# New Horizons SDC Post-Launch Checkout Raw 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, including updates found in the KEM1 Encounter phase version, providing light edits to the text, format, flow, and to make the description to better conform to this PDS4 data collection.


## Abstract

This data set contains Raw data taken by the New Horizons Student Dust Counter (SDC) instrument during the post-LAUNCH checkout mission phase.

The SDC instrument was commissioned on March 2, 2006 and stepped through a checkout of all instrument functionality successfully. Following these activities, SDC collected science data intermittently throughout the first year of the mission.

Changes since the prior versions include re-running of the ancillary data, updated geometry from newer SPICE kernels, minor editing of documentation, and resolution of liens from December 2014 and May 2016 SDC data reviews.

There were no new observations added with this version.

These data were migrated from the previously released PDS3 data set NH-X-SDC-2-LAUNCH-V4.0.


## Data Set Overview

This data set contains Raw data taken by the New Horizons Student Dust Counter (SDC) instrument during the post-LAUNCH checkout mission phase.

The mission of the SDC is to analyze the size and distribution of Interplanetary Dust Particles (IDPs) along the New Horizons trajectory to the Kuiper Belt. SDC comprises twelve thin, permanently polarized polyvinylidene fluoride (PVDF) plastic film sensors, with a combined area of about 0.1 $m^2$, mounted on the top surface of a support panel and normal to the spacecraft ram direction (flight velocity). In addition, there are two reference sensors, identical to the top surface sensors, mounted on the back side of the detector support panel and protected from any dust impacts, used to monitor background noise levels.

An impacting IDP causes a depolarization charge when it penetrates the PVDF film on one of the sensors. That charge is then measured by that sensor's electronics (channel); if the measurement is above a preset level, the instrument records and stores the event for later downlink. The level preset is adjusted based on in-flight Noise Floor Calibrations, and there are extensive autonomy rules adjusting SDC behavior, even turning channels off for up to thirty days at a time, to avoid overloading the storage system with noise.

SDC was designed to detect events for particles down to about one picogram at Pluto (see Bagenal et al. (2016)); that detection limit is lower than earlier in the mission where the spacecraft velocity was higher. The SDC instrument has a temperature- and velocity-dependent calibration, first converting the raw measurement to charge, then converting charge to particle mass.

The common data product is a binary table of downlinked event data: time; sensor channel; magnitude; threshold magnitude. Associated data products are housekeeping data such as instrument temperatures for calibration and near-in-time spacecraft thruster events, which may induce false positives i.e. SDC events not caused by IDPs. The channels in the binary table for raw data are numbered from 0 to 13; the channel in the binary table for calibrated data are numbered from 1 to 14.

Some time between instrument delivery to the spacecraft and launch, the detector on one channel began exhibiting symptoms of degraded electrical contacts to the PVDF; data from that channel (channel number 10 in raw data; channel number 11 in calibrated data) are still processed but should be ignored.

Note that some SDC data files have the same stop and start time and a zero exposure time. The reason for this is that the start and stop time for SDC data files are the event times for the first and last events in the files, so for files that contain a single event, these two values are the same.

The SDC instrument was commissioned on March 2, 2006 and stepped through a checkout of all instrument functionality successfully. Following these activities, SDC collected science data intermittently throughout the first year of the mission.

Every observation provided in this data set was taken as a part of a particular sequence. For this data set, these sequences can be found in the SDC document collection under PDS4 LID `urn:nasa:pds:nh_documents:sdc:seq_sdc_launch`. Please note that some sequences provided may have zero corresponding observations.

As a result of thruster-induced events, many SDC detector channels are switched off during some spacecraft maneuvers by autonomy processing, for prolonged periods. Autonomy rules can also affect SDC threshold settings; threshold settings are designed to keep the SDC detection limit above a noise floor. Refer to Horanyi et al. (2008) for descriptions of the SDC autonomy rules, threshold parameters, and how they affect instrument behavior and recorded data.

