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

OSIRIS-REx Laser Altimeter (OLA) Uncalibrated / Calibrated Data Product Software Interface Specification

UA-SIS-9.4.4-302, Rev. 6.0

Revision – 6.0

September 30, 2021

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
OLA Uncalibrated/Calibrated Data Product SIS

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DOCUMENT CHANGE LOG

REV/VERSION LEVEL	DESCRIPTION OF CHANGE	APPROVED BY	DATE APPROVED
1.0	Initial Release		09/25/2014
1.1	Updated formats for consistency with pipeline software version 1.3_F	ECR-0023	01/09/2015
1.2	Updated file formats based on feedback from PDS Peer Review.	ECR-0023	01/08/2016
1.2	Updated Signature Page	ECR-0023	02/01/2016
1.2	Updated Applicable Documents	ECR-0023	02/01/2016
2.0	Release	ECR-0023	05/11/2016
3.0	Update per ECR	ECR-0072	04/19/2017
4.0	Update per Change Request	CR-124	08/21/2017
5.0	Updates per PDS Peer Review		01/01/2020
6.0	Updates per Change Request	CR-467	06/11/2020

LIST OF TBDs/TDRs

SECTION ID	DESCRIPTION OF TBD/TBR	DATE OF RESOLUTION
2	OLA Instrument Paper	11/1/2019
2	OSIRIS-REx Archive Volume SIS	11/1/2019
Table 4	Update Data Volume on revision of Design Reference Mission	11/1/2019
4.4.3	OSIRIS-REx Coordinate System Plan	11/1/2019

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1 Purpose and Scope

The data products described by this Software Interface Specification (SIS) are the OSIRIS-REx Laser Altimeter (OLA) uncalibrated and calibrated data products. The OSIRIS-REx Science Processing and Operation Center located at the University of Arizona produces these data products and distributes them to both the OSIRIS-REx Science Team and the Planetary Data System.

The purpose of this document is to provide users of the data products with a detailed description of the product and a description of how it was 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 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 30, 2016.
3. PDS4 Information Model Specification, V.1.7.0.0, September 29, 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, 1.0 October 2013.
6. OSIRIS-REx Laser Altimeter (OLA) Investigation and Instrument, Space Science Reviews, 2017
7. SPOC – OLA Interface Control Document, UA-9.4.4-1003.

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 Relationships 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
OLA Science Raw	Product	SPOC
OLA State of Health Raw	Product	SPOC
OLA Science Uncalibrated	Product	SPOC
OLA State of Health Uncalibrated Converted	Product	SPOC
OLA Science Calibrated	Product	SPOC
OLA Pipeline Software	Software	SPOC

Name	Type	Owner
SPOC Archive Packager	Software	SPOC
OSIRIS-REx Science Data Management Plan	Document	Project

4 Data Product Characteristics and Environment

4.1 *Instrument Overview*

The OSIRIS-REx Laser Altimeter (**OLA**) is a two-axis scanning lidar (Light Detection and Ranging) instrument that will provide high-resolution topographical information throughout the entire mission.

OLA has a single common receiver and two complementary transmitter assemblies, which enhance the resolution of its data. OLA's high-energy laser transmitter (HELT) is used for ranging and mapping from 1 to 7.5 km and collects returns at 100Hz. The low-energy laser transmitter (LELT) collects returns at 10kHz and is used for ranging and imaging at smaller distances (~200 m to 1 km). The repetition rate of these transmitters sets the data acquisition rate of OLA. Laser pulses from both the low and high energy transmitters are directed onto a movable scanning mirror, which is co-aligned with the field of view of the receiver telescope limiting the effects of background solar radiation. Each pulse provides target range, azimuth, elevation, received intensity and a time-tag.

OLA has 4 operational modes. These are:

(1) Initialization - Optical head is off, communications and data transfer enabled.

(2) Standby- Transmitter temperatures are controlled to operational temperatures, communications and data transfer enabled.

(3) High Energy – For mission phases when the range is ≥1 km, OLA uses the high-energy transmitter, data collection is enabled; and

(4) Low Energy - For mission phases when the range is <1 km, OLA uses the low-energy transmitter, data collection is enabled.

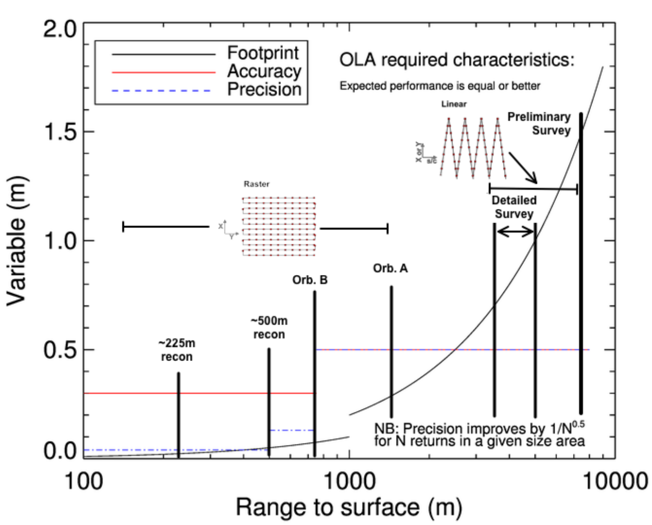

Figure 1. OLA's scan pattern and required precision and accuracy

OLA is capable of scanning in two main patterns: (1) A one mirror axis side to side scan (linear), when combined with the motion of the spacecraft results in a raster scan, and (2) A full two-dimensional (raster) scan (Figure 1). These two patterns are applicable and adequate for all mission phases. OLA exceeds the mission requirements in all phases. In addition to its enhanced precision, after Orbital Phase B, OLA exceeds the coverage and data quality of all previous missions, surpassing the Hayabusa mission coverage of Itokawa by a factor of 20, and the NEAR laser rangefinder results at 433 Eros by a factor of 2 after correcting for the significant difference in size between Eros and Bennu. The OLA data will therefore provide fundamental and unprecedented asteroid science on asteroid shape and topography, providing invaluable insights on the surface processes controlling the evolution of Bennu, and on the source materials of the sample collected by the OSIRIS-REx spacecraft. OLA will also enhance performance of the other remote sensing instruments (images and spectra) by setting precise range, scale, and surface slope information.

OLA data exists for a variety of mission phases. The range of Scan IDs delineates the data by mission phase. These are shown in Table 2.

Table 2. OLA Observations

Mission Phase	Observation Scan ID Ranges
Outbound Cruise and Approach	0-999
Preliminary Survey	1000-1999
Detailed Survey	2000-2999
Orbit A	3000-3999
Orbital B	4000-4999
Orbital C	5000-5999
Reconnaissance	6000-6999
Farewell	7000-7999

4.2 Data Product Overview

This SIS describes science and state of health (housekeeping) data acquired by OLA. Data are acquired on a schedule set by the mission Design Reference Mission (DRM). Science data are acquired at variable rates depending on the transmitter utilized. When the HELT is used, OLA collects ~225 bytes per s. When the LELT is used, OLA collects data at ~22.5 kbytes per s. The science data are to be sorted by transaction ID (scan identifier field in the OLA telemetry data that associates the data to a specific OLA collection event), and day when this transaction was initiated. State of Health (SoH) records are acquired at a rate of 10 Hz and are stored as a single binary table file sorted by Power Cycle counter. The Power Cycle counter is incremented by one whenever the instrument is turned on. All SOH records generated by the instrument contain the same Power Cycle counter while the instrument is on. Thus, a single SOH file contains data from a single power on/power off instrument cycle. The Power Cycle counter is also stored in the OLA Science data records, making it easy to correlate a given SOH file with OLA science data.

The specific data products described by this SIS are:

1. **OLA Raw (L0) Science Data** – These data are reconstructed from instrument telemetry and include time of observation, time of flight, intensity, and instrument positional data in digital numbers (DN).
2. **OLA Raw (L0) State of Health Data** - These data are reconstructed from instrument telemetry and include instrument rates, status, and temperatures in DN.
3. **OLA Calibrated (L1) Science Data** – Similar in format to the OLA Raw (L0) Science Data, but with engineering conversions applied resulting in data in physical units.
4. **OLA Calibrated (L1) State of Health Data** - Similar in format to the OLA Raw (L0) State of Health Data, but with engineering conversions applied resulting in data in physical units.
5. **OLA Calibrated Data (L2)** – These data are a table of time, range, scan type flag, and Bennu surface position of the observation.
6. **OLA Strip Adjusted Calibrated Data (L2A)** – These are L2 data whose Bennu surface and spacecraft position values have been adjusted to minimize differences between individual OLA

scans. See section 4.3.2.4 for further details.

4.3 Data Processing

This section should provide general information about the data product content, format, size, and production rate. Details about data format should be specified later in section 6.

4.3.1 Data Processing Level

Describe the product in terms of its NASA and/or CODMAC processing levels.

Table 3. OLA Data Products

OLA Product	Data Collection Name	OSIRIS-REx Processing Level	Description
N/A	N/A	N/A	OLA Science Telemetry
OLA Raw Science	data_raw	L0	OLA science observations packaged by scan sequence ID and UTC Day of year corresponding to the timestamp of the first scan in the scan sequence.
OLA Raw SoH	data_hkl0	L0	OLA state of health observations packaged by Power Cycle.
OLA Reduced Science	data_reduced data_reduced_v2	L1	OLA reduced science observations packaged by scan sequence ID and UTC Day of year corresponding to the timestamp of the first scan in the scan sequence, converted to physical units.
OLA Reduced SoH	data_hkl1	L1	OLA reduced (converted to physical units) state of health observations packaged by Power Cycle.
OLA Cal Science	data_calibrated data_calibrated_v2	L2	These data are a table of time, range, scan type flag, and Bennu surface position of the observation packaged by scan sequence ID and UTC Day of year corresponding to the timestamp of the first scan in the scan sequence.
OLA Cal Science Level 2A	data_calibrated_2a	L2A	These are L2 data whose Bennu surface and spacecraft positions have been adjusted to minimize differences between individual OLA scans. These are derived data products to be delivered at the end of the asteroid encounter.

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 life cycle, 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.

4.3.2.1 Level-0 Raw Data

The processing of OLA is conceptually simple (Figure 2). Prior to ingest, OLA telemetry data will be cleaned by the SPOC. Cleaning includes removal of spacecraft headers and duplicate data and correction of any DSN transmission errors. OLA Data will enter ingest un-corrupted. OLA did not generate any low priority data.

OLA ingest algorithms take OLA raw telemetry and compute the OLA level 1 data product in several steps. The first step is to split OLA telemetry into science data and state of health (SoH) data. These data products are known as the OLA Level 0 science data product and the OLA level 0 SoH. Their units are digital numbers and/or voltages (i.e., not physical or engineering units).

