# New Horizons Encounter with the Pluto System: Time-Averaged Solar Wind Particle and Ion Fluxes – Overview

This data set contains higher level data products generated by the New Horizons Particles and Plasma science team from data taken by the Pluto Energetic Particle Spectrometer Science Investigation (PEPSSI) instrument team during the PLUTO mission phase.

## PEPSSI Instrument

PEPSSI is a particle telescope and a time-of-flight (TOF) spectrometer that measures ions and electrons over a broad range of energies and angles. Particle composition and energy spectra are measured for H to Fe from ~ 30 keV to ~1 MeV (but not all species are uniquely separated) and for electrons from ~30 keV to 700 keV. PEPSSI comprises a time-of-flight (TOF) section and a solid-state detector (SSD) array that measures particle energy. The combination of measured energy and TOF provides unique particle identification by mass and particle energy depending on the range: for protons from ~30 keV to ~1 MeV; for heavy (CNO) ions from ~80 keV to ~1 MeV. Lower-energy (>3 keV) ion fluxes are measured by TOF only, but without the SSD signal, providing velocity spectra at these energies as well. Due to storage and bandwidth limitations, all event data cannot be stored or telemetered to the ground. Instead, a round-robin algorithm is used to save Energy, TOF, and timing data for select events.

## Coordinate System

A new coordinate system is defined for this dataset, where data is described with respect to PSH X, Y, and Z, where PSH is Plutocentric Solar Heliographic, based on the HelioCentric Inertial (HCI) reference frame, where HCI Z is the solar north rotational axis, and X is the solar ascending node on the J2000 ecliptic.

## Data Products

The headers and contents for these higher level derived data products are described below.

These data products are averages for various PEPSSI channels based on calibrated PEPSSI data and contain fluxes averaged over Sectors 0-2.

### pep_encounter_l4_triples_3h

The file pep_encounter_l4_triples_3h.csv includes 3 hour averages of:

- B01 proton fluxes averaged over S0-S2 w/ statistical uncertainties
- B02 proton fluxes averaged over S0-S2 w/ statistical uncertainties
- B03 proton fluxes averaged over S0-S2 w/ statistical uncertainties
- B09 helium fluxes averaged over S0-S2 w/ statistical uncertainties
- B10 helium fluxes averaged over S0-S2 w/ statistical uncertainties

with 11 columns of data:

Epoch (SCET), B01, B01Unc, B02, B02Unc, B03, B03Unc, B09H, B09HUnc,B10H, B10HUnc

with all data in units of 1/s/ster/cm^2/keV.

The lower and upper bounds for B01, B02, and B03, for the species H+, respectively, in keV are:

Lower Bound: 25.713, 56.421, 119.63;
Upper Bound: 55.183, 118.48, 217.92.

The lower and upper bounds for B09 and B10, for the species He+, respectively, in keV are:

Lower Bound: 13.03, 255.9;
Upper Bound: 254.63, 1199.6.

### pep_encounter_l4_doubles_5min and pep_encounter_l4_doubles_5sec.csv

Both of the doubles files include 5 columns:

Epoch (SCET), L09H, L09HUnc, L11H, L11HUnc

with all data in units of nuc/s/ster/cm^2/keV.

L09H and L09HUnc are the L09 Total Ion fluxes for He+ averaged over S0-S2 w/ statistical uncertainties; and L11H and L11HUnc are the L11 Total Ion fluxes for He+ averaged over S0-S2 w/ statistical uncertainties.

The lower and upper bounds for L09H, in keV/nuc, for species He+, are:

Lower Bound: 11.946;
Upper Bound: 22.001.

The lower and upper bounds for L11H, in keV/nuc, for species He+, are:

Lower Bound: 6.2758;
Upper Bound: 11.858.

## Coverage

This dataset contains averaged data where the time tag is centered in the time range bin. Time averages were chosen such that they were appropriate for the statistics for the number of counts seen during the Pluto Encounter. If the time range for the average is too large, there is not enough time resolution, and if it is too small there could be no counts recorded.

The overall time period of this dataset covers the 4 days which correspond to when PEPSSI was in its highest resolution mode (Encounter Mode). The most interesting channels were chosen, where the L channels are indicative of the suprathermal population, and the B channels are indicative of energetic particles.

This dataset was downselected from the full Pluto dataset, which can be found in the lower level Pluto Encounter datasets for PEPSSI. The dataset contains the cleanest channels with the lowest background. The B channels are Time-Of-Flight (TOF) vs. energy which allows for composition separation, and the L channels are TOF only. Please see the SOC to Instrument ICD, included in this dataset, for a description of the PEPSSI channels.

## Uncertainties

The statistical uncertainties given in this dataset are based on Poisson statistics on counts. Poisson errors are propagated through from counts into intensity. The uncertainties do not include any systematic uncertainty.

