

Las Cumbres Observatory (LCOGT) Uncalibrated/Calibrated Data Product Software Interface Specification for Data Collected in Support of DART Mission

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Revision Log

Revision	Author	Description	Date
0.1	T. Lister	Initial version	4/23/2021
0.2	T. Lister	Added mosaic/dither/photcal keywords. Update directory structure and small tweaks to photometry file table field positions.	10/22/2021
0.3	T. Lister	<p>Address issues from PDS review:</p> <ul style="list-style-type: none">• weblinks replaced with references• Improve file naming table, documenting tel. class better, instrument combinations. Create table for fields for master calibration frames.• Adjust directory structure and naming.• Improve description for DATASUM/CHECKSUM in pri. HDU, DATADICV, OBSTYPE, FILTERx, FILTERIx, {INS,TEL,ENG,TCS,AZ,ALT}STATE state keywords, CONFMODE, GAIN, DETSIZE, xyzSEC section keywords, P/GCOUNT, CCDSUM, EXTVER, OVERSCNx• Adjust field location in photometry table for file, ZP_sig, aprad. Rename extension to '.tab'. <p>Add new TRACFRAC keyword</p>	2/16/2022
0.4	T. Lister	Add filter column to photometry table. Add explanation of LCOGT filter naming for Sloan filters. Document population of PCRECIPE and PPRECIPE headers.	9/2/2022
0.5	T. Lister	Add validity flag column to photometry table.	3/3/2023
0.6	T. Lister	Update document to include details of the FLI dataset and FITS photometry tables.	5/12/2023

0.7	T. Lister	Update Section 5.1. Data Product Structure and Organization for the new calibration subfolder. Fix typo found in PDS review.	10/6/2023
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1. Purpose and Scope of This Document

The data products described by the Software Interface Specification (SIS) are the Las Cumbres Observatory (LCOGT¹) uncalibrated and calibrated data products. Tim Lister from LCOGT produces these data products and distributes them to the DART SOC for redistribution to the DART Investigation Team and the Planetary Data System (PDS). The purpose of this document is to provide users of the data products with a detailed description of the product and a description of how it was generated, including data sources and destinations. The document is intended to provide enough information to enable users to read and understand the data products. The users for whom this document is intended are the scientists who will analyze the data, including those associated with the DART mission and those in the general planetary science community.

1.1. DART Mission Purpose and Goals

DART is a low-cost technology demonstration of the kinetic impactor technique to divert a hazardous asteroid. DART's primary objectives are to:

- Perform a full-scale demonstration of the spacecraft kinetic impact technique for deflection of an asteroid by targeting an object large enough to qualify as a potentially hazardous asteroid.
- Confirm and measure the resulting asteroid deflection by telescopic observations.
- Improve the understanding of high-speed collision effects on an asteroid and thereby improve the validation of performance models by constraining the momentum transfer enhancement due to ejecta through comparison to pre-impact predictions.

To achieve these objectives the DART spacecraft will intercept the secondary of the binary near-Earth asteroid (65803) Didymos. The primary member of the binary system will be referred to as Didymos and the secondary as Dimorphos. The system as a whole is also referred to as Didymos. As part of the baseline level 1 Mission Investigation requirements the DART project shall obtain data, in collaboration with ground-based observations and data from another spacecraft to constrain the location and surface characteristics of the impact site and to allow the estimation of the dynamical changes in the Didymos system resulting from the DART impact and the coupling between the body rotation and the orbit.

1.2. Las Cumbres Observatory Observations

To interpret the deflection due to the DART impact, equally high-quality lightcurves of the Didymos system must be available from periods both prior to and following the DART impact. In addition, LCOGT has telescopic facilities located in South Africa which will be in darkness at the time of the DART impact, allowing observations of the potential ejecta to be made. A contract

¹ We use the abbreviation for the former (and current legal) name of Las Cumbres Observatory Global Telescope Network (LCOGT) in this document to avoid possible confusion with the abbreviation of Las Campanas Observatory.

will be established with Las Cumbres Observatory to acquire telescopic data from the LCOGT Network in support of the DART mission. The telescopic data made available as part of this contract will be archived by LCOGT in their science archive as a normal part of LCOGT Network operations and by the DART project. Didymos and Dimorphos will be sufficiently far from the Earth and are sufficiently close together that they will not be resolved from one another, but instead will appear as a single point of light in these measurements. When Didymos is referred to below, it can be taken to be referring to the system as a whole rather than the primary body, unless otherwise specified.

The Las Cumbres Observatory (LCOGT) Network is a global telescope network consisting of two 2-meter telescopes, one each at Haleakala, Maui HI and Siding Spring Observatory, NSW, Australia, twelve 1-meter telescopes with two telescopes at two location in the northern hemisphere (McDonald Observatory, TX and Teide Observatory, Canary Islands, Spain) and eight telescopes at three locations in the southern hemisphere (CTIO, Chile; SAAO, South Africa; Siding Spring Observatory, NSW, Australia). The telescopes are all remote and robotic with the operations supervised (see Section 4.1) from LCOGT headquarters in Goleta, CA. Additional monitoring of the network is carried out by LCOGT personnel in Maui, Australia and the UK.

The observations in support of the DART mission will make use of the 1-meter telescope network and the Sinistro CCD imagers (see Section 4.2). The data will include for each night of observation from each telescope raw fits images, calibrated (bias and dark subtracted, flat field corrected, astrometrically solved) versions of those images with associated calibration frames, data tables of measured Didymos photometry.

2. Applicable Documents and Constraints

This Data Product SIS is consistent with the following Planetary Data System documents:

1. Planetary Data System Standards Reference, Version 1.15.0.0, Oct 2, 2020
2. PDS4 Data Dictionary, Abridged, Version 1.15.0.0, Dec 23, 2020
3. PDS4 Information Model Specification, Version 1.15.0.0, Dec 23, 2020
4. FITS Standard document, version 4.0, July 22, 2016

This SIS is responsive to the following DART documents:

5. DART Data Management and Archive Plan (DMAP), Rev 2.5

3. Relationships with Other Interfaces

The data transfer procedure to the DART SOC is via `rsync` from a machine hosted at LCOGT that has access to the reduced data from the reduction server at LCOGT and allows access to a specific set of IP addresses from the DART SOC at APL.

No other documentation is affected by the changes to the data products described in this SIS.

4. Data Products Characteristics and Environment

4.1. Observatory Overview

LCOGT operates its global telescope network of robotic telescopes remotely over the Internet. This was setup through MOUs with hosting institutions which operate existing telescope observatories. Observation requests for approved telescope programs are submitted through either a web-based Observing Portal or through API endpoints. Observation requests from all programs that are currently valid and unobserved are considered by the LCOGT global scheduler which considers all of these requests and the current state of the network to produce an optimal plan for each telescope for the next 7 days which is sent out to each site to be observed by the telescopes at that site. The scheduler then repeats this cycle with the updated set of observations requests and new network state with a cycle time of approximately 10 minutes, depending on the request load. The observing portal system, request database and scheduler operate in the Amazon Web Services (AWS) cloud in the `us-west-2` region in Oregon.

Raw data is returned from the instruments at site to the LCOGT Science Archive as soon as exposures are completed and passed through the BANZAI pipeline (McCully et al 2018) with calibrated data products also being stored in the LCOGT Science Archive. All of these activities also take place or are stored in the AWS cloud.

4.2. Instruments Overview

The LCOGT 1-meter telescopes have two instruments that were used for the DART observations: the main Sinistro imaging CCD camera (used for the lightcurve and long-term ejecta monitoring observations) and the FLI autoguider cameras which were used for the time of impact observations on 2022-09-26/27 only. They are described in more detail in the following subsections.

