Software Interface Specification for the Hayabusa2 NIRS3 Products

Version 1.0

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Change Log

DATE	CHANGE	AFFECTED SECTIONS
2017-10-27	INITIAL DRAFT	
2020-04-24	Modify based on Kate Crombie's comments	5.3 and 6.2
2020-10-20	Modify per Change Request	All
2020-12-12	Improved descriptions based on reviewer's comments	5.3.2.3, 5.3.4, 6.2.4
2021-02-19	Improved descriptions based on reviewer's comments	2, 5.3.2.1, 5.3.2.3, 5.3.2.4, 5.3.3, 5.3.4, 6.2.4

Acronyms and Abbreviations

Acronym/Abbreviation	Definition
ASCII	American Standard Code for Information Interchange
C-SODA	Center for Science satellite Operation and Data Archive
CSV	Comma-Separated Values
DAC	Data Archive team
DN	Digital Number
EDVEGA	Electric Delta-V Earth Gravity Assist
FITS	Flexible Image Transport System
FOV	Field of View
FPGA	Field Programmable Gate Array
HDU	Header Data Unit
HK	Housekeeping
IAU	International Astronomical Union
InAs	Indium-Arsenide
IPDA	International Planetary Data Alliance
ISAS	Institute of Space and Astronautical Science
JAXA	Japan Aerospace Exploration Agency
NIRS3	Near-Infrared Spectrometer
PDS	Planetary Data System
RAD	RADiometric calibration lamp
RCC	Radiometric Calibration Coefficient
SBN	Small Bodies Node
SCLK	Spacecraft Clock
SELENE	SELenological and ENgineering Explorer (Kaguya)
SIS	Software Interface Specification
SPICE	Spacecraft, Planet, Instruments, C-Matrix, Events
SIRIUS	Scientific Information Retrieval and Integrated Utilization System
TI	Time Indicator
UTC	Coordinated Universal Time
WAV	WAVelength calibration lamp
XML	Extensible Markup Language

1 Purpose and Scope of Document

The purpose of this Data Product Software Interface Specification (SIS) is to provide users of the calibrated and derived data products from the Hayabusa2 Near Infrared Spectrometer (NIRS3) with a detailed description of the products, and a description of how the products were generated, including sources and destinations. The products defined in this document are raw data, calibrated reflectance data, and ancillary data.

The SIS is intended to provide enough information to enable users to read and understand the NIRS3 data products as stored in PDS. The users for whom this SIS is intended are software developers of the programs used in generating the NIRS3 products and scientists who will analyze the data, including those associated with the Hayabusa2 mission, NIRS3 instrument and those in the general planetary science community.

2 Applicable Documents

This SIS is consistent with the following Planetary Data System Documents as adopted by the International Planetary Data Alliance (IPDA):

1. Planetary Data System Standards Reference, Version 1.14.0, May 22, 2020.
2. PDS4 Data Dictionary – Abridged – Version 1.14.0.0, March 23, 2020.
3. PDS4 Information Model, V.1.14.0.0, March 23, 2020.

This SIS is responsive to the following Hayabusa2 mission documents:

4. Science Policy for Hayabusa2 Project, Version 3.0 May 14, 2018.

This SIS makes reference to the following documents:

5. Iwata et. al, NIRS3: The Near Infrared Spectrometer on Hayabusa2, *Space Science Reviews,* **208**, 317-337, https://doi.org/10.1007/s11214-017-0341-0, 2017.
6. Pence et al., Definition of the Flexible Image Transport System (FITS), version 3.0, *A&A*, **524**, A42, https://doi.org/10.1051/0004-6361/201015362, 2010.

3 Configuration Management

The Hayabusa2 NIRS3 team controls the data products described in this document, as well as the document itself. Requests for changes to the data products, or the scope and contents of the document are made to the Science PI of the Hayabusa2 NIRS3 team, Kohei Kitazato. An engineering change request will be evaluated against its impact on the NIRS3 ground data processing system before acceptance. Once a change request has been approved, software and documentation are updated, version numbers incremented, tested, and finally released for production.

The data products and documentation described in this SIS as well as the SIS itself have completed a formal PDS peer review and lien resolution process. The peer review ensures that all data products described by this SIS comply with PDS4 standards as noted in Section 2 – Applicable Documents. The PDS peer review panel consisted of members of the PDS Small Bodies Node (SBN) and members of the planetary science community. Any changes to data products subsequent to the peer review, will be reviewed internally by the PDS SBN to determine if an additional peer review is necessary.

4 Relationships with Other Interfaces

Changes to the data products described in this SIS affect the following software, products or document:

Table 1. Interface relationships

Name of Interface	Type	Owner
NIRS3 Database Schema	Product	NIRS3 Team
NIRS3 Raw Science Data	Product	NIRS3 Team
NIRS3 Raw Housekeeping Data	Product	NIRS3 Team
Science Policy for Hayabusa2	Document	Project
NIRS3 Ground Data Processing	Software	NIRS3 Team
NIRS3 Archive Software	Software	DAC Team

A systems engineering approach is used to evaluate how changes in any one of these interfaces affects the others. It is possible that changes to one of these items will not affect any other item.

