New Horizons MVIC Pluto Encounter 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 Multispectral Visible Imaging Camera (MVIC) instrument during the PLUTO ENCOUNTER mission phase.

This data set contains MVIC observations taken during the Approach (Jan-Jul, 2015), Encounter, Departure, and Transition mission sub-phases, including flyby observations taken on 14 July, 2015, and departure and calibration data through late October, 2016. This data set completes the Pluto mission phase deliveries for MVIC.

Changes since prior versions include the addition of data downlinked between the end of January, 2016 and the end of October, 2016, completing the delivery of all data covering the Pluto Encounter and subsequent Calibration Campaign. This dataset includes multi-map observations from the Approach phase, observations of the moons, hi-res, full-frame observations from Pluto Encounter and Departure, and ring search observations. There may be some overlap between prior datasets and this dataset, due to only partial, windowed, or lossy data in prior datasets. For any data previously delivered as sub-frame windows, this delivery will fill in the image data outside those windows. This dataset also includes functional tests from the Calibration Campaign, including calibration observations of the M6 and M7 clusters, and HD205905.

These data were migrated from the previously released PDS3 data set NH-P-MVIC-2-PLUTO-V3.0.

Data Set Overview

This data set contains Raw data taken by the New Horizons Multispectral Visible Imaging Camera (MVIC) instrument during the PLUTO ENCOUNTER mission phase. The closest approach to Pluto occurred on July 14, 2015, at approximately 11:50 UTC.

MVIC is a visible and near-infrared imager. MVIC comprises seven separate Charge-Coupled Device detectors (CCD) two-dimensional arrays; all rows are 5024 pixels across with twelve pixels at either end of each row optically inactive. The single Pan Frame array is a panchromatic frame-transfer imager, 5024x128 pixels, that typically takes multiple frames in each observation. The common Pan Frame data product is an image cube in three dimensions: spatial; spatial; image frame, equivalent to time. Of the remaining six arrays, 5024x32 pixels each, two are panchromatic (unfiltered), and the remaining four are under filters and called the

color arrays: Near-InfraRed (NIR); methane (CH4); Red; Blue. All six are operated in Time-Delay Integration (TDI) mode; the TDI arrays are in some ways similar to line cameras. In TDI mode, the spacecraft and MVIC boresight scanned across the target at a rate that matches the charge transfer clock rate across the rows of the CCDs. Ideally the rates are matched, as the charges are read by the analog-to-digital converter off the last line of the array, each pixel reading is near-proportional to the brightness of the same piece of the target as its image moved across the array, accumulating charge on each row. In TDI mode it is the product of the per-row charge clock rate and the duration of the observation that determines the number of rows in each image, and the image can be arbitrarily long; the number of rows (32) in each array is not relevant in determining the size of the image. The common data product for each of the TDI arrays is a 2-D image, of arbitrary length as noted earlier.

During the Pluto Charon Encounter mission phase starting in January, 2015, there were several sub-phases: three Approach sub-phases, (AP1, AP2 and AP3); a CORE sequence for the Pluto flyby on 14.July, 2015 (Day Of Year 195), sometimes also referred to as NEP (Near-Encounter Phase); three Departure sub-phases (DP1, DP2, DP3); a Transition sub-phase ending in late October, 2016 and closing out the Pluto Encounter mission phase. For this final Ralph-MVIC delivery for the Pluto mission phase, this data set includes the Approach data plus plus all CORE and Departure sequences' data, including observations of a low-resolution Pluto ring search taken in November, 2015, and finally Transition sequence data covering functional tests and star calibrations performed in mid-2016.

On Approach during April, May and June of 2015, MVIC operations included the following: functional tests; full color observations of the Pluto, Charon and the other Plutonian satellites; Critical and Non-critical Optical Navigation (OpNav or NAV) observations. The color observations were grouped over several 6-day periods to obtain a full rotation of Pluto and Charon.

This dataset includes the first PC_VISUV_MAP for MVIC at about 19 days before encounter, a color TDI observation looking for changes in color and composition over multiple rotations, to meet the goal of understanding the time variability of Pluto's surface. These observations were repeated daily over that week leading up to encounter. From the day of encounter, this data set includes data from three CORE observations: (1) Pluto/Charon color map (PC_MULTI_MAP) about a day before the Time of Closest Approach (P-1d); (2) Pluto and Charon color scan at P-5h (PC_COLOR_1); (3) Nix color scan (N_COLOR_2).