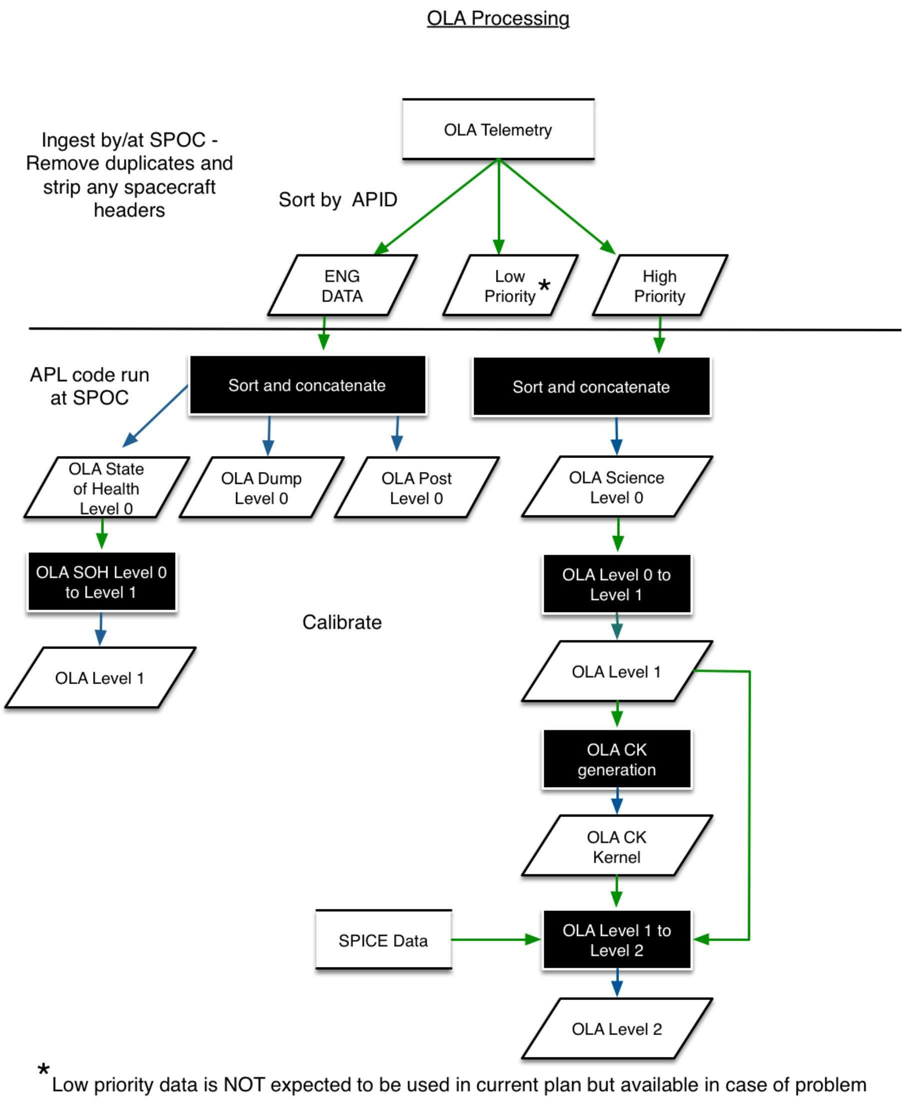

Figure 2. OLA Processing Pipeline

OLA Science Level 0 data product (OLA L0) contains the most basic OLA measurement data in a binary table format separated by collection day and transaction ID (scan identifier field in the OLA telemetry data that associates the data to a specific OLA collection event). OLA L0 data has no corrections applied. Here data is stored in non-physical units (i.e., voltages and digital numbers) and no calibration is required. Data are reformatted to match acceptable PDS data types and data type lengths. One data record is available for each OLA shot fired. OLA SoH Level 0 data will be in binary table format separated by Power Cycle. Here data is also stored in uncalibrated, non-physical units.

4.3.2.2 Level-1 Calibrated Science and SoH

OLA level 0 data products are converted to level 1 data products (science and SoH), which have the same information in physical or engineering units. This conversion requires a calibration table. The calibration table consists of both a set of lookup tables and a series of coefficients for polynomials, which relate the non-physical units of Level 0 data to physical units used in these OLA Level 1 data products. MacDonald, Dettwiler and Associates (MDA), the manufactures of the OLA instrument, and the OLA science team, provide the coefficients and lookup table values. These values were updated in flight: The calibration table filenames have a version number and date range for which the calibration table applies. The values that get corrected in the science data include the range, intensity in and out, and the mirrors azimuth and elevation. There is also an update to the OLA status flag, to highlight when the OLA demodulator is on (starts with 100). This demodulator impacts the intensity measurement collected by OLA, and to a much lesser extent the range accuracy.

Updates to the calibration tables and to the calibration algorithm which take into account the OLA demodulator state led to the complete reprocessing of the Level-1 science data. The reprocessed data is contained in the data_reduced_v2 collection (Table 3).

The Mission Event Time (MET), and corresponding MET offset for each lidar shot is also correctly computed using the inputs from the level 0 data. The MET is equivalent to the spacecraft clock time (sometime also called Spacecraft Clock time or SCLK) used with other data on the OSIRIS-REx mission. The use of MET is preferred by the OLA and Altimetry working group to avoid any confusion with the NAIF SPICE spacecraft clock kernel (also called a SCLK kernel or file), which is used to compute a corresponding UTC in the OLA Level 1 data products. See Section 4.4.2 Time Standards for additional information on time calculations.

The list of variables that are corrected via polynomials in the SoH Level 0 are much more extensive and include all the relevant temperatures, the minimum and average range measured over 500 shots, and all the voltages. Times are also adjusted correctly in the SoH, using a MET, and MET offset. A corresponding UTC is also computed, by making use of a SPICE spacecraft clock kernel.

OLA Science Level 1 data product (OLA L1) contains the most basic OLA measurement data in a binary table format separated by collection day and transaction ID (scan identifier field in the OLA telemetry data that associates the data to a specific OLA collection event). OLA L1 data are stored in calibrated physical units (i.e., ranges in meters and scan angles in radians as opposed to voltages and digital numbers). One data record is available for each OLA shot fired. Not all OLA L0 fields are necessary for data analysis. As a result, OLA L1 data has these fields removed. OLA L1 science data has a time correction applied to the scan_ola_time, with the sclk offset applied to the scan_ola_time. During a scan the OLA software injects fake timestamped records flagged with Flag_Status = 3. These records are removed from the dataset during the L0 to L1 processing. The first record rom each L0 file is also removed from each L1 data file.

There are two lookup tables in the calibration file that are used to calibrate the range data in the OLA L1 file. One to calibrate the range for the High Energy Laser Transmitter (RANGE_HELT) and another for the Low Energy Laser Transmitter (RANGE_LELT). The first value in the table is the fixed offset. The uncalibrated intensity value is then used as an index into the table to find the value which must be added to the uncalibrated range according to the following algorithm:

Calibrated Range(mm) = Uncalibrated Range (mm) + fixed offset (mm) + LUT[uncalibrated intensity]

where uncalibrated intensity is rounded to the nearest integer.

OLA SoH Level 1 data are also in binary table format separated by Power Cycle. SoH L1 data has physical variables (such as temperatures) that are calibrated. Some of the Boolean flags have been consolidated into one flag, which is the product of several boolean flags from SoH L0. Also, the alignment into 32-bit words is removed so there are no spare bits to reduce the size of the files. Note that for SOH Level 0 and Level 1 the initial rows in the binary table may show invalid values for the OLA time tag (t0_seconds for SOH L0 and soh_ola_time for SOH L1). These values reflect that there is a finite elapsed time between instrument powerup and receipt of the first reference time from the S/C clock. A value greater than zero in the time_ref_seconds field in the OLA SOH L0 table is an indicator of when the OLA time tag is valid.

4.3.2.3 Level-2 Calibrated Data

Pipeline processing begins by converting OLA level 0 science data products to OLA level 1 science data products. Then OLA SPICE C-kernels are generated that describe the attitude of the OLA mirror in the OLA reference frame from the OLA level 1 science data products. Finally, the OLA SPICE C-kernels with the ranges and scan angles (OLA Level 1) are converted to body fixed coordinates (OLA Level 2) using the appropriate SPICE data. In other words, a 3-D point cloud is created from OLA measurements. OLA Level 2 data products are then used by the Altimetry Working Group to create subsequent shape models using the University of Hawaii’s School of Ocean and Oceanography (SOEST) Generic Mapping Tool (GMT) block median directly or with several steps involving splitting the data into subsets (“mapolas”) and then recombining them. The second workflow is similar to the process the OSIRIS-REx imaging team is undertaking using Bob Gaskell’s Stereo Photoclinometry (SPC) processing. The resulting data products are described in an accompanying Altimetry Working Group Data SIS.

The creation of the reprocessed Level-1 Reduced Data, which used updates to the calibration tables and to the calibration algorithm which take into account the OLA demodulator state, resulted in the reprocessing of the Level-2 science data. The reprocessed Level-2 science data is contained in the data_calibrated_v2 collection (Table 3).

OLA Science Level 2 data product (OLA L2) contain all the information in OLA L1 along with body-fixed point cloud data obtained via s/c ephemerides SPICE kernels. Time calculations are described in Section 4.4.2

The OLA L2 records are determined form the OLA L1 record, OLA CK, and relevant SPICE kernels using the SPICE library as follows:

olaPos = SPKPOS("ORX_OLA_ART", et, "IAU_BENNU", "NONE", "BENNU");

scPos = SPKPOS("ORX", et, "IAU_BENNU", "NONE", "BENNU");

ola_frame = "ORX_OLA_HIGH" or "ORX_OLA_LOW" depending on the level 1 record laser selection

laser2body = PXFORM(ola_frame, "IAU_BENNU", et);

boresightDir = MXV(laser2body, {0.0, 0.0, 1.0});

convert olaPos from km to meters

convert scPos from km to meters

r = OLA range from level 1 record converted to meters

OLA level 2 spacecraft position = scPos

OLA level 2 target position = olaPos + r * boresightDir

OLA level 2 elongitude, latitude is determined from target position using SPICE RECLAT

An example of the SPICE kernel list (meta-kernel) required for processing OLA data from L1 to L2 are as follows:

ik/orx_ola_v01.ti',

lsk/naif0012.tls,
sclk/orx_sclkscet_00046.tsc',
fk/orx_v14.tf,
pck/pck00010.tpc',
pck/bennu_v14.tpc,
spk/orx_struct_v04.bsp', '
ck/orx_sc_rel_181203_181209_v01.bc',
ck/orx_ola_181204_scil2id01000.bc',
spk/de424.bsp', '
spk/bennu_refdrmc_v1.bsp',
spk/ orx_181203_190302_190104_od085_v1.bsp',
dsk/ bennu_g_03170mm_spc_obj_0000n00000_v020.bds',

Note the versions and dates of these kernels will change over the course of the mission, but the types of kernels will remain the same. OLA CK kernels can be acquired from https://naif.jpl.nasa.gov/pub/naif/pds/pds4/orex/orex_spice/spice_kernels/ck/. The NAIF supplied subset function will not return OLA CKs. The OLA CK files must be downloaded manually. These files are related to the observations by scanid number (idxxxxxx). Alternatively, all the information needed to determine the scan mirror position is included in the corresponding L1 SOH data product. The algorithm for this computation is given in "OLA_level1_to_CK_description.txt" located in the document collection.

