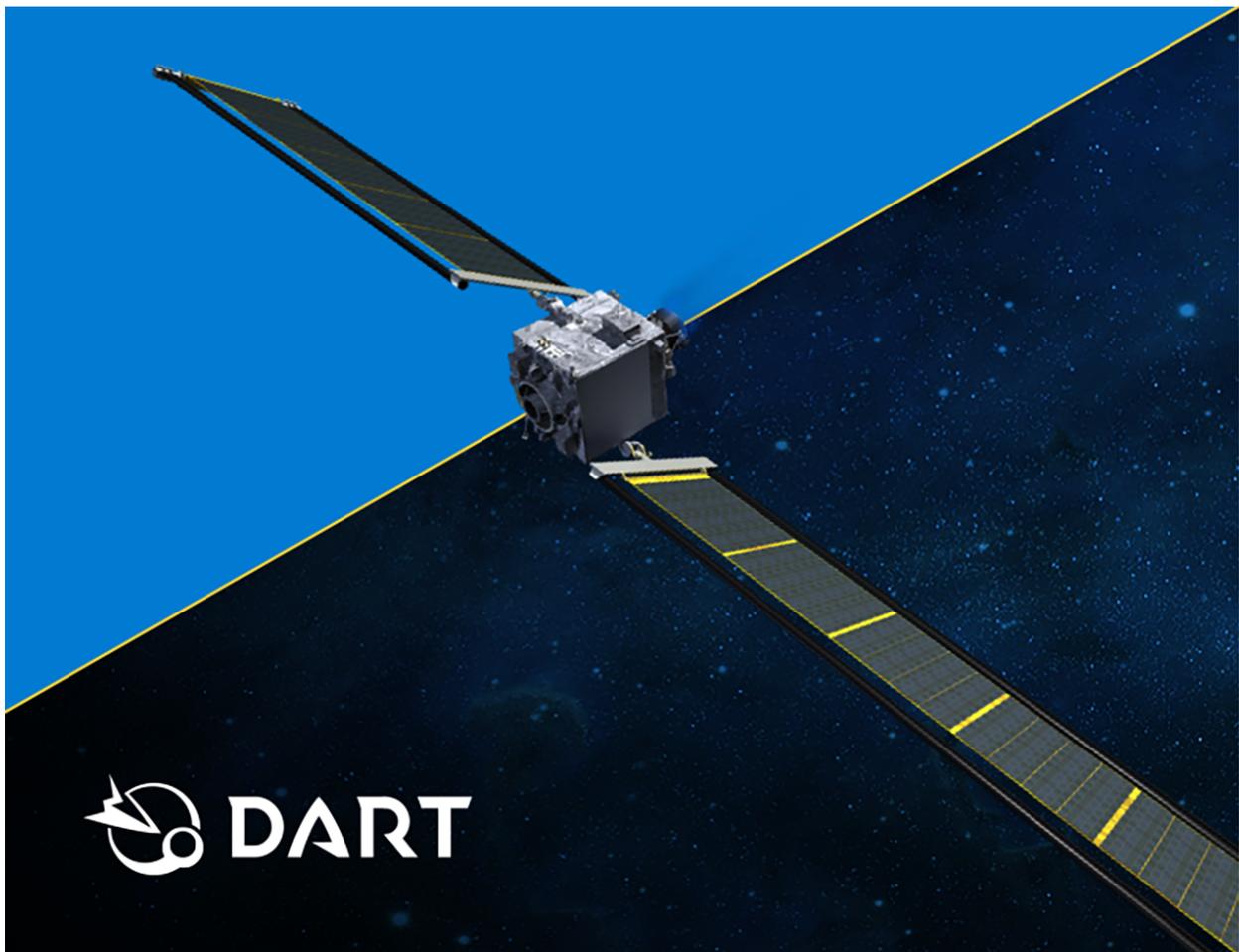


Didymos Reconnaissance and Asteroid Camera for OpNav (DRACO) Uncalibrated/Calibrated Data Product Software Interface Specification



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DRACO Keyword Cheat Sheet



Certain keywords in FITS header can help you find images that suit your needs. Other keywords flag images to avoid or pixels to be aware of. The following is a cheat sheet to those subsets of keywords.

Avoid images with these keyword values*.

Keyword	Values to look for	What these values mean
TSTPTRN	STATHORZ, DYNAHORZ, TWOBX, FLAT	These values indicate that the image is a test pattern.
BADIMAGE	TRUE	If BADIMAGE = 'TRUE', then the metadata and image contain invalid information. Do not use images with BADIMAGE=TRUE for any analyses.

*Look out for these in raw images. No calibrated images should have these keyword values.

Be cautious when analyzing images with these keyword values†.

