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The GOES-16 Energetic Heavy Ion Sensor (EHIS) Ion Composition and Flux Measurements

J. J. Connell and C. Lopate, University of New Hampshire, Department of Physics and Space Science Center

Abstract. The Energetic Heavy Ion Sensor (EHIS) was built by the University of New Hampshire, subcontracted to Assurance Technology Corporation, as part of the Space Environmental In-Situ Suite (SEISS) on the GOES-16 (formerly GOES-R) satellite launched 19 November 2016 to Geostationary orbit. EHIS measures energetic ions over the range 10-200 MeV for protons, and energy ranges for heavy ions corresponding to the same stopping range (e.g., 19-207 MeV/u for carbon and 38-488 MeV/u for iron). EHIS uses the Angle Detecting Inclined Sensors (ADIS) technique to provide single-element charge resolution. Though on an operational mission for Space Weather monitoring, EHIS can thus provide a new source of high quality Solar Particle Event (SPE) data for science studies. With a high rate of on-board processing (~2000 events/s), EHIS will provide exceptional statistics for ion composition measurements in large SPE's. For the GOES Level 1-B and Level 2 data products, heavy ions are distinguished in EHIS using pulse-height analysis with on-board processing producing charge histograms for five energy bands. Fits to these data are normalized to priority rate data on the ground. The instrumental cadence for histograms is 1 minute and the primary Level 1-B heavy ion data products are 1-minute and 5-minute averages. We discuss the preliminary EHIS heavy ion data results which show elemental peaks from H to Fe, with peaks for the isotopes D and ^{3}He.

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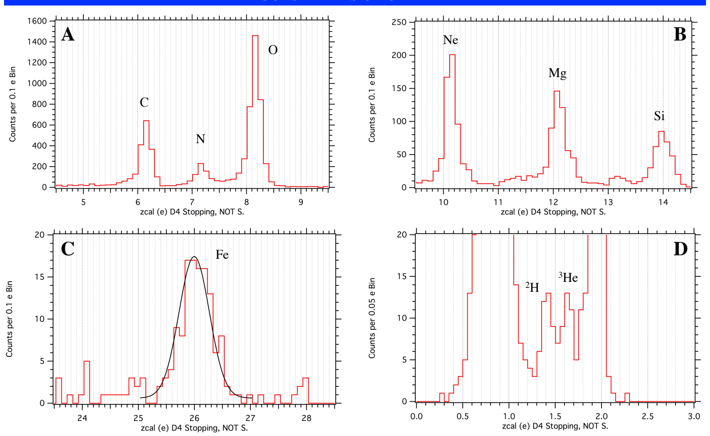
GOES-16/EHIS On-Orbit Data



EHIS produces two major science data products: event rate counts and pulse-height analysis (PHA) data.

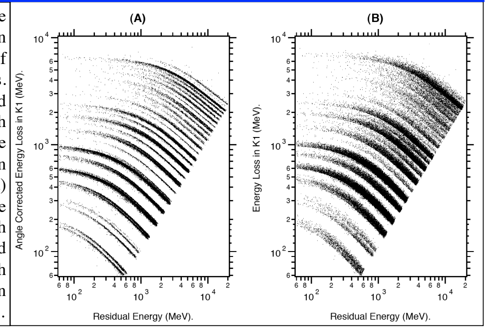
Rates are used directly to determine H and He fluxes (see Lopate & Connell poster SH31B-2727). A priority scheme, lowest (P3) for H ions, intermediate (P2) for He, and highest (P1) to heavier ions, governs PHA event processing. Thus the PHA events constitute an unbiased sample that can be normalized to priority rate data to determine fluxes. Because of the simplicity of the ADIS system, energetic ion charges are calculated on-board by the EHIS processor and complied into histograms included in telemetry on a 1-minute cadence. The EHIS microprocessor can analyze ~2000 events/s, providing unprecedented statistics in high flux conditions.

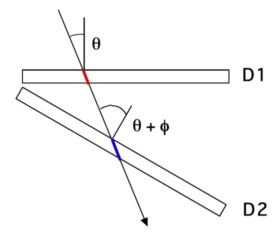
Above plots A, B, and C, show charge histograms of PHA data for heavy ions stopping in D4 from 1/8/2017 to 9/26/2017. These data are dominated by Solar energetic particles from the 9/7/2017 to 9/15/2017 active period. Elemental peaks are clearly seen. Fit to Fe (plot C) has $\sigma = 0.27 \pm 0.02$ e charge resolution.

Plot D shows data 1/8/2017 to 3/23/2017 which is dominated by Galactic Cosmic Rays (GCR's). The charge calculation assumes a fixed relation between charge Z, and mass number A. Deviations from this relation result in slightly different values of calculated charge. The isotopes ^{2}H (D) and ^{3}He are apparent, with abundancies consistent with GCR's. ^{3}He is of considerable interest in Solar events as it is often enhanced.