OLA L2 do not account for any corrections to the ephemeris that has been derived from the science team after their generation. Any such corrections will be delivered as Altimetry Level 1 and 2 OLA products and are part of the Altimetry Working group data flow that is also discussed in the accompanying Altimetry Working Group Data SIS. The OLA L2 data products possess calibrated physical units (i.e., ranges in meters and scan angles in degrees or radians as opposed to voltages and digital numbers). One data record is available for each OLA shot fired. The number of records in a level-1 and level-2 file is expected to be identical.

4.3.2.4 Level-2A Strip-adjusted Calibrated Data

OLA Level 2 files are produced in the OLA pipeline using reconstructed SPICE SPK (ephemeris) and C-Kernels (pointing) to provide an initial estimate of the location of the 3-D point cloud produced by OLA in the asteroid body-fixed reference frame. However, these points will not necessarily match up with other OLA L2 point clouds due to errors in the spacecraft trajectories and pointing. These errors can be minimized through a process we call strip-adjustment (also sometimes known as cross-over analysis). Each individual OLA scan is adjusted using either a keypoint approach or an iterative closest-point algorithm where differences between individual OLA scans are minimized. This minimization is done judiciously to ensure that the shape model closes appropriately across its circumference such that no offsets exist. Once these adjustments have been applied to all OLA L2 files, and all the scans are further adjusted to be in-line with the bests estimates of the spacecraft trajectory provided by the OSIRIS-REx flight dynamics team, we provide a new set of OLA L2 files called OLA Level 2A. The 'A' implies that the files have been adjusted and will match the OLA derived shape models produced by the AltWG. Additional information on the details of the adjustment is provided in the AltWG SIS.

OLA Science Level 2A data product (OLA L2A) contains all the information in OLA L2. The only difference is that the body-fixed point cloud data and the spacecraft position will differ from what is found in an original OLA L2 file to account for the adjustment applied to the OLA L2 files to produce the OLA L2A. OLA L2A, thus, do account for any corrections to the ephemeris that has been derived from the science team after their generation. The OLA L2A data products possess calibrated physical units (i.e., ranges in meters and scan angles in degrees or radians as opposed to voltages and digital numbers). One data record is available for each OLA shot fired. The OLA L2A files also have several additional status flags: a flag status of 4 implies a possible particle detection; flag status of 5 is for mirror positions that are at the beginning or edge of a scan. Flags 4 and 5 are not used for strip-adjustments since Flag 4 data are off-body and flag 5 data can preferentially weight scan edges in adjustments. Flag 6 is valid data with the value of albedo channel updated to provide a calibrated relative albedo estimate. See additional details in section 5.2.6. The flags 100 to 106 are identical to 0-6 but also indicate that the OLA demodulator is on. The OLA L2A products are derived (OSIRIS-REx L3) data products referred to as "L2" because they are identical in format and usage to the L2 products described above. They are expected to be delivered to the PDS with OLA derived products from the mission.

4.3.3 Data Flow

OLA uncalibrated and calibrated 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 OLA data processing pipeline queries the SPOC data repository directly for new raw science. The OLA data files generated by the OLA pipeline are returned to the SPOC data repository for storage. The OSIRIS-REx Instrument and Science Teams access the data repository through a query tool.

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 OLA files are named. The generalized OLA file naming convention for the science data is as follows is:

UTCTime + "_" + Instrument(3) + "_" + Product Type + "." + PDS Type(3)

Where UTC Time in the OLA case is YYYYMMDD calculated from the SCLK time of the first record in the data file. SCLK time is time data taken in spacecraft clock ticks. UTC time is included in the filename to uniquely identify the data in case of rollover of the start scan id or the Power Cycle counter.

The instrument is one of the following:

Table 4. Instrument Abbreviations

Instrument Name	Abbreviation
MapCam	map
PolyCam	pol
SamCam	sam
OLA	ola
OVIRS	ovr
OTES	ote
REXIS	rex

The product type and processing level defines the data product type and the level of processing done on the data. The product types and processing levels for OLA are:

Table 5. OLA Data Product Type

file name string	Definition
scil0idxxxxx	OLA Level 0 science data product
sohl0idxxxxx	OLA Level 0 state of health data product

scil1idxxxxx	OLA Level 1 science data product
sohl1idxxxxx	OLA Level 1 state of health data product
scil2idxxxxx	OLA Level 2 science data product
scil2aidxxxxx	OLA Level 2A science data product

where idxxxxx is the start scan id of the product for OLA science data, or the power cycle counter for the OLA state of health data.

The PDS type file suffix indicates the type of file. OLA science and SOH data products have one file type suffix, .dat for binary tables. All OLA files are created with detached PDS labels. The labels are PDS compliant XML format labels with the file type suffix of .xml. Examples of labels can be found in Section 7.3. An example filename for an OLA Level 2 science data product binary table is:

20190306_olal2id60000.dat

Data that has been re-processed using the updated calibration method will have identical filenames as the previously processed data. The updated files will be distinguishable by their collection. Updated products will reside in versioned collections: data_reduced_v2 and data_calibrated_v2.

4.4 Standards Used in Generating Data Products

4.4.1 PDS Standards

All data products described in this SIS conform to the 1.7 PDS4 Information Model and 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.

4.4.2 Time Standards

Time Standards used by the OSIRIS-REx mission conform to PDS time standards. All OSIRIS-REx data products above Level 0 contain both the spacecraft clock time of data acquisition in SCLK and a conversion to UTC to facilitate comparison of data products. The level 0 data products only contain the time information as kept by the OLA CPU clock; updated at intervals by the spacecraft clock. This time information is known as OLA time and is converted to SCLK and UTC for products above level 0.

The OLA L0 product contains time stamp information for each shot fired – scan ola time. The shot rate is such that the smallest time increment between two successive shots is 0.0135ms. This is smaller than resolution of the spacecraft clock, which is 0.01526ms. Thus, the OLA L1, L2 and L2A products also specify an SCLK offset for each shot in addition to SCLK. This is a value in units of spacecraft clock ticks (2^{-16} seconds) that should be added to the SCLK value to derive a precise timestamp for the shot.

The OLA L0 data contain several time fields which are used to arrive at a level 1 timestamp for a given laser point:

- Scan Block Time Seconds and Subseconds: This time refers to the time assigned by the I/O FPGA for the first point in each scan block. This field will have the same value for all points in a scan block. This field is not used in the time calculations as its value is represented in the Scan OLA Time field, mentioned below.
- Time Reference Seconds and Subseconds: This is a sampling of the OLA CPU time for the first point in each scan block. This field will have the same value for all points in a scan block. Its value is derived from a measurement from a point that it not necessary the first point in a block (data collection packets, where the measurement is made are not the same as scan blocks).
- Time Delta to MRTU Ref: The difference between the OLA CPU's time and the spacecraft's time, updated at 1 Hz. This field will have the same value for several blocks in a row.

- Scan OLA Time – This field is calculated during ingest from the OLA scan block and represents the I/O FPGA assigned time for each laser point.

The OLA level 1 data contain the following time field:

- Scan OLA Time: This is computed from the time fields in the level 0 data and represents a spacecraft time for each laser point. Note that when looking at the L0 and L1 data products the Scan OLA time is different between the two products. The L1 Scan OLA Time is the corrected time.

The general outline of time calculations is as follows: The CPU time samples for the first point in each block are used to scale the I/O FPGA assigned time for each point, yielding a CPU time for each point. Then the Time Delta to MRTU Ref values are used to interpolate spacecraft times for each point.

When converting from I/O FPGA time to CPU time, if the difference between the CPU time and I/O time for a block has not changed from the previous block, the current block's CPU time is not used in the calculation. In this case, the CPU time estimate is considered to be stale (not a unique measurement for the block). With these redundant CPU times discarded, the algorithm is a straightforward linear interpolation of the I/O times to the CPU time space.

When converting from CPU time to spacecraft time, if the value of the Time Delta to MRTU Ref field has not changed since the last block, the value is considered stale and discarded. Since the update could have arrived from the spacecraft at any time during the previous block, the delta is applied to a point one half block time in the past. These assignments are then used in a linear interpolation of the CPU times to arrive at a spacecraft time for each point.

UTC is determined from OLA level 1 MET and MET offset using the SPICE library as follows:

```
scid = -64;

encodedSclk = SCENCD(scid, met) + met_offset;

et = SCT2E(scid, encodedSclk);

utc = ET2UTC(et, "ISOD", 6);
```

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" found in the archive documents directory.

4.4.4 Data Storage Conventions

All OLA data products are stored as little-endian binary table formats.

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 types of 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.

5 Detailed Data Product Specifications

The following sections provide detailed data product specifications for each OLA L0 data product. These specifications will provide sufficient detail, so that data product users can read and interpret the products.