4.2.1. Sinistro Instruments

The Sinistro optical imagers are the main imaging cameras used by the LCOGT 1-meter telescopes. Sinistro uses a Fairchild CCD486 back illuminated CCDs with 4096 x 4097 pixels with Archon CCD controllers developed by Semiconductor Technology Associates, Inc (STA). The imager is mounted on the straight through port of the 'OxBox' instrument cube which is mounted on the back of the 1-meter mirror cell.

Sinistro provides a 26.5 x 26.5 arcminute field of view with 15 micron pixels. In the default unbinned mode, this provides a pixel scale of 0.389 arcsec/pixel with a readout time of 28 s. There is a central readout mode which reads out the central 2048 x 2048 pixels, with 2x2 pixel binning, and with a readout overhead of 9 seconds. Read noise is approximately 9 electrons depending on the camera. The CCD quantum efficiency is 64% for 350 - 400 nm, 72% at 500 nm, rising to 80-90% over 600-800 nm and declining to 24% at 1000 nm. The quantum efficiency falls off very sharply below 350 nm.

Three eight position filter wheels in the Sinistro instrument provide 21 filter slots. A common set of filters are provided in all the Sinistro imagers including the Bessell UBVRI and Sloan/PanSTARRS u'g'r'i'zs along with a PanSTARRS w broad filter equivalent to g'+r'+i'. (In the FITS headers, the prime (') of the Sloan filters is replaced by a 'p' e.g. Sloan g' appears as FILTER = 'gp' in the headers)

4.2.2. FLI Instruments

The ancillary autoguider cameras for the Sinistro instruments (described above) for the LCOGT 1-meter Telescopes are called the FLI Imagers. Although normally used as autoguiders, they are capable of being operated as science instruments for observations where the much shorter readout time than Sinistro (1.5s vs 28s) is useful. The FLI imagers compromise a Finger Lakes Instrumentation (FLI) ML4720 camera containing a e2v back-illuminated monolithic frame transfer CCD with 1024 x 1024 x 13um pixels combined with a LCOGT constructed corrector, focus stage and filterwheel. The instrument is mounted on one of the side ports on the LCOGT 1-meter instrument support structure, allowing simultaneous use (as a guider) along with Sinistro.

The FLI imager is a 1k x 1k CCD providing a 5.8 arc minute square field of view. The device is back illuminated and has 13-micron pixels. The instrument can be operated in 1x1 or 2x2 pixel binning; in the unbinned mode, this provides a pixel scale of 0.340 arcsec/pixel, or 0.680 arcsec/pixel in the binned 2x2 mode. The chip is linear up to 65k ADU and has dual amplifiers which can readout at either 500 kHz or 2MHz. Read noise is typically 7.5 electrons with 500 kHz readout and 16.3 electrons in 2 MHz readout. The readout and processing time is 2.1 seconds for unbinned images, and 1.78 seconds for the binned 2x2 mode. The CCD quantum efficiency is 15% for 300-350 nm, 50% at 400, 90% at 500 nm, rising to 90-95% over 500-700 nm and declining smoothly to 12% at 1000 nm.

A single ten position filter wheel in the FLI instrument provides 9 filter slots. A common set of filters are provided in all the FLI imagers including the Bessell B and V and Sloan/PanSTARRS g'r'i'zs along with a 'clear' broad filter with a very sharp cut-on at 400 nm and a roll-off at 1000 nm down to ~50% transmission at 1200 nm.

4.3. Data Product Overview

The specific data products described by this SIS are:

1. Raw Image Data
2. Calibrated Image Data
3. Master Bias Data
4. Master Dark Data
5. Flat Frame Data

6. Photometry Tables

4.4. Data Processing

Initial data processing is performed by LCOGT in the AWS cloud. Data is then retrieved from the LCOGT Science Archive and processed at LCOGT. This section provides general information about data product content, format, and size.

4.4.1. Data Processing Levels

The following table describes the products and their data processing levels.

LCOGT Product	LCOGT Reduction Level	NASA Product Level	Description
Raw Image	00	Level-0	raw images
Calibrated Image	92	Level-2	calibrated image frame
Master Bias	91	Level-2	master bias frame
Master Dark	91	Level-2	master dark frame
Master Flat	91	Level-2	master flat frame
Photometry Tables	N/A	Level-2	photometry tables

4.4.2. Data Product Generation

All LCOGT data products will be generated by LCOGT and transferred to the DART SOC.

4.5. Data Products

This section gives a more detailed description of each data product, including the process by which the product is generated.

4.5.1. Raw Image Data

FITS images are obtained with the Sinistro imagers at the LCOGT telescopes. Raw image data includes expose (night sky) frames, bias and dark frames and flat fields. Flat fields are obtained at evening and morning twilight by taking dithered images at the anti-Sun point. Bias and dark frames are taken during the local site afternoon before sunset and flat fields are automatically scheduled by the calibration system for those filters that have the oldest master flatfields.

4.5.2. Calibrated Image Data

Calibrated expose frames that have been bias and dark subtracted and flat fielded and which have had an astrometric WCS solution determined via the Gaia-DR2 catalog. See section 4.5.5 for more details of the data flow.

4.5.3. Master Bias, Dark and Flatfield Frame Data

Median combined stacks of bias, dark and flat field images are used to create master calibration frames for each instrument each night. They are compared with previous versions from prior nights and marked as good and used for processing the raw data if they meet certain criteria. The application of these master frames to the raw data, e.g. bias and dark subtraction and division by the normalized flat field, result in the calibrated image data.

4.5.4. Photometry Table Data

ASCII summary table of the measured photometry of Didymos on each sky frame. The format of the table is specified in section 5.1.2.

4.5.5. Data Flow and Processing

This section provides a high-level overview of how the calibrated image data are created from the Raw Image data, how master bias, dark and flat frames are created, how the reference stars are used, and how the lightcurve tables are generated.

Raw image data are calibrated by the BANZAI pipeline (McCully et al. 2018, SPIE, Volume 10707, article id 107070K, doi:10.1117/12.2314340) in 8 steps:

1. Overscan subtraction: all images with a valid BIASSEC header keyword have a median value removed estimated from the BIASSEC region
2. Crosstalk correction (1m Sinistro imagers only): these imagers readout through 4 amplifiers and there is crosstalk between the quadrants which is removed using linear coefficients that relate each quadrant to every other quadrant.
3. Gain correction: All pixels in the frame are multiplied by the gain, using the GAIN header keyword. Thus, the science frames output by BANZAI are all in units of electrons.
4. Mosaic (1m Sinistro imagers only): If the file has multiple extensions, BANZAI produces a single mosaiced frame. This uses the DETSEC header keywords.
5. Trim: After being mosaiced, the data is trimmed to a usable region for science. This is set based on the TRIMSEC header keyword.
6. Bias Subtraction: Full frame master bias images are subtracted from each of the darks, flat field images, and science frames. The master bias frame that was taken closest in time to the current data will be used. If no bias frame exists for this instrument, the data will not be reduced and an exception will be raised.
7. Dark Subtraction: Full-frame master dark frames, scaled to the exposure time of the frame, are subtracted from all flat-field and science images. The most recent master dark frame is used, normally this is taken on the same day.

8. Flat Field Correction: Master flat field images (normalized to unity using the inner quarter of the image) are divided out of every science frame. The most recent master flat-field image for the given telescope, filter, and binning is used.

