Hayabusa2 NIRS3 Thermal Excess Removed I/F Spectra Software Interface Specification

Version 1.0

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Prepared by

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Table of Contents

Change Log

DATE	CHANGE	AFFECTED SECTIONS
2025-01-23	INITIAL DRAFT	
2025-12-12	Version 1.0 draft	All

2026-07-14	Version 1.0
	- Updated the cover page title.
	- Revised the LID prefix for the External product.
	- Added the .lblx extension to the file naming convention.
	- Revised collection titles.
	- In response to review liens:
	  - Fixed typo.
	  - Revised descriptions in Table 4, 5, and 6 to ensure consistency with the corresponding FITS header comments.
	  - Separated the descriptions for incidence angle and emission angle in Table 7 for clarity.
		Cover page,
		4.3.4, 5.1.1, 5.1.2, 5.2.1, 5.2.2

Acronyms and Abbreviations

Acronym/Abbreviation	Definition
CRS	Coordinate Reference System
CSV	Comma-Separated Values
DAC	Data Archive team
FITS	Flexible Image Transport System
FOV	Field of View
GIS	Geographic Information System
GSFC	Goddard Space Flight Center
HDU	Header Data Unit
I/F	Radiance Factor
IAU	International Astronomical Union
IPDA	International Planetary Data Alliance
JAXA	Japan Aerospace Exploration Agency
MSE	Mean Squared Error
NASA	National Aeronautics and Space Administration
NIRS3	Near-Infrared Spectrometer
OGC	Open Geospatial Consortium
PDF	Portable Document Format
PDS	Planetary Data System
PDS4	Planetary Data System Version 4
PI	Principal Investigator
RADF	Radiance Factor
SBN	Small Bodies Node
SIS	Software Interface Specification
SPICE	Spacecraft, Planet, Instruments, C-Matrix, Events
STD	Standard Deviation
UTC	Coordinated Universal Time
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 the thermal excess removed data generated from the calibrated science data in Hayabusa2 Near Infrared Spectrometer (NIRS3) bundle [1].

The SIS is intended to provide enough information to enable users to read and understand the NIRS3 derived data products. The users for whom this SIS is intended are software developers of the programs used in generating the NIRS3 derived data 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.

This document provides a description of two types of data bundles:

1. PDS4- compliant dataset:
   NIRS3 Level 2D thermal excess removed I/F spectra and geometry data bundle,
2. PDS4 non-compliant dataset:
   NIRS3 I/F spectra with/without thermal excess removal GeoPackage data bundle.

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 1.24.0, March 31, 2025.
   https://doi.org/10.17189/6eda-pv69
2. PDS4 Data Dictionary – Abridged – Version 1.24.0.0, April 28, 2025.
3. PDS4 Information Model, Version 1.24.0.0, April 28, 2025.

This SIS makes reference to the following documents:

4. Definition of the Flexible Image Transport System (FITS), Version 4.0 (language-edited), IAU FITS Working Group, 22 July 2016 (approved), 13 August 2018 (language-edited publication), NASA GSFC, PDF available at:
   https://fits.gsfc.nasa.gov/standard40/fits_standard40aa-le.pdf.
5. Open Geospatial Consortium, OGC GeoPackage Encoding Standard, Version 1.4.0, 2023.
   https://docs.ogc.org/is/12-128r19/12-128r19.html

3 Configuration Management

The Hayabusa2# international visibility enhancement 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 Hayabusa2# international visibility enhancement team. Once a change request has been approved, software and documentation are updated, version numbers incremented, tested, and finally released for production.

For data compliant with PDS4, 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 in the PDS4-compliant data bundle 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 Data Product Characteristics and Environment

4.1 *Instrument Overview*

For details on this section, refer to the NIRS3 SIS document [2].

4.2 *Data Product Overview*

The data products described in this SIS are:

1. NIRS3 Thermal excess removed I/F Data: Thermal excess removed I/F data in FITS format [3]
2. NIRS3 Geometry data: Footprint geometry and photometric conditions associated with each spectrum in CSV format.
3. NIRS3 Spectra with Geometry Data: Spectra with polygon footprint geometries for observation locations in GeoPackage format [4].
4. NIRS3 Thermal Excess Removed Spectra with Geometry Data: Thermal excess removed data, photometric conditions for spectral data, and estimated surface temperature stored as attributes in GeoPackage format [4].

4.3 *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 5.

4.3.1 Data Processing Level

The data described in this SIS are thermal-corrected radiance factor data derived from the NIRS3 Calibrated Science Data and computed geometry. Table 1 describes the data processing level of each type of data product.

Table 1. NIRS3 derived data product processing levels

NIRS3 Product	PDS4 Processing Level	Hayabusa2 NIRS3 Processing Level	Product Description
Thermal Excess Removed I/F Data	Derived	L2D	Thermal excess removed data from NIRS3 Calibrated Science Data.
Geometry Data	Derived	-	Footprint geometry and photometric conditions for spectral data.

NIRS3 Product	PDS4 Processing Level	Hayabusa2 NIRS3 Processing Level	Product Description
NIRS3 Spectra with Geometry Data	Derived	-	Footprint geometry and calibrated spectra data in GeoPackage format.
Thermal Excess Removed Spectra with Geometry Data	Derived	-	Footprint geometry and thermal excess removed spectra data in GeoPackage format.

4.3.2 Data Product Generation

4.3.2.1 Thermal Excess Removed Data

The Thermal Excess Removed I/F Data contains radiance factor data derived from the calibrated science data, with the influence of solar thermal radiation removed and the Ryugu surface temperature used to estimate the thermal radiation.

The derivation method of the above correction formula is as follows.