Keyword	Values to look for	What these values mean
MISPCNT	> 0	MISPCNT >0 indicates a partial image. Missing pixels are set to the value indicated in MISPV.
CALIB	ON	CALIB relates to an onboard calibration table used by SMART Nav. CALIB = ON indicates that on-board calibration was applied to the image. It does <u>not</u> mean that the image was calibrated by the SOC. Images calibrated by the SOC are located in the DRACO Calibrated Data Collection. See the Calibration Pipeline Description for details on how a calibrated image is created when on-board calibration is applied.
ATT_VAL	0	0 means that the attitude information in the FITS header is considered invalid.

†Assuming you've already removed any images users should avoid.

Use these keywords to identify images that meet your needs.

Keyword	Possible values	What these values mean
OBSTYPE	See Table 2 in SIS. Example values include TERMINAL, LIGHTCURVE, STAR_CLUSTER, BADIMAGE, PARTIAL_HDR, etc.	This keyword describes the type of observation during which a DRACO image was taken. Filter on this keyword if you want to hone in a particular set of images (e.g., lightcurve observations).
MPHASE	PRELAUNCH, COMMISSIONING, CRUISE, APPROACH, TERMINAL, FINAL	The DART mission is divided into phases; this keyword states the phase during which the image was acquired. Use this later in the mission to identify the high-resolution FINAL phase images.

Keyword	Possible values	What these values mean
IMGMOD	GLOBAL, ROLLING	Shutter mode used to acquire image. Rolling shutter has better sensitivity but introduces some distortion due to readout.
GAIN	1X, 2X, 10X, 30X	Detector gain setting. The bias, readnoise, etc. levels differ among gain states.
EXPTIME	Image integration time in seconds	Common values are 25, 50, and 90 ms; bias frames have an 87.467 μ s EXPTIME.
WINDOWH	512; 1024	All DRACO image FITS files are 1024x1024. In some cases, the spacecraft sends down a 512x512 window, which the MOC correctly positions in the 1024x1024 frame. If WINDOWH = 512, then pixels outside of that window are set to the value in PXOUTWIN.
ACQ.UTC		This is the image time of validity—the time when the attitude information in the FITS header is valid. See Table 8 for additional detail on how this is calculated.
SMEARIN*	0 to 0.2	Smear in the X, Y, and Z directions, respectively. Images with larger values may look more smeared. See Table 8 and Section 4.3.2.1 for additional details, as well as for some additional keywords to look at if these keywords are blank for a particular image.

Be aware of pixels with these special values[‡].

Keyword	Pixel value to look for	What the value(s) mean
MISPXVAL	-32768 (raw images) 1E10 (calibrated images)	This is the value assigned to missing pixels. You will encounter this value in partial images.
PXOUTWIN	32767 (raw images) -1E10 (calibrated images)	All of the pixels outside of the 512x512 window will be set to this value, in the case of a 512x512 image.
SATPXVAL	1E09 (calibrated images only)	Pixels with this value were saturated.
BADMASKV	-1E09 (calibrated images only)	Pixels with this value have a bad photoresponse and should be ignored.
OORADLUT	+1E08 (calibrated images only)	The DN value in this pixel was too large to be radiometrically calibrated, but the corresponding pixel in the raw image was not saturated.
IOVRFLAG	-1E08 (I/F calibrated images only)	The DN value in this pixel was negative before conversion to I/F.

[‡]An image with these values might look funny with an autostretch.

Full details on all keywords are in this SIS and the Calibration Pipeline Description.

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1. Purpose and Scope

This Software Interface Specification (SIS) describes the Didymos Reconnaissance and Asteroid Camera for OpNav (DRACO) uncalibrated and calibrated data products. The DART Science Operations Center (SOC) located at Johns Hopkins University Applied Physics Laboratory (APL) produces these products and distributes them to the DART Investigation Team (IT) and the Planetary Data System (PDS).

This document provides users with a detailed description of the data products, how they were generated, and how they are organized in the archive. The document is intended to provide sufficient information to enable users to read and understand the data products. The intended audience is the scientists who will analyze the data, including those associated with the DART mission and those in the general planetary science community.

2. Applicable Documents and Constraints

This DRACO 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 DRACO data product SIS is responsive to the following DART documents:

1. DRACO Calibration Pipeline Description, July 2022
2. DART Coordinate System for Didymos and Dimorphos, March 2021

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

1. Fletcher et al., 2022. Didymos Reconnaissance and Asteroid Camera for Opnav (DRACO): Design, Fabrication, Test and Operation, Proc. SPIE, Astronomical Telescopes and Instrumentation 2022.
2. Fletcher et al., Design of the Didymos Reconnaissance and Asteroid Camera for OpNav (DRACO) on the Double Asteroid Redirection Test (DART), Proc. SPIE 10698, Space Telescopes and Instrumentation 2018: Optical, Infrared, and Millimeter Wave, 106981X (6 July 2018), doi: [10.1117/12.2310136](https://doi.org/10.1117/12.2310136)
3. Bekker, D., Smith, R., Tran, M. Q., 2021. Guiding DART to impact – the FPGA SoC design of the DRACO image processing pipeline. 2021 IEEE Space Computing Conference, 122–133. doi: [10.1109/SCC49971.2021.00020](https://doi.org/10.1109/SCC49971.2021.00020)
4. Chen et al., Small-Body Maneuvering Autonomous Real-Time Navigation (SMART Nav): Guiding a Spacecraft to Didymos for NASA’s Double Asteroid Redirection Test (DART), Proc. Advances in the Astronautical Sciences AAS/AIAA Guidance, Navigation and Control 2018, 164, AAS 18-063.

