

New Horizons LORRI KEM1 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 LORRI dataset catalog file, 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 LOng Range Reconnaissance Imager (LORRI) instrument during the KEM1 ENCOUNTER mission phase.

This version includes Distant Kuiper Belt Object (DKBO) observations of 2011 HF103, 2011 HK103, 2011 HZ102, 2011 JA32, 2011 JW31, 2011 JX31, 2011 JY31, 2014 OE394, 2014 OJ394, 2014 OS393, 2014 PN70, 2020 KP11, 2020 KR11, and 2020 KT11, plus data from a Cosmic Optical Background Demo and a Microlensing demo. There are also observations of 50000 QUAOAR (2002 LM60), ASTEROID 307261 (2002 MS4), ASTEROID 486958 (2014 MU69), HD 37962, INTERPLANETARY DUST, M7, NGC 3532, PROXIMA CENTAURI, TRITON, and WOLF 359.

It includes images of the approach and departure field around Arrokoth. The data cover the actual Arrokoth encounter.

These data were migrated from the previously released PDS3 data set NH-A-LORRI-2-KEM1-V6.0.

Data Set Overview

This data set contains Raw data taken by the LOng Range Reconnaissance Imager (LORRI) instrument during the KEM1 ENCOUNTER 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).

The data set contains many observations of Distant Kuiper Belt Objects (DKBOs), as well as images of the approach and departure field around ASTEROID 486958 Arrokoth (2014 MU69). The imaged DKBOs include: 2011 HK103, 2011 JW31, 2011 JY31, 2011 HF103, 2014 OS393, 2014 PN70, 2011 HZ102, 2014 OE394, 2011 JA32, 2004 LW31, 2018 MF13, 2011 JX31, and 2014 OJ394. The approach field images were used for navigation and hazard avoidance purposes.

LORRI performed LightCurves and Imaging during the Arrokoth encounter. LORRI also observed Triton, M7, NGC3532, HD37962, Quaoar, MS4, Zodiacal Light, Proxima Centauri, and Wolf 359.

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 V6.0)

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

- the calibration files, documents, and data products were reorganized into separate collections of calibration files, documents, and data products, instead of being in a single package as it was in prior PDS3 data set versions.
- the geometry keywords were recalculated using the most recent spice kernels available at the time and updated in the PDS4 labels only. Note that the FITS headers have not been updated.

PDS3 V6.0 (NH-A-LORRI-2-KEM1-V6.0)

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

This version includes new DKBO observations of 2020 KP11, 2020 KR11, and 2020 KT11, as well as data from a Cosmic Optical Background Demo and a Microlensing demo. Previous DKBO observations of 2011 HF103, 2011 HK103, 2011 HZ102, 2011 JA32, 2011 JW31, 2011 JX31, 2011 JY31, 2014 OE394, 2014 OJ394, 2014 OS393, 2020 KO11, 2020 KT11, 2020 KP11, 2020 KR11, 2018 MG13, 2020 KH42, and 2014 PN70 are also included, along with observations of 50000 QUAOAR (2002 LM60), ASTEROID 307261 (2002 MS4), ASTEROID 486958 (2014 MU69), HD 37962, INTERPLANETARY DUST, M7, NGC 3532, PROXIMA CENTAURI, TRITON, Eris, Haumea, Voyager1, and WOLF 359.

DKBO 2020 KH42 was observed using the temporary name 'P4856186'. The target name has been corrected everywhere in this dataset except the DOCUMENT/SEQ_LORRI_KEM1.TAB file (*now found in PDS with PDS4 LID: urn:nasa:pds:nh_documents:lorri:seq_lorri_kem1*), which reflects the best information available at the time of observation sequencing.

Earlier in the KEM1 mission phase, some playbacks of LORRI images used windowing to save downlink bandwidth. In this version of the dataset, the New Horizons Science Operations Center (SOC) continues the long process of playing back many of these windowed files in full-file format. See the V5.0 section below for relevant information about the WINDOW_MISMATCHES partition. Also, many thumbnail files have changed due to the full-file playbacks.

Playbacks included test data from a flight software (FSW) update that provides a new image 'Co-Adding' mode. Since this test data duplicates data that has already been included in previous dataset versions, it has not been included in this dataset version. Uniquely co-added data in future datasets will utilize two new Application IDs (ApIDs): 0x63c and 0x63d. Since this dataset version doesn't contain any co-added data, a description of the co-adding process will be included in a future dataset version.

PDS Citation Information: Stern, A., NEW HORIZONS RAW LORRI KEM1 V6.0, NH-A-LORRI-2-KEM1-V6.0, NASA Planetary Data System, 2023.

[PDS3 V5.0 \(NH-A-LORRI-2-KEM1-V5.0\)](#)

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

This version includes DKBO observations of 2011 HF103, 2011 HK103, 2011 HZ102, 2011 JA32, 2011 JW31, 2011 JX31, 2011 JY31, 2014 OE394, 2014 OJ394, 2014 OS393, 2020 KO11, 2020 KT11, 2020 KP11, 2020 KR11, 2018 MG13, 2020 KH42, and 2014 PN70. There were also observations of 50000 QUAOAR (2002 LM60), ASTEROID 307261 (2002 MS4), ASTEROID 486958 (2014 MU69), HD 37962, INTERPLANETARY DUST, M7, NGC 3532, PROXIMA CENTAURI, TRITON, Eris, Haumea, Voyager1, and WOLF 359.