First, the observed radiance can be divided into two components: sunlight reflection and thermal emission.

$$I_{\mathrm{obs}}(\lambda) = I_{\mathrm{ref}}(\lambda) + I_{\mathrm{thermal}}(\lambda)$$

The sunlight reflection I_{ref} can be expressed by the following equation using $p(\lambda)$, $F_{\mathrm{sun}}(\lambda)$, $I_{\mathrm{sun}}(\lambda)$, and D_{AS}.

$$I_{\mathrm{ref}}(\lambda) = p(\lambda) * F_{\mathrm{sun}}(\lambda) = p(\lambda) * I_{\mathrm{sun}}(\lambda)/\pi D_{\mathrm{AS}}^2$$

$p(\lambda)$: radiance factor (I/F)

$F_{\mathrm{sun}}(\lambda) = \frac{I_{\mathrm{sun}}(\lambda)}{\pi D_{\mathrm{AS}}^2}$: Solar radiance on the asteroid surface [W/m^2/µm/sr]

$I_{\mathrm{sun}}(\lambda)$: Solar Irradiance [W/m^2/µm] (provided from E490 [5])

D_{AS}: Sun-asteroid distance [AU]

λ: wavelength [µm]

Similarly, the thermal emission $I_{\mathrm{thermal}}(\lambda)$ can be expressed by the following equation using $\epsilon(\lambda)$ and $B(\lambda)$.

$$I_{\mathrm{thermal}}(\lambda) = \epsilon(\lambda) B(\lambda)$$

$\epsilon(\lambda)$: Emissivity

$B(\lambda)$: Thermal radiation [W/m^2/µm/sr]

Blackbody radiation can be expressed by the following equation:

$$B(\lambda) = \frac{2hc^2}{\lambda^5} \frac{1}{e^{\frac{hc}{\lambda k_B T}} - 1}$$

where h is Planck's constant, c is the speed of light, k_B is the Boltzmann constant, and T is the absolute temperature of the object.

From Kirchhoff's law, where $\epsilon(\lambda)$ is expressed by the following equation, the above correction formula is derived.

$$\epsilon = 1 - p$$

p is what we want to derive in this case.

To calculate the thermal correction factor using this formula, it is necessary to estimate the surface temperature of Ryugu. In this version, the spectrum with the least solar influence from the NIRS3 observation data was selected as the reference. The temperature that results in the most linear ratio with the reference spectrum was estimated as the surface temperature, and the correction was applied.

The reference spectrum is selected from all observation data observed from November 2018 to February 2019 when Ryugu was farthest from the Sun and the phase angle was smallest.

For the reference spectrum, it was assumed that the spectral slope in the long-wavelength region (1.9–3.1 µm) matches that in the 2.1–2.3 µm range. A thermal correction was then applied at the temperature that makes these slopes equal. The corrected spectrum was subsequently used as the reference for thermal corrections to data from other observation dates.

The method for determining the temperature that results in the most linear ratio with the reference spectrum is as follows.

First, for temperature estimation, the observation spectrum data in the wavelength range of 1.9 to 3.1 µm were used, normalized by the observation spectrum at 2.1 µm. The ratio of the observed spectrum to the reference spectrum was approximated by a linear function using the least squares method based on the observed wavelengths. Slope a and intercept b of the approximation formula for the linear function are calculated using the following equation.

$$\mathrm{a} = \frac{n\sum xy - \sum x \sum y}{n\sum x^2 - (\sum x)^2}$$

$$\mathrm{b} = \frac{\sum \mathrm{y} - a\sum x}{n}$$

x : NIRS3 wavelength

y : The ratio of the observed spectrum to the reference spectrum

n : The number of channels used for temperature estimation

The actual observed data and the results estimated from the approximation formula above were used to calculate the mean squared error (MSE). The temperature estimation was performed in 1-degree increments, and the temperature corresponding to the smallest MSE value was selected. Blackbody radiation was calculated based on that temperature.

$$\mathrm{MSE} = \frac{1}{n}\sum_{i=1}^{n}(y_i - \widehat{y}_i)^2$$

y_i : NIRS3 Observed data for the i-th channel

$\widehat{y}_i$: Estimated data from the approximation formula for the i-th channel

n : The number of channels used for temperature estimation

The temperature estimation and thermal correction were performed for each observed spectrum, and the corrected data were generated.

The valid observation wavelength range is channels 27–116, as described in the NIRS3 bundle SIS [2]. Channels outside this range have very low signal levels due to the characteristics of the detector and optics and should not be used for analysis.

The thermal excess removed data and the estimated temperature data are stored into one FITS file; the thermal excess removed data are stored to the primary HDU, and the estimated temperature data are stored to the third HDU as IMAGE extension.

4.3.2.2 Geometry Data

NIRS3 geometry information includes observation time, longitudes and latitudes of the observed area, and photometric conditions (phase angle, incidence angle, and emission angle) for each observation. Each row contains the longitudes and the latitudes of five locations where the boresight and the four corners of NIRS3 footprint with the surface of target body, Ryugu or Moon, i.e., the locations where the extended 5 vectors for boresight and corners intercept with the surface of Ryugu or Moon, phase angle, incidence angle, and emission angle. In addition to these values, position of the surface point with the boresight vector in the target body's body-fixed coordinate which is equivalent to longitude, latitude, and radius for the boresight vector is also provided for plotting in three dimensions. The target body, Ryugu or Moon, is the same throughout each file, and described in the first line of the file as a comment.

The values were calculated with SPICE Toolkit and the meta-kernel of hyb2_nirs3_geom_v*VV*.tm where *VV* is version number in zero-padded two digits, available in Hayabusa2 SPICE Kernel Archive Bundle [6]. Filename of the meta-kernel used to create geometry information is found in the XML label for the geometry information file. If value could not be calculated, e.g., the boresight vector did not intercept with Ryugu's surface, missing value -999.0 was used.

Incidence angle and emission angle for the footprint are calculated as follows: field of view is evenly divided into 3×3 sub-regions. Incidence angle and emission angle for center of each sub-region are calculated, and then taking median of incidence angles and emission angles for the nine sub-regions, respectively. If the vector from the FOV's origin to center of sub-region doesn't intercept the surface of the target body, it will be set to the missing value, and it's excluded for the median calculation. In contrast to the incidence angle and emission angle, phase angles at any points in the observed area should have only a small variation, therefore phase angle for the footprint is calculated as phase angle at surface intercept point on the target body of the boresight vector.