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 DRACO SIS and the DRACO Calibration Pipeline Description, the SIS takes precedence.

Table 1. Interface Relationships

Name	Type	Owner
DRACO Calibration Pipeline Description	Document	DART SOC

4. Data Product Characteristics and Environment

4.1. Instrument Overview

The Didymos Reconnaissance and Asteroid Camera for OpNav (DRACO) is a narrow field-of-view imager on NASA's Double Asteroid Redirection Test (DART) spacecraft (Figure 1). DRACO is designed to support optical navigation of the spacecraft and ensure impact with Dimorphos (the secondary member of the Didymos system), to refine system properties (e.g., orbit, rotation rate, pole), to characterize the surface characteristics and shape of Dimorphos during the Terminal and Final mission phases, and to constrain the location of the impact site. The latter observations will allow insight into target properties, presence or absence of blocks at the impact site, and impact angle, which will feed into the estimation of dynamical changes in the Didymos system resulting from the DART impact.

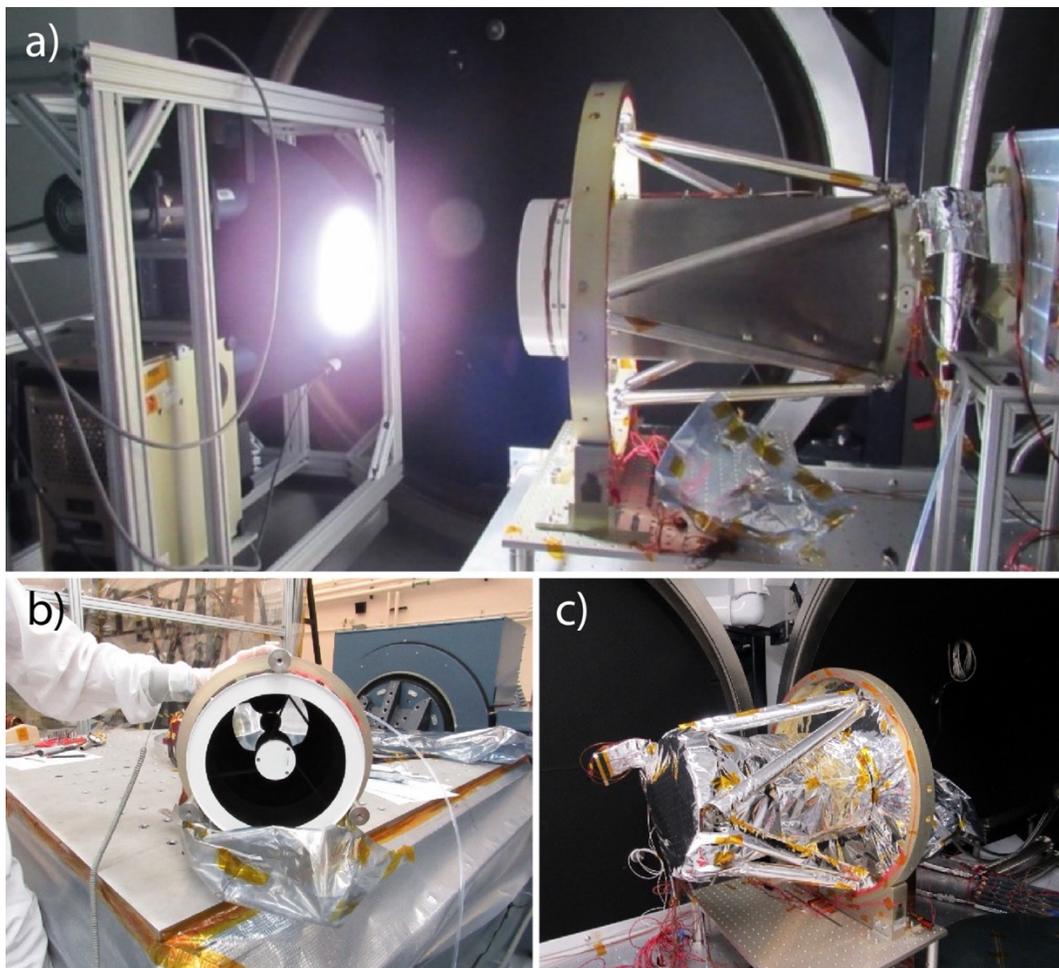


Figure 1. Photographs of DRACO during ground testing: a) throughput testing; b) before vibration testing; c) during setup of thermal testing.



Figure 2. Location of DRACO on the DART spacecraft. The cover is shown in its open position.

