

# New Horizons LORRI KEM2 Cruise Partially Processed Data Overview

## Abstract

This data set contains partially processed data taken by the New Horizons Long Range Reconnaissance Imager instrument during the KEM2 CRUISE mission phase. It contains stellar flux calibrations, high phase angle imaging of Saturn, cosmic background and dust observations, and distant imaging of the KBO 2020 KS11.

## Data Set Overview

This data set contains Partially Processed data taken by the New Horizons Long Range Reconnaissance Imager (LORRI) instrument during the KEM2 CRUISE mission phase.

LORRI is a narrow angle (Field Of View, FOV = 0.29 degree square), high resolution (5 microradian/pixel), telescope. A two-dimensional (2-D) CCD (Charged Coupled Device) detector, with 1024x1024 pixels (optically active region) operates in standard frame-transfer mode. LORRI can also perform on-chip 4x4 binning to produce images of 256x256 pixels. LORRI has no color filters and so provides panchromatic imaging over a wide bandpass extending approximately from 350 nm to 850 nm. The common data product is a 2-D image of brightnesses that can be calibrated to physical units once color spectrum information is known. Refer to the Science Operations Center (SOC) Instrument Interface Control Document (ICD) within the PDS for more details (PDS4 LID

`urn:nasa:pds:nh_documents:mission:soc_inst_icd`).

This version includes stellar flux calibrations, high phase angle imaging of Saturn, and cosmic background and dust observations. It also includes distant imaging of the KBO 2020 KS11.

## 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

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 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, high phase angle imaging of Saturn, and cosmic background and dust observations. It also adds distant imaging of the KBO 2020 KS11.

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 LORRI data is available in the SOC Instrument Interface Control Document (ICD) within the PDS (PDS4 LID

`urn:nasa:pds:nh_documents:mission:soc_inst_icd`). The LORRI calibration will only be briefly summarized here; refer to the ICD for details about what is summarized here.

N.B. The units of the RDR image data are calibrated Data Number (DN); responsivity factors are provided in the PDS label (within the *nh:Radiometric\_Conversion\_Constants* class) and FITS headers to convert the calibrated DNs to physical units; the factor to use is dependent on the target scene spectrum. Refer to the ICD and other LORRI documentation, Cheng et al. (2008), Morgan et al. (2005) for more detail. Note also that some versions of Cheng et al. (2008), including the published version, have an error in the units of its Figure 9 ordinate.

The calibration of LORRI images involves all of the following steps in order:

- 1) Bias subtraction
- 2) Signal linearization
- 3) Charge transfer inefficiency (CTI) correction
- 4) Dark subtraction
- 5) Smear removal
- 6) Flat-fielding
- 7) Absolute calibration (DN with scene-dependent radiance divisors)

Ground testing has demonstrated that the linearization, CTI and dark subtraction steps are not necessary i.e. the output from the Bias subtraction step may be passed directly to Smear removal step.

In addition, the calibration procedure calculates the error and a data quality flag for each pixel and includes those results in the calibrated data product as additional PDS OBJECTs (FITS

extensions) appended to the main OBJECT with the data image. The quality flag PDS OBJECT 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. Each quality extension pixel value is an accumulated sum of individual quality flag values. The list below contains the quality flag value associated with each condition:

Quality Flag Value	Quality Flag Description
0	Good pixel
1	Defect in reference deltabias image (0 or NaN)
2	Defect in reference flatfield image (0 or NaN)
4	Permanent CCD defect (e.g. dead pixel) *
8	Hot Pixel identified in hotpixel map *
16	Saturated pixel in level1 data (A/D value of 4095)
32	Missing level1 data (assume fill value of 0 )
64	unused at present

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 PDS OBJECT (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 PDS OBJECT should always be checked when looking at these data.

Ongoing in-flight calibration observations will be analyzed to assess the long term stability of the calibration, including whether the currently unused steps may need to be implemented in the future.

\* As of late 2016, there are no known dead or hot pixels on the LORRI detector, so all hot and dead pixel map calibration files contain all zeroes. From the current flat-field calibration file it can be seen that there are many pixels with relative sensitivities up to six times the mean (unity), those called warm pixels. Those pixels are calibrated in the flat-field step.