5 Data Product Characteristics and Environment

5.1 Instrument Overview

The Hayabusa2 Near Infrared Spectrometer (NIRS3) is a point spectrometer with a square 0.1˚ field of view (FOV) that takes continuous spectra over the effective wavelength range from 1.8 to 3.2 µm (Iwata et al., 2017). The role of NIRS3 is to acquire spectral data in the 3-µm wavelength region, where fundamental OH stretching and H_2O bending vibrational modes occur, and to map the distribution of hydrated minerals on the surface of the target asteroid (162173) Ryugu. The NIRS3 design is based on the Hayabusa NIRS instrument design (Abe et al., 2006) and is expanded to shift the spectral region to the 3-µm region.

NIRS3 consists of three components: the Spectrometer Unit (NIRS3-S), the Analogue Electronics Unit (NIRS3-AE), and the Harness Cable (NIRS3-HNS). NIRS3-S is mounted on the exterior of the -X panel of the spacecraft with its boresight pointed along the -Z axis. NIRS3-AE is mounted inside the -X panel and is connected to NIRS3-S by NIRS3-HNS. Figure 1 shows a picture of the flight model of NIRS3.

NIRS3-S is a transmission grating spectrometer that utilizes silicon and germanium lenses. The objective lens with an aperture of 30 mm in diameter gathers light and images the incoming scene at a slit. The slit has a 50 µm square aperture which provides a FOV size of 0.1˚ × 0.1˚. After passing through the slit, light is dispersed by a diffraction grating and falls on an indium-arsenide (InAs) linear array detector. The detector has 128 InAs photodiode elements and a selectable gain of High (0.5 pF) or Low (10 pF). The size of an InAs element was designed to be 50 µm × 100 µm. NIRS3-S is thermally isolated from the spacecraft and the optics and detector are cooled passively by heat radiation to less than -80 ˚C in flight. Because the noise contribution of dark current at the nominal detector temperature (-85 ˚C) is much larger compared to that of readout, NIRS3-S uses an optical chopper that periodically interrupts the light path at a rate of ~100 Hz. This allows more precise dark subtraction and noise reduction. NIRS3-S is equipped with two small halogen lamps called RAD and WAV for in-flight radiometric and spectral calibrations, respectively. Table 2 summarizes the NIRS3 specifications. More detailed descriptions of the NIRS3 instrument design are presented in Iwata et al. (2017).

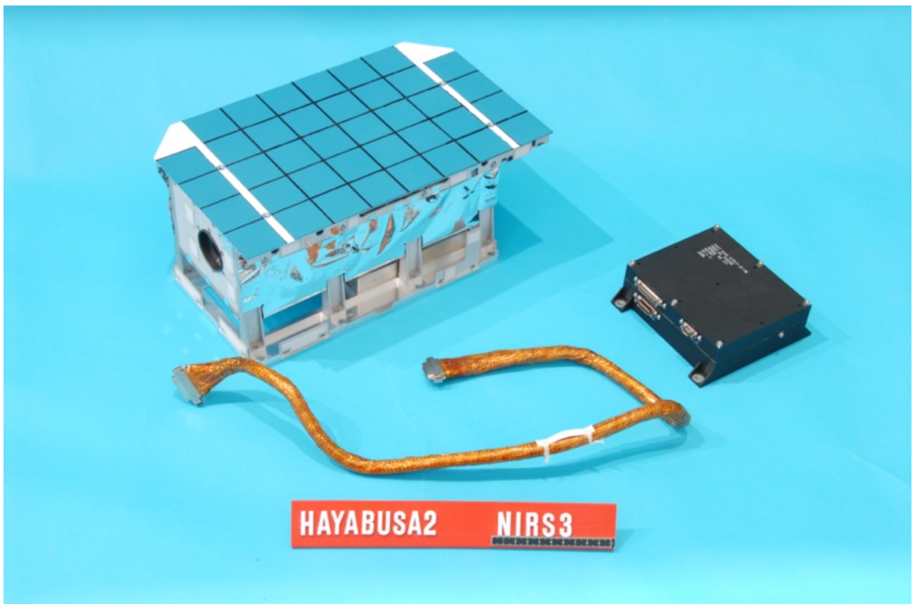

Fig. 1. Picture of the NIRS3 flight model.

