Lucy
SOFTWARE INTERFACE SPECIFICATION
Thermal Emission Spectrometer (LTES) Data Products

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SwRI® Project 22668

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Contract NNM16AA08C

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TABLE OF CONTENTS

Page

REVISION NOTICE

Revision Number	Change Number	Sections Affected	Change Description	Release Date
0	0	All	(DRAFT, R0)	01/25/2021
0	0	All	(DRAFT, R1)	06/2021
0	0	All	(DRAFT, R2)	9/2023
0	0	2.4.1.1	File naming convention updates per PR-0313 and TCR 2311	6/30/2024
0	0	All	PDS pipeline review lien response	6/30/2024
0	0	ALL	INITIAL RELEASE	7/2024

TBD/TBS RESOLUTION SCHEDULE

Location	Description	Resolution Date
Table 1-1	LTES Instrument Paper	6/2024
2.4.1.1	Need to define the TES CDP data product naming convention	6/2024
All	2023 PDS Peer Review updates	6/2024

1. INTRODUCTION

1.1 Purpose and Scope

The purpose of this Software Interface Specification (SIS) is to provide the consumers of the *Lucy* Thermal Emission Spectrometer (LTES) raw and calibrated data products with a detailed description of the data 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 product. 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.

Raw data products described in this SIS are uncalibrated, uncorrected data products reassembled from spacecraft telemetry as acquired by the instrument. Uncalibrated products are known as either “raw”, “engineering (eng)” or “uncalibrated”. These files may contain instrument status or instrument status and interferogram data. Calibrated data products described in this SIS are corrected and calibrated data products with values given in physically meaningful data units. Calibrated products are referred to as either “calibrated” or “science (sci)” products and contain calibrated spectra. The *Lucy* Science Operations Center located at the Southwest Research Institute, Boulder, Colorado produces these data products and distributes them to both the *Lucy* Science Team and the Planetary Data System (PDS).

1.2 Contents

This Data Product SIS describes how the raw data products are acquired by LTES and how the products are processed, formatted, labeled, and uniquely identified. This SIS also describes how the calibrated data products are derived from the raw data or other calibrated data products. The document discusses standards used in generating the products, and software that may be used to access the products. The raw and calibrated data product structure and organization is described in sufficient detail to enable a user to read the product. Processing is described at a high level, and full definitions of all metadata attributes are provided.

1.1 Applicable Documents

This SIS is meant to be consistent with the contract negotiated between the *Lucy* Project, the LTES Instrument Principal Investigator and the *Lucy* Science Operations Center (SOC). Product label keywords/attributes may be added to future revisions of this SIS. Therefore, it is recommended that software designed to process products specified by this SIS should be robust to (new) unrecognized keywords. Similarly, entirely new products may be added over time.

This Data Product SIS is responsive to the following documents:

Table 1-1. List of Applicable Documents

Document ID	Title	Release Date	Revision
JPL D-7669, Part 2	Planetary Data System Standards Reference	June 2023	1.20
n/a	Data Provider's Handbook, Archiving Guide to the PDS4 Data Standards	June 2023	1.20
n/a	Planetary Data System Common Dictionary Document	June 2023	1.20
22702-DMAP-01	*Lucy* Data Management and Archive Plan		current revision unless revision is specified
22668.07-ST-ICD-01	*Lucy* Science Operations Center to Science Team ICD		current revision unless revision is specified
unassigned	*Lucy* – PDS SBN Configuration Control Plan		current revision unless revision is specified
unassigned	*The Lucy Thermal Emission Spectrometer (L'TES) Instrument*	December, 2023	doi: 10.1007/s11214-023-01029-y

1.2 Relationship with Other Interfaces

This SIS could be affected by changes to the *Lucy* Data Management and Archive Plan (DMAP) or the *Lucy*-SBN Interface Control Document (ICD). Where possible, references are made to the DMAP or ICD rather than duplicating information in this document. This SIS may be revised by consent of the signatories. The following table is a list of other interfaces where changes may affect the contents of this SIS. The SIS will be updated when necessary.

Table 1-2. List of Interface Relationships

Name	Type	Owner
Lucy SOC Database Schema	Product	SOC
LTES Uncalibrated Data	Product	Instrument Team
LTES Calibrated Data	Product	Instrument Team
LTES Pipeline Software	Software	SOC/Instrument Team
Lucy SOC-SBN Configuration Control Plan	Document	SOC
Lucy SOC-SBN ICD	Document	SOC
Lucy DMAP	Document	Project

2. DATA PRODUCT CHARACTERISTICS AND ENVIRONMENT

2.1 Instrument Overview

The LTES instrument measures the thermal infrared emission from each Trojan asteroid and target of opportunity including the Earth, Moon, Dinkinesh, and others to obtain the temperature of the asteroid's surface (Christensen et al. 2024). These observations address one of the Level 1 science requirements: determining the thermal inertia of the surface. The LTES is a near-copy of the OTES instrument on OSIRIS-REx (Christensen et al. 2018), where OTES is used to derive the surface composition and thermal inertia of the asteroid Bennu. However, because the Trojan asteroids at 5 AU are much colder than Bennu, the Lucy mission does not plan to use LTES to derive surface composition. Instead, LTES will be used primarily to infer regolith properties.

LTES is a Fourier transform infrared point spectrometer built at Arizona State University and Dr. Phil Christensen is the Instrument Principal Investigator. LTES has the same optical-mechanical design as OTES, including a 15.2 cm diameter Cassegrain telescope, a Michelson interferometer with chemical vapor deposited diamond beamsplitter, and an uncooled, deuterated L-alanine doped triglycine sulfate (DLATGS) pyroelectric detector. LTES has only small differences from the heritage instrument including removing a potential stray light path by modifying the telescope baffle and primary mirror inner diameter and improvements to the metrology laser system. An internal calibration cone blackbody target provides radiometric calibration. The LTES instrument collects data in the spectral range 5.71–100 µm (1750–100 cm^{-1}) with spectral sampling intervals of 8.64, 17.3, and 34.6 cm^{-1} and has a noise equivalent spectral radiance (NESR) of 2.2×10^{-8} W cm^{-2} sr^{-1}/cm^{-1} between 300 cm^{-1} and 1350 cm^{-1}. For surfaces with temperatures greater than 75 K, LTES will determine the temperature with an accuracy of 2 K. The 50% encircled energy of the instrument subtends 6.5 mrad. See Christensen et al. 2024 (https://doi.org/10.1007/s11214-023-01029-y) for the full instrument description.

LTES begins collecting telemetry when power is applied. In standby mode, LTES telemetry is collected every 2.0 seconds. In data collection mode, LTES continuously collects interferograms (every 0.5, 1.0, or 2.0 sec) and transfers them to the spacecraft for storage before downlink. The instrument will start collecting data one day before closest approach, which is before the target fills the instrument's field of view. The data collection will continue until one day after closest approach. The instrument regularly interleaves observations of an internal calibration target while taking science data.

The LTES instrument will measure the radiance of each Trojan asteroid, at different local times of day, with the additional requirement that one observation measures a location within 30° of the sub-solar point and another measures the un-illuminated surface (Figure 2-1). This observation is conducted by scanning the LTES FOV across the asteroid (using the spacecraft Instrument Pointing Platform, IPP). The measurements are converted into temperatures by fitting one or more blackbody curves (for known temperatures) to the measured, calibrated radiance. These temperatures are inputs to models of thermal inertia, which are used to infer regolith properties.

Figure 2-1 Idealized LTES scan of an idealized Trojan asteroid (not to scale). To observe different local times of day, Lucy will use the IPP to scan the LTES instrument across the Trojan asteroid. The scan will start on the dark limb of the Trojan asteroid and progress across the lit hemisphere (scan from the right to the left in this diagram). For each of the Lucy Trojan targets, there is a time when the LTES field of view is smaller than the unilluminated region allowing a measure of the night side of the Trojan asteroid. There is a pointing uncertainty of 1/8 of the Trojan's diameter and that is accounted for when planning the timing of the scan. Instrument planners use Monte Carlo simulations to plan actual observations over a range of asteroid shapes and to model observational uncertainties. See Good et al. 2022 for a full discussion of Lucy's Terminal Tracking observation methodology.

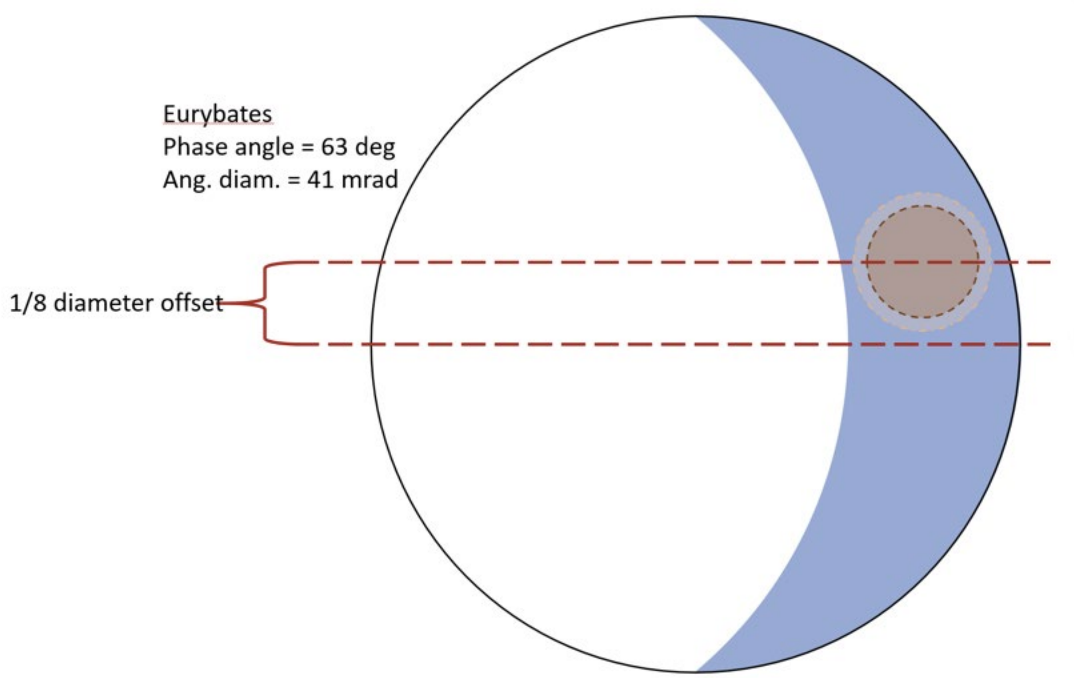


Table 2-1. List of Instrument Properties

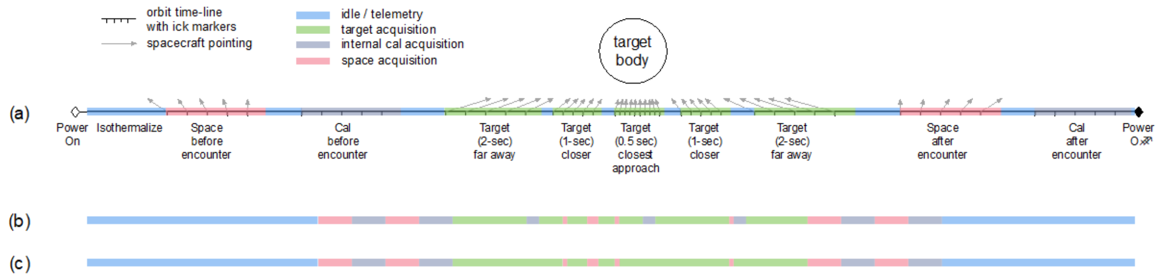
Attribute	Value
Nominal Spectral Sampling	8.64 cm^{-1} (in 2-sec mode)
Spectral Range	1750-100 cm^{-1} (5.7 – 100 µm)
Telescope Aperture	15.2 cm
Detectors	Single, uncooled DLATGS detector
Michelson Mirror Travel	±0.3 mm (in 2-sec mode)
Mirror Velocity (physical travel)	0.33 mm/sec (in 2-sec mode)
Laser Fringe Reference Wavelength	851 nm
Interferometer Sample Rate	772 Hz
Field of View (FOV)	10.0 mrad (100% encircled energy)
Number of Samples per Interferogram (2 sec mode)	~1414
Number of Bits per Sample of Interferogram	16
Cycle Time per Measurement (or Individual Collection Interval (ICK) Duration)	2 sec, 1 sec, 0.5 sec
Dimensions (width x depth x height)	38 x 29 x 30 cm
Mass	6.47 kg
Average Power	12.6 watts
Operating Temperature Range (AFT)	-10 to +40 °C
Non-Operating Temperature Range (AFT)	-30 to +55 °C