Master Calibration Frames

BANZAI creates the master bias, dark and flat frames required for the reduction of science frames. For all instruments, we take many full-frame bias and dark exposures every afternoon and morning. We use a “robust standard deviation” (rstd) based on the median absolute deviation (mad - related to the std by $\sigma \approx 1.4826 \times \text{mad}$) to estimate the scatter of the distribution and mask pixels more than 3 rstd reliably and take a mean of the remaining pixels as usual. When creating the master dark frame, each individual frame is scaled by the exposure time (read from the header).

Twilight flats are taken every day but not in every filter, because twilight is not long enough to take all 18 filters in a single night. Typically, a master flat field is produced about once every 3 clear days for any given filter. Flat-field images for a given filter are taken in the evening and morning twilight, to allow quality control. The frames are dithered so that we can remove stars in the combined master flat field.

Each individual flat-field image is normalized to unity before combining them. The normalization is calculated finding the robust sigma clipped mean (3.5 rstd outliers are rejected) of the central region of the image. For the central region, we choose the central 25% of the field (the region has dimensions that are half of the full image). The flat-field frames are then stacked using a sigma clipped mean, similar to the master bias and dark frames, again with 3 rstd outlier rejection.

NEOexchange Solar System Pipeline

The astrometric solution performed by BANZAI does not incorporate focal plane distortions and the source catalogs produced by BANZAI are too shallow for most of the fainter NEO targets. Following initial processing by BANZAI, data for Solar System object processing is downloaded from the LCOGT Science Archive and additional processing is performed by the NEOexchange Solar System pipeline to create the calibrated images.

The Solar System object processing and photometry of Didymos is performed using the open source NEOexchange system (Lister et al. 2021, Icarus, Volume 364, article id. 114387, doi:10.1016/j.icarus.2021.114387) available on GitHub (<https://github.com/LCOGT/neoexchange>). This pipeline astrometrically solves images, including third-order distortions, including the based on the measured position of Gaia DR2 stars in the field, photometrically calibrates the zero point of the images based on the measured flux of field stars that have known catalog magnitudes (against the Gaia-DR2 catalog since the majority of LCOGT telescopes are in the South; an option to calibrate against the PanSTARRS catalog will be developed for those targets far enough North to be covered), and then using these astrometric and photometric solutions derives a calibrated magnitude for Didymos. The source

catalogs and photometry tables included in this dataset are outputs of this pipeline. The pipeline is built upon the tools SExtractor (E. Bertin and S. Arnouts. SExtractor: Software for source extraction. A&AS, 117:393–404, June 1996. doi:10.1051/aas:1996164) and SCAMP (Bertin 2006: Automatic Astrometric and Photometric Calibration with SCAMP, ASP Conference Series, Vol. 351, 2006, C. Gabriel, C. Arviset, D. Ponz, and E. Solano, eds., p. 112).

All observations of Didymos will be obtained with a broad PanSTARRS w-band filter (>95% throughput from roughly 400-835 nm) and calibrated to r-band magnitudes in the PanSTARRS catalog.

4.5.6. Labeling and Identification

Raw and Calibrated Images

Raw Sinistro images consist of a single FITS file containing a primary header and 4 image extensions corresponding to the individual quadrants and amplifiers of the CCD. The calibrated images consist of a single FITS file containing the stitched together calibrated data, the bad pixel mask, the catalog of extracted sources and the variance array. They are named according to the following LCOGT-wide convention:

<site><tel. class><tel. #>-<instrument>-<yyyymmdd>-<iiii>-<type><red. level>.fits

where:

filename section	Description
<site>	LCOGT site code (one from {ogg, coj, lsc, cpt, elp, tfn, ngq}) See table below for description of site codes
<tel. class>	Size/class of telescope (one from {2m0, 1m0, 0m4}). The <tel. class> is the size of the primary mirror in meters with the decimal point replaced by 'm' e.g. 2.0 meters->2m0, 0.4 meters->0m4.
<tel. #>	telescope serial number within size class
<instrument>	LCOGT instrument code e.g. 'fa15' where the first letter indicates CCD manufacturer (f=Fairchild), second letter indicates controller manufacturer (a=Archon) and the 2 digits indicate serial number. For these data, the possible combinations are (most likely first): fa: Fairchild CCD + Archon controller (1m Sinistro) ef: e2v CCD + FLI controller (1m Autoguider)
<yyyymmdd>	UTC date of the start of the night (defined to be UTC date at 1600 local time at the site). Does not change if the site observes through UTC midnight.
<iiii>	four digit image counter for that instrument, resets at start of new

	night (defined as above). Counter starts at 0001
<type>	Type of file. One of {a=arc, b=bias, d=dark, e=exposure, s=standard, f=sky flat, l=lambert flat, w=lamp flat, x=experimental})
<red level>	Reduction level from 00-99 with higher numbers indicating higher levels of data processing. In practice, one of {00=raw, 91=BANZAI processed, 92=NEOexchange processed}

e.g. `coj1m011-fa12-20210408-0176-e91.fits` is a processed expose(sky) data product from the Siding Spring Observatory (coj), from 1-meter telescope #11 and the fa12 Sinistro instrument from the night of 2021-04-08. It is the 176th image taken by that instrument on that night.

The LCOGT site codes (which are based on the IATA code of the nearest airport) are defined as follows:

LCOGT Site code	Site location description
ogg	Haleakala, Maui, HI, USA
coj	Siding Spring Observatory, NSW, Australia
lsc	Cerro Tololo Inter-American Observatory, Chile
cpt	South African Astronomical Observatory, Sutherland, South Africa
elp	McDonald Observatory, Texas, USA
tfn	Teide Observatory, Tenerife, Canary Islands, Spain
ngq	Ali Observatory, western Tibet, China
sin	Meta site for all Sinistro cameras in the network

Master Bias, Dark and Flat Field Frames

These follow the same general format as the Raw and Calibrated Images above but the <type> and <reduction level> sections are replaced by a <calib config> section:

<site><tel. class><tel. #>-<instrument>-<yyyymmdd>-<iiii>-<calib config>.fits

The <calib config> section is made up of:

<calib type>-<readout window (Opt.)>-<readout speed (Opt.)>-bin<X binning>x<Y binning>-<filter>
as detailed in the following table

filename section	Description
<calib type>	Calibration type. One of: <ul style="list-style-type: none"> • bpm (bad pixel mask), • bias (master bias), • dark (master dark), • skyflat (master sky flatfield) • fakeflat (a unity/all 1's synthetic flatfield; ef autoguider only)
[readout window]	(Optional) one of {full_frame, center}; 1m Sinistro imagers only
[readout speed]	(Optional) the readout speed mode used. Possible values: <ul style="list-style-type: none"> • MUSCAT_FAST, MUSCAT_SLOW (2m MuSCAT data only) • 2MHz (ef autoguider only)
<X binning/Y binning>	Number of pixels being binned in the X or Y direction
<filter>	Filter name (skyflat or fakeflat; calib types only)

Some examples of these combinations are:

ogg2m001-ep02-20210122-skyflat-MUSCAT_FAST-bin1x1-rp.fits

which is a SDSS-r' skyflat for the Maui, HI (ogg site) 2m telescope's ep02 camera of the MuSCAT3 instrument from 2021-01-22 taken in the MUSCAT_FAST readout mode with 1x1 binning. Another two examples are:

cpt1m012-fa06-20210402-dark-bin1x1.fits and

cpt1m012-fa06-20210402-bias-bin1x1.fits

which are master dark and bias calibration frames for 1x1 binning from LCOGT 1m #12 in South Africa (cpt site) from 2021-04-02.