During spacecraft checkout activities in the first six months of the Post-LAUNCH Checkout mission phase, spacecraft activity was high and these autonomous off/on transitions occurred quite frequently. There were several periods, some weeks or months long, where SDC was either completely off (or on) for only hours or minutes at a time. Later during the Post-LAUNCH Checkout phase, and much later during the PLUTO CRUISE phase, the autonomy levels for turning off channels were relaxed, and the transition to more frequent hibernation operations meant that autonomous off/on transitions occurred less frequently.

All per-channel off and on transitions, whether initiated by autonomy or by spacecraft on/off commands to the entire instrument, are recorded for the entire mission in a table that can be found in the SDC document collection under PDS4 LID `urn:nasa:pds:nh_documents:sdc:sdc_on_off_times_alt`. The high frequency of off/on transitions, as described in the previous paragraph, is apparent in this table.

N.B. The duration of the off, as well as the on, periods must be considered in making any calculation of average dust detection event rates.

## 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 v1.0 (migration from PDS3 V4.0)

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 V4.0 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.
- The purpose for some data in this phase was changed.
- The PDS4 data labels were produced using the PDS3 data labels and/or FITS headers, and so any fixes and/or updates to the PDS3 label pipeline as found in future mission phases may not have been implemented here.

### PDS3 V4.0 (NH-X-SDC-2-LAUNCH-V4.0)

This is VERSION 4.0 of this data set. The pipeline (see Processing below) was re-run on these data and for each version since the first (PDS3 V1.0).

The previous delivery (V3.0) went through peer review with many Pluto Cruise data sets in December, 2014. When subsequent versions of the latter were being delivered with additional data (from August, 2014 through January, 2015) before all of those liens were resolved, those data sets were left as is, with those liens folded into the newer data sets. The same path was chosen for this data set. V4.0 is ultimately lien resolved.

The pipeline re-run may have changed ancillary data in the data product and updated geometry from newer SPICE kernels. This version includes minor editing of the documentation, catalogs, etc., and resolution of liens from the December, 2014 review, plus those from the May, 2016 review of the Pluto Encounter data sets. This may affect, for example, the calibration of the data if parameters such as the velocity or orientation of the target relative to the instrument, or the recorded target itself, have changed. No new observations were added with Version 4.0.

PDS Citation Information: Horányi M., NEW HORIZONS Raw SDC POST-LAUNCH CHECKOUT V4.0, NH-X-SDC-2-LAUNCH-V4.0, NASA Planetary Data System, 2017.

### PDS3 V3.0 (NH-X-SDC-2-LAUNCH-V3.0)

This is VERSION 3.0 of this data set. Updates were made to the electronics box temperature calibration and the full calibration, including all model parameters and coefficients, is described in James et al. (2010).

Additionally, the dust impact velocity calculation was updated to use the Ecliptic J2000 reference frame, instead of the Earth Mean frame, to estimate Keplerian orbits; this was a small correction as the spacecraft trajectory is generally near the line to the first point of Aries.

The stimulus calibration table was added and can be found in the SDC document collection under PDS4 LID `urn:nasa:pds:nh_documents:sdc:sdc_stim`, so the user can assess when these operations may have generated false positive events.

PDS Citation Information: Horányi M., NEW HORIZONS Raw SDC POST-LAUNCH CHECKOUT V3.0, NH-X-SDC-2-LAUNCH-V3.0, NASA Planetary Data System, 2014.

### PDS3 V2.0 (NH-X-SDC-2-LAUNCH-V2.0)

This is VERSION 2.0 of this data set. The data files look the same, including the data formats. The changes were improvements to the processing code. There were 3 changes made to the code:

Change to dust impact velocity assumption

An assumption is needed for the dust impact velocity to calculate its mass. Before this update the pipeline used only the normal component of the total velocity between the dust and instrument (assuming the particle is in Keplerian orbit). Now this has been changed to the total relative velocity of the particle (still assumed to be in Keplerian orbit) and the instrument.