Table 2. NIRS3 specifications

Characteristic	**Specification**
Mass	4.46 kg (S: 3.58 kg, AE: 0.60 kg, HNS: 0.28 kg)
Power	9.9 W (nominal), 14.9 W (maximum)
Aperture diameter	30 mm
f-number	1.0
Slit size	50 µm × 50 µm
FOV	0.1˚ × 0.1˚
Detector	128-element InAs linear array detector
Detector element size	50 µm × 100 µm
Detector operational temperature	-85 ˚C (nominal)
Effective spectral range	1.8–3.2 µm
Spectral sampling	18 nm/channel (average)
Chopper frequency	100 Hz (nominal)

5.1.1 Data Processing Modes

NIRS3 data are acquired through the use of command sequences that specify the instrument parameters listed in Table 3. When starting an observation, NIRS3-AE samples output voltage signals for 128 detector elements at a selected rate and converts them to digital numbers (DNs). Then, it accumulates the DN values for a selected number of times and generates a spectral data that contains mean and variance values in DN for 128 detector elements. Note that only the channel 1 data is a reference voltage value for troubleshooting. In Field Programmable Gate Array (FPGA) mode, the DN values of shutter-open dark signal are output from NIRS3-AE, while those of dark-subtracted signal are output in three Chopper modes (C11, C31, and C42).

Table 3. NIRS3 instrument parameters

Parameters	Values
Chopper power	ON/OFF
Heater power	ON/OFF
RAD lamp power	ON/OFF
WAV lamp power	ON/OFF
InAs detector gain	High/Low
Sampling mode	FPGA/C11/C31/C42 (FPGA: FPGA-triggered sampling, C11: chopper synchronous single sampling, C31: chopper synchronous 3-to-1 multiple sampling, C42: chopper synchronous 4-to-2 multiple sampling)
Exposure time	0.01–10 msec
Number of stacked data	1–1024

5.2 Data Product Overview

Instrument data and processed spectral data are natively stored as binary Flexible Image Transport System (FITS) files. Housekeeping data (HK) are appended to the spectral data products in the FITS headers and in ancillary data files. Calibration and ancillary data files needed to process spectral data are stored as ASCII files.

The data products described in this SIS are:

1. **NIRS3 Raw Science Data**: Raw instrument science data with appended relevant housekeeping data. Data are time ordered and in units of DN.
2. **NIRS3 Calibration Data**: Data used to convert raw DN values to reflectance units.
3. **NIRS3 Calibrated Science Data**: Instrument data that has been calibrated to reflectance units. Reflectance spectra are unitless.
4. **NIRS3 Ancillary Data**: Time variant data necessary to process spectral data.

5.3 Data Processing

This section of the SIS provides general information about data product content, format, size, and production rate. The specifics of the data product formats are discussed in Section 6.

5.3.1 Data Processing Level

NIRS3 will deliver both raw and calibrated data to PDS. Table 4 describes the data processing level of each type of data product.

Table 3. NIRS3 data product processing levels

NIRS3 Product	PDS4 Processing Level	Hayabusa2 NIRS3 Processing Level	Product Description
Raw Science Data	Raw	L1A	Raw instrument science data with appended relevant housekeeping data.
Calibration Data	Derived	-	Data used to derive calibrated data
Calibrated Science Data	Calibrated	L2C	Instrument data calibrated to reflectance units.
Ancillary Data	Derived	-	Ancillary data such as temperatures of instrument and geometry

5.3.2 Data Product Generation

5.3.2.1 Raw Data

NIRS3 science and HK telemetry are downlinked from the spacecraft and stored as sorted telemetry in the telemetry database called SIRIUS, operated by C-SODA (Science Satellite Operation and Data Archive Unit) at ISAS, JAXA. NIRS3 team ingests and stores the sorted telemetry as raw science data. The raw data contains mean and variance values of 128 detector channels calculated onboard, which are identical to those of telemetry. The channel values correspond to dark and dark-subtracted signals in FPGA and Chopper modes, respectively. In Chopper mode, the lower 25 channels (channels 2-26) register very low signal due to the limited transmission range of germanium lens. The channel 1 data is a reference voltage value for troubleshooting. In addition, the upper 12 channels (channels 117-128) also have very low signal levels due to the InAs detector cutoff. The measured data in the Chopper mode are dark-subtracted signals, so the measured data and those average values which are included in the telemetry can be negative, especially in the low signal ranges. The raw average data and the raw variance data are stored into one FITS file; the raw average data are stored to the primary HDU, and the raw variance data are stored to the secondary HDU as IMAGE extension.