Table 2 and Figure 1 describe definition of phase angle, incidence angle, and emission angle for reference.

Table 2. Definition of geometry data

Name	**Definition**	**Unit**	**Range**[1]
Phase angle	Angle between a scatterer-Sun vector and a scatterer-observer vector. This is calculated by the *ilumin_c* function in the SPICE toolkit.	degrees	[0,180]
Incidence angle	Angle between a surface normal vector and a scatterer-Sun vector. This is calculated by the *ilumin_c* function in the SPICE toolkit.	degrees	[0,180]
Emission angle	Angle between a surface normal vector and a scatterer-observer vector. This is calculated by the *ilumin_c* function in the SPICE toolkit.	degrees	[0,180]

1 Note that the brackets, [and] mean including the endpoints at the left and at the right of the interval, and the parentheses () mean excluding the endpoints at the left and at the right of the interval.

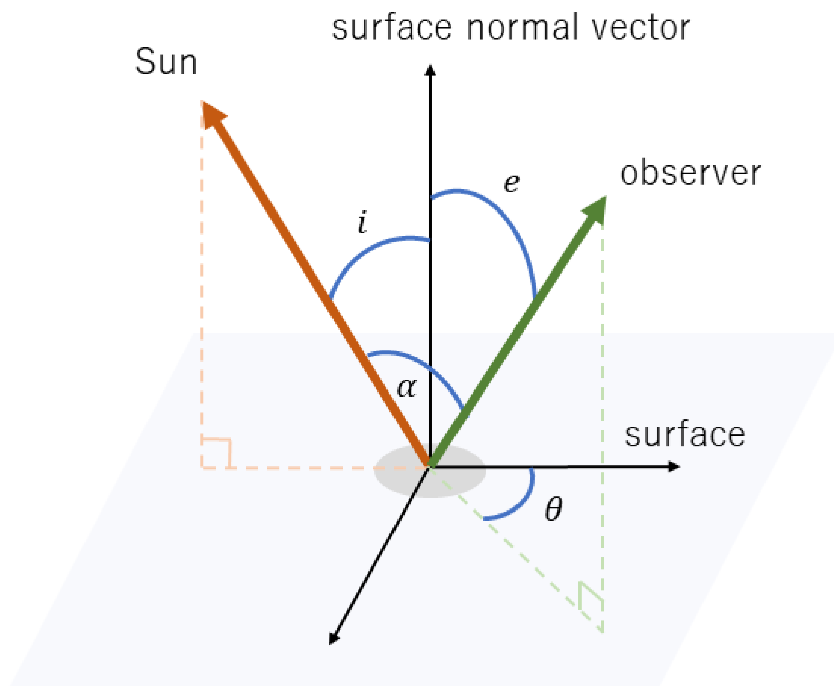

Figure 1. Definition of a phase angle α, an incidence angle i, an emission angle e, and an azimuthal angle θ. This figure is drawn in isometric view. The gray elliptical region shows a small disk on the spherical surface of the target body where scatterer or emitter exists. The surface including the disk is approximated by a plane shaded by light blue. A scatterer-Sun vector, a scatterer-observer vector, and the surface normal vector are shown as a thick dark red arrow, a thick dark green arrow, and a black arrow, respectively. The vector emanating from the scatterer from left to right on the surface shown as a thin black arrow is opposite vector of the projection of the scatterer-Sun vector onto the surface. This vector can be interpreted as a vector that is a projected vector of the Sun-scatterer vector onto the surface with origin at the scatterer.

Note that the four corners of NIRS3 footprint are placed on the boundary of the FOV, and they differ from the centers of sub-regions during calculation of incidence angle and emission angle as illustrated in Figure 2.

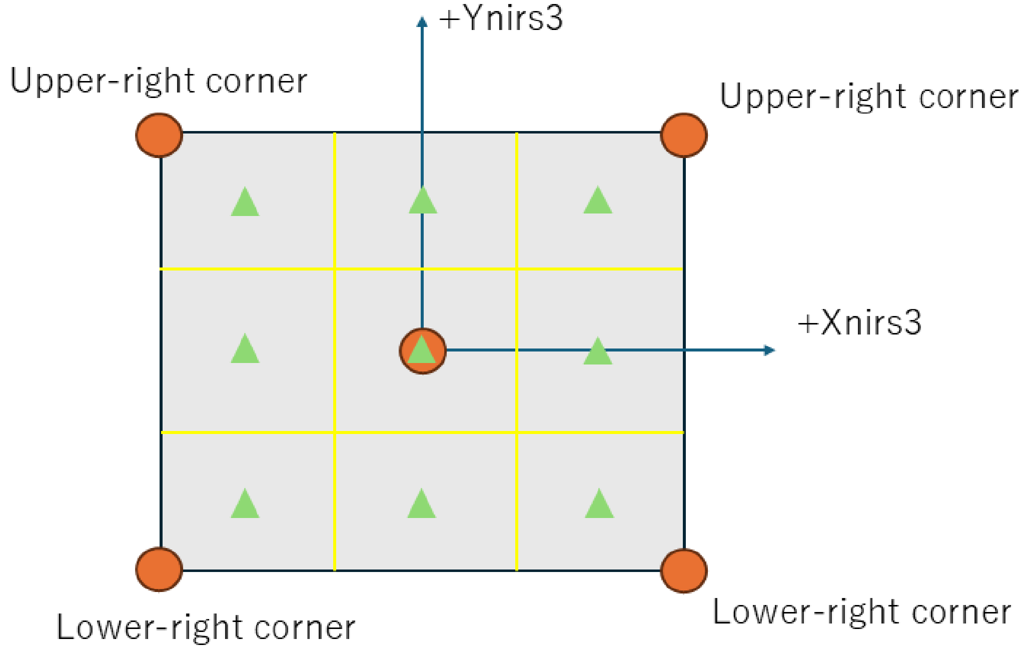

Figure 2 Schematic diagram of the FOV for geometry calculation. Black solid lines are the rectangular boundary of the FOV and bluish arrows are +X and +Y axes of the NIRS3 instrument coordinate. Solid lines in light yellow represent boundary for the sub-regions. Circles filled with dark orange are center and four corners of the FOV. Triangles in light green show centers of sub-regions.