Photometry tables

The ASCII and FITS photometry summary tables are named according to the following convention:

lcogt_<site>_<inst.>_<YYYYMMDD>_<request #>_<astname#>_photometry.<e>

where:

- <site> is the LCOGT site code as defined in the table above,
- <inst.> is the LCOGT instrument code as defined in the table above,
- <YYYYMMDD> is the date of the start of data collection for that night
- <request number> is the unique LCOGT (integer) identifier assigned to the observation request by the LCOGT Observing Portal
- <astname#> is the asteroid name and number in PDS-compatible identifier format i.e. all lowercase
- <e> is the extension: .tab for ASCII tables and .fits for FITS tables

An example would be

`lcogt_tfn_fa11_20211013_2678874_12923zephyr_photometry.tab` for a photometry file for Didymos simulat (12923) Zephyr from the fa11 instrument at Tenerife from 2021-10-13.

4.6. Standards used in Generating Data Products

4.6.1. PDS Standards

All data products described in this SIS conform to PDS4 standards as described in the PDS Standards document noted in the Applicable Documents section of this SIS. Prior to public release, all data products will have passed a data product format PDS peer review to ensure compliance with applicable standards.

4.6.2. Time Standards

Time standards used by the DART mission conform to PDS time standards.

4.6.3. Coordinate Systems

All coordinate systems used by the DART mission conform to IAU standards.

4.6.4. Data Storage Conventions

All raw fits files store the image data as MSB 16-bit integers. All calibrated fits files and the master calibration files store the image data as 32-bit floats. The photometry table is stored as ASCII text.

5. Detailed Data Product Specifications

5.1. Data Product Structure and Organization

The LCOGT PDS archive is part of the DART Telescopic Observation Bundle, as outlined in the DART DMAP. There are specific LCOGT collections: `collections: "data_lcogtraw"`,

"data_lcogtcal", "data_lcogtddp", "data_lcogt_fliraw", "data_lcogt_flicl", "data_lcogt_fliddp". These comprise the LCOGT Raw Data Collection, LCOGT Calibrated Data Collection, and the LCOGT Derived Data Collection and the same three collections for the FLI instruments respectively. Documentation such as this SIS and instrument descriptions are organized in the "document_lcogt" Document collection.

The LCOGT data collections are stored in a directory tree organized by collection and then by telescope+instrument+date of observation. This structure allows a user to navigate to a specific collection, telescope and instrument combination and then by observing date, and finally browse the data product types.

The directory structure for the LCOGT data collections is shown below. The "data_lcogt_raw" folder contains the raw FITS files and their associated XML labels for images generated by the 1-meter telescope network and Sinistro CCD imagers. The "data_lcogt_cal" folder contains the calibrated FITS files, and the master calibration fits files used to calibrate the "data_lcogt_raw" data are stored in a "calibration" subfolder of the "data_lcogt_cal" folder.

LCOGT light curve data associated with the observation is contained in the derived data product folder, "data_lcogt_ddp". A similar naming convention is used for the collections obtained by the FLI imagers: "data_lcogt_fliraw", "data_lcogt_flicl", "data_lcogt_fliddp", designating the raw, calibrated, and derived product processing levels for images generated by the FLI instrument. As an example:

```
data_lcogt_raw/  
    lcogt_1m0_12_fa06_YYYYMMDD/  
data_lcogt_cal/  
    calibration/  
        lcogt_1m0_12_fa06_YYYYMMDD/  
data_lcogt_ddp/  
    lcogt_1m0_04_fa03_YYYYMMDD/  
data_lcogt_fliraw/  
    lcogt_1m0_10_ef02_YYYYMMDD/  
data_lcogt_flicl/  
    calibration/  
        lcogt_1m0_10_ef02_YYYYMMDD/  
data_lcogt_fliddp/
```

where "lcogt_1m0_12_fa06" refers to the LCOGT 1-m telescope #12 and the fa06 Sinistro instrument, "lcogt_1m0_04_fa03" refers to the LCOGT 1-m telescope #04 and the fa03 Sinistro instrument, "lcogt_1m0_10_ef02" refers to the LCOGT 1-m telescope #10 and the ef02 FLI instrument and "YYYYMMDD" is the UTC YearMonthDay of the start of night.

A separate "document_lcogt" folder is created under the root documentation folder. This will distinguish documentation specific to the LCOGT data collection from other telescopic data collections for example:

```
bundle root/
```



```

document_lcogt/
    LCOGT_DART_uncalibrated_calibrated_sis.pdf
    sinistro_description.txt
    fli_description.txt
    other LCOGT documentation files.

```

5.1.1. Raw Image FITS Files

Image data products are stored in the FITS file format 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. The following table describes the format and content of the FITS header. The Class.Attribute Name column shows the mapping of the fits keyword to the class and attribute in the PDS4 XML label. Blank fields indicate where the metadata only exists in the fits keyword.

Raw Sinistro FITS data are stored as a Multi-Extension FITS (MEF) file with a primary header (detailed below) and 4 per-amplifier FITS extensions with the per-amplifier/quadrant details. Note: The primary FITS Header Data Unit does not contain an image array, only a fits header and hence NAXIS1 and NAXIS2 are zero. For keywords that appear in both the primary header and the extensions (CCDSUM, DETSEC, BIASSEC, DATASEC, GAIN), the values in the extensions override those in the primary header (this is done to keep a consistent header format across all of LCO's instrument classes and instruments, most of which do not have FITS extensions for the raw data).

Class.Attribute Name	Keyword and example	Description
n/a	SIMPLE = T	required in FITS standard
element_array.data_type	BITPIX = 16	array data type
axes	NAXIS = 2	number of array dimensions
axis_array.sequence_number	NAXIS1 = 0	length of FITS data axis 1. Equivalent to PDS 'sample'
axis_array.sequence_number	NAXIS2 = 0	length of FITS data axis 2. Equivalent to PDS 'line'.
	BSCALE = 1.0	
element_array.value_offset	BZERO = 32768	
	CHECKSUM= '9nAkAm6k4mAk9m3k'	HDU checksum
	DATASUM = '2141115488'	data unit checksum ²

² For the primary header of raw data (which have no data array) this will always be '0'

	DATADICV= 'LCOGT-DIC.FITS-0.10.0'	Version number of the LCOGT data dictionary used for FITS definitions
	HDRVER = 'LCOGT-HDR-1.3.0'	Version number of the headers
	ORIGIN = 'LCOGT '	Organization responsible for the data
	SITEID = 'cpt '	ID code of the Observatory site
	SITE = 'LCOGT node at SAAO'	Site of the Observatory
	ENCID = 'domc '	ID code of the Enclosure
	ENCLOSUR= 'Dome-07 '	Building containing Telescope
	TELID = '1m0a '	ID code of the Telescope
	TELESCOP= '1m0-12 '	The Name of the Telescope
	LATITUDE= -32.3829000	[deg North] Telescope Latitude
	LONGITUD= 20.8125200	[deg East] Telescope Longitude
	HEIGHT = 1760.000	[m] Altitude of Telescope above sea level
	OBSGEO-X= 5041025.307	[m] Cartesian X co-ord of telescope (WGS84)
	OBSGEO-Y= 1916166.474	[m] Cartesian Y co-ord of telescope (WGS84)
	OBSGEO-Z= -3397306.585	[m] Cartesian Z co-ord of telescope (WGS84)
Target_Identification.type	OBSTYPE = 'EXPOSE '	<p>Observation type. One of</p> <ul style="list-style-type: none"> • EXPOSE: regular open shutter exposures of an astronomical source, • STANDARD: open shutter exposures of a photometric standard star (such as a Landolt standard), • CATALOG: an extracted catalog of sources detected on an image, • BIAS: a 0s closed shutter bias frame for measuring the bias level, • BPM: bad pixel mask image, • DARK: a closed shutter dark frame for measuring dark current,