DRACO is mounted on the $-Z$ side of the spacecraft (Figure 2). Looking down the Z axis, DRACO's frame is rotated approximately -135° from the spacecraft frame (Figure 3; see DRACO frames kernel for more details). A set of twelve hydrazine thrusters provide spacecraft attitude control and precision pointing for DRACO. DRACO is thermally isolated and operated at -80°C (telescope structure) to -20°C (detector). A cover mounted to the spacecraft was closed during integration and test, launch, and early commissioning. It provided protection for DRACO by preventing direct sunlight hitting the back mirror and providing thermal dissipation via the thermal strap.

DRACO is a narrow-angle, panchromatic, visible light imager consisting of an optical telescope assembly (OTA), a focal plane array with associated electronics, and image processing software. DRACO is derived from the Long Range Reconnaissance Imager (LORRI) on New Horizons (Cheng et al., 2008). DRACO has a Ritchey-Chrétien telescope with an aperture of 208 mm, operates at $f/12.6$, and has a field of view of 0.29° . The focal plane array is a 2560×2160 pixel, panchromatic, front-side illuminated complementary metal–oxide–semiconductor (CMOS) sensor with $6.5 \mu\text{m}$ pixels with digital output. The instantaneous field of view (IFOV) is $2.48 \mu\text{rad}$ unbinned, or $4.96 \mu\text{rad}$ binned. The detector is sensitive to light from 400–1000 nm (Figure 4).

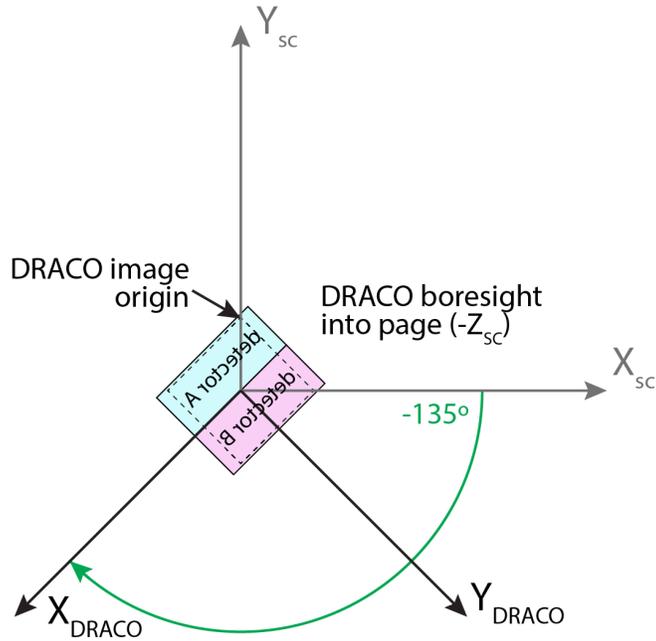


Figure 3. The DART spacecraft (DART_SPACECRAFT) and DRACO (DART_DRACO) frames oriented correctly with respect to one another. The origin of the DRACO frame is at the camera focal point. See the DART frames kernel and DART DRACO instrument kernel for more information. Detector A and B labels are purposefully backwards to illustrate that the view is looking out the DRACO boresight (i.e., looking through the back of the detector). The dashed box shows the location of Window 1.

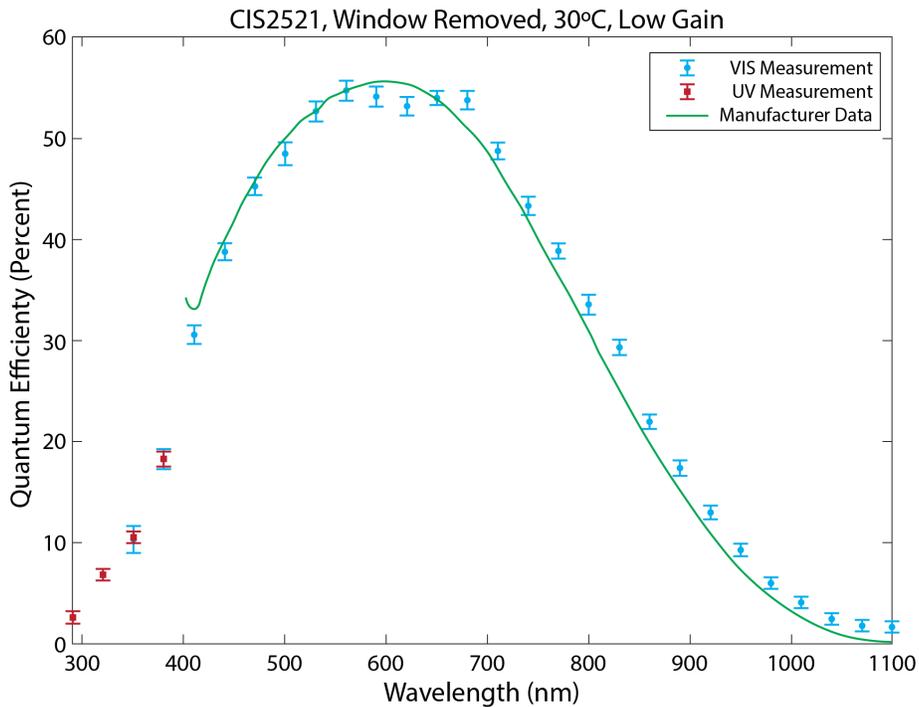


Figure 4. Quantum efficiency of the DRACO detector.

