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

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

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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
6.0	Update per CR-429	CR-429	04/19/2019	04/24/2019	04/24/2019

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

			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 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 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
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.

eom.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 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 = '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 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 momentum rate in spacecraft body frame at the ATT_TIME
mission_area.att_rate_y	ATTRATE2		The y-axis component of the spacecraft angular momentum rate in spacecraft body frame at the ATT_TIME
mission_area.att_rate_z	ATTRATE3		The z-axis component of the spacecraft angular momentum rate 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	Millisec	TAGCAMS Mini Header spacecraft clock time in sub-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.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).
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 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 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	Fields Locations	Data Type	Field Length	Field Length	Units	Description
	Number	(Start Byte)		(bits)	(bytes)		
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
bram_ecc_status_register	29	101	UnsignedMSB4	32	4	n/a	Block random access memory error correction code (BRAM ECC) status register

Fields Name	Field	Fields Locations	Data Type	Field Length	Field Length	Units	Description
	Number	(Start Byte)		(bits)	(bytes)		
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_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
bram_ecc_status_register	29	101	UnsignedMSB4	32	4	n/a	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 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 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.