4.3.2.3 NIRS3 Spectra with Geometry Data

The NIRS3 Spectra with Geometry Data is vector data generated from the coordinates of the four corners of the footprint stored in the Geometry Data. As attribute information, the data includes photometric conditions such as phase angle and incidence angle, and radiance factor data, which are directly taken from the Level 2C product.

Footprint Geometry Data is generated from the coordinates of the four corners of the footprint stored in the Geometry Data using Python libraries. Polygon function from the shapely library is used to generate the vector data.

4.3.2.4 Thermal Excess Removed Spectra with Geometry Data

The Thermal Excess Removed Spectra with Geometry Data is vector data generated from the coordinates of the four corners of the footprint stored in the Geometry Data. As attribute information, the data includes photometric conditions such as phase angle and incidence angle, the estimated target body’s surface temperature at the time of observation, and thermal excess removed spectra data, which are directly taken from the Level 2D product.

Footprint Geometry Data is generated from the coordinates of the four corners of the footprint stored in the Geometry Data using Python libraries. Polygon function from the Shapely library is used to generate the vector data.

4.3.3 Data Flow

NIRS3 derived data products are built up in sequential data processing steps addressing specific corrections or calibrations. Figure 3 is a schematic that shows the NIRS3 derived data flow from NIRS3 science calibrated data to derived data products.

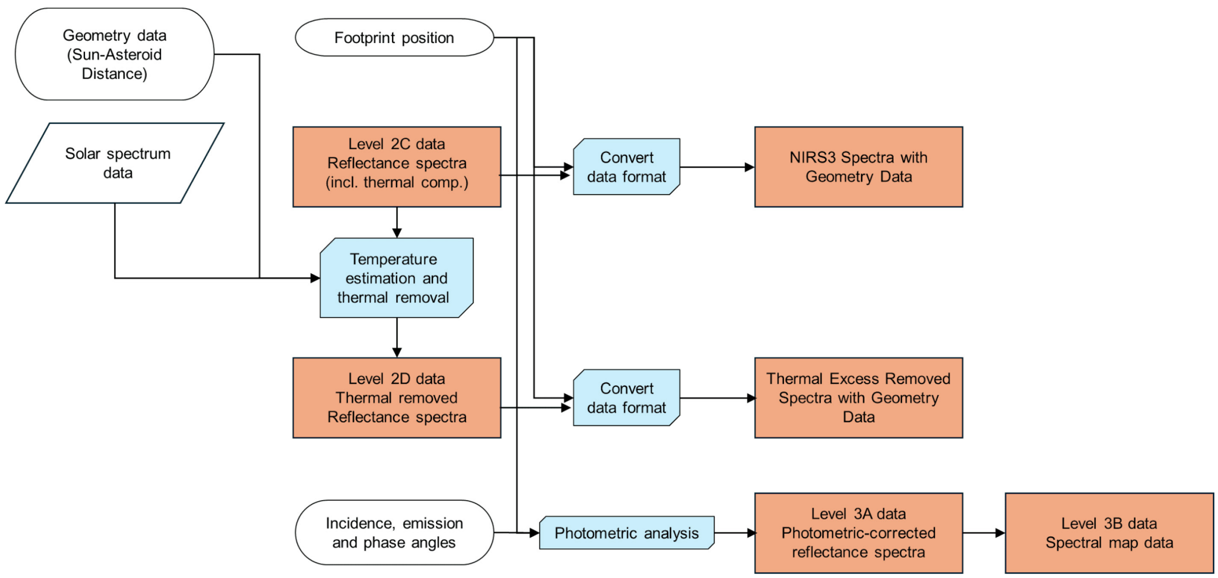

Figure 3. Schematic diagram of the NIRS3 derived data flow.

Table 3 shows the NIRS3 derived data collection by mission phase.

Table 3. Data volume by mission phase

Mission Phase	**Commis sioning**	**EDVEG A**	**Earth Swing-by**	**Transfe r**	**Approa ch**	**Asteroid Proximi ty**	**Retur n**
Thermal Excess Removed Data (MiB)	0	0	0.4	0	5	508	0
NIRS3 Spectra with Geometry Data (MiB)	0	0	0	0	0	575	0
Thermal Excess Removed Spectra with Geometry Data (MiB)	0	0	0	0	0	575	0
Geometry Data (MiB)	0	0	0.2	0	1	190	0

4.3.4 Labeling and Identification

All NIRS3 derived 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 a lblx extension.

For PDS4-compliant products, 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_sp:<collection>:<file_name_root>,
      e.g., urn:jaxa:darts:hyb2_nirs3_sp:data_iof_thermalcorr:hyb2_nirs3_20180630_01_l2d
    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
    Mission_Area – Hayabusa2 mission specific attributes needed to describe data product
    Discipline_Area – discipline 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.
    Header – defines a header of the estimated temperature data.
    Array_1D_Spectrum – defines a two-dimensional array of estimated temperature data.

For PDS4 non-compliant products, labels are constructed with the PDS4 Product_External class, Product_External sub-class. The Product_External sub-class describes a set of information objects produced by an observing system. A hierarchical description of the contents of Product_External products appears below:

Product_External
  Identification_Area – attributes that identify and name an object
    logical_identifier – a unique identifier
      urn:jaxa:darts-ext:hyb2_nirs3_sp_gpkg:<collection>:<file_name_root>,

e.g., urn:jaxa:darts-ext:hyb2_nirs3_sp_gpkg:data_iof_thermalcorr: hyb2_nirs3_20180630_01_l2d
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_External)

Context_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
Mission_Area – Hayabusa2 mission specific attributes needed to describe data product
Discipline_Area – discipline specific attributes needed to describe data product

Reference_List – describes list of references associated with this product

File_Area_External - describes a file and one or more tagged_data_objects contained within the file.
File – identifies the file that contains one or more data objects.
Encoded_External – describes an encoded byte stream that has been encoded using an encoding scheme that is compliant to an external standard.