2.1.1 Observation Profile and Data Acquisition

The Lucy mission consists of five flybys of Trojan asteroids to investigate the differences in their surface and internal properties across the population of Trojan asteroids. From these five encounters we will be able to observe eight Trojan asteroids: Eurybates and its small satellite Queta, Polymele and its small satellite (informally known as "Shaun"), Leucus, Orus, Patroclus and Menoetius (Fig. 1). Three of the flybys will encounter multiple Trojan asteroids. The first Lucy Trojan flyby in 2027 will be of Eurybates and its recently discovered small moon and the last encounter in 2033 is of the near-equal size binary system: Patroclus and Menoetius. Lucy will also fly by two Main Belt asteroid targets of opportunity: (152830) Dinkinesh in 2023, and (52246) Donaldjohanson in 2025, prior to reaching the Trojans, and will use these encounters to test terminal tracking and other aspects of mission operations.

During the flybys, the spacecraft is moving relative to the Trojan asteroids with a velocity of 6-9 km/s making time a critical resource. The mission is designed to maximize the data collected around closest approach which requires efficiency in observing the Trojan asteroids. Figure 2-2 shows the notional LTES observation sequence.

Figure 2-2. Notional LTES Observation Sequences. Time increases from left to right. Colors represent where the instrument is idle (blue), collecting data from target body (green), acquiring internal calibration data (gray), space calibration (red). Sub-figure (a) shows ticks representing ick markers and arrows representing pointing. The tick markers spacing change as the scan length is changed from 2s, 1s, 0.5s, then back to 1s and 2s. Sub-figures (b) and (c) show cases where different amounts of space and internal calibration observations are sprinkled during target observation collection.



Most observations and actions on the spacecraft are commanded to execute at a given time. However, during the close approach subphase most science observations will be initiated based on the range of the spacecraft to the Trojan asteroid target. At the beginning of this period, the range is estimated based on an on-board ephemeris. As the spacecraft approaches the target and the image of the target is resolved in the Terminal Tracking Cameras, the on-board terminal-tracking state estimation begins to provide an estimate of the Trojan's location relative to the spacecraft. This terminal tracking allows the Lucy spacecraft to have updated knowledge of the target which allows for a more efficient observing strategy. The large uncertainty in the target location (relative to its size) is collapsed by the on-board terminal tracking system.

2.2 Data Product Overview

The basic unit of data from the LTES instrument is a record consisting of either engineering status words only (data_rawhk) or status plus interferograms (data_raw). These data are reformatted into PDS standard format files and are processed to convert Digital Numbers (DN) to physical units (e.g., temperature, voltages and currents). The ***interferogram*** data files for an entire ***LTES Observation Sequence*** are processed together and converted to physical units and then calibrated into radiance spectra. The calibrated spectra are stored in calibrated spectra files following the PDS standards.

Within each uncalibrated (eng) or calibrated (sci) file, data are organized into parameter specific arrays in a time sequential (or chronological) order. Position in the data arrays indicate correlated measurements, e.g. clock array index 3 corresponds to temperature array index 3. A complete description of the various files is given in the Detailed Data Product Specifications.

2.3 Data Processing

The Lucy Science Operations Center (SOC) is responsible for all Lucy science data processing. LTES telemetry is received by the SOC via the Mission Operations Center (MOC). LTES telemetry data are reconstructed, sorted, and stored in the SOC data repository. LTES data are retrieved from the data repository and fed into the LTES-specific data processing software. The pipeline produces the LTES uncalibrated raw and raw housekeeping data (eng) and calibrated science (sci) data products. The data are stored in HDF5 file format.

Production rates of calibrated spectra vary over the course of the mission and are dependent on observing campaigns during specific mission phases. Specific file sizes will vary dependent on the number of data collections in each sequence, and how long the instrument idles returning status records, which is driven by the mission operations plan. The contents (and thus size) of an LTES product are tied to the observation identifier or ObsID (i.e., all packets tagged with a given ObsID belong to the same observation sequence) and so are determined on the uplink side by how LTES is commanded. The longer the overall observation sequence duration and the shorter the individual collection interval (ICK) period, the more packets are generated for that ObsID. For example, the ground testing sequence for the Polymele encounter Science Validation Test (SVT) contained 15 science observation sequences: 8 of commanded length (typically around 30 minutes, but a couple about half that size), and 7 “indefinite” length observations, terminated by explicit abort commands. Also, 10 calibrations were commanded (30 seconds in length each). Each of those 25 total observation sequences used a 2-second scan period. This resulted in typical calibrated data product sizes of about 5MB.

2.3.1 Data Processing Level

The LTES data products comply with NASA processing level standards as shown in Table 2-2. LTES data products are produced sequentially, with the raw uncalibrated data converted to intermediate units of measure, calibrated science data, and subsequently turned into derived products.

Table 2-2. Data Processing Levels

Lucy Archive Data Product	PDS4 Processing Level	Description
N/A	Telemetry	An encoded byte stream used to transfer data from one or more instruments to temporary storage where the raw instrument data will be extracted. PDS does not archive telemetry data.
Uncalibrated Data Product (Known as "raw", "uncalibrated' or "eng"	Raw	Original data from an instrument. If compression, reformatting, packetization, or other translation has been applied to facilitate data transmission or storage, those processes will be reversed so that the archived data are in a PDS approved archive format. Lucy LTES raw status (data_rawhk) and interferogram data (data_raw) in units of DN are examples of raw data products.
	Partially Processed	Data that have been processed beyond the raw stage, but which have not yet reached calibrated status.
Calibrated Data Product (Known as "calibrated" or "sci"	Calibrated	Data converted to physical units, which makes values independent of the instrument. Lucy LTES data in physical or radiance units are calibrated data products
	Derived	Results that have been distilled from one or more calibrated data products (for example, maps, gravity or magnetic fields, or ring particle size distributions). Supplementary data, such as calibration tables or tables of viewing geometry, used to interpret observational data should also be classified as "derived" data if not easily matched to one of the other three categories.

2.3.2 Data Product Generation

The LTES uncalibrated "eng" files will be generated by the SOC from the downlinked LTES telemetry. The uncalibrated products will contain raw, uncalibrated data, formatted according to the uncalibrated format defined in this SIS. The uncalibrated data is broken into two collections, data_raw for the actual observation (science sequence) data, and data_rawhk for the status data acquired during instrument warm up, which is housekeeping only. New versions of the products will be identified using a version identifier in the filename, as indicated in Section 2.4.1.1 and by the version_id field in the PDS label. On successful completion through the LTES data processing pipeline software, the SOC will be responsible for inserting the output file data into the SOC Data Repository. In case of errors, any messages produced as well as the error file will be saved for further diagnosis by the LTES engineers.

Calibrated data "sci" files will be automatically produced by the data processing pipeline software directly from the uncalibrated data files. New versions of calibrated data will be generated should the raw data, the instrument/spacecraft geometry, the calibration algorithm, or the calibration software components change. Changes to the calibration algorithm and software components will be rare events. It is more likely that an update to geometry will cause re-processing. New versions of the calibrated spectra will be identified by incrementing the version identifiers (filename version and PDS label version_id) in the data. All versions of the data products are retained in the SOC repository for reference, however only certified valid products are released to the PDS. Should products need to be updated in the archive, the new certified valid products will replace the older (deprecated) versions.

The SOC will monitor the records being downlinked and correlate them with the uplinked commands to ensure that all commanded data have been accounted for.

2.3.2.1 Uncalibrated Data Product Generation

LTES packet telemetry is received from the Mission Operations Center (MOC) via a dedicated connection. The packet data are ingested into the SOC data repository using the Database Downlink Ingestion Tool (DDIT) which is responsible for decompression, database communication, parsing, engineering conversion, data insertion, and querying. Once LTES packet data are sorted, parsed, and inserted in the SOC data repository, they are ready for instrument specific processing. The Pipeline Executive (PExe) process controls the SOC data processing environment by managing and initiating all pipeline functions. Using either scheduled or manual jobs, PExe calls the main Unprocessed Data Processing (UDP) module that manages the setup and execution of the individual instrument pipeline functions. The LTES UDP module builds uncalibrated data products, in HDF5 format, containing status or interferogram datasets. The data packets included within a given HDF5 product file are determined by the Acquisition ID (aka Observation ID = ObsID) defined within the packets. The status only and interferogram data are sorted into different collections one for status only instrument warm up data (data_rawhk) and one for science sequence interferogram data (data_raw). The LTES UDP module returns both UDP products and logfile information.

2.3.2.2 Calibrated Data Product Generation

The interferograms acquired during an LTES observation sequence are converted into voltage spectra. These spectra are then converted into calibrated radiance spectra (calrad array), using the LTES calibration software which uses the space and internal calibration observations taken just before and just after the science observations, as available. Note that index of each row in the HDF5 2-d array corresponds to the index of a metadata term in the 1-d arrays. For example, the third interferogram in the ifgm 2-d array (row 3) corresponds to the time given in the third index of the 1-d spacecraft clock (sclk) array. The LTES data calibration flow and algorithms are documented in the LTES instrument paper [Christensen et al., 2024] with a general overview also provided by Christensen et al. [2018].

The LTES CDP (Calibrated Data Processing) software queries the SOC database for products ready to be processed. The CDP process retrieves the uncalibrated science “eng” files and their associated observation spatial and geometric information for a single ***LTES Observation Sequence*** as inputs from the SOC database. The geometric information for each LTES individual collection interval is needed for optimal calibration of LTES data. The geometric quantities are calculated after uncalibrated products are inserted into the SOC database for use by CDP. The LTES CDP module transforms each interferogram (ifgm array) into a voltage spectrum (vspec array). The transformation is done by performing a Discrete Fourier Transform (DFT) on the raw interferogram. The voltage spectra are calibrated using the following equation (Christensen et al., 2018, equation 18, also repeated in Christensen et al., 2024) resulting in a calibrated radiance spectrum (calrad array):

$$\varepsilon_{scene}B_{scene} = \left(\frac{V_{scene} - V_{space}}{V_{cal} - V_{space}}\right)\left(\frac{\varepsilon_{cal}B_{cal}\rho_{flag} + \varepsilon_{flag}B_{flag} - \left(\varepsilon_{primary}B_{primary}\rho_{secondary} + \varepsilon_{secondary}B_{secondary}\right)}{\tau_{fore}} - \varepsilon_{space}B_{space}\right) + \varepsilon_{space}B_{space}$$

Terms in this equation are listed below:

Table 2-3. LTES Calibration Coefficient Terms

Equation Term	Value, Data Source or Definition
$\varepsilon_{scene}B_{scene}$	Radiance of the scene
V_{scene}	Voltage value of the scene, which is the Fourier transform value of the interferogram.
V_{space}	Voltage value of space, which is the Fourier transform value of the interferogram.
V_{cal}	Voltage value of the calibration target, which is the Fourier transform value of the interferogram.
ε_{cal}	Emissivity of the calibration target vs. wavenumber (currently all 1.0, not delivered to PDS. If a change is made, it will be noted in delivery release notes.)
B_{cal}	The black body radiation of the calibration target from the associated engineering data (cal_ref_temp array in uncalibrated data product)
ρ_{flag}	0.998
B_{flag}	The black body radiation of the calibration target flag from associated engineering data (cal_act_temp array in uncalibrated data product)
ε_{flag}	0.002
$\varepsilon_{primary}$	0.002
$B_{primary}$	The black body radiation of the primary mirror from associated engineering data (pri_mirror_temp array in uncalibrated data product)
$\rho_{secondary}$	0.998
$\varepsilon_{secondary}$	0.002

$B_{secondary}$	The black body radiation of the secondary mirror from associated engineering data (sec_mirror_temp(1, 2) array in uncalibrated data product)
τ_{fore}	0.996004 (= 0.998^2)
ε_{space}	1.00000
B_{space}	Black body spectrum at T=3 K

Remember that the interferograms, voltage spectra, and calibrated spectra are related to one another by sclk (spacecraft clock time), which is how these values are related to the engineering terms in the equation. The resulting data and associated telemetry are stored in an LTES Calibrated HDF5 file, which is stored in the SOC repository. Note that there are several uncalibrated "eng" files associated with each calibrated "sci" data files. Figure 2-3 shows the data flow of the LTES CDP processing.

