# Origins Spectral Interpretation Resource Identification Security-Regolith Explorer (OSIRIS-REx) Project

## OSIRIS-REx Touch-and-Go Camera Suite (TAGCAMS) Data Product Software Interface Specification

UA-SIS-9.4.4-322, 7.0

Revision – 7.0

11/08/2020

## CM FOREWORD

This document is an OSIRIS-REx Project controlled document.  Changes to this document require prior approval of the OSIRIS-REx Configuration Control Board (CCB) and Configuration Management Lead (CML).  Proposed changes shall be submitted to the OSIRIS-REx Project CML, along with supportive material justifying the proposed change.

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# OSIRIS-REx Project
# TAGCAMS Data Product SIS

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DOCUMENT CHANGE LOG

| Rev/ Version Level | Description of Change | APPROVED BY | DATE DRAFT ISSUED (MM/DD/YYYY) | DATE REVIEW COMPLETED (MM/DD/YYYY) | VERSION RELEASE DATE (MM/DD/YYYY) |
|---|---|---|---|---|---|
| 1.1 | Initial Release | | | | 06/08/2015 |
| 2.0 | Update Status Packet values from Last Opcode to DVR +5V from 8-bit to 32-bit to correct error in Version 1.0 SIS | | | | 11/04/2015 |
| | Clarify description of L1 Status data product | | | | |
| | Add Status L1 data product specification | | | | |
| | Make data format descriptions consistent with TAGCAMS Users Guide 4/9/2015 | | | | |
| | In Image Format, break ATT_QUAT keyword into 4 keywords, break ATT_RATE keyword into 3 keywords | | | | |
| | Table 2. Insert row for Instrument Alignment and Calibrations | | | | |
| | Updated signature page | | | | |
| | Updated data formats descriptions consistent with TAGCAMS Users Guide July1, 2105 | | | | |
| | Added MID-OBS, DELTAOBS, INST_QA, INST_QX, INST_QY, INST_QZ, RADESYS, EQUINOX, CKQUAL, MISSPACK, CHCKSUM keywords to image header | | | | |
| | Removed TARGET, MPHASE, ACTIVITY, ATLTGTID, SCISEQID, DESCRIPT, OBJECT, OBJECTRA, OBJECTDEC, COORDSYS, LAT, and LONG keywords from the image FITS header information. | | | | |

| Rev/ Version Level | Description of Change | APPROVED BY | DATE DRAFT ISSUED (MM/DD/YYYY) | DATE REVIEW COMPLETED (MM/DD/YYYY) | VERSION RELEASE DATE (MM/DD/YYYY) |
|---|---|---|---|---|---|
| | Changed spacecraft quaternion keywords in the image FITS header from SC_Q0, SC_Q1, SC_Q2, SC_Q3 to SC_QA, SC_QX, SC_QY, SC_QZ | | | | |
| | Change ET time to be mid-observation time instead of start-observation time in the image FITS header | | | | |
| | Update section 4.3.2 to update OPNAV image delivery method to the FOB | | | | |
| | Removed reference to PDS Label Example | | | | |
| | Update INSTRU keyword to INSTRUME (FITS Standard) | | | | |
| 2.1 | Update per ECR-0047 | ECR-0047 | | | 08/10/2016 |
| 2.2 | Update per ECR-0061 Updated D-PI from Ed Beshore to Heather Enos Removed Ground Segment Manager signature | ECR-0061 | | | 11/15/2016 |
| 3.0 | Update per ECRs and changes from 2.n update cycle | | | | 03/09/2017 |
| 4.0 | Update per CR-144 | CR-144 | | | 05/03/2018 |
| 5.0 | Update per CR-323 | CR-323 | | | 10/23/2018 |
| 5.n | Update per CR-429 | CR-429 | 04/19/2019 | | 04/29/2019 |
| 6.n | Update per CR-465 | CR-465 | 09/10/2020 | | |
| | | | | | |
| | | | | | |

LIST OF TBDs/TDRs

| SECTION ID | DESCRIPTION OF TBD/TBR | DATE OF RESOLUTION |
|---|---|---|
| 2 | OSIRIS-REx Archive Volume SIS (Deprecated document, removed from applicable documents) | |
| 4.4.3 | Coordinate System Document Reference | 9/1/2015 |
| 7.5 | PDS Label Examples (to be completed after Version 1.2 is signed) Removed this document section 9/1/2015 | 9/1/2015 |
| 4.3.3 | Table 4. Data Volume – to be updated with latest rev of the DRM | |
| 4.2 | Rate of status packet data collections | 6/5/2015 |

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# 1   Purpose and Scope

The data products described by this Software Interface Specification (SIS) are the OSIRIS-REx Touch-and-Go Camera Suite (TAGCAMS) raw and uncalibrated data products. TAGCAMS consists of three similar camera heads:  NavCam 1, NavCam 2 and StowCam, each suited for a particular purpose. NavCam 1 is the primary Navigation Camera (NavCam) and is a wide-angle framing camera used for optical navigation. NavCam 2 is the primary Natural Feature Tracking Camera (NFTCam) used for landmark identification and autonomous feature tracking to aid in sample acquisition. Finally, the Stowage Camera (StowCam) is used to document the insertion of the sample collection head into the Sample Return Capsule (SRC). The OSIRIS-REx Science Processing and Operation Center located at the University of Arizona produces these data products and distributes them to the OSIRIS-REx Flight Dynamics Team, the Lockheed Martin Mission Support Area, the Science Team and the Planetary Data System.

The purpose of this document is to provide users of these data products with detailed descriptions of the products and how they were generated, including data sources and destinations. The document is intended to provide enough information to enable users to read and understand the data products. The users for whom this document is intended are the flight dynamicists and mission operations personnel who will use the data, and the scientists who will analyze the data, including those associated with the project and those in the general planetary science community.

# 2   Applicable Documents and Constraints

This Data Product SIS is consistent with the following Planetary Data System Documents:

1.  Planetary Data System Standards Reference, Version 1.7.0, September 15, 2016.
2.  PDS4 Data Dictionary – Abridged – Version 1.7.0.0, September 28, 2016.
3.  PDS4 Information Model Specification, V.1.7.0.0, September 28, 2016.

This Data Product SIS is responsive to the following OSIRIS-REx documents:

4.  OSIRIS-REx Science Data Management Plan, UA-PLN-9.4.4-004, Rev 4.0, May 26, 2016.
5.  OSIRIS-REx Science Processing and Operations Center and Planetary Data System Small Bodies Node Interface Control Document, UA-ICD-9.4.4-101, Rev 1.0, October 2013.
6.  OSIRIS-REx Mission Support Area and Science Processing and Operations Center Interface Control Document, NFP3-PN-12-OPS-6A.
7.  OIA_ORX_092, OPNAV Images (NavCam and OCAMS), April 7, 2015.
8.  OSIRIS-REx TAGCAMS Users Guide, MSSS-TAG-REQ-4401, August 18, 2016.

9.  OSIRIS-REx Science Processing and Operations Center and Flight Dynamics Interface Control Document UA-ICD-9.0.0-100, Rev 3.0, June 1, 2016.
10. OSIRIS-REx Coordinate System for Bennu, Version 2.0, January 14, 2016.

Finally, this SIS is meant to be consistent with the contract negotiated between the OSIRIS-REx Project and the Science Processing and Operations Center.

# 3   Relationship with Other Interfaces

Changes to the data products described in this SIS effect the following software, products or documents:

Table 1 - Interface Relationships

| Name | Type | Owner |
|------|------|-------|
| SPOC Database Schema | Product | SPOC |
| NavCam Image Data | Product | SPOC |
| NFTCam Image Data | Product | SPOC |
| STOWCam Image Data | Product | SPOC |
| TAGCAMS Raw Status Data | Product | SPOC |
| TAGCAMS Processed Status Data | Product | SPOC |
| SPOC Archive Packager | Software | SPOC |
| MSA-SPOC ICD | Document | MSA |
| SPOC-FDS ICD | Document | SPOC |
| OSIRIS-REx Science Data Management Plan | Document | Project |

# 4   Data Product Characteristics and Environment

## *4.1  Instrument Overview*

The OSIRIS-REx Touch-and-Go Camera Suite (TAGCAMS) is a framing imaging system to be used for navigation and engineering support imaging on the OSIRIS-REx asteroid sample return spacecraft. The instrument is provided by Malin Space Science Systems (MSSS) and is a configuration of the MSSS commercial ECAM system with custom software and optics. The instrument consists of two redundant DVR4s, each with a single M50 navigation camera head, NavCam and NFTCam respectively. The DVR with the NFTCam also has a C50 camera head (StowCam) for viewing sample stowage. Supplemental information about the generic specifications of the camera system can be found at http://www.msss.com/space-cameras/.

