

# New Horizons PEPSSI KEM1 Encounter

## Calibrated Data Overview

During the migration to the Planetary Data System's (PDS) PDS4 data standards, this current description was adapted from the PDS3 dataset catalog file, providing light edits to the text, format, flow, and to make the description better conform to this PDS4 data collection.

### Abstract

This data set contains Calibrated data taken by the New Horizons Pluto Energetic Particle Spectrometer Science Investigation (PEPSSI) instrument during the KEM1 ENCOUNTER mission phase.

This version includes data acquired by the spacecraft between 08/14/2018 and 09/30/2022. It only includes data downlinked before 05/01/2024. Future datasets may include more data acquired by the spacecraft after 08/13/2018 but downlinked after 04/30/2024.

This dataset contains PEPSSI Plasma Rolls, approach and departure observations of Arrokoth, and post-Arrokoth data.

In all FITS data files in this dataset, non-finite (NaN and Inf) values have been replaced with INVALID\_CONSTANT values.

This dataset corresponds to New Horizons NAIF SPICE distribution v0008.

### Data Set Overview

This data set contains Calibrated data taken by the New Horizons Pluto Energetic Particle Spectrometer Science Investigation (PEPSSI) instrument during the KEM1 ENCOUNTER mission phase. The closest approach to asteroid (486958) Arrokoth was on January 1, 2019, at approximately 05:33 UTC.

PEPSSI (Pluto Energetic Particles Spectrometer Science Investigation) 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. The common data products contain these event and summary measurements, accumulated over fixed periods of 86,400 seconds, with each period in a single

file comprising multiple binary tables. A more detailed description of the data format can be found in Science Operations Center (SOC) Instrument Interface Control Document (ICD) (see PDS4 LID [urn:nasa:pds:nh\\_documents:mission:soc\\_inst\\_icd](#)) and the PEPSSI document collection (see PDS4 LID [urn:nasa:pds:nh\\_documents:pepssi](#)).

## Version History

Each subsection below details the major changes between the prior versions of this data set, listing the newest versions before older versions.

### PDS4 v2.0

Version 2.0 includes data acquired by the spacecraft between 08/14/2018 and 09/30/2022. It only includes data downlinked before 05/01/2024 and after 04/30/2022. Future datasets may include more data acquired by the spacecraft after 08/13/2018 but downlinked after 04/30/2024.

After a lengthy hibernation period, the New Horizons spacecraft resumed data playback on DOY 2023\_060 (March 1, 2023). The spacecraft collected PEPSSI data throughout its hibernation, but most of that data has not been downlinked yet. As a result, this version will contain substantial gaps in the data. These gaps will be filled in later versions.

On April 10, 2022 at 10:17 UTC, the PEPSSI flight software was updated to version 5 (FSW5). The changes to the data are small, but the way the instrument is operated has changed. Refer to section 11.3.6 (Flight Software Version 5 Changes to Operations) in the SOC Instrument (PDS4 LID [urn:nasa:pds:nh\\_documents:mission:soc\\_inst\\_icd](#)) for a brief description of the changes.

All KEM1 ENCOUNTER calibrated mission data in the earlier PDS3 NH-A-PEPSSI-3-KEM2-V1.0 dataset has been moved into this dataset version.

### PDS4 v1.0 (migration from PDS3 V6.0)

This data collection was migrated from Planetary Data System's (PDS) PDS3 archive standards to the PDS4 archive standards, which involved changing the PDS formatted product labels. The products themselves have remained unchanged. The major changes from the PDS3 V6.0 data set are:

- the calibration files, documents, and data products were reorganized into separate collections of calibration files, documents, and data products, instead of being in a single package as it was in prior PDS3 data set versions.
- the geometry keyword values found within the PDS4 labels were calculated using the most recent spice kernels available at label creation. Note that the FITS headers have not been updated and their geometry keyword values therefore remain unchanged.