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 derived data products included in this bundle are identified by file names with the following elements:

hyb2_nirs3_*date_number_processing-level_version.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
- *processing-level* (Hayabusa2 NIRS3 Processing Level)
  - l2c,
  - l2d, or
  - geo
- *version* (data processing version. The number will be updated when there are changes to the processing algorithms or similar aspects.) = vNN
  - NN is the release version starting from 01
- *extension*
  - fit (FITS file for thermal excess removed data),

- gpkg (GeoPackage file for NIRS3 spectra with footprint geometry data),
- csv (CSV file for geometry data),
- jpg (quick-look image), or
- lblx (PDS4 label)

NIRS3 derived 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_20180630_01_l2c_v01.fit
hyb2_nirs3_20180630_01_l2c_v01.gpkg
hyb2_nirs3_20180630_01_l2c_v01.jpg
hyb2_nirs3_20180630_01_l2c_v01.lblx
hyb2_nirs3_20180630_01_l2d_v01.fit
hyb2_nirs3_20180630_01_l2d_v01.gpkg
hyb2_nirs3_20180630_01_l2d_v01.jpg
hyb2_nirs3_20180630_01_geo_v01.csv
hyb2_nirs3_20180630_01_geo_v01.jpg

4.4 Standards Used in Generating Data Products

4.4.1 PDS Standards

For data products compliant with PDS4, all data products 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.

The data products which are not compliant with PDS4 are labeled as Product_External class defined in the PDS Standards document noted in the Applicable Documents section of this SIS.

The products described in this document shall conform to version 1.24.0.0 of the PDS4 information model. However, the products may reference different versions of specific Discipline Dictionaries.

4.4.2 Time Standards

All products described in this document use UTC time, which is basically inherited from the source products and used as is.

4.4.3 Coordinate Systems

All coordinate systems used by the Hayabusa2 mission conform to IAU standards except for Ryugu's, as of the time of writing this document. A complete discussion of the coordinate systems for Ryugu and how they are deployed in the mission can be found in Ryugu Coordinate System Description[7] prepared by Naru Hirata, PI of the Hayabusa2 Shape Model team, included in document collection of the Hayabusa2 mission bundle.

The GeoPackage-format data use a coordinate reference system (CRS) for projection that assumes Ryugu is a rotating ellipsoid. The coordinate reference system is defined as follows. The radius is based on Watanabe et al. (2019) [8] which is also referenced in the Ryugu Coordinate System Description document.

```
GEOGCRS["162173 Ryugu (JAXA2024) - Sphere",
    DATUM["162173 Ryugu (JAXA2024) - Sphere",
        ELLIPSOID["162173 Ryugu (JAXA2024) - Sphere", 448, 0,
            LENGTHUNIT["metre", 1]]],
    PRIMEM["Prime", 0,
        ANGLEUNIT["degree", 0.0174532925199433]],
    CS[ellipsoidal,2],
        AXIS["Planetocentric latitude", north,ORDER[1],
            ANGLEUNIT["degree", 0.0174532925199433]],
        AXIS["Planetocentric longitude", east,ORDER[2],
            ANGLEUNIT["degree", 0.0174532925199433]]]
```

4.4.4 Data Storage Conventions

All Thermal excess removed data products are stored as either FITS files or GeoPackage files. FITS files follow the FITS 4.0 Standard. GeoPackage files follow the GeoPackage 1.4.0 version.

4.5 Data Validation

Hayabusa2# international visibility enhancement team conducts spot checks to validate that software is producing data products correctly. Most of the calibrated spectra have been visually checked one by one.

In addition to software verification and validation, data compliant with PDS4 standards has been peer reviewed for both PDS data format acceptability and scientific usefulness. No changes are expected to data formats after peer review. If any changes are necessary, the configuration control process will be followed and documented.

When data is prepared for submission to the PDS, the DAC team and Hayabusa2# international visibility enhancement team will use PDS / mission-provided validation tools for conformance to the PDS4 standards. Hayabusa2# international visibility enhancement team members and DAC team members will validate the data contained within the derived data products.

5 Detailed Data Product Specifications

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

5.1 Data Product Structure and Organization

There are two bundles containing the NIRS3 derived data products; one is the NIRS3 Level 2D Thermal Excess Removed I/F Spectra and Geometry Data Bundle which contains PDS4-compliant products, and the other is NIRS3 I/F Spectra with/without Thermal Excess Removed GeoPackage Data Bundle which contains non-PDS4-compliant products.

5.1.1 NIRS3 Level 2D Thermal Excess Removed I/F Spectra and Geometry Data Bundle

The NIRS3 Level 2D Thermal Excess Removed I/F Spectra and Geometry Data Bundle includes two products: NIRS3 Thermal excess removed I/F Data (FITS) and NIRS3 Geometry data (CSV). The directory structure is organized first by processing level, and then by mission phase. Data products are stored under each mission phase directory, which is located directly under the data collection directory.

The directory structure is as follows:

hyb2_nirs3_sp/
- data_iof_thermalcorr – NIRS3 Level 2D Thermal Excess Removed I/F Spectra Collection
- geometry – NIRS3 Geometry Collection
- document – NIRS3 Level 2D Thermal Excess Removed I/F Spectra and Geometry Data Document Collection
- browse – NIRS3 Level 2D Thermal Excess Removed I/F Spectra and Geometry Data Browse Collection

5.1.2 NIRS3 I/F Spectra with/without Thermal Excess Removed GeoPackage Data Bundle

NIRS3 I/F Spectra with/without Thermal Excess Removed GeoPackage Data Bundle includes two products: NIRS3 Spectra with Geometry Data (GeoPackage) and NIRS3 Thermal Excess Removed Spectra with Geometry Data (GeoPackage). The directory structure is organized first by processing level, and then by mission phase. Data products are stored under each mission phase directory, which is located directly under the data collection directory.