		<ul style="list-style-type: none"> • SKYFLAT: an open shutter observation of the twilight sky for measuring the flat field and pixel to pixel variation.
	FRAMENUM= 73	Running frame number
	MOLTYPE = 'REPEAT_EXPOSE'	Molecule type
	MOLNUM = 54	Molecule number
	MOLFRNUM= 1	Exposure number within molecule
	FRMTOTAL= 1	Total number of exposures within molecule
	ORIGNAME= 'cpt1m012-fa06-20210418-0073-e00.fits'	Fname written by ICS
	OBSTELEM= 'N/A '	Link to observation telemetry
	TIMESYS = 'UTC '	Time system used
	DATE = '2021-04-18T17:20:15.135552'	[UTC] Date this FITS file was written
Time_Coordinates.start_date_time	DATE-OBS= '2021-04-18T17:15:30.216'	[UTC] Start date and time of the observati
	DAY-OBS = '20210418'	[UTC] Date at start of local observing night
	UTSTART = '17:15:30.216'	[UTC] The start time of the observation
Time_Coordinates.stop_date_time	UTSTOP = '17:15:40.196'	[UTC] The finish time of the observation
	MJD-OBS = 59322.7189557	[UTC days] Start date/time (Modified Julian Date)
img:exposure_duration	EXPTIME = 9.9800000	[s] Exposure length
	REQTIME = 10.0000000	[s] Requested exposure length
	FILTER1 = 'air '	The first filter wheel filter type ³
	FILTERI1= 'Air '	The first filter wheel filter id
	FILTER2 = 'w '	The second filter wheel filter type
	FILTERI2= 'PSTR-WX-180'	The second filter wheel filter id
	FILTER3 = 'air '	The third filter wheel filter type

³ FILTER{1,2,3} contains the human-readable filter name (or 'air') e.g 'B' or 'gp' whereas FILTERI{1,2,3} has the (unique) LCOGT filter serial number. FILTER contains the concatenation of all non-air filters.

	FILTERI3= 'Air '	The third filter wheel filter id
	FILTER = 'w '	Filter used
	FWID = 'fws1m-02'	ID/Serial number of the Filter Wheel mechanism
	INSTRUME= 'fa06 '	Instrument used
	INSSTATE= 'OKAY '	The instrument status. One of the LCOGT State Values ⁴
	ICSVVER = 'master@0xf48f57c'	Version number of the ICS software
	CONFMODE= 'full_frame'	Camera mode configuration. One of: <ul style="list-style-type: none"> • 'full_frame' or 'central_2k_2x2' (1m Sinistro) • '2_MHz' or '500_KHz' (1m ef autoguiders) • 'default' (0.4m SBIG and 2m Spectral imagers) • 'MUSCAT_FAST' or 'MUSCAT_SLOW' (2m MuSCAT3 imager)
	CONFNAME= 'N/A '	The instrument configuration used
	DETECTOR= 'UNKNOWN '	Detector type
	DETECTID= 'DB-49 '	Detector serial number
	GAIN = 1.0	[electrons/count] Pixel gain
	RDNOISE = 7.6000000	[electrons/pixel] Read noise
	DARKCURR= 0.0000000	[electrons/pixel/s @ 200K] Dark current
	SATURATE= 151050.0	[ADU] Saturation level
	MAXLIN = 127200.0	[ADU] Non-linearity level
	RDSPEED = 60.0000000	[kpix/s] Readout speed used
	DETSIZE = '[1:4096,1:4096]'	[pixel] Detector size in unbinned pixels
	AMPNAME = 'default '	Amplifier name
	CCDSEC = 'UNKNOWN '	[pixel] Region of CCD read

⁴ The possible values for LCOGT State Variables are: {OKAY (most common), INVALID, INIT (initializing), STANDBY, WARNING, FAILED, OFF, TIMEOUT, SUSPEND}

	CCDSUM = '1 1 '	CCD on-chip bin factors applied during readout, given as the number of pixels summed in the x and y directions.
	BIASSEC = 'UNKNOWN '	[binned pixel] Section of bias/overscan data
	DATASEC = '[1:4096,1:4096]'	[binned pixel] Data section ⁵
	TRIMSEC = '[1:4096,1:4096]'	[binned pixel] Trim section ⁵
	ROI = 'UNKNOWN '	[binned pixel] Region of interest ⁵ UNKNOWN or MULTIPLE
	DETSEC = '[1:4096,1:4096]'	[binned pixel] Section of useful data ⁵
	CCDXPIXE= 0.0000150	[m] Size of pixels
	CCDYPIXE= 0.0000150	[m] Size of pixels
	PIXSCALE= 0.3890000	[arcsec/pixel] Nominal pixel scale on sky
	CCDSTEMP= -90.0000000	[deg C] CCD required temperature
	CCDATEMP= -90.0014267	[deg C] CCD actual temperature
	CCDSESIG= 'N/A '	[mK] CCD temp control servo error signal
	TELMODE = 'AUTOMATIC'	Telescope mode
	TAGID = 'UNSPECIFIED'	Time Allocation Group ID
	USERID = 'neox_robot'	User ID
	PROPID = 'KEY2020B-009'	Proposal ID
	GROUPID = '14F2601_1M0-20210417'	Group ID
	OBSID = 'UNSPECIFIED'	Observation ID
	OBSNOTE = 'Submitted by NEOexchange (by tlister@lcogt.net)'	Observation Note
	SCHEDNAM= 'POND '	Name of scheduler in control
	TRACKNUM= '1192552 '	Request DB tracking number

⁵ These are 'ccd section' formats of the form and specify the range of data in x and y (indexed starting at 1) in the form [x1:x2, y1:y2]. The data array includes pixels from x1 to x2-1 and y1 to y2-1.

	REQNUM = '2454829 '	Request DB request number
	MOLUID = '311471304'	Molecule unique ID
	BLKTYPE = 'POND '	Group type
	BLKUID = '224695671'	Group unique ID
	BLKSDATE= '2021-04-18T17:05:07'	[UTC] Block start date
	BLKEDATE= '2021-04-18T17:24:50'	[UTC] Block end date
	BLKNOMEX= 1183.0000000	[s] Block nominal exec time
	BLKMNPB = 'N/A '	[(0-1)] Maximum lunar phase required
	BLKMNDST= 30.0000000	[deg] Minimum lunar distance required
	BLKSEECO= 'N/A '	Minimum seeing required (Constraint currently not implemented - always 'N/A')
	BLKTRNCO= 'N/A '	Minimum transparency required (Constraint currently not implemented - always 'N/A')
	BLKAIRCO= '1.74'	Maximum airmass required
	SCHEDSEE= 2.3227562	[arcsec] Estimated seeing when group scheduled
	SCHEDTRN= 'N/A '	[(0-1)] Estimated transparency when group sched (Currently not implemented - always 'N/A')
	TRIGGER = 'N/A '	External trigger ID (Currently not used - always 'N/A')
	MOSAIC ='UNSPECIFIED'	Mosaic Pattern Description. One of 'UNSPECIFIED' (default), 'line', 'grid' or 'custom' .
	DITHER = 'UNSPECIFIED'	Dither Pattern Description. One of 'UNSPECIFIED' (default), 'line', 'grid', 'spiral' or 'custom'.
	OBRECIPE= 'N/A '	Observing Recipes required/used (Currently not used - always 'N/A')
	PCRECIPE= 'BANZAI '	Processing Recipes required/used (always 'BANZAI')
	PPRECIPE= 'NEOEXCHANGE '	Post-Processing Recipes required/used. One of 'NEOEXCHANGE' or 'PHOTOMETRYPIPELINE'