Earlier in the KEM1 mission phase, some playbacks of LORRI images used windowing to save downlink bandwidth. The New Horizons Science Operations Center (SOC) has now begun the long process of playing back many of these windowed files in full-file format. The names of affected files will not change. However, the new file versions may contain a binary table partition called WINDOW_MISMATCHES. This partition holds information on byte-by-byte differences within the previous window boundaries and is mainly used by the SOC for internal verification. Users are advised to ignore the WINDOW_MISMATCHES partition because the difference algorithm lends itself to false positives. Also, at least one line of (false) output is always generated even for files that were not previously windowed.

This version also includes 64 'ZeroDark' files with a SEQUENCE_ID value of K2LR_ZeroDark65_144_L4_2020158 in data/20200606_045371 . Though ZeroDark files resemble normal 4x4 FITS files and include a FIRST34 housekeeping extension as described in the Data Coverage and Quality section, these files do not contain any image pixel data. Only a single bias column (256) has been populated. The LORRI science team uses these files to estimate CCD dark current values. Exposure times for ZeroDark files oscillate between 0 seconds and 64.967 seconds. Since these files lack any image pixel data, they cannot be calibrated (i.e. they will only appear in raw LORRI datasets).

PDS Citation Information: Weaver, H., NEW HORIZONS RAW LORRI KEM1 V5.0, NH-A-LORRI-2-KEM1-V5.0, NASA Planetary Data System, 2022.

[PDS3 V4.0 \(NH-A-LORRI-2-KEM1-V4.0\)](#)

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

This version included DKBO observations of 2011 HF103, 2011 HK103, 2011 HZ102, 2011 JA32, 2011 JW31, 2011 JX31, 2011 JY31, 2014 OE394, 2014 OJ394, 2014 OS393, and 2014 PN70. There were also observations of 50000 QUAOAR (2002 LM60), ASTEROID 307261 (2002 MS4), ASTEROID 486958 (2014 MU69), HD 37962, INTERPLANETARY DUST, M7, NGC 3532, PROXIMA CENTAURI, TRITON, and WOLF 359.

PDS Citation Information: Weaver, H., NEW HORIZONS RAW LORRI KEM1 V4.0, NH-A-LORRI-2-KEM1-V4.0, NASA Planetary Data System, 2021.

[PDS3 V3.0 \(NH-A-LORRI-2-KEM1-V3.0\)](#)

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

The CRPIX1 and CRPIX2 values in the FITS headers of all LORRI images were increased by 1.0. This fixes an off-by-one error for the (x,y) location of the reference pixel in all prior LORRI releases.

PDS Citation Information: Weaver, H., NEW HORIZONS RAW LORRI KEM1 V3.0, NH-A-LORRI-2-KEM1-V3.0, NASA Planetary Data System, 2020.

[PDS3 V2.0 \(NH-A-LORRI-2-KEM1-V2.0\)](#)

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

Based on a thorough scientific analysis of LORRI images in past mission phases, all exposure times were increased by 0.6 ms. Two digits of precision were also added to the EXPOSURE_DURATION value in all LORRI data labels. This applies for all data delivered after 03/06/2020. Read LORRI_EXPOSURE_OFFSET_PDS_V3.PDF for details.

PDS Citation Information: Weaver, H., NEW HORIZONS RAW LORRI KEM1 V2.0, NH-A-LORRI-2-KEM1-V2.0, NASA Planetary Data System, 2020.

[PDS3 V1.0 \(NH-A-LORRI-2-KEM1-V1.0\)](#)

This version includes data acquired by the spacecraft between 08/14/2018 and 12/31/2018. It only includes data downlinked before 01/01/2019.

It includes a number of distant Kuiper Belt Objects (DKBOs). It also includes images of the approach field where MU69 was expected to reside during the MU69 encounter on Jan. 1, 2019.

Citation Information: Weaver, H., NEW HORIZONS RAW LORRI KEM1 V1.0, NH-A-LORRI-2-KEM1-V1.0, NASA Planetary Data System, 2019.

[General statement about data set versions after V1.0](#)

The pipeline (see Processing below) was re-run on these data for each version since the first (V1.0). A pipeline rerun usually changes the FITS headers but not the FITS data of raw data sets. In some cases, partially processed or 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 partially processed or 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.

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

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_kem1) to assess the possibility that there was an intended target. These two keywords are especially useful for star targets as often stars are used as part of instrument calibrations and are included as part of the sequencing description which is captured in these keywords.

Ancillary Data

The geometry items included in the data labels were computed using the SPICE kernels archived in the New Horizons SPICE data set, NH-J/P/SS-SPICE-6-V1.0.

Every observation provided in this data set was taken as a part of a particular sequence. 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:

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

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_kem1). 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 (AplIDs 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.

Observation descriptions in this overview file

Some users will expect to find descriptions of the observations in this data set here. This data set follows the more common convention of placing those descriptions under the Data Set Overview section of this overview file.

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: Harold A Weaver, Southwest Research Institute

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