## 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.:

```
lor_0123456789_0x630_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
LOR	LORRI

See the SOC Instrument ICD for more details:

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)
0x630	LORRI High-res Lossless (CDH 1)/LOR
0x636	LORRI High-res Lossless (CDH 2)/LOR
0x632	LORRI High-res Lossy (CDH 1)/LOR
0x638	LORRI High-res Lossy (CDH 2)/LOR
0x631	LORRI High-res Packetized (CDH 1)/LOR
0x637	LORRI High-res Packetized (CDH 2)/LOR
0x633	LORRI 4x4 Binned Lossless (CDH 1)/LOR
0x639	LORRI 4x4 Binned Lossless (CDH 2)/LOR
0x635	LORRI 4x4 Binned Lossy (CDH 1)/LOR
0x63B	LORRI 4x4 Binned Lossy (CDH 2)/LOR
0x634	LORRI 4x4 Binned Packetized (CDH 1)/LOR
0x63A	LORRI 4x4 Binned Packetized (CDH 2)/LOR
0x63C	LORRI Co-added 4x4 Binned Lossless (CDH 1)
0x63D	LORRI Co-added 4x4 Binned Lossless (CDH 2)

There are other ApIDs that contain housekeeping values and other values. See the SOC Instrument ICD within the PDS for more details (PDS4 LID `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 LORRI instrument overview:  
`urn:nasa:pds:nh_documents:lorri:lorri_inst_overview`
- LORRI Space Science Review (SSR) paper:  
`urn:nasa:pds:nh_documents:lorri:lorri_ssr`
- SOC Instrument ICD: `urn:nasa:pds:nh_documents:mission:soc_inst_icd`
- LORRI SPICE Instrument Kernel: `urn:nasa:pds:nh_documents:lorri:nh_lorri_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`
- LORRI SPICE Instrument Kernel: `urn:nasa:pds:nh_documents:lorri:nh_lorri_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:lorri:seq_lorri_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 LORRI document collection (see PDS4 LID `urn:nasa:pds:nh_documents:lorri`) 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 ( $\pm 1s$ ) 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 or 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 partially processed or calibrated 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 file that can be found within the PDS (with PDS4 LID `urn:nasa:pds:nh_documents:lorri: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.

The LORRI instrument replaces the first 34 12-bit pixels of each LORRI image (408 bits; 51 bytes) with encoded binary header information, so those first 34 pixel values in the first row are not representative of the brightness of the imaged scene at those locations; these pixels are in the bottom-left corner of images displayed left-to-right and bottom-to-top. Furthermore, if the image was LOSSY-compressed before downlink (ApIDs 0x632, 0x635, 0x638, 0x63B), the header information corrupts the first 40 pixels of the first 8 rows of the image because of the Discrete Cosine Transform compression algorithm. The SOC pipeline extracts these data into the FIRST34 extension of LORRI FITS files, which is also corrupt in LOSSY-compressed files. The SOC calibration pipeline also flags these pixels as bad in the QUALITY\_MAP extension of partially processed or calibrated FITS files; no such flags are available in the raw FITS files; the SOC pipeline did not flag the additional corrupt pixels beyond the first 34 in LOSSY-compressed data until the Pluto P2 delivery late in 2016.

## 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.



## SCANRATE and LORRI 'noodles'

The LORRI instrument normally is not active during Ralph (MVIC or LEISA) scans. However, LORRI imaging works just fine during these scans as long as the exposure time is kept short enough to prevent significant point smearing. This allows the creation of LORRI 'noodles', long sequences of images collected during a 'ride-along' with a Ralph scan. The highest resolution images of New Horizons fly-by targets are actually acquired in this mode.

The SCANRATE keyword in the FITS header is intended to capture the rate of spacecraft movement, but this functionality cannot be implemented in LORRI files. Therefore, the SCANRATE keyword value for all LORRI images defaults to a placeholder value of '-999'. To find an accurate SCANRATE value for any LORRI image acquired during a Ralph scan, consult the Scan Rates table found within the PDS (PDS4 LID

`urn:nasa:pds:nh_documents:lorri:scan_rates`).

## Contact Information

For any questions regarding the data format of the archive, contact the New Horizons LORRI Principal Investigator: Olivier Barnouin, Johns Hopkins University:

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## Further Reading

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