		depending on which pipeline was used.
geom:right_ascension_angle	RA = '11:15:59.2892'	[HH:MM:SS.sss] RA where telescope is pointing
geom:declination_angle	DEC = '-49:42:49.235'	[sDD:MM:SS.ss] Dec where telescope is pointing
geom:Reference_Frame_Identification	RADESYS = 'ICRS '	[FK5,ICRS] Coordinate system of the observation
	LST = '08:26:41.45'	[HH:MM:SS.ss] LST at start of current observation
	CAT-RA = '11:15:58.475'	[HH:MM:SS.sss] Catalog RA of the object
	CAT-DEC = '-49:42:47.16'	[sDD:MM:SS.ss] Catalog Dec of the object
	CAT-EPOCH= 2000.0000000	[Year] Catalog epoch of the coordinates
	OFST-RA = '11:15:58.475'	[HH:MM:SS.sss] Catalog RA plus pointing offsets
	OFST-DEC= '-49:42:47.16'	[sDD:MM:SS.ss] Catalog Dec plus pointing offset
	TPT-RA = '11:16:17.554'	[HH:MM:SS.sss] Telescope demand RA
	TPT-DEC = '-49:38:32.99'	[sDD:MM:SS.ss] Telescope demand Dec
Target_Identification.name	OBJECT = '14F2601 '	Object name
	SRCTYPE = MINORPLANET '	Source type
	PM-RA = 0.0000000	[sec/year] Proper motion in RA of the object
	PM-DEC = 0.0000000	[arcsec/year] Proper motion in Dec of the object
	PARALLAX= 0.0000000	[arcsec] Parallax of the object
	RADVEL = 0.0000000	[km/s] Radial velocity of the object
	RATRACK = 0.0000000	[arcsec/s] Non-sidereal tracking in RA
	DECTRACK= 0.0000000	[arcsec/s] Non-sidereal tracking in Dec
	TRACFRAC= 0.5000000	Fraction of the ephemeris rate that telescope is tracking at (MINORPLANET and COMET Source type only)

	TELSTATE= 'OKAY '	Current telescope status. One of the LCOGT State Values ⁴
	ENGSTATE= 'UNKNOWN '	Engineering override state (Not currently used)
	TCSSTATE= 'OKAY '	TCS state. One of the LCOGT State Values ⁴
	TCSVER = '0.4 '	Version number of the TCS software
	TPNTMODL= '20210418170409'	Version number of the pointing model
	UT1-UTC = -0.1779600	[s] UT1-UTC
	POLARMOX= 0.0922000	[arcsec] Polar motion X
	POLARMOY= 0.4264000	[arcsec] Polar motion Y
	EOPSRC = 'IERS BULL. A 2021/04/15'	Source of the EOP Values
	ROLLERDR= 0.0000000	[rad] Driven roller encoder angle
	ROLLERND= 0.0000000	[rad] Non-driven roller encoder angle
	AZDMD = 131.8548020	[deg] Azimuth axis demand
	AZIMUTH = 131.8548101	[deg] Azimuth axis position
	AZSTAT = 'OKAY '	Azimuth axis state. One of the LCOGT State Values ⁴
	ALTDMD = 54.1381120	[deg] Altitude axis demand
	ALTITUDE= 54.1381064	[deg] Altitude axis position
	ALTSTAT = 'OKAY '	Altitude axis state. One of the LCOGT State Values ⁴
	AIRMASS = 1.2328407	Effective mean airmass
	AMSTART = 1.2333181	Airmass at start of observation
	AMEND = 1.2323633	Airmass at end of observation
	ENC1STAT= 'OPEN '	Enclosure shutter 1 state
	ENC2STAT= 'OPEN '	Enclosure shutter 2 state
	ENCAZ = 130.2927328	[deg] Enclosure azimuth
	ENCWLIGHT= 'OFF '	Enclosure white lights state
	ENCRLIGHT= 'OFF '	Enclosure red lights state
	FOLDSTAT= 'N/A '	Fold mirror state
	FOLDPORT= '1 '	Fold mirror port
	FOLDPOSN= 'N/A	N/A'

	M1COVER = 'STOWED '	M1 mirror cover state
	M1HRTMN = 'UNKNOWN '	M1 Hartmann screen state
	FOCDMD = 0.0000000	[mm] Demanded focus position in focal plane
	FOCPOSN = 0.0012756	[mm] Actual focus position in focal plane
	FOCTELZP= 0.1000000	[mm] Telescope default focus
	FOCINOFF= 0.0000000	[mm] Instrument focus offset
	FOCTOFF = -0.0201080	[mm] Thermal correction value
	FOCZOFF = 0.0284520	[mm] Zenith compression correction
	FOCAFOFF= 0.4530000	[mm] Autofocus offset in focal plane
	FOCOBOFF= 0.0000000	[mm] Observer focus offset/defocus in focal pla
	FOCFLOFF= -1.0000000	[mm] Filter focus offset in focal plane
	FOCSTAT = 'HALTED '	Focus state
	M2PITCH = -378.0000000	[arcsec] M2 tilt about vertex in pitch directio
	M2ROLL = 60.0000000	[arcsec] M2 tilt about vertex in roll direction
	CTYPE1 = 'RA---TAN'	Type of WCS Projection
	CTYPE2 = 'DEC--TAN'	Type of WCS Projection
	CRPIX1 = 2048.5	[pixel] Coordinate of reference point (axis 1)
	CRPIX2 = 2048.5	[pixel] Coordinate of reference point (axis 2)
	CRVAL1 = 168.9970383	[deg] RA at the reference pixel
	CRVAL2 = -49.7136764271	[deg] Dec at the reference pixel
	CUNIT1 = 'deg '	Units of RA
	CUNIT2 = 'deg '	Units of Dec
	CD1_1 = 0.000108205489726	WCS CD transformation matrix
	CD1_2 = 1.2508250396E-06	WCS CD transformation matrix
	CD2_1 = 1.2508250396E-06	WCS CD transformation matrix
	CD2_2 = -0.000108205489726	WCS CD transformation matrix
	WMSSTATE= 'OKAY '	WMS system state

	WMSHUMID= 21.6000004	[%] Current percentage humidity
	WMSTEMP = 20.2999992	[deg C] External temperature
	WMSPRES = 830.1986011	[mbar] Atmospheric pressure
	WINDSPEE= 14.1480002	[km/h] Windspeed
	WINDDIR = 254.0000000	[deg E of N] Wind direction
	WMSRAIN = 'CLEAR '	Rain alert
	WMSMOIST= 259.3999939	[mV] Moisture level
	WMSDEWPT= -2.4000001	[deg C] Dewpoint
	WMSCLOUD= -21.6500000	[deg C] Boltwood sky temperature
	WMSSKYBR= 20.2652419	[mag/arcsec^2] Measured sky brightness
	SKYMAG = 20.2652419	[mag/arcsec^2] Computed (expected) sky brightne
	TUBETEMP= 18.9413877	[deg C] Temperature of the telescope tube
	M1TEMP = 'UNKNOWN '	[deg C] Primary mirror temperature
	FOCTEMP = 19.5699997	[deg C] Focus temperature
	ISSTEMP = 'UNKNOWN '	[deg C] ISS temperature
	REFPRES = 830.0652299	[mbar] Pressure used in refraction calculation
	REFTEMP = 20.6000004	[deg C] Temperature used in refraction calculat
	REFHUMID= 21.1000004	[%] Humidity used in refraction calculation
	AGSTATE = 'GUIDING_CLOSED_LOOP'	Autoguider software state
	AGCAM = 'ef04 '	Camera used for autoguiding
	AGLCKFRC= 100.00	[%] Fraction of time AG locked
	AGMODE = 'MAYBE '	Autoguider mode
	AGRA = 169.0260971	[deg] RA of guide star
	AGDEC = -49.0379762	[deg] Dec of guide star
	AGGMAG = 'UNKNOWN '	[mag] Autoguider guide star mag
	AGFWHM = 6.3322300	[arcsec] Autoguider FWHM
	AGMIRDMD= 'UNKNOWN '	[mm] Autoguider mirror demand
	AGMIRPOS= 'N/A,N/A'	Autoguider mirror position
	AGMIRST = 'N/A '	Autoguider mirror state

