New Horizons REX 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 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 Radio Science Experiment (REX) instrument during the KEM1 ENCOUNTER mission phase.

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.

The REX datasets over the mission include calibrations using known radio sources, Jupiter, and cold sky measurements; operational readiness tests (ORTs); internal test pattern calibration; and prime science radiometry and occultation observations during the Arrokoth Encounter.

These data were migrated from the previously released PDS3 data set NH-A-REX-2-KEM1-V5.0.

Data Set Overview

This data set contains Raw data taken by the New Horizons Radio Science Experiment (REX) instrument during the KEM1 ENCOUNTER mission phase. The closest approach to asteroid (486958) Arrokoth was on January 1, 2019, at approximately 05:33 UTC.

The REX instrument measures the amplitude and phase of radio signals captured by the New Horizons high-gain antenna. The main investigation is an occultation experiment which uses radio signals transmitted from Earth to probe the atmosphere and ionosphere of Pluto and Charon. Ancillary investigations include measurements of the 4 cm wavelength radiothermal emission from planets or other radio sources. Phase data may also be combined with Pluto encounter tracking data, derived from the Radio Science Subsystem separately from REX and to be archived in separate non-REX data set(s), to infer the influence of gravitational fields on the spacecraft as it moves through the Pluto system.

The main investigation requires coordinated use of the Earth-based transmitters and the spacecraft receiver as the two physical elements of the REX instrument. The 'Ground Element' comprises DSN (Deep Space Network) hardware and operations facilities on Earth, and the 'Flight Element' includes signal processing hardware and software onboard the spacecraft.

Unless inclusion of tuning profiles for one-way uplink transmissions is noted below, this data set includes only samples taken and measurements made by the REX system hardware on-board the New Horizons spacecraft, either of one-way uplink signals or of 4cm-wavelength thermal emission.

REQUIRED UNDERSTANDING: the REX and the New Horizons (NH) regenerative ranging tracker (see DeBolt et al. (2005)) are ***separate and independent*** subsystems that both use the radio frequency (RF) and telecommunication subsystems. Tracking data may not be archived in REX data sets.

More details are provided in the REX Activities in KEM1 Approach, Encounter, and Cruise document found within the PDS (see PDS4 LID `urn:nasa:pds:nh_documents:rex:rex_activities_kem1`).

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 REX document collection under PDS4 LID `urn:nasa:pds:nh_documents:rex:seq_rex_kem1`. 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 newest versions before older versions.

PDS4 v1.0 (migration from PDS3 V5.0)

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 documents and data products were reorganized into separate collections of documents and REX raw/calibrated data products and TNF 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.

PDS3 V5.0 (NH-A-REX-2-KEM1-V5.0)

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 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 data for several new Application IDs (ApID) related to flight software updates on the New Horizons spacecraft:

- 0x7b4: 9970 files
- 0x7b6: 7099 files
- 0x7b7: 28162 files
- 0x7b8: 0 files (see below)
- 0x7b9: 0 files (see below)

146 0x7b8 files and 144 0x7b9 files have been removed from the dataset because the New Horizons team downlinked the files as part of an internal test suite. The corresponding REX data has already been archived in previous dataset releases.

See the Filename/Product IDs section for a brief description of each new data file ApID.

PDS Citation Information: Linscott, I., NEW HORIZONS RAW REX KEM1 V5.0, NH-A-REX-2-KEM1-V5.0, NASA Planetary Data System, 2023.

PDS3 V4.0 (NH-A-REX-2-KEM1-V4.0)
Version 4.0 includes data acquired by the spacecraft between 08/14/2018 and 03/01/2021. It only includes data downlinked before 03/01/2021. Future datasets may include more data acquired by the spacecraft after 08/13/2018 but downlinked after 02/28/2021.

This version includes Radio Path Characterization and Test Patterns Verification prior to and after the ASTEROID 486958 Arrokoth (2014 MU69) encounter. Radiometric Measurement around Arrokoth, and Thermal Emission Scan and Bistatic Detection around Arrokoth. Radiometric Measurement with the Sun, Cygnus-A, Taurus-A, and Cass-A, Cold Sky Calibration, and Calibration Activities.

Downlink for a series of REX files (MET 408628681 to 408628996) began on 02/28/2021 and finished on 03/02/2021 after the dataset cutoff date above. To ensure this dataset only contains complete files, the New Horizons team has added additional data into the final file received on 02/28/2021 (MET 408628857). The entire series of data files will be included in the next dataset version.

PDS Citation Information: Linscott, I., NEW HORIZONS RAW REX KEM1 V4.0, NH-A-REX-2-KEM1-V4.0, NASA Planetary Data System, 2022.

