Lucy
L'LORRI DART Observation Archive User's Guide

Version 2.0

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1. Overview

This document is a quick start guide to the Lucy LOng Range Reconnaissance Imager (L'LORRI) Didymos/Double Asteroid Redirection Test (DART) data archive. This document is intended to give users a basic understanding of the archive, where to find relevant data products and information, and identify any caveats on data collection.

Over the last year, the Lucy team found that the Lucy spacecraft and the L'LORRI instrument in particular would be able to image the DART impact experiment on the Didymos system (**65803** Didymos and its binary companion Dimorphos, S/2003 (65803) 1, the impactor's target). The Lucy spacecraft observed the DART mission impact on 2022 September 26 with the L'LORRI instrument for about 36 hours surrounding the time of impact, resulting in 1549 observational products.

1.1. What is L'LORRI?

L'LORRI is a panchromatic high-resolution imager. The primary mirror has a diameter of 20.8 cm, the system has a focal length of 262 cm, and the detector is a 1024x1024 thinned back-illuminated frame transfer CCD with 2 additional covered columns from Teledyne e2v. Each pixel subtends 5 µrad. L'LORRI is required to have a point spread function (PSF) with a full width half maximum (FWHM) of less than 15 µrad, where FWHM refers to the geometric mean of the major and minor axis diameters of the best-fit gaussian. L'LORRI is mounted in the Lucy spacecraft Instrument Pointing Platform (IPP). The imager design is derived from the New Horizon's LORRI instrument (NH-LORRI), which is described in Cheng et al. 2008. The in-flight performance of NH-LORRI is described in Weaver et al. 2020. A L'LORRI specific instrument paper is in preparation by the L'LORRI team.

1.2. How will L'LORRI operate?

L'LORRI has two modes of operation: 1x1 mode (unbinned data) and 4x4 mode (binning the pixels 4x4 during read out). The primary purpose for the 4x4 mode is to increase sensitivity for the satellite search on approach to encounter targets. To accomplish the satellite search, L'LORRI is required to have a SNR ≥ 7 in 4x4 mode for a 10 second exposure time on a V=15.8 magnitude source. For the high-resolution imaging of a resolved source the instrument needs to have a SNR ≥ 25 in 100 ms exposure time for I/F = 0.00148 at 5.7 AU. The I/F corresponds to a Trojan asteroid with a geometric albedo of 3% at a phase angle of 82° with a phase curve of 0.04 mag/degree. The Lucy mission can accomplish the science objectives for each encounter on just one asymptote, preferably the one with the smaller solar phase angle as it has the most illuminated terrain. Across all encounters the minimum phase angles span from the smallest solar phase angle at Orus (54°) to the largest value 82° for Polymele. The operational scenarios developed for the Trojan Asteroid encounters allows the L'LORRI instrument to image Didymos during the DART encounter.

1.3. The L'LORRI Preliminary Archive Bundle

The data acquired by L'LORRI is archived in the PDS within the **lucy.llorri** bundle. The bundle contains collections of L'LORRI products based on encounter name and data processing level. Products are identified by the file naming convention of:

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

inst = lor (L'LORRI))
acqtime = spacecraft clock data acquisition time
obsid = 16-bit integer observation ID
level = data processing level (eng = raw uncalibrated data, sci = calibrated data)
version = internal product version number
ext = file type (e.g., "fit", "hdf", "jpg", etc.)

The structure of the **lucy.lorri** bundle is:

> **lucy.llorri**
>> data_didymos_raw
>>> Raw uncalibrated L'LORRI images
>>
>> data_didymos_partially_processed
>>> Partially processed L'LORRI images that include calibration coefficients.
>>
>> Calibration
>>> Calibration files used in the calibration pipeline
>>
>> Document
>>> L'LORRI User's Guide (this document)

1.4. Relationships Between Products

The relationship between data products collected by the L'LORRI instrument can be determined based on the spacecraft clock and observation identifier assigned to all products collected during the same L'LORRI observation set. There are several ways that these characters are indicated.

1. L'LORRI Filenames: The L'LORRI specific spacecraft clock and observation identifier are indicated in L'LORRI file names. For example:
   ```
   a. lor_0705960615_02254_00002_sci_01.xml
   b. lor_0705960615_02254_00002_sci_01.fit
   c.
   ```

2. L'LORRI PDS4 XML Labels: The L'LORRI observation identifier can be found in the L'LORRI PDS4 XML labels in the <observation_id> metadata attribute, and can also be found in the OBSID keyword in the FITs file header.