Angle Detecting Inclined Sensors (ADIS)

Telescopes of stacked silicon Solid State Detectors (SSDs) are the most common method to measure ions in the energy range of 10-100s MeV/u. The energy loss ($\Delta E/\Delta x$) vs. residual energy (E') technique is exhibited (right) using data from the *Ulysses* High Energy Telescope (HET), a heritage instrument for EHIS. Measuring ion composition with good (single element) resolution requires that the angle of incidence be determined. The figure shows data with the proper angle corrections included (A) and with no corrections (B). Tracks of both elements (Li-Ni) and isotopes are apparent in (A) while much of the resolution is lost in (B).





$$\frac{E_1}{E_2} = \frac{\sec(\theta)}{\sec(\theta + \phi)}$$

The most common method to obtain angle corrections is to use complex Position Sensing Detectors (PSD's), as in the *Ulysses* HET. The Angle Detecting Inclined Sensor (ADIS) system [1] uses detectors inclined to the instrument axis to determine the angle of incidence. Consider an ion traversing a solid state detector (D1 left). The signal from that detector depends upon the detector material traversed (red), which increases with the angle of incidence — exactly the effect that degrades charge resolution. If a second detector, inclined to the first is added (D2), the particle pathlength (blue) will vary with the sum of angle of incidence plus the (known) angle of inclination. By inverting the equation, the angle of incidence in a plane can be determined.

Space Weather and Science

EHIS is an operational instrument capable of providing science-mission quality data.

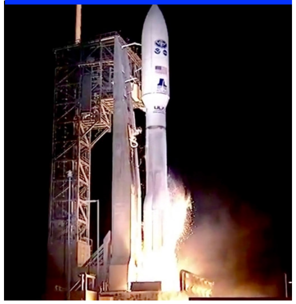
NOAA requirement included measuring fluxes in the largest of Solar Particle Events, achieved by using active baseline restore and modest geometrical factors. Extensive accelerator calibrations provided dead-time corrections and effective geometrical factors. A detailed analysis of systematics was also required.

To determine absolute fluxes, a maximum-likelihood fit is made to the charge histograms. The peak areas are normalized to dead-time corrected priority rates. Effective geometrical factors and energy bin widths are applied. Statistical and systematic error estimates are included.

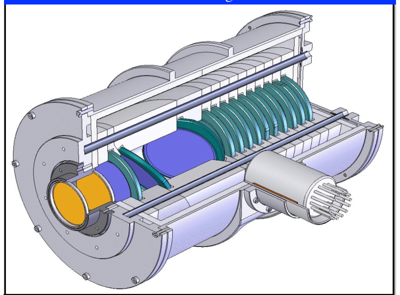
NAOA ground processing is for Space weather applications and does not make full use of EHIS's capabilities (capabilities that are needed to meet NAOAA requirements). An example of this is that NOAA proton and He analysis is entirely rate based, excluding analysis of D and ^{3}He. NOAA also operates on a fixed 1- or 5-minute cadences, whereas a science analysis would choose a cadence based upon the species of interest, the flux and and time scales of the phenomena under study.

It is our hope to develop science analysis software with funding from other sources (e.g. NASA) to support the science community.

GOES-16 Launch



EHIS Design



For a full ADIS system, at least one more inclined detector is added. For EHIS, above, a third detector (D3) below D2, inclined at the same angle (30°) to the axis, but rotated 90° about the axis, is used. With D1, D2 and D3, the angle of incidence (and also the azimuthal angle) are determined.

D1-3 are 50 µm SSDs. Below D3, are D4, D5 and D6, each consisting of three 1500 µm (total 4.5 mm) SSDs. A final 1500 µm SSD (R) identifies penetrating events. The detector stack is surrounded by a plastic scintillator system viewed by a PMT. A thin, gold plated window covers the entrance aperture, providing light-tightness and completing the Faraday cage formed by the housing. Below are EHIS general characteristics.

Mass: 9.2 kg Power: 4.9 W (avg.)
Telemetry: 1536 bps
FOV: 28° (half-angle)
Geometrical factor: 1.5 to 0.5 cm^2 ster
Energy in five semi-logarithmic bands.
C: 19-207 MeV/u. Fe: 38-488 MeV/u

[1] J. J. Connell, C. Lopate and K. R. McLaughlin "Accelerator Test of an Improved Angle Detecting Inclined Sensor (ADIS) Prototype with Beams of ^{78}Kr and Fragments," **Nuclear Instruments and Methods in Physics Research A 837**, 11-15 (2016) and references therein.