4.1.1. Detector Layout

The detector consists of two independent halves (“detector A” and “detector B”), each 2560×1080 pixels in size (Figure 5). The image is read out starting with the row along the centerline dividing the two detector halves. Readout starts with column 0 and proceeds along the row from left to right. Corresponding pixels from both halves are read out simultaneously. Subsequent rows are read out away from the centerline. The full image is assembled within the Focal Plane Electronics (FPE) and transferred to the Single Board Computer (SBC) Field Programmable Gate Array (FPGA) via a high-speed SERDES link. Section 4.1.4 describes the DRACO On-board Image Processing Pipeline.

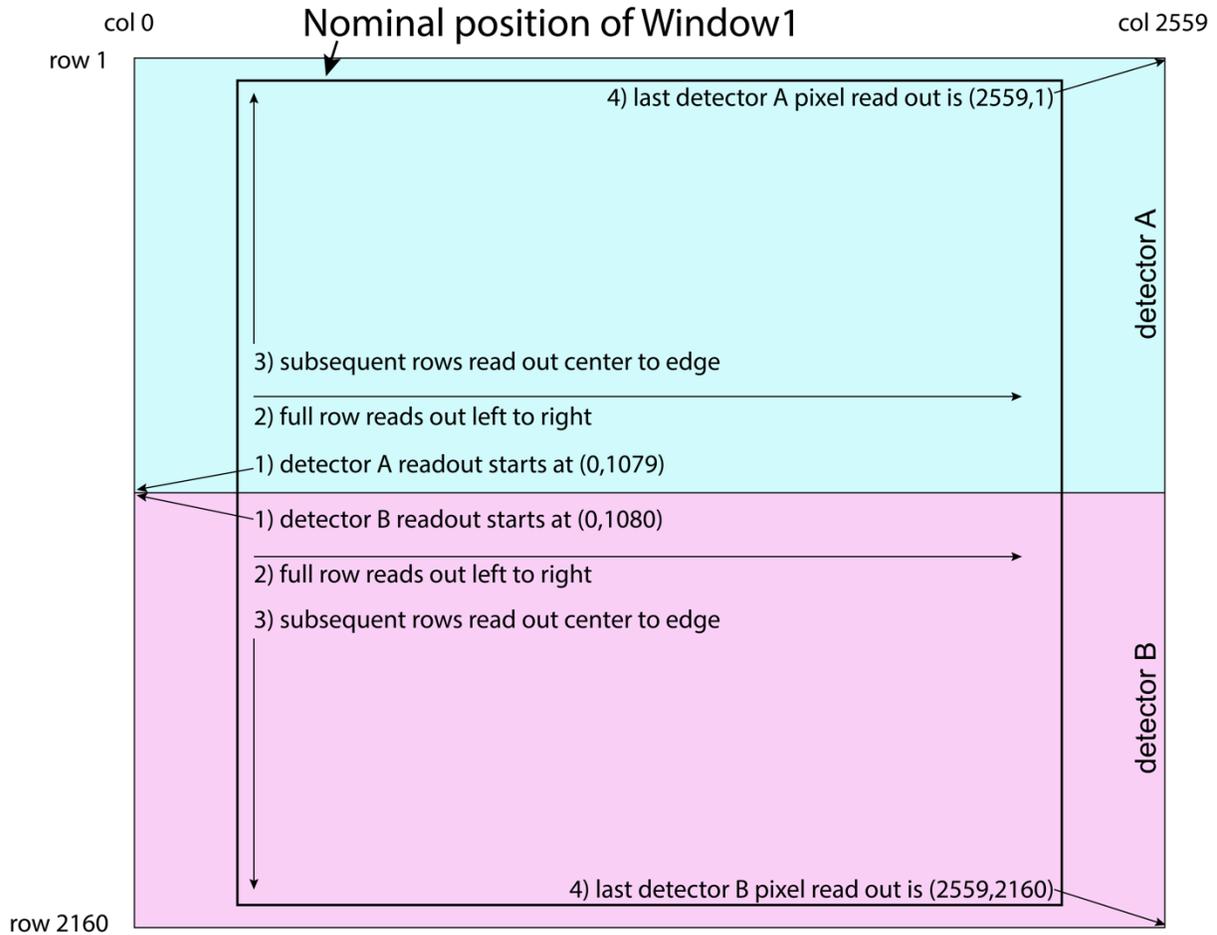


Figure 5. Diagram of the DRACO detector, indicating pixel numbering, readout direction, and the position of Window1 (see Section 4.1.4.1). Rows are numbered starting from 1 to account for the due to the header row (see Section 4.1.4). Corresponding pixels from both halves are read out simultaneously. Note, to show an image as an observer looking out the DRACO boresight would see, it has to be flipped vertically to place the origin at the lower left (see Section 4.1.6.2).