Using multiple thermistors for per-channel temperature correction

There are two thermistors on the analog board; those analog board temperatures are used for calibrating all channels on the board. Before this update, for a given channel the temperature of the closest thermistor to that channel (nearest neighbor interpolation). For this update and later, a linear fit to the temperatures is used, based on the relative positions of the thermistors and channels (linear interpolation).

New charge-velocity-mass calibration curve

The calibrated data contains the mass of the particle. The charge to mass curve used to be:

Q=3.18E17*m^1.3*v^3.0

where m is the mass, Q is the charge and v is the relative speed. This was the Simpson-Tuzzolino curve. The new curve is a function of detector temperature as well:

Q=(1.15E15+6.75E12*T)*m^1.052*v^2.883

where T is the temperature. A paper with this new calibration curve was published in James et al. (2010).

<u>PDS Citation Information</u>: Horányi M., NEW HORIZONS Raw SDC POST-LAUNCH CHEKCOUT V2.0, NH-X-SDC-2-LAUNCH-V2.0, NASA Planetary Data System, 2007.

### PDS3 V1.0 (NH-X-SDC-2-LAUNCH-V1.0)

This is VERSION 1.0 of this data set. This is the first SDC delivery for the post-LAUNCH checkout mission phase.

<u>PDS Citation Information</u>: Horányi M., NEW HORIZONS Raw SDC POST-LAUNCH CHECKOUT V1.0, NH-X-SDC-2-LAUNCH-V1.0, NASA Planetary Data System, 2007.

### 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.

SDC data calibration is a two-step process: raw data numbers from a particle impact are converted to a charge, and the charge is converted to a particle mass via the ground calibrations obtained at a dust acceleration facility. Refer to the provided documentation for more information. The latest calibration procedure is described in James et al. (2010).

# 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.:

```
sdc_0123456789_0x700_eng.fit
^^^ ^^^^^^^^^^ ^^^^^ ^^^\__/
|         |       |     |   ^^
|         |       |     |    |
|         |       |     |   +--File type (includes dot)
|         |       |     |      - .FIT for FITS file
|         |       |     |      - .LBLX for PDS label
|         |       |     |      - not part of LID
|         |       |     |
|         |       |    +--ENG for CODMAC Level 2 data
|         |       |       SCI for CODMAC Level 3 data
|         |       |
|         |      +--Application ID (ApID) of the telemetry data
|         |         packet from which the data come
|         |         N.B. ApIDs are case-insensitive
|         |
|        +--MET (Mission Event Time) i.e. Spacecraft Clock
|
+--Instrument designator
```

### Instrument Designator(s):

| **Instrument Designator** | **Description** |
| --- | --- |
| SDC | SDC |

See SOC Instrument Interface Control Document (ICD) within the PDS for more details (PDS4 LID `urn:nasa:pds:nh_documents:mission:soc_inst_icd`).

### Mission Event Time (MET)

Note that, depending on the observation, the Mission Event Time (MET) in the data filename and in the LID may be similar to the MET of the actual observation acquisition, but should not be used as an analog for the acquisition time. The MET is the time that the data are transferred from the instrument to spacecraft memory and is therefore not a reliable indicator of the actual observation time. The PDS labels are better sources to use for the actual timing of any observation. The specific keywords for which to look are:

- start_date_time
- stop_date_time
- start_clock_count
- stop_clock_count

Also note that a dust hit may be recorded in more than one data product. The product name reflects the MET when data was transferred from instrument memory. More than one transfer may have been requested for any given interval from start_date_time to stop_date_time. When processing the data, check these intervals carefully. Obvious cases of duplicate dust hit data spanning long time intervals have already been removed from this dataset.