### [PDS3 V6.0 \(NH-A-PEPSSI-3-KEM1-V6.0\)](#)

This version includes data acquired by the spacecraft between 08/14/2018 and 04/30/2022. It only includes data downlinked before 05/01/2022. Future datasets may include more data acquired by the spacecraft after 08/13/2018 but downlinked after 04/30/2022.

Data acquired after April 10, 2022 has been held back until the next dataset version because it was collected and downlinked with a new flight software version. The results and format have not been verified by the New Horizons science teams yet.

This version includes observations from prior to, during, and after the ASTEROID 486958 Arrokoth (2014 MU69) encounter.

The PEPSSI science team has greatly improved the quality of the differential intensity calibration of the data for this release. They have also changed the format of some data files to support the new instrument flight software which was activated on the spacecraft on April 10, 2022. Some minor usability improvements have been included, in the form of new columns as documented below. The calib/calpars files (found in the PEPSSI calibration files collection, PDS4 LID `urn:nasa:pds:nh_pepssi:calibration_files`) also document these column changes.

The calibrated data files in this release differ from previous releases in the following ways:

- The energy calibrations are much more accurate and include efficiency calculations to adjust for the time dependent changes to instrument sensitivity after power cyclings.
- New STATUS quantities (i.e. columns) support new capabilities added to the instrument flight software on April 10, 2022. Note that these quantities are not actually used in the data in this delivery since no data post-April 10 is included.
- Several uncalibrated bins (B00,B17,B18,L00,L02,...) were added for convenience. These bins remain without differential intensity ('flux') calibrations but they are converted to counts per second rates.
- Low Energy Ion PHA Events now contain a column (calculated on the ground) that reports what number energy bin they would have been classified into ('Lo\_Bin').
- Rate Normalized Weight and Rate Normalized Weight with 1-day integration are now included for High Energy Ion PHA Events. The instrument team now feels these quantities are understood well enough to include (at least for pre-April 10 data).
- 'Raw' energy and time of flight values are included (in instrument units). These values are just copied from the raw data files, for ease of use.
- In all FITS data files in this dataset, non-finite (NaN and Inf) values have been replaced with INVALID\_CONSTANT values.

PDS Citation Information: McNutt, R. Jr., NEW HORIZONS CALIBRATED PEPSSI KEM1 V6.0, NH-A-PEPSSI-3-KEM1-V6.0, NASA Planetary Data System, 2023.

### [PDS3 V5.0 \(NH-A-PEPSSI-3-KEM1-V5.0\)](#)

Version 5.0 of this data set included data acquired by the spacecraft between 08/14/2018 and 03/01/2021. It only included data downlinked before 03/01/2021.

The Version 5 data for October 2020 forward was incomplete. Additional data was downloaded in May/June 2021.

This version included observations from prior to, during, and after the ASTEROID 486958 Arrokoth (2014 MU69) encounter.

PDS Citation Information: McNutt, R. Jr., NEW HORIZONS CALIBRATED PEPSSI KEM1 V5.0, NH-A-PEPSSI-3-KEM1-V5.0, NASA Planetary Data System, 2022.

#### [PDS3 V4.0 \(NH-A-PEPSSI-3-KEM1-V4.0\)](#)

Version 4.0 of this data set included data acquired by the spacecraft between 08/14/2018 and 04/30/2020. It only included data downlinked before 05/01/2020.

This version included observations from prior to, during, and after the Arrokoth encounter.

PDS Citation Information: McNutt, R. Jr., NEW HORIZONS CALIBRATED PEPSSI KEM1 V4.0, NH-A-PEPSSI-3-KEM1-V4.0, NASA Planetary Data System, 2021.

#### [PDS3 V3.0 \(NH-A-PEPSSI-3-KEM1-V3.0\)](#)

Version 3.0 of this dataset included data acquired by the spacecraft between 08/14/2018 and 07/31/2019. It only included data downlinked before 08/01/2019.