4.1.2. Shutter Mode

The DRACO detector runs in both global and rolling shutter readout modes. In global shutter readout mode the entire detector integrates over the same time period. Global shutter images will have higher noise relative to rolling shutter images, but no spatial distortion beyond that caused by the optics ($\leq 0.1\%$). In particular, global shutter images exhibit “popcorn noise” (see [Figure 6](#)) - single (unbinned) pixels that exhibit elevated DN values related to charge traps near the source follower amplifier that capture and emit charge that looks like signal coming from the sense node. Some of the popcorn noise is random telegraph signal (RTS) and is observed to transition rapidly (e.g., turning on and off in successive images one second apart). Some of the popcorn noise is flicker noise that transitions between multiple levels and not just on and off. The longest timeframe over which the RTS or flicker noise can remain hot is not known, but can persist for months. Global shutter mode can be used to minimize spatial distortion due to spacecraft jitter and drift. Global shutter mode requires the readout of a reset frame along with every data frame. The final image is created within the FPE by subtracting the reset frame from the data frame before it is transferred to the FPGA. Reset frames with no signal have a slightly larger signal average than the data frame with no signal. The image bottoms out at zero DN. As a result, the backgrounds of raw and calibrated global shutter images will contain many pixels with DN=0.

In rolling shutter mode each row of the detector integrates over the same amount of time, but the exact moment in time captured by each line is different (i.e., each line begins integrating one line time, 87.467 μ s, after the previous line). For DRACO, each half of the detector is read out independently, from the centerline outwards ([Figure 5](#)). Rolling shutter images do not exhibit “popcorn noise”. Rolling shutter images will have lower noise relative to global shutter images, but can cause apparent motion if the spacecraft is not stable over the course of image acquisition. DRACO typically employs rolling shutter mode to maximize the signal-to-noise ratio (SNR) when imaging faint sources (e.g., stars, early detection of Didymos). Because rolling shutter images do not have reset frames subtracted before transmission to the FPGA, the fixed pattern noise (the variable response of the detector halves and columns) can be seen in raw rolling shutter images (see [Figure 6](#)). This bias pattern is removed in the calibration step (see [Section 4.3.2.2](#) and the DRACO Calibration Pipeline Description for more details).

