New Horizons PEPSSI Instrument Overview

This document is an overview of the New Horizons Pluto Energetic Particle Spectrometer Science Investigation (PEPSSI) instrument. This PEPSSI description was originally adapted from the New Horizons website, the Science Operations Center (SOC) Instrument Interface Control Document (ICD), and McNutt et al. (2008). During migration to PDS4, this current copy was adapted from the PDS3 PEPSSI instrument catalog file, providing light edits to the text, format, and flow.

Instrument Overview

PEPSSI is a medium-energy particle spectrometer.

Specifications

NAME:	PEPSSI
DESCRIPTION:	Medium energy particle spectrometer
PRINCIPAL INVESTIGATOR:	Ralph McNutt, Applied Physics Laboratory
ENERGY RANGE:	25-1000 keV (protons)
	60-1000 keV (atomic ions)
	100-1000 keV (molecular ions)
	25-500 keV (electrons)
FIELD OF VIEW:	160 x 12 degrees
ANGULAR RESOLUTION:	25 x 12 degrees
ENERGY/TOF RESOLUTION:	250 eV / 167 ps Granularity

Description

PEPSSI (Pluto Energetic Particle Spectrometer Science Investigation) is a hockey-puck-size (7.6cm diameter by 2.5cm thick), time-of-flight (TOF) spectrometer that measures ions and electrons over a broad range of energies and pitch angles. Particle composition and energy spectra are measured for H to Fe from ~25 keV/nucleon to 1 MeV/nucleon and for electrons from 25 keV to 500 keV. The PEPSSI instrument traces its heritage back to the MESSENGER Energetic Particle Sensor (EPS) instrument. EPS/PEPSSI was developed with the support of a NASA Planetary Instrument Definition and Development (PIDDP) grant aimed at designing a low-mass, low-power sensor that can measure energetic pickup ions produced near planets and comets (see Andrews et al. (1998) and McNutt et al. (1996)). The overall PEPSSI instrument weighs 1.5 kg and uses a maximum of 1.4 W of power.

Scientific Objectives

Summary

1. Determine the escape rate of Pluto's atmosphere.
2. Measure the interaction of the solar wind with Pluto's ionosphere.
3. Determine the source and nature of energetic particles found near Pluto and Arrokoth.

Details

PEPSSI's primary objective is to determine the mass, energy spectra, and directional distributions of energetic particles, with a resolution able to discriminate between the various types of species expected at Pluto/Arrokoth.

PEPSSI will also search for neutral atoms that escape Pluto's atmosphere and subsequently become charged by their interaction with the solar wind.

Finally, PEPSSI will determine the composition and density of pick-up ions from Pluto, which indirectly addresses the atmospheric escape rate.

Detector

Summary

A time-of-flight (TOF) section feeds a solid-state silicon detector (SSD; a.k.a. 'pixel') array. PEPSSI's field of view (FOV) is fan-like and measures 160 degrees x 12 degrees, divided into six angular sectors of 25 degrees x 12 degrees each. Each sector has two SSDs: 3 of the sectors have one electron SSD and one ion SSD each; three sectors have two ion SSDs each. Ions entering the PEPSSI FOV generate secondary electrons as they pass through entrance and exit foils in the TOF section, providing 'start' and 'stop' signals detected by a microchannel plate (MCP).

Details

PEPSSI is a compact particle telescope with a time-of-flight (TOF) section and a solid-state detector (SSD; a.k.a. 'pixel') array. A mechanical collimator defines the acceptance angles for the incoming ions and electrons. The TOF section is axially symmetric; entrance and exit apertures are 6 mm wide with an azimuthal opening angle of 160 degrees. The entry apertures are covered by a thin polyimide/aluminum/polyimide foil. The stop foil is a polyimide/palladium/polyimide foil. The foils are mounted on high-transmittance stainless-steel grids. The foil thickness and composition is a compromise to minimize the energy threshold, secondary electron production, and scattering of particles in the foil while blocking UV (UltraViolet) from the direct Sun and Lyman-alpha background. PEPSSI measures the ion TOF using secondary electrons generated as the ion passes through the entrance and exit foils in the spectrometer. Total energy is measured by the SSD array comprising six sectors. Each of the six sectors comprises two SSDs; sectors 2, 4, and 5 are dedicated for ion measurement with two ion SSDs each; sectors 1, 3, and 6 each have one ion SSD and one SSD covered with ~1E-6 m Al absorber, to block low energy ions and permit measurements of electrons. The fan-like collimator together with the internal geometry defines the acceptance angles. The FOV is 160 degrees by 12 degrees with six angular sectors of 25 degrees each; the total geometric factor is ~0.15 cm^2 sr. As an ion passes through the sensor, it is first accelerated by the potential of ~3 kV on the front foil prior to contact. The ion generates secondary electrons at the foils, which are then electrostatically steered to well-defined separate regions on a single micro channel plate (MCP), providing 'start' and 'stop' signals for the TOF measurements (from 1 ns to 320 ns). The segmented MCP anode, with one start segment for each of the six angular entrance segments, allows determination of the direction of travel even for lower-energy ions that do not give an SSD signal above threshold.