5.1 Data Product Structure and Organization

The OSIRIS-REx data archive is organized by instrument. The OLA portion of the archive is organized by, processing level, mission phase and finally by data product type. OLA SoH and Science data are stored as a PDS4 compliant binary tab, with a detached PDS labels. Data are collected in files by Earth Day

5.2 Data Format Descriptions

5.2.1 OLA L0 Science

Field (table field name)	Field Number	Description	Size (Bytes)	Data Type	Units	Range	Default	Resolution	Frequency
Laser Selection (scan_laser_selection)	1	Specifies whether scan command applies to High Energy or Low Energy Laser	2	UnsignedLSB2	n/a	0:HELT 1:LELT	n/a		Each return
Power Cycle (ola_pwrup_counter)	2	Power Cycle counter. Incremented by 1 for every Power On Self Test.	2	UnsignedLSB2	n/a		n/a		Each return
Scan Specific ID (scan_specific_id)	3	Unique identifier for active scan sequence (per Scan start command)	2	UnsignedLSB2	n/a	0 – 16383	n/a		Each return
Parameter Laser Selection (param_laser_selection)	4	Specifies whether parameter set applies to High Energy (0) or Low Energy Laser (1)	2	UnsignedLSB2	n/a	0:HELT 1:LELT	n/a		Each return
Spare (param_spare)	5	Spare column	2	UnsignedLSB2	n/a		0		Each return
Parameter Set ID (parm_set_id)	6	Unique identifier for this parameter set	2	UnsignedLSB2	n/a	0 – 16383	n/a		Each return

Field (table field name)	Field Number	Description	Size (Bytes)	Data Type	Units	Range	Default	Resolution	Frequency
Block Number (block_number)	7	Scan data block within this scanning sequence (since turn on).	2	UnsignedLSB2	n/a		0	1	Each return
Num Points In Block (block_point_count)	8	Number of points within this scan block.	2	UnsignedLSB2	n/a	0 - 500	500	1	Each return
Final Block (block_final_indicator)	9	Final block indicator.	2	UnsignedLSB2	n/a	0:not last block 1: final block in scan data sequence	0	n/a	Each return
Decimation Factor (decimation_factor)	10	Decimation rate applied to current scan data.	2	UnsignedLSB2	n/a	0:Undecimated 1:2 2:10 3:100 4:1000	n/a	n/a	Each return
Scan Point Alignment Scale Factor (scan_point_alignment_scale)	11	Value of scan point alignment LSBit.	2	UnsignedLSB2	n/a	0: 1 ms 1: 10 ms 2: 100 ms 3: 1000 ms			Each return
Scan Pattern (scan_pattern)	12	Selected Scan Pattern.	2	UnsignedLSB2	n/a	0: Raster 1:Linear 2: Fixed	n/a		Each return

Field (table field name)	Field Number	Description	Size (Bytes)	Data Type	Units	Range	Default	Resolution	Frequency
Scan Orientation (scan_orientation)	13	Scan orientation.	2	UnsignedLSB2	n/a	0:azimuth 1: elevation			Each return
Imaging Settings (imaging_settings)	14	Imaging Settings.	2	UnsignedLSB2	n/a	1: Image with positive returns and nulls 2: Test Pattern	n/a		Each return
Scan Mode (scan_mode)	15	Scan sweep mode.	2	UnsignedLSB2	n/a	0: continuous 1:single-sweep	n/a		Each return
Receiver Threshold (receiver_threshold)	16	Receiver threshold.	2	UnsignedLSB2	n/a	0: low threshold 1: high threshold	n/a		Each return
Spare (scan_block_spare)	17	Spare column.	2	UnsignedLSB2	n/a		0		Each return
SC Clock Partition (patition)	18	Spacecraft clock partition used for processing.	2	UnsignedLSB2	n/a		1		Each return
Scan Block Time Seconds (seconds_raw)	19	Reference time for first point in scan block in 32-bit seconds since 2000-01-01T12:00:00.	4	UnsignedLSB4	sec		n/a	1	Each return

Field (table field name)	Field Number	Description	Size (Bytes)	Data Type	Units	Range	Default	Resolution	Frequency
Scan Block Time Subseconds (subseconds_raw)	20	Subseconds counts of reference time for first point in scan block, 1/(2**16) seconds per count.	2	UnsignedLSB2			n/a	2.00E-16	Each return
First Point of Block Seconds (first_point_block_sec)	21	Time of generation of first point in the block in 32-bit seconds since 2001-01-01T12:00:00	4	UnsignedLSB4	sec		n/a	1	Each return
First Point of Block Subseconds (first_point_block_sub)	22	Subseconds counts of most recent time update received from spacecraft, 1/(2**16) seconds per count.	2	UnsignedLSB2			n/a	2.00E-16	Each return
Time Delta To MRTU Ref (tdelta_to_mrtu_ref)	23	Time offset between OLA Time and most recent time update command.	4	UnsignedLSB4	Micro-seconds	Time of generation of first point in the block in 32-bit seconds since 2001-01-01T00:00:00	0	1us	Each return
Scan OLA Time (scan_ola_time)	24	Ola Time tag for this scan record.	8	IEEE754LSBDouble	sec		n/a		Each return
Spare	25	Spare column.	2	UnsignedLSB2	n/a		0		Each return

Field (table field name)	Field Number	Description	Size (Bytes)	Data Type	Units	Range	Default	Resolution	Frequency
(time_ref_spare)									
Range (range)	26	Range in millimeters.	8	IEEE754LSBDouble	mm		n/a	1mm	Each return
Azimuth (azimuth_signed)	27	Azimuth in milliradians.	8	IEEE754LSBDouble	mrad		n/a	0.05mrad	Each return
Elevation (elevation_signed)	28	Elevation in milliradians.	8	IEEE754LSBDouble	mrad		n/a	0.05mrad	Each return
Intensity T0 (intensity_t0)	29	Intensity of outgoing pulse.	8	IEEE754LSBDouble			n/a		Each return
Intensity TRR (intensity_trr)	30	Intensity of received pulse.	8	IEEE754LSBDouble			n/a		Each return
Flag Status (flag_status)	31	Status of return. Reported by the instrument.	2	UnsignedLSB2		0: valid return 1: valid return with overflow 2: no return 3: missing sample			Each return
Scan Point Align Diff (alignment_diff_signed)	32	Scan point difference relative to expected time offset:	2	SignedLSB2	Micro-seconds	-8192 to 8191			Each return

Field (table field name)	Field Number	Description	Size (Bytes)	Data Type	Units	Range	Default	Resolution	Frequency
		scan point time - (scan point -1)/scan rate.							

5.2.2 OLA L0 SoH

Field (table field name)	Field Number	Description	Size (Bytes)	Data Type	Units	Range	Default	Resolution	Frequency
Power Cycle (ola_pwrup_counter)	1	Power Cycle counter. Incremented by 1 for every Power On Self Test. (POST)	2	UnsignedLSB2	n/a		n/a		
Clock Partition (partition)	2	Integer that defines spacecraft clock partition employed for processing.	2	UnsignedLSB2	n/a		n/a		
T0 Sec (t0_seconds)	3	Time of generation of SoH record in 32-bit seconds since 2000-01-01T12:00:00 UTC.	4	UnsignedLSB4	sec	2**32-1	n/a		10Hz
T0 Subsec (t0_subseconds)	4	Time of generation of SoH record in subsecond counts. 1/(2**16) seconds per count.	2	UnsignedLSB2	sec	2**16-1	n/a		10Hz
Spare (spare1)	5	Spare column	2	UnsignedLSB2	n/a		0		
TRef Sec	6	Most recent time update received from	4	UnsignedLSB4	n/a	2**32-1	n/a		

Field (table field name)	Field Number	Description	Size (Bytes)	Data Type	Units	Range	Default	Resolution	Frequency
(time_ref_seconds)		spacecraft in 32-bit seconds since 2000-01-01T12:00:00UTC.							
TRef Subsec (time_ref_subseconds)	7	Most recent time update in subsecond counts. 1/(2**16) seconds per count.	2	UnsignedLSB2	n/a				
Spare (spare2)	8	Spare column.	2	UnsignedLSB2	n/a		0		
Time Delta MRTU (mrtu_ref_delta)	9	Time offset between OLA Time and spacecraft time per most recent time update command.	4	UnsignedLSB4	microsecond	-8388608 to 8388607	0		
Spare (spare3)	10	Spare column.	2	UnsignedLSB2	n/a		0		
Last Msg Inst (last_idp_msg_instance)	11	Most recent command instance received from spacecraft.	2	UnsignedLSB2	n/a	Limit not req			
Last Msg ID (last_idp_msg_id)	12	ID of most recent command instance received from spacecraft.	2	UnsignedLSB2					
Cmd Exe Counter (cmd_exe_cnt)	13	Counter for the number of commands executed (excluding Time Update command).	2	UnsignedLSB2	n/a	Limit not req			
Last Cmd Inst	14	Instance index of the last executed	2	UnsignedLSB2	n/a	Limit not req			

Field (table field name)	Field Number	Description	Size (Bytes)	Data Type	Units	Range	Default	Resolution	Frequency
(last_cmd_exe_instance)		instrument command, excluding time update and noop commands.							
Last Cmd ID (last_cmd_exe_id)	15	Command ID (IDP) of the last executed instrument command (excluding Time Update and NOOP commands).	2	UnsignedLSB2	n/a	Limit not req			
Cmd Rej Counter (cmd_rjct_cnt)	16	Counter for the number of commands rejected.	2	UnsignedLSB2	n/a	Limit not req			
No Op Counter (noop_cnt)	17	Number of NOOP commands received since OLA Powerup, with rollover at 65535.	2	UnsignedLSB2	n/a				
Ola State (state)	18	Indication of state of OLA software.	2	UnsignedLSB2	n/a	1:idle 2: standby 3: armed 4: operate 5: diagnostic			
Helt Power (helt_power)	19	HELT power status.	2	UnsignedLSB2	n/a	0: off 1: on	0		
Lelt Power	20	LELT power status.	2	UnsignedLSB2	n/a	0: off	0		

Field (table field name)	Field Number	Description	Size (Bytes)	Data Type	Units	Range	Default	Resolution	Frequency
(lelt_power)						1: on			
Spare (spare4)	21	Spare column.	2	UnsignedLSB2	n/a		0		
Current Min Range (current_min_range)	22	When scan command is active, returns the current minimum valid range.	4	UnsignedLSB4	cm	16777215	n/a		
Avg Range (current_avg_range)	23	When scan command is active, return the average running valid range.	4	UnsignedLSB4	cm	Limit not req	n/a		
Msg Sent (msg_sent)	24	Count of messages sent to spacecraft, excluding state of health messages.	4	UnsignedLSB4	n/a	Limit not req			
Scan Duration (duration_last_scan)	25	Time (duration) of last scan completed.	4	UnsignedLSB4	n/a	Limit not req			
Time Upd Not Present (time_upd_timeout)	26	Indication that a valid Time Update command has not been received for >= 30 seconds.	2	UnsignedLSB2	n/a	0: no fault 1: fault	1		
Time Tick Not Present (time_tick_timeout)	27	Indication that a valid time tick has not been received for >= 30 seconds.	2	UnsignedLSB2	n/a	0: no fault 1: fault	1		
Msg Rej Wrong Block Length	28	Wrong block length message.	2	UnsignedLSB2	n/a	0: no fault	0		