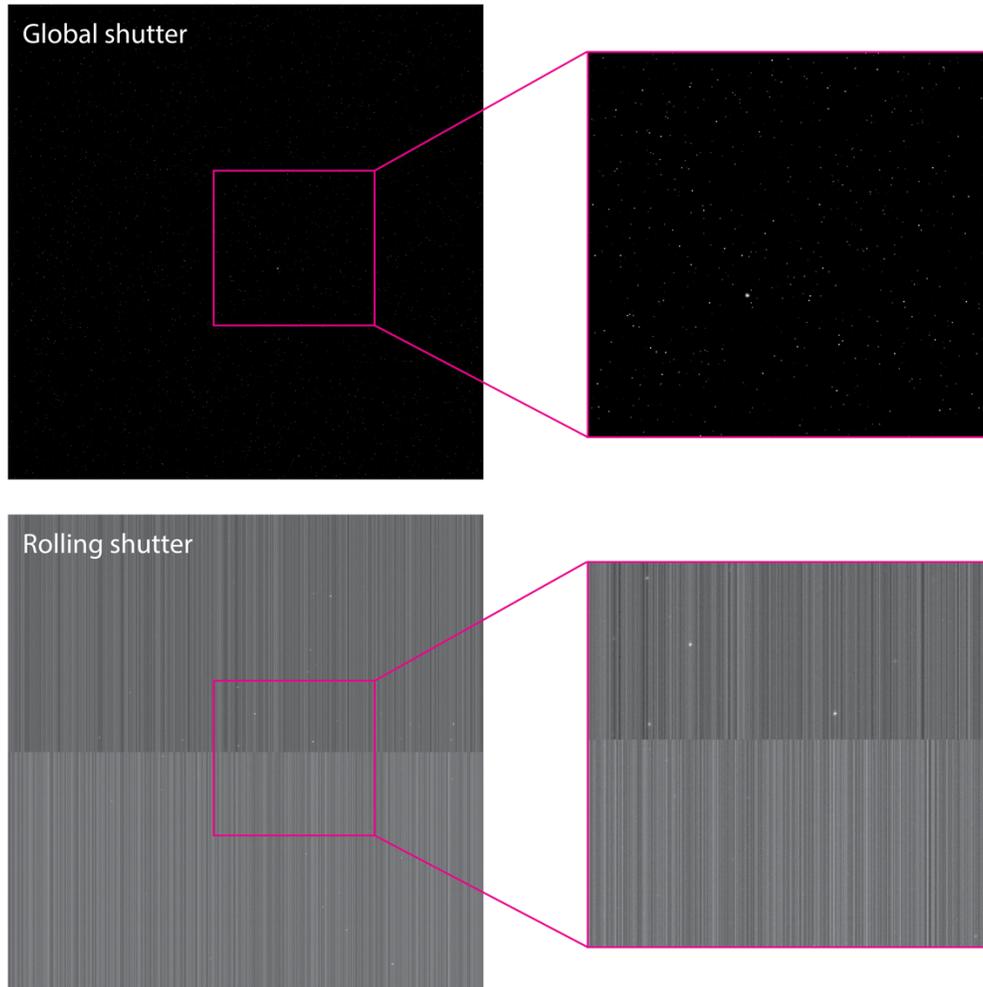


Figure 6. Examples of raw global and rolling shutter images. Top: Raw global shutter image of a star cluster. A reset frame was subtracted on board the spacecraft. In addition to a number of stars, single-pixel “popcorn” noise can be observed. Bottom: Raw rolling shutter image of a star cluster. The fixed-pattern noise is obvious because a bias frame has not yet been subtracted. Rolling shutter images do not exhibit popcorn noise. Images here are shown with the origin at the lower left to match the scene an observer looking out the DRACO boresight would see.

4.1.3. Gain

The DRACO detector has dual high and low gain output, although only one output can be recorded at a time. The gain of each amplifier can be selected to maximize the full-well capacity (low gain) or to maximize the SNR (by minimizing read noise; high gain). There are four possible gain settings: low gain amplification can be set to 1× or 2×; high gain amplification can be set to 10× or 30×. DRACO typically employs high gain, 30× when operating in rolling shutter mode to maximize the SNR, and low gain, 1× when operating in global mode during the Terminal and Final mission phases to prevent saturation and maximize the dynamic range of the images.

4.1.4. DRACO On-board Image Processing Pipeline

The on-board image processing pipeline receives data from the FPE over a SERDES link. This data stream includes both the image data (2560×2160) and one row of header data that comes in front of the image data. Effectively, the dimensions of the data received by the FPGA are 2560×2161 . This “header row” is a separate packet from the image, but travels with the image through the on-board image processing pipeline until downlink and receipt at the MOC. The MOC ground software correlates the header row with the image data and uses the metadata in the header row to populate fits keywords for each image (see Section 4.3.3).

Figure 7 illustrates the two paths taken by images through the DRACO on-board image processing pipeline. The remainder of this section describes these steps in detail. Further detail on the DRACO on-board image processing pipeline can be found in Bekker et al. (2021). Additional processing steps are applied onboard the spacecraft to images of Didymos and Dimorphos taken during the Terminal and Final mission phases (see Section 4.1.6) to provide information to the on-board autonomous navigation software, which is called SMART Nav (Small-body Maneuvering Autonomous Real-Time Navigation; Chen et al., 2018). These “SMART Nav Data Path” steps are described Section 4.1.4.6 and produce information used to populate several keywords.

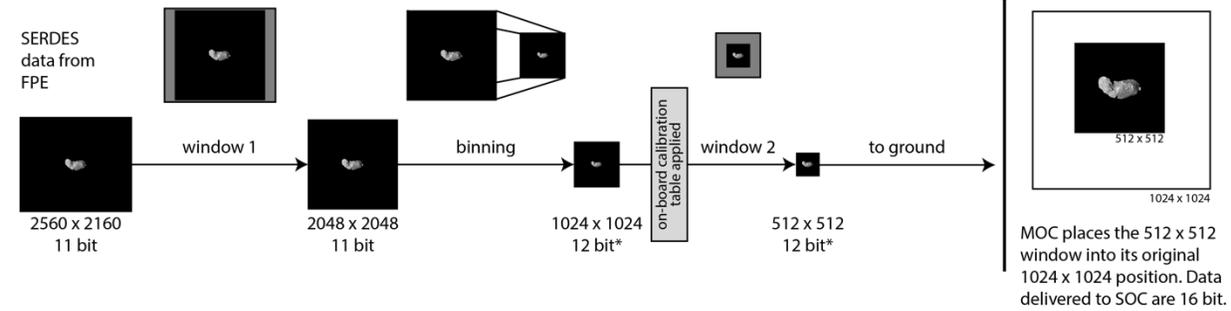
4.1.4.1. Windowing 1

Detector data from the FPE board comes into the SBC FPGA via a high-speed SERDES link. In the first windowing step, the 11-bit image data (no header row) is windowed from 2560×2160 pixels (format of detector) to 2048×2048 pixels. The WIN1SIZE keyword defines the size of Window 1. The location of Window 1 is at the center of the 2560×2160 detector. The keywords WIN1XSTA, WIN1XEND, WIN1YSTA, and WIN1YEND define the location of Window 1 with respect to the full 2560×2160 detector with header row and unbinned pixels. Because the position of Window 1 is fixed, WIN1XSTA=256, WIN1XEND=2303, WIN1YSTA=57, and WIN1YEND=2104 in all DRACO images. For all keywords describing Window 1, the image dimensions are effectively 2560×2161 , where row 0 is the header row.