2. Documents

These publications or websites describe the Planetary Data System Standards used to produce the L'LORRI archive. These documents are archived in the PDS system and are not found specifically in the archive.

[1] PDS4 Concepts Document, version 1.19.0.0, DOI:10.17189/6h0f-ng87, October 1, 2021, https://pds.nasa.gov/datastandards/documents/concepts/.
[2] Planetary Data System Standards Reference, version 1.18.0.0, March 31, 2022, https://pds.nasa.gov/datastandards/documents/sr/.

[3] Planetary Data System Data Provider's Handbook, version 1.18.0.0, April 1, 2022, https://pds.nasa.gov/datastandards/documents/dph/.
[4] PDS4 Common Data Dictionary, Abridged, version 1.18.0.0, June, 2022, https://pds.nasa.gov/datastandards/documents/dd/.
[5] PDS4 Information Model Specification, version 1.18.0.0, June 6, 2022, https://pds.nasa.gov/datastandards/documents/im/.

These documents describe the specifics of the archive and the archive data products and will be found in the L'LORRI document collection (i.e., lucy.llorri:document) when they are written.

[6] Lucy PDS Archive Overview. (TBW)
[7] Lucy Software Interface Specification LOng Range Reconnaissance Imager (L'LORRI) Data Products, Document No 22668.01-LLORRI-SIS-01, June, 2021. (TBW)

These papers describe in detail the Lucy mission and the L'LORRI instrument. These papers are published with open access and can be downloaded by following the DOI.

[8] Catherine B. Olkin *et al* 2021 *Planet. Sci. J.* **2** 172, doi: 10.3847/PSJ/abf83f.
[9] Harold F. Levison *et al* 2021 *Planet. Sci. J.* **2** 171, doi: 10.3847/PSJ/abf840
[10] L'LORRI Instrument Paper (TBW).

3. Raw Products

The L'LORRI raw data products are uncalibrated products. Generally, these products are in units of digital number as reported by the instrument. All raw products are found in the **lucy.llorri: data_didymos_raw** collection. There is a single type of L'LORRI raw image:

1. **L'LORRI Raw Image-** Raw instrument image data reconstructed from telemetry in units of Digital Number (DN). The raw data file is a 4-Header Data Unit (HDU) FITS file with image data, histogram data, image header, and image descriptor data. Image data are 16-bit pixel values, with array sizes of either 1028x1024 in 1x1 binning, or 258x256 in 4x4 binning mode. These arrays include four (in 1x1 mode) and two (in 4x4 mode) covered columns used to compute a robust average of the global bias level. Image header data are an array of fifty-five 8-bit values that are a subset of the data provided in the image descriptor extension. During downlink from the spacecraft, this data is sent along with the image data, providing a way to interpret the image in the event that the image descriptor is not received (see section 9.1). Image descriptor data are an array of eighty 8-bit values that indicate the state of the instrument at the time the image was acquired, providing sampled values for currents, voltages, temperatures, and instrument settings. These values are in engineering units and must be calibrated as part of the conversion to scientific units. The converted values are given in the primary HDU header. The image descriptor is sent as low-rate housekeeping data separate from image to provide the LORRI instrument team with valuable information prior to downlinking the image itself (see section 9.2). Metadata attached to the raw L'LORRI images (found in the FITs headers) describes the geometry and conditions at the time of the observation.

4. Partially Processed Products

The L'LORRI calibrated data products are calibrated products. All calibrated products can be found in the **lucy.llorri: data_didymos_partially_processed** collection:

1. **L'LORRI Partially Processed Image** - The L'LORRI calibrated data product is a three data array (HDU) fits file. The primary data array is a 2-dimensional primary image data array of 32-bit real values in units of DN in an array size of 1024x1024 or 256x256 depending on image binning. The secondary data array is a 2-dimensional error image data array of 32-bit real values in units of DN in an array size identical to the primary array. The tertiary data array is a 2-dimensional quality flag data array of 16-bit unsigned integer values in an array size identical to the primary array. For the interim Didymos delivery, the error and quality flag images have not been implemented in the data processing pipeline. These images are set to "0". The images will be updated in the final Didymos data delivery. Metadata attached to the partially processed L'LORRI images (found in the FITs headers) describes the geometry and conditions at the time of the observation.