In Version 3.0 there are a combination of data gaps and a lot of attitude changes by the spacecraft (as New Horizons did a lot of communication leading up to its encounter with Arrokoth). The Low Ions are sensitive to the attitude with respect to the solar wind.

PDS Citation Information: McNutt, R. Jr., NEW HORIZONS CALIBRATED PEPSSI KEM1 V3.0, NH-A-PEPSSI-3-KEM1-V3.0, NASA Planetary Data System, 2020.

#### [PDS3 V2.0 \(NH-A-PEPSSI-3-KEM1-V2.0\)](#)

Version 2.0 included data acquired by the spacecraft between 08/14/2018 and 01/31/2019. It only included data downlinked before 02/01/2019.

Two digits of precision have also been added to the EXPOSURE\_DURATION value in all data labels after V1.0.

PDS Citation Information: McNutt, R. Jr., NEW HORIZONS CALIBRATED PEPSSI KEM1 V2.0, NH-A-PEPSSI-3-KEM1-V2.0, NASA Planetary Data System, 2020.

#### [PDS3 V1.0 \(NH-A-PEPSSI-3-KEM1-V1.0\)](#)

This version includes data acquired by the spacecraft between 08/14/2018 and 12/31/2018. It only includes data downlinked before 01/01/2019. Future datasets may include more data acquired by the spacecraft after 08/13/2018 but downlinked after 12/31/2018.

PDS Citation Information: McNutt, R. Jr., NEW HORIZONS CALIBRATED PEPSSI KEM1 V1.0, NH-A-PEPSSI-3-KEM1-V1.0, NASA Planetary Data System, 2019.

### General statement about data set versions after V1.0

The pipeline (see Processing below) was re-run on these data for each version since the first (V1.0). A pipeline rerun usually changes the FITS headers but not the FITS data of raw data sets. In some cases, calibrated FITS data may change because the calculated geometry of an observation has changed. See data set version-specific sections above for significant exceptions to this general statement, i.e., changes to pipeline processing, calibration processing, and data delivered.

Note that even if this is not a calibrated data set, calibration changes are listed as the data will have been re-run and there will be updates to the calibration files, to the documentation and to the steps required to calibrate the data.

Also note that file names may change between versions if start/stop times are updated when additional data are downlinked.

### Processing

The data in this data set were created by a software data processing pipeline on the Science Operations Center (SOC) at the Southwest Research Institute (SwRI), Department of Space Operations. This SOC pipeline assembled data as FITS files from raw telemetry packets sent down by the spacecraft and populated the data labels with housekeeping and engineering values, and computed geometry parameters using SPICE kernels. The pipeline did not resample the data.

### Data

The observations in this data set are stored in data files using standard Flexible Image Transport System (FITS) format. Each FITS file has a corresponding detached PDS label file, named according to a common convention. The FITS files may have image and/or table extensions. See the PDS label plus the document collection for a description of these extensions and their contents.

This Data section comprises the following sub-topics:

- Filename/Product IDs
- Instrument description
- Other sources of information useful in interpreting these Data
- Visit Description, Visit Number, and Target in the Data Labels

#### Filename/Product IDs

The filenames and Local product Identifiers (LID) of observations adhere to a common convention, e.g.:



ApIDs	Data product description/Prefix(es)
0x691	PEPSSI High Priority Science (long integration)
0x692	PEPSSI Medium Priority Science (short integration)
0x693	PEPSSI Low Priority Science (Up to 500 PHA events)
0x694	PEPSSI Low Priority Science (Up to 500 PHA events)
0x695	PEPSSI High Priority Science Diagnostic Mode data
0x696	PEPSSI Medium Priority Science Diagnostic Mode data
0x697	PEPSSI Diagnostic Mode Event data
0x698	PEPSSI Diagnostic Mode Event data

For historical reasons, PEPSSI products always use an ApID of '0x691' in the filename. Each product actually contains all the data types (ApIDs) available for that day.

ApIDs '0x693' and '0x694' are combined during ground processing. So are ApIDs '0x697' and '0x698'.

