

LICIACube LEIA/LUKE Uncalibrated/Calibrated Data Software Interface Specification

Version 2.0

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Prepared by

Angelo Zinzi (ASI) – LICIACube SOC Lead

Vincenzo Della Corte (INAF) – LICIACube co-PI and Instrument Scientist

Revised by the LICIACube Team



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1 Purpose and Scope

The data products described by this Software Interface Specification (SIS) are the reconstructed images from telemetry (raw), calibrated and derived images from the LICIAcube (LCC) LEIA (Liciacube Explorer Imaging for Asteroid) and LUKE (Liciacube Unit Key Explorer) instruments. The LCC Science Operation Center (LSOC) located at the Space Science Data Center of the Italian Space Agency (SSDC-ASI) produces these data products, sharing them with the DART (Double Asteroid Redirection Test) Science Operation Center (SOC) that subsequently distributes them to the Planetary Data System (PDS).

The purpose of this document is to provide a detailed description of the data products, how they were generated, and how they are organized in the archive, 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 analyse the data, including those associated with the DART and LICIAcube project and those in the general planetary science community.

2 Applicable Documents and Constraints

This LICIAcube data product SIS is consistent with the following Planetary Data System documents:

1. Planetary Data System Standards Reference, Version 1.14.0, May 22, 2020
2. PDS4 Data Dictionary, Abridged, Version 1.14.0.0, March 23, 2020
3. PDS4 Information Model Specification, Version 1.14.0.0, March 23, 2020

This LICIAcube data product SIS is responsive to the following DART and LICIAcube project documents:

- AD1. 7482-9060 Data Management and Archive Plan Double Asteroid Redirection Test (DART)
- AD2. 7482-9168 LICIAcube and DART-SOC Interface Control Document (ICD)
- AD3. JPL D-7669, Part 2 – Planetary Data System Standards Reference – Version 1.14.0

This LICIAcube data product SIS is consistent with the following documents:

Dotto, E., Della Corte, V., Amoroso, M., Bertini, I., Brucato, J.R., Capannolo, A., Cotugno, B., Cremonese, G., Di Tana, V., Gai, I., Ieva, S., Impresario, G., Ivanovski, S.L., Lavagna, M., Lucchetti, A., Mazzotta Epifani, E., Meneghin, A., Miglioretti, F., Modenini, D., Pajola, M., Palumbo, P., Perna, D., Pirrotta, S., Poggiali, G., Rossi, A., Simioni, E., Simonetti, S., Tortora, P., Zannoni, M., Zanotti, G., Zinzi, A., Cheng, A.F., Rivkin, A.S., Adams, E.Y., Reynolds, E.L., Fretz, K., 2021. LICIAcube - The Light Italian Cubesat for Imaging of Asteroids In support of the NASA DART mission towards asteroid (65803) Didymos. *Planetary and Space Science* 199, 105185. <https://doi.org/10.1016/j.pss.2021.105185>

3 Relationships with Other Interfaces

Changes to the data products described in this SIS may affect the documents listed in Table 1. In the event of a conflict between the LICIACube SIS and the **LICIACube Calibration Pipeline Description**, the pipeline description takes precedence. In the event of a conflict between the LICIACube SIS and the DRACO DMAP, the DMAP takes precedence.

Table 1: Interface relationships

Name	Type	Owner
DRACO Data Management and Archive Plan	Document	DART SOC
LICIACube and DART-SOC Interface Control Document (ICD)	Document	DART SOC
TBR		

4 Data Product Characteristics and Environment

4.1 Instruments Overview

DART is a low-cost technology demonstration of the kinetic impactor technique to divert a hazardous asteroid. DART carries LICIACube, a 6U CubeSat, which is to be deployed some days before DART impacts Dimorphos, the moon of the asteroid Didymos, and will image the impact and ejecta plume evolution thereafter. The LICIACube mission possesses two cameras, named LEIA and LUKE, here detailed:

4.1.1 LEIA

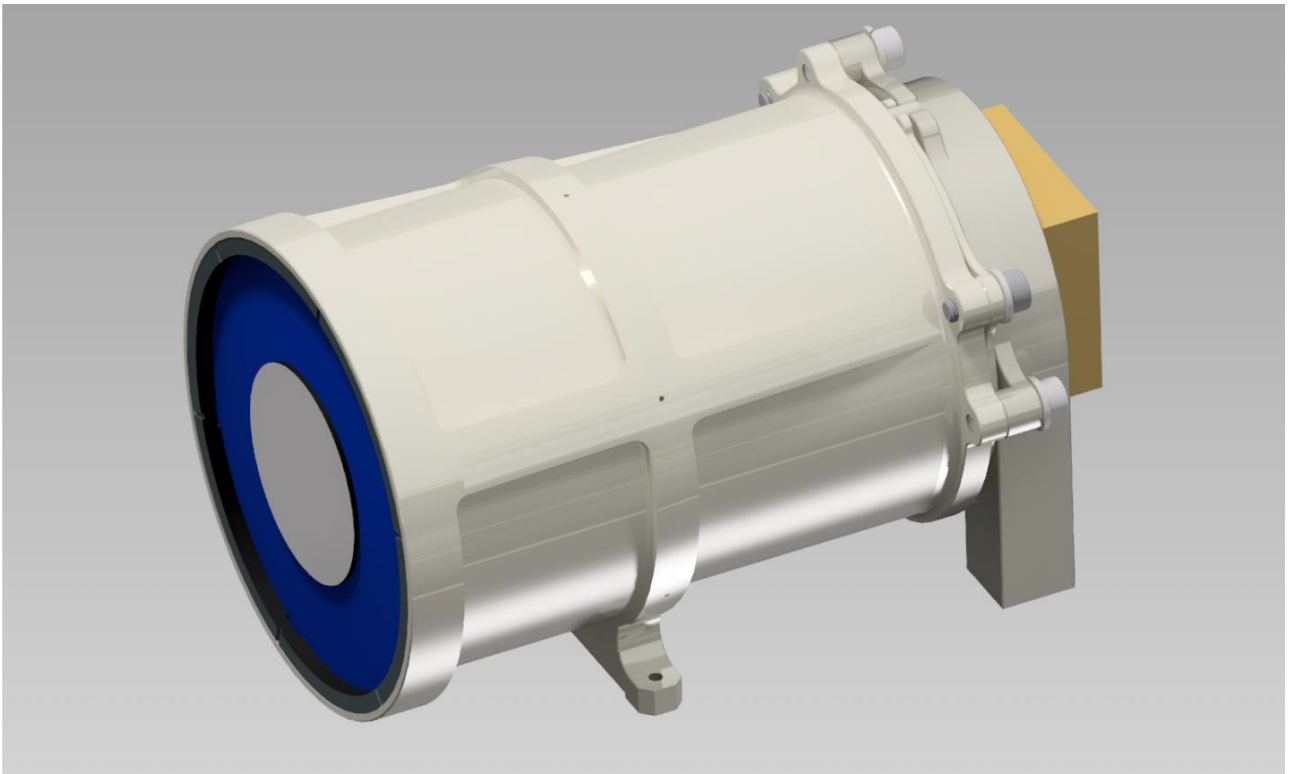


Figure 1 – CAD rendering of the LEIA Instrument

LEIA (Fig. 1) is composed by a catadioptric telescopic camera with 2 reflective and 3 refractive elements. The Field of View (FoV) is equal to $\pm 2.06^\circ$ on the sensor diagonal (i.e., 2.9° on both the horizontal and vertical axis). The detector is a CMOS sensor (CMV4000) with 2048x2048 pixel. It is a highly miniaturized, compact (35x35x23mm) and high-performance camera. It integrates a reconfigurable Flash-based FPGA, its frame rate is equal to 7 fps saving in RAM and 0.5 fps saving in the payload mass memory (flash memory) at 12 bit resolution. It is a panchromatic detector, which also integrates clock and timing generators, as well as image signal processor functions, an on-chip temperature sensor, programmable gain amplifier and offset regulators. LEIA is aimed at acquiring pictures from long distance (close approach at ~ 50 km from Dimorphos), providing high level of details of the frame field.

4.1.1.1 Optical properties

The main optical properties of the cameras are reported into Table 2.

Table 2 - LEIA optical properties

#	Requirement	Description
1	Diagonal FoV	± 2.06 deg (2048x2048 px – 5.5 μ m)
2	Focal Length	222.55 mm
3	IFOV (n $^\circ$ pixel)	24.71 μ rad (5.5 μ m pixel)
4	F/N	3
6	Wave length	450-900 nm
7	Transmission (obscuration not considered)	More than 87%

8	Resolution	Diffraction Limit
9	Distortion	< 1%
10	Relative Illumination	> 90%

The design is optimized in order to achieve an average residual reflection less than 0.3% in the range 400-900nm. This means an overall transmission of 48% (including obscuration) that is equivalent to 92% if obscuration is not considered.

4.1.1.2 Detector Properties

The detector is a panchromatic CMOS sensor (CMV4000) with 2048x2048 pixel. The image array consists of 5.5 μ m x 5.5 μ m pipelined global shutter pixels which allow exposure during read-out, while performing CDS operation. The image sensor has sixteen 10- or 12-bit digital LVDS outputs (serial)

In Table 3 the detector characteristics are reported.

Table 3 – ~~Detector characteristics~~

#	Feature	Description
1	Sensor	CMOS CMV4000
2	Number of pixels	2048 x 2048
3	Pixel size	5.5 μ m
4	Colour filters	Panchromatic (400-900 nm)
5	Pixel reading resolution	10bit or 12 bit
6	Integration time range	From 0.1ms up to seconds
7	Integration time granularity	0.1 ms

An analog gain and ADC gain can be applied to the output signal. The analog gain is applied by a PGA in every column. The digital gain is applied by the ADC. The two parameters are set to 1x.

The captured images are 2048x2048-pixel raw image, with 12-bits per pixel, has a size 8MB (each pixel is considered saved in 2 byte). The payload acquires pictures in raw format, i.e., raw extracted data without any processing. In order to reduce the picture dimensions two different manipulations are possible: binning (2x2) and windowing. The 2x2 binning manipulation interpolates together group of four pixels reducing the picture dimension by a factor of 4. This aggregation, although associated with loss of information, reduces the amount of data to be processed. All the pictures have a depth of 12-bit, which results in pictures with size of 8 Mbyte.

4.1.2 LUKE

LUKE is a dioptric camera composed by 4 refractive elements, with a diagonal FoV of 10°. The detector is a CMOS sensor (CMV2000) with 2048x1088 pixel. It is interfaced with the NanoCU, the data elaboration unit of the camera, through a flexible PCB, to minimize any mechanical stresses. The pictures acquired by LUKE are in raw format, which represents the raw data extracted by the photo sensor, without any processing. All the pictures have a depth of 8-bit, which yields ~~to have~~ pictures with size of about 2 Mbyte.

4.1.2.1 Optical properties

The payload is a dioptric camera composed by 4 refractive elements (see Figure 2). In this paragraph the design of the optic will be presented.

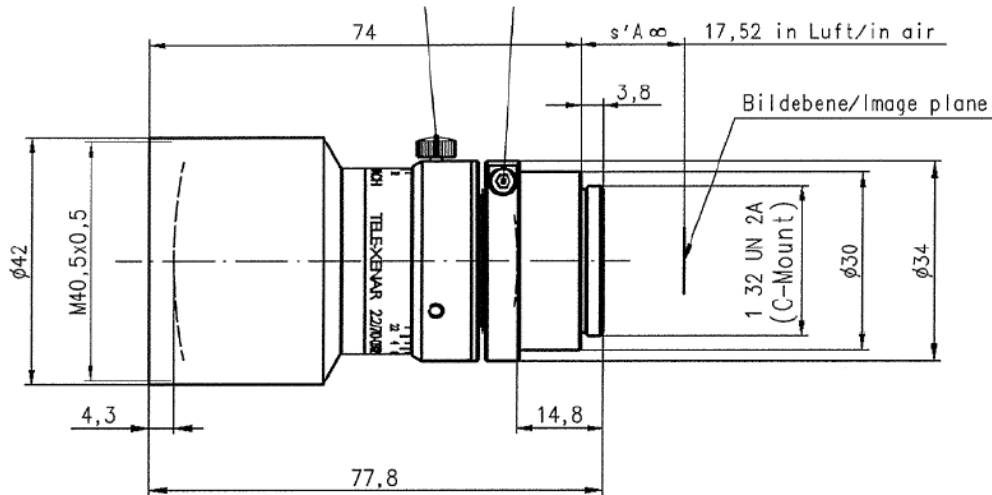


Figure 2 – Lens design

The main optical properties of the cameras are reported in Table 4

Table 4 - PL main optical properties

#	Requirement	Description
1	Diagonal FoV	10 deg (2048x1088 px – 5.5µm)
2	Focal Length	70.5 mm
3	IFOV (n° pixel)	78.01 µrad (5.5µm pixel)
4	F/N	2.2
6	Wavelength	450-700 nm

An AR coating will be included to be compliant with transmission requirements.

4.1.2.2 Detector Properties

The detector is a CMOS sensor (CMV2000) with 2048x1088 pixel. It is interfaced with the NanoCU, the data elaboration unit of the camera, through a flexible PCB, to minimize any mechanical stresses.

The pixel array consists of 2048 x 1088 square global shutter pixels with a pitch of 5.5µm (5.5µm x 5.5µm). This results in an optical area of close to 2/3 optical inch (12.7mm).

The detector acquires a full-size 2048x1088-pixel raw image with 10-bit per pixel, but the payload electronics store a full-size 2048x1088-pixel raw image with 8-bit per pixel saving the first 8-bit per pixel. The RAW image dimension is 2Mbyte. Table 5 reports the main detector characteristics.

Table 5 – Detector characteristics

#	Feature	Description
1	Sensor	CMOS CMV2000
2	Number of pixels	2048 x 2088
3	Pixel size	5.5 μm
4	Colour filters	Bayer Filter
5	Pixel reading resolution	10bit
6	Integration time range	From 0.1ms up to seconds
7	Integration time granularity	0.1 ms

An analog gain and ADC gain can be applied to the output signal. The analog gain is applied by a PGA in every column. The digital gain is applied by the ADC. The two parameters are set to 1x.

4.2 Data Product Overview

This SIS describes image and engineering data acquired by LEIA and LUKE instruments of LICIACube. Images from these imagers and their associated calibration files use the same binary Flexible Image Transport System (FITS) file format with similar keywords for both raw and calibrated images.

4.2.1 LICIACube LEIA Data Product Overview

Images from LEIA will be constituted by a 2048x2048 pixel 2-D array (i.e., NAXIS = 2) at 16-bit for raw data and 32-bit for calibrated data and, since these products will be delivered to PDS labelled according to PDS4 standard, it is important to note that image axis labelling from the FITS standard to the PDS standard is opposite. The FITS standard is first-index-fastest, where NAXIS1 is the most quickly changing subscript, whereas the PDS axis labelling is last-index-fastest notation. This means that:

- NAXIS2 is labelled in the PDS4 array as axis 1 with an <axis name> of “line”;
- NAXIS1 is labelled as axis 2 with an <axis name> of “sample”.

In this document the FITS axis labelling standard is used to refer to all axes in data products.

The specific data products described by this SIS are:

- LEIA raw images (digital numbers)
- LEIA calibrated images (radiance)
- LEIA calibration files (files needed to process raw image data into calibrated images)

TBC

4.2.2 LICIACube LUKE Data Product Overview

Raw images from LUKE will be constituted by a 2048x1088 pixel 2-D array (i.e., NAXIS = 2) at 8-bit, whereas calibrated images from LUKE will have 3 channels (i.e., RGB, NAXIS = 3), each of them made of a 2048x1088 pixel 32-bit. Since this product will be delivered to PDS labelled according to PDS4 standard, it is important to note that image axis labelling from the FITS standard to the PDS standard is opposite. The FITS standard is first-index-fastest, where NAXIS1 is the most

quickly changing subscript, whereas the PDS axis labelling is last-index-fastest notation. For the calibrated images this results in:

- NAXIS3 is labelled in the PDS4 array as axis 1 with an <axis name> of “band”;
- NAXIS2 is labelled in the PDS4 array as axis 2 with an <axis name> of “line”;
- NAXIS1 is labelled as axis 3 with an <axis name> of “sample”.

In this document the FITS axis labelling standard is used to refer to all axes in data products.

The specific data products described by this SIS are:

- LUKE raw images (digital numbers)
- LUKE calibrated images (radiances)
- LUKE calibration files (files needed to process raw image data into calibrated images)

4.3 Data Processing

All LICIACube mission science data processing is performed at the LSOC. LEIA science and housekeeping telemetries are received by the LSOC via the Argotec Mission Control Center (MCC) as soon as they are downlinked through the Deep Space Network (DSN). Telemetry data are reconstructed at the MCC and stored in the LSOC data repository, where they are also converted in FITS format, to be compliant to the PDS4 standard.

Reconstructed Telemetry raw image and housekeeping data are retrieved by the data repository, housekeeping physical unit conversions are applied and stored, and raw image data are fed into the LCC specific data processing pipeline. The pipeline produces raw (Level-0) and calibrated (Level-2) LCC LEIA and LUKE images written as FITS files. Image data are also stored in the SOC database. Production rates of images vary over the course of the mission, as images are acquired to meet specific science goals. Reconstructed Telemetry raw image data are approximately 8 MB for LEIA and 2 MB for LUKE; calibrated images 16 MB for LEIA and 18 MB for LUKE.

4.3.1 Data Processing Level

Table 6 shows the LICIACube data processing levels of all science data products described by this SIS. Correlation to NASA and CODMAC data processing levels and definitions can be found in [AD1].

Table 6. LICIACube LEIA and LUKE Data Processing Levels

LICIACube Data Product	NASA Product Level	PDS4 Data Processing Level	Description
LEIA Raw Images	Level-0	Raw	Images reassembled from downlinked packets
LEIA Calibrated Images	Level-2	Calibrated	Images calibrated to physical units (radiance)

LEIA Calibration Files	Level-4	Calibrated	Files needed to process raw image data
LUKE Raw Images	Level-0	Raw	Images reassembled from downlinked packets
LUKE Calibrated Images	Level-2	Calibrated	Images calibrated to physical units (radiance)
LUKE Calibration Files	Level-4	Calibrated	Files needed to process raw image data

4.4 Data Product Generation

As mentioned previously, all LICIACube science data processing is completed at the LSOC located at ASI-SSDC. The decision was made early in the mission lifecycle, that all processing would be centralized to facilitate the relatively quick turnaround needed by the science and operations teams to identify and assess the DART impact site and ejecta.

4.4.1 LICIACube LEIA Level-0 Raw Images

LCC LEIA image and housekeeping telemetry are received by the MCC from the DSN. The MCC reconstructs images from the raw telemetry, sending the resulting 16-bit image to the LSOC, which populates a suite of FITS keywords, which includes information on LEIA mode, and records of any windowing, binning, and calibration done via the on-board image processing pipeline, together with the TARGET and MPHASE (mission phase) keywords. The LSOC also stores the image in the FITS file in 16-bit integer format. The resultant `fits` header is defined in Section 5.2.1 and compliant to what is described in [AD2]. Keyword values are directly derived from LCC telemetry (including the LCC header row), the GNC correlation packet, and some other spacecraft telemetry packets to which the MCC has direct access.

Each final Level-0 raw PDS4 data product will consist of:

- A 16-bit FITS file with one Header Data Unit (HDU) containing the metadata header fields and the data unit of the array (2048 pixels x 2048 pixels for not windowed nor binned images). Windowed or binned images have less pixels than this original format: information about the windowed image position and dimension can be retrieved by means of the WINXSTA, WINXEND, WINYSTA, WINYEND FITS keywords. The data are represented as DN.
- A browse PNG created from the raw FITS file, with its same dimension in pixel.

4.4.2 LICIACube LEIA Level-2 Calibrated Images

LCC LEIA calibrated images have gone all the way through the calibration pipeline at the SOC, as described in Section 4.4.2.1 and we will describe more accurately the calibration process in a subsequent LICIACube Calibration Document. The calibration pipeline appends additional keywords to the FITS header keywords of the raw images (defined in Section 5.2.2). Some raw images will not

be turned into calibrated images (e.g., in-flight bias and dark current images). [Note for PDS sample data review: The process for determining which images will not be turned into calibrated images is still being developed and this document will be updated once that process is finalized.] Additional data needed to interpret the calibrated images, such as, for example, bias frames, dark current frames, and flat field, are part of the LCC Calibrated Dataset.

Each final Level-2 calibrated PDS4 data product will consist of:

- A 32-bit FITS file with a single HDU containing header metadata records and a data unit of the radiometrically calibrated windowed array (2048 pixels x 2048 pixels for not windowed nor binned images). Windowed or binned images have less pixels than this original format: information about the windowed image position and dimension can be retrieved by means of the WINXSTA, WINXEND, WINYSTA, WINYEND FITS keywords. The data are represented in radiance ($W\ m^{-2}\ nm^{-1}\ sr^{-1}$). Additional FITS keywords are added by the SOC to capture metadata relevant to the calibrated image, such as calibration files used.
- A browse PNG created from the raw FITS file, with its same dimension in pixel.

4.4.2.1 LICIACube LEIA Level-4 Calibration Files

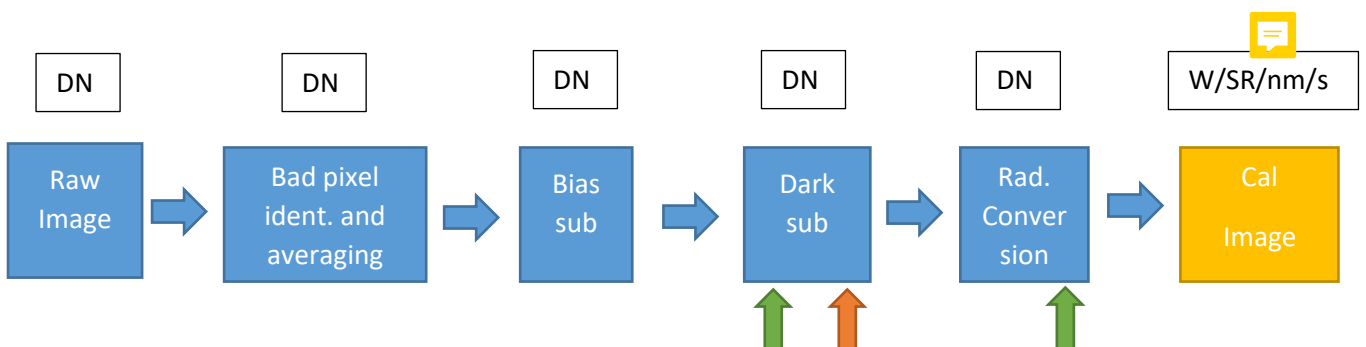
The following calibration files will be developed from in-flight and/or ground calibration data: Calibration FITS cubes (1 for LEIA and 1 for LUKE). Calibration files will be saved in FITS file format.

A detailed description of the calibration files and the calibration process follows.

The calibrations FITS file for LEIA is a 7 x 2048 x 2048 (number of bands can raise in further calibration pipeline versions):

- Plane 0: bias for corresponding (i,j) pixel in DN
- Plane 1: bad pixel map conventional value for the bad pixels
- Plane 2: Dark rate in DN/s
- Plane 3: coeff x0 of the $x_0+x_1*DN+x_2*DN^2+x_3*DN^3$ radiometric conversion polynomial for corresponding (i,j) pixel
- Plane 4: coeff x1 of the $x_0+x_1*DN+x_2*DN^2+x_3*DN^3$ radiometric conversion polynomial for corresponding (i,j) pixel
- Plane 5: coeff x2 of the $x_0+x_1*DN+x_2*DN^2+x_3*DN^3$ radiometric conversion polynomial for corresponding (i,j) pixel
- Plane 6: coeff x3 of the $x_0+x_1*DN+x_2*DN^2+x_3*DN^3$ radiometric conversion polynomial for corresponding (i,j) pixel

The calibration pipeline can be represented by the workflow in Fig. 3:



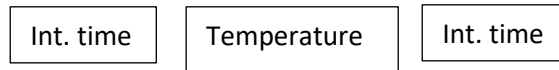


Figure 3: DATA flow from raw to calibrated images

4.4.2.2 LICIACube LUKE Level-0 Raw Images

LCC LUKE image and housekeeping telemetry are received by the MCC from the DSN. The MCC reconstructs 8-bit images from the raw telemetry by performing the cut of the signal to the 8 chosen bit per pixel per channel (i.e., most or least significant ones), in order to select the best part of the acquired histogram for LUKE. Then it sends the resulting image to the LSOC, which populates a suite of FITS keywords, which includes information on LUKE mode, spacecraft attitude, and records of any windowing, binning, and calibration done via the on-board image processing pipeline, together with the TARGET and MPHASE (mission phase) keywords. The LSOC also stores the image in the FITS file in 8-bit integer format. The resultant FITS header is defined in Section **Errore. L'origine riferimento non è stata trovata.**5.2.5 and compliant to ~~what described~~ in [AD2]. Keyword values are directly derived from LCC telemetry (including the LCC header row), the GNC correlation packet, and some other spacecraft telemetry packets to which the MCC has direct access.

Each final Level-0 raw PDS4 data product will consist of:

- A 8-bit FITS file with one Header Data Unit (HDU) containing the metadata header fields and the data unit of the windowed array (2048 pixels x 1088 pixels for not windowed nor binned images). Windowed or binned images have less pixels than this original format. The data are represented as DN.
- A browse PNG created from the raw FITS file, with its same dimension in pixel.

4.4.2.3 LICIACube LUKE Level-2 Calibrated Images

LCC LUKE calibrated images have gone ~~all-way~~ through the calibration pipeline at the SOC, as described in 4.3.2.6 and we will describe more accurately the calibration process in a subsequent LICIACube Calibration Document. The calibration pipeline appends keywords to the FITS header keywords of the raw images (defined in Section 5.2.6). Some raw images will not be turned into calibrated images (e.g., in-flight bias and dark current images). **[Note for PDS sample data review: The process for determining which images will not be turned into calibrated images is still being developed and this document will be updated once that process is finalized.]** Additional data needed to interpret the calibrated images, such as bias frames, dark current frames, and flat field, are included in the ~~as part of the~~ LUKE Calibrated Data.

Each final Level-2 calibrated PDS4 data product will consist of:

- A 32-bit FITS file with a single HDU containing header metadata records and a data unit of the radiometrically calibrated windowed array (3 x 2048 pixels x 1088 pixels for not windowed nor binned images). Windowed or binned images have less pixels than this original format, but the same number of bands. The data are represented in radiance ($W\ m^{-2}\ nm^{-1}\ sr^{-1}$). Additional FITS keywords are added by the SOC to capture metadata relevant to the calibrated image, such as calibration files used.
- A browse PNG created from the raw FITS file, with its same dimension in ~~pixel~~.

4.4.2.4 LICIACube LUKE Level-4 Calibration Files

The following calibration files will be developed from in-flight and/or ground calibration data: Calibration FITS cubes (1 for LEIA and 1 for LUKE). Calibration files will be saved in FITS file format.

A detailed description of the calibration files and the calibration process follows.

The calibrations FITS file for LUKE is a 7 x 2048 x 1088 (number of bands can raise in further calibration pipeline versions):

- Plane 0: bias for corresponding (i,j) pixel in DN
- Plane 1: bad pixel map conventional value for the bad pixels
- Plane 2: Dark rate in DN/s
- Plane 3: coeff x0 of the $x_0+x_1*DN+x_2*DN^2+x_3*DN^3$ radiometric conversion polynomial for corresponding (i,j) pixel
- Plane 4: coeff x1 of the $x_0+x_1*DN+x_2*DN^2+x_3*DN^3$ radiometric conversion polynomial for corresponding (i,j) pixel
- Plane 5: coeff x2 of the $x_0+x_1*DN+x_2*DN^2+x_3*DN^3$ radiometric conversion polynomial for corresponding (i,j) pixel
- Plane 6: coeff x3 of the $x_0+x_1*DN+x_2*DN^2+x_3*DN^3$ radiometric conversion polynomial for corresponding (i,j) pixel

The calibration pipeline can be represented by the workflow in Fig. 4:

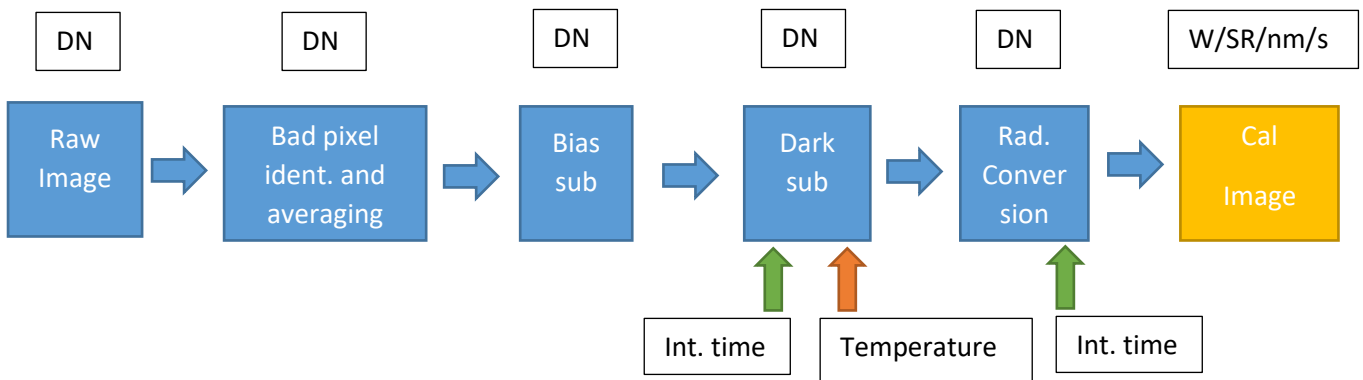


Figure 4: DATA flow from raw to calibrated images

The obtained images for LUKE shall be de-bayerized to obtain the 3 plane of the fits by a standard algorithm used for the RGB scheme of LUKE detector.

At the present time the filter used is a CFA 'RGGB' one, but it can be modified for in-flight images.

4.4.3 Data Flow

The MCC reconstructs LCC LEIA/LUKE images from the raw telemetry. LSOC populates a suite of FITS keywords (see also Sections 4.3.2.1, 4.2.3.2, 4.2.3.4 and 4.3.2.5). Calibrated images are created by the LICIACube Calibration Pipeline (see also Sections 4.3.2.3 and 4.3.2.6). If data reprocessing leads to more than one version of a raw, calibrated, or derived data product (due to, e.g., updated

SCLK information, updated calibration files, shape models), re-processed images can be identified by the two-digit version number in the file name (see Section 4.3.4; Table 7). Raw, calibrated, and derived data products are stored at the LSOC. These products, with the calibration files and associated documentation, are combined to form the LEIA and LUKE collections within the LICIACube Spacecraft Bundle, which is delivered to the Small Bodies Node (SBN) of the PDS. The full list of collections described in this SIS is:

- LEIA Raw Data Collection
- LEIA Calibrated Data Collection
- LUKE Raw Data Collection
- LUKE Calibrated Data Collection
- Documentation collection specifically for the LICIACube documentation.

This archive provides one public access point to the LICIACube data. The raw, calibrated, and derived data products are also available in the Small Body Mapping Tool (SBMT; <https://sbmt.jhuapl.edu>), which includes image search, 3D visualization, and download capabilities.

LICIACube data will be also available from the SSDC MATISSE tool (<https://tools.ssdsc.asi.it/Matisse>) with advanced search and visualization capabilities directly from the web.

4.4.4 Labeling and Identification

All LEIA and LUKE data products are labelled with PDS4 compliant detached XML labels. These labels describe the content and format of the associated data product. Labels and products are associated by file name with the label having the same name as the data product but with the .xml extension.

Additional information regarding the XML labels and PDS4 data product specification can be found in the PDS documents referenced in Section 2.

LEIA and LUKE uncalibrated and calibrated data products are identified with file names in the format of:

liciacube_****_IK_SSSSSSSSSS_#####.<extension>

Table 7. Definition of LICIACube filename

File section	name	Description
****		payload source (leia, luke)
K		level of processing (0=Raw image, 2=calibrated, 4=derived)
SSSSSSSSSS		10-digit value of SCLK (seconds, raw 32-bit value)
#####		5-digit value of SCLK (sub-seconds, raw 16-bit value)
##		two digit version number, e.g., “01”

<extension>	the file extension. “.fits” for FITS file format, “.png” for PNG files, “.xml” for XML labels
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The naming convention for the LICIAcube calibration files is shown in Table 8.

Table 8. File formats and naming conventions of calibration inputs

Pipeline input	File format	File naming scheme	Quantity expected per delivery
Input Files			
LEIA Calibration “cube” file	7x2048x2048 32-bit floating point FITS	liciacube_leia_cal_001.fits	One.
LUKE Calibration “cube” file	7x2048x1088 32-bit floating point FITS	liciacube_luke_cal_001.fits	One.

4.5 Standards Used in Generating Data Products

4.5.1 PDS Standards

All data products described in this SIS conform to PDS4 standards as described in [AD3]. 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.

4.5.2 Time Standards

Time Standards used by the LICIAcube mission conform to PDS time standards. All LICIAcube data products contain the spacecraft clock time at the start of the data acquisition to facilitate comparison of data products.

4.5.3 Coordinate Systems

All coordinate systems used by the LICIAcube 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 “DART Coordinate System Plan” found in the archive documents directory.

4.5.4 Data Storage Conventions

FITS data products are stored according to the FITS 3.0 Standard. Binary data products are stored as big-endian (MSB) binary.

4.5.5 Data Validation

The LSOC has a comprehensive Verification and Validation Plan for all software used at or developed by the LSOC. All software is configuration controlled and any changes made follow the LSOC Configuration Control Plan, which includes substantive testing of changes. During the day-to-day production of Level-0 data products from telemetry, check sums and spot checks are used to validate that software is producing data products correctly. [TBD]

In addition to software verification and validation, each LICIACube LEIA and LUKE 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 LSOC Configuration Control Plan governs any changes, should they be needed.

When data is prepared for submission to the PDS, the Teams will use PDS / mission-provided validation tools for conformance to the PDS4-standards.

5 Detailed Data Product Specification

5.1 Data Product Structure and Organization

The LICIACube data archive, for what regards image data, is organized by: instrument (LEIA/LUKE), mission phase, level (raw/calibrated). All image data is stored as FITS files with a detached PDS label. The detached PDS labels are PDS4 compliant XML labels that describe the contents of the image file and record the significant portions of the FITS header for data processing and interpretation. See the Label Example sub-directory in the LICIACube LEIA document collection for an example label [TBR].

The LICIACube bundle directory structure is as follows:

- LICIACube
 - leia_raw
 - approach
 - terminal
 - final
 - post-impact
 - leia_calibrated
 - approach
 - terminal
 - final
 - post-impact
 - luke_raw

- approach
 - terminal
 - final
 - post-impact
- luke_calibrated
 - approach
 - terminal
 - final
 - post-impact
- document

5.2 Data Format Descriptions

All LICIACube image data are stored natively in FITS file formats and delivered to the PDS in PDS4 compliant arrays.

LEIA images will be stored as PDS4 compliant 2D arrays. Reconstructed Telemetry (raw) image (Level-0) FITS headers and PDS Labels contain raw (DN) telemetry values. Calibrated (Level-2) FITS headers and PDS labels have DN values that are converted to physical units, e.g. radiance.

LUKE images will be stored as PDS4 compliant 2D arrays (raw) and 3D arrays (calibrated). Reconstructed Telemetry (raw) image (Level-0) FITS headers and PDS Labels contain raw (DN) telemetry values. Calibrated (Level-2) FITS headers and PDS labels have DN values that are converted to physical units, e.g. radiance.

5.2.1 LICIACube LEIA Raw Image Data

The Level-0 (raw) image format is single HDU FITS files containing a 2048 (line) x 2048 (sample) active image array in 16-bit DN units. Windowed or binned images have less pixels than this original format.

Metadata contained in the FITS header and its mapping to class and attribute in the PDS4 .xml label structure is listed in Table 9. Metadata descriptions may be abbreviated in the FITS header, with full descriptions in the label.

The Class.Attribute Name column is left blank for FITS keywords not mapped to the .xml label.

Table 9. LEIA Level-0 image metadata

Class.Attribute Name	Keyword and example	Description	Range of values
	SIMPLE = T / file conforms to FITS standard	Required in FITS standard	T
Element_Array. data_type	BITPIX = 16 / number of bits per data pixel	LEIA raw images delivered to the SOC will always be 16 bit. Calibrated images are the result of applying the calibration files, themselves in 32-bit floating point, to the raw images. All are stored in big-endian as per the FITS standard.	16

	NAXIS = 2 / number of data axes	Number of data axes. All LEIA images have 2 axes	2
Axis_Array. sequence_number	NAXIS1 = 2048 / length of data axis 1	Number of rows.	1 to 2048
Axis_Array. sequence_number	NAXIS2 = 2048 / length of data axis 2	Number of columns.	1 to 2048
dart>window_x_start	WINXSTA = '-1' / X origin of window	Column where window starts. Window coordinates are with respect to a 2048 x 2048 image. The upper left hand corner of the image plus header row is coordinate 0,0. -1 if second windowing not applied.	-1 to 2047
dart>window_y_start	WINYSTA = '-1' / Y origin of window	Row where window starts. Window coordinates are with respect to a 2048 x 2048 image. The upper left hand corner of the image plus header row is coordinate 0,0. -1 if second windowing not applied.	-1 to 2047
dart>window_x_end	WINXEND= '2048' / X end of window	Column where window ends. Window coordinates are with respect to a 2048 x 2048 image. The upper left hand corner of the image plus header row is coordinate 0,0. -1 if second windowing not applied.	2 to 2048
dart>window_y_end	WINYEND= '2048' / X end of window	Row where window ends. Window coordinates are with respect to a 2048 x 2048 image. The upper left hand corner of the image plus header row is coordinate 0,0. -1 if second windowing not applied.	2 to 2048
	EXTEND = T / FITS dataset may contain extensions	By default, set to T so that we can add extensions if needed.	T
Modification_History. modification_date	DATE = '2018-08-25T09:23:89' / FITS header creation date YYYY-MM-DDTHH:MM:SS	Time fits file was created by the SOC. For calibrated and derived it is the creation time of the product	YYYY-MM-DDTHH:MM:SS
Investigation_Area. name	MISSION = 'DART / Mission: DART	Name of mission	DART
Observing_System. name	HOSTNAME = 'LICIACube' / spacecraft name	LEIA is on the spacecraft named LICIACube	LICIACube
Observing_System_Component. name	INSTRUME = 'LEIA' / Instrument name	Instrument name	LEIA
	APID	Application ID of science image data: the images themselves	TBR
	TARGET = 'DIDYMOS / Target Object	Primary target object	"DIDYMOS", "DIMORPHOS", "JUPITER_SYSTEM", "M11", "NA", etc.
dart>mission_phase	MPHASE = 'TERMINAL' / phase of the mission	The DART mission is divided into phases; this keyword states the phase	"PRELAUNCH", "COMMISIONNING", 'CRUISE',

		during which the image was acquired.	“APPROACH”, “TERMINAL”, “FINAL”. (TBD)
dart:liciacube_sclk_image_time	IMG_TIME = '298271898.013220' / [sec] image TOV	Start of image capture time in spacecraft clock notation. Numeric number preceding the decimal point is integer seconds. Numeric number after the decimal point is subsecond clock ticks, where each tick represents TBD microseconds.	Time since t=0, as defined in the SCLK kernel. Left blank when not available.
	IMG_UTC = '2022 OCT 01 10:28:09.600' / Image TOV _i in UTC	Start of image capture time in UTC.	
	SCLKNAME = 'liciacube_sclk_0000.tsc' / SCLK file used for IMG_UTC	Name of SCLK file used to compute IMG_UTC	
dart:readout_time	READOUT = '87.46666' / Readout time in microsec	Global readout time.	TBD
img:exposure_duration	EXPTIME = '0.156789' / [sec] Exposure time	Image exposure time in seconds	0.00002882s to 338.16s.
dart:gain	GAIN= 1 /Gain setting	Detector gain setting	1., 2., 10., or 30. Float
dart:binning	BINNING = 'ON' / Binning status	If binning is on or not.	'ON' or 'OFF'
	TRUNC= 'MSB' / Truncation mode	Defines whether the data are truncated using MSB or LSB. When binning is enabled, the truncation mode is MSB. When binning is disabled, the truncation mode is LSB.	“MSB” or “LSB”.
	RCNTTHST = 1 / thruster firing flag	Flag whether thrusters were fired within one settling time before this image. =1 true, =0 false (TBR)	0 or 1. Integer
	AOCWX = 0 / [deg/s] rotation speed on X axis	Rotation speed of LICIAcube frame X axis	
	AOCWY = 0 / [deg/s] rotation speed on Y axis	Rotation speed of LICIAcube frame Y axis	
	AOCWZ = 0 / [deg/s] rotation speed on Z axis	Rotation speed of LICIAcube frame Z axis	
dart:detector_temp	DETTEMP = 18.333 / [degC] Detector temperature	LEIA detector temperature	
	EPHMETA = 'LCC210701-EMK-RN-L211124-V001.mk' / Ephemeris metakernel to be used	Ephemeris metakernel to be used	
	ATTMETA = 'LCC201228-AMK-RN-L221124-V001.mk' / Attitude metakernel to be used	Attitude metakernel to be used	
dart.correct_image_time	CORT_UTC	UTC time at mid-exposure time (= IMGTIME+0.5EXPTIME) used to define attitude and representative observing geometry.	Time at mid exposure used to define attitude and representative geometric attributes. Since the acquisition operation is verified to be successful after a 250 ms delay, from the

			effective time of acquisition (tCUC), this value is computed as: CORT.UTC = tCUC - 0.250s + EXPTIME/2
	CORTJDAT	Julian Ephemeris Date based at mid exposure (= IMGTIME+0.5EXPTIME) used to define attitude and representative observing geometry.	Time at mid exposure used to define attitude and representative geometric attributes. Since the acquisition operation is verified to be successful after a 250 ms delay, from the effective time of acquisition (tCUC), this value is computed converting in Julian Ephemeris Date the following value: CORT.UTC = tCUC - 0.250s + EXPTIME/2
	SOCQUATA = '0.10808003767484.' /SC quaternion in J2000 (q0) using A CORT.UTC	Spacecraft quaternion computed by the SOC using SPICE and CORT.UTC	
	SOCQUATX= '-0.674302095900066' /SC quaternion in J2000 (q1) using CORT.UTC		
	SOCQUATY= '-0.32453616895850' /SC quaternion in J2000 (q2) using CORT.UTC		
	SOCQUATZ = '0.65445524213556' /SC quaternion in J2000 (q3) using appropriate CORT.UTC time		
	BORE_RA = '326.459994' / [deg] Boresight right ascension	Boresight right ascension	0 to 360 degrees.
	BORE_DEC = '-38.093559' / [deg] Boresight declination	Boresight declination	-90 to 90 degrees
	CELN_CLK = '28.16' / [deg] Celestial north clock angle	Celestial north clock angle	0 to 360 degrees.
	ECLN_CLK = '49.30' / [deg] Ecliptic north clock angle	Ecliptic north clock angle	0 to 360 degrees.
	SUN_CLK= '318.40' / [deg] Sun clock angle	Sunward direction clock angle	0 to 360 degrees.
	PXARCS = '1.02' / [arcsec] Pixel scale	Pixel scale in arcsec	Either 1.02 arcsec if BINNING = ON or 0.512 arcsec if BINNING = OFF.
	PXMRAD= '4.96' / [microradians] Pixel scale	Instantaneous field of view of a pixel, in microradians.	Either 4.96 urad if BINNING = ON or

		If BINNING = ON, this value is reported for a 2x2 binned pixel.	2.48 urad if BINNING = OFF.
	PHDIST='1.04' / [AU] Heliocentric distance - Primary	Distance between the sun and the primary target, in AU	Calculated for selected TARGET values only (e.g., Didymos, Dimorphos, etc.), otherwise set to -1E32.
	PSCRNG = '4.2622E+02' / [km] Spacecraft range - Primary	Distance between the spacecraft and the primary target center, in km	Calculated for selected TARGET values only (e.g., Didymos, Dimorphos, etc.), otherwise set to -1E32.
	PSPHASE = '55.98' / [deg] Solar phase angle - Primary	Angle between the sunward direction and the direction to the spacecraft, as observed from the primary target.	0 to 180 degrees. Calculated for selected TARGET values only (e.g., Didymos, Dimorphos, etc.), otherwise set to -1E32.
	PSELON = '73.49' / [deg] Solar elongation - Primary	Angle between the sunward direction and the direction to the primary target, as observed from the spacecraft.	0 to 180 degrees. Calculated for selected TARGET values only (e.g., Didymos, Dimorphos, etc.), otherwise set to -1E32.
	PPPCLK = '228.64' / [deg] Positive pole clock angle - Primary	Positive pole clock angle of the primary target	0 to 360 degrees. Calculated for selected TARGET values only (e.g., Didymos, Dimorphos, etc.), otherwise set to -1E32.
	PSUBLAT = '38.04' / [deg] Sub-observer latitude - Primary	Sub-observer latitude of the primary target	-90 to 90 degrees. Calculated for selected TARGET values only (e.g., Didymos, Dimorphos, etc.), otherwise set to -1E32.
	PSUBLON = '146.65' / [deg] Sub-observer longitude - Primary	Sub-observer east longitude of the primary target	0 to 360 degrees. Calculated for selected TARGET values only (e.g., Didymos, Dimorphos, etc.), otherwise set to -1E32.
	PSSOLLAT = '-1.07' / [deg] Sub-solar latitude - Primary	Sub-solar latitude of the primary target	-90 to 90 degrees. Calculated for selected TARGET values only (e.g., Didymos, Dimorphos, etc.), otherwise set to -1E32.
	PSSOLLON = '190.18' / [deg] Sub-solar longitude - Primary	Sub-solar east longitude of the primary target	0 to 360 degrees. Calculated for selected TARGET values only (e.g., Didymos, Dimorphos, etc.), otherwise set to -1E32.
	SHDIST = '1.04' / [AU] Heliocentric distance - Secondary	Distance between the sun and the secondary target, in AU	Calculated for selected SECTAR values only (e.g., Didymos,

			Dimorphos, etc.), otherwise set to -1E32.
	SSCRNG = '4.2623E+02' / [km] Spacecraft range - Secondary	Distance between the spacecraft and the secondary target center, in km	Calculated for selected SECTAR values only (e.g., Didymos, Dimorphos, etc.), otherwise set to -1E32.
	SSPHASE = '56.14' / [deg] Solar phase angle - Secondary	Angle between the sunward direction and the direction to the spacecraft as seen from the secondary target	0 to 180 degrees. Calculated for selected SECTAR values only (e.g., Didymos, Dimorphos, etc.), otherwise set to -1E32.
	SSELON = '73.59' / [deg] Solar elongation - Secondary	Angle between the sunward direction and the direction to the secondary target, as observed from the spacecraft.	0 to 180 degrees. Calculated for selected SECTAR values only (e.g., Didymos, Dimorphos, etc.), otherwise set to -1E32.
	SPPCLK = '228.64' / [deg] Positive pole clock angle - Secondary	Positive pole clock angle of the secondary target	0 to 360 degrees. Calculated for selected SECTAR values only (e.g., Didymos, Dimorphos, etc.), otherwise set to -1E32.
	SSUBLAT = '38.09' / [deg] Sub-observer latitude - Secondary	Sub-observer latitude of the secondary target	-90 to 90 degrees. Calculated for selected SECTAR values only (e.g., Didymos, Dimorphos, etc.), otherwise set to -1E32.
	SSUBLON = '146.46' / [deg] Sub-observer longitude - Secondary	Sub-observer east longitude of the secondary target	0 to 360 degrees. Calculated for selected SECTAR values only (e.g., Didymos, Dimorphos, etc.), otherwise set to -1E32.
	SSSOLLAT = '-1.07' / [deg] Sub-solar latitude - Secondary	Sub-solar latitude of the secondary target	-90 to 90 degrees. Calculated for selected SECTAR values only (e.g., Didymos, Dimorphos, etc.), otherwise set to -1E32.
	SSSOLON = '190.18' / [deg] Sub-solar longitude - Secondary	Sub-solar east longitude of the secondary target	0 to 360 degrees. Calculated for selected SECTAR values only (e.g., Didymos, Dimorphos, etc.), otherwise set to -1E32.

5.2.2 LICIACube LEIA Calibrated Image Data

The Level-2 (calibrated) image format is single HDU FITS files containing a 2048 (line) x 2048 (sample) active image array in 32-bit floating point radiance units. Windowed or binned images have less pixels than this original format.

Metadata contained in the Level-2 LEIA images FITS header and its mapping to class and attribute in the PDS4 .xml label structure is listed in Table 10, where different or absent in Table 9 referring to Level-0 LEIA images. Metadata descriptions may be abbreviated in the FITS header, with full descriptions in the label.

The Class.Attribute Name column is left blank for FITS keywords not mapped to the .xml label.

Table 10. LEIA Level-2 additional image metadata

Class.Attribute Name	Keyword and example	Description	Range of values
Element_Array. data_type	BITPIX = 32 / number of bits per data pixel	LEIA raw images delivered to the SOC will always be 16 bit. Calibrated images are the result of applying the calibration files, themselves in 32-bit floating point, to the raw images. All are stored in big-endian as per the FITS standard.	32
	RADCONV = 1.0 / Radiance conversion factor	Radiance conversion factor	
	CALFILE='liciacube_leia_cal_001.fits' / ref calibration file	Name of calibration file used.	Determined by file naming convention.
	BADMASKV = '-1E30' / Value assigned to bad pixels	Pixel value assigned to bad pixels by the SOC	-1E30
Special_Constants. missing_constant	MISPXVAL = '1E32' / Value assigned to missing pixels	Keyword created by MOC; value updated by pipeline	1E32
Special_Constants. high_instrument_saturation	SATPXVAL = '1E30' / Value assigned to saturated pixels	Pixel value assigned to saturated pixels by the SOC	1E30

5.2.3 LICIACube LEIA Raw Pixel Values

Non-valid pixels (e.g., downlink problems, missing data, dead pixels, etc.) may be present in small numbers within the calibrated image arrays:

- Bad pixels will be associated with the value -1E30
- Missing pixels (e.g. due to downlink problems) will be associated to the value 1E32

- Saturated pixels will be associated to 1E30

5.2.4 LICIACube LEIA Calibration File Formats

LICIACube LEIA has a single “cube” file with 2048 lines, 2048 samples and at least 7 bands (the number is still to be defined), containing: bad pixel map, bias, dark, flat and radiometric calibration coefficients, as described in Table 11.

Table 11. LEIA Level-4 additional image metadata

Class.Attribute Name	Keyword and example	Description	Range of values
	SIMPLE = T / file conforms to FITS standard	Required in FITS standard	T
Element_Array. data_type	BITPIX = 32 / number of bits per data pixel	LEIA calibration files has 32 bit per pixel	32
	NAXIS = 3 / number of data axes	Number of data axes. All LEIA calibration data have 3 axes	3
Axis_Array. sequence_number	NAXIS1 = 2048 / length of data axis 1	Number of rows. Non windowed, nor binned LEIA have 2048 rows	2048
Axis_Array. sequence_number	NAXIS2 = 2048 / length of data axis 2	Number of rows. Non windowed, nor binned LEIA have 2048 columns	2048
Axis_Array. sequence_number	NAXIS3 = 7 / length of data axis 3	Number of bands. LEIA calibration files have at least 7 bands	7 or more
	CALFILE='liciacube_leia_cal_001.fits' / ref calibration file	Name of calibration file used.	Determined by file naming convention.
	PLANE1 = 'BIAS' / Bias Plane	Bias plane	'BIAS'
	PLANE2 = 'BAD PIXEL MAP' / Bad pixel map plane.	Bad pixel map plane, =0 good pixel, =1 bad pixel	'BAD PIXEL MAP'
	PLANE3 = 'DARK' / Dark current plane	Dark current plane	'DARK'
	COMMENT = 'The following 4 planes contain coefficients to use in the radiance polynomial: $x_0 + x_1*DN + x_2*DN^2 + x_3*DN^3$ '	Comment to explain the following 4 planes	'The following planes contain coefficients to use in the radiance polynomial: $x_0 + x_1*DN + x_2*DN^2 + x_3*DN^3$ '
	PLANE4 = 'X0' / Constant term of radiance polynomial	X0 coefficient of the $x_0+x_1*DN+x_2*DN^2+x_3*DN^3$ conversion plane	'X0'
	PLANE5 = 'X1' / 1st degree term of radiance polynomial	X1 coefficient of the $x_0+x_1*DN+x_2*DN^2+x_3*DN^3$ conversion plane	'X1'
	PLANE6 = 'X2' / 2nd degree term of radiance polynomial	X2 coefficient of the $x_0+x_1*DN+x_2*DN^2+x_3*DN^3$ conversion plane	'X2'

	PLANE7 = 'X3' / 3rd degree term of radiance polynomial	X3 coefficient of the $x_0+x_1*DN+x_2*DN^2+x_3*DN^3$ conversion plane	'X3'
	BADMASKV = '-1E30' / Value assigned to bad pixels	Pixel value assigned to bad pixels by the SOC	-1E30

5.2.5 LICIACube LUKE Raw Image Data

The LUKE Level-0 (raw) image format is single HDU FITS files containing a 1088 (samples) x 2048 (lines) active image array in 8-bit DN units. Windowed or binned images have less pixels than this original format.

Metadata contained in the FITS header and its mapping to class and attribute in the PDS4 .xml label structure is listed in Table 12. Metadata descriptions may be abbreviated in the FITS header, with full descriptions in the label.

The Class.Attribute Name column is left blank for FITS keywords not mapped to the .xml label.

Table 12. LUKE Level-0 image metadata

Class.Attribute Name	Keyword and example	Description	Range of values
	SIMPLE = T / file conforms to FITS standard	Required in FITS standard	T
Element_Array. data_type	BITPIX = 8 / number of bits per data pixel	LUKE raw images delivered to the SOC will always be 8 bit. Calibrated images are the result of applying the calibration files, themselves in 32-bit floating point, to the raw images. All are stored in big-endian as per the FITS standard.	8
	NAXIS = 2 / number of data axes	Number of data axes. All LUKE raw images have 2 axes	2
Axis_Array. sequence_number	NAXIS1 = 2048 / length of data axis 1	Number of rows.	1 to 2048
Axis_Array. sequence_number	NAXIS2 = 1088 / length of data axis 2	Number of columns.	1 to 1088
	EXTEND = T / FITS dataset may contain extensions	By default, set to T so that we can add extensions if needed.	T
Modification_History. modification_date	DATE = '2018-08-25T09:23:89' / FITS header creation date YYYY-MM-DDTHH:MM:SS	Time fits file was created by the SOC. For calibrated and derived it is the creation time of the product	YYYY-MM-DDTHH:MM:SS
Investigation_Area. name	MISSION = 'DART' / Mission: DART	Name of mission	DART
Observing_System. name	HOSTNAME = 'LICIACube' / spacecraft name	LUKE is on the spacecraft named LICIACube	LICIACube
Observing_System_Component. name	INSTRUME = 'LUKE' / Instrument name	Instrument name	LUKE
	APID	Application ID of science image data: the images themselves	TBR

	TARGET = 'DIDYMOS' / Target Object	Primary target object	"DIDYMOS", "DIMORPHOS", "JUPITER_SYSTEM", "M11", "NA", etc.
dart:mission_phase	MPHASE = 'TERMINAL' / phase of the mission	The DART mission is divided into phases; this keyword states the phase during which the image was acquired.	"PRELAUNCH", "COMMISSIONING", 'CRUISE', "APPROACH", "TERMINAL", "FINAL". (TBD)
dart:liciacube_sclk_image_time	IMG_TIME = '298271898.012320' / [sec] image TOV	Start of image capture time in spacecraft clock notation. Numeric number preceding the decimal point is integer seconds. Numeric number after the decimal point is subsecond clock ticks, where each tick represents TBD microseconds.	Time since t=0, as defined in the SCLK kernel. Left blank when not available.
	IMG_UTC = '2022 OCT 01 10:28:09.600' / Image TOV in UTC	Start of image capture time in UTC.	
	SCLKNAME = 'liciacube_sclk_0000.tsc' / SCLK file used for IMG_UTC	Name of SCLK file used to compute IMG_UTC	
dart:readout_time	READOUT = '87.46666' / Readout time in microsec/line	Global readout time.	TBD
img:exposure_duration_	EXPTIME = '0.156789' / [sec] Exposure time	Image exposure time in seconds	0.00002882s to 338.16s.
dart:gain	GAIN= 1 /Gain setting	Detector gain setting	1., 2., 10., or 30. Float
dart:binning	BINNING = 'ON' / Binning status	If binning is on or not.	'ON' or 'OFF'
dart>window_x_start	WINXSTA = '0' / X origin of window	Column where window starts. Window coordinates are with respect to a 1088 x 2048 image. The upper left hand corner of the image plus header row is coordinate 0,0. -1 if second windowing not applied.	-1 to 1087
dart>window_y_start	WINYSTA = '0' / Y origin of window	Row where window starts. Window coordinates are with respect to a 1088 x 2048 image. The upper left hand corner of the image plus header row is coordinate 0,0. -1 if second windowing not applied.	-1 to 2047
dart>window_x_end	WINXEND= '2048' / X end of window	Column where window ends. Window coordinates are with respect to a 1088 x 2048 image. The upper left hand corner of the image plus header row is coordinate 0,0. -1 if second windowing not applied.	2 to 1088

dart>window_y_end	WINYEND= '2048' / X end of window	Row where window ends. Window coordinates are with respect to a 1088 x 2048 image. The upper left hand corner of the image plus header row is coordinate 0,0. -1 if second windowing not applied.	2 to 2048
	TRUNC= 'MSB' / Truncation mode	Defines whether the data are truncated using MSB or LSB. When binning is enabled, the truncation mode is MSB. When binning is disabled, the truncation mode is LSB.	"MSB" or "LSB".
	RCNTTHST = 1 / thruster firing flag	Flag whether thrusters were fired within one settling time before this image. =1 true, =0 false (TBR)	0 or 1. Integer
	AOCWX = 0 / [deg/s] rotation speed on X axis	Rotation speed of LICIACube frame X axis	
	AOCWY = 0 / [deg/s] rotation speed on Y axis	Rotation speed of LICIACube frame Y axis	
	AOCWZ = 0 / [deg/s] rotation speed on Z axis	Rotation speed of LICIACube frame Z axis	
dart:detector_temp	DETTEMP = 18.333 / [degC] Detector temperature	Detector temperature	
	EPHMETA = 'LCC210701-EMK-RN- L211124-V001.mk' / Ephemeris metakernel to be used	Ephemeris metakernel to be used	
	ATTMETA = 'LCC201228-AMK-RN- L221124-V001.mk' / Attitude metakernel to be used	Attitude metakernel to be used	
dart.correct_image_time	CORT.UTC	UTC time at mid-exposure time (= IMGTIME+0.5EXPTIME) used to define attitude and representative observing geometry.	Time at mid exposure used to define attitude and representative geometric attributes. Since the delay due to task execution (tdelay) is variable from 10 to 160 ms (depending on the scheduler), from the effective time of acquisition (tCUC), this value is computed as: CORT.UTC = tCUC - tdelay - EXPTIME/2
	CORTJDAT	Julian Ephemeris Date based at mid exposure (= IMGTIME+0.5EXPTIME) used to define attitude and representative observing geometry.	Time at mid exposure used to define attitude and representative geometric attributes. Since the delay due to task execution (tdelay) is variable from 10 to

			160 ms (depending on the scheduler), from the effective time of acquisition (tCUC), this value is computed converting in Julian Ephemeris Date the following value: CORT_UTC = tCUC - tdelay - EXPTIME/2
	SOCQUATA = '0.10808003767484.' /SC quaternion in J2000 (q0) using A CORT_UTC	Spacecraft quaternion computed by the SOC using SPICE and CORT_UTC	
	SOCQUATX= '-0.674302095900066' /SC quaternion in J2000 (q1) using CORT_UTC		
	SOCQUATY= '-0.32453616895850' /SC quaternion in J2000 (q2) using CORT_UTC		
	SOCQUATZ = '0.65445524213556' /SC quaternion in J2000 (q3) using appropriate CORT_UTC time		
	BORE_RA = '326.459994' / [deg] Boresight right ascension	Boresight right ascension	0 to 360 degrees.
	BORE_DEC = '-38.093559' / [deg] Boresight declination	Boresight declination	-90 to 90 degrees
	CELN_CLK = '28.16' / [deg] Celestial north clock angle	Celestial north clock angle	0 to 360 degrees.
	ECLN_CLK = '49.30' / [deg] Ecliptic north clock angle	Ecliptic north clock angle	0 to 360 degrees.
	SUN_CLK = '318.40' / [deg] Sun clock angle	Sunward direction clock angle	0 to 360 degrees.
	PXARCS = '1.02' / [arcsec] Pixel scale	Pixel scale in arcsec	Either 1.02 arcsec if BINNING = ON or 0.512 arcsec if BINNING = OFF.
	PXMRAD= '4.96' / [microradians] Pixel scale	Instantaneous field of view of a pixel, in microradians. If BINNING = ON, this value is reported for a 2x2 binned pixel.	Either 4.96 urad if BINNING = ON or 2.48 urad if BINNING = OFF.
	PHDIST='1.04' / [AU] Heliocentric distance - Primary	Distance between the sun and the primary target, in AU	Calculated for selected TARGET values only (e.g., Didymos,

			Dimorphos, etc.), otherwise set to -1E32.
	PSCRNG = '4.2622E+02' / [km] Spacecraft range - Primary	Distance between the spacecraft and the primary target center, in km	Calculated for selected TARGET values only (e.g., Didymos, Dimorphos, etc.), otherwise set to -1E32.
	PSPHASE = '55.98' / [deg] Solar phase angle - Primary	Angle between the sunward direction and the direction to the spacecraft, as observed from the primary target.	0 to 180 degrees. Calculated for selected TARGET values only (e.g., Didymos, Dimorphos, etc.), otherwise set to -1E32.
	PSELON = '73.49' / [deg] Solar elongation - Primary	Angle between the sunward direction and the direction to the primary target, as observed from the spacecraft.	0 to 180 degrees. Calculated for selected TARGET values only (e.g., Didymos, Dimorphos, etc.), otherwise set to -1E32.
	PPPCLK = '228.64' / [deg] Positive pole clock angle - Primary	Positive pole clock angle of the primary target	0 to 360 degrees. Calculated for selected TARGET values only (e.g., Didymos, Dimorphos, etc.), otherwise set to -1E32.
	PSUBLAT = '38.04' / [deg] Sub-observer latitude - Primary	Sub-observer latitude of the primary target	-90 to 90 degrees. Calculated for selected TARGET values only (e.g., Didymos, Dimorphos, etc.), otherwise set to -1E32.
	PSUBLON = '146.65' / [deg] Sub-observer longitude - Primary	Sub-observer east longitude of the primary target	0 to 360 degrees. Calculated for selected TARGET values only (e.g., Didymos, Dimorphos, etc.), otherwise set to -1E32.
	PSSOLLAT = '-1.07' / [deg] Sub-solar latitude - Primary	Sub-solar latitude of the primary target	-90 to 90 degrees. Calculated for selected TARGET values only (e.g., Didymos, Dimorphos, etc.), otherwise set to -1E32.
	PSSOLLON = '190.18' / [deg] Sub-solar longitude - Primary	Sub-solar east longitude of the primary target	0 to 360 degrees. Calculated for selected TARGET values only (e.g., Didymos, Dimorphos, etc.), otherwise set to -1E32.
	SHDIST = '1.04' / [AU] Heliocentric distance - Secondary	Distance between the sun and the secondary target, in AU	Calculated for selected SECTAR values only (e.g., Didymos, Dimorphos, etc.), otherwise set to -1E32.
	SSCRNG = '4.2623E+02' / [km] Spacecraft range - Secondary	Distance between the spacecraft and the secondary target center, in km	Calculated for selected SECTAR values only (e.g., Didymos,

			Dimorphos, etc.), otherwise set to -1E32.
	SSPHASE = '56.14' / [deg] Solar phase angle - Secondary	Angle between the sunward direction and the direction to the spacecraft as seen from the secondary target	0 to 180 degrees. Calculated for selected SECTAR values only (e.g., Didymos, Dimorphos, etc.), otherwise set to -1E32.
	SSELON = '73.59' / [deg] Solar elongation - Secondary	Angle between the sunward direction and the direction to the secondary target, as observed from the spacecraft.	0 to 180 degrees. Calculated for selected SECTAR values only (e.g., Didymos, Dimorphos, etc.), otherwise set to -1E32.
	SPPCLK = '228.64' / [deg] Positive pole clock angle - Secondary	Positive pole clock angle of the secondary target	0 to 360 degrees. Calculated for selected SECTAR values only (e.g., Didymos, Dimorphos, etc.), otherwise set to -1E32.
	SSUBLAT = '38.09' / [deg] Sub-observer latitude - Secondary	Sub-observer latitude of the secondary target	-90 to 90 degrees. Calculated for selected SECTAR values only (e.g., Didymos, Dimorphos, etc.), otherwise set to -1E32.
	SSUBLON = '146.46' / [deg] Sub-observer longitude - Secondary	Sub-observer east longitude of the secondary target	0 to 360 degrees. Calculated for selected SECTAR values only (e.g., Didymos, Dimorphos, etc.), otherwise set to -1E32.
	SSOLLAT = '-1.07' / [deg] Sub-solar latitude - Secondary	Sub-solar latitude of the secondary target	-90 to 90 degrees. Calculated for selected SECTAR values only (e.g., Didymos, Dimorphos, etc.), otherwise set to -1E32.
	SSOLON = '190.18' / [deg] Sub-solar longitude - Secondary	Sub-solar east longitude of the secondary target	0 to 360 degrees. Calculated for selected SECTAR values only (e.g., Didymos, Dimorphos, etc.), otherwise set to -1E32.

5.2.6 LICIACube LUKE Calibrated Image Data

The LUKE Level-2 (calibrated) image format is single HDU FITS files containing a 3 (bands) x 1088 (lines) x 2048 (samples) active image array in 32-bit floating point radiance units. Windowed or binned images have less pixels than this original format.

Metadata contained in the Level-2 LEIA images FITS header and its mapping to class and attribute in the PDS4 .xml label structure is listed in Table 13, where different or absent in Table 12 referring to Level-0 LUKE images. Metadata descriptions may be abbreviated in the FITS header, with full descriptions in the label.

The Class.Attribute Name column is left blank for FITS keywords not mapped to the .xml label.

Table 13. LUKE Level-2 additional image metadata

Class.Attribute Name	Keyword and example	Description	Range of values
Element_Array. data_type	BITPIX = 32 / number of bits per data pixel	LUKE raw images delivered to the SOC will always be 8 bit. Calibrated images are the result of applying the calibration files, themselves in 32-bit floating point, to the raw images. All are stored in big-endian as per the FITS standard.	32
	RADCONV = 1.0 / Radiance conversion factor	Radiance conversion factor	
	NAXIS = 3 / number of data axes	Number of data axes. All LUKE calibrated images have 3 axes	3
Axis_Array. sequence_number	NAXIS3 = 3 / length of data axis 3	Number of bands. LUKE calibrated have 3 bands	3
dart:liciacube_calibration_file	CALFILE='LICIACube_LUKE_CAL_001.fits' / ref calibration file	Name of calibration file used.	Determined by file naming convention.
	PLANE1 = 'RED' / Color of image plane	Color of image plane.	'RED'
	PLANE2 = 'GREEN' / Color of image plane	Color of image plane.	'GREEN'
	PLANE3 = 'BLUE' / Color of image plane	Color of image plane.	'BLUE'
	BADMASKV = '-1E30' / Value assigned to bad pixels	Pixel value assigned to bad pixels by the SOC	-1E30
Special_Constants. missing_constant	MISPXVAL = '1E32' / Value assigned to missing pixels	Keyword created by MOC; value updated by pipeline	1E32
Special_Constants. high_instrument_saturation	SATPXVAL = '1E30' / Value assigned to saturated pixels	Pixel value assigned to saturated pixels by the SOC	1E30

5.2.7 LICIACube LUKE Raw Pixel Values

Non-valid pixels (e.g., missing data, dead pixels, etc.) may be present in small numbers within the calibrated image arrays:

- Bad pixels will be associated with the value -1E30
- Missing pixels (e.g. due to downlink problems) will be associated to the value 1E32
- Saturated pixels will be associated to 1E30

5.2.8 LICIACube LUKE Calibration File Formats

LICIACube LEIA has a single “cube” file with 2048 samples, 1088 lines and at least 7 bands (the number is still to be defined), containing: bad pixel map, bias, dark, flat and radiometric calibration coefficients, as described in Table 14.

Table 14. LUKE Level-4 additional image metadata

Class.Attribute Name	Keyword and example	Description	Range of values
	SIMPLE = T / file conforms to FITS standard	Required in FITS standard	T
Element_Array. data_type	BITPIX = 32 / number of bits per data pixel	LUKE calibration files has 32 bit per pixel	32
	NAXIS = 3 / number of data axes	Number of data axes. All LUKE calibration data have 3 axes	3
Axis_Array. sequence_number	NAXIS1 = 2048 / length of data axis 1	Number of rows. Non windowed, nor binned LUKE have 2048 lines	2048
Axis_Array. sequence_number	NAXIS2 = 1088 / length of data axis 2	Number of rows. Non windowed, nor binned LUKE have 1088 samples	1088
Axis_Array. sequence_number	NAXIS3 = 7 / length of data axis 3	Number of bands. LUKE calibration files have at least 7 bands	7 or more
	CALFILE='liciacube_luke_cal_001.fits' / ref bias file	Name of calibration file used.	Determined by file naming convention.
	PLANE1 = 'BIAS' / Bias Plane	Bias plane	'BIAS'
	PLANE2 = 'BAD PIXEL MAP' / Bad pixel map plane.	Bad pixel map plane, =0 good pixel, =1 bad pixel	'BAD PIXEL MAP'
	PLANE3 = 'DARK' / Dark current plane	Dark current plane	'DARK'
	COMMENT = 'The following 4 planes contain coefficients to use in the radiance polynomial: x0 + x1*DN + x2*DN^2 + x3*DN^3'	Comment to explain the following 4 planes	'The following planes contain coefficients to use in the radiance polynomial: x0 + x1*DN + x2*DN^2 + x3*DN^3'

	PLANE4 = 'X0' / Constant term of radiance polynomial	X0 coefficient of the $x_0+x_1*DN+x_2*DN^2+x_3*DN^3$ conversion plane	'X0'
	PLANE5 = 'X1' / 1st degree term of radiance polynomial	X1 coefficient of the $x_0+x_1*DN+x_2*DN^2+x_3*DN^3$ conversion plane	'X1'
	PLANE6 = 'X2' / 2nd degree term of radiance polynomial	X2 coefficient of the $x_0+x_1*DN+x_2*DN^2+x_3*DN^3$ conversion plane	'X2'
	PLANE7 = 'X3' / 3rd degree term of radiance polynomial	X3 coefficient of the $x_0+x_1*DN+x_2*DN^2+x_3*DN^3$ conversion plane	'X3'
	BADMASKV = '-1E30' / Value assigned to bad pixels	Pixel value assigned to bad pixels by the SOC	-1E30

5.3 Label and Header Descriptions

All LICIACube LEIA science and ancillary data products contain date and time information that can be used to sort and correlate data products. Data product labels are in XML format and are PDS4 compliant. Example labels can be found in the “TBD” folder of the bundle document collection in a sub-directory named “example_labels”. There are example labels for each type of LICIACube data product.

6 Applicable Software

TBD

7 Appendices

TBD