The directory structure is as follows:

hyb2_nirs3_sp_gpkg /
- data_iof – NIRS3 I/F Spectra GeoPackage Collection
- data_iof_thermalcorr – NIRS3 Thermal Excess Removed I/F Spectra GeoPackage Collection
- document – NIRS3 I/F Spectra with/without Thermal Excess Removed GeoPackage Document Collection
- browse – NIRS3 I/F Spectra with/without Thermal Excess Removed GeoPackage Browse Collection

5.2 Data Format Descriptions

5.2.1 NIRS3 Thermal excess removed I/F Data

The Thermal excess removed I/F Data product is a FITS file with two extensions. The primary data unit is an array of thermal excess removed reflectance value. The primary header is inherited from the NIRS3 calibrated science data and updated for the thermal excess removed version. The second data unit gives the standard deviation value for each element. It is the same as the second data of NIRS3 calibrated science data. The third data unit gives the estimated temperature of Ryugu used for thermal correction.

Header keywords for the primary HDU, the secondary HDU and the third HDU are described in Table 4, Table 5, and Table 6, respectively.

Table 4. Header keyword list for primary HDU of NIRS3 thermal excess removed data

PDS4 class/attribute	**FITS Keyword**	**Example/ Default**	**Description**
Not assigned	SIMPLE	T	comforms to FITS standard
Array_2D_Spectrum / Element_Array / data_type	BITPIX	-32	array data type
Array_2D_Spectrum / axes	NAXIS	2	number of array dimensions
Array_2D_Spectrum / Axis_Array / elements	NAXIS1	128	length of data axis 1
Array_2D_Spectrum / Axis_Array / elements	NAXIS2	139	length of data axis 2
Not assigned	EXTEND	T	FITS dataset may contain extensions
Not assigned	DATE	'2025-01-06'	Creation date of this file
Not assigned	FILEVERS	2.0	Version of this file format
Not assigned	INSTRUME	'NIRS3 '	Name of instrument
Not assigned	DETECTOR	'InAs '	Name of detector
Array_2D_Spectrum / Axis_Array / elements	NDETE	128	Number of detector elements
Target_Identification / name	OBJECT	'Ryugu '	Name of observed object
Array_2D_Spectrum / Element_Array / unit	BUNIT	'Radiance factor'	Physical unit of binary data
Array_2D_Spectrum / Axis_Array / elements	NSPECTRA	139	Number of spectra in this file
Time_Coordinates / start_date_time	DATE-BEG	2018-06-30T06:59:21.9'	UTC date & time of first spectrum
Time_Coordinates / stop_date_time	DATE-END	'2018-06-30T14:58:48.2'	UTC date & time of last spectrum
hyb2:NIRS3_Instrument_Attributes / hyb2:chopper_status	CHPSTAT	'ON '	Chopper status (ON/OFF)
hyb2:NIRS3_Instrument_Attributes / hyb2:heater_status	HEASTAT	'OFF '	Heater status (ON/OFF)
hyb2:NIRS3_Instrument_Attributes / hyb2:radiometric_calibration_lamp_status	RADSTAT	'OFF '	RAD lamp status (ON/OFF)
hyb2:NIRS3_Instrument_Attributes / hyb2:wavelength_calibration_lamp_status	WAVSTAT	'OFF '	WAV lamp status (ON/OFF)

PDS4 class/attribute	FITS Keyword	Example/ Default	Description
hyb2:NIRS3_Instrument_Attributes / hyb2:detector_gain	DETGAIN	'High '	InAs detector gain (High/Low)
hyb2:NIRS3_Instrument_Attributes / hyb2:sampling_mode	SMPLMODE	'C11 '	Sampling mode (FPGA/C11/C31/C42)
hyb2:NIRS3_Instrument_Attributes / hyb2:exposure_duration sp:Spectral_Characteristics / sp:Observation_Parameters / sp:net_integration_time	XPOSURE	0.0025	Exposure time (sec)
hyb2:NIRS3_Instrument_Attributes / hyb2:number_of_stack	NSTACK	1024	Number of stacked data for each spectrum
Not assigned	OPTT-AVE	-84.91	Average of optics temperature (degC)
Not assigned	OPTT-MAX	-84.88	Maximum of optics temperature (degC)
Not assigned	OPTT-MIN	-85.43	Minimum of optics temperature (degC)
Not assigned	DETT-AVE	-87.21	Average of InAs detector temperature (degC)
Not assigned	DETT-MAX	-87.17	Maximum of InAs detector temperature (degC)
Not assigned	DETT-MIN	-87.23	Minimum of InAs detector temperature (degC)
Not assigned	SBPT-AVE	-16.16	Average of NIRS3-S base plate temperature (degC)
Not assigned	SBPT-MAX	-15.92	Maximum of NIRS3-S base plate temperature (degC)
Not assigned	SBPT-MIN	-16.48	Minimum of NIRS3-S base plate temperature (degC)
Not assigned	ABPT-AVE	2.47	Average of NIRS3-AE base plate temperature (degC)
Not assigned	ABPT-MAX	2.47	Maximum of NIRS3-AE base plate temperature (degC)
Not assigned	ABPT-MIN	2.47	Minimum of NIRS3-AE base plate temperature (degC)
Not assigned	CHPF-AVE	95.95	Average of chopper frequency (Hz)
Not assigned	CHPF-MAX	95.95	Maximum of chopper frequency (Hz)
Not assigned	CHPF-MIN	95.95	Minimum of chopper frequency (Hz)
Not assigned	CHPA-AVE	86.90	Average of chopper amplitude
Not assigned	CHPA-MAX	88.88	Maximum of chopper amplitude
Not assigned	CHPA-MIN	84.80	Minimum of chopper amplitude

