

New Horizons MVIC KEM2 Cruise Partially Processed Data Overview

Abstract

This data set contains calibrated data taken by the New Horizons Ralph/MVIC instrument during the KEM2 CRUISE mission phase. It contains stellar flux calibrations and high phase angle imaging of Saturn, Uranus, and Neptune.

Data Set Overview

This data set contains partially processed data taken by the New Horizons Multispectral Visible Imaging Camera instrument during the KEM2 CRUISE mission phase.

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.

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 v2.0

This version includes data acquired by the spacecraft between 10/01/2022 and 01/01/2026. It only includes data downlinked before 01/01/2026. Future datasets may include more data acquired by the spacecraft after 10/01/2022 but downlinked after 01/01/2026.

This version provides the results of new functional tests for MVIC.

This dataset corresponds to New Horizons NAIF SPICE distribution v0010.

PDS4 v1.0

This version includes data acquired by the spacecraft between 10/01/2022 and 04/30/2024. It only includes data downlinked before 05/01/2024. Future datasets may include more data acquired by the spacecraft after 10/01/2022 but downlinked after 04/30/2024.

This version adds stellar flux calibrations and high phase angle imaging of Saturn, Uranus, and Neptune.

This dataset corresponds to New Horizons NAIF SPICE distribution v0008.

General statement about data set versions

Data files in versions after PDS4 v1.0 will not be reprocessed if the only updates are normal SPICE improvements.

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.

Calibration

Detailed information about calibration of MVIC data is available in the SOC Instrument Interface Control Document (ICD): `urn:nasa:pds:nh_documents:mission:soc_inst_icd`.

The MVIC calibration will only be briefly summarized here; refer to the ICD for details about what is summarized here.

The calibration of MVIC images comprises the following steps:

- 1) Remove bias and flat-field pattern.
 - a. The result is an absolute calibration in raw Data Number (DN), with pixel values proportional to the incoming signal.
- 2) Supply target source spectrum-dependent factors to scale from absolute DN to scientific (flux and radiance) units; refer to the ICD for more detail.

In addition, the calibration procedure calculates the error and a data quality flag for each pixel and includes those results in the partially processed data product as additional FITS extensions. The quality flag is an image of values of the same size as the main image product, with each quality flag pixel mapped to the corresponding pixel in the main product. A quality flag value of zero indicates a valid pixel; a non-zero value indicates an invalid pixel (e.g., missing data outside the window(s) of data intended to be downlinked).

Note that for windowed products, all pixels in an image are not returned in the downlink telemetry. In the raw data, the pipeline sets such pixels to zero DN (Data Number); the calibration processes those zero-DN pixels as if they were real raw values, but also flags them as missing data in the quality flag FITS extension. Displaying such images using an automatic stretch (contrast enhancement) may result in a confusing result with the majority of the displayed image appearing as an inverse of the calibration (calibration of zero values); therefore the quality flag should always be checked when looking at these data.

Note also that, at the time these data were created (late 2014), the Science Operations Center (SOC) data processing pipeline did not have the capability to merge multiple windows from a single observation. As a result, in some cases one observation's products in raw and partially processed data sets may come from different windows. This is normal, but it can have some noticeable side-effects:

- i. Mismatches in windowing parameters between raw and products for the same observation. Either the windowing differ, or one may be windowed and the other a non-windowed, full image.
- ii. `start_date_time` and `stop_date_time` mismatches between versions of the same TDI observations with different windows. The start and stop times of TDI MVIC products are dependent on the start and stop lines of the window: if the first line of the window is not the first line of the observation, the `start_date_time` of the product will be delayed from the start time of the observation; similarly the last line of a window that is not the last line of the observation results in a `stop_date_time` that is earlier than the stop time of the observation. Since there is only one version of each observation in any single MVIC data set, this will not be noticeable within any single data set. However, when comparing versions of the same observation from raw and partially processed data sets, it is possible that the `start_date_time` and `stop_date_time` values for that observation will differ between the data sets.
- iii. The shift in start and stop times will also affect the calculation of mid-observation times.
- iv. The mid-observation time is used as the lookup in SPICE calls, so the shift in time will affect calculated geometry values.

As part of the preparation for the Pluto flyby in Spring, 2015, the SOC pipeline was updated to allow it to merge multiple windows and/or full images of the same observation into a single product. So it is expected that future MVIC data sets will have raw and partially processed products with consistent windowing parameters, times and geometries.

A PDS FITS extension with a correction for geometric distortion, present in previous versions of MVIC data sets, has been removed from these and future PDS partially processed data sets. Geometric distortion will be addressed in higher-level products, as it involves resampling 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 (CH ₄) 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_kem2`) 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.

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 (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 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, 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:

$$\text{JD TDB} = 2453755.256337 + (\text{MET} / 86399.9998693)$$

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.

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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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 file that can be found within the PDS (with PDS4 LID `urn:nasa:pds:nh_documents:ralph:seq_lorri_kem2`). 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.

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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>