The combination of measured energy and TOF provides unique particle identification by mass and particle energy in the range: for protons from 15 keV to 1 MeV; for heavy (CNO) ions from 80 keV to 1 MeV. Lower-energy (>3 keV) ion fluxes are measured by TOF and pulse-height analysis (PHA) of the signal they produce in the MCP, providing particle identification and velocity spectra at these energies as well. Molecular ions, expected from Pluto's atmosphere and near Arrokoth, will break up in the foil prior to their full detection, but will be detected as high-mass events. Internal event classification electronics determine the mass and produce an eight-point energy spectrum for each of four species for six arrival directions. Energetic electrons are measured simultaneously in the dedicated electron pixels in the range from 20 to 700 keV. Only protons with energies > 300 keV (expected to be very rare at Pluto) can penetrate the absorbers on these pixels, and even those would be eliminated by on-board MCP coincidence requirements and ground comparisons with the simultaneously measured ion flux.

Electronics

Extensive uses of miniaturization and custom electronics in the design allows PEPSSI to weigh less than 1.5 kg and consume less than 1.4 W. PEPSSI is made up of six modular 10 cm x 10 cm slices. They consist of:

1. Energy board;
2. High Voltage Power Supply (HVPS);
3. TOF board;
4. Digital processing board;
5. Common event processor board; and
6. Low Voltage Power Supply (LVPS) board.

See the SOC Instrument ICD and McNutt et al. (2008) for further details.

Operational Modes

The PEPSSI instrument can operate in two modes: Normal and Diagnostic. On the spacecraft, each event generates a PHA record. This record is classified by event type: Electron, High-Energy Ion (or 'Hi-Ion' or 'Triple'), or low-energy ion (or 'Low-Ion,' 'Double,' or 'TOF-only'). In diagnostic mode, events are not classified; alternatively, all events are 'diagnostic events'. Events of a given type are further classified into 'Rate Boxes' by their energy and/or time of flight (TOF). Thus each event has a type, a rate box, and a detector in which it occurred.

Data sampling and priority for TOF-only data

Data set users may notice a different TOF distribution for the 'high resolution' data (also called 'N2 data' or ApID 0x692 data) and 'low resolution' data (also called 'N3 data' or ApID 0x693, 0x694 data). For completeness there is also 'N1 data' (ApID 0x691), but it only produces 10 PHA events per hour during the Pluto encounter, it will be ignored here. Note that during the Pluto

Encounter period the instrument recorded N1, N2, and N3 data at intervals of 1 hour, 1 second, and 2 hours, respectively.

PEPSSI has two kinds of ion data, TOF vs. E (time-of-flight vs. energy) and TOF-Only (also known as 'high ion' and 'low ion' data, triple coincidence and double coincidence data, and are associated with B-rates and L-rates, respectively). The data are dominated by TOF-Only data because the triple coincidence TOF vs. E data requires a higher energy (thus a lower flux in nearly all situations) to trigger the measurement, has a lower background level (due to the additional coincidence logic), and a smaller geometric factor. For the TOF-Only data, the events with TOF < 20 ns are in a different priority group than the TOF > 20 ns. In the TOF-Only data the shorter TOFs are particles with enough energy to penetrate the SSDs, but they can also miss the SSDs, so some of them would be events that could be detected in the TOF vs. E mode and some not. Due to this ambiguity, and the fact that for higher energies there is the valuable addition of the solid state detector (SSD) measurement, the TOF < 20 ns data were judged not to be the main TOF-Only product. They were put in a different priority group so their relatively high count rate wouldn't suppress the more desirable TOF > 20 ns events. Additionally, the N3 PHA data uses a different priority scheme than the N2 PHA data. In the N3 PHA the TOF < 20 ns priority group is only rarely (if ever) the top priority group, but there could be TOF < 20 ns from the rare triple coincidence data or in the TOF-Only data from the rare period when a very low probability event happens to be detected and not overwritten by the priority scheme. In the N2 PHA data the priority groups have rotating priority so that all data groups get representation; not so with the N3 data. Thus there are PHA events both above and below 20 ns in the N2 data, but almost no PHA events below 20 ns in the N3 data.

See the SOC Instrument ICD and McNutt et al. (2008) for more details about the above and the two subsections below.

Data validity

Some subset of the PHA event data is noise or other instrumental artifacts. PHA events with parameters outside the stated instrument sensitivity limits (see the Specifications section above) should be ignored, or, at the very least, used with extreme caution.