5. Calibration Products

There are several calibration products used in the L'LORRI calibration pipeline. These products are found in the **lucy.llorri: calibration** collection:

1. **FLAT** – The L'LORRI flat field calibration data product is a single data array (HDU) fits file. The data array is a 2-dimensional image data array of 32-bit real values in units of DN in an array size of 1024x1024 for 1x1 binning or 256x256 for 4x4 binning. Flat field image files are named llorri_flat_1x1.fits and llorri_flat_4x4.fits respectively and are chosen by the calibration algorithm based on image binning. (Found in observational image header format or cformat keywords)

2. **SUPERBIAS-** The L'LORRI superbias (or delta-bias) calibration data product is a single data array (HDU) fits file. The data array is a 2-dimensional image data array of 32-bit real values in units of DN in an array size of 1024x1024 for 1x1 binning or 256x256 for 4x4 binning. Superbias image files are named llorri_superbias_1x1.fits and llorri_superbias_4x4.fits respectively and are chosen by the calibration algorithm based on image binning. (Found in observational image header format or cformat keywords)

3. **TOFFSETS** - The L'LORRI toffset (time offset) calibration data product is a two-column text file. The first column is the image exposure time in milliseconds. The second column is the offset time in milliseconds to five significant digits. Toffset text files are named llorri_toffset_1x1.txt and llorri_toffset_4x4.txt respectively and are chosen by the calibration algorithm based on image binning. (Found in observational image header format or cformat keywords)

6. Calibration Procedure

The L'LORRI calibration pipeline includes the following steps:

6.1. Exposure Time Correction

The exposure time reported with the telemetry must be corrected due to an effect referred to as "jitter". It is related to the timing of CCD control pulses, the commanded exposure times, and the restriction of using integer exposure times in milliseconds. The correction only affects the fractional portion of the exposure time in milliseconds. The correction is implemented as a pair of look up tables indexed by instrument format (1x1 vs 4x4). The filenames for these lookup tables are stored in the LLORRI calibration collection with the following names:

Image Format	Exposure Time Offset Filename
1x1	llorri_toffsets_1x1.txt
4x4	llorri_toffsets_4x4.txt

The lookup value in the first column is the fractional portion of the commanded exposure time (milliseconds portion) and the exposure time offset value is given in the second column. To compute the correct exposure time, the offset is subtracted from the commanded exposure time. This corrected exposure time is used in the remaining calculations of the calibration process.

6.2. Bias subtraction

The bias subtraction is a two-step process: determination and subtraction of the global bias and then the subtraction of the super bias to account for the pixel-to-pixel variations. First, the global bias is determined by computing a robust mean of the dark columns and then adding an offset that accounts for the difference in mean signal level between the bias and the active regions of the CCD. For 1x1 images (i.e., Uncalibrated Data Products (UDP) having 1028x1024 pixels), the dark columns are in columns 0-3. For UDP 4x4 images, the dark columns are in columns 0-1. The definition of the robust mean of the dark columns for this application is the mean of dark column pixel DN values that are within some number (nsigma) of standard deviations from the mean of all dark column pixels. The value for nsigma is configurable and is currently set to 3. The offset is a constant that corrects for the difference in the mean signal level between the bias and the active regions of the CCD. For 1x1 UDP data, this offset is 3.2 DN, while for 4x4 UDP data, the offset is 5.1 DN. The global bias is a scalar value consisting of the sum of the robust mean of the dark columns and the offset. The super bias image captures the pixel-to-pixel variations in the bias and is specific to the mode of the instrument. These images are available in the calibration collection with the following names:

Image Format	Super bias filename
1x1	llorri_superbias_1x1.fits
4x4	llorri_superbias_4x4.fits

The bias subtracted image is computed by subtracting the scalar global bias value from the original image followed by subtracting the superbias image.

6.3. Smear Removal

L'LORRI does not have a shutter, so the CCD is exposed to whatever scene is in the field of view. In particular, the CCD records signal from the scene during both the "frame scrub" portion of the CCD clocking scheme, which occurs before the commanded exposure begins, and during the "frame transfer" portion of the clocking, when the charge is transferred from the active portion of the CCD to its storage area. Both of these processes result in a smearing of the observed scene. Fortunately, this smear can be removed to high accuracy using the correction algorithm. When bright objects are observed, the readout smear makes the UDP image difficult to use for analysis purposes.