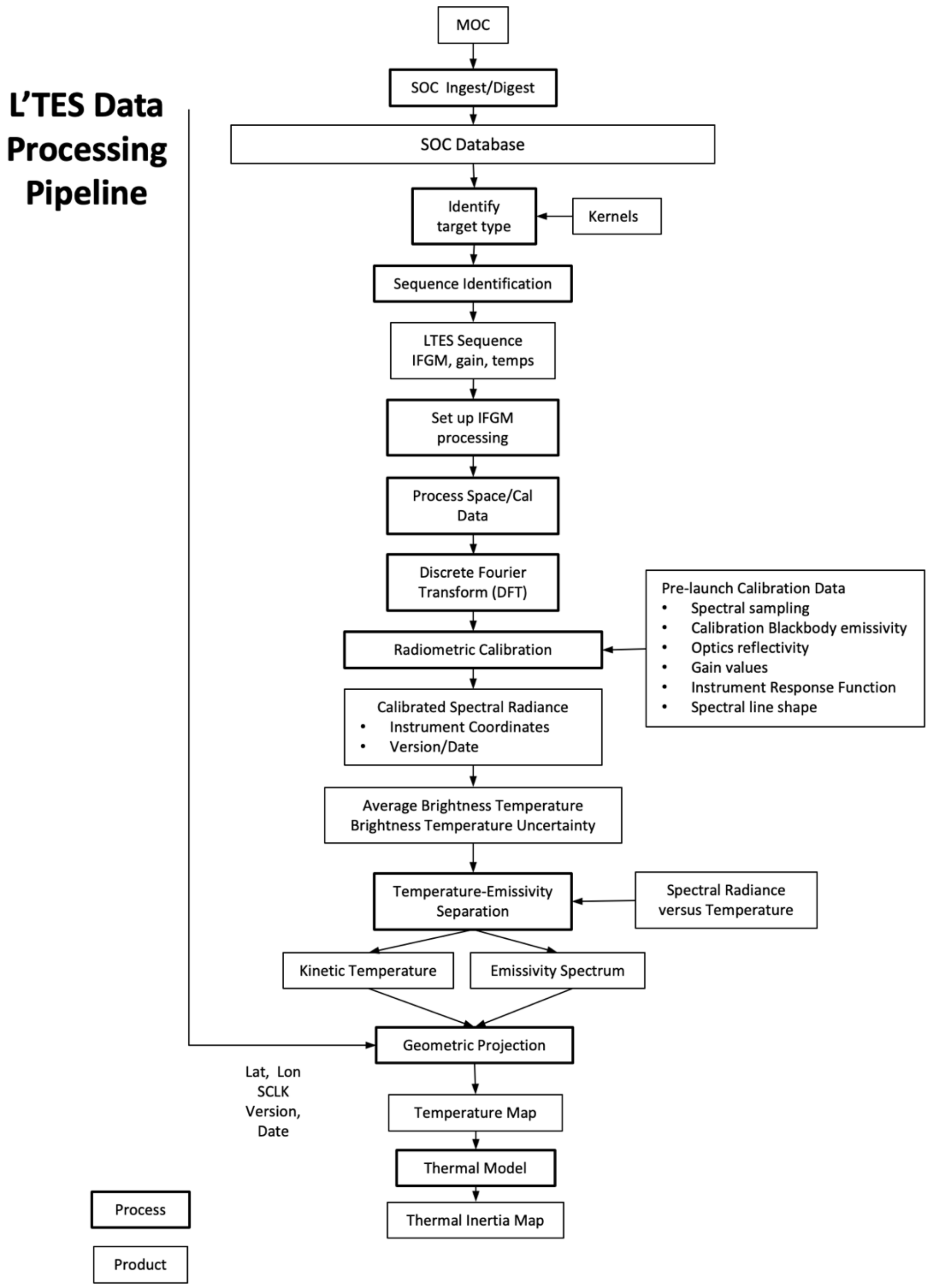


Figure 2-3 Calibration Processing Pipeline

Processing log messages (including error messages) generated during data processing are captured by the SOC Pipeline Executive into log files. The log files will be used by the LTES team for diagnosis in case of a processing failure but will not be archived.

2.3.3 Data Flow

LTES 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 SOC data repository system. The LTES calibration pipeline queries the SOC data repository for the raw telemetry, science, and ancillary data. Figure 2-4 illustrates the SOC LTES data processing pipeline data flow.

Figure 2-4. SOC Data Processing Diagram

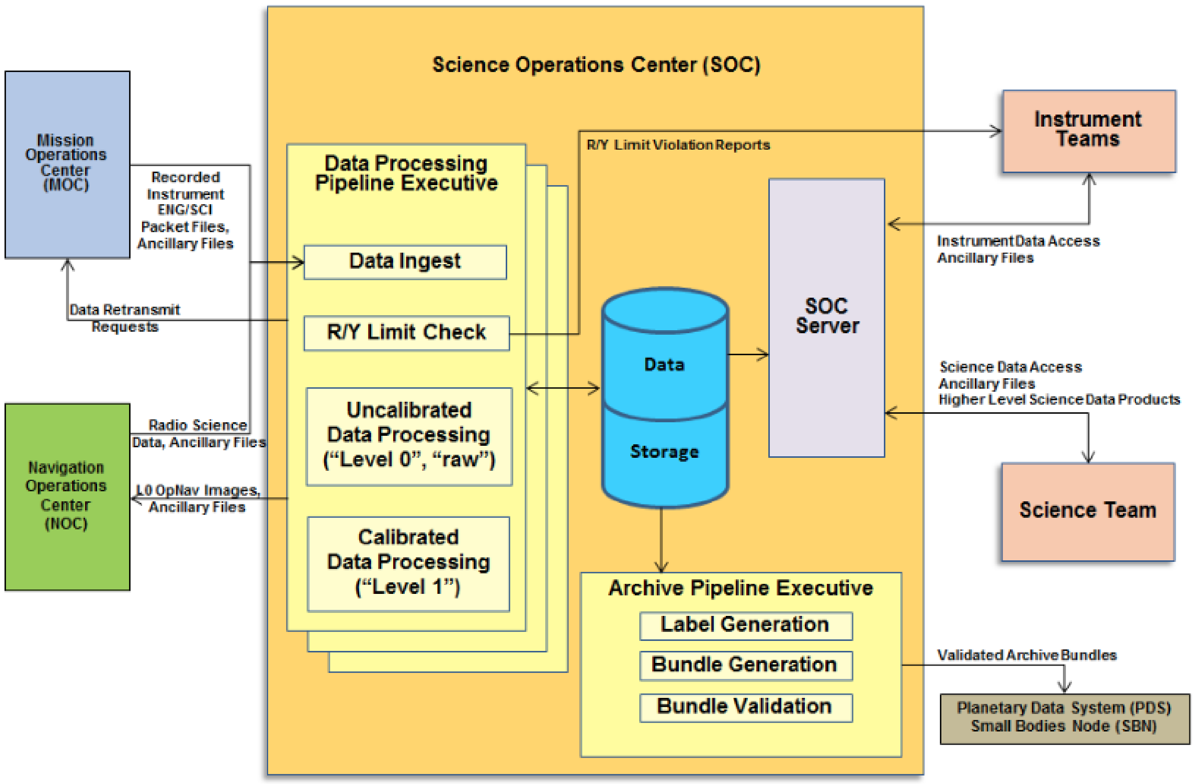


Figure 3-1: Science Operations Center Downlink Overview

2.4 Labeling and Identification

All LTES products consist of a data file (HDF5) and a PDS4-compliant detached XML label that describes the content and format of the associated HDF5 data file. These labels describe the content and format of the associated data product. Labels and products are associated by file name with the label having the same name as the data product except that the label file has an .xml extension. Labels are constructed with the PDS4 Product Class, Product_Observational sub-class. The Product_Observational sub-class describes a set of information objects produced by an observing system. A hierarchical description of the contents of an LTES Product_Observational is presented below.

Product_Observational
- Identification_Area - attributes that identify and name an object.
  - Logical_Identifier - name/location of file
  - Version_ID - version of product
  - Title - Name of file
  - 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.
  - 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 – Lucy mission specific classes and attributes needed to describe data product.
    - Lucy_Observation_Planning – class giving mission specific observation planning information.
    - Lucy_Observation_Time_Information – class giving mission specific observation time information.
    - Lucy_Target_List – class giving information about targets found in the FOV of the data product. These are incidental targets rather than the intended target of the observation.
    - Lucy_Prodcut_Information – class giving additional product tracking information.
  - Discipline_Area – discipline specific attributes collected by specific discipline areas.
    - Spectral_Characteristics – classes and attributes that describe the spectrometer and spectra.
    - Geometry – classes and attributes that describe the geometry of the data product.
    - Mission_Information – classes and attributes giving common mission attributes.
    - Processing_Information – classes and attribute describing the software and data processing used to create the data product.
- Reference_List – a list of related data products or documents.
- File_Area_Observational - describes the primary data file and one or more tagged_data_objects contained within. In the LTES case the file is an HDF5 file
  - File - identifies the HDF5 file that contains one or more data objects as described below.
    - Array_* - contains classes that describe a number of 1D, 2D or 3D arrays, typically images or spectra.
    - Stream_Text – contains text blocks that give various metadata descriptions.

To find the specific metadata attribute definitions see https://pds.nasa.gov/datastandards/dictionaries.

Information in the preceding paragraphs was distilled from the PDS4 Information Model provided by PDS. Additional information on product labels can be found at https://pds.nasa.gov/pds4/about/index.shtml.

LTES PDS4 metadata labels are populated using information that is stored in the HDF5 header stream text array. This information is similar to all other Lucy instrument primary FITS headers. Table 3-3 provides that mapping from the header array to the PDS4 label attributes.