### 4.1.1 Observational Profile and Data Acquisition

Each instrument aboard OSIRIS-REx has specific scientific/engineering objectives in support of the overall mission objective of collecting and returning to Earth a pristine sample of the asteroid Bennu. Instrument specific observation campaigns have been outlined for each phase of the mission to support sample site selection and overall Bennu characterization. The TAGCAMS observation profile is as follows:

**Table 2 - NavCam Observation Profile**

| Mission Phase | Observation Campaign Description |
|---|---|
| *Outbound Cruise* | |
| | Instrument Health Check (All) |
| | Operational Performance (All) |
| | Instrument Alignment and Calibrations (All) |
| | Earth-Moon Flyby Observations (NavCam) |
| *Approach* | |
| | Optical Navigation Imaging (NavCam) |
| *Preliminary Survey* | |
| | Optical Navigation Imaging (NavCam) |
| *Orbit A (1.5km)* | |
| | Optical Navigation Imaging (NavCam) |
| | Instrument Alignments and Calibrations (All) |
| *Detailed Survey* | |
| | Optical Navigation Imaging (NavCam) |
| *Orbital B (1.0km)* | |
| | Optical Navigation Imaging (NavCam) |
| | Radio Science Gravity Field Monitoring (NavCam) |
| | Instrument Alignments and Calibrations (All) |
| *Reconnaissance* | |
| | Optical Navigation Imaging (NavCam) |
| *TAG-Rehearsal* | |
| | Optical Navigation Imaging (NavCam) |
| | Natural Feature Tracking (NFTCam) |
| *Sample Collection* | |
| | Optical Navigation Imaging (NavCam) |
| | Natural Feature Tracking (NFTCam) |
| | Sample Stow imaging (STOWCam) |

## *4.2 Data Product Overview*

This SIS describes image and instrument status (engineering) data acquired by TAGCAMS. Primary Optical Navigation and Natural Feature Tracking Images are stored as binary Flexible Image Transport System (FITS) files. STOWCam and other images are stored as JPEGs. Engineering Status data are stored as a single binary table file per day. Status records are acquired every 120 (default) seconds. The default value is expected to be updated in-flight to support more frequent aliveness checking. A value of 5 seconds may be more typical. The data products described by this SIS are:

1. TAGCAMS Raw Images – These images are reconstructed science packet telemetry with immediately received associated timing and spatial information in a FITS format. These images are found in the data_raw collection.
2. TAGCAMS JPEG Images – These images are the natively downlinked data primarily from the StowCam that are used to record the stowage of the

sampler head in the sample return capsule. It is possible that NavCam or NFTCam images may be downlinked as JPEGs, however these images would not be used for Optical Navigation or Natural Feature Tracking purposes and would be archived at the conclusion of the mission as supplemental information. The comment section of SPOC generated JPEG images contains the same information that is normally found in FITS image headers. Should we have any of these images to archive, they would be found in the data_supplemental collection.

3. TAGCAMS Raw Status – Raw DN value of 48 channels of camera status information. These products are found in the data_hkl0 collection.

4. TAGCAMS Processed Status –Processed (DN to engineering unit) status information in physical units. These products are found in the data_hkl1 collection.

## *4.3  Data Processing*

All OSIRIS-REx mission science data processing is performed at the University of Arizona Science Processing and Operations Center (SPOC). In addition to science processing, the SPOC stores and processes spacecraft engineering camera suite (TAGCAMS) images to standard outputs for further processing by the engineering and science team.

TAGCAMS image and status telemetry are received by the SPOC via the Lockheed Martin Mission Support Area (MSA) and the DSN. TAGCAMS data are reconstructed from telemetry frames (packets) and stored in the SPOC data repository as raw data (OREx Level 0). Level 0 raw status data are then processed to convert digital number values to engineering units resulting in the L1 processed status data product. This product is also stored in the SPOC data repository.

Raw image data are approximately 10.772MB in size. Immediately received spacecraft orientation information (SPICE S/C C-kernels) taken concurrently with the imagery is processed to provide timing and attitude data that is attached to the raw images. Status data are acquired nominally once every 120 seconds (although may be taken more frequently) and are packaged into a single data file per day. Status file size dependent on the number of reading taken per day, but with nominal settings is on the order of 39Kb for both the L0 raw and L1 processed products.

### 4.3.1  Data Processing Level

Table 3 shows the OSIRIS-REx data processing levels of all science data products described by this SIS. Correlation to NASA and CODMAC data processing levels and definitions can be found in Appendix 7.1. Calibration file data processing levels are not discussed, as calibration files require special production techniques.

**Table 3 - TAGCAMS Data Processing Levels**

| Data Product | NASA Product Level | OSIRIS-REx Data Processing Level | Description |
|---|---|---|---|
| TAGCAMS Raw FITS Images | Level-0 | L0 | Reconstructed Telemetry with associated timing and attitude information |
| TAGCAMS JPEG Images | Level-0 | L0 | Reconstructed Telemetry with associated timing and attitude information |
| TAGCAMS Raw Status Binary Table Data | Level-0 | L0 | Reconstructed telemetry with engineering DN values |
| TAGCAMS Processed Status Binary Table Data | Level-1 | L1 | DN engineering values converted to physical units |

## 4.3.2  Data Product Generation

As mentioned previously, all OSIRIS-REx science data processing is completed at the SPOC located at the University of Arizona. The decision was made early in the mission lifecycle, that all processing would be centralized to facilitate the relatively quick turn-around needed by the science and operations teams to make tactical decisions about sample site selection. NavCam and NFTCam images will also be processed by the SPOC and made available to FDS and the MSA through the Flight Operations Bucket (FOB) that uses e-mail to notify interested users. FDS and MSA may also use the OSIRIS-REx WebQuery Tool to identify and access NavCam, NFTCam and STOWCam image and status records of interest from the SPOC data repository. Raw NavCam images will be available to FDS within 30 minutes of receipt of the images by the SPOC.

### 4.3.2.1 L0 and L1 Processing

TAGCAMS image and status telemetry are received from the DSN and passed through the LM MSA Front End Data System (FEDS) to the SPOC FEDS. The SPOC ingests, sorts, reconstructs, decompresses (if necessary) and stores telemetry data as raw observational data that includes observations, timing, spatial and spacecraft attitude information. Timing, spatial and spacecraft attitude information are attached to image headers using spacecraft pointing information (quaternions) that has been received from the spacecraft just prior to receipt of image telemetry. This information is in the form of a SPICE C-kernel that is produced at the Navigational and Ancillary Information Facility (NAIF) and made available to the SPOC via the Flight Operations Bucket (FOB). Spacecraft attitude information is also received in the NavCam and NFTCam telemetry via a 72-byte attitude header attached to images. The C-kernel, attitude header and other

timing information is processed by the SPOC to yield the timing, spatial and ancillary information to be attached to the Level 0 raw image headers. A list of all image header values can be found in Section 5.2. Complete image files are sent from the SPOC to the FOB, and interested users are notified by e-mail that images are available

STOWCam images may be received from the spacecraft via telemetry in a JPEG format. These images are received and stored at the SPOC in the same way as the NavCam or NFTCam data are received. The JPEG images will have timing and attitude data attached to the JPEG comment. The included meta-data will be identical to the meta-data provide in the NavCam and NFTCam FITS headers and PDS labels.

TAGCAMS Status data (housekeeping, hk) are processed through the SPOC to sort and record status records as DN values. The status DN values are then converted into physical units (temperatures, voltages, currents) according to instrument specific conversion polynomials (L0 raw to L1 processed processing). The converted values are then stored along with the original values in the SPOC data repository. Once stored in the SPOC data repository L0 and/or L1 status information can be written to files as specified in Section 5.

Once processing has been completed, images are uploaded to the FOB, and FDS and MSA are notified by e-mail that images are ready. Consumers may then also use the OSIRIS-REx WebQuery Tool to identify and download images or status products of interest. The entire process from receipt of image and attitude data from the MSA to e-mail notification takes less than 30 minutes.

