Science Reviews.

Figure 6: H fluence spectra for the GLE event depicted in Figure 5.

References

[1] R.A. Mewaldt, et al., Observations of the December 2006 solar energetic particle events with the Low Energy Telescope (LET) on STE-REO, this conference.

[2] C.M.S. Cohen, et al., Comparing observations and expectations of SEP composition in the two December 2006 events, this conference.