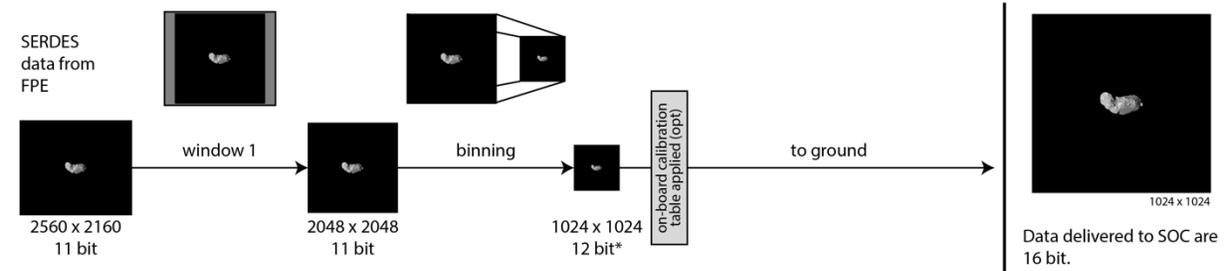
In order to improve the SNR and further reduce the data volume, each image is 2×2 binned (i.e., four adjacent pixels are added together). This operation reduces the overall number of pixels to 1024×1024 , but grows the pixel bitwidth to 13 bits. In order to simplify downstream processing and packing, the data is truncated to 12 bits. Binning is only applied to images that are 2048×2048 pixels after windowing 1 step. The keyword BINNING indicates whether binning was on or off for a particular image. The keyword TRUNC indicates whether the most significant bits or least significant bits were kept.

4.1.4.2. Binning

a) Path for Terminal, Terminal Rehearsal, and Final Phase images



b) Path for OpNav, calibration, and lightcurve images



*Cropped from a 13-bit summation. See MSB keyword to determine the truncation method.

Figure 7. The baseline path of an image through the DRACO on-board image processing pipeline for images sent to a) the radio for downlink to Earth (e.g., Terminal and Final phase images) and b) the SSR for downlink at a later time (e.g., OpNav, calibration, lightcurve images).

4.1.4.3. On-board Calibration

A 1024×1024 (12-bit) calibration table can be subtracted from binned data (unsigned, floors at 0). This calibration table is stored onboard, and can be updated at various points in the mission. This table also contains a map of bad pixels (1-bit per pixel). The calibration table subtraction is effectively a bias subtraction, and improves the performance of SMART Nav targeting. The baseline plan is to subtract the on-board calibration table from all images during the Terminal and Final phases of the mission and during SMART Nav tests. Section 5.2.3 provides further details on the structure of the on-board calibration table and bad pixel map as delivered to the PDS. See this same section to understand how the DRACO Calibration Pipeline reverses the on-board calibration table on the ground. The keyword CALIB indicates whether the on-board calibration step is on or off, and the CALFILE keyword lists the name of the file uploaded for the on-board calibration step. On the spacecraft, the calibration table and bad pixel map are combined into a single file, so only a single filename is listed in CALFILE. On the ground, these are represented in two separate files whose file naming conventions are detailed in Section 4.3.4, Table 7.

4.1.4.4. Buffering in SRAM

After the optional on-board calibration step, the image data is stored into Static Random-Access Memory (SRAM) in a triple-buffering scheme. From here, image data are either sent to the radio for downlink to Earth or are sent to non-volatile flash memory (solid state recorder, SSR) for

storage. The keyword DATAMODE describes whether the images were directly downlinked or recorded and played back.

4.1.4.5. **Windowing 2**

In order to support real-time downlink of images at the 3 Mbps radio transmission rate, the data can be further windowed (Figure 7) to 512×512 pixels (12-bit). This reduced size allows for continuous image downlinking before impact during the Terminal and Final phases of the mission. This second windowing step can be bypassed. The keywords WIN2XSTA, WIN2XEND, WIN2YSTA, and WIN2YEND define the location of Window 2 with respect to a 1024×1024 image with header row following the Window 1 and/or binning process. The position of Window 2 is not fixed (see next paragraph). For these keywords, the image dimensions are effectively 1024×1025 , where row 0 is the header row. These keywords are populated from information in the header row.

The location of Window 2 is centered on the region of interest (ROI; the unresolved Didymos system at first, switching to Dimorphos closer to impact) based upon centroid information from SMART Nav (see Section 4.1.4.6). Upon receipt at the MOC, each 512×512 image is placed back into its original location within the binned, 1024×1024 image display frame (now with no header row). The PXOUTWIN keyword defines the pixel value used by ground software to populate