5.3.2.2 Calibration Data

NIRS3 calibration data includes the values of center wavelength, spectral sampling interval, solar spectral irradiance, radiometric calibration coefficient (RCC) and electronic offset for all NIRS3 channels. The center wavelengths of NIRS3 channels are determined from the pre-flight spectral calibration and are given by

$$\lambda(n) = 1230.33 + 18.5651n - 0.00492138n^2 \text{ nm} \quad (1)$$

where n is the detector element number 1-128, and the derivative of this equation gives the spectral sampling intervals. The ASTM E490-00a (2006) solar spectral irradiance is adopted by convolving to the NIRS3 spectral resolution. RCC values were initially derived from on-ground measurements using a calibrated commercial blackbody as the radiometric source. Those data were acquired with the NIRS3 instrument in a thermal vacuum chamber viewing the external blackbody source through a CaF_2 window. The initial RCC was refined during flight and operations at Ryugu by using the RAD lamp data to remove ambiguities in atmospheric correction during the on-ground measurements, and effects due to differences in thermal conditions of NIRS3 was verified through observations of the Moon conducted before and after an Earth swing-by on December 3, 2015. The lunar spectral radiance derived from NIRS3 data is within 15% of SELENE, a Japanese lunar explorer, Spectral Profiler model values (Kouyama et al., 2016). The electronic offsets are derived from the dark sky data in flight. A paper with more detailed descriptions of the NIRS3 calibration is in preparation.

5.3.2.3 Calibrated Data

The NIRS3 calibrated science data contains mean and standard deviation data of radiance factor (I/F). The raw mean DN value at each element of wavelength λ stored in the primary HDU of raw data FITS file is converted to averaged radiance factor $\mathrm{I/F}_\lambda$ using the equation,

$$\mathrm{I/F}_\lambda = \frac{\pi\left(\mathrm{DN}_{\mathrm{mean},\lambda} - \mathrm{DN}_{\mathrm{offset},\lambda}\right)\mathrm{RCC}_\lambda d^2}{F_{0,\lambda}} \tag{2}$$

Here, $\mathrm{DN}_{\mathrm{offset},\lambda}$ is the electronic offsets derived from the dark sky data in flight, RCC_λ is the radiometric calibration coefficient (RCC) that is used to convert DN values to units of radiance ($\mathrm{W\ m^{-2}\ nm^{-1}\ sr^{-1}}$), $F_{0,\lambda}$ is the solar irradiance at 1 AU, and d is the Sun-target distance in AU.

The raw variance DN value stored in the secondary HDU of raw data FITS file is converted to standard deviation of the radiance factor SD_λ using the equation,

$$\mathrm{SD}_\lambda = \frac{\pi\sqrt{\mathrm{DN}_{\mathrm{var},\lambda}}\,\mathrm{RCC}_\lambda d^2}{F_{0,\lambda}} \tag{3}$$

Note that raw data for calibration that means dark data (sampling mode is "FPGA") or data acquired with the RAD lamp or the WAV lamp could not be converted to radiance factor, so there are no calibrated data associated to the raw data for calibration. If raw data acquired for science, but NIRS3 points to deep space, one cannot calculate d, so there are no corresponding calibrated data.

The calibrated average data and the calibrated standard deviation data are stored into one FITS file; the calibrated average data are stored to the primary HDU, and the calibrated standard deviation data are stored to the secondary HDU as IMAGE extension.

5.3.2.4 Ancillary Data

NIRS3 ancillary data includes the values of observation time, distance and instrument status, which are tied with each spectral data product. The details of those values can be found in Section 6.2.4.

5.3.3 Data Flow

NIRS3 raw, calibrated and derived data products are built up in sequential data processing steps addressing specific corrections or calibrations. All data products are built from raw telemetry ingested into the SIRIUS database. The NIRS3 data processing pipelines query the database directly for new raw science data. The NIRS3 data files generated by the pipelines are returned for storage. Figure 2 is a schematic that shows the NIRS3 data flow from raw telemetry to derived data products.