PDS4 class/attribute	FITS Keyword	Example/ Default	Description
Not assigned	CHPC-AVE	86.23	Average of chopper current (mA)
Not assigned	CHPC-MAX	86.72	Maximum of chopper current (mA)
Not assigned	CHPC-MIN	85.16	Minimum of chopper current (mA)
Not assigned	PAC-AVE	26.45	Average of preamplifier current (mA)
Not assigned	PAC-MAX	26.45	Maximum of preamplifier current (mA)
Not assigned	PAC-MIN	26.45	Minimum of preamplifier current (mA)
Not assigned	HEAC-AVE	7.26	Average of heater current (mA)
Not assigned	HEAC-MAX	7.26	Maximum of heater current (mA)
Not assigned	HEAC-MIN	7.26	Minimum of heater current (mA)

Table 5. Header keyword list for secondary HDU of NIRS3 thermal excess removed data

PDS4 class/attribute	FITS Keyword	Example/ Default	Description
Not assigned	XTENSION	‘IMAGE’	Image extension
Array_2D_Spectrum / Element_Array / data_type	BITPIX	-32	array data type
Array_2D_Spectrum / axes	NAXIS	2	number of array dimensions
Array_2D_Spectrum / Axis_Array / elements	NAXIS1	128	length of data axis 1
Array_2D_Spectrum / Axis_Array / elements	NAXIS2	139	length of data axis 2
Not assigned	PCOUNT	0	number of parameters
Not assigned	GCOUNT	1	number of groups
Not assigned	EXTNAME	‘Standard deviation’	
Not assigned	DATE	'2025-01-06'	Creation date of this file
Target_Identification / name	OBJECT	'Ryugu'	Name of observed object
Array_2D_Spectrum / Element_Array / unit	BUNIT	'Radiance factor'	Physical unit of binary data
Time_Coordinates / start_date_time	DATE-BEG	2018-06-30T06:59:21.9'	UTC date & time of first spectrum
Time_Coordinates / stop_date_time	DATE-END	'2018-06-30T14:58:48.2'	UTC date & time of last spectrum

Table 6. Header keyword list for third HDU of NIRS3 thermal excess removed data

PDS4 class/attribute	**FITS Keyword**	**Example/ Default**	**Description**
Not assigned	XTENSION	‘IMAGE’	Image extension
Array_2D_Spectrum / Element_Array / data_type	BITPIX	-32	array data type
Array_2D_Spectrum / axes	NAXIS	2	number of array dimensions
Array_2D_Spectrum / Axis_Array / elements	NAXIS1	128	length of data axis 1
Array_2D_Spectrum / Axis_Array / elements	NAXIS2	139	length of data axis 2
Not assigned	PCOUNT	0	number of parameters
Not assigned	GCOUNT	1	number of groups
Not assigned	EXTNAME	‘Estimated temperature of Ryugu’	
Not assigned	DATE	'2025-01-06'	Creation date of this file
Target_Identification / name	OBJECT	'Ryugu '	Name of observed object
Array_2D_Spectrum / Element_Array / unit	BUNIT	'K'	estimated temperature of Ryugu
Time_Coordinates / start_date_time	DATE-BEG	2018-06-30T06:59:21.9'	UTC date & time of first spectrum
Time_Coordinates / stop_date_time	DATE-END	'2018-06-30T14:58:48.2'	UTC date & time of last spectrum

5.2.2 NIRS3 Geometry Data

The geometry data product is an ASCII comma separated value (CSV) file and is described in Table 7. To describe which geometry data is included in the file, there is a target body name string in the first line of the file as follows:

target: ryugu

Table 7. NIRS3 Geometry data format

Column	**Name**	**Unit**	**Description**
1	Observation time	YYYY-mm-ddTHH:MM:SS.sZ	Mid-exposure time calculated by [End time] – 0.5*[Number of stacked data] / [Chopper frequency]
2	Longitude at the center of the FOV	deg	Longitude, Latitude, and Radius of surface intercept point on a target body of the boresight vector
3	Latitude at the center of the FOV	deg	
4	Radius at the center of the FOV	km	
5	X position at the center of the FOV	km	

Column	Name	Unit	Description
6	Y position at the center of the FOV	km	X, Y, and Z in the target body-fixed coordinate of surface intercept point on a target body of the boresight vector.
7	Z position at the center of the FOV	km	
8	Longitude at the lower-right corner of the FOV	deg	Longitude, Latitude, and Radius of surface intercept point on a target body of the ray along the lower-right corner, lower-left corner, upper-left corner, and upper-right corner of the field of view.
9	Latitude at the lower-right corner of the FOV	deg	
10	Radius at the lower-right corner of the FOV	km	
11	Longitude at the lower-left corner of the FOV	deg	
12	Latitude at the lower-left corner of the FOV	deg	
13	Radius at the lower-left corner of the FOV	km	
14	Longitude at the upper-left corner of the FOV	deg	
15	Latitude at the upper-left corner of the FOV	deg	
16	Radius at the upper-left corner of the FOV	km	
17	Longitude at the upper-right corner of the FOV	deg	
18	Latitude at the upper-right corner of the FOV	deg	
19	Radius at the upper-right corner of the FOV	km	
20	Phase angle	deg	Phase angle of the field of view which is derived as phase angle at surface intercept point on a target body of the boresight vector
21	Incidence angle	deg	Incidence angle in the field of view which is calculated by taking median of incidence angles calculated for center of each sub-region of the field of view divided into 3 x 3
22	Emission angle	deg	Emission angle in the field of view which is calculated by taking median of emission angles calculated for center of each sub-region of the field of view divided into 3 x 3

Column	Name	Unit	Description
23	Distance from the NIRS3 and the target body's surface	km	Distance from the origin of the NIRS3 field-of-view to the intercept point with the target body's surface for the NIRS3's boresight vector
24	Distance from Sun to target body	km	Distance from the center of Sun to the center of the target body

5.2.3 NIRS3 Spectra with Geometry Data

The NIRS3 Spectra with Geometry Data is provided as GeoPackage file. The product contains footprint geometry data generated from NIRS3 Geometry Data. As attribute information, it includes photometric conditions such as phase angle and incidence angle, and radiance factor data. The dataset consists of three layers: RADF, STD, and metadata_info. The RADF layer corresponds to the data in the first HDU of the Level 2C FITS product, while the STD layer corresponds to the data in the second HDU. The metadata_info layer is generated from the FITS header information, which is stored as attribute fields in this layer. The attribute lists for these layers are provided in Table 8, Table 9, and Table 10, respectively.