There may be other ApIDs that contain housekeeping values and other values. See SOC Instrument ICD for more details: [urn:nasa:pds:nh\\_documents:mission:soc\\_inst\\_icd](urn:nasa:pds:nh_documents:mission:soc_inst_icd)

Please note that not all ApIDs may be found in this data set.

### Instrument description

Refer to the following files for a description of this instrument:

- New Horizon PEPSSI instrument overview:  
[urn:nasa:pds:nh\\_documents:pepssi:pepssi\\_inst\\_overview](urn:nasa:pds:nh_documents:pepssi:pepssi_inst_overview)
- PEPSSI Space Science Review (SSR) paper:  
[urn:nasa:pds:nh\\_documents:pepssi:pepssi\\_ssr](urn:nasa:pds:nh_documents:pepssi:pepssi_ssr)
- SOC Instrument ICD: [urn:nasa:pds:nh\\_documents:mission:soc\\_inst\\_icd](urn:nasa:pds:nh_documents:mission:soc_inst_icd)
- PEPSSI SPICE Instrument Kernel:  
[urn:nasa:pds:nh\\_documents:pepssi:nh\\_pepssi\\_ti](urn:nasa:pds:nh_documents:pepssi:nh_pepssi_ti)

### Other sources of information useful in interpreting these Data

Refer to the following files for more information about these data:

- NH Mission Trajectory Table:  
[urn:nasa:pds:nh\\_documents:mission:nh\\_mission\\_trajectory](urn:nasa:pds:nh_documents:mission:nh_mission_trajectory)
- Field of View Illustration: [urn:nasa:pds:nh\\_documents:mission:nh\\_fov](urn:nasa:pds:nh_documents:mission:nh_fov)
- PEPSSI SPICE Instrument Kernel:  
[urn:nasa:pds:nh\\_documents:pepssi:nh\\_pepssi\\_ti](urn:nasa:pds:nh_documents:pepssi:nh_pepssi_ti)

### Visit Description, Visit Number, and Target in the Data Labels

The observation sequences were defined in Science Activity Planning (SAP) documents and grouped by Visit Description and Visit Number. The SAPs are spreadsheets with one Visit Description & Number per row. A nominal target is also included on each row and included in the data labels but does not always match with the target name field's value in the data labels. In some cases, the target was designated as right\_ascension\_angle, declination\_angle pointing values in the form "right\_ascension\_angle, declination\_angle =123.45,-12.34" indicating Right Ascension and Declination, in degrees, of the target from the spacecraft in the Earth Equatorial

J2000 inertial reference frame. This indicates that either the target was a star, or the target's ephemeris was not loaded into the spacecraft's attitude and control system which in turn meant the spacecraft could not be pointed at the target by a body identifier and an inertial pointing value had to be specified as Right Ascension and Declination values. PDS-SBN practices do not allow putting a value like `right_ascension_angle`, `declination_angle =...` in the PDS target name keyword's value. In those cases, the PDS target purpose value is set calibration. Target name may be None for a few observations in this data set; typically, that means the observation is a functional test so None is an appropriate entry for those targets, but the PDS user should also check the `nh:observation_description` and `nh:sequence_id` keywords in the PDS label, plus the provided sequence list (`urn:nasa:pds:nh_documents:pepssi:seq_pepssi_kem1`) to assess the possibility that there was an intended target. These two keywords are especially useful for star targets as often stars are used as part of instrument calibrations and are included as part of the sequencing description which is captured in these keywords.

## Ancillary Data

The geometry items included in the data labels were computed using the SPICE kernels archived in the New Horizons SPICE data set, NH-J/P/SS-SPICE-6-V1.0, <https://doi.org/10.17189/1520109>.

Every observation provided in this data set was taken as a part of a particular sequence. A list of these sequences has been provided within the NH PEPSSI document collection (PDS4 LID `urn:nasa:pds:nh_documents:pepssi`) within the PDS, one file for each mission phase. The sequence identifier and description are included in the PDS label for every observation.