'Statistical uncertainties' in the PEPSSI data are calculated by propagating the Poisson error of the individual measurements. So, for each accumulation period, the square root of the total number of events observed for a given channel is taken as the absolute plus or minus uncertainty of the measurement, this is then propagated through the calculation of counts/sec and intensity to yield a 'statistical uncertainty' in the intensity measurement.

## Summary

The triples are averaged over 3 hours because they contain the B channels, which are high energy channels, and general trends can be seen by looking over a longer period of time. The 3 hour averages over the 4 day period of this dataset showed there was no predominant energetic particle activity as there was no large signal. The 3 hour rate was needed to have enough counts to have reasonable statistics.

For the 5 second doubles, L09 is much lower than L11. L11 is a longer TOF and hence a lower energy box than L09, so it is expected to have higher intensities than L09. There is a dependence of intensity on energy, and it is not necessarily geometry leading to the difference. The spectral shape is important.

The quantization that can be seen in the 5 second doubles is due to low count statistics.

PEPSSI counting rates are telemetered using a lossy logarithmic compression scheme, so that, if rates are very high (as they are for channels such as 'L09' and 'L11'), the resulting derived count rates and fluxes will appear 'quantized'. Since the L09 and L11 channels have different conversions to intensity units (e.g. their efficiencies at the time of the Pluto encounter were a bit less than a factor of 2 different), they will appear to be 'quantized' by different sized 'steps'.

## Attitude and Ephemeris

In general, it is important to look at the attitude of the spacecraft in order to interpret the data correctly because there are large angular dependencies due to the spacecraft attitude.

The file pep_encounter_l4_attitude_and_ephemeris.csv includes these Attitude and Ephemeris quantities at 1s cadence (the precision of the values are from SPICE kernels):

- Epoch (in spacecraft time SCET, converted to YYYY-DOYTHH:MM:SS format)

- PSH X - Plutocentric Solar Heliographic X, in Rp
- PSH Y - Plutocentric Solar Heliographic Y, in Rp
- PSH Z - Plutocentric Solar Heliographic Z, in Rp
- PSH R - Distance from Pluto, in Rp
- HCI R (distance to the Sun), in AU
- PEPSSI S1 Pluto Cone Angle, in degrees
- PEPSSI S1 Pluto Clock Angle, in degrees
- PEPSSI S1 Sun Cone Angle, in degrees
- PEPSSI S1 Sun Clock Angle, in degrees
- SC-Sun-Pluto Line, in km - this value equals sqrt(PSHY^2 + PSHZ^2)

Cone and clock angle are designed to provide attitude information by describing the orientation of a given boresight is relationship to a specific body (more precisely a particular body reference frame). In our case the body is either Pluto or the Sun. Cone angle is the angle between the s/c-to-body vector and the boresight vector. It is zero when the boresight is looking at the body (either the Sun or Pluto) and it can be as large as 180 degrees when looking in the opposite direction. We define the following attitude (att) frame of reference to determine these values.

Zatt is SC-to-body [this is the s/c-body vector referenced above]

Xatt = -Zatt x Zbod

[Zbod is the body Z-axis; e.g., PSH Z-axis or Sun spin axis]

Yatt = +Zatt x +Xatt

(unit vector normalization not shown)

We get the cone angle by calculating the co-latitude in the Xatt,Yatt,Zatt reference frame. The clock angle is the longitude in this Xatt,Yatt,Zatt frame, meaning that when the boresight vector Vbore = (Vx,Vy,Vz) = ( Vbore.Xatt, Vbore.Yatt, Vbore.Zatt) is aligned with the Xatt axis, the clock angle is 0 degrees and when it's aligned with the Yatt axis it's 90 degrees, etc. Explicitly this should correspond to:

CONEangle = arccos ( Vz/V )

CLOCKangle = arccos ( Vx/sqrt(Vx^2+Vy^2) )

. is scalar (dot) product
x is vector (cross) product

The SC-Sun-Pluto Line is important because the solar wind flows radially, and this value tells you where you are based on the shadow of Pluto - it goes to zero when the spacecraft is directly behind Pluto (in Pluto's shadow during the occultation).

Rp is the radius of Pluto, defined as 1187 km in this dataset. 1 AU is an Astronomical Unit, defined as 149597871 km in this dataset.

## Notes

The level of unit precision given in these files are large because of the use of the mission SPICE kernels, and is based on the default SPICE precision.

This data set contains higher level products derived from data taken by the PEPSSI instrument. More details about how PEPSSI data is processed and the reliability of the most recent calibration effort can be found in the raw and calibrated data sets from the Pluto Encounter, NH-P-PEPSSI-2-PLUTO-V3.0 and NH-P-PEPSSI-3-PLUTO-V3.0.

[Ed. Note] *The PDS4 identifiers for the PDS3 data sets mentioned above are:*

> *urn:nasa:pds:nh_pepssi:pluto_raw::1.0*
> *urn:nasa:pds:nh_pepssi:pluto_cal::1.0*