Also, only TOF vs. E event data following the TOF(E) curves/tracks (going from long TOF and small energy to short TOF and high energy) of the PEPSSI instrument are valid. These tracks roughly follow the channel boxes shown in Fig. 11-6 in the SOC to Instrument Pipeline ICD. Events with TOF < 5 ns and deposited energy > 1 MeV or < 40 keV are artifacts.

Event data (both TOF vs. E and TOF-only) is not weighted by the instrumental efficiency and therefore cannot be used as-is to determine energy spectra in physical units. Most notably, the event-counts peak around 100 ns in the TOF-only data is not an intensity peak.

Some channels nominally respond to real particles, if they are present, but predominantly or completely respond to background during most or all of the flight. Therefore, they should not be used for scientific analysis:

- After the Jupiter phase, the 'electron' channels should not be used because penetrating radiation dominates the response. These are channels R00, R01, and R02, all sectors (S0-S5).
- Background or electronic noise dominates the following triple coincidence channels after 2007 DOY (Day Of Year) 144: B00, B07, B08, B17, and B18. The B00 channel is a dump channel. B07 and B08 were designed to be He-3 channels, but there is no sign of this isotope so they contain only the wings of the He-4 distribution. The B17 and B18 channels are 'ultra heavies' but have shown no evidence of responding to such particles. Also B06, nominally measuring high-energy protons, is unreliable. Beyond these channels, the channels B14, B15, B16 are nominally measuring sulfur but are dominated by noise in the interplanetary medium far from Jupiter. Before 2007 DOY 144, the similar issues with background and noise as described above exist but the channel definitions are different. Background or electronic noise dominates the dump channels B00 and B18. The B05 channel measuring high energy protons is at background, except in near-Jupiter environment.
- Other channels also have background (energetic particle measurements always have background). The ones listed above should be ignored because they show no signs of a foreground signal.

  B rates in sectors 4 and 5 (B*S04, B*S05) are contaminated or dominated by counts from the internal alpha source of the instrument and are therefore only useful for diagnostic purposes of the instrument. B rates in the affected sectors (like B01S04, B01S05, etc) should therefore not be used for science. Make sure to not average over all sectors. Also any L*S04 and L*S05 channels should be ignored due to contamination by the internal alpha source.

  Background or electronic noise dominates the following B channels after 2007 DOY 144: B00, B06, B07, B08, B17, and B18.

  B06, B14, B15, and B16 should only be used close to Jupiter with significant foreground of energetic protons and sulfur. Before 2007 DOY 144, similar issues exist but the channel definitions are different: B00 and B18 show noise. B05 measures energetic protons only during significant foreground. The channels measuring sulfur respond well during this period.

The PEPSSI measurements are very sensitive to spacecraft attitude. Particles, depending on energy and species, can be very anisotropic.

The PEPSSI integration intervals change frequently, and multiple integration intervals are used simultaneously. The user must be aware of the current integration interval (the DT (Delta Time) column in the FITS tables) when selecting an averaging interval to avoid effects such as aliasing. Also, be sure to select an averaging interval that results in sufficient statistics.

Please refer to the data collections' overview documents for additional details on the applicability and use of the Primary HDU and extensions of data products in the raw and calibrated datasets.

Bad Time Intervals (BTIs)

Various instrument conditions can make the PEPSSI data difficult or impossible to use for scientific purposes. Powering down, ramping the high voltage power up or down, running in diagnostic mode, etc. will all make the PEPSSI data unusable for standard analysis. The 'Bad Time Intervals' table file contains a table of which should not be used for science analysis.

Measured Parameters

Particle energy information, measured by the SSD, is combined with TOF information to identify the particle's composition. Each particle's direction is determined by the particular 25 degrees sector in which it is detected. Event classification electronics determine incident mass and energy, with 12 channels of energy resolution.

A typical measurement includes 8-point spectra for protons and electrons and reduced resolution energy spectra for heavier ions for all six look directions.

In calibration, the rate, in counts/s, of each energy and/or TOF bin is converted to flux i.e., differential intensity (cm^{-2} sr^{-1} s^{-1} keV^{-1}).

Calibration

Calibration of the PEPSSI instrument continues to be an active process for the instrument team and further refinements are expected in the future. The PEPSSI team is now confident in the spectral shape resulting from the current calibrations but work on the absolute, particularly time dependent, efficiency is ongoing. Comparing count rates and calibrated fluxes of B rate protons before and after the instrument off time in September 2017 will provide the data user with an example of the still unreliable time dependent efficiency calculations as the calculated flux appears to decrease precipitously. Further refinements will be present in future deliveries. They might still change in the course of calibration efforts of the team.