The desmear operation implements the equation given below:

desmear = (image - (tframe/nrows) *
        total(image,2)/(texp+tframe*(nrows-1)/nrows)) *
        texp/(texp-tframe/nrows)

where:

desmear = desmeared image
image = smeared image
texp = requested exposure time after correction
tframe = 11.7762 milliseconds and represents the frame transfer time
        from the active area to storage area of the CCD
total(image,2) = sum of all values in each column of smeared image (vector)

Note that the input image should be debiased (i.e., either a bias image, or a bias level, has been subtracted from the image before it is desmeared).

There are saturation issues with rows 0 and 1 of the detector in both modes (1x1 & 4x4). As part of the desmear operation, these rows are replaced with the pixel data from row 2.

The python code fragment below illustrates the desmear algorithm making use of the numpy library:

```
column_sum = np.sum(image, axis=0, dtype='float64')
subtract_term = (tframe / nrows) * column_sum / \
        (texp + tframe * (nrows - 1.0) / nrows)
multiply_factor = texp / (texp - tframe / nrows)

# subtract the column vector from each column in the image
desmeared = np.zeros(image.shape)
for row in range(num_rows):
```

   desmeared[row, :] = image[row, :] - subtract_term

  desmeared *= multiply_factor

It should be noted that when the raw data is saturated, the resulting readout smear correction will be inaccurate. The algorithm relies on an accurate accumulation of charge in all rows of each column and if the raw data is clipped for lack of dynamic range to capture that integrated signal, the effect of readout smear cannot be completely and properly removed.

6.4. Conversion from DN to physical Units

The L'LORRI calibration pipeline provides photometrically corrected images, but the intensities are still in engineering units (DN). Pixel intensities can be converted to scientific units using photometry keywords provided in the image data file. Photometry keywords are provided in the table below for objects with three different Spectral Energy Distributions (SEDs): solar-like, similar to the average "red" Trojan spectrum, and similar to the average "gray" Trojan spectrum. Two examples are provided showing how to convert from engineering units to physical units: one for a diffuse target and one for a point (i.e., unresolved) target.

The keywords in the table below starting with "R" are diffuse target sensitivity keywords and their values have units of
    $(DN\ s^{-1}\ pixel^{-1})) / (ergs\ cm^{-2}\ s^{-1}\ Angstrom^{-1}\ sr^{-1})$.

The keywords starting with "P" are point target sensitivity keywords
and their values have units of
    $(DN\ s^{-1})) / (ergs\ cm^{-2}\ s^{-1}\ Angstrom^{-1})$.

For point targets, the signal refers to values integrated over the entire instrumental PSF.

Keyword	Value(1x1)	Value (4x4)
RSOLAR	2.382e5	4.026e6
RTROJANR	2.444e5	4.130e6
RTROJANG	2.381e5	4.024e6
PSOLAR	9.669e15	1.021e16
PTROJANR	9.920e15	1.048e16
PTROJANG	9.663e15	1.021e16

The "pivot" wavelength, is one way of characterizing the "effective" wavelength for a broadband optical instrument. The pivot wavelength for L'LORRI is calculated to be 603.0 nm.

Consider a diffuse target whose spectrum is similar to that of red Trojan globally averaged SED. In this case, the RTROJANR photometry keyword in the table above should be used to convert from the observed count rate in a pixel to a radiance value at L'LORRI's pivot wavelength:

 $I = S / t\_exp / RTROJANR$ (for a diffuse target)

where:

I is the diffuse target radiance at the pivot wavelength with units of
  (ergs cm^(-2) s^(-1) Angstrom^(-1) sr^(-1))
S is the measured signal in a pixel (DN)
t_exp is the exposure time (s)
RTROJANR is the L'LORRI diffuse photometry keyword for targets with an SED similar to a
  red   Trojan

Since the solar flux F_dot at a heliocentric distance of 1 AU at the L'LORRI pivot wavelength is 176 ergs cm^(-2) s^(-1) Angstrom^(-1), the value for the radiance can be converted to I/F (where pi*F = F_dot), which is a standard photometric quantity used in planetary science, using:

I/F = pi * I * r^(2) / F_dot

therefore

I/F = (S / t_exp / RTROJANR) * pi * r^(2) / F_dot

where "r" is the target's heliocentric distance in AU.