	AGFOCDMD= -8.7000000	[mm] Autoguider focus demand
	AGFOCUS = -8.7340000	[mm] Autoguider focus position
	AGFOCOFF= 0.0000000	[mm] Autoguider relative focus offset
	AGFOCST = 'In position'	Autoguider focus state
	AGFILTER= 'air '	Autoguider filter
	AGFILTID= 'Unknown'	Unknown
	AGFILST = 'Enabled '	Autoguider filter state
	MOONSTAT= 'UP '	[{UP
	MOONFRAC= 0.3432066	[(0 - 1)] Lunar Illuminated Fraction
	MOONDIST= 96.6917668	[deg] Lunar distance from target
	MOONALT = 26.7509074	[deg] Lunar altitude
	SUNDIST = 130.3860739	[deg] Solar distance from target
	SUNALT = -14.0927250	[deg] Solar altitude
	CLKMODE = 1	Sinistro Readout Mode
	AMPMASK = 15	Sinistro Active Amplifier Mask
	CRSTLK12= 0.00057	[Crosstalk coefficient] Signal from Q1 onto Q2
	CRSTLK13= -0.00001	[Crosstalk coefficient] Signal from Q1 onto Q3
	CRSTLK14= -0.00001	[Crosstalk coefficient] Signal from Q1 onto Q4
	CRSTLK23= 0.00001	[Crosstalk coefficient] Signal from Q2 onto Q3
	CRSTLK21= 0.00067	[Crosstalk coefficient] Signal from Q2 onto Q1
	CRSTLK24= -0.00001	[Crosstalk coefficient] Signal from Q2 onto Q4
	CRSTLK32= -0.00000	[Crosstalk coefficient] Signal from Q3 onto Q2
	CRSTLK31= -0.00000	[Crosstalk coefficient] Signal from Q3 onto Q1
	CRSTLK34= 0.00060	[Crosstalk coefficient] Signal from Q3 onto Q4
	CRSTLK42= -0.00001	[Crosstalk coefficient] Signal from Q4 onto Q2
	CRSTLK43= 0.00064	[Crosstalk coefficient] Signal from Q4 onto Q3

	CRSTLK41= 0.00000	[Crosstalk coefficient] Signal from Q4 onto Q1
	END	

Per-quadrant/amplifier extension header

Class.Attribute Name	Keyword and example	Description
n/a	XTENSION= 'IMAGE '	marks beginning of new HDU
element_array.data_type	BITPIX = 16	Bits per pixel
axes	NAXIS = 2	number of axes
axis_array.sequence_number	NAXIS1 = 2080	
axis_array.sequence_number	NAXIS2 = 2058	
	PCOUNT = 0	Required for FITS extension. Originated for use with FITS Random Groups and represented the number of parameters preceding each group. Not applicable in this case and is hardcoded to 0.
	GCOUNT = 1	Required for FITS extension. Originated for use with FITS Random Groups and specified the number of random groups present. Not applicable in this case and is hardcoded to 1.
	CHECKSUM= '6dAH7Z996dAE6Z79'	checksum for the current HDU
	DATASUM = '2057222353'	checksum of the data records
element_array.value_offset	BZERO = 32768	Number to offset data values by
	CCDSUM = '1 1 '	CCD on-chip bin factors applied during readout, given as the number of pixels summed in the x and y directions.
	DETSEC = '[1:2048,4096:2049]'	[binned pixel] Detector section ⁵
	BIASSEC = '[2055:2080,1:2048]'	[binned pixel] Section of overscan data ⁵
	DATASEC = '[1:2048,1:2048]'	[binned pixel] Data section ⁵

	GAIN = 3.18	CCD gain in electrons per ADU
	EXTVER = 1	Extension instance (Indexing starts at 1)
	EXTNAME = 'SCI '	Extension name
	END	

5.1.2. Calibrated Image FITS Files

Calibrated image FITS files are substantially similar to the Raw image FITS files described above. The main differences are:

- Images are 32bit floats and have no extensions, unlike the 16bit and 4 per-amplifier extensions of the raw data
- The nominal World Coordinate System produced by the telescope control system is updated with the results of the astrometric fit and distorted focal plane keywords are added:

Class.Attribute Name	Keyword and example	Description
	CTYPE1 = 'RA---TPV'	Type of WCS Projection
	CTYPE2 = 'DEC--TPV'	Type of WCS Projection
	CRPIX1 = 2048.5	[pixel] Coordinate of reference point (axis 1)
	CRPIX2 = 2048.5	[pixel] Coordinate of reference point (axis 2)
	CRVAL1 = 188.5365245349	[deg] RA at the reference pixel
	CRVAL2 = 3.934391651307	[deg] Dec at the reference pixel
	CUNIT1 = 'deg '	Units of RA
	CUNIT2 = 'deg '	Units of Dec
	CD1_1 = 0.0001083186419759	WCS CD transformation matrix
	CD1_2 = 7.086566054434E-07	WCS CD transformation matrix
	CD2_1 = 7.134961664775E-07	WCS CD transformation matrix
	CD2_2 = -0.0001083161667394	WCS CD transformation matrix
	PV1_0 = -1.250944646442E-05	TPV distortion coefficient
	PV1_1 = 1.000268945595	TPV distortion coefficient
	PV1_2 = 8.84252138448E-05	TPV distortion coefficient

	PV1_4 = -0.000461714016623	TPV distortion coefficient
	PV1_5 = 0.0004958034330851	TPV distortion coefficient
	PV1_6 = 0.001630130798225	TPV distortion coefficient
	PV1_7 = -0.0110891845677	TPV distortion coefficient
	PV1_8 = -0.00265089866223	TPV distortion coefficient
	PV1_9 = -0.004308891434818	TPV distortion coefficient
	PV1_10 = 0.002733305056832	TPV distortion coefficient
	PV2_0 = 1.657105368321E-05	TPV distortion coefficient
	PV2_1 = 1.000120406293	TPV distortion coefficient
	PV2_2 = -3.608604311969E-05	TPV distortion coefficient
	PV2_4 = -0.00070667792436	TPV distortion coefficient
	PV2_5 = 0.0003298170833812	TPV distortion coefficient
	PV2_6 = -0.0003041124685338	TPV distortion coefficient
	PV2_7 = -0.008090894122916	TPV distortion coefficient
	PV2_8 = 0.001180414469635	TPV distortion coefficient
	PV2_9 = -0.0007768690575623	TPV distortion coefficient
	PV2_10 = 0.004274779664745	TPV distortion coefficient

- Additional FITS keywords are added at the end (following the `CRSTKL41` keyword) by the BANZAI and NEOexchange pipelines:

Class.Attribute Name	Keyword and example	Description
	L1IDMASK= 'cpt1m012-fa06-20200508-bpm-full_frame.fits.fz'	Id. of mask file use
	SATFRAC = 4.43858862226209E-06	Fraction of Pixels that are Saturated
	EXTNAME = 'SCI '	
	L1STATOV= '1 '	Status flag for overscan correction
	OVERSCN1= '3603.83 '	Overscan value that was subtracted ⁶
	OVERSCN2= '3702.52 '	Overscan value that was subtracted ⁶
	OVERSCN3= '5647.39 '	Overscan value that was subtracted ⁶
	OVERSCN4= '5859.05 '	Overscan value that was subtracted ⁶
	BIASLVL = 0.5121187924080999	Bias level that was removed after overscan

⁶ This is the overscan value that is determined from the BIASSEC region in each quadrant and corresponding FITS extension. So OVERSCN1 comes from CCD quadrant 1 marked by EXTVER=1 in the corresponding HDU.