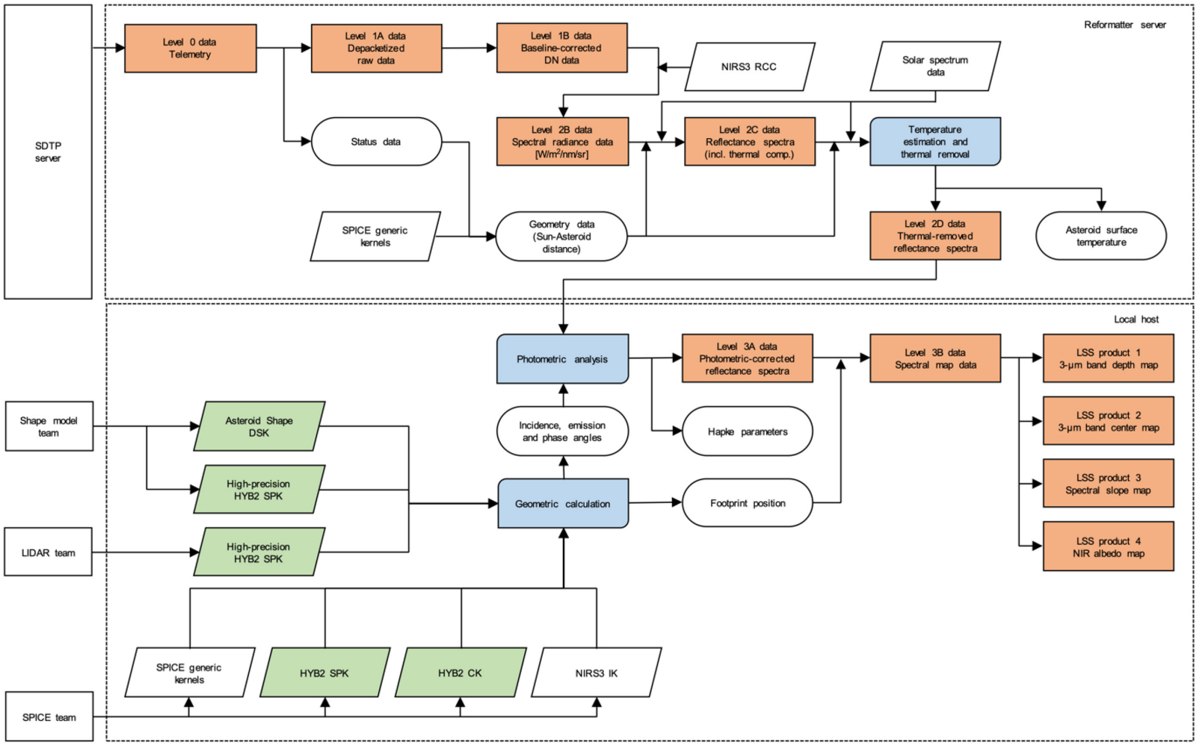

Fig. 2. Schematic of the NIRS3 data flow.

Table 5 shows the NIRS3 science data collection by mission phase. The number of observations is specified as well as the data volume of the processed data products.

Table 4. Data volume by mission phase

Mission Phase	Commi ssioning	EDVEGA	Earth Swing-by	Transfer	Approach	Asteroid Proximity	Return
Number of Observations (day)	2	6	12	17	14	113	3
Raw Science Data (MiB)	2	5	12	39	12	370	2
Calibrated Science Data (MiB)	0	0	17	66	5	701	0
Ancillary Data (MiB)	1	3	5	14	4	115	2

5.3.4 Labeling and Identification

All NIRS3 data products are labeled with PDS4 compliant detached XML labels. These labels describe the content and format of the associated data product. Labels and products are associated by file name with the label having the same name as the data product except that the label file has an .xml extension.

Labels are constructed with the PDS4 Product Class, Product_Observational sub-class. The Product_Observational sub-class describes a set of information objects produced by an observing system. A hierarchical description of the contents of Product_Observational products appears below:

Product_Observational
- Identification_Area – attributes that identify and name an object
    - logical_identifier – a unique identifier
      urn:jaxa:darts:hyb2_nirs3:<collection>:<file_name_root>,
      e.g., urn:jaxa:darts:hyb2_nirs3:data_calibrated:hyb2_nirs3_20180630_01_cal
    - version_id – version of product
    - title – Short description of product used as the PDS4 search return
    - information_model_version – version of PDS4 information model used to create product
    - product_class – attribute provides the name of the product class (Product_Observational)
- Observation_Area – attributes that provide information about the circumstances under which the data were collected.
    - Time_Coordinates – time attributes of data product
    - Primary_Results_Summary – high-level description of the types of products included in the collection or bundle
    - Investigation_Area – mission, observing campaign or other coordinated, large-scale data collection attributes
    - Observing_System – observing system (instrument) attributes
    - Target_Identification – observation target attributes
    - Discipline_Area – discipline specific attributes needed to describe data product
    - Mission_Area – Hayabusa2 mission specific attributes needed to describe data product
- Reference_List – describes list of references associated with this product
- File_Area_Observational - describes a file and one or more tagged_data_objects contained within.
    - File – identifies the file that contains one or more data objects
    - Header – defines a header of the average of spectral data
    - Array_2D_Spectrum – defines a two-dimensional array of spectral data.
    - Header – defines a header of the variance/standard deviation of spectral data
    - Array_2D_Spectrum – defines a two-dimensional array of spectral data.

Information in the preceding paragraphs was distilled from the PDS4 Information Model provided by PDS. Additional information on product labels can be found at https://pds.nasa.gov/datastandards/about/.

NIRS3 data products are identified with file names that describe the following elements:

hyb2_nirs3_*date_number_type*.*extension*

where

- *date* (observation date) = *YYYYMMDD*
  - *YYYY* is year in 4 digits,
  - *MM* is zero-padded month in 2 digits, and
  - *DD* is zero-padded day in 2 digits
- *number* (observation sequence number for each day)
  - zero-padded two digits of decimal starting from 01
- *type* (product type)
  - raw (raw science data),
  - cal (calibrated science data), or
  - anc (ancillary data)
- *extension*
  - fit (FITS file for raw and cal data product types), or
  - csv (comma delimited ASCII file for ancillary data product type)

NIRS3 data products are daily collections from midnight to midnight of the day of interest, but they are divided into each observation sequence according to changes of instrument parameters.