The PC_MULTI_MAP observation, the last one of which is included in this dataset, met multiple goals including imaging for color and surface composition maps of the Pluto and Charon hemispheres, Pluto and Charon phase integrals with resolved whole-disk images near 15 degrees, and imaging Pluto hazes on approach. Secondary goals are Pluto and Charon color high and low phase imaging to enable integrating over wavelength to determine the bolometric Bond albedo, and also to investigate the surface microphysics of Pluto and Charon, studying compositional and textural stratification in the surface as a function of terrain type. The N_COLOR series provided Nix high-resolution resolved color images.

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 Ralph document collection under PDS4 LID `urn:nasa:pds:nh_documents:ralph:seq_mvic_pluto`. Please note that some sequences provided may have zero corresponding observations.

Version History

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

PDS4 v1.0 (migration from PDS3 V3.0)

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 labels. The products themselves have remained unchanged. The major changes from the PDS3 V3.0 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 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 V3.0 (NH-P-MVIC-2-PLUTO-V3.0)

This is VERSION 3.0 of this data set. This P3 Pluto Encounter dataset release includes all data from the previous two Pluto deliveries and adds data that was downlinked from 1/31/2016 through 10/31/2016. This dataset completes delivery of all data covering the Pluto Encounter and subsequent Calibration Campaign.

Also, updates were made to the calibration files, documentation, and catalog files.

For any data previously delivered as sub-frame windows, this delivery will fill in the image data outside those windows.

Changes to the calibration involved only changes to the spectrum-specific calibration constants provided in FITS headers and in PDS labels; the calibrated Data Number values in the calibrated data set, excluding image data outside the sub-frame windows mentioned above, will not be substantively changed.

As of V3.0, targets for some stars and radio sources have been updated so that the TARGET_NAME keyword in the label is accurate and more descriptive than only STAR or CALIBRATION. However the user should confirm that targets from the data FITS files, if applicable for a given instrument, match the label name, as there are a few instances where the FITS keywords for TARGET, SPCCBTNM, and PNTMTHD are not accurate. The simplest way to

check is to instead look at the RA and Dec in the keywords SPCBRRA and SPCBRDEC in the FITS file. This issue mostly only occurs with star targets.

Citation Information: Stern, A., NEW HORIZONS RAW MVIC PLUTO ENCOUNTER V3.0, NH-P-MVIC-2-PLUTO-V3.0, NASA Planetary Data System, 2018.

PDS3 V2.0 (NH-P-MVIC-2-PLUTO-V2.0)

This is VERSION 2.0 of this data set. This P2 Pluto Encounter dataset release provides updates to the Pluto dataset between P1 (data on the ground by 7/31/2015) and P2 (data on the ground by 1/31/2016). Some data that had been downlinked as a subframe in the last delivery now has been re-downlinked for the full frame image. All liens from the initial Pluto delivery have also now been resolved.

Citation Information: Stern, A., NEW HORIZONS RAW MVIC PLUTO ENCOUNTER V2.0, NH-P-MVIC-2-PLUTO-V2.0, NASA Planetary Data System, 2016.

PDS3 V1.0 (NH-P-MVIC-2-PLUTO-V1.0)

This is VERSION 1.0 of this data set. For this first Ralph-MVIC delivery for the Pluto mission phase, this data set includes only the Approach data plus the subset of the CORE sequence data that was downlinked through the end of July, 2015. Liens were never resolved for this data set version but will be in the next version.

Citation Information: Stern, A., NEW HORIZONS RAW MVIC PLUTO ENCOUNTER V1.0, NH-P-MVIC-2-PLUTO-V1.0, NASA Planetary Data System, 2016.

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, partially processed 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.

An all-instrument Calibration Campaign occurred in July 2016. For most instruments, calibrations were updated as of April 2017 which changed the data in the calibrated data sets. Calibration changes are described in the data set version-specific sections.

Note that even if this is not a partially processed 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.