Field (table field name)	Field Number	Description	Size (Bytes)	Data Type	Units	Range	Default	Resolution	Frequency
(msg_rej_wrong_block_len_msg)						1: fault			
Msg Rej Bad Cmd ID (msg_rej_bad_cmd_id)	29	Bad command ID.	2	UnsignedLSB2	n/a	0: no fault 1: fault	0		
Msg Rej Bad Checksum (msg_rej_bad_checksum)	30	Bad checksum.	2	UnsignedLSB2	n/a	0: no fault 1: fault	0		
Msg Rej Invalid Cmd Data (msg_rej_invalid_cmd_data)	31	Invalid command data received vs ICD.	2	UnsignedLSB2	n/a	0: no fault 1: fault	0		
Msg Rej Invalid State (msg_rej_invalid_state_	32	Command not valid in current OLA state.	2	UnsignedLSB2	n/a	0: no fault 1: fault	0		
Msg Rej Active Fault (msg_rej_per_active_fault)	33	Command rejected due to active fault.	2	UnsignedLSB2	n/a	0: no fault 1: fault	0		
Cmd Err Invalid Azimuth Scan (invalid_az_scan_ang_spacing)	34	Invalid azimuth scan angular spacing.	2	UnsignedLSB2	n/a	0: no fault 1: fault	0		

Field (table field name)	Field Number	Description	Size (Bytes)	Data Type	Units	Range	Default	Resolution	Frequency
Cmd Err Invalid Elevation Scan (invalid_el_scan_ang_spacing)	35	Invalid elevation scan angular spacing	2	UnsignedLSB2	n/a	0: no fault 1: fault	0		
Cmd Err Invalid Window Size (invalid_window_size)	36	Invalid window size.	2	UnsignedLSB2	n/a	0: no fault 1: fault	0		
Cmd Err Invalid Window Center Pos (invalid_window_center_pos)	37	Invalid window center position.	2	UnsignedLSB2	n/a	0: no fault 1: fault	0		
Cmd Err Invalid Scan Pattern (invalid_scan_pattern)	38	Invalid scan pattern.	2	UnsignedLSB2	n/a	0: no fault 1: fault	0		
Cmd Err Invalid Scan Type (invalid_scan_type)	39	Invalid scan type.	2	UnsignedLSB2	n/a	0: no fault 1: fault	0		
Cmd Err Invalid Raw Req (invalid_raw_scan_data_req)	40	Invalid raw scan data request.	2	UnsignedLSB2	n/a	0: no fault 1: fault	0		
Cmd Err Laser Not On	41	Laser component is not powered (it should be turned on prior to	2	UnsignedLSB2	n/a	0: no fault 1: fault	0		

Field (table field name)	Field Number	Description	Size (Bytes)	Data Type	Units	Range	Default	Resolution	Frequency
(sel_laser_not_on)		the Scan Start command).							
Cmd Err Invalid Input Check (invalid_input_check)	42	Invalid combination of scan window size and center position.	2	UnsignedLSB2	n/a	0: no fault 1: fault	0		
Cmd Err Invalid Load File Cmd (file_cmd_err)	43	Invalid load file command (e.g., invalid file ID, block out of order, byte count out of range, etc.) or invalid Store File command or invalid Reboot command.	2	UnsignedLSB2	n/a	0: no fault 1: fault	0		
Scan Az Out of FOV (scanning_az_outside_fov)	44	Flag indicating detection of scanning azimuth outside the Field of View (FOV).	2	UnsignedLSB2	n/a	0: no fault 1: fault	0		
Scan El Out of FOV (scanning_el_outside_fov)	45	Flag indicating detection of scanning elevation outside the Field of View (FOV).	2	UnsignedLSB2	n/a	0: no fault 1: fault	0		
IP UDP Hdr Err (idp_udp_hdr_err)	46	Flag indicating error detected in IP or UDP Header.	2	UnsignedLSB2	n/a	0: no fault 1: fault	0		
CIP Hdr Err (cip_hdr_err)	47	Flag indicating error detected in CIP Header.	2	UnsignedLSB2	n/a	0: no fault 1: fault	0		

Field (table field name)	Field Number	Description	Size (Bytes)	Data Type	Units	Range	Default	Resolution	Frequency
IDP Err (idp_err)	48	Flag indicating error detected in IDP.	2	UnsignedLSB2	n/a	0: no fault 1: fault	0		
Scan Buffer Overflow (scan_buffer_overflow)	49	Flag indicating OLA scan buffer overflow.	2	UnsignedLSB2	n/a	0: no fault 1: fault	0		
Generic Sw Err (generic_sw_err)	50	General software exception.	2	UnsignedLSB2	n/a	0: no fault 1: fault	0		
Laser Check Fail (laser_check_failure)	51	Flag indicating laser power on condition detected from an unpowered laser.	2	UnsignedLSB2	n/a	0: no fault 1: fault	0		
Power Fail (laser_power_failure)	52	Flag indicating power not applied or uncommanded loss of laser power after commanded.	2	UnsignedLSB2	n/a	0: no fail 1: fail	0		
Active Flash Write (active_flash_write)	53	Flag indicating OLA is currently writing data to Flash.	2	UnsignedLSB2	n/a	0: Inactive 1: Active	0		
Dmod Heater Status (dmod_heater_status)	54	Status of OLA command of DMOD heater	2	UnsignedLSB2	n/a	0: off 1: on			

Field (table field name)	Field Number	Description	Size (Bytes)	Data Type	Units	Range	Default	Resolution	Frequency
Comm Err (comm_err)	55	Communication error (e.g., framing, parity, etc)	2	UnsignedLSB2	n/a	0: No fault 1: Fault			
Spare (spare5)	56	Spare column.	2	UnsignedLSB2	n/a				
Data Buffer Util (scan_data_buf_util)	57	Percent utilization of Scan Data Overflow buffer.	2	UnsignedLSB2	percent	0-100	0		
Missed Time Ticks (missed_time_tick_counter)	58	Count of seconds since the most recently received Time Tick.	2	UnsignedLSB2	sec	0-255	255		
Missed Time Updates (missed_time_uodate_counter)	59	Count of seconds since the most recently received valid Time Update.	2	UnsignedLSB2	sec	0-255	255		
Scan Completion Status (scan_completion_status)	60	Status of most recently executed (or currently executing) scan.	2	UnsignedLSB2	n/a	0:ok 1: FIFO Overflow 2: Send/ receive thread sync timeout			
Las Pulse Rep Rate	61	Calculated laser pulse rate from the	2	UnsignedLSB2	n/a		0		

Field (table field name)	Field Number	Description	Size (Bytes)	Data Type	Units	Range	Default	Resolution	Frequency
(laser_rep_rate)		TIM/PEAK board in units of pulse/100 ms							
Laser Over Temp (laser_over_te mp_	62	Laser over temperature flag monitor.	2	UnsignedLSB2	n/a	0: no fault 1: fault			
Laser Under Temp (laser_under_t emp)	63	Laser under temperature flag monitor.	2	UnsignedLSB2	n/a	0: no fault 1: fault			
Curr Report HELT (laser_ready_h elt)	64	Laser input current monitor for HELT	2	UnsignedLSB2	n/a	0: off 1: on			
Curr Report LELT (laser_ready_le lt)	65	Laser input current monitor for LELT	2	UnsignedLSB2	n/a	0: off 1: on			
DMOD Temp Failure (dmod_temper ature_failure)	66	Failure of sensor head demodulator chassis temperature sensor.	2	UnsignedLSB2	n/a	0: no fault 1: fault			
Spare (spare6)	67	Spare column	2	UnsignedLSB2		n/a			
Spare (hw_status_wo rd2)	68	Spare column	4	UnsignedLSB4		n/a			

Field (table field name)	Field Number	Description	Size (Bytes)	Data Type	Units	Range	Default	Resolution	Frequency
Spare (spare8)	69	Spare column	4	UnsignedLSB4		n/a			
Mirror Temp (mirror_therm)	70	Mirror Temperature.	2	SignedLSB2		-32768 to 32767			
Electronics Temp (case_therm)	71	Main electronics temperature sensor.	2	SignedLSB2		-32768 to 32767			
Sensor Head Pos Temp (sensor_therm)	72	Sensor Head position temperature sensor.	2	SignedLSB2		-32768 to 32767			
Head Chassis 1 Temp (sh_temp_1)	73	Sensor Head Chassis temperature sensor 1.	2	SignedLSB2		-32768 to 32767			
Head Chassis 2 Temp (sh_temp_2)	74	Sensor Head Chassis temperature sensor 2.	2	SignedLSB2		-32768 to 32767			
Head Chassis 3 Temp (sh_temp_3)	75	Sensor Head Chassis temperature sensor 3.	2	SignedLSB2		-32768 to 32767	-		
ADP Temp (rx_apd_temp)	76	ADP Temperature sensor.	2	SignedLSB2		-32768 to 32767			
DMOD Kaman Temp (dmod_temp)	77	DMOD Temperature sensor.	2	SignedLSB2		-32768 to 32767	-		

Field (table field name)	Field Number	Description	Size (Bytes)	Data Type	Units	Range	Default	Resolution	Frequency
Hi Pow Las TEC 1 Temp (helt_tec_diode_temp)	78	High Power Laser (TEC) temperature sensor 1.	2	SignedLSB2		-32768 to 32767	-		
Hi Pow Las TEC 2 Temp (helt_tec_crystal_temp)	79	High Power Laser (TEC) temperature sensor 2.	2	SignedLSB2		-32768 to 32767	-		
Low Pow Las TEC 1 Temp (lelt_tec_diode_temp)	80	Low Power Laser (TEC) temperature sensor 1.	2	SignedLSB2		-32768 to 32767			
Low Pow Las TEC 2 Temp (lelt_tec_crystal_temp)	81	Low Power Laser (TEC) temperature sensor 2.	2	SignedLSB2		-32768 to 32767			
ADC Bias Plus Refv (adc_bias_pos_ref_volt)	82	ADC Bias positive reference voltage.	2	SignedLSB2		-32768 to 32767			
ADC Bias Neg Refv (adc_bias_neg_ref_volt)	83	ADC Bias negative reference voltage	2	SignedLSB2		-32768 to 32767			
AD590 Spare Temp (spare_ad590_temp)	84	Spare AD590 temperature sensor.	2	SignedLSB2		-32768 to 32767			

Field (table field name)	Field Number	Description	Size (Bytes)	Data Type	Units	Range	Default	Resolution	Frequency
Tim Board Temp (tim_pk_temp)	85	TIM/Peak board temperature.	2	SignedLSB2		-32768 to 32767			
IO Board 1 Temp (io_brd_temp1)	86	IO Board CCA Temp 1.	2	SignedLSB2		-32768 to 32767			
IO Board 2 Temp (io_brd_temp2)	87	IO Board CCA Temp 2.	2	SignedLSB2		-32768 to 32767			
Head Heater 1 Temp (helt_chassis_temp_plus_y)	88	Sensor Head HELT Chassis temperature sensor in the +Y direction.	2	SignedLSB2		-32768 to 32767			
Head Heater 2 Temp helt_chassis_temp_neg_y)	89	Sensor Head HELT Chassis temperature sensor in the -Y direction.	2	SignedLSB2		-32768 to 32767			
Plus5V (plus_5v_rail)	90	Voltage monitor of the +5V input rail.	2	SignedLSB2		-32768 to 32767			
Neg5V (neg_5v_rail)	91	Voltage monitor of the -5V input rail.	2	SignedLSB2		-32768 to 32767			
Plus15V (plus_15v_rail)	92	Voltage monitor of the +15V input rail.	2	SignedLSB2		-32768 to 32767			