### 4.3.3  Data Flow

Raw and processed 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 SPOC data repository system. The OSIRIS-REx Instrument, Operations, Flight Dynamics and Science Teams access the data repository through a query tool.

Table 4 shows the expected TAGCAMS data collection by camera and mission phase. The number of expected images is specified as well as the expected data volume of the processed data products. (Note: 1944 x 2592 pixels, at 16-bits per pixel plus header information equals 11.04 MB per image raw, raw data volume is currently calculated as this number times the number of images. Also note that the 11.04MB used for volume calculations is slightly larger than current data product size of 10.772MB, and therefore should be thought of as an upper bound)

**Table 4 - TAGCAMS Data Products/ Volume by Mission Phase**

| Mission Phase | Launch | Cruise | Approach | Prelim Survey | Orbit A | Detailed Survey | Orbit B | Recon | TAG Rehearsal | Sample Collection |
|---|---|---|---|---|---|---|---|---|---|---|
| NavCam # Images | 75 | 450 | 100 | 680 | 1054 | 1386 | 191 | 2210 | 924 | 308 |
| NavCam Raw (MB) | 828 | 4968 | 1104 | 7507 | 11636 | 15301 | 2109 | 24398 | 10201 | 3400 |

| Mission Phase | Launch | Cruise | Approach | Prelim Survey | Orbit A | Detailed Survey | Orbit B | Recon | TAG Rehearsal | Sample Collection |
|---|---|---|---|---|---|---|---|---|---|---|
| NFTCam # Images | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | 98 | 203 |
| NFTCam Raw (MB) | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | 1082 | 2241 |
| STOWCam # Images | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | 270 |
| STOWCam Raw (MB) | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | 2981 |
| Status # of Observations | 720 | 4320 | 67680 | 14400 | 22320 | 45360 | 43200 | 70560 | 30240 | 16560 |
| Status (MB) | 0.14 | 0.86 | 13.54 | 2.88 | 4.46 | 9.07 | 8.64 | 14.11 | 6.05 | 3.31 |

It is possible that more than one version of the Raw or Processed data products maybe produced. This is not intended to be routine but may occur if one or more calibration files needs to be updated. Any changes to the data processing pipeline are configuration controlled and follow the standard OSIRIS-REx configuration control process. Re-processed images are identified in the filename (see Section 4.3.4) and are noted as to why re-processing was necessary.

## 4.3.4  Labeling and Identification

OSIRIS-REx science data products are named according to the OSIRIS-REx Naming Conventions Document (UA-HBK-9.4.4-905). The following paragraphs are excerpts of this document that describe how NAVCAM image and housekeeping files are named. The generalized file naming convention is:


UTC Time(21) + "_" + Instrument(3) + "_" + Product Type + "." + PDS Type

The UTC time is the time of data acquisition derived from the spacecraft clock time.

The instrument is one of the following:

**Table 5 - Instrument Abbreviations**

| Instrument Name | Abbreviation |
|---|---|
| NavCam | ncm |
| NFTCam | nft |
| STOWCam | sto |

The product type is:

**Table 6 - Data Product Type**

| Product Type | Definition |
|---|---|
| L0 | Raw Image, reconstructed telemetry |
| L0J | JPEG Image, reconstructed telemetry |

| L0S | Raw Status Packet |
|-----|-------------------|
| L1S | Status Packet DNs converted to physical units |

The PDS type file suffix indicates the type of file the data product is. TAGCAMS data products have one of three file type suffixes, .FITS for image files, .DAT for binary status tables or .JPG for JPEGS.

It should be noted that early data products delivered to the PDS may contain a version number after the product type. This is an internal version number and should be disregarded.

All TAGCAMS image and status files are created with detached PDS labels. The labels are PDS4 compliant XML format labels with the required sections for ARRAYs and TABLE_BASE.

Image data products contain headers. The header meta-data are identical for all TAGCAMS image types and contain information about when and how the image was acquired. Data processing status is also indicated in the header.

## *4.4  Standards Used in Generating Data Products*

### 4.4.1  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 both a data product format PDS peer review and a data product production pipeline PDS peer review to ensure compliance with applicable standards.

All 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 .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 is:

Product_Observational
      Identification_Area - attributes that identify and name an object.
            Logical_Identifier - name/location of file
            Version_ID - version of product
            Title – Descriptive name of product
            Information_model_version - version of PDS4 information model used to create product
            Product_Class - attribute provides the name of the product class (Product_Observational)
            Modification_History - attributes describing changes in data product
      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 to facilitate data discovery
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 - mission specific attributes needed to describe data product
File_Area_Observational - 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
Table_Binary - defines a simple binary table.

Information in the preceding paragraphs was distilled from the PDS4 Information Model provided by PDS. Additional information on PDS4 product labels can be found by selecting "How to Approach a PDS4 Data Set" on the Small Bodies Node web site at http://sbn.pds.nasa.gov.

## 4.4.2 Time Standards

Time Standards used by the OSIRIS-REx mission conform to PDS time standards. The spacecraft clock (SCLK) reference is 1/1/2000 12:00:00 UTC, with a minimum range date from 1/1/2010 to 1/1/2030. Onboard time tagging is the standard 32-bit seconds and 16-bit subseconds. The spacecraft clock string reported in various data products contains the spacecraft clock partition at a number before a slash as well as the seconds dot subseconds, e.g. 3/0545586959.34560. It is possible that the seconds portion of the sclk string at the beginning of a science sequence may be noticeably small (seconds <100), this is due to data collections prior to an instrument - spacecraft clock time synchronization. All OSIRIS-REx data products contain both the spacecraft clock time of data acquisition and a conversion to UTC to facilitate comparison of data products. In the case of TAGCAMS spacecraft clock time is given at the start of the acquisition. TAGCAMS data also contain Ephemeris Time (ET) and Ground Receive Time (GRT) to facilitate processing.

## 4.4.3 Coordinate Systems

All coordinate systems used by the OSIRIS-REx mission conform to IAU standards.  A complete discussion of the coordinate systems and how they are deployed in the mission can be found in the document "OSIRIS-REx Coordinate System Plan" (AP-10) archived in the OSIRIS-REx archive mission bundle documents collection. This document is consistent with the coordinate system plans found in other internal project documents:

1. PLA-OSIRIS-REx-SC-CDRL-0153, Coordinate Systems Definition Document
2. PLA-OSIRIS-REx-SPEC-0010, OSIRIS-REx Trajectory Standards Document

Internal project documents will not be archived but are included here as a reference for project personnel.

### 4.4.4  Data Storage Conventions

FITS data products are stored according to the FITS 3.0 Standard.  Binary data products are stored as big-endian (MSB) binary. Data formats are explicitly described in Section 5 of the document.

## *4.5  Data Validation*

The SPOC has a comprehensive Verification and Validation Plan for all software used at or developed by the SPOC. All software is configuration controlled and any changes made follow the SPOC Configuration Control Plan, which includes substantive testing of changes. During day-to-day production of L0 data products from telemetry, check sums and spot checks are used to validate that software is producing data products correctly.

In addition to software verification and validation, each OSIRIS-REx 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. The SPOC Configuration Control Plan governs any changes, should they be needed.

When data is prepared for submission to the PDS, the SPOC will use automated PDS / mission-provided validation tools for conformance to the PDS4 standards. Validation of the scientific data contained within the NavCam data products will be performed by OSIRIS-REx team members.

# 5  Detailed Data Product Specification

## *5.1  Data Product Structure and Organization*

The OSIRIS-REx data archive is organized by instrument. The TAGCAMS portion of the archive is organized with collections for NavCam, NFTCam, StowCam, and Housekeeping (Status). Scientific image data is stored as a 2-part file with a detached PDS label. The detached PDS labels are PDS4 compliant XML label that describes the contents of the image file. See Appendix 7.5 for an example label.
The 2-part FITS image file consists of:

1.  A primary ASCII header of keyword-value pairs
2.  A primary binary 2-d array (image)

StowCam data may be transmitted from the spacecraft as JPEG images.  These images are archived as supplementary information in JPEG format with meta-data attached.  A PDS4 compliant XML label that describes the contents of the image file. See Appendix 7.5 for an example label.