PDS3 V3.0 (NH-A-REX-2-KEM1-V3.0)
Version 3.0 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 Radio Path Characterization and Test Patterns Verification prior to and after the Arrokoth encounter. Radiometric Measurement around Arrokoth, and Thermal Emission Scan and Bistatic Detection around Arrokoth. Radiometric Measurement with the Sun, Cygnus-A, Taurus-A, and Cass-A, Cold Sky Calibration, and Calibration Activities.

TRK-2-23 files were added in this version. The media calibration data that are provided by the Radiometric Modeling and Calibration Subsystem (RMC). These calibrations are used by project navigation and radio science teams, multi-mission spacecraft navigation, and other investigators to improve the accuracy of spacecraft orbit determination and radio science investigations by compensating for the media transmission effects of the Earth's troposphere and ionosphere on the propagation of radiometric signals.

PDS Citation Information: Linscott, I., NEW HORIZONS RAW REX KEM1 V3.0, NH-A-REX-2-KEM1-V3.0, NASA Planetary Data System, 2021.

PDS3 V2.0 (NH-A-REX-2-KEM1-V2.0)
Version 2.0 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.

PDS Citation Information: Linscott, I., NEW HORIZONS RAW REX KEM1 V2.0, NH-A-REX-2-KEM1-V2.0, NASA Planetary Data System, 2020.

PDS3 V1.0 (NH-A-REX-2-KEM1-V1.0)
Only a small amount of data was downlinked prior to 02/01/2019 for Version 1. This version includes data acquired by the spacecraft between 08/14/2018 and 12/31/2018. It only includes data downlinked before 02/01/2019. Future datasets may include more data acquired by the spacecraft after 08/13/2018 but downlinked after 01/31/2019.

PDS Citation Information: Linscott, I., NEW HORIZONS RAW REX KEM1 V1.0, NH-A-REX-2-KEM1-V1.0, NASA Planetary Data System, 2020.

General statement about data set versions after V1.0
The pipeline (see Processing below) was re-run on these data for each version since the first (V1.0). A pipeline rerun usually changes the FITS headers but not the FITS data of raw data sets. In some cases, calibrated FITS data may change because the calculated geometry of an observation has changed. See data set version-specific sections above for significant exceptions to this general statement, i.e., changes to pipeline processing, calibration processing, and data delivered.

Note that even if this is not a calibrated data set, calibration changes are listed as the data will have been re-run and there will be updates to the calibration files, to the documentation and to the steps required to calibrate the data.

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.:

```
rex_0123456789_0x7B0_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
REX	REX
RLM	Rex Logfile Missing error condition (ApID 0x7b4)
RFE	Rex Frame Error occurred on the spacecraft (ApID 0x7b4)
RBB	Rex BroadBand thresholding applied (ApIDs 0x7b6/7)
RNB	Rex NarrowBand thresholding applied (ApIDs 0x7b6/7)

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)
0x7b0	REX Lossless Compressed Data (CDH 1)/REX
0x7b1	REX Packetized Data (CDH 1)/REX
0x7b2	REX Lossless Compressed Data (CDH 2)/REX
0x7b3	REX Packetized Data (CDH 2)/REX
0x7b4	REX Instrument Housekeeping Data/REX
0x7b5	Error Log for Incomplete Playbacks/REX
0x7b6	REX Frames where Flight Software Detected Sample Over Threshold (CDH 1)/REX
0x7b7	REX Frames where Flight Software Detected Sample Over Threshold (CDH 2) /REX
0x7b8	REX Radiometer Sampled by the Flight Software from Each REX Frame (CDH 1)/REX
0x7b9	REX Radiometer Sampled by the Flight Software from Each REX Frame (CDH 2)/REX

There are other ApIDs that contain housekeeping values and other values. See 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 REX instrument overview:
  `urn:nasa:pds:nh_documents:rex:rex_inst_overview`
- REX Space Science Review (SSR) paper: `urn:nasa:pds:nh_documents:rex:rex_ssr`
- SOC Instrument ICD: `urn:nasa:pds:nh_documents:mission:soc_inst_icd`

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`

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 (PDS4 LID `urn:nasa:pds:nh_documents:rex:seq_rex_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, 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 REX document collection (see PDS4 LID

`urn:nasa:pds:nh_documents:rex`) within the PDS, one file for each mission phase. The sequence identifier (REQID) are included in the PDS label for every observation.

N.B. While every observation has an associated sequence, every sequence may not have associated observations. Some sequences may have failed to execute due to spacecraft events (e.g., safing). No attempt has been made during the preparation of this data set to identify such empty sequences.

Time

There are several time systems, or units, in use in this dataset: New Horizons spacecraft MET (Mission Event Time or Mission Elapsed Time), UTC (Coordinated Universal Time), and TDB (Barycentric Dynamical Time).

This section will give a summary description of the relationship between these time systems. For a complete explanation of these time systems the reader is referred to the documentation distributed with the Navigation and Ancillary Information Facility (NAIF) SPICE toolkit from the PDS NAIF node, (see http://naif.jpl.nasa.gov/).

The most common time unit associated with the data is the spacecraft MET. MET is a 32-bit counter on the New Horizons spacecraft that runs at a rate of about one increment per second starting from at value of zero at "19.January, 2006 18:08:02 UTC" or "JD2453755.256337 TDB."

The leapsecond adjustment (DELTA_ET = ET - UTC) was 65.184s at NH launch, and the first four additional leapseconds occurred at the ends of 12/2009, 06/2012, 06/2015, and 12/2016. Refer to the NH SPICE data set, NH-J/P/SS-SPICE-6-V1.0, https://doi.org/10.17189/1520109, and the SPICE toolkit documentation, for more details about leapseconds.

The data labels for any given product in this dataset usually contain at least one pair of common UTC and MET representations of the time at the middle of the observation. Other portions of the products, for example tables of data taken over periods of up to a day or more, will only have the MET time associated with a given row of the table.

For the data user's use in interpreting these times, a reasonable approximation (+/- 1s) of the conversion between Julian Day (TDB) and MET is as follows:

```
JD TDB = 2453755.256337 + ( MET / 86399.9998693 )
```

For more accurate calculations the reader is referred to the NAIF/SPICE documentation as mentioned above.

Reference Frame

Geometric Parameter Reference Frame

Earth Mean Equator and Vernal Equinox of J2000 (EMEJ2000) is the inertial reference frame used to specify observational geometry items provided in the data labels. Geometric parameters are based on best available SPICE data at time of data creation.

Epoch of Geometric Parameters

All geometric parameters provided in the data labels were computed at the epoch midway between the start_date_time and stop_date_time label fields.

Software

The observations in this data set are in standard FITS format with PDS labels and can be viewed by a number of PDS-provided and commercial programs. For this reason, no special software is provided with this data set.

Confidence Level Overview

During the processing of the data in preparation for delivery with this volume, the packet data associated with each observation were used only if they passed a rigorous verification process including standard checksums.

In addition, raw (CODMAC Level 2) observation data for which adequate contemporary housekeeping and other ancillary data are not available may not be reduced to calibrated (CODMAC Level 3) data. This issue is raised here to explain why some data products in the raw data set may not have corresponding data products in the calibrated data set.

Known Issues in REX data

The following item assumes familiarity with the REX, REX terminology and the required reading and other documentation provided with this data set.

Time tag anomalies in ROF sequences

REX places ten incrementing time tags in each REX Output Frame (ROF). The time tags can be used both to identify any breaks in a sequence of ROFs, and to determine the time between any two ROFs within a sequence.

The normal sequence for time tags is to start at zero in the first ROF and increment ten times per ROF, so the first time tag of the second ROF is 10, that of the third ROF is 20, etc. In practice, the first and last ROFs in a sequence do not always show simple zero starts and clean finishes, respectively, indicating data corruption in just those ROFs. There is no indication of corruption elsewhere in ROF streams, and REX commanding ensures there are always adequate ROFs before and after any observation, so discarding starting and ending ROFs in a sequence based on simple inspection of time tags is the way to handle this issue.

For more detail, refer to the REX Instrument Description section in the SOC Instrument ICD found within the PDS (see PDS4 LID `urn:nasa:pds:nh_documents:mission:soc_inst_icd`).

Data coverage and quality

Every observation provided in this data set was taken as a part of a particular sequence. For this data set, these sequences can be found in the REX document collection under PDS4 LID `urn:nasa:pds:nh_documents:rex:seq_rex_kem1`. Please note that some sequences provided may have zero corresponding observations.

Refer to the Confidence Level Overview section above for a summary of steps taken to assure data quality.

The Time Tag counter values included with REX data normally increment nine times within each data file and once between consecutive frames. However, there are sometimes anomalous departures from this behavior at the start and end of contiguous runs of data files (see the REX instrument overview, via PDS4 LID `urn:nasa:pds:nh_documents:rex:rex_inst_overview`, for a brief discussion of such an issue related to compression). Files with such anomalies are few compared to the total number of data files, and excluding those files with anomalous Time Tag data from data analysis will not significantly affect the results of the REX investigation. Refer to the SOC Instrument ICD (via PDS4 LID `urn:nasa:pds:nh_documents:mission:soc_inst_icd`) for more detail about REX Time Tags; there is adequate information there for users to identify anomalous files.

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 REX Principal Investigator:

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Further Reading

DeBolt, R., D.J. Duven, C.B. Haskins, C.C. DeBoy, and T.W. LeFevere, A Regenerative Pseudonoise Range Tracking System for the New Horizons Spacecraft, 2005. https://api.semanticscholar.org/CorpusID:8101048

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