Example file names are:

hyb2_nirs3_20151015_01_raw.fit
hyb2_nirs3_20151015_01_cal.fit
hyb2_nirs3_20151015_01_anc.csv

NIRS3 calibration files are named according to the following convention:

nirs3_*period*_*version*.*extension*

where

- *period* (applicable period) = *YYYYMMDD-YYYYMMDD*
  - First *YYYYMMDD* indicates start date of the applicable period
  - Second *YYYYMMDD* indicates stop date of the applicable period
    - *YYYY* is year in 4 digits,
    - *MM* is zero-padded month in 2 digits, and
    - *DD* is zero-padded day in 2 digits
- *version* = v*VV*
  - *VV* is zero-padded two digits of decimal
- *extension* = csv

Example file names are:

nirs3_20151015-20190221_v01.csv
nirs3_20190227-20190711_v01.csv
nirs3_20190725-20191104_v01.csv

5.4 Standards Used in Generating Data Products

5.4.1 PDS Standards

All data products described in this SIS conform to PDS4 standards as described in the PDS Standards document noted in the Applicable Documents section of this SIS. Prior to public release, all data products will have passed a PDS peer review to ensure compliance with applicable standards.

In consultation with the PDS, the Hayabusa2 Mission shall use the 1.14.0.0 version of the PDS4 information model. All Hayabusa2 products will conform to this standard, however products may have various versions of specific Discipline Dictionaries.

5.4.2 Time Standards

The Hayabusa2 NIRS3 data products contain a UTC time that has been derived from the Hayabusa2 spacecraft SpaceWire clock that is different with the Hayabusa2 spacecraft clock. The transformation from the spacecraft SpaceWire clock to UTC is performed by the tool prepared by C-SODA. This transformation tool is proprietary. The SpaceWire clock is transformed to TI of the spacecraft, and then transformed to UTC time using transformation table between TI and UTC. The transformation result is almost same as that of non-SpaceWire time, i.e., UTC time calculated from TI of the spacecraft. Difference between UTC time derived from SpaceWire clock and UTC time derived from TI is roughly evaluated less than 1 ms.

5.4.3 Coordinate Systems

All coordinate systems used by the Hayabusa2 mission conform to IAU standards. A complete discussion of the coordinate systems and how they are deployed in the mission can be found in Ryugu Coordinate System Description prepared by the Hayabusa2 Shape Model team, included in document collection of the Hayabusa2 mission bundle.

5.4.4 Data Storage Conventions

All NIRS3 data products are stored as either FITS files or ASCII delimiter separated variable tables. The standard delimiter of comma has been chosen by the team. FITS files follow the FITS 3.0 standard.

5.5 Data Validation

The NIRS3 team conducts spot checks to validate that software is producing data products correctly during day-to-day production of data products from sorted telemetry. Most of the calibrated spectra have been visually checked one by one.

In addition to software verification and validation, each data product has been peer reviewed for both PDS data format acceptability and scientific usefulness. No changes are expected to data formats after peer review. Should any changes be needed, the configuration control process will be followed and documented.

When data is prepared for submission to the PDS, the DAC team and NIRS3 team will use PDS / mission-provided validation tools for conformance to the PDS4 standards. NIRS3 team members and DAC team members will validate the data contained within the NIRS3 data products.

6 Detailed Data Product Specifications

The following sections provide detailed data product specifications for each NIRS3 data product. These specifications will provide sufficient detail, so that data product users can read and interpret the products.

6.1 Data Product Structure and Organization

The Hayabusa2 data archive is organized as bundles by instrument. The NIRS3 bundle of the archive is organized by processing level and product type and then by mission phase. Data products are stored under each mission phase directory which is just under data collection directory. Product_Observational/Observation_Area/Time_Coordinates/start_date_time determines which mission phase period a product is stored.

The NIRS3 bundle directory structure is as follows:

hyb2_nirs3/
- data_raw – NIRS3 raw data collection
- data_calibrated – NIRS3 calibrated data collection
- data_ancillary – NIRS3 ancillary data collection
- calibration – NIRS3 calibration collection
- document – NIRS3 document collection

6.2 Data Format Descriptions

6.2.1 NIRS3 Raw Science Data

The NIRS3 raw science data product is a 2-extention FITS file. The primary data unit is an array of mean DN values with format 128 × Spectra, where 128 is the number of detector elements and spectra are the number of acquired spectra. The second data unit gives the variance value for each element. The FITS header and XML PDS4 label contain the relevant instrument metadata as described in Table 6.