For unresolved targets (e.g., planetary targets observed at large ranges), the absolutely calibrated flux (also called the ``irradiance'') at the L'LORRI pivot wavelength can be determined using the point source photometry keywords. For a target with an SED similar to that of gray Trojan, the observed count rate integrated over the LORRI PSF can be related to the flux (not to be confused with "F" in "I/F") at the L'LORRI pivot wavelength by:

F = S_total / t_exp / PTROJANG   (for a point target)

where:

F is the point target flux, or
        irradiance (ergs cm^(-2) s^(-1) Angstrom^(-1))
S_total is the total signal from the target integrated over the PSF (DN)
t_exp is the exposure time (s)
PTROJANG is the L'LORRI point source photometry keyword for targets with an SED
        similar to a gray Trojan

7. Data Collection and Caveats
7.1. Data Collection

L'LORRI observations of the DART impact event may provide unique data on the early temporal evolution of the impact eject plume. The science objectives of the Lucy DART observations are:

1. Characterize the time evolution of the ejecta and the ejecta morphology, including the spatial distribution and orientation;
2. Measure the velocity and velocity distribution from the temporal evolution of the ejecta;
3. Estimate the total ejecta mass from the brightness of ejecta;
4. Constrain the particle size and size distribution of ejecta material.

L'LORRI can guarantee observations at the exact time of impact (to within 1 sec) and can provide essentially continuous coverage of the early development of the impact plume.

L'LORRI observing circumstances at time of impact (TOI)

TOI = 2022-Sep-26 23:14:24.183 +/- 0.0015 UTC at Didymos; OWLT is ~62.761 s for L'LORRI. So, TOI at Lucy is 2022-Sep-26 23:15:26.944 +/- 0.002, 1 sigma.

r = 1.046 au (Didymos heliocentric distance)

D = 0.126 au (LLORRI-Didymos distance)

phase = 31.9 deg (sun-Didymos-LLORRI angle = solar phase angle)

SEA = 144 deg (sun-LLORRI-Didymos angle = solar elongation angle)

Stereo convergence angle relative to Earth = 23.0 degrees
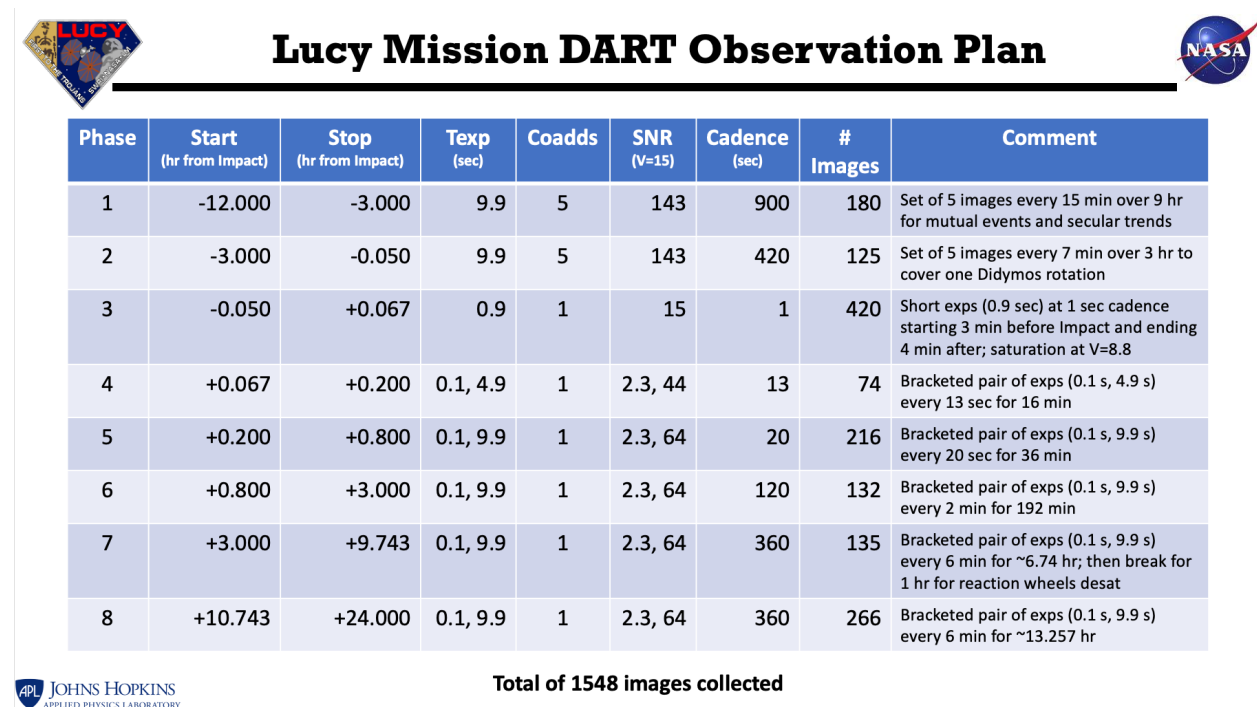
V = 15.0 (JPL Horizons for Didymos pre-impact)