Field (table field name)	Field Number	Description	Size (Bytes)	Data Type	Units	Range	Default	Resolution	Frequency
Neg15V (neg_15v_rail)	93	Voltage monitor of the -15V input rail	2	SignedLSB2		-32768 to 32767			
Plus16DOT5V (plus_16_5v_rail)	94	Voltage monitor of the +16.5V input rail	2	SignedLSB2		-32768 to 32767			
Ground (ground_ref)	95	Voltage monitor of the ground reference.	2	SignedLSB2		-32768 to 32767			
Last Gain AZ Autocal Plus5V (mir_pos_acs_az_plus_5v)	96	Last reading of the Mirror Position Sensor Azimuth ADC auto-calibration +5V gain.	2	SignedLSB2		-32768 to 32767			
Last Gain EL Autoal Plus5V (mir_pos_acs_el_plus_5v)	97	Last reading of the Mirror Position Sensor Elevation ADC auto-calibration +5V gain.	2	SignedLSB2		-32768 to 32767			
Last Gain AZ Autocal Neg5V (mir_pos_acs_az_neg_5v)	98	Last reading of the Mirror Position Sensor Azimuth ADC auto-calibration -5V gain.	2	SignedLSB2		-32768 to 32767			
Last Gain EL Autocal Neg5V mir_pos_acs_el_neg_5v)	99	Last reading of the Mirror Position Sensor Elevation ADC auto-calibration -5V gain.	2	SignedLSB2		-32768 to 32767			
Last Ground AZ Autocal	100	Last reading of the Mirror Position Sensor Azimuth ADC auto-	2	SignedLSB2		-32768 to 32767			

Field (table field name)	Field Number	Description	Size (Bytes)	Data Type	Units	Range	Default	Resolution	Frequency
(mir_pos_acs_ az_ground)		calibration ground reference							
Last Ground EL Auctocal mir_pos_acs_e l_ground)	101	Last reading of the Mirror Position Sensor Elevation ADC auto-calibration ground reference.	2	SignedLSB2		-32768 to 32767			
OLA Reserved Word1 (reserved1)	102	OLA reserved word.	4	UnsignedLSB4					
OLA Reserved Word2 (reserved2)	103	OLA reserved word.	4	UnsignedLSB4					
OLA Reserved Word3 (reserved3)	104	OLA reserved word.	4	UnsignedLSB4					

5.2.3 OLA L1 Science

OLA Science Level 1 data product (OLA L1) contains the most basic OLA measurement data in a binary table format separated by day and scan sequence ID (which corresponds to a single OLA observation). OLA L1 data has a time correction applied to the scan_ola_time, with the sclk offset applied to the scan_ola_time (see Section 4.4.2). During a scan the OLA software injects fake timestamped records flagged with Flag_Status = 3. These records are removed from the dataset during the L0 to L1 processing. OLA L1 data are stored in calibrated physical units (i.e., ranges in meters and scan angles in degrees or radians as opposed to voltages and digital numbers). One data record is available for each OLA shot fired. The table below provides the type and size of each parameter.

Field (table field name)	Field Number	Description	Size (Bytes)	Data Type	Units	Range	Default	Resolution	Frequency
MET (met)	1	Spacecraft clock time.	18	ASCII_String	s/c ticks		n/a		Each return
MET Offset (met_offset)	2	Value in units of ticks (2^-16 seconds) that should be added to MET to give precise time. This is needed because there is not enough precision in the MET field. Example: If MET is 1/0521165299.31170 and MET OFFSET is 0.5, then the lidar point was acquired at exactly midway between 1/0521165299.31170 and 1/0521165299.31171.	8	IEEE754LSBDouble	s/c ticks		n/a		Each return
Scan OLA Time (scan_ola_time)	3	Ola Time tag for this scan record.	8	IEEE754LSBDouble	sec		n/a		Each return
Power Cycle (power_cycle)	4	Power Cycle counter. Incremented by 1 for every Power On Sself Test.	2	SignedLSB2	n/a		n/a		Each return
Laser Selection (laser_selectio n)	5	Specifies whether scan command applies to High Energy or Low Energy Laser	2	SignedLSB2	n/a	0:HELT 1:LELT	n/a		Each return
Scan Pattern	6	Selected Scan Pattern.	1	SignedLSB	n/a	0: Raster	n/a		Each return

(scan_mode)						1: Linear 2: Fixed			
Flight Software Version (sw_version_detected cal v2.0: fsw_version, cal v1.0)	7	Flight software version number.	1	UnsignedLSB	n/a	0: old 1: new	n/a		Each Return
Flag Status (flag_status)	8	Status of return. Supplemented with additional information from the OLA state of health; indicating whether or not demodulator was on at the time of return.	2	SignedLSB2	n/a	0: valid return 1: valid return with overflow 2: no return 3: missing sample 100: valid, demodulator on 101: valid return with overflow, demodulator on 102: no return, demodulator on 103: missing sample,			Each return

						demodulat or on			
Range (range)	9	Range in millimeters.	8	IEEE754LSBDouble	mm		n/a	1mm	Each return
Azimuth (azimuth)	10	Azimuth in milliradians.	8	IEEE754LSBDouble	mrad		n/a	0.05mrad	Each return
Elevation (elevation)	11	Elevation in milliradians.	8	IEEE754LSBDouble	mrad		n/a	0.05mrad	Each return
Intensity T0) (intensity_t0	12	Intensity of outgoing pulse.	8	IEEE754LSBDouble			n/a		Each return
Intensity TRR (intensity_trr)	13	Intensity of received pulse.	8	IEEE754LSBDouble			n/a		Each return

5.2.4 OLA L1 SoH

OLA SoH Level 1 data will be in binary table format separated by day. Here data is stored in physical units obtained via a calibration table. SoH L1 data will have calibrated values (such as temperatures). Some of the Boolean flags have been consolidated into one flag, which is the product of several boolean flags from SoH L0. Also, the 32-bit word requirement is removed so there are no spare bits.

Field (table field name)	Field Number	Description	Size (Bytes)	Data Type	Units	Range	Default	Resolution	Frequency
MET (met)	1	Spacecraft clock time	18	ASCII_String	s/c ticks		n/a		
UTC (soh_ola_date)	2	UTC Time (yyyy-doyThh:mm:ss.ssssss)	24	ASCII_String	n/a		n/a		
SOH OLA Time	3	Ola Time tag for this SOH record.	8	IEEE754LSBDouble			n/a		

Field (table field name)	Field Number	Description	Size (Bytes)	Data Type	Units	Range	Default	Resolution	Frequency
(soh_ola_time)									
Power Cycle (ola_pwrup_counter)	4	Power Cycle counter. Incremented by 1 for every POST.	2	UnsignedLSB2	n/a		n/a		
Current Min Range (current_min_range)	5	When scan command is active, returns the current minimum valid range.	8	IEEE754LSBDouble	cm	16.777215 km			
Avg Range (current_avg_range)	6	When scan command is active, return the average running valid range.	8	IEEE754LSBDouble	cm	Limit not req			
Duration_Last_Scan (duration_last_scan_x)	7	Time (duration) of last scan completed . in units of 0.01 seconds.	8	IEEE754LSBDouble	0.01 seconds	Limit not req			
Mirror Temp (mirror_therm_x)	8	Mirror Temperature.	8	IEEE754LSBDouble	celsuis	55 yellow high 60 red high			
Electronics Temp (case_therm_x)	9	Main electronics temperature sensor.	8	IEEE754LSBDouble	celsius	50 yellow high 55 red high			
Sensor Head Pos Temp (sensor_therm_x)	10	Sensor Head position temperature sensor.	8	IEEE754LSBDouble	celsius	Limit not req			

Field (table field name)	Field Number	Description	Size (Bytes)	Data Type	Units	Range	Default	Resolution	Frequency
Head Chassis 1 Temp (sh_temp_1_x)	11	Sensor Head Chassis temperature sensor 1.	8	IEEE754LSBDouble	celsius	Limit not req			
Head Chassis 2 Temp (sh_temp_2_x)	12	Sensor Head Chassis temperature sensor 2.	8	IEEE754LSBDouble	celsius	Limit not req			
Head Chassis 3 Temp (sh_temp_3_x)	13	Sensor Head Chassis temperature sensor 3.	8	IEEE754LSBDouble	celsius	Limit not req			
ADP Temp (rx_apd_temp_x)	14	ADP Temperature sensor.	8	IEEE754LSBDouble	celsius	45 yellow high 50 red high			
DMOD Kaman Temp (dmod_temp_x	15	DMOD Temperature sensor.	8	IEEE754LSBDouble	celsius	47 yellow high 50 red high			
Hi Pow Las TEC 1 Temp (helt_tec_diode_temp_x)	16	High Power Laser (TEC) temperature sensor 1.	8	IEEE754LSBDouble	celsius	Limit not req			
Hi Pow Las TEC 2 Temp (helt_tec_crystal_temp_x)	17	High Power Laser (TEC) temperature sensor 2.	8	IEEE754LSBDouble	celsius	Limit not req			
Low Pow Las TEC 1 Temp	18	Low Power Laser (TEC) temperature sensor 1.	8	IEEE754LSBDouble	celsius	Limit not req			

Field (table field name)	Field Number	Description	Size (Bytes)	Data Type	Units	Range	Default	Resolution	Frequency
(lelt_tec_diode _temp_x)									
Low Pow Las TEC 2 Temp (lelt_tec_crystal_temp_x)	19	Low Power Laser (TEC) temperature sensor 2.	8	IEEE754LSBDouble	celsius	Limit not req			
ADC Bias Plus Refv (adc_bias_pos _ref_volt_x)	20	ADC bias positive reference voltage.	8	IEEE754LSBDouble	volts	4.5 red low 4.2 yellow low 5.25 red high 5.5 red high			
ADC Bias Neg Refv (adc_bias_neg _ref_volt_x)	21	ADC bias negative reference voltage.	8	IEEE754LSBDouble	volts	-5.5 red low -5.25 yellow low -4.75 yellow high -4.5 red high			
AD590 Spare Temp (spare_ad590_ temp_x)	22	Spare AD590 temperature sensor.	8	IEEE754LSBDouble	celsius	Limit not req			