N.B. While every observation has an associated sequence, every sequence may not have associated observations. Some sequences may have failed to execute due to spacecraft events (e.g., safing). No attempt has been made during the preparation of this data set to identify such empty sequences.

## Time

There are several time systems, or units, in use in this dataset: New Horizons spacecraft MET (Mission Event Time or Mission Elapsed Time), UTC (Coordinated Universal Time), and TDB (Barycentric Dynamical Time).

This section will give a summary description of the relationship between these time systems. For a complete explanation of these time systems the reader is referred to the documentation distributed with the Navigation and Ancillary Information Facility (NAIF) SPICE toolkit from the PDS NAIF node, (see <http://naif.jpl.nasa.gov/>).

The most common time unit associated with the data is the spacecraft MET. MET is a 32-bit counter on the New Horizons spacecraft that runs at a rate of about one increment per second starting from a value of zero at "19.January, 2006 18:08:02 UTC" or "JD2453755.256337 TDB."

The leapsecond adjustment ( $\Delta ET = ET - UTC$ ) was 65.184s at NH launch, and the first four additional leapseconds occurred at the ends of 12/2009, 06/2012, 06/2015, and 12/2016.



Refer to the NH SPICE data set, NH-J/P/SS-SPICE-6-V1.0, <https://doi.org/10.17189/1520109>, and the SPICE toolkit documentation, for more details about leapseconds.

The data labels for any given product in this dataset usually contain at least one pair of common UTC and MET representations of the time at the middle of the observation. Other portions of the products, for example tables of data taken over periods of up to a day or more, will only have the MET time associated with a given row of the table.

For the data user's use in interpreting these times, a reasonable approximation (+/- 1s) of the conversion between Julian Day (TDB) and MET is as follows:

$$JD_{TDB} = 2453755.256337 + (MET / 86399.9998693)$$

For more accurate calculations the reader is referred to the NAIF/SPICE documentation as mentioned above.

## Reference Frame

### Geometric Parameter Reference Frame

Earth Mean Equator and Vernal Equinox of J2000 (EMEJ2000) is the inertial reference frame used to specify observational geometry items provided in the data labels. Geometric parameters are based on best available SPICE data at time of data creation.

### Epoch of Geometric Parameters

All geometric parameters provided in the data labels were computed at the epoch midway between the start\_date\_time and stop\_date\_time label fields.

## Software

The observations in this data set are in standard FITS format with PDS labels and can be viewed by a number of PDS-provided and commercial programs. For this reason, no special software is provided with this data set.

## Confidence Level Overview

During the processing of the data in preparation for delivery with this volume, the packet data associated with each observation were used only if they passed a rigorous verification process including standard checksums.

In addition, raw (CODMAC Level 2) observation data for which adequate contemporary housekeeping and other ancillary data are not available may not be reduced to calibrated (CODMAC Level 3) data. This issue is raised here to explain why some data products in the raw data set may not have corresponding data products in the calibrated data set.

## Data coverage and quality

Every observation provided in this data set was taken as a part of a particular sequence. For this data set, these KEM1 sequences can be found in the PEPSSI document collection under

PDS4 LID [urn:nasa:pds:nh\\_documents:pepssi:seq\\_pepssi\\_kem1](#). Please note that some sequences provided may have zero corresponding observations.

Refer to the Confidence Level Overview section above for a summary of steps taken to assure data quality.

For PEPSSI, electron detector channels are dominated by cosmic rays in post-Jupiter mission phases.

The PEPSSI data are considered suspect for the first forty minutes after an instrument power-on event, called a Bad Time Interval (BTI); this file lists those time windows. The entire Post-launch commissioning mission phase is also considered a BTI.