## Application ID (ApID)

Here is a summary of the types of files generated by each ApID (N.B. ApIDs are case-insensitive) along with the instrument designator that go with each ApID:

| **ApIDs** | **Data product description/Prefix(es)** |
|---|---|
| 0x700 | SDC Science Data/SDC |

There are other ApIDs that contain housekeeping values and other values. See the SOC Instrument ICD for more details: `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 SDC instrument overview: `urn:nasa:pds:nh_documents:sdc:sdc_inst_overview`
- SDC Space Science Review (SSR) paper: `urn:nasa:pds:nh_documents:sdc:sdc_ssr`
- SOC Instrument ICD: `urn:nasa:pds:nh_documents:mission:soc_inst_icd`
- SDC SPICE Instrument Kernel: `urn:nasa:pds:nh_documents:sdc:nh_sdc_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`
- Field of View Illustration: `urn:nasa:pds:nh_documents:mission:nh_fov`
- SDC SPICE Instrument Kernel: `urn:nasa:pds:nh_documents:sdc:nh_sdc_ti`
- SDC Summary Student Dust Counter (SDC) boresight direction: `urn:nasa:pds:nh_documents:sdc:sdcram`

### 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 to 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 (PDS4 LID `urn:nasa:pds:nh_documents:sdc:seq_sdc_launch`) 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.

For SDC the target name is always Dust.

## 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 SDC document collection (PDS4 LID `urn:nasa:pds:nh_documents:sdc`) 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 at 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 sequences can be found in the SDC document collection under PDS4 LID `urn:nasa:pds:nh_documents:sdc:seq_sdc_launch`. 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 SDC, the stimulus calibration activity is known to generate false positive events in the science data. This data set includes a table, found within the SDC document collection under PDS4 LID `urn:nasa:pds:nh_documents:sdc:sdc_stim`, that lists time periods when stimulus calibrations were active (several times during Launch and Jupiter mission phases, and about half an hour per year during Annual CheckOuts (ACO) in the Pluto Cruise mission phase). Eventually, the Science Operations Center (SOC) operational pipeline may be enhanced to filter individual events that occur near stimulus events.

## 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.

## Contact Information

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

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## Reference List

Bagenal, F., M. Horányi D.J. McComas, R.L. McNutt Jr, H.A. Elliott, M.E. Hill, L.E. Brown, P.A. Delamere, P. Kollmann, S.M. Krimigis, M. Kusterer, C.M. Lisse, D.G. Mitchell, M. Piquette, A.R. Poppe, D.F. Strobel, J.R. Szalay, P. Valek, J. Vandegriff, S. Weidner, E.J. Zirnstein, S.A. Stern, K. Ennico, C.B. Olkin, H.A. Weaver, L.A. Young, and New Horizons Science Team, Pluto's interaction with its space environment: Solar wind, energetic particles & dust, Science, Volume 351, Issue 6279, 18 Mar 2016. https://doi.org/10.1126/science.aad9045

## Further Reading

Horanyi, M., V. Hoxie, D. James, A. Poppe, C. Bryant, B. Grogan, B. Lamprecht, J. Mack, F. Bagenal, S. Batiste, N. Bunch, T. Chantanowich, F. Christensen, M. Colgan, T. Dunn, G. Drake, A. Fernandez, T. Finley, G. Holland, A. Jenkins, C. Krauss, E. Krauss, O. Krauss, M. Lankton, C. Mitchell, M. Neeland, T. Resse, K. Rash, G. Tate, C. Vaudrin, J. Westfall, The Student Dust Counter on the New Horizons Mission, Space Sci. Rev., Volume 140, Numbers 1-4, pp. 387-402, 2008. https://doi.org/10.1007/s11214-007-9250-y

James, D., V. Hoxie, and M. Horanyi, Polyvinylidene fluoride dust detector response to particle impacts, Review of Scientific Instruments, Volume 81, Issue 3, id. 034501-034501-8, 2010. https://doi.org/10.1063/1.3340880

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