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.:

```
mc0_0123456789_0x530_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:

Instrument Design	Description
MC0	MVIC, Color TDI, Red filter
MC1	MVIC, Color TDI, Blue filter
MC2	MVIC, Color TDI, Near-InfraRed (NIR) filter
MC3	MVIC, Color TDI, Methane (CH4) filter
MP1	MVIC, Panchromatic TDI CCD 1
MP2	MVIC, Panchromatic TDI CCD 2
MPF	MVIC, Panchromatic frame (5024 pixels)

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

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)
0x530	MVIC Panchromatic TDI Lossless (CDH 1)/MP1,MP2
0x53f	MVIC Panchromatic TDI Lossless (CDH 2)/MP1,MP2
0x531	MVIC Panchromatic TDI Packetized (CDH 1)/MP1,MP2
0x540	MVIC Panchromatic TDI Packetized (CDH 2)/MP1,MP2
0x532	MVIC Panchromatic TDI Lossy (CDH 1)/MP1,MP2
0x541	MVIC Panchromatic TDI Lossy (CDH 2)/MP1,MP2
0x533	MVIC Panchromatic TDI 3x3 Binned Lossless (CDH 1)/MP1,MP2 *
0x542	MVIC Panchromatic TDI 3x3 Binned Lossless (CDH 2)/MP1,MP2 *
0x534	MVIC Panchromatic TDI 3x3 Binned Packetized (CDH 1)/MP1,MP2 *
0x543	MVIC Panchromatic TDI 3x3 Binned Packetized (CDH 2)/MP1,MP2 *
0x535	MVIC Panchromatic TDI 3x3 Binned Lossy (CDH 1)/MP1,MP2 *
0x544	MVIC Panchromatic TDI 3x3 Binned Lossy (CDH 2)/MP1,MP2 *
0x536	MVIC Color TDI Lossless (CDH 1)/MC0,MC1,MC2,MC3
0x545	MVIC Color TDI Lossless (CDH 2)/MC0,MC1,MC2,MC3
0x537	MVIC Color TDI Packetized (CDH 1)/MC0,MC1,MC2,MC3
0x546	MVIC Color TDI Packetized (CDH 2)/MC0,MC1,MC2,MC3

0x538	MVIC Color TDI Lossy (CDH 1)/MC0,MC1,MC2,MC3
0x547	MVIC Color TDI Lossy (CDH 2)/MC0,MC1,MC2,MC3
0x539	MVIC Panchromatic Frame Transfer Lossless (CDH 1)/MPF
0x548	MVIC Panchromatic Frame Transfer Lossless (CDH 2)/MPF
0x53a	MVIC Panchromatic Frame Transfer Packetized (CDH 1)/MPF
0x549	MVIC Panchromatic Frame Transfer Packetized (CDH 2)/MPF
0x53b	MVIC Panchromatic Frame Transfer Lossy (CDH 1)/MPF
0x54a	MVIC Panchromatic Frame Transfer Lossy (CDH 2)/MPF
0x54e	MVIC Co-added Panchromatic Frame Transfer Lossless (CDH 1)
0x54f	MVIC Co-added Panchromatic Frame Transfer Lossless (CDH 2)

* as of October, 2014, 3x3 modes have not been used

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 MVIC instrument overview: urn:nasa:pds:nh_documents:ralph:mvic_inst_overview
- Ralph Space Science Review (SSR) paper: urn:nasa:pds:nh_documents:ralph:ralph_ssr
- SOC Instrument ICD: urn:nasa:pds:nh_documents:mission:soc_inst_icd
- Ralph SPICE Instrument Kernel: urn:nasa:pds:nh_documents:ralph:nh_ralph_v100_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
- Ralph SPICE Instrument Kernel: urn:nasa:pds:nh_documents:ralph:nh_ralph_v100_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:ralph:seq_mvic_pluto`) 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 Ralph document collection (see PDS4 LID `urn:nasa:pds:nh_documents:ralph`) 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 partially processed (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 partially processed data set.

Data coverage and quality

Every observation provided in this data set was taken as a part of a particular sequence. A list of these sequences has been provided in the Ralph document collection:

- seq_mvic_kem1.tab: `urn:nasa:pds:nh_documents:ralph:seq_mvic_kem1`

- seq_mvic_kemcruise1.tab: `urn:nasa:pds:nh_documents:ralph:seq_mvic_kemcruise1`
- seq_mvic_pluto.tab: `urn:nasa:pds:nh_documents:ralph:seq_mvic_pluto`
- seq_mvic_plutocruise.tab: `urn:nasa:pds:nh_documents:ralph:seq_mvic_plutocruise`

N.B. 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.

During functional tests, some TDI images with prefixes like mc0, mc1, mc2, mc3, mp1, and mp2 will have a height (PDS keyword elements) of less than 100 lines (values of 32, 33, 52, and 96 are common) and a width (elements) of 5024, giving the impression of a noodle-like image. These images were only generated to confirm proper operation of MVIC and are unlikely to have any scientific value. Functional test images can usually be identified by the case-insensitive string 'func' in the value of the nh:sequence_id keyword in the PDS label.

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 RALPH Principal Investigator: Alan Stern, Southwest Research Institute

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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