Table 5. NIRS3 raw science data format

FITS Keyword	Example/Default	Description
BITPIX	16	number of bits per data pixel
NAXIS	2	number of data axes
NAXIS1	128	length of data axis 1
NAXIS2	139	length of data axis 2
EXTEND	T	FITS dataset may contain extensions
DATE	'2020-09-25'	Creation date of this file
FILEVERS	2.0	Version of this file format
INSTRUME	'NIRS3 '	Name of instrument
DETECTOR	'InAs '	Name of detector
NDETE	128	Number of detector elements
OBJECT	'Earth '	Name of observed object
BUNIT	'DN '	Physical unit of binary data
NSPECTRA	139	Number of spectra in this file
DATE-BEG	'2015-11-26T02:29:17.0'	UTC date & time of first spectrum
DATE-END	'2015-11-26T02:53:50.0'	UTC date & time of last spectrum
CHPSTAT	'ON '	Chopper status (ON/OFF)
HEASTAT	'OFF '	Heater status (ON/OFF)
RADSTAT	'OFF '	RAD lamp status (ON/OFF)
WAVSTAT	'OFF '	WAV lamp status (ON/OFF)
DETGAIN	'High '	InAs detector gain (High/Low)
SMPLMODE	'C11 '	Sampling mode (FPGA/C11/C31/C42)
XPOSURE	0.0025	Exposure time (sec)
NSTACK	1024	Number of stacked data for each spectrum

6.2.2 NIRS3 Calibration Data

The NIRS3 calibration data file is formatted as an ASCII comma-separated values (CSV) file and is described in Table 7.

Table 7. NIRS3 calibration data format

Column	Name	Notation	Units	Description
1	Channel number	n	–	InAs detector element number (1-128)
2	Center wavelength	λ	nm	The center wavelengths of all NIRS3 channels were determined from the pre-flight spectral calibration and no changes were found throughout the mission phase.
3	Solar spectral irradiance	$F_{0,\lambda}$	$W/m^2/nm$	Solar irradiance convolved to the NIRS3 spectral resolution at 1 AU
4	Radiometric calibration coefficients	RCC_λ	$W/m^2/nm/sr/DN$	The RCC values were initially derived from on-ground measurements and were refined during flight and operations at Ryugu by using the RAD lamp data.
5	Electronic offsets	$DN_{offset,\lambda}$	DN	Averaged dark-subtracted signals generated from the data of inflight observations

6.2.3 NIRS3 Calibrated Science Data

The NIRS3 calibrated science data product is a 2-extension FITS file. The primary data unit contains an array of reflectance values. The second data unit gives the standard deviation value for each element. The FITS header and XML PDS4 label contain the relevant instrument metadata as described in Table 8.

Table 8. NIRS3 calibrated science data format

FITS Keyword	Example/Default	Description
BITPIX	-32	number of bits per data pixel
NAXIS	2	number of data axes
NAXIS1	128	length of data axis 1
NAXIS2	139	length of data axis 2
EXTEND	T	FITS dataset may contain extensions
DATE	'2020-09-25'	Creation date of this file
FILEVERS	2.0	Version of this file format
INSTRUME	'NIRS3 '	Name of instrument
DETECTOR	'InAs '	Name of detector
NDETE	128	Number of detector elements
OBJECT	'Earth '	Name of observed object
BUNIT	'Radiance factor'	Physical unit of binary data
NSPECTRA	139	Number of spectra in this file
DATE-BEG	'2015-11-26T02:29:17.0'	UTC date & time of first spectrum
DATE-END	'2015-11-26T02:53:50.0'	UTC date & time of last spectrum
CHPSTAT	'ON '	Chopper status (ON/OFF)
HEASTAT	'OFF '	Heater status (ON/OFF)
RADSTAT	'OFF '	RAD lamp status (ON/OFF)
WAVSTAT	'OFF '	WAV lamp status (ON/OFF)
DETGAIN	'High '	InAs detector gain (High/Low)
SMPLMODE	'C11 '	Sampling mode (FPGA/C11/C31/C42)
XPOSURE	0.0025	Exposure time (sec)
NSTACK	1024	Number of stacked data for each spectrum