Table 8. Attribute list of NIRS3 calibrated data (RADF layer)

Attribution	Example/Default	Description
Observation time (UTC)	2018-06-30T06:59:21.9Z	UTC date & time of observation
phase_angle	18.2	Phase angle stored in the geometry data (deg)
incidence_angle	42.3	Incidence angle stored in the geometry data (deg)
emission_angle	46.7	Emission angle stored in the geometry data (deg)
boresight_range	19.5	Distance from the origin of the NIRS3 field-of-view to the intercept point with the target body's surface for the NIRS3's boresight vector (km)
sun_distance	147575882	Distance from the center of Sun to the center of the target body (km)
wl1~128	0.0213	Radiance factor data for each channel

Table 9. Attribute list of NIRS3 calibrated data (STD layer)

Attribution	Example/Default	Description
Observation time (UTC)	2018-06-30T06:59:21.9Z	UTC date & time of observation
wl1~128	0.00118	Standard deviation data for each channel

Table 10 Attribute list of NIRS3 calibrated data (metadata_info layer)

FITS Keyword	Example/Default	Description
DATE	'2025-01-06'	Creation date of this file
FILEVERS	2.0	Version of this file format
BUNIT	'Radiance factor'	Physical unit of binary data
NSPECTRA	139	Number of spectra in this file

FITS Keyword	Example/Default	Description
DATE-BEG	2018-06-30T06:59:21.9'	UTC date & time of first spectrum
DATE-END	'2018-06-30T14:58:48.2'	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)
Source_file	hyb2_nirs3_20180630_01_cal.fit	Source data used to generate this product
Source_geometry_file	hyb2_nirs3_20180630_01_geo_v01.csv	Source file for geometry

5.2.4 NIRS3 Thermal Excess Removed Spectra with Geometry Data

The NIRS3 Thermal Excess Removed Spectra with Geometry Data product is provided as GeoPackage file. The product contains footprint geometry data generated from NIRS3 Geometry Data. As attribute information, they include photometric conditions such as phase angle and incidence angle, the estimated Ryugu surface temperature, and thermal excess removed spectra data. The dataset consists of three layers: RADF, STD, and metadata_info. The RADF layer corresponds to the data in the first HDU of the Level 2D FITS product, while the STD layer corresponds to the data in the second HDU. The metadata_info layer is generated from the FITS header information, which is stored as attribute fields in this layer. The attribute lists for these layers are provided in Table 11, Table 12, and Table 13, respectively.

Table 11. Attribute list of thermal excess removed data (RADF layer)

Attribution	**Example/Default**	**Description**
Observation time (UTC)	2018-06-30T06:59:21.9Z	UTC date & time of observation
phase_angle	18.2	Phase angle stored in the geometry data (deg)
incidence_angle	42.3	Incidence angle stored in the geometry data (deg)
emission_angle	46.7	Emission angle stored in the geometry data (deg)
boresight_range	19.5	Distance from the origin of the NIRS3 field-of-view to the intercept point with the target body's surface for the NIRS3's boresight vector (km)
sun_distance	147575882	Distance from the center of Sun to the center of the target body (km)
temperature	350	The estimated temperature (K)
wl1~128	0.0213	Thermal excess removed radiance factor data for each channel

Table 12. Attribute list of thermal excess removed data (STD layer)

Attribution	**Example/Default**	**Description**
observation time (UTC)	2018-06-30T06:59:21.9Z	UTC date & time of observation
wl1~128	0.00118	Standard deviation data for each channel

Table 13. Attribute list of thermal excess removed data (metadata_info layer)

FITS Keyword	**Example/Default**	**Description**
DATE	'2025-01-06'	Creation date of this file
FILEVERS	2.0	Version of this file format
BUNIT	'Radiance factor'	Physical unit of binary data
NSPECTRA	139	Number of spectra in this file
DATE-BEG	2018-06-30T06:59:21.9'	UTC date & time of first spectrum
DATE-END	'2018-06-30T14:58:48.2'	UTC date & time of last spectrum
CHPSTAT	'ON '	Chopper status (ON/OFF)
HEASTAT	'OFF '	Heater status (ON/OFF)

FITS Keyword	Example/Default	Description
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)
Source_file	hyb2_nirs3_20180630_01_cal.fit	Source data used to generate this product
Source_geometry_file	hyb2_nirs3_20180630_01_geo_v01.csv	Source file for geometry

5.3 Label and Header Descriptions

All data products described in this SIS contain date and time information that can be used to sort and correlate data products from other instruments. FITS header information or metadata is duplicated in the PDS4 XML label to enable analyses in either standard FITS tools or PDS4 tools.

As for GeoPackage file, there is metadata_info layer which stores FITS header of the source product to facilitate use of data. In addition, a subset of the metadata stored in metadata_info is also recorded in the PDS4 XML label. Data product labels are written in XML format and following the PDS4 Information Model.

6 Applicable Software

6.1 Utility Programs

Currently, the release of mission-specific utility programs is not planned. However, the data can still be handled using the following methods.

The FITS-format data can be read by any FITS-compatible viewer or library function.

The GeoPackage files can be opened with standard GIS software such as ArcGIS or QGIS, as well as with Python libraries like GeoPandas. We are also engaged in the development of QGIS plugins for analysis, which will be made publicly available.

The geometry files are plain text and can be opened with any standard text editor or handled with Python libraries.

6.2 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/ .

6.3 Software Distribution and Update Procedures

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

7 Appendices

7.1 References

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7.2 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.