The R channels nominally measure electrons and the calibration quantities assume this. This is applicable in the Jupiter environment. At all other times, the R channel count rates were found to be dominated by penetrating particles consistent with cosmic rays. Therefore electron fluxes cannot be provided for this period. Calibration of the cosmic ray response of the R channels is under development at this time.

The L channels do not distinguish ion species. Attempts to deconvolve their response are ongoing. We currently do not provide detection efficiencies for the L channels and only correct for their time dependent efficiency. The PEPSSI sectors of the L channels that nominally distinguish different look directions show electronic crosstalk that makes it difficult to determine the true intensity distribution as a function of direction. Comparisons between different sectors are therefore not meaningful, and should remain independent if count rates or the provided formal fluxes are used.

Brief summaries of the flux and PHA calibrations are given here. See McNutt et al. (2008) and the SOC Instrument Interface Control Document for details. On November 29, 2016, the PEPSSI flight software was updated to allow for better understanding of the data. For now, calibrated data taken after the flight software change will look somewhat different than data taken before the change, with certain problematic channels and sectors removed.

Flux Calibration

The calibration quantities are energy pass-band ($\Delta E = E_{hi} - E_{lo}$, lower and upper limit of the energies of the particles measured), measurement efficiency (N, the fraction of valid incident particles that are actually measured), the geometry factor (G, the measurement of the physical detector size and solid angle subtended by the field of view). These values are all given and applied with uncertainties in the calibrated files.

The differential intensity, j ($cm^{-2}\ sr^{-1}\ s^{-1}\ keV^{-1}$), is calculated in terms of the counts C, time coverage T (s), geometric factor G (cm^2 sr), upper and lower energy bounds E_{hi} and E_{lo} (keV), and detection efficiency N:

$$j = (C/T)/(G * dE * N),$$

where $dE = E_{hi} - E_{lo}$.

The uncertainty values assume Poisson statistics for C, no error in T, absolute errors in G, E_{hi}, E_{lo} and relative error in N. I.e., formally the counts are C = C +/- deltaC, the energies are E = E +/- deltaE, the geometry factor is G = G +/- deltaG. The efficiency is N = [N * epsilon or N / epsilon], where epsilon = deltaN/N, to one sigma confidence.

The PEPSSI measurements throughout the mission are supplied both as instrument specific data (e.g., count rates) as well as physical instrument-independent units (e.g., differential intensity). It must be stressed that these are preliminary values that should not be used without effort from the user to understand their limitations (see the SOC Instrument ICD).

PHA Event Calibration

The following quantities are provided in the calibrated data products. The linear calibration constants are in the data labels; see the SOC Instrument ICD and McNutt et al. (2008) for details.

- Calibrated Deposited Energy and/or TOF values
- Speed column from the TOF assuming a 6.0 cm flight path.
- The PHA_HIGH_ION calibrated data contain additional quantities, where each value indicates the Incident energy assuming that the event is of that (H, He, O, or S) species:
    - H_Incident_Energy
    - He_Incident_Energy
    - O_Incident_Energy
    - S_Incident_Energy

Events with the multi-hit (cross talk) flag set have been excluded. Quantities of limited usefulness (such as Heavy Ion Discriminator triggers) have been excluded. Because of the difficulty of removing priority scheme biases from non-N2 PHA data, only N2 (APID == 0x692) PHA data is present in the calibrated PHA data.

Priority group artifacts have been removed from quantities in the Rate_Normalized_Weight column of the PHA_HIGH_ION extension using the procedure described in the SOC Instrument ICD. This column is usually used in making histograms of the High Energy Ion PHA data.

Filters, Optics, Locations, Subsystems

N/A

References

McNutt, R.L., S.A. Livi, R.S. Gurnee, M.E. Hill, K.A. Cooper, G.B. Andrews, and 21 others, The Pluto Energetic Particle Spectrometer Science Investigation (PEPSSI) on the New Horizons Mission, Space Science Review, Vol. 140, 315–385, 2008. https://doi.org/10.1007/s11214-008-9436-y (preprint provided in the PDS with LID urn:nasa:pds:nh_documents:pepssi:pepssi_ssr)

Further Reading

Andrews, G.B., R.E. Gold, E.P. Keath, D.G. Mitchell, R.W. McEntire, R.L. McNutt Jr., and N.P. Paschalidis, Compact particle detector for space measurements: prototype performance, Proc. SPIE 3442, Missions to the Sun II, 1998. https://doi.org/10.1117/12.330248

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Bad Time Intervals table, urn:nasa:pds:nh_documents:pepssi:pep_bti, NASA Planetary Data System.

SOC Instrument Interface Control Document (ICD), urn:nasa:pds:nh_documents:mission:soc_inst_icd, NASA Planetary Data System.