OPTT-AVE	-84.91	Average of optics temperature (degC)
OPTT-MAX	-84.88	Maximum of optics temperature (degC)
OPTT-MIN	-85.43	Minimum of optics temperature (degC)
DETT-AVE	-87.21	Average of InAs detector temperature (degC)
DETT-MAX	-87.17	Maximum of InAs detector temperature (degC)
DETT-MIN	-87.23	Minimum of InAs detector temperature (degC)
SBPT-AVE	-16.16	Average of S base plate temperature (degC)
SBPT-MAX	-15.92	Maximum of S base plate temperature (degC)
SBPT-MIN	-16.48	Minimum of S base plate temperature (degC)
ABPT-AVE	2.47	Average of AE base plate temperature (degC)
ABPT-MAX	2.47	Maximum of AE base plate temperature (degC)
ABPT-MIN	2.47	Minimum of AE base plate temperature (degC)
CHPF-AVE	95.95	Average of chopper frequency (Hz)
CHPF-MAX	95.95	Maximum of chopper frequency (Hz)
CHPF-MIN	95.95	Minimum of chopper frequency (Hz)
CHPA-AVE	86.90	Average of chopper amplitude
CHPA-MAX	88.88	Maximum of chopper amplitude
CHPA-MIN	84.80	Minimum of chopper amplitude
CHPC-AVE	86.23	Average of chopper current (mA)
CHPC-MAX	86.72	Maximum of chopper current (mA)
CHPC-MIN	85.16	Minimum of chopper current (mA)
PAC-AVE	26.45	Average of preamplifier current (mA)
PAC-MAX	26.45	Maximum of preamplifier current (mA)
PAC-MIN	26.45	Minimum of preamplifier current (mA)
HEAC-AVE	7.26	Average of heater current (mA)
HEAC-MAX	7.26	Maximum of heater current (mA)
HEAC-MIN	7.26	Minimum of heater current (mA)

6.2.4 NIRS3 Ancillary Data

The NIRS3 ancillary data file is formatted as an ASCII comma separated variable (CSV) file and is described in Table 9.

Table 9. NIRS3 ancillary data format

Column	Name	Units	Description
1	End time	YYYY-mm-ddTHH:MM:SS.s	The end time of the data accumulation, UTC, HK data
2	Mid-exposure time	YYYY-mm-ddTHH:MM:SS.s	Mid-exposure time calculated by [End time] – 0.5*[Number of stacked data]/[Chopper frequency]
3	Sun-target range	AU	Range from Sun to target center calculated by the SPICE system
4	Optics temperature	˚C	Temperature of optics, HK data
5	InAs detector temperature	˚C	Temperature of detector, HK data
6	S base plate temperature	˚C	Temperature of NIRS-S base plate, HK data
7	AE base plate temperature	˚C	Temperature of NIRS-AE base plate, HK data
8	Chopper frequency	Hz	Frequency of chopper, HK data
9	Chopper amplitude	–	Amplitude of chopper, HK data
10	Chopper current	mA	Current of chopper, HK data
11	Preamplifier current	mA	Current of preamplifier, HK data
12	Heater current	mA	Current of heater, HK data

The values of the Sun-target range were derived using the SPICE kernels described in the meta-kernel of “hyb2_nirs3_v*VV*.tm” where *VV* is version number in zero-padded two digits.

6.3 Label and Header Descriptions

All NIRS3 data products contain date and time information that can be used to sort and correlate data products.

Data product labels are in XML format and are PDS4 compliant.

7 Applicable Software

7.1 Utility Programs

At the current time, the Hayabusa2 project has no plans to release any mission specific utility programs.

7.2 Applicable PDS Software Tools

Data products found in the Hayabusa2 archive can be viewed with any PDS4 compatible software utility. A listing of these tools can be found at https://pds.nasa.gov/tools/about/ .

7.3 Software Distribution and Update Procedures

As no Hayabusa2 specific software will be released to the public, this section is not applicable.

8 Appendices

8.1 References

Iwata et. al, NIRS3: The Near Infrared Spectrometer on Hayabusa2, Space Science Reviews, 208:317-337, https://doi.org/10.1007/s11214-017-0341-0, 2017.

Abe et al., Near-Infrared Spectral Results of Asteroid Itokawa from the Hayabusa Spacecraft, Science, 312, 1334, https://doi.org/10.1126/science.1125718, 2006.

Kouyama et al., Development of an application scheme for the SELENE/SP lunar reflectance model for radiometric calibration of hyperspectral and multispectral sensors, Planetary and Space Science, 124, 76-83, https://doi.org/10.1016/j.pss.2016.02.003, 2016.

ASTM E490-00a (2006), Standard Solar Constant and Zero Air Mass Solar Spectral Irradiance Tables, ASTM International, West Conshohocken, PA, https://doi.org/10.1520/E0490-00AR06, 2006, www.astm.org

8.2 Definitions of Data Processing Levels

PDS4 Data Processing Levels (From PDS Policy on Data Processing Levels (2013-03-11):

Telemetry: An encoded byte stream used to transfer data from one or more instruments to temporary storage where the raw instrument data will be extracted.

Raw: Original data from an instrument. If compression, reformatting, packetization, or other translation has been applied to facilitate data transmission or storage, those processes will be reversed so that the archived data are in a PDS approved archive format.

Partially Processed: Data that have been processed beyond the raw stage but which have not yet reached calibrated status.

Calibrated: Data converted to physical units, which makes values independent of the instrument.

Derived: Results that have been distilled from one or more calibrated data products (for example, maps, gravity or magnetic fields, or ring particle size distributions). Supplementary data, such as calibration tables or tables of viewing geometry, used to interpret observational data should also be classified as 'derived' data if not easily matched to one of the other three categories.