L0 and L1 Status Data are stored in the TAGCAMS DATA_HK_(L0/1) collections as binary tables with a detached PDD4 compliant XML label. The detached PDS labels describe the specific structure of the binary table. The binary tables contain 53 fields and have fixed-length records of 200 bytes. Status data is packaged as one Earth day's-worth of status records, with a nominal file size of 720 records per day. The number of records

is strictly dependent on the commanded rate of status packet acquisition, with a nominal rate of 1 packet every 120 seconds.

The TAGCAMS bundle directory structure is as follows:
orex.tagcams
       data_hkl0 – raw level 0 status (housekeeping)
            cruise_1
            ega
            cruise_2
            approach
            preliminary survey
            orbital a,
            detailed survey
            orbital b
            reconnaissance
            rehearsal
            TAG (Touch-and-go)
       data_hkl1 – reduced level 1 status (housekeeping)
            cruise_1
            ega
            cruise_2
            approach
            preliminary survey
            orbital a,
            detailed survey
            orbital b
            reconnaissance
            rehearsal
            TAG (Touch-and-go)
       data_raw – level 0 raw image products
            cruise_1
            ega
            cruise_2
            approach
            preliminary survey
            orbital a,
            detailed survey
            orbital b
            reconnaissance
            rehearsal
            TAG (Touch-and-go)
       document – TAGCAMS documentation

## *5.2 Data Format Descriptions*

### 5.2.1 Images

Optical Navigation and NFTCam image data are stored in FITS file formats with a single header and data unit (HDU). Header keywords are filled as data processing occurs either by the SPOC Ingest/Digest processing or by the SPOC Spatial Generation processing. The FITS image header that contains meta-data describing the conditions under which the image was taken is described in Table 7. The meta-data are also translated into the PDS4 XML label and appears in the Observation_Area Class. Descriptions of attributes in the

table below are either abbreviated or truncated in the product FITS files due to line length limitations in the FITS standards. For all image products sample refers to the fastest changing axis, and line refers to the second fastest changing axis.

**Table 7 - Data Format Descriptions: Image Attributes**

| Attribute Name | FITS Keyword | Units | Description |
|---|---|---|---|
| element_array.data_type | BITPIX | | number of bits per data pixel (16 for L0, -32 for L1) |
| axes | NAXIS | | number of data axes |
| axis_array.sequence_number | NAXIS1 | | length of data axis 1 |
| axis_array.sequence_number | NAXIS2 | | length of data axis 2 |
| n/a - FITS specific | EXTEND | | FITS dataset may contain extensions |
| n/a - FITS specific | BZERO | | offset data range to that of unsigned short |
| n/a - FITS specific | BSCALE | | 1= default scaling factor |
| investigation_area.name | MISSION | | Mission: OSIRIS-REx |
| observing_system.name | HOSTNAME | | Spacecraft hostname |
| observing_system_component.name | INSTRUME | | Instrument: OSIRIS-REx Navigation Camera (or OCAMS or NFTCAM if either instrument is used for OPNAV purposes) ncm = NavCam, nft = NFTCAM, sto = STOWCAM, map= MapCam, pol= PolyCam, sam = SamCam |
| n/a - FITS specific | ORIGIN | | University of Arizona Science Processing and Operations Center |
| mission_area.apid | APID | | Spacecraft Application Identification Number used to indicate the type of data packet received from the spacecraft. |
| mission_area.ground_receipt_time | GRT | | Ground Receive Time in coordinated universal time (YYYY-MM-DDThh:mm:ss.sss) |
| mission_area.spoc_date | SPOCDATE | | Coordinated Universal Time file was created by SPOC (YYYY-MM-DDThh:mm:ss.sss) |
| mission_area.creator | CREATOR | | SPOC GIT repository identifier that uniquely identifies code version used to create the data product. |
| mission_area.date_of_observation | DATE_OBS | | YYYY-MM-DDThh:mm:ss.sss observation start, Timestamp (in coordinated universal |

| Attribute Name | FITS Keyword | Units | Description |
|---|---|---|---|
| | | | time) from image acquisition, derived from the second and sub-second values. This is the timestamp at the start of the observation. |
| mission_area.mid_obs | MIDOBS | | Spacecraft mid-observation time (YYYY-MM-DDThh:mm:ss.sss) in coordinated universal time calculated by (DATE_OBS + .5*EXPTIME). |
| mission_area.sclk_string | SCLK_STR | | Spacecraft Clock String at start of observation time. SCLK_STR is formatted as clock partition/seconds.subseconds. |
| mission_area.mid_obs_et | ET | Sec | Ephemeris Time (seconds past J2000 epoch, TDB - Barycentric Dynamical Time) at the mid-observation time. |
| mission_area.exposure | EXPTIME | Sec | Actual exposure time in seconds, derived from commanded exposure time. |
| mission_area.delta_obs | DELTAOBS | Sec | Delta between mid-observation time and spacecraft clock string (Mid-observation time) (SCLK_STR timestamp), in seconds used to verify exposure time. |
| geom.qcos | SC_QA | | Spacecraft quaternion in J2000 ($q0 = \cos(t/2)$) obtained from the NAIF provided C kernel. SPICE convention conversion to 3x3 matrix transforms vector in spacecraft frame to J2000 frame. This value is calculated using the SPICE interface and numbers will be accurate to the accuracy of the SPICE kernels. Calculations will be based on the MIDOBS time. SPICE quaternion standard is that Q0 is the scalar value. |
| geom.qsin1 | SC_QX | | Spacecraft quaternion in J2000 ($q1 = \sin(theta/2)$) obtained from the NAIF provided C kernel. SPICE convention conversion to 3x3 matrix transforms vector in spacecraft frame to J2000 frame. This value is calculated using the SPICE interface and numbers will be |

| Attribute Name | FITS Keyword | Units | Description |
|---|---|---|---|
|  |  |  | accurate to the accuracy of the SPICE kernels. Calculations will be based on the MIDOBS time. SPICE quaternion standard is that Q0 is the scalar value. |
| geom.qsin2 | SC_QY |  | Spacecraft quaternion in J2000 (q2= sin(theta/2)) obtained from the NAIF provided C kernel. SPICE convention conversion to 3x3 matrix transforms vector in spacecraft frame to J2000 frame. This value is calculated using the SPICE interface and numbers will be accurate to the accuracy of the SPICE kernels. Calculations will be based on the MIDOBS time. |
| geom.qsin3 | SC_QZ |  | Spacecraft quaternion in J2000 (q3= sin(theta/2)) obtained from the NAIF provided C kernel. SPICE convention conversion to 3x3 matrix transforms vector in spacecraft frame to J2000 frame. This value is calculated using the SPICE interface and numbers will be accurate to the accuracy of the SPICE kernels. Calculations will be based on the MIDOBS time. |
| geom.qcos0 | INST_QA |  | Instrument quaternion in J2000 (q0 = cos(t/2)) obtained from the NAIF provided C kernel. SPICE convention conversion to 3x3 matrix transforms vector in instrument frame to J2000 frame. This value is calculated using the SPICE interface and numbers will be accurate to the accuracy of the SPICE kernels. Calculations will be based on the MIDOBS time. SPICE quaternion standard is that Q0 is the scalar value. |
| geom.qsin1 | INST_QX |  | Instrument quaternion in J2000 (q1= sin(theta/2)) obtained from the NAIF provided C kernel. SPICE convention conversion to 3x3 matrix transforms vector in instrument frame to J2000 |

| Attribute Name | FITS Keyword | Units | Description |
|---|---|---|---|
| | | | frame. This value is calculated using the SPICE interface and numbers will be accurate to the accuracy of the SPICE kernels. Calculations will be based on the MIDOBS time. |
| geom.qsin2 | INST_QY | | Instrument quaternion in J2000 (q2= sin(theta/2)) obtained from the NAIF provided C kernel. SPICE convention conversion to 3x3 matrix transforms vector in instrument frame to J2000 frame. This value is calculated using the SPICE interface and numbers will be accurate to the accuracy of the SPICE kernels. Calculations will be based on the MIDOBS time. |
| geom.qsin3 | INST_QZ | | Instrument quaternion in J2000 (q3= sin(theta/2)) obtained from the NAIF provided C kernel. SPICE convention conversion to 3x3 matrix transforms vector in instrument frame to J2000 frame. This value is calculated using the SPICE interface and numbers will be accurate to the accuracy of the SPICE kernels. Calculations will be based on the MIDOBS time. |
| mission_area.ctype1 | CTYPE1 | | Coordinate type for reference pixel, values are either "RA---TAN" = gnomic or tangent plane or "SIP" - simple image polynomial. |
| mission_area.ctype2 | CTYPE2 | | Coordinate type for the reference pixel, values are either "DEC--TAN" = gnomic or tangent plane or "SIP" - simple image polynomial. |
| geom.right_ascension_angle | CRVAL1 | Deg | Right ascension of the reference pixel or boresight vector in degrees. |
| geom.declination_angle | CRVAL2 | Deg | Declination of reference pixel or boresight vector in degrees. |
| mission_area.cunit1 | CUNIT1 | Deg | Units for the reference pixel 1 |
| mission_area.cunit2 | CUNIT2 | Deg | Units for the reference pixel 2 |