Field (table field name)	Field Number	Description	Size (Bytes)	Data Type	Units	Range	Default	Resolution	Frequency
Tim Board Temp (tim_pk_temp_x)	23	TIM/Peak board temperature.	8	IEEE754LSBDouble	celsius	80 yellow high 85 red high			
IO Board 1 Temp (io_brd_temp1_x)	24	IO Board CCA Temp 1.	8	IEEE754LSBDouble	celsius	80 yellow high 85 red high			
IO Board 2 Temp (io_brd_temp2_x)	25	IO Board CCA Temp 2.	8	IEEE754LSBDouble	celsius	80 yellow high 85 red high			
Head Heater 1 Temp (helt_chassis_temp_plus_y_x)	26	Sensor Head HELT chassis Temperature in the +Y direction.	8	IEEE754LSBDouble	celsius	Limit not req			
Head Heater 2 Temp (helt_chassis_temp_neg_y_x)	27	Sensor Head HELT chassis temperature in the –Y direction.	8	IEEE754LSBDouble	celsius	Limit not req			
Plus5V (plus_5v_rail_x)	28	Voltage monitor of the +5V input rail.	8	IEEE754LSBDouble	volts	4.5 red low 4.75 yellow low 5.25. yellow high 5.5 red high			

Field (table field name)	Field Number	Description	Size (Bytes)	Data Type	Units	Range	Default	Resolution	Frequency
Neg5V (minus_5v_rail_x)	29	Voltage monitor of the -5V input rail.	8	IEEE754LSBDouble	volts	-5.5 red low --5.25 yellow low -4.75 yellow high -4.5 red high			
Plus15V (plus_15v_rail_x)	30	Voltage monitor of the +15V input rail.	8	IEEE754LSBDouble	volts	14 red low 14.25 yellow low 15.75 yellow high 16 red high			
Neg15V (minus_15v_rail_x)	31	Voltage monitor of the -15V input rail	8	IEEE754LSBDouble	volts	-16 red low -15.75 yellow low -14.25 yellow high -14 red high			
Plus16DOT5V (plus_16_5v_rail_x)	32	Voltage monitor of the +16.5V input rail	8	IEEE754LSBDouble	volts	15.2 red low			

Field (table field name)	Field Number	Description	Size (Bytes)	Data Type	Units	Range	Default	Resolution	Frequency
						16.05 yellow low 16.95 yellow high 17.8 red high			
Ground (ground_ref)	33	Voltage monitor of the ground reference.	8	IEEE754LSBDouble	volts	-0.5 red low -0.25 yellow low 0.25 yellow high 0.5 red high			
Last Gain AZ Autocal Plus5V (mir_pos_acs_ az_plus_5v_x_	34	Last reading of the Mirror Position Sensor Azimuth ADC auto-calibration +5V gain.	8	IEEE754LSBDouble	volts	Limit not req			
Last Gain EL Autocal Plus5V (mir_pos_acs_ el_plus_5v_x)	35	Last reading of the Mirror Position Sensor Elevation ADC auto-calibration +5V gain.	8	IEEE754LSBDouble	volts	Limit not req			
Last Gain AZ Autocal Neg5V (mir_pos_acs_ az_minus_5v_ x)	36	Last reading of the Mirror Position Sensor Azimuth ADC auto-calibration -5V gain.	8	IEEE754LSBDouble	volts	Limit not req			

Field (table field name)	Field Number	Description	Size (Bytes)	Data Type	Units	Range	Default	Resolution	Frequency
Last Gain EL Autocal Neg5V (mir_pos_acs_el_minus_5v_x)	37	Last reading of the Mirror Position Sensor Elevation ADC auto-calibration -5V gain.	8	IEEE754LSBDouble	volts	Limit not req			
Last Ground AZ Autocal (mir_pos_acs_az_ground_x)	38	Last reading of the Mirror Position Sensor Azimuth ADC auto-calibration ground reference	8	IEEE754LSBDouble	volts	Limit not req			
Last Ground EL Auctocal (mir_pos_acs_el_ground_x)	39	Last reading of the Mirror Position Sensor Elevation ADC auto-calibration ground reference.	8	IEEE754LSBDouble	volts	Limit not req			

5.2.5 OLA L2 Science

OLA Science Level 2 data product (OLA L2) contains all the information in OLA L1 along with body-fixed point cloud data obtained via s/c ephemerides spice kernels. OLA L2 data has no corrections applied. Here data is stored in calibrated physical units (i.e., ranges in meters and scan angles in degrees or radians as opposed to voltages and digital numbers). One data record is available for each OLA shot fired. The table below provides the type and size of each parameter.

Field (table field name)	Field Number	Description	Size (Bytes)	Data Type	Units	Range	Default	Resolution	Frequency
MET (met)	1	Spacecraft clock time	18	ASCII_String	s/c ticks		n/a		Each return
MET Offset	2	Value in units of ticks (2^-16 seconds) that	8	IEEE754LSBDouble	s/c ticks		n/a		Each return

Field (table field name)	Field Number	Description	Size (Bytes)	Data Type	Units	Range	Def ault	Resolution	Frequency
(met_offset)		should be added to MET to give precise MET. This is needed because there is not enough precision in the MET field. Example: If MET is 1/0521165299.31170 and MET OFFSET is 0.5, then the lidar point was acquired at exactly midway between 1/0521165299.31170 and 1/0521165299.31171.							
UTC (utc)	3	UTC Time (yyyy-doyThh:mm:ss.ssssss)	24	ASCII_Time	n/a		n/a		Each return
ET (et)	4	Ephemeris time	8	IEEE754LSBD ouble	second				Each return
Scan OLA Time (scan_ola_time)	5	Ola Time tag for this scan record.	8	IEEE754LSBD ouble	sec		n/a		Each return
Power Cycle (power_cycle)	6	Power Cycle counter. Incremented by 1 for every POST.	2	SignedLSB2	n/a		n/a		Each return
Laser Selection (laser_selectio n)	7	Specifies whether scan command applies to High Energy (0) or Low Energy Laser (1)	2	SignedLSB2	n/a	0:HELT 1:LELT	n/a		Each return

Field (table field name)	Field Number	Description	Size (Bytes)	Data Type	Units	Range	Default	Resolution	Frequency
Scan Pattern (scan_mode)	8	Selected Scan Pattern.	2	SignedLSB2	n/a	0: Raster 1: Linear 2: Fixed	n/a		Each return
Flag Status (flag_status)	9	Status of return. Supplemented with additional information from the OLA state of health; indicating whether or not demodulator was on at the time of return.	2	SignedLSB2	n/a	0: valid return 1: valid return with overflow 2: no return 3: missing sample 100: valid, demodulator on 101: valid return with overflow, demodulator on 102: no return, demodulator on 103: missing sample, demodulator on			Each return
Range (range)	10	Range in millimeters.	8	IEEE754LSBDouble	mm		n/a	1mm	Each return
Azimuth (azimuth)	11	Azimuth in milliradians.	8	IEEE754LSBDouble	mrad		n/a	0.05mrad	Each return
Elevation (elevation)	12	Elevation in milliradians.	8	IEEE754LSBDouble	mrad		n/a	0.05mrad	Each return
Intensity T0 (intensity_t0)	13	Intensity of outgoing pulse.	8	IEEE754LSBDouble			n/a		Each return

Field (table field name)	Field Number	Description	Size (Bytes)	Data Type	Units	Range	Default	Resolution	Frequency
Intensity TRR (intensity_trr)	14	Intensity of received pulse.	8	IEEE754LSBDouble			n/a		Each return
X (x)	15	X position of lidar point.	8	IEEE754LSBDouble	meters		n/a		Each return
Y (y)	16	Y position of lidar point.	8	IEEE754LSBDouble	meters		n/a		Each return
Z(z)	17	Z position of lidar point.	8	IEEE754LSBDouble	meters		n/a		Each return
ELongitude (elongitude)	18	East longitude of lidar point.	8	IEEE754LSBDouble	deg		n/a		Each return
Latitude (latitude)	19	Latitude of lidar point.	8	IEEE754LSBDouble	deg		n/a		Each return
Radius (radius)	20	Radius of lidar point.	8	IEEE754LSBDouble	km		n/a		Each return
SCX (scx)	21	X position of spacecraft.	8	IEEE754LSBDouble	meters		n/a		Each return
SCY (scy)	22	Y position of spacecraft.	8	IEEE754LSBDouble	meters		n/a		Each return
SCZ (scz)	23	Z position of spacecraft.	8	IEEE754LSBDouble	meters		n/a		Each return

5.2.6 OLA L2A Science

OLA Science Level 2A data product (OLA L2A) contains all the information in OLA L2 except that the original body-fixed point cloud data and s/c position data has been adjusted to minimize differences between individual OLA scans. These data produced the final derived altimetry global and local digital models generated during the OSIRIS-REx mission. Therefore, the OLA L2A data has been corrected. Here data is stored in calibrated physical units (i.e., ranges in meters and scan angles in degrees or radians as opposed to voltages and digital numbers). One data record is available for each OLA shot fired. The table below provides the type and size of each parameter. The OLA L2A and OLA L2 products possess identical formats, except that several additional flag statuses are available. A flag status of 4 found in the OLA L2A files means that OLA measured a valid return but that the return is thought to be a particle ejected from Bennu. A flag of 6 is identified as valid data suitable for assessing relative surface albedo when emission angles and range limits are within suitable limits. The value of the intensity in the original L2 (Section (5.2.5) was converted to relative reflectance by using 14.364/(14.728-0.0008*(id-4000)) * Range^2. The constants in the formulation were derived by assessing the signal to noise characteristics of OLA during the mission (Neumann et al., 2020). As the OLA L2A products are derived science products they are to be delivered at the end of the asteroid encounter.

Field	Field Number	Description	Size (Bytes)	Data Type	Units	Range	Default	Resolution	Frequency
MET	1	Spacecraft clock time	18	ASCII_String	s/c ticks		n/a		Each return
MET Offset	2	Value in units of ticks (2^-16 seconds) that should be added to MET to give precise MET.	8	IEEE754LSBDouble	s/c ticks		n/a		Each return
UTC	3	UTC Time (yyyy-doyThh:mm:ss.ssssss)	24	ASCII_Time	n/a		n/a		Each return
ET	4	Ephemeris time	8	IEEE754LSBDouble	second				Each return
Scan OLA Time	5	Ola Time tag for this scan record.	8	IEEE754LSBDouble	second		n/a		Each return
Power Cycle	6	Power Cycle counter. Incremented by 1 for every POST.	2	SignedLSB2	n/a		n/a		Each return
Laser Selection	7	Specifies whether scan command applies to High Energy or Low Energy Laser	2	SignedLSB2	n/a	0:HELT 1:LELT	n/a		Each return
Scan Pattern	8	Selected Scan Pattern.	2	SignedLSB2	n/a	0: Raster	n/a		Each return

Field	Field Number	Description	Size (Bytes)	Data Type	Units	Range	Default	Resolution	Frequency
						1:Linear 3: Fixed			
Flag Status	9	Status of return.	2	SignedLSB2	n/a	0: valid return 1: valid return with overflow 2: no return 3: missing sample 4: possible particle 5: scan edge or scan start 6: valid with albedo update 7: not used in any strip adjustment 100-107: same as above except demodulator on			Each return

Field	Field Number	Description	Size (Bytes)	Data Type	Units	Range	Default	Resolution	Frequency
Range	10	Range in millimeters.	8	IEEE754LSBDouble	mm		n/a	1mm	Each return
Azimuth	11	Azimuth in milliradians.	8	IEEE754LSBDouble	mrad		n/a	0.05mrad	Each return
Elevation	12	Elevation in milliradians.	8	IEEE754LSBDouble	mrad		n/a	0.05mrad	Each return
Intensity T0	13	Intensity of outgoing pulse.	8	IEEE754LSBDouble			n/a		Each return
Intensity TRR	14	Intensity of received pulse.	8	IEEE754LSBDouble			n/a		Each return
X	15	X position of lidar point.	8	IEEE754LSBDouble	meters		n/a		Each return
Y	16	Y position of lidar point.	8	IEEE754LSBDouble	meters		n/a		Each return
Z	17	Z position of lidar point.	8	IEEE754LSBDouble	meters		n/a		Each return
ELongitude	18	East longitude of lidar point.	8	IEEE754LSBDouble	deg		n/a		Each return
Latitude	19	Latitude of lidar point.	8	IEEE754LSBDouble	deg		n/a		Each return
Radius	20	Radius of lidar point.	8	IEEE754LSBDouble	km		n/a		Each return
SCX	21	X position of spacecraft.	8	IEEE754LSBDouble	meters		n/a		Each return
SCY	22	Y position of spacecraft.	8	IEEE754LSBDouble	meters		n/a		Each return
SCZ	23	Z position of spacecraft.	8	IEEE754LSBDouble	meters		n/a		Each return

5.3 Label and Header Descriptions

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

See Section 7.3 for examples of the OLA L0 through L2 data product labels. Data product labels are in XML format and are PDS4 compliant.

6 Applicable Software

6.1 Utility Programs

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

6.2 Applicable PDS Software Tools

Data products found in the OSIRIS-REx archive can be viewed with any PDS4 compatible software utility. OSIRIS-REx image data and portions of the spectrometer data are formatted as FITS data files, which can be read by any FITS compatible viewer or library function.

6.3 Software Distribution and Update Procedures

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

7 Appendices

7.1 Acronyms

Phrase/Acronym	Description
CODMAC	Committee on Data Management and Computation
CPU	Central Processing Unit
DRM	Design Reference Mission
DSN	Deep Space Network
FITS	Flexible Image Transport System
GMT	Greenwich Mean Time
HELT	High-Energy Laser Transmitter
IAU	International Astronomical Union
ID	Identification
L2A	OLA Science Level 2A data product
LELT	Low-Energy Laser Transmitter
LIDAR	Light Detection and Ranging
MDA	MacDonald, Dettwiler and Associates
MET	Mission Elapsed Time
NAIF	Navigation and Ancillary Information Facility
NASA	National Aeronautics and Space Administration
OLA	OSIRIS-REx Laser Altimeter
OSIRIS-REx	Origins, Spectral Interpretation, Resource Identification, Security and Regolith Explorer
PDS	Planetary Data System
SCLK	Spacecraft Clock Time
SIS	Software Interface Specification
SOEST	University of Hawaii's School of Ocean and Oceanography
SoH/SOH	State of Health
SPICE	NASA's ancillary space information system which is comprised of kernels (SPICE comes from Spacecraft ephemeris (SPK), Physical constants kernels (PCK), Instrument kernels (IK), Pointing kernel (CK), and Events kernel (EK))
SPK kernel	NAIF Ephemeris SPICE kernel
SPOC	Science Processing and Operations Center
TAG	Touch And Go
UTC	Coordinated Universal Time

Phrase/Acronym	Description
XML	Extensible Markup Language

7.2 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.

Level	***Definition***	
Low-Level Products	Any data product assigned to OSIRIS-REx Level 0 through Level 2	
	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	*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. This data will be archived to the PDS
	OREx Level 2	*Processed*. Same as level 1 but contains additional fields that are calculated using SPICE kernel files. This data will be archived to the PDS

7.3 Example PDS Label

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

7.4 Reference

Neumann, G.A. et al., Global and Local Variations in 1064-nm Normal Albedo of Bennu from the OSIRIS-REx Laser Altimeter. *LPI* ..., (2326), p.2032.

7.5 OLA PDS Calibration File Parse

Python parser (https://github.com/michaelaye/ola_calib) for calibration file of OSIRIS-REX OLA instrument written by K.-Michael Aye during the review of the OLA products. This parser is included for the convenience of the end-user.

Instructions:

Locate the calibration file (potential file name: `ola_cal_file.txt`) for the OLA calibration and put it next to this Python module (ola_cal.py)

Use as indicated in the notebook, use object inspection for all the things stored in the `cal` object.

```
import numpy as np


class OLA_CAL_READER:
    def __init__(self, fname):
        self.fname = fname
        self.read_lines()
        self.get_indices()
        self.parse_range_coeffs()
        self.parse_az_el_coeffs()
        self.parse_rest()

    def read_lines(self):
        data = []
```

```
        with open(self.fname) as f:
            for line in f:
                line = line.strip()
                if line.startswith('#') or len(line) == 0:
                    continue
                data.append(line)
        self.data = data

    def get_indices(self):
        indices = []
        for i, line in enumerate(self.data):
            if line.split()[0].isupper():
                indices.append(i)
        self.indices = indices

    def parse_group_to_array(self, index):
        group = self.data[self.indices[index] + 1:self.indices[index +
1]]
        bucket = []
        for line in group:
            bucket.extend(np.array(line.strip('\\').split(),
dtype='float'))
        return np.array(bucket)

    def parse_range_coeffs(self):
        self.RANGE_HELT_FIXED = float(self.data[0].split()[1])
        self.RANGE_HELT_LUT = self.parse_group_to_array(0)
        self.RANGE_LELT_FIXED =
float(self.data[self.indices[1]].split()[1])
        self.RANGE_LELT_LUT = self.parse_group_to_array(1)

    def parse_az_el_coeffs(self):
        self.AZIMUTH_HELT = self.parse_group_to_array(2)
        self.AZIMUTH_LELT = self.parse_group_to_array(3)
        self.ELEVATION_HELT = self.parse_group_to_array(4)
        self.ELEVATION_LELT = self.parse_group_to_array(5)

    def parse_rest(self):
        for index in self.indices[6:]:
            tokens = self.data[index].split()
            setattr(self, tokens[0], np.array(tokens[1:],
dtype='float'))
```

Example notebook (example.ipynb)


```
{
 "cells": [
  {
   "cell_type": "code",
   "execution_count": 1,
   "metadata": {},
   "outputs": [],
   "source": [
    "from ola_calib import OLA_CAL_READER"
```

```
   ]
  },
  {
   "cell_type": "code",
   "execution_count": 2,
   "metadata": {},
   "outputs": [],
   "source": [
    "cal = OLA_CAL_READER(\"./ola_cal_file.txt\")"
   ]
  },
  {
   "cell_type": "code",
   "execution_count": 4,
   "metadata": {},
   "outputs": [
    {
     "data": {
      "text/plain": [
       "array([-0.01234098,  1.01449806, -0.03878473,  0.03512159, -
0.00218885,\n",
       "        0.03002791, -0.8554585 ,  0.03818734,  0.07648011, -
0.14134251,\n",
       "       -0.40992896, -0.13666116,  0.94534425, -0.52998789, -
1.65820117])"
      ]
     },
     "execution_count": 4,
     "metadata": {},
     "output_type": "execute_result"
    }
   ],
   "source": [
    "cal.AZIMUTH_HELT"
   ]
  },
  {
   "cell_type": "code",
   "execution_count": 5,
   "metadata": {},
   "outputs": [
    {
     "data": {
      "text/plain": [
       "array([0.   , 0.001, 0.   , 0.   , 0.   , 0.   ])"
      ]
     },
     "execution_count": 5,
     "metadata": {},
     "output_type": "execute_result"
    }
   ],
   "source": [
    "cal.ADC_BIAS_NEG_REF_VOLTAGE"
   ]
```

```
  },
  {
   "cell_type": "code",
   "execution_count": 6,
   "metadata": {},
   "outputs": [
    {
     "data": {
      "text/plain": [
       "array([-1.73277685e-02,  1.98466594e-02,  1.03549939e+00, -
2.93306954e-03,\n",
       "       -1.53076409e-02, -2.30560149e-01, -1.72898594e-02, -
3.20868689e-01,\n",
       "       -6.79769957e-02, -1.74335480e+00, -3.30069325e-02,
4.59325863e-01,\n",
       "        2.51398211e-01, -1.25332528e+00,  5.38166676e+00])"
      ]
     },
     "execution_count": 6,
     "metadata": {},
     "output_type": "execute_result"
    }
   ],
   "source": [
    "cal.ELEVATION_HELT"
   ]
  },
  {
   "cell_type": "code",
   "execution_count": 9,
   "metadata": {},
   "outputs": [
    {
     "data": {
      "text/plain": [
       "array([-25.168553, -25.180376, -25.191883, ...,  46.996854,
46.996959,\n",
       "        46.997064])"
      ]
     },
     "execution_count": 9,
     "metadata": {},
     "output_type": "execute_result"
    }
   ],
   "source": [
    "cal.RANGE_HELT_LUT"
   ]
  },
  {
   "cell_type": "code",
   "execution_count": null,
   "metadata": {},
   "outputs": [],
   "source": []
```

```
   }
  ],
  "metadata": {
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    "display_name": "Python [conda env:py37] *",
    "language": "python",
    "name": "conda-env-py37-py"
   },
   "language_info": {
    "codemirror_mode": {
     "name": "ipython",
     "version": 3
    },
    "file_extension": ".py",
    "mimetype": "text/x-python",
    "name": "python",
    "nbconvert_exporter": "python",
    "pygments_lexer": "ipython3",
    "version": "3.7.3"
   },
   "widgets": {
    "application/vnd.jupyter.widget-state+json": {
     "state": {},
     "version_major": 2,
     "version_minor": 0
    }
   }
  },
  "nbformat": 4,
  "nbformat_minor": 4
 }
```