Galactic latitude = -67 deg (from L'LORRI)

L'LORRI 1x1 pixel = 91.3 km (but Didymos system is too faint to use this format)

L'LORRI 4x4 pixel = 365 km

The Lucy observation plan is broken into eight phases described in the table below:

Lucy Mission DART Observation Plan

Phase	Start (hr from Impact)	Stop (hr from Impact)	Texp (sec)	Coadds	SNR (V=15)	Cadence (sec)	# Images	Comment
1	-12.000	-3.000	9.9	5	143	900	180	Set of 5 images every 15 min over 9 hr for mutual events and secular trends
2	-3.000	-0.050	9.9	5	143	420	125	Set of 5 images every 7 min over 3 hr to cover one Didymos rotation
3	-0.050	+0.067	0.9	1	15	1	420	Short exps (0.9 sec) at 1 sec cadence starting 3 min before Impact and ending 4 min after; saturation at V=8.8
4	+0.067	+0.200	0.1, 4.9	1	2.3, 44	13	74	Bracketed pair of exps (0.1 s, 4.9 s) every 13 sec for 16 min
5	+0.200	+0.800	0.1, 9.9	1	2.3, 64	20	216	Bracketed pair of exps (0.1 s, 9.9 s) every 20 sec for 36 min
6	+0.800	+3.000	0.1, 9.9	1	2.3, 64	120	132	Bracketed pair of exps (0.1 s, 9.9 s) every 2 min for 192 min
7	+3.000	+9.743	0.1, 9.9	1	2.3, 64	360	135	Bracketed pair of exps (0.1 s, 9.9 s) every 6 min for ~6.74 hr; then break for 1 hr for reaction wheels desat
8	+10.743	+24.000	0.1, 9.9	1	2.3, 64	360	266	Bracketed pair of exps (0.1 s, 9.9 s) every 6 min for ~13.257 hr

Total of 1548 images collected

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Note that Phase 7 contains 136 images rather than 135, as these are bracketed pair observations for a total of 1549 images.

7.2. Caveats

The images presented in these data collections were acquired on a best effort basis by the Lucy Mission. There was no plan in the original Lucy Mission timeline to observe the DART impact on the Didymos/Dimorphos system. By circumstance of launch date, the Lucy spacecraft was in position to make these observations. The Lucy ground system was developed to the extent that an imaging command sequence was able to be radiated and implemented on the spacecraft to record the DART impact on Dimorphos on September 26, 2022. The images acquired by the L'LORRI instrument were then returned to Earth from the Lucy spacecraft over the following two weeks. 1549 images were returned and processed through the proto L'LORRI data processing pipeline. The data processing pipeline yielded 1549 telemetry reconstructed raw images and 1549 calibrated images with attached metadata. The pipeline used for calibration is not the final L'LORRI calibration pipeline, so the reported metadata quantities may change. At the completion of data processing pipeline development, the Dimorphos images will be re-processed.

Additionally, the Lucy archive pipeline to create configuration-controlled, peer-reviewed and validated PDS4 labels is not complete. This pipeline is on schedule based on the original Lucy Data Management Plan, but it is not ready to create labels for the Didymos system image products. To expedite release of the DART observations to the community, the Lucy Archive Team and the PDS Small Bodies Node worked together to create an "interim" dataset that contains the raw and calibrated (to the extent available in the current L'LORRI data processing pipeline) image products with minimal PDS4 XML labels. Once the L'LORRI data processing

pipeline and the lucy archive pipeline are complete, the "interim" products will be updated and re-delivered to the PDS.

8. Appendix 1 – How to Read a PDS4 Label

All PIXL products consist of a PDS4-compliant detached XML label that describes the content and format of the associated data files. 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. Other Product_* type sub-classes have similar, but not identical structures to the Product_Observational class.