| Attribute Name | FITS Keyword | Units | Description |
|---|---|---|---|
| geom.horizontal.coordinate_pixel | CRPIX1 | | X coordinate pixel number of the boresight of the image of the reference point to which the projection and the rotation refer. |
| geom.vertical.coordinate.pixel | CRPIX2 | | Y coordinate pixel number of the boresight of the image of the reference point to which the projection and the rotation refer. |
| mission_area.cd1_1 | CD1_1 | Deg | Change in RA per pixel along first axis (sample) evaluated at reference pixel |
| mission_area.cd1_2 | CD1_2 | Deg | Change in RA per pixel along second axis (line) evaluated at reference pixel |
| mission_area.cd2_1 | CD2_1 | Deg | Change in DEC per pixel along first axis (sample) evaluated at reference pixel |
| mission_area.cd2_2 | CD2_2 | Deg | Change in DEC per pixel along second axis (line) evaluated at reference pixel |
| mission_area.bennana | n/a | Deg | Azimuth of the North polar Axis of the target named in FITS keyword BENNURDT (typically Bennu), positive from the +NAXIS2 direction toward the +NAXIS1 direction; see also BENNURDQ for a statement of the quality of this value; assumes undistorted optics; will be -999 if the calculation fails |
| mission_area.bennu_ra | n/a | Deg | Right Ascension of the vector, expressed in the Earth Mean Equator of the J2000 Epoch, from the ORX spacecraft toward the target named in FITS keyword BENNURDT (typically Bennu); see also BENNURDQ for a statement of the quality of this value |
| mission_area.bennu_dec | n/a | Deg | Declination of the vector, expressed in the Earth Mean Equator of the J2000 Epoch, from the ORX spacecraft toward the target named in FITS keyword BENNURDT (typically Bennu); see also BENNURDQ for a statement of the quality of this value |
| mission_area.bennu_naxis1_offset | n/a | Pixel | Approximate offset from CRPIX1 pixel in +NAXIS1 direction of the location of the center of the target |

| Attribute Name | FITS Keyword | Units | Description |
|---|---|---|---|
| | | | named in FITS keyword BENNURDT (typically Bennu); see also BENNURDQ for a statement of the quality of this value; assumes undistorted optics |
| mission_area.bennu_naxis2_offset | n/a | Pixel | Approximate offset from CRPIX2 pixel in +NAXIS2 direction of the location of the center of the target named in FITS keyword BENNURDT (typically Bennu); see also BENNURDQ for a statement of the quality of this value; assumes undistorted optics |
| mission_area.bennu_radec_target | n/a | | Target for the BENNURA, BENNUDEC, BENNUNX1 and BENNUNX2 FTIS keywords; typically, BENNU; may be NONE if the calculation failed. Target is not required to be in the field of view. |
| mission_area.bennu_radec_quality | n/a | | (Quality: provenance) for the BENNURA, BENNUDEC, BENNUNX1, BENNUNX2 FITS keywords. This will be one of three values: (BEST: SPK), meaning the geometry was obtained from SPICE SP-Kernels; (POOR: osculating elements; +/- 1E6km), meaning the geometry was obtained from osculating orbital elements of Bennu w.r.t the Sun, and will have uncertainties of order 1E6km; (NONE: FAILURE), meaning both the SPK and elements methods failed; the parentheses, (), are only delimiters here and not part of the quality:provenance values. |
| mission_area.radesys | RADESYS | | International Celestial Reference System (ICRS) |
| geom.name | EQUINOX | | Epoch of mean equator and equinox (J2000) |
| geom.celestial_north_clock_angle | ORIENTAT | Deg | The angle (in degrees) between the image positive y-axis and celestial north. |
| geom.spice_kernel_file_name | META_KER | | Metakernel that holds all the spice kernels used for processing |
| mission_area.ckqual | CKQUAL | | Quality of C-Kernel (nominal = |

| Attribute Name | FITS Keyword | Units | Description |
|---|---|---|---|
| | | | 'RECONSTRUCT', contingency = 'PREDICT') |
| mission_area.misspxls | MISSPXLS | | Count of pixels where data is missing in the image |
| mission_area.checksum_result | CHCKSUM | | The pass/fail state of the image check sum |
| mission_area.quaternion0 | ATTQUAT0 | | Spacecraft quaternion in J2000 (q0 = cos(t/2)) obtained at the ATT_TIME. Quaternion values are telemetry values based on the ATT_TIME parameter and may differ from the SPICE calculated quaternions at mid-observation time by several seconds. This value is to be used with caution as the timing many not be for the boresight of the corresponding image. SPICE quaternion standard is that Q0 is the scalar value which is followed here. |
| mission_area.quaternion1 | ATTQUAT1 | | Spacecraft quaternion in J2000 (q1= sin(theta/2) obtained at the ATT_TIME. Quaternion values are telemetry values based on the ATT_TIME parameter and may differ from the SPICE calculated quaternions at mid-observation time by several seconds. This value is to be used with caution as the timing many not be for the boresight of the corresponding image. |
| mission_area.quaternion2 | ATTQUAT2 | | Spacecraft quaternion in J2000 (q2= sin(theta/2))obtained at the ATT_TIME. Quaternion values are telemetry values based on the ATT_TIME parameter and may differ from the SPICE calculated quaternions at mid-observation time by several seconds. This value is to be used with caution as the timing many not be for the boresight of the corresponding image. |
| mission_area.quaternion3 | ATTQUAT3 | | Spacecraft quaternion in J2000 (q3= sin(theta/2)) obtained at the ATT_TIME. Quaternion values are telemetry values based on the |

| Attribute Name | FITS Keyword | Units | Description |
|---|---|---|---|
| | | | ATT_TIME parameter and may differ from the SPICE calculated quaternions at mid-observation time by several seconds. This value is to be used with caution as the timing many not be for the boresight of the corresponding image. |
| mission_area.att_rate_x | ATTRATE1 | | The x-axis component of the spacecraft angular rate (rad/s) in spacecraft body frame at the ATT_TIME |
| mission_area.att_rate_y | ATTRATE2 | | The y-axis component of the spacecraft angular rate (rad/s) in spacecraft body frame at the ATT_TIME |
| mission_area.att_rate_z | ATTRATE3 | | The z-axis component of the spacecraft angular rate (rad/s) in spacecraft body frame at the ATT_TIME |
| mission_area.att_time | ATT_TIME | | The spacecraft clock time when attitude data was collected |
| mission_area.powered_on_dvr | DVRON | | Touch and Go Camera Suite Powered On Digital Video Recorder: 0 = TAGCAMS_DVR_1,1 = TAGCAMS_DVR_2 |
| mission_area.image_len | IMG_LEN | Bytes | Recorded image length |
| mission_area.sequence_id | TCSEQID | | TAGCAMS commanded sequence identifier |
| mission_area.image_id | TCIMGID | | TAGCAMS Commanded Image Identifier |
| mission_area.seconds | TCSCLKS | Sec | TAGCAMS Mini Header spacecraft clock time in seconds. The spacecraft clock time tag is the start of exposure for line 1 of the image plus or minus 0.1 seconds. |
| mission_area.subseconds | TCSCLKSS | 1/65535$^{ths}$ | TAGCAMS Mini Header spacecraft clock time fractional numerator out of 65535. The spacecraft clock time tag is the start of exposure for line 1 of the image plus or minus 0.1 seconds. |
| mission_area.img_cmd_opcode | TCOPCODE | | TAGCAMS Command 8-bit Operations Code (Opcode) |
| mission_area.img_cmd_cam | TCCAM | | Specifies which camera to use. Legal values are 1 (for both DVR-4s) and 2 (for the DVR-4 with StowCam attached). |