	L1IDBIAS= 'cpt1m012-fa06-20210418-bias-bin1x1.fits.fz'	ID of bias frame
	L1STATBI= 1	Status flag for bias frame correction
	L1IDDARK= 'cpt1m012-fa06-20210418-dark-bin1x1.fits.fz'	ID of dark frame
	L1STATDA= 1	Status flag for dark frame correction
	L1IDFLAT= 'cpt1m012-fa06-20210417-skyflat-bin1x1-w.fits.fz'	ID of flat frame
	L1STATFL= 1	Status flag for flat field correction
	L1MEAN = 106.6193832216579	[counts] Sigma clipped mean of frame background
	L1MEDIAN= 106.4729690551758	[counts] Median of frame background
	L1SIGMA = 0.9677982788085937	[counts] Robust std dev of frame background
	L1FWHM = 1.663800605954238	[arcsec] Frame FWHM in arcsec
	L1ELLIP = 0.2005233413580252	Mean image ellipticity (1-B/A)
	L1ELLIPA= -1.74591402200518	[deg] PA of mean image ellipticity
	WCSERR = 0	Error status of WCS fit. 0 for no error
	PNTOFST = 8.165086369994761	[arcsec] offset of requested and solved center
	L1ZP = 23.69728360103057	Instrumental zeropoint [mag]
	L1ZPERR = 0.002882112647467849	Error on Instrumental zeropoint [mag]
	L1COLORU= 'r-i '	Color used for calibration
	L1COLOR = 0.003469565616307295	Color coefficient [mag]
	L1COLERR= 0.009591620279204063	Error on color coefficient [mag]
	RLEVEL = 91	Reduction level
	PIPEVER = '1.5.5 '	Pipeline version
	L1PUBDAT= '2022-04-18T17:15:30.216000'	[UTC] Date the frame becomes public
	EXTNAME = 'SCI'	extension name
	L1FILTER= 'w '	Copy of FILTER for SCAMP
	END	

5.1.3. Photometry ASCII Table Files

Photometry data are stored as a PDS4 ASCII fixed-width table according to the following format. Note that Field Location uses the PDS4 definition, which is the location, in bytes, of the first character in the field and that location counting begins at one, not zero.

Field	Field Number	Description	Field Location (bytes)	Length (bytes)
validity_flag	1	Flag for photometric validity due to potential blending	1	1
file	2	file name of the calibrated image where data was measured	2	36
julian_date	3	UTC Julian date of the exposure midtime	40	15
mag	4	Calibrated PanSTARRS r-band apparent magnitude of Didymos	56	8
sig	5	1-sigma error on the apparent magnitude	66	6
ZP	6	Calibrated zero point magnitude in PanSTARRS r-band	73	8
ZP_sig	7	1-sigma error on the zero point magnitude	83	6
inst_mag	8	Instrumental magnitude of Didymos	91	8
inst_sig	9	1-sigma error on the instrumental magnitude	101	8
filter	10	Filter used for calibration	111	6
SExtractor_flag	11	Flags associated with the SExtractor photometry measurements, see sextractor_flags.txt in the documents folder for this archive for more detailed description.	119	15
aprad	12	Radius in pixels of the aperture used for the photometry measurement	136	5

5.1.4. Photometry FITS Table Files

Photometry data from the time of impact observations with the FLI imagers are stored as a FITS binary table according to the following format. Note that Field Location uses the PDS4 definition, which is the location, in bytes, of the first character in the field and that location counting begins at one, not zero.

Field	Field #	Description	Field Location (bytes)	Length (bytes)
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filename	1	file name of the calibrated image where data was measured	1	36
mjd	2	UTC Modified Julian date of the exposure midtime	37	8
obs_midpoint	3	ISO8601 datetime string of the exposure midpoint	45	36
exptime	4	Exposure time (seconds)	81	8
filter	5	Name of the filter used	89	36
obs_ra	6	Observed right ascension of Didymos (degrees)	125	8
obs_dec	7	Observed declination of Didymos (degrees)	133	8
flux_radius	8	Radius of the aperture with 50% of the flux (pixels)	141	8
fwhm	9	Full Width Half Maximum of the frame (arcsec)	149	8
mag_aperture_0	10	Magnitude of Didymos in the 0th aperture	157	8
mag_err_aperture_0	11	Magnitude error of Didymos in the 0th aperture	165	8
mag_aperture_1	12	Magnitude of Didymos in the 1st aperture	173	8
mag_err_aperture_1	13	Magnitude error of Didymos in the 1st aperture	181	8
mag_aperture_2	14	Magnitude of Didymos in the 2nd aperture	189	8
mag_err_aperture_2	15	Magnitude error of Didymos in the 2nd aperture	197	8
mag_aperture_3	16	Magnitude of Didymos in the 3rd aperture	205	8
mag_err_aperture_3	17	Magnitude error of Didymos in the 3rd aperture	213	8
mag_aperture_4	18	Magnitude of Didymos in the 4th aperture	221	8
mag_err_aperture_4	19	Magnitude error of Didymos in the 4th aperture	229	8
mag_aperture_5	20	Magnitude of Didymos in the 5th aperture	237	8
mag_err_aperture_5	21	Magnitude error of Didymos in the 5th aperture	245	8
mag_aperture_6	22	Magnitude of Didymos in the 6th aperture	253	8
mag_err_aperture_6	23	Magnitude error of Didymos in the 6th aperture	261	8
mag_aperture_7	24	Magnitude of Didymos in the 7th aperture	269	8
mag_err_aperture_7	25	Magnitude error of Didymos in the 7th aperture	277	8
mag_aperture_8	26	Magnitude of Didymos in the 8th aperture	285	8
mag_err_aperture_8	27	Magnitude error of Didymos in the 8th aperture	293	8
mag_aperture_9	28	Magnitude of Didymos in the 9th aperture	301	8
mag_err_aperture_9	29	Magnitude error of Didymos in the 9th aperture	309	8
mag_aperture_10	30	Magnitude of Didymos in the 10th aperture	317	8
mag_err_aperture_10	31	Magnitude error of Didymos in the 10th aperture	325	8

5.2. Label and Header Descriptions

All LCOGT data products contain time and date information that can be used to sort and correlate data products. LCOGT will generate example PDS4 labels for each data product type.

6. Applicable Software

6.1. Utility Programs

At the current time the DART project has no plans to release any mission specific utility programs.

6.2. Applicable PDS Software Tools

Data products found in the DART Telescopic Observations Bundle can be viewed with any PDS4 compatible software utility. Image data are formatted as FITS data files which can be read by any FITS compatible software viewer or FITS library.

6.3. Software Distribution and Update Procedures

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