Within the PDS, see the SOC Instrument ICD (PDS4 LID [urn:nasa:pds:nh\\_documents:mission:soc\\_inst\\_icd](#)) and the BTI TABLE file (PDS4 LID [urn:nasa:pds:nh\\_documents:pepssi:pep\\_bti](#)) for more detail.

The PEPSSI Time Of Flight only (TOF-only) Pulse Height Analysis (PHA) event data may show differences in the 'N2 data' and 'N3 data' taken simultaneously but using different collection algorithms. Refer to the instrument description in the PEPSSI instrument overview document (PDS4 LID [urn:nasa:pds:nh\\_documents:pepssi:pepssi\\_inst\\_overview](#)) under 'Data sampling and priority for TOF-only data' in the 'Operational modes' section.

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 in the PEPSSI instrument overview document (PDS4 LID [urn:nasa:pds:nh\\_documents:pepssi:pepssi\\_inst\\_overview](#))) should be ignored, or, at the very least, used with extreme caution.

It should be noted that the Primary HDU and the first 5 extension HDUs (the Image HDUs containing spectrograms) of the level 3 data are 'quick-look' or 'browse' products only. They are constructed with one minute averages for the whole mission, so that, if the data collection period (the DT in the table in the FLUX extension) is not an even multiple or factor of 1 minute, the spectrogram image will exhibit aliasing artifacts. Further, the second extension, the Helium spectrogram includes the Alpha source channels (see above). In short, the Image HDUs in the level 3 data are not for scientific use but for browsing or quick-look purposes and for researchers to determine if they are able to correctly read the data in the table extensions.

Low energy channels (aka 'doubles' or 'L' rates) are presented in multiple calibrations. Since we do not know the ion species of 'double' events, we present the calibrated fluxes as if the events were known to be protons, oxygen ions, etc. A non-species calibrated flux channel will also duplicate the calibration for what the instrument team believes to be the 'most likely' species for that channel. See the SOC Instrument ICD (PDS4 LID [urn:nasa:pds:nh\\_documents:mission:soc\\_inst\\_icd](#)) for details.

Please see the 'Data Validity' section of PEPSSI instrument overview document (PDS4 LID `urn:nasa:pds:nh_documents:pepssi:pepssi_inst_overview`) for details regarding information on channels which should be excluded from analysis.

## Caveat about target name in PDS labels and observational

The downlink team on New Horizons has created an automated system to take various uplink products, decode things like Chebyshev polynomials in command sequences representing celestial body ephemerides for use on the spacecraft to control pointing, and infer from those data what the most likely intended target was at any time during the mission. This works well during flyby encounters and less so during cruise phases and hibernation.

The user of these PDS data needs to be cautious when using the target name and other target-related parameters stored in this data set. This is less an issue for the plasma and particle instruments, more so for pointed instruments. To this end, the heliocentric ephemeris of the spacecraft, the spacecraft-relative ephemeris of the inferred target, and the inertial attitude of the instrument reference frame are provided with all data, in the J2000 inertial reference frame, so the user can check where that target is in the Field Of View (FOV) of the instrument.

Finally, note that, within the FITS headers of the data products, the sequence tables, and other NH Project-internal documents used in this data set, informal names are often used for targets instead of the canonical names used within the PDS labels. For example, during the Pluto mission phase, instead of the target name '15810 ARAWN (1994 JR1)' there might be found any of the following: 1994JR1; 1994 JR1; JR1. However, within the context of this data set, these project abbreviations are not ambiguous (e.g. there is only one NH target with 'JR1' in its name), so there has been, and will be, no attempt to expand such abbreviations where they occur outside formal PDS keyword values.

## Contact Information

For any questions regarding the data format of the archive, contact the New Horizons PEPSSI Principal Investigator:

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## Further Reading

Steffl, A.J., J. Peterson, B. Carcich, L. Nguyen, and S.A. Stern, NEW HORIZONS SPICE KERNELS, V1.0, NH-J/P/SS-SPICE-6-V1.0, NASA Planetary Data System, 2007.

<https://doi.org/10.17189/1520109>