| Attribute Name | FITS Keyword | Units | Description |
|---|---|---|---|
| mission_area.img_cmd_seq | TCSEQ | | The sequence identifier to assign to these images. Legal values are 1 to 255. |
| mission_area.img_cmd_num_imgs | TCN_IM | | The number of images to acquire in this sequence. Legal values are 1 to 255. |
| mission_area.img_cmd_exp | TCEXP | | The commanded 16-bit exposure time for each image. For values from 0 to 5000, exposure time is in units of 0.1 msec, providing exposures of 0 to 0.5 seconds. From 5001 to 65535, exposure time is in units of 0.5msec with an offset of 0.5 seconds, so that the maximum exposure time is 0.5e-3*(65535-5000) +0.5= 30.7675 seconds. |
| mission_area.img_cmd_int | TCINT | Sec | The 16-bit time interval between images in seconds, from 0 (as fast as possible) to 65535 seconds. |
| mission_area.img_cmd_sx | TCSX | Pixel | The starting X of the area of the image sensor to read, in multiples of 16 pixels. If 0 is used for all values, then the full frame is read. (Full frames = 2592x1944 pixels with dark pixels off, 2752x2004 pixels with dark pixels on. Other values are valid if windowing is enabled) Reading outside the bounds of the image array is illegal. |
| mission_area.img_cmd_sy | TCSY | Pixel | The starting Y of the area of the image sensor to read, in multiples of 16 pixels. If 0 is used for all values, then the full frame is read (Full frame = 2592x1944 pixels with dark pixels off, 2752x2004 pixels with dark pixels on. Other values are valid if windowing is enabled) Reading outside the bounds of the image array is illegal. |
| mission_area.img_cmd_w | TCW | Pixel | The starting Z of the area of the image sensor to read, in multiples of 16 pixels. If 0 is used for all values, then the full frame is read (Full frame = 2592x1944 pixels with dark pixels off, 2752x2004 pixels with dark pixels on. Other values are valid if |

| Attribute Name | FITS Keyword | Units | Description |
|---|---|---|---|
| | | | windowing is enabled) Reading outside the bounds of the image array is illegal. |
| mission_area.img_cmd_h | TCH | Pixel | The starting height of the area of the image sensor to read, in multiples of 16 pixels. If 0 is used for all values, then the full frame is read (Full frame = 2592x1944 pixels with dark pixels off, 2752x2004 pixels with dark pixels on. Other values are valid if windowing is enabled) Reading outside the bounds of the image array is illegal. |
| mission_area.img_cmd_mode | TCMODE | | 0- 12-to-8 bit companding on/off; 1-3 companding mode (0 = square root, 1-7 linear divide by exp2(N-1)); 4- dark pixels on/off; test pattern control (on=1/off=0); 6 enable additional sensor register settings (enable=1/disable=0); 7 reserved |
| mission_area.img_cmd_gain | TCGAIN | Gain Factor | The sensor analog gain value. Legal values are 8-31 and 40-63. Values from 8 to 31 specify gains in the range 1 to 3.875 in steps of 0.125; values from 40 to 63 specify gain in the range 2 to 7.75 in steps of 0.25. Gains in the range (2, 4) are commanded using the first range |
| mission_area.img_cmd_subsample | TCSSMPL | | The subsampling to use when acquiring the image. Legal values for this field are 0 (no subsampling), 1 (bin 2x2), 4 (bin 4x4), and 16-23 (skip (N-14)*(N-14)). |
| mission_area.img_cmd_compress | TCCOMP | | Take image hardware image compression mode. 0 means no compression; 0xff means lossless compression; 1-99 means JPEG compression quality N, 4:2:2 color subsampling if applicable; 101-199 means JPEG compression quality N, 4:4:4 color subsampling if applicable. Hardware compression is only available in 8-bit mode; if companding |

| Attribute Name | FITS Keyword | Units | Description |
|---|---|---|---|
| | | | is turned off, this value must be 0. |
| mission_area.bpp | TCBPP | bits/pixel | Records the pixel depth of the transmitted image. If the image was initially acquired as 12 bits, then it can be sent as 12 bits or 8 bits. If the image was initially acquired as 8 bits, then this value is ignored, and the output is always 8 bits. The companding mode is only significant if companding is turned on. Keyword may be blank if the transmit-image-raw command was used to acquire image. |
| mission_area.trans_cmd_compression | TCTRCOMP | | Compression mode. 0 means no compression; 0xff means lossless compression; 1-99 means JPEG compression quality N, grayscale; 101-199 means JPEG compression quality N, 4:2:2 color subsampling. JPEG compression can only be applied to 8-bit data. Note that if a color camera's image is compressed as grayscale, compression efficiency may be degraded. Keyword may be blank if the transmit-image-raw command was used to acquire image. |
| mission_area.trans_cmd_summing | TCSUM | | Turns 2x2 summing on or off. Legal values are 1 (no summing) and 2 (2x2 summing.) Summing can only be applied to 8-bit data. Images with both compression and summing selected will be compressed but not summed. Keyword may be blank if the transmit-image-raw command was used to acquire image. |
| mission_area.camera_head_temp | TCCHTEMP | DN | Camera head temperature in digital number (if available). |
| mission_area.spare | TCSPR | | Spare |
| mission_area.image_size_estimate | TCINSZ | Bytes | initial size estimate for image in flash |

## 5.2.2  L0 Status Data Product

The L0 status data product is the raw engineering data generated by TAGCAMS.

Table 8 - L0 Status Data Product Fields

| Fields Name | Field Number | Fields Locations (Start Byte) | Data Type | Field Length (bits) | Field Length (bytes) | Units | Description |
|---|---|---|---|---|---|---|---|
| seconds_raw | 1 | 1 | UnsignedMSB4 | 32 | 4 | seconds | seconds portion of the timestamp of the status reading |
| subseconds_raw | 2 | 5 | UnsignedByte | 8 | 1 | milliseconds | milliseconds portion of the timestamp of the status reading |
| spare0 | 3 | 6 | UnsignedByte | 8 | 1 | n/a | spare |
| spare1 | 4 | 7 | UnsignedByte | 8 | 1 | n/a | spare |
| command_opcode | 5 | 8 | UnsignedByte | 8 | 1 | n/a | opcode of command producing this packet, or 0x20 for status |
| last_opcode | 6 | 9 | UnsignedMSB4 | 32 | 4 | n/a | last opcode received |
| valid_cmds_cnt | 7 | 13 | UnsignedMSB4 | 32 | 4 | n/a | valid commands received since power-on |
| rejected_cmds_cnt | 8 | 17 | UnsignedMSB4 | 32 | 4 | n/a | rejected commands received since power-on |
| inst_sw_ver | 9 | 21 | UnsignedMSB4 | 32 | 4 | n/a | instrument software version |
| checksum | 10 | 25 | UnsignedMSB4 | 32 | 4 | n/a | checksum of instrument software |
| num_bad_flash_blocks | 11 | 29 | UnsignedMSB4 | 32 | 4 | n/a | number of bad flash blocks |
| num_free_flash_blocks | 12 | 33 | UnsignedMSB4 | 32 | 4 | n/a | number of free flash blocks |
| total_usable_flash_blocks | 13 | 37 | UnsignedMSB4 | 32 | 4 | n/a | total number of usable flash blocks |
| num_products_in_use | 14 | 41 | UnsignedMSB4 | 32 | 4 | n/a | number of products in use |
| num_pages_used | 15 | 45 | UnsignedMSB4 | 32 | 4 | n/a | number of flash pages used in products |
| flash_err_cnt | 16 | 49 | UnsignedMSB4 | 32 | 4 | n/a | flash error count in last built-in self-test |
| dram_errors | 17 | 53 | UnsignedMSB4 | 32 | 4 | n/a | Dynamic random access memory errors in last built-in self-test |
| num_correctable_ecc_errors | 18 | 57 | UnsignedMSB4 | 32 | 4 | n/a | number of correctable error correcting code (ECC) errors |
| num_sequences_stored | 19 | 61 | UnsignedMSB4 | 32 | 4 | n/a | number of sequences stored in flash |
| camera_statu | 20 | 65 | UnsignedMSB4 | 32 | 4 | n/a | camera status as bitmask |
| num_uncorrectable_ecc_errors | 21 | 69 | UnsignedMSB4 | 32 | 4 | n/a | number of uncorrectable error correcting code (ECC) errors |
| num_camera_head_upsets | 22 | 73 | UnsignedMSB4 | 32 | 4 | n/a | number of camera head command errors |
| ext_err_code | 23 | 77 | UnsignedMSB4 | 32 | 4 | n/a | extended error code for last command ending in error |
| text_data_checksum | 24 | 81 | UnsignedMSB4 | 32 | 4 | n/a | text+data checksum |
| flash_device_status | 25 | 85 | UnsignedMSB4 | 32 | 4 | n/a | flash device status as bitmask |
| dram_device_status | 26 | 89 | UnsignedMSB4 | 32 | 4 | n/a | bitmask of dynamic random access memory (DRAM) device status from last built-in self-test, nominal 0 |
| num_flash_op_timouts | 27 | 93 | UnsignedMSB4 | 32 | 4 | n/a | number of flash operation timeouts |
| num_flash_op_timouts | 28 | 97 | UnsignedMSB4 | 32 | 4 | n/a | execution time of last command in ticks, if measured |