2.4.1.1 Product Naming

All LTES UDP data products are named using the following naming conventions:

<inst>_<acqtime>_<obsid>_<level>_<version>.<ext>

where
inst = 3-letter instrument ID: tes (LTES)
acqtime = 10-digit SCLK value (seconds) at the start of the acquisition
obsid = 5-digit integer observation ID
level = 3-letter data processing level ("eng" for raw/uncalibrated)
version = 2-digit integer product version number
ext = 3-letter file type extension: hdf (Hierarchical Data Format)

All LTES CDP data products are named using the following naming conventions:

<inst>_<acqtime>_<target>_<level>_<version>.<ext>

where

inst = 3-letter instrument ID: tes (LTES)
acqtime = 10-digit SCLK value (seconds) at the start of the acquisition of the earliest source UDP
target = the standard NAIF name of the target body (lowercased)

level = 3-letter data processing level: "sci" for PDS delivered Level 2 calibrated products.
version = 2-digit integer product version number
ext = 3-letter file type extension: hdf (Hierarchical Data Format)

LTES data products are HDF5 file type so therefore have suffixes of ".hdf". All LTES files are created with detached PDS labels, indicated by the ".xml" file extension. The labels are PDS4 compliant XML format.

2.5 Standards Used in Generating Data Products

2.5.1 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.

2.5.2 Time Standards

Time Standards used by the Lucy mission conform to PDS time standards.

2.5.3 Coordinate Systems

All coordinate systems used by the *Lucy* 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 "***Lucy* Mission Coordinate System Plan"** found in the archive documents directory.

A summary of the Lucy Mission coordinate system process is as follows.

The Lucy project will establish a task force to define coordinate systems for each target. The coordinate systems will be reviewed and validated by PDS prior to data delivery, as outlined in the PDS Policy on Acceptable Body-Fixed Coordinate Systems (PDS Mission Proposer's Archiving Guide v4-r5, 21 Sept. 2016). In parallel, the Lucy team will engage the International Astronomical Union (IAU) Working Group on Cartographic Coordinates and Rotational Elements (WGCCRE) coordinate system standards for an official approval of the proposed coordinate systems. Based on our experience, IAU may take several months to approve a coordinate system, and therefore the Lucy team will proceed with PDS delivery using the coordinate systems agreed upon by the project and the PDS. Once final approval by IAU is achieved, the Lucy project will redeliver georeferenced data to PDS, as needed. Upon PDS validation of all the coordinate systems for each Trojan asteroid, all archive instrument products will be updated with the accepted coordinate system for delivery to the PDS. It is expected that this process will be completed by 4.5 months after last data downlink for each flyby (except for Eurybates and Polymele). PDS will also review the science content of flyby deliverables. Derived products will be produced with the approved coordinate system or updated with this information when it becomes available.

2.5.4 Data Storage Conventions

LTES data products will be stored as HDF5 files and conform to the standard: http://docs.opengeospatial.org/is/18-043r3/18-043r3.html.

2.6 Data Validation

The SOC has a comprehensive Verification and Validation (V&V) Plan for all software used at or developed by the SOC. All software is configuration controlled and any changes made follow the SOC Configuration Management Plan, which includes substantive review and testing of changes. During day-to-day production of raw 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 *Lucy* 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 SOC – SBN Configuration Control Plan governs any changes, should they be needed.

When data are prepared for submission to the PDS, both the LTES and SOC teams will use PDS / mission-provided automated validation tools for conformance to the PDS4 standards. The PDS supplied validation tool is called validate and can be found at https://nasa-pds.github.io/validate/. Validation of the science data contained within the LTES data products will, however, occur as a manual inspection by the LTES team and the *Lucy* science team.

3. DETAILED DATA PRODUCT SPECIFICATIONS

General statement of what the data products to be described are.

3.1 Data Products Structure and Organization

The *Lucy* archive is organized into bundles for each instrument/detector, bundles for each discipline-specific set of higher-order data products, and a mission bundle with mission-wide documentation, context and schema information. Each bundle contains data collections for each mission phase and data processing level of each data type. Each PDS bundle also contains a document collection, to provide the appropriate ancillary information to properly interpret and use the data. LTES data products are structured as HDF5 data files. LTES data products are organized by mission phase and data processing level.

The LTES bundle structure is as follows:

Table 3-1. LTES Bundle Structure

Bundle	*Collection*	*LID*
LTES	data_cruise1_raw	urn:nasa:pds:lucy.ltes:data_cruise1_raw
	data_cruise1_rawhk	urn:nasa:pds:lucy.ltes:data_cruise1_rawhk
	data_cruise1_calibrated	urn:nasa:pds:lucy.ltes:data_cruise1_calibrated
	data_ega1_raw	urn:nasa:pds:lucy.ltes:data_ega1_raw
	data_ega1_rawhk	urn:nasa:pds:lucy.ltes:data_ega1_rawhk
	data_ega1_calibrated	urn:nasa:pds:lucy.ltes:data_ega1_calibrated
	data_didymos_raw	urn:nasa:pds:lucy.ltes:data_didymos_raw
	data_didymos_rawhk	urn:nasa:pds:lucy.ltes:data_didymos_rawhk
	data_didymos_calibrated	urn:nasa:pds:lucy.ltes:data_didymos_calibrated
	data_cruise2_raw	urn:nasa:pds:lucy.ltes:data_cruise2_raw
	data_cruise2_rawhk	urn:nasa:pds:lucy.ltes:data_cruise2_rawhk
	data_cruise2_calibrated	urn:nasa:pds:lucy.ltes:data_cruise2_calibrated
	data_dinkinesh_raw	urn:nasa:pds:lucy.ltes:data_dinkinesh_raw
	data_dinkinesh_rawhk	urn:nasa:pds:lucy.ltes:data_dinkinesh_rawhk
	data_dinkinesh_calibrated	urn:nasa:pds:lucy.ltes:data_dinkinesh_calibrated
	data_cruise3_raw	urn:nasa:pds:lucy.ltes:data_cruise3_raw
	data_cruise3_rawhk	urn:nasa:pds:lucy.ltes:data_cruise3_rawhk

Bundle	*Collection*	*LID*
	data_cruise3_calibrated	urn:nasa:pds:lucy.ltes:data_cruise3_calibrated
	data_donaldjohanson_raw	urn:nasa:pds:lucy.ltes:data_donaldjohanson_raw
	data_donaldjohanson_rawhk	urn:nasa:pds:lucy.ltes:data_donaldjohanson_rawhk
	data_donaldjohanson_calibrated	urn:nasa:pds:lucy.ltes:data_donaldjohanson_calibrated
	data_cruise4_raw	urn:nasa:pds:lucy.ltes:data_cruise4_raw
	data_cruise4_rawhk	urn:nasa:pds:lucy.ltes:data_cruise4_rawhk
	data_cruise4_calibrated	urn:nasa:pds:lucy.ltes:data_cruise4_calibrated
	data_eurybates-polymele_raw	urn:nasa:pds:lucy.ltes:data_eurybates-polymele_raw
	data_eurybates-polymele_rawhk	urn:nasa:pds:lucy.ltes:data_eurybates-polymele_rawhk
	data_eurybates-polymele_calibrated	urn:nasa:pds:lucy.ltes:data_eurybates-polymele_calibrated
	data_cruise5_raw	urn:nasa:pds:lucy.ltes:data_cruise5_raw
	data_cruise5_rawhk	urn:nasa:pds:lucy.ltes:data_cruise5_rawhk
	data_cruise5_calibrated	urn:nasa:pds:lucy.ltes:data_cruise5_calibrated
	data_leucus_raw	urn:nasa:pds:lucy.ltes:data_leucus_raw
	data_leucus_rawhk	urn:nasa:pds:lucy.ltes:data_leucus_rawhk
	data_leucus_calibrated	urn:nasa:pds:lucy.ltes:data_leucus_calibrated
	data_cruise6_raw	urn:nasa:pds:lucy.ltes:data_cruise6_raw
	data_cruise6_rawhk	urn:nasa:pds:lucy.ltes:data_cruise6_rawhk
	data_cruise6_calibrated	urn:nasa:pds:lucy.ltes:data_cruise6_calibrated
	data_orus_raw	urn:nasa:pds:lucy.ltes:data_orus_raw
	data_cruise6_rawhk	urn:nasa:pds:lucy.ltes:data_cruise6_rawhk
	data_orus_calibrated	urn:nasa:pds:lucy.ltes:data_orus_calibrated
	data_cruise7_raw	urn:nasa:pds:lucy.ltes:data_cruise7_raw
	data_cruise7_rawhk	urn:nasa:pds:lucy.ltes:data_cruise7_rawhk
	data_cruise7_calibrated	urn:nasa:pds:lucy.ltes:data_cruise7_calibrated

Bundle	*Collection*	*LID*
	data_patroclus-menoetius_raw	urn:nasa:pds:lucy.ltes:data_patroclus-menoetius_raw
	data_patroclus-menoetius_rawhk	urn:nasa:pds:lucy.ltes:data_patroclus-menoetius_rawhk
	data_patroclus-menoetius_calibrated	urn:nasa:pds:lucy.ltes:data_patroclus-menoetius_calibrated
	document	urn:nasa:pds:lucy.ltes:document

3.2 Data Format Descriptions

The following sections describe in detail the formats of LTES uncalibrated through calibrated data products.

3.2.1 Uncalibrated Data Product Format

The uncalibrated engineering data will be stored in an HDF5 file. The file will have an associated PDS4 label describing the array and stream text structures. Table 3-2 describes the uncalibrated data structure by identifying array index number (0 indexed as per PDS4 viewer), array name, PDS4 data type, item count, units, and a description of the array. Stream text (string) fields are also described in the table, but do not have an array index number. The stream text blocks are indicated in the order in which they appear in the data product labels. Array index is given for all arrays. Starred arrays will not be present in the data_rawhk collection products or data_raw housekeeping only products, as these are the interferogram specific arrays. Array index number in parentheses are the array index numbers for status data, which are the products produced when no science interferograms are collected.

Table 3-2. LTES Uncalibrated Data Product

Array Index Number	Array Name	Data Type	Item Count (if > 1)	Units	Description
0	acq_cmd_executing	UnsignedByte			Acquisition command executing, 0=Not executing, 1=Executing
1	acq_id	SignedMSB4			This ID helps correlate the science data frames with the command.
2	acq_scan_count	SignedMSB4			Counts the number of acquisitions taken during the current acquisition sequence
3	bb_temp1	IEEE754MSBSingle		degC	Blackbody temperature 1
4	bb_temp2	IEEE754MSBSingle		degC	Blackbody temperature 2
5	board_temp1	IEEE754MSBSingle		degC	FPGA temperature on the control board

Array Index Number	Array Name	Data Type	Item Count (if > 1)	Units	Description
6	board_temp2	IEEE754MSBSingle		degC	DC/DC converter temperature on control board
7	bsplit_temp	IEEE754MSBSingle		degC	Beam Splitter temperature
8	cal_act_temp	IEEE754MSBSingle		degC	Calibration flag actuator temperature
9	cal_flag_prot	UnsignedByte			Calibration flag protection, 0=Disabled, 1=Enabled
10	cal_flag_prot_timeout	UnsignedByte			Calibration flag protection timeout
11	cal_flag_status	UnsignedByte			Commanded calibration flag status, 0=Open, 1=Closed.
12	cal_ref_temp	IEEE754MSBSingle		degC	Calibration flag doghouse (reference) temperature (used in calibration processing)
13	cal_res1	IEEE754MSBSingle		Ohm	Calibration resistance 1
14	cal_res2	IEEE754MSBSingle		Ohm	Calibration resistance 2
15	cmd_fc_echo	UnsignedByte			Echo of last valid instrument command received.
16	cmd_rej_count	UnsignedByte			Number of rejected commands.
17	cmd_seq_echo	UnsignedByte			Echo of the sequence ID of the last valid instrument command received.
18	det_temp1	IEEE754MSBSingle		degC	Detector temperature 1
19	det_temp2	IEEE754MSBSingle		degC	Detector temperature 2
20	edac_single_bit_errs	UnsignedByte			Single bit error detected in SRAM. Single bit errors are corrected.
21	flash_pwr_status	UnsignedByte			Flash power status, 0=Off, 1=On
22	fringe_count	SignedMSB4			Fringe count indicated the number of fringes that occur over the scan interval.
23	fringe_offset	IEEE754MSBSingle			Fringe reading
24	gravity_comp_status	UnsignedByte			Gravity compensation status, 0=Off, 1=On

Array Index Number	Array Name	Data Type	Item Count (if > 1)	Units	Description
n/a	header	7-bit ASCII Text			Text block of header information used by the archive pipeline to fill in label metadata values. A full explanation of header terms, definitions and translations to the PDS4 xml header is found in Table 3-3
25	ick_counter	SignedMSB4			Resettable scan counter
26*	ifgm	IEEE754MSBSingle	1414	V	Interferogram. The interferogram array may not be present in all data products. If the instrument is in idle mode, not interferogram is collected
27*	ifgm_chksum	IEEE754MSBDouble			Interferogram checksum. The interferogram checksum is only present in data products with an interferogram.
28 (26)	image_boot_select	UnsignedByte			Identifies which boot image is running. Reflects the lower 3 bits of the image select register at 0xA1000018
29 (27)	image_check_checksum	IEEE754MSBDouble			Indicates checksum of the image data (written to SRAM), in response to the image check command.
30 (28)	image_exp_checksum	IEEE754MSBDouble			Indicates the expected checksum from the image store command.
31 (29)	image_store_checksum	IEEE754MSBDouble			Indicates checksum calculated by FSW of image data written to SRAM which is to be copied with the image store command. A value of 0xFAFAFA indicates byte-by-byte comparison by FSW of flash written and the SRAM source has failed.
32 (30)	instr_cmd_acc_count	UnsignedByte			Number of accepted instrument commands.
33 (31)	ir_gain	UnsignedByte			IR gain, 0=1x, 1=2x gain
34 (32)	laser_temp	IEEE754MSBSingle		degC	Laser temperature
35 (33)	led1_pwr_status	UnsignedByte			Linear motor LED 1 power status, 0=Off, 1=On
36 (34)	led2_pwr_status	UnsignedByte			Linear motor LED 2 power status, 0=Off, 1=On

Array Index Number	Array Name	Data Type	Item Count (if > 1)	Units	Description
37 (35)	linear_mtr_pwr_status	UnsignedByte			Linear motor power status, 0=Off, 1=On
38 (36)	m12v_status	IEEE754MSBSingle		V	-12V Status
39 (37)	m5v_status	IEEE754MSBSingle		V	-5V Status
40 (38)	missing_time_tic_ctr	UnsignedByte			Missing time tic counter
41 (39)	motor_temp	IEEE754MSBSingle		degC	Motor temperature
42 (40)	nsamples	SignedMSB4			Number of valid entries in the science data section
43 (41)	os_pos	SignedMSB4			Linear motor optical switch position
44 (42)	p12v_status	IEEE754MSBSingle		V	+12V Status
45 (43)	p1v_status	IEEE754MSBSingle		V	+1V Status
46 (44)	p2_5v_status	IEEE754MSBSingle		V	+2.5V Status
47 (45)	p3_3v_status	IEEE754MSBSingle		V	+3.3V Status
48 (46)	p5v_status	IEEE754MSBSingle		V	+5V Status
49 (47)	p5vd_status	IEEE754MSBSingle		V	+5V digital Status
50 (48)	peak_fringe	IEEE754MSBSingle			Peak to peak fringe amplitude
51 (49)	pps_timer_mode	UnsignedByte			PPS timer mode. 1=Oscillator, 2=Nominal, 4=PPS, 8=Command mode
52 (50)	pri_mirror_temp	IEEE754MSBSingle		degC	Primary mirror temperature 1
53 (51)	sample_dir	UnsignedByte			Sample direction status, 0=Forward, 1=Backward direction
54 (52)	scan_period	UnsignedByte			Scan period, 0=2 second, 1=1second, 2=0.5 second scan
55 (53)	sci_data_size	SignedMSB4			Size of science data IDP size in bytes. 0x0 for engineering data packets, variable (max 3312 bytes) for science data packets
56 (54)	sclk	SignedMSB4		Sec	LTES time in seconds
57 (55)	sclk_sub	SignedMSB4			LTES time in sub-seconds. Each count represents 1/(2^16) seconds
58 (56)	sec_mirror_temp1	IEEE754MSBSingle		degC	Secondary mirror temperature 1
59 (57)	sec_mirror_temp2	IEEE754MSBSingle		degC	Secondary mirror temperature 2

Array Index Number	Array Name	Data Type	Item Count (if > 1)	Units	Description
60 (58)	seq_count	SignedMSB4			Number of telemetry (housekeeping / science) packets sent (resets on power up).
61 (59)	servo_ctl_tim_status	UnsignedByte			Servo controller / sample timing status, 0=Closed loop/fringe based, 1=Closed loop/timer based, 2=Open loop/fringe based, 3=Open loop/timer-based samples
62 (60)	subcom_param1	SignedMSB4			Sub-commutated parameter 1
63 (61)	subcom_param2	SignedMSB4			Sub-commutated parameter 2
64 (62)	subcom_param3	SignedMSB4			Sub-commutated parameter 3
65 (63)	subcom_param4	SignedMSB4			Sub-commutated parameter 4
66 (64)	subcom_param5	SignedMSB4			Sub-commutated parameter 5
67 (65)	subcom_param6	SignedMSB4			Sub-commutated parameter 6
68 (66)	subcom_param7	SignedMSB4			Sub-commutated parameter 7
69 (67)	subcom_param8	SignedMSB4			Sub-commutated parameter 8
70 (68)	subcom_param_subaddr	SignedMSB4			Sub-commutated parameter sub-address. Identifies the subcommutated parameter block.
71 (69)	sw_cmd_acc_cnt	UnsignedByte			Number of commands software has accepted
72 (70)	sw_cmd_rej_cnt	UnsignedByte			Number of commands software has rejected
73 (71)	tic_ctr	UnsignedByte			Number of tic pulses received (Pulses Per Second).
74 (72)	time_upd_acc_count	UnsignedByte			Number of accepted time update commands
75 (73)	watchdog_status	UnsignedByte			Watchdog status, 0=Disabled, 1=Enabled

The uncalibrated data product text header that is used to populate many of attributes in the PDS4 .xml label is described in the following table. The text header terms are correlated with their .xml class/attribute and are defined. Not all text header keywords are populated in every label.

Table 3-3. Product header keywords to xml label class/attribute translation.

Header Keyword	PDS XML Label Xpath	Description
MISSION	/Product_Observational[1]/Observation_Area[1]/Investigation_Area[1]/name[1]	mission name (Lucy)
HOSTNAME	/Product_Observational[1]/Observation_Area[1]/Observing_System[1]/Observing_System_Component[1]	instrument host name (Lucy)
HOSTID	/Product_Observational[1]/Observation_Area[1]/Observing_System[1]/Observing_System_Component[1]	instrument host ID (Lucy)
INSTRUME	/Product_Observational[1]/Observation_Area[1]/Observing_System[1]/Observing_System_Component[2]	name of instrument (L'TES)
OBSID	/Product_Observational[1]/Observation_Area[1]/Mission_Area[1]/lucy:Lucy_Observation_Time_Information[1]/lucy:observation_id[1]	observation ID
STRTSCLK	/Product_Observational[1]/Observation_Area[1]/Mission_Area[1]/lucy:Lucy_Observation_Time_Information[1]/lucy:start_sclk[1]	observation start time (SCLK seconds)
MIDSCLK	/Product_Observational[1]/Observation_Area[1]/Mission_Area[1]/lucy:Lucy_Observation_Time_Information[1]/lucy:mid_sclk[1]	observation midpoint (SCLK seconds)
STOPSCLK	/Product_Observational[1]/Observation_Area[1]/Mission_Area[1]/lucy:Lucy_Observation_Time_Information[1]/lucy:stop_sclk[1]	observation stop time (SCLK seconds)
STARTUTC	/Product_Observational[1]/Observation_Area[1]/Time_Coordinates[1]/start_date_time[1]	observation start time (UTC, ISOT format)
MIDUTC	/Product_Observational[1]/Observation_Area[1]/Mission_Area[1]/lucy:Lucy_Observation_Time_Information[1]/lucy:mid_utc[1]	observation midpoint (UTC, ISOT format)
STOPUTC	/Product_Observational[1]/Observation_Area[1]/Time_Coordinates[1]/stop_date_time[1]	observation stop time (UTC, ISOT format)
MIDSCLKS	/Product_Observational[1]/Observation_Area[1]/Mission_Area[1]/lucy:Lucy_Observation_Time_Information[1]/lucy:mid_sclk_string[1]	observation midpoint (full SCLK string)
MIDUTCID	/Product_Observational[1]/Observation_Area[1]/Mission_Area[1]/lucy:Lucy_Observation_Time_Information[1]/lucy:mid_utc_doy[1]	observation midpoint (UTC, ISO DOY format)
MIDUTCJD	/Product_Observational[1]/Observation_Area[1]/Mission_Area[1]/lucy:Lucy_Observation_Time_Information[1]/lucy:mid_utc_jd[1]	observation midpoint (Julian date)
MIDET	/Product_Observational[1]/Observation_Area[1]/Mission_Area[1]/lucy:Lucy_Observation_Time_Information[1]/lucy:mid_ephemeris_time[1]	observation midpoint (ET, seconds past J2000)
EXPTIME	n/a for L'TES	[s] Exposure time
FILENAME	/Product_Observational[1]/File_Area_Observational[1]/File[1]/file_name[1]/node()[1]	product file name
DATE	/Product_Observational[1]/File_Area_Observational[1]/File[1]/creation_date_time[1]	product creation time (UTC, ISOT format)
ORIGIN	/Product_Observational[1]/Observation_Area[1]/Discipline_Area[1]/proc:Processing_Information[1]	organization responsible for product
LOCATION	/Product_Observational[1]/Observation_Area[1]/Discipline_Area[1]/proc:Processing_Information[1]/proc:Process[1]/proc:process_owner_institution_name[1]	location where product was generated

Header Keyword	PDS XML Label Xpath	Description
CCSDSCLK	/Product_Observational[1]/Observation_Area[1]/Mission_Area[1]/lucy:Lucy_Observation_Time_Information[1]/lucy:ccsds_sclk_time[1]	CCSDS timestamp, playback time (SCLK seconds)
PRODLVL	n/a	Lucy internal processing level
PRODVER	/Product_Observational[1]/Observation_Area[1]/Mission_Area[1]/lucy:Lucy_Product_Information[1]/lucy:internal_product_version_id[1]	Lucy internal data processing product version
UDPVER	/Product_Observational[1]/Observation_Area[1]/Discipline_Area[1]/proc:Processing_Information[1]/proc:Process[2]/proc:Software[1]/proc:software_version_id[1]/node()[1]	UDP software version
CDPVER	/Product_Observational[1]/Observation_Area[1]/Discipline_Area[1]/proc:Processing_Information[1]/proc:Process[2]/proc:Software[2]/proc:software_version_id[1]	CDP software version
APID	n/a	packet application ID of source data
OBSCOMPL	/Product_Observational[1]/Observation_Area[1]/Mission_Area[1]/lucy:Lucy_Observation_Time_Information[1]/lucy:observation_complete[1]	observation complete?
MISSPKT	/Product_Observational[1]/Observation_Area[1]/Mission_Area[1]/lucy:Lucy_Observation_Time_Information[1]/lucy:observation_missing_packets[1]	number of missing packets
UDPFILE	n/a in uncalibrated product;	input UDP filename
LOADID	/Product_Observational[1]/Observation_Area[1]/Mission_Area[1]/lucy:Lucy_Observation_Planning[1]/lucy:load_identifier[1]	command sequence load ID
MSNSEG	/Product_Observational[1]/Observation_Area[1]/Mission_Area[1]/lucy:Lucy_Observation_Planning[1]/lucy:mission_segment[1]	mission segment (i.e. mission phase)
SAPID	/Product_Observational[1]/Observation_Area[1]/Mission_Area[1]/lucy:Lucy_Observation_Planning[1]/lucy:sap_identifier[1]	science activity plan identifier
VISITNAM	/Product_Observational[1]/Observation_Area[1]/Mission_Area[1]/lucy:Lucy_Observation_Planning[1]/lucy:visit_name[1]	visit name
SIDE	/Product_Observational[1]/Observation_Area[1]/Mission_Area[1]/lucy:Lucy_Observation_Planning[1]/lucy:instrument_side[1]/node()[1]	instrument side requested
LORSTAT	/Product_Observational[1]/Observation_Area[1]/Mission_Area[1]/lucy:Lucy_Observation_Planning[1]/lucy:llorri_status[1]	LORRI instrument status
RLPSTAT	/Product_Observational[1]/Observation_Area[1]/Mission_Area[1]/lucy:Lucy_Observation_Planning[1]/lucy:lralph_status[1]	Ralph instrument status
TESSTAT	/Product_Observational[1]/Observation_Area[1]/Mission_Area[1]/lucy:Lucy_Observation_Planning[1]/lucy:ltes_status[1]	TES instrument status
TTCSTAT	/Product_Observational[1]/Observation_Area[1]/Mission_Area[1]/lucy:Lucy_Observation_Planning[1]/lucy:ttcam_status[1]	TTCam instrument status
TARGET	/Product_Observational[1]/Observation_Area[1]/Target_Identification[1]/name[1]	name of intended primary target
TARGETID	/Product_Observational[1]/Observation_Area[1]/Target_Identification[1]/alternate_identification[1]	SPICE ID of intended primary target

Header Keyword	PDS XML Label Xpath	Description
SPCINSQA	/Product_Observational[1]/Observation_Area[1]/Discipline_Area[1]/geom:Geometry[1]/geom:Image_Display_Geometry[1]/geom:Quaternion_Plus_To_From[1]	cos(theta/2), instr. -> J2000 SPICE quat.
SPCINSQX	/Product_Observational[1]/Observation_Area[1]/Discipline_Area[1]/geom:Geometry[1]/geom:Image_Display_Geometry[1]/geom:Quaternion_Plus_To_From[1]	sin(theta/2)*X, instr. -> J2000 SPICE quat.
SPCINSQY	/Product_Observational[1]/Observation_Area[1]/Discipline_Area[1]/geom:Geometry[1]/geom:Image_Display_Geometry[1]/geom:Quaternion_Plus_To_From[1]	sin(theta/2)*Y, instr. -> J2000 SPICE quat.
SPCINSQZ	/Product_Observational[1]/Observation_Area[1]/Discipline_Area[1]/geom:Geometry[1]/geom:Image_Display_Geometry[1]/geom:Quaternion_Plus_To_From[1]	sin(theta/2)*Z, instr. -> J2000 SPICE quat.
SPCSCQA	/Product_Observational[1]/Observation_Area[1]/Discipline_Area[1]/geom:Geometry[1]/geom:Image_Display_Geometry[1]/geom:Quaternion_Plus_To_From[2]	cos(theta/2), S/C -> J2000 SPICE quat.
SPCSCQX	/Product_Observational[1]/Observation_Area[1]/Discipline_Area[1]/geom:Geometry[1]/geom:Image_Display_Geometry[1]/geom:Quaternion_Plus_To_From[2]	sin(theta/2)*X, S/C -> J2000 SPICE quat.
SPCSCQY	/Product_Observational[1]/Observation_Area[1]/Discipline_Area[1]/geom:Geometry[1]/geom:Image_Display_Geometry[1]/geom:Quaternion_Plus_To_From[2]	sin(theta/2)*Y, S/C -> J2000 SPICE quat.
SPCSCQZ	/Product_Observational[1]/Observation_Area[1]/Discipline_Area[1]/geom:Geometry[1]/geom:Image_Display_Geometry[1]/geom:Quaternion_Plus_To_From[2]	sin(theta/2)*Z, S/C -> J2000 SPICE quat.
RATEX	n/a	angular rate about inst. frame +X axis (urad/s)
RATEY	n/a	angular rate about inst. frame +Y axis (urad/s)
RATEZ	n/a	angular rate about inst. frame +Z axis (urad/s)
RATEXY	n/a	magnitude of [RATEX,RATEY] pair (urad/s)
RATEYZ	n/a	magnitude of [RATEY,RATEZ] pair (urad/s)
RATEXZ	n/a	magnitude of [RATEX,RATEZ] pair (urad/s)
RATEMAG	n/a	magnitude of [RATEX,RATEY,RATEZ] vector. (urad/s)
IPIGANG	n/a	IPP inner gimbal angle (deg)
IPIGRATE	n/a	IPP inner gimbal angle rate (deg/sec)
IPOGANG	n/a	IPP outer gimbal angle (deg)
IPOGRATE	n/a	IPP outer gimbal angle rate (deg/sec)
BSRASTRT	/Product_Observational[1]/Observation_Area[1]/Discipline_Area[1]/geom:Geometry[1]/geom:Image_Display_Geometry[1]/geom:Object_Orientation_RA_Dec[1]/geom:right_ascension_angle[1]	Boresight RA at obs start (deg)

Header Keyword	PDS XML Label Xpath	Description
BSDCSTRT	/Product_Observational[1]/Observation_Area[1]/Discipline_Area[1]/geom:Geometry[1]/geom:Image_Display_Geometry[1]/geom:Object_Orientation_RA_Dec[1]/geom:declination_angle[1]	Boresight Dec at obs start (deg)
BSRAMID	n/a	Boresight RA at mid-obs time (deg)
BSDCMID	n/a	Boresight Dec at mid-obs time (deg)
BSRASTOP	n/a	Boresight RA at obs end (deg)
BSDCSTOP	n/a	Boresight Dec at obs end (deg)
TRGFOV1	/Product_Observational[1]/Observation_Area[1]/Mission_Area[1]/lucy:Lucy_Target_List[1]/lucy:target_fov_name[1]	Target 1 in Field of View
TRGFOVN	/Product_Observational[1]/Observation_Area[1]/Mission_Area[1]/lucy:Lucy_Target_List[1]/lucy:target_fov_count[1]	number of possible targets in Field of View (SPICE-derived)
PA_XINST	n/a	pos. ang. +X axis, E of proj. EMEJ2K N (deg)
PA_YINST	n/a	pos. ang. +Y axis, E of proj. EMEJ2K N (deg)
PA_ZINST	n/a	pos. ang. +Z axis, E of proj. EMEJ2K N (deg)
PA_SUN	n/a	pos. ang. proj. Sun, E of proj. EMEJ2K N (deg)
PA_SUN_X	n/a	pos. ang. proj. Sun, E of inst. +X axis (deg)
PA_SUN_Y	n/a	pos. ang. proj. Sun, E of inst. +Y axis (deg)
PA_SUN_Z	n/a	pos. ang. proj. Sun, E of inst. +Z axis (deg)
TGT_ELON	n/a	ang. betw. target and inst. boresight (deg)
SOL_ELON	/Product_Observational[1]/Observation_Area[1]/Discipline_Area[1]/geom:Geometry[1]/geom:Geometry_Orbiter[1]/geom:Illumination_Geometry[1]/geom:Illumination_Specific[1]/geom:solar_elongation[1]	ang. betw. Sun and inst. boresight (deg)
EAR_ELON	n/a	ang. betw. Earth and inst. boresight (deg)
SPCQUAL	/Product_Observational[1]/Observation_Area[1]/Discipline_Area[1]/geom:Geometry[1]/geom:SPICE_Kernel_Files[1]/geom:SPICE_Kernel_Identification[1]/geom:kernel_provenance[1]	SPICE quality
SPCSTAT	n/a	SPICE status
SPCSCNM	/Product_Observational[1]/Observation_Area[1]/Discipline_Area[1]/geom:Geometry[1]/geom:Image_Display_Geometry[1]/geom:Object_Orientation_RA_Dec[1]/geom:Reference_Frame_Identification[1]/geom:frame_spice_name[1]	SPICE spacecraft bus frame name
SPCSCID	n/a	SPICE spacecraft bus frame ID
SPCINSNM	n/a	SPICE instrument frame name
SPCINSID	n/a	SPICE instrument frame ID

Header Keyword	PDS XML Label Xpath	Description
SPCTSCX	/Product_Observational[1]/Observation_Area[1]/Discipline_Area[1]/geom:Geometry[1]/geom:Geometry_Orbiter[1]/geom:Vectors[1]/geom:Vectors_Cartesian_Specific[1]/geom:Vector_Cartesian_Position_Spacecraft_To_Target[1]/geom:x_position[1]	S/C pos vec wrt target, X, EMEJ2000 (km)
SPCTSCY	/Product_Observational[1]/Observation_Area[1]/Discipline_Area[1]/geom:Geometry[1]/geom:Geometry_Orbiter[1]/geom:Vectors[1]/geom:Vectors_Cartesian_Specific[1]/geom:Vector_Cartesian_Position_Spacecraft_To_Target[1]/geom:y_position[1]	S/C pos vec wrt target, Y, EMEJ2000 (km)
SPCTSCZ	/Product_Observational[1]/Observation_Area[1]/Discipline_Area[1]/geom:Geometry[1]/geom:Geometry_Orbiter[1]/geom:Vectors[1]/geom:Vectors_Cartesian_Specific[1]/geom:Vector_Cartesian_Position_Spacecraft_To_Target[1]/geom:z_position[1]	S/C pos vec wrt target, Z, EMEJ2000 (km)
SPCTSCVX	/Product_Observational[1]/Observation_Area[1]/Discipline_Area[1]/geom:Geometry[1]/geom:Geometry_Orbiter[1]/geom:Vectors[1]/geom:Vectors_Cartesian_Specific[1]/geom:Vector_Cartesian_Velocity_Spacecraft_Relative_To_Target[1]/geom:x_velocity[1]	S/C vel vec wrt target, X, EMEJ2000 (km/s)
SPCTSCVY	/Product_Observational[1]/Observation_Area[1]/Discipline_Area[1]/geom:Geometry[1]/geom:Geometry_Orbiter[1]/geom:Vectors[1]/geom:Vectors_Cartesian_Specific[1]/geom:Vector_Cartesian_Velocity_Spacecraft_Relative_To_Target[1]/geom:y_velocity[1]	S/C vel vec wrt target, Y, EMEJ2000 (km/s)
SPCTSCVZ	/Product_Observational[1]/Observation_Area[1]/Discipline_Area[1]/geom:Geometry[1]/geom:Geometry_Orbiter[1]/geom:Vectors[1]/geom:Vectors_Cartesian_Specific[1]/geom:Vector_Cartesian_Velocity_Spacecraft_Relative_To_Target[1]/geom:z_velocity[1]	S/C vel vec wrt target, Z, EMEJ2000 (km/s)
SPCTRANG	/Product_Observational[1]/Observation_Area[1]/Discipline_Area[1]/geom:Geometry[1]/geom:Geometry_Orbiter[1]/geom:Distances[1]/geom:Distances_Specific[1]/geom:spacecraft_target_center_distance[1]	S/C range to target center (km)
SPCTPHAS	n/a	Sun-target-S/C angle (deg)
SPCTSOX	/Product_Observational[1]/Observation_Area[1]/Discipline_Area[1]/geom:Geometry[1]/geom:Geometry_Orbiter[1]/geom:Vectors[1]/geom:Vectors_Cartesian_Specific[1]/geom:Vector_Cartesian_Position_Sun_To_Spacecraft[1]/geom:x_position[1]	Sun pos vec wrt target, X, EMEJ2000 (km)
SPCTSOY	/Product_Observational[1]/Observation_Area[1]/Discipline_Area[1]/geom:Geometry[1]/geom:Geometry_Orbiter[1]/geom:Vectors[1]/geom:Vectors_Cartesian_Specific[1]/geom:Vector_Cartesian_Position_Sun_To_Spacecraft[1]/geom:y_position[1]	Sun pos vec wrt target, Y, EMEJ2000 (km)
SPCTSOZ	/Product_Observational[1]/Observation_Area[1]/Discipline_Area[1]/geom:Geometry[1]/geom:Geometry_Orbiter[1]/geom:Vectors[1]/geom:Vectors_Cartesian_Specific[1]/geom:Vector_Cartesian_Position_Sun_To_Spacecraft[1]/geom:z_position[1]	Sun pos vec wrt target, Z, EMEJ2000 (km)
SPCTSOVX	/Product_Observational[1]/Observation_Area[1]/Discipline_Area[1]/geom:Geometry[1]/geom:Geometry_Orbiter[1]/geom:Vectors[1]/geom:Vectors_Cartesian_Specific[1]/geom:Vector_Cartesian_Velocity_Target_Relative_To_Sun[1]/geom:x_velocity[1]	Sun vel vec wrt target, X, EMEJ2000 (km/s)
SPCTSOVY	/Product_Observational[1]/Observation_Area[1]/Discipline_Area[1]/geom:Geometry[1]/geom:Geometry_Orbiter[1]/geom:Vectors[1]/geom:Vectors_Cartesian_Specific[1]/geom:Vector_Cartesian_Velocity_Target_Relative_To_Sun[1]/geom:y_velocity[1]	Sun vel vec wrt target, Y, EMEJ2000 (km/s)
SPCTSOVZ	/Product_Observational[1]/Observation_Area[1]/Discipline_Area[1]/geom:Geometry[1]/geom:Geometry_Orbiter[1]/geom:Vectors[1]/geom:Vectors_Cartesian_Specific[1]/geom:Vector_Cartesian_Velocity_Target_Relative_To_Sun[1]/geom:z_velocity[1]	Sun vel vec wrt target, Z, EMEJ2000 (km/s)

Header Keyword	PDS XML Label Xpath	Description
SPCTSORN	/Product_Observational[1]/Observation_Area[1]/Discipline_Area[1]/geom:Geometry[1]/geom:Geometry_Orbiter[1]/geom:Distances[1]/geom:Distances_Specific[1]/geom:target_heliocentric_distance[1]	Sun center range to target center (km)
SPCTEOX	/Product_Observational[1]/Observation_Area[1]/Discipline_Area[1]/geom:Geometry[1]/geom:Geometry_Orbiter[1]/geom:Vectors[1]/geom:Vectors_Cartesian_Specific[1]/geom:Vector_Cartesian_Position_Earth_To_Target[1]/geom:x_position[1]	Earth pos vec wrt target, X, EMEJ2000 (km)
SPCTEOY	/Product_Observational[1]/Observation_Area[1]/Discipline_Area[1]/geom:Geometry[1]/geom:Geometry_Orbiter[1]/geom:Vectors[1]/geom:Vectors_Cartesian_Specific[1]/geom:Vector_Cartesian_Position_Earth_To_Target[1]/geom:y_position[1]	Earth pos vec wrt target, Y, EMEJ2000 (km)
SPCTEOZ	/Product_Observational[1]/Observation_Area[1]/Discipline_Area[1]/geom:Geometry[1]/geom:Geometry_Orbiter[1]/geom:Vectors[1]/geom:Vectors_Cartesian_Specific[1]/geom:Vector_Cartesian_Position_Earth_To_Target[1]/geom:z_position[1]	Earth pos vec wrt target, Z, EMEJ2000 (km)
SPCTEOVX	/Product_Observational[1]/Observation_Area[1]/Discipline_Area[1]/geom:Geometry[1]/geom:Geometry_Orbiter[1]/geom:Vectors[1]/geom:Vectors_Cartesian_Specific[1]/geom:Vector_Cartesian_Velocity_Target_Relative_To_Earth[1]/geom:x_velocity[1]	Earth vel vec wrt target, X, EMEJ2000 (km/s)
SPCTEOVY	/Product_Observational[1]/Observation_Area[1]/Discipline_Area[1]/geom:Geometry[1]/geom:Geometry_Orbiter[1]/geom:Vectors[1]/geom:Vectors_Cartesian_Specific[1]/geom:Vector_Cartesian_Velocity_Target_Relative_To_Earth[1]/geom:y_velocity[1]	Earth vel vec wrt target, Y, EMEJ2000 (km/s)
SPCTEOVZ	/Product_Observational[1]/Observation_Area[1]/Discipline_Area[1]/geom:Geometry[1]/geom:Geometry_Orbiter[1]/geom:Vectors[1]/geom:Vectors_Cartesian_Specific[1]/geom:Vector_Cartesian_Velocity_Target_Relative_To_Earth[1]/geom:z_velocity[1]	Earth vel vec wrt target, Z, EMEJ2000 (km/s)
SPCTEORN	/Product_Observational[1]/Observation_Area[1]/Discipline_Area[1]/geom:Geometry[1]/geom:Geometry_Orbiter[1]/geom:Distances[1]/geom:Distances_Specific[1]/geom:target_geocentric_distance[1]	Earth center range to target center (km)
SPCSCSX	/Product_Observational[1]/Observation_Area[1]/Discipline_Area[1]/geom:Geometry[1]/geom:Geometry_Orbiter[1]/geom:Vectors[1]/geom:Vectors_Cartesian_Specific[1]/geom:Vector_Cartesian_Position_Sun_To_Spacecraft[1]/geom:x_position[1]	Sun pos vec wrt S/C, X, EMEJ2000 (km)
SPCSCSY	/Product_Observational[1]/Observation_Area[1]/Discipline_Area[1]/geom:Geometry[1]/geom:Geometry_Orbiter[1]/geom:Vectors[1]/geom:Vectors_Cartesian_Specific[1]/geom:Vector_Cartesian_Position_Sun_To_Spacecraft[1]/geom:y_position[1]	Sun pos vec wrt S/C, Y, EMEJ2000 (km)
SPCSCSZ	/Product_Observational[1]/Observation_Area[1]/Discipline_Area[1]/geom:Geometry[1]/geom:Geometry_Orbiter[1]/geom:Vectors[1]/geom:Vectors_Cartesian_Specific[1]/geom:Vector_Cartesian_Position_Sun_To_Spacecraft[1]/geom:z_position[1]	Sun pos vec wrt S/C, Z, EMEJ2000 (km)
SPCSCSVX	/Product_Observational[1]/Observation_Area[1]/Discipline_Area[1]/geom:Geometry[1]/geom:Geometry_Orbiter[1]/geom:Vectors[1]/geom:Vectors_Cartesian_Specific[1]/geom:Vector_Cartesian_Velocity_Spacecraft_Relative_To_Sun[1]/geom:x_velocity[1]	Sun vel vec wrt S/C, X, EMEJ2000 (km/s)
SPCSCSVY	/Product_Observational[1]/Observation_Area[1]/Discipline_Area[1]/geom:Geometry[1]/geom:Geometry_Orbiter[1]/geom:Vectors[1]/geom:Vectors_Cartesian_Specific[1]/geom:Vector_Cartesian_Velocity_Spacecraft_Relative_To_Sun[1]/geom:y_velocity[1]	Sun vel vec wrt S/C, Y, EMEJ2000 (km/s)

Header Keyword	PDS XML Label Xpath	Description
SPCSCSVZ	/Product_Observational[1]/Observation_Area[1]/Discipline_Area[1]/geom:Geometry[1]/geom:Geometry_Orbiter[1]/geom:Vectors[1]/geom:Vectors_Cartesian_Specific[1]/geom:Vector_Cartesian_Velocity_Spacecraft_Relative_To_Sun[1]/geom:z_velocity[1]	Sun vel vec wrt S/C, Z, EMEJ2000 (km/s)
SPCSCSRN	/Product_Observational[1]/Observation_Area[1]/Discipline_Area[1]/geom:Geometry[1]/geom:Geometry_Orbiter[1]/geom:Distances[1]/geom:Distances_Specific[1]/geom:spacecraft_heliocentric_distance[1]	Sun center range to S/C (km)
SPCESCX	/Product_Observational[1]/Observation_Area[1]/Discipline_Area[1]/geom:Geometry[1]/geom:Geometry_Orbiter[1]/geom:Vectors[1]/geom:Vectors_Cartesian_Specific[1]/geom:Vector_Cartesian_Position_Earth_To_Spacecraft[1]/geom:x_position[1]	S/C pos vec wrt Earth, X, EMEJ2000 (km)
SPCESCY	/Product_Observational[1]/Observation_Area[1]/Discipline_Area[1]/geom:Geometry[1]/geom:Geometry_Orbiter[1]/geom:Vectors[1]/geom:Vectors_Cartesian_Specific[1]/geom:Vector_Cartesian_Position_Earth_To_Spacecraft[1]/geom:y_position[1]	S/C pos vec wrt Earth, Y, EMEJ2000 (km)
SPCESCZ	/Product_Observational[1]/Observation_Area[1]/Discipline_Area[1]/geom:Geometry[1]/geom:Geometry_Orbiter[1]/geom:Vectors[1]/geom:Vectors_Cartesian_Specific[1]/geom:Vector_Cartesian_Position_Earth_To_Spacecraft[1]/geom:z_position[1]	S/C pos vec wrt Earth, Z, EMEJ2000 (km)
SPCESCVX	/Product_Observational[1]/Observation_Area[1]/Discipline_Area[1]/geom:Geometry[1]/geom:Geometry_Orbiter[1]/geom:Vectors[1]/geom:Vectors_Cartesian_Specific[1]/geom:Vector_Cartesian_Velocity_Spacecraft_Relative_To_Earth[1]/geom:x_velocity[1]	S/C vel vec wrt Earth, X, EMEJ2000 (km/s)
SPCESCVY	/Product_Observational[1]/Observation_Area[1]/Discipline_Area[1]/geom:Geometry[1]/geom:Geometry_Orbiter[1]/geom:Vectors[1]/geom:Vectors_Cartesian_Specific[1]/geom:Vector_Cartesian_Velocity_Spacecraft_Relative_To_Earth[1]/geom:y_velocity[1]	S/C vel vec wrt Earth, Y, EMEJ2000 (km/s)
SPCESCVZ	/Product_Observational[1]/Observation_Area[1]/Discipline_Area[1]/geom:Geometry[1]/geom:Geometry_Orbiter[1]/geom:Vectors[1]/geom:Vectors_Cartesian_Specific[1]/geom:Vector_Cartesian_Velocity_Spacecraft_Relative_To_Earth[1]/geom:z_velocity[1]	S/C vel vec wrt Earth, Z, EMEJ2000 (km/s)
SPCESCRN	/Product_Observational[1]/Observation_Area[1]/Discipline_Area[1]/geom:Geometry[1]/geom:Geometry_Orbiter[1]/geom:Distances[1]/geom:Distances_Specific[1]/geom:spacecraft_geocentric_distance[1]	S/C range to Earth center (km)
SPCKMK	/Product_Observational[1]/Observation_Area[1]/Discipline_Area[1]/geom:Geometry[1]/geom:SPICE_Kernel_Files[1]/geom:SPICE_Kernel_Identification[1]/geom:kernel_type[1]/node()[1]	SPICE meta kernel
SPCKNUM	n/a	count of loaded SPICE kernels
SPCKn	/Product_Observational[1]/Observation_Area[1]/Discipline_Area[1]/geom:Geometry[1]/geom:SPICE_Kernel_Files[1]/geom:SPICE_Kernel_Identification[number]	SPICE kernel [n] (repeats for each kernel used)

Note that the vector to and from directions may be in the opposite direction from the header keywords to the PDS .xml label. The proper translation has been calculated.

3.2.2 Calibrated Data Product Format

The calibrated (science) data is stored in an HDF5 file. The file has an associated PDS4 label describing the product structure and its various data arrays. Most arrays contain values for each spectrum in the science sequence, however arrays indicated with an asterisk (*) contain a single number that applies to each spectrum. Entries with n/a in the Array Index Number column appear in the HDF5 file as text strings and are not translated into the PDS4 xml label as arrays. Generally, these values appear as attributes in the PDS4 label. The LTES calibrated structure is given below:

Table 3-4. Calibrated Science Format

Array Index Number	Array Name	Array type	Data Type	Element Count (if > 1)	Units	Description
0	bore_intcpt	Array_2d	IEEE754MSB Single	3 (x,y,z)	Km	Boresight intercept x, y, z coordinates in the body frame for each observation
1	brightness_temp	Array-2d	IEEE754MSB Single	400	K	Calculated brightness temperature
2	calibrated_radiance	Array_2d_Spectrum	IEEE754MSB Single	400	W cm–2 sr–1 /cm–1	Calibrated radiance spectrum
3	emission_angle	Array_1d	IEEE754MSB Single		Deg	Emission angle for each observation
n/a	calseq_file	Stream_Text				Name of the calibration segment file.
4	calseqid*	Array_1d	SignedMSB4			Calibration sequence identifier.
5	geo_sw_version*	Array_1d	SignedMSB4			Software version of the geometry calculation software.
n/a	inputs_file	Stream_Text				Name of the file that contains all inputs to the instrument processing pipeline
n/a	instrument	Stream_Text				Name of the instrument that produced the data included in the data product.
n/a	intended_target	Stream_Text				Name of the intended target of the observation. This may be different than the actual target.
6	kernel_count*	Array_1d	SignedMSB4			Count of SPICE kernels used in calibration processing.
n/a	kernels	Stream_Text				List of the kernel files used in the data processing
n/a	loadid	Stream_Text				Name of the observation load identifier.
n/a	lorri_stat	Stream_Text				Lorri operational status at time of observation
n/a	meta_kernel	Stream_Text				Name of the meta kernel used in the data processing

Array Index Number	Array Name	Array type	Data Type	Element Count (if > 1)	Units	Description
7	midsclk*	Array_1d	IEEE754MSB Double			Spacecraft clock time at the middle of the data collection sequence.
8	missing_packets*	Array_1d	SignedMSB4			Number of missing telemetry packets in the processed calibration sequence.
n/a	mission	Stream_Text				Name of the mission (Lucy)
n/a	mission_segment	Stream_Text				Name of the mission segment during which the observation occurred.
n/a	obs_param	Stream_Text				List of the observation parameters during data collection.
9	obsids	Array_1d	SignedMSB4			List of the unique observation identifiers included in the calibrated data product.
10	pipeline_version*	Array_1d	IEEE754MSB Single			Version of the pipeline software used to perform data calibration.
n/a	ralph_stat	Stream_Text				Ralph operational status at the time of the observation
n/a	run_date	Stream_Text				Data and time of data processing
n/a	sapid	Stream_Text				List of operational planning calibration files used in the data processing
n/a	source_files	Stream_Text				List of uncalibrated LTES files used to construct the calibrated data product.
n/a	spacecraft	Stream_Text				Spacecraft name
11	stopsclk*	Array_1d	IEEE754MSB Double			Ending spacecraft clock time of the data product.
12	strtsclk*	Array_1d	IEEE754MSB Double			Starting spacecraft clock time of the data product.
n/a	tes_stat	Stream_Text				LTES operational status at time of the data collection
n/a	ttcam_stat	Stream_Text				TTCam operational status at time of the data collection
n/a	visit_name	Stream_Text				List of the names of the observational asteroid visit files used in the data processing
13	ick	Array_1d	SignedMSB4			Individual collection interval counter
14	incidence_angle	Array_1d	IEEE754MSB Single		Deg	Incidence angle of each observation in the data product

Array Index Number	Array Name	Array type	Data Type	Element Count (if > 1)	Units	Description
15	l_sub_s	Array_1d	IEEE754MSB Single		Deg	Ls (solar longitude – indicates season)
16	lat	Array_1d	IEEE754MSB Single		Deg	Latitude of each observation in the data product.
n/a	local_time	Stream_Text				Local time.
17	lon	Array_1d	IEEE754MSB Single		Deg	Longitude of each observation in the data product.
18	nsamples	Array_1d	SignedMSB4			Actual number of samples in the interferogram of each observation in the data product.
19	phase_angle	Array_1d	IEEE754MSB Single		Deg	Phase angle of each observation in the data product.
20	range_to_ctr	Array_1d	IEEE754MSB Single		Km	Center-to-center distance between spacecraft and the target body of each observation in the data product.
21	range_to_surf	Array_1d	IEEE754MSB Single		Km	Range from the spacecraft to the target body surface of each observation in the data product.
22	sample_dir	Array_1d	UnsignedByte			Interferogram sampling direction (0=forwards, 1=backward) for each observation in the data product.
23	sc_pos	Array_2d	IEEE754MSB Single	3 (x,y,z)	Km	Spacecraft position (x, y,z) with respect to the target body for each observation in the data product.
24	scan_len	Array_1d	IEEE754MSB Single		Second	Scan length in seconds with possible values of 2, 1, 0.5.
25	scan_serial_num	Array_1d	SignedMSB4			Counts groups of observations collected with a particular scan length. Note that the instrument can be switched to different scan lengths during a fly by.
26	sclk	Array_1d	SignedMSB4		Second	Spacecraft clock seconds of each observation in the data product.
27	sclk_sub	Array_1d	SignedMSB4		1/65536 Second	Spacecraft clock sub-seconds of each observation in the data product.
28	sol_dist	Array_1d	IEEE754MSB Single		Km	Spacecraft solar distance of each observation in the data product.
29	sub_sc_lat	Array_1d	IEEE754MSB Single		Deg	Sub-spacecraft point latitude of each observation in the data product.

Array Index Number	Array Name	Array type	Data Type	Element Count (if > 1)	Units	Description
30	sub_sc_lon	Array_1d	IEEE754MSB Single		Deg	Sub-spacecraft point longitude of each observation in the data product.
31	sub_sc_pt	Array_2d	IEEE754MSB Single	3	Km	Sub-spacecraft point (x,y,z) of each observation in the data product.
32	sub_sol_lat	Array_1d	IEEE754MSB Single		Deg	Sub-solar point latitude of each observation in the data product.
33	sub_sol_lon	Array_1d	IEEE754MSB Single		Deg	Sub-solar point longitude of each observation in the data product.
34	sub_sol_pt	Array_2d	IEEE754MSB Single	3	Km	Sub-solar point (x,y,z) of each observation in the data product.
35	target_type_num	Array_1d	SignedMSB4			Target type number (1=space, 2=internal cal, 3=target) of each observation in the data product
n/a	utc	Stream_Text				UTC time of each observation in the data product.
36	vspec	Array_2d	IEEE754MSB Single	400	V	Voltage spectrum for each observation in the data product.
37	xaxis	Array_2d_Spectrum	IEEE754MSB Single	400	cm^{-1}	Wavenumbers for each channel of the spectral fields (vspec, calibrated_radiance, brightness_temp)
38	zpd	Array_1d	SignedMSB4			Index of the sample at zero-path-difference in the interferogram of each. observation in the data product

3.3 Label and Header Descriptions

All LTES data products are produced with PDS4 compliant detached XML labels. Examples of these labels can be found in the mission bundle, document collection.

The correlation between header keyword text values and PDS4 xml label files is presented in Table 3-3.

4. APPLICABLE SOFTWARE

The LTES team will use “Davinci” (http://davinci.mars.asu.edu) to examine, display and analyze the data products. Davinci is a hyperspectral image processing software produced by the Mars Space Flight Facility at Arizona State University, Tempe, AZ 85287. It has been used as the calibration and analysis software for multiple missions, including MGS/TES, 2001 Mars Odyssey/THEMIS, OSIRIS-REx/OTES, and MER/Mini-TES. The minimum release number for Davinci to access and open PDS4, HDF5 and FITS files is 2.17.

Davinci will be maintained by the Davinci development team at ASU. Feature requests and bugs may be submitted via email to the Davinci development team.

PDS4 XML labels can be opened using most XML aware text editors.

4.1 Utility Programs

Davinci depends upon "gnuplot" for its plotting needs and an external image viewer to display images. Location of both is controlled via environment variables as described on the Davinci website. Standard complement of Linux/Unix tools and scripting languages will be used in conjunction as needed. Examples of such utilities include "od", "dd", "awk", "perl" (http://www.perl.org), "xmlstarlet" (http://xmlstar.sourceforge.net) for data dump, selection, formatting and xml query, etc.

4.2 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 (https://pds.nasa.gov/tools/about/) for additional information on these tools.
PDS4 utility programs such as the PDS4 Viewer and other IDL- and Python based PDS4 readers are available through the PDS Tool Registry (https://pds.nasa.gov/tools/tool-registry/).

4.3 Instrument Software Distribution and Update Procedures

Current and future releases of Davinci will be available from its website (http://davinci.mars.asu.edu) in both source and binary forms. Its documentation is hosted on the same site.

5. APPENDICES

5.1 ACRONYM LIST

Table 5-1: Acronym List

Acronym	Definition
DMAP	Data Management and Archive Plan
DPI	Deputy Principal Investigator
ICD	Interface Control Document
ICK	Individual collection Interval
LDAT	*Lucy* Data Archive Team
LEISA	Linear Etalon Imaging Spectral Array
L'LORRI	*Lucy* Long Range Reconnaissance Imager
L'Ralph	Instrument comprised of LEISA and MVIC
LTES	*Lucy* Thermal Emission Spectrometer

MGSS	Multi-Mission Ground System and Services
MOC	Mission Operations Center
MVIC	Multi-spectral Visible Imaging Camera
NAIF	Navigation and Ancillary Information Facility
NAV	Navigation
NOC	Navigation Operations Center
NSSDCA	National Space Science Data Coordinated Archive
OPS	Operations
PDS	Planetary Data System
PI	Principal Investigator
PMB	Patroclus and Menoetius Binary
SBN	Small Bodies Node
SC	Spacecraft
SCLK	Spacecraft clock
SIS	Software Interface Specification
SOC	Science Operations Center
SPICE	Data sets that are called kernel files and stand for: • **S**pacecraft trajectory, given as a function of time (SPK kernels). • **P**lanet, satellite, comet, asteroid, associated physical, and cartographic constants (PCK kernels). • **I**nstrument information, including internal timing and other geometric information (IK kernels). • **C** matrix, time-tagged orientation data of mounted structures and instruments (CK kernels). • **E**vents for the spacecraft and ground data system, both planned and unplanned (EK kernels).
ST	Science Team
SwRI	Southwest Research Institute
TTCAM	Terminal Tracking Camera
TBD	To Be Determined
TBR	To Be Rectified

5.2 References

Christensen, P. R. *et al.* The OSIRIS-REx Thermal Emission Spectrometer (OTES) Instrument. *Space Science Reviews* **214**, 1–39 (2018).

Christensen, P. R. *et al.* The Lucy Thermal Emission Spectrometer (L'TES) Instrument. *Space Science Reviews* **220**, (2024).

Good, P.G.; Faiks, P.; Pisano, W.J.; Terminal Tracking for the Lucy Trojan Asteroid Mission. AAS 22-131. In 44th Annual AAS Guidance, Navigation and Control Conference, February 2022.