A hierarchical description of the contents of Product_Observational products is:

Product_Observational
> **Identification_Area** - attributes that identify and name an object
>> **logical_identifier** - name/location of file that uniquely identifies the product in the PDS system
>> **version_id** – ersion number of the data 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)
>> **Alias_List** - class of attributes that describes alternate names for the data product
>> **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
> **Investigation_Area** - mission, observing campaign or other coordinated, large-scale data acquisition attributes
> **Observing_System** - observing system (instrument) attributes
> **Target_Identification** - observation target attributes
> **Mission_Area** - mission or instrument specific attributes needed to describe the data product
> **Discipline_Area** – discipline specific meta-data attributes needed to describe the data product such as geometry, mission_surface, processing_information etc.
> **File_Area_Observational** - describes a file and one or more tagged_data_objects contained within.
> **File** - identifies the file that contains one or more data objects
> **Data_Objects** – classes of meta-data that describe the structure of the data, such as Header, Table_Character, Table_Binary, Array_2d, Array_3d, etc.

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.

9. Appendix 2 – Image Header and Image Descriptor Format Information

9.1. Image Header

telemetry parameter	start_byte	MSb	num_bits
fpu_l_i	0	7	16
dpu_5v_i	2	7	16
fpu_h_i	4	7	16
heater18v_i	6	7	16
primary_i	8	7	16
fpu_v_l	10	7	16
fpu_v_h	12	7	16
dpu_5v_v	14	7	16
heater18v_v	16	7	16
dpu_p0_t	18	7	16
fpu_p1_t	20	7	16
ota1_p2_t	22	7	16
ota2_p3_t	24	7	16
spare_p1_t	26	7	16
spare_p2_t	28	7	16
dpu_33v_v	30	7	16
ccd_t	32	7	16
fpe_t	34	7	16
ccd_osr	36	7	16
fpe_29v_v	38	7	16
ccd_osl	40	7	16
fpe_13v_v	42	7	16
fpe_6v_v	44	7	16
latch_count	46	7	16
exposure	48	7	16
cal_lamp2_level	50	7	16
cal_lamp1_level	52	7	16
dpu_id	54	7	1
cal_lamp2_enable	54	6	1
cal_lamp1_enable	54	5	1
source	54	4	3
img_format	54	1	1
exp_mode	54	0	1

* all binary values are given in big-endian format

* the actual image header as downlinked includes several additional parameters that are also provided in the image descriptor given in a different extension. That data has been removed to prevent duplication.

* based on the Lucy LORRI Flight Software Specification
   7504-9016 Rev C, Table 62, pg 85

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9.2. Image Descriptor

telemetry parameter	start_byte	MSb	num_bits
obsid	0	7	16
obsid_count	2	7	16
img_type	4	7	16
start_time(seconds)	6	7	32
start_time(subseconds)	10	7	16
end_time(seconds)	12	7	32
end_time(subseconds)	16	7	16
fpu_l_i	18	7	16
dpu_5v_i	20	7	16
fpu_h_i	22	7	16
heater18v_i	24	7	16
primary_i	26	7	16
fpu_v_l	28	7	16
fpu_v_h	30	7	16
dpu_5v_v	32	7	16
heater18v_v	34	7	16
dpu_p0_t	36	7	16
fpu_p1_t	38	7	16
ota1_p2_t	40	7	16
ota2_p3_t	42	7	16
spare_p1_t	44	7	16
spare_p2_t	46	7	16
dpu_33v_v	48	7	16
ccd_t	50	7	16
fpe_t	52	7	16
ccd_osr	54	7	16
fpe_29v_v	56	7	16
ccd_osl	58	7	16
fpe_13v_v	60	7	16
fpe_6v_v	62	7	16
latch_count	64	7	16
exposure	66	7	16
cal_lamp2_level	68	7	16
cal_lamp1_level	70	7	16
spare1	72	7	8
dpu_id	73	7	1
cal_lamp2_enable	73	6	1
cal_lamp1_enable	73	5	1
source	73	4	3
img_format	73	1	1
exp_mode	73	0	1
flush	74	7	16
postamble	76	7	32

* all binary values are given in big-endian format

* the actual image descriptor includes the histogram as a set of 32 bins, 32 bits each following the parameters given above. The histogram has been removed since it is provided separately in a different extension.

* based on the Lucy LORRI Flight Software Specification
   7504-9016 Rev C, Table 47, pg 76