| Fields Name | Field Number | Fields Locations (Start Byte) | Data Type | Field Length (bits) | Field Length (bytes) | Units | Description |
|---|---|---|---|---|---|---|---|
| bram_ecc_status_register | 29 | 101 | UnsignedMSB4 | 32 | 4 | n/a | Block random access memory error correction code (BRAM ECC) status register |
| num_spacewire_timeouts< | 30 | 105 | UnsignedMSB4 | 32 | 4 | n/a | number of Spacewire timeouts |
| num_received_char_overruns | 31 | 109 | UnsignedMSB4 | 32 | 4 | n/a | number of receiver character overruns |
| orrectable_bram_ecc_ers_cnt | 32 | 113 | UnsignedMSB4 | 32 | 4 | n/a | count of correctable Block random access memory error correction code (BRAM ECC) errors |
| last_image_id | 33 | 117 | UnsignedMSB4 | 32 | 4 | n/a | last image identifier acquired |
| num_images_acquired | 34 | 121 | UnsignedMSB4 | 32 | 4 | n/a | number of images acquired |
| last_time_update_msg_time | 35 | 125 | UnsignedMSB4 | 32 | 4 | n/a | time of last time update message (seconds) |
| num_time_ticks_seen | 36 | 129 | UnsignedMSB4 | 32 | 4 | n/a | number  time ticks seen |
| fpga_logic_version | 37 | 133 | UnsignedMSB4 | 32 | 4 | n/a | FPGA (field-programmable gate array) logic version |
| camera_0_current | 38 | 137 | UnsignedMSB4 | 32 | 4 | DN | camera 0 current |
| camera_1_current | 39 | 141 | UnsignedMSB4 | 32 | 4 | DN | camera 1 current |
| camera_2_current | 40 | 145 | UnsignedMSB4 | 32 | 4 | DN | camera 2 current |
| camera_3_current | 41 | 149 | UnsignedMSB4 | 32 | 4 | DN | camera 3 current |
| camera_0_voltage | 42 | 153 | UnsignedMSB4 | 32 | 4 | DN | camera 0 voltage |
| camera_1_voltage | 43 | 157 | UnsignedMSB4 | 32 | 4 | DN | camera 1 voltage |
| camera_2_voltage | 44 | 161 | UnsignedMSB4 | 32 | 4 | DN | camera 2 voltage |
| camera_3_voltage | 45 | 165 | UnsignedMSB4 | 32 | 4 | DN | camera 3 voltage |
| camera_0_temp | 46 | 169 | UnsignedMSB4 | 32 | 4 | DN | camera 0 temperature |
| camera_1_temp | 47 | 173 | UnsignedMSB4 | 32 | 4 | DN | camera 1 temperature |
| camera_2_temp | 48 | 177 | UnsignedMSB4 | 32 | 4 | DN | camera 2 temperature |
| camera_3_temp | 49 | 181 | UnsignedMSB4 | 32 | 4 | DN | camera 3 temperature |
| dvr_pos1_2v | 50 | 185 | UnsignedMSB4 | 32 | 4 | DN | Digital Video Recorder plus 1.2 Volt or internal temperature monito.r |
| dvr_pos2_5v | 51 | 189 | UnsignedMSB4 | 32 | 4 | DN | Digital video recorder plus 2.5 volt monito.r |
| dvr_pos3_3v | 52 | 193 | UnsignedMSB4 | 32 | 4 | DN | Digital video recorder plus 3.3 volt monitor. |
| dvr_pos5v | 53 | 197 | UnsignedMSB4 | 32 | 4 | DN | Digital video recorder plus 5 volt monitor. |

## 5.2.3 L1 Status Data Product

The L1 Status data product contains engineering values converted from DNs to physical units.

| Fields Name | Field Number | Field Location (Start Byte) | Data Type | Field Length (bits) | Field Length (bytes) | Units | Description |
|---|---|---|---|---|---|---|---|
| seconds_raw | 1 | 1 | UnsignedMSB4 | 32 | 4 | seconds | seconds portion of the timestamp of the status reading |
| subseconds_raw | 2 | 5 | UnsignedByte | 8 | 1 | milliseconds | milliseconds portion of the timestamp of the status reading |
| spare0 | 3 | 6 | UnsignedByte | 8 | 1 | n/a | spare |
| spare1 | 4 | 7 | UnsignedByte | 8 | 1 | n/a | spare |
| command_opcode | 5 | 8 | UnsignedByte | 8 | 1 | n/a | opcode of command producing this packet, or 0x20 for status |
| last_opcode | 6 | 9 | UnsignedMSB4 | 32 | 4 | n/a | last opcode received |
| valid_cmds_cnt | 7 | 13 | UnsignedMSB4 | 32 | 4 | n/a | valid commands received since power-on |
| rejected_cmds_cnt | 8 | 17 | UnsignedMSB4 | 32 | 4 | n/a | rejected commands received since power-on |
| inst_sw_ver | 9 | 21 | UnsignedMSB4 | 32 | 4 | n/a | instrument software version |
| checksum | 10 | 25 | UnsignedMSB4 | 32 | 4 | n/a | checksum of instrument software |
| num_bad_flash_blocks | 11 | 29 | UnsignedMSB4 | 32 | 4 | n/a | number of bad flash blocks |
| num_free_flash_blocks | 12 | 33 | UnsignedMSB4 | 32 | 4 | n/a | number of free flash blocks |
| total_usable_flash_blocks | 13 | 37 | UnsignedMSB4 | 32 | 4 | n/a | total number of usable flash blocks |
| num_products_in_use | 14 | 41 | UnsignedMSB4 | 32 | 4 | n/a | number of products in use |
| num_pages_used | 15 | 45 | UnsignedMSB4 | 32 | 4 | n/a | number of flash pages used in products |
| flash_err_cnt | 16 | 49 | UnsignedMSB4 | 32 | 4 | n/a | flash error count in last BIST |
| dram_errors | 17 | 53 | UnsignedMSB4 | 32 | 4 | n/a | DRAM errors in last BIST |
| num_correctable_ecc_errors | 18 | 57 | UnsignedMSB4 | 32 | 4 | n/a | number of correctable ECC errors |
| num_sequences_stored | 19 | 61 | UnsignedMSB4 | 32 | 4 | n/a | number of sequences stored in flash |
| camera_statu | 20 | 65 | UnsignedMSB4 | 32 | 4 | n/a | camera status as bitmask |
| num_uncorrectable_ecc_errors | 21 | 69 | UnsignedMSB4 | 32 | 4 | n/a | number of uncorrectable ECC errors |
| num_camera_head_upsets | 22 | 73 | UnsignedMSB4 | 32 | 4 | n/a | number of camera head command errors |
| ext_err_code | 23 | 77 | UnsignedMSB4 | 32 | 4 | n/a | extended error code for last command ending in error |
| text_data_checksum | 24 | 81 | UnsignedMSB4 | 32 | 4 | n/a | text+data checksum |
| flash_device_status | 25 | 85 | UnsignedMSB4 | 32 | 4 | n/a | flash device status as bitmask |

| Fields Name | Field Number | Field Location (Start Byte) | Data Type | Field Length (bits) | Field Length (bytes) | Units | Description |
|---|---|---|---|---|---|---|---|
| dram_device_status | 26 | 89 | UnsignedMSB4 | 32 | 4 | n/a | bitmask of DRAM device status from last BIST, nominal 0 |
| num_flash_op_timo uts | 27 | 93 | UnsignedMSB4 | 32 | 4 | n/a | number of flash operation timeouts |
| num_flash_op_timo uts | 28 | 97 | UnsignedMSB4 | 32 | 4 | n/a | execution time of last command in ticks, if measured |
| bram_ecc_status_re gister | 29 | 101 | UnsignedMSB4 | 32 | 4 | n/a | BRAM ECC status register |
| num_spacewire_tim eouts< | 30 | 105 | UnsignedMSB4 | 32 | 4 | n/a | number of Spacewire timeouts |
| num_received_char _overruns | 31 | 109 | UnsignedMSB4 | 32 | 4 | n/a | number of receiver character overruns |
| orrectable_bram_ec c_ers_cnt | 32 | 113 | UnsignedMSB4 | 32 | 4 | n/a | count of correctable BRAM ECC errors |
| last_image_id | 33 | 117 | UnsignedMSB4 | 32 | 4 | n/a | last image identifier acquired |
| num_images_acquir ed | 34 | 121 | UnsignedMSB4 | 32 | 4 | n/a | number of images acquired |
| last_time_update_m sg_time | 35 | 125 | UnsignedMSB4 | 32 | 4 | n/a | time of last time update message (seconds) |
| num_time_ticks_see n | 36 | 129 | UnsignedMSB4 | 32 | 4 | n/a | number of lost time ticks |
| fpga_logic_version | 37 | 133 | UnsignedMSB4 | 32 | 4 | n/a | FPGA logic version |
| camera_0_current | 38 | 137 | IEEE754MSBSingle | 32 | 4 | Milliamps | camera 0 current |
| camera_1_current | 39 | 141 | IEEE754MSBSingle | 32 | 4 | Milliamps | camera 1 current |
| camera_2_current | 40 | 145 | IEEE754MSBSingle | 32 | 4 | Milliamps | camera 2 current |
| camera_3_current | 41 | 149 | IEEE754MSBSingle | 32 | 4 | Milliamps | camera 3 current |
| camera_0_voltage | 42 | 153 | IEEE754MSBSingle | 32 | 4 | Volts | camera 0 voltage |
| camera_1_voltage | 43 | 157 | IEEE754MSBSingle | 32 | 4 | Volts | camera 1 voltage |
| camera_2_voltage | 44 | 161 | IEEE754MSBSingle | 32 | 4 | Volts | camera 2 voltage |
| camera_3_voltage | 45 | 165 | IEEE754MSBSingle | 32 | 4 | Volts | camera 3 voltage |
| camera_0_temp | 46 | 169 | IEEE754MSBSingle | 32 | 4 | degC | camera 0 temperature |
| camera_1_temp | 47 | 173 | IEEE754MSBSingle | 32 | 4 | degC | camera 1 temperature |
| camera_2_temp | 48 | 177 | IEEE754MSBSingle | 32 | 4 | degC | camera 2 temperature |
| camera_3_temp | 49 | 181 | IEEE754MSBSingle | 32 | 4 | degC | camera 3 temperature |
| dvr_pos1_2v | 50 | 185 | IEEE754MSBSingle | 32 | 4 | Volts | Digital Video Recorder plus 1.2 Volt or internal temperature monitor |
| dvr_pos2_5v | 51 | 189 | IEEE754MSBSingle | 32 | 4 | Volts | Digital video recorder plus 2.5 volt monitor |
| dvr_pos3_3v | 52 | 193 | IEEE754MSBSingle | 32 | 4 | Volts | Digital video recorder plus 3.3 volt monitor |
| dvr_pos5v | 53 | 197 | IEEE754MSBSingle | 32 | 4 | Volts | Digital video recorder plus 5 volt monitor |

For the current, voltage, and temperature channels, the DN-to-EU mapping will be of the form $eu = a*dn+b$, where a and b will be supplied for each channel after characterization.

For the voltage channels, the nominal conversion is a=610.352e-6, b=0, EU is in volts.

For the current channels, the nominal conversion is a=0.1525879, b=0, EU is in milliamps.

For the temperature channels, the nominal conversion is a=0.15259, b=-273.14, EU in degrees C. Characterization of the flight units shows that the best-fit value of b is -275.02 for NavCam (primary DVR) and-273.43 for NFTCam and StowCam (secondary DVR.)

## 5.3  Label and Header Description

All data products are produced with PDS4 compliant detached XML labels.  Examples of these labels can be found in Appendix7.5. FITS headers are described in Section 5.2

# 6  Applicable Software

The following sections describe display software that may be used to examine, display, or analyze the NavCam data products.

## 6.1  Utility Programs

At the current time, the OSIRIS-REx project has no plans to release any mission specific utility programs. As most TAGCAMS data products are FITS formatted files, any viewer with the capability of reading FITS files can be used to view the data products. Some examples of these viewers are IDL, J-Mars (http://jmars.asu.edu/download), and FV. A complete list of FITS viewers can be found at *http://fits.gsfc.nasa.gov/fits_viewer.html*.

## 6.2  Applicable PDS Software Tools

The PDS supplies a number of software tools that can be used in conjunction with PDS data products.  Please refer to the PDS4 software website (*http://pds.nasa.gov/pds4/software/index.shtml*) for additional information on these tools.

## 6.3  Software Distribution and Update Procedure

As the OSIRIS-REx project will not be providing software, this section is not applicable.

# 7 Appendices

## 7.1 *Definitions of Data Processing Levels*

Table 10 shows the comparison of OSIRIS-REx, NASA and CODMAC data processing levels. The OSIRIS-REx team generally uses descriptions when classifying data rather than data levels.

**Table 9 - Definitions of Data Processing Levels**

| OSIRIS-REx | NASA | CODMAC | Description |
|---|---|---|---|
|  | Packet data | Raw - Level 1 | Telemetry data stream as received at the ground station, with science and engineering data embedded. |
| Level 0 - Raw | Level 0 | Edited - Level 2 | Instrument science data (e.g., raw voltages, counts) at full resolution, time ordered, with duplicates and transmission errors removed. |
| Level 1- Uncalibrated | Level 1A | Calibrated - Level 3 | NASA Level 0 data that have been located in space and may have been transformed (e.g., calibrated, rearranged) in a reversible manner and packaged with needed ancillary and auxiliary data (e.g., radiances with the calibration equations applied). |
| Level 2 - Calibrated | Level 1B | Resampled - Level 4 | Irreversibly transformed (e.g., resampled, remapped, calibrated) values of the instrument measurements (e.g., radiances, magnetic field strength). |
| Level 3 - Processed | Level 1C | Derived - Level 5 | NASA Level 1A or 1B data that have been resampled and mapped onto uniform space-time grids. The data are calibrated (i.e., radiometrically corrected) and may have additional corrections applied (e.g., terrain correction). |
| Level 4 - Derived | Level 2 | Derived - Level 5 | Geophysical parameters, generally derived from Level 1 data, and located in space and time commensurate with instrument location, pointing, and sampling. |

| Level 4 - Derived | Level 3 | Derived - Level 5 | Geophysical parameters mapped onto uniform space-time grids. |
|---|---|---|---|

| OSIRIS-REx Data Product Level Definitions | |
|---|---|
| **Level** | **Definition** |
| OREx Level 0 | *Telemetry*. Raw instrument data reconstructed from telemetry with header and ancillary information appended. Appended header and ancillary data is data necessary for further processing. |
| OREx Level 1 | *Uncalibrated.* Data in one of the fundamental structures. |
| OREx Level 2 | *Reversibly calibrated.* Data in units proportional to physical units. Since PDS allows offsets and scaling factors in its array and table structures, this would be the minimum level capable of satisfying the "in physical units" requirement. |
| OREx Level 3 | *Irreversibly processed.* Higher-level products from a single source that cannot be losslessly converted back to the lower-level products from which they were derived. These might also satisfy the "in physical units" requirement. |
| OREx Level 4 | *Derived data.* Products created by combining data from more than one source (instrument, observer, etc.). |

## 7.2 Example PDS Labels

Example labels can be found in the TAGCAMS bundle document collection in a sub-directory named "example_labels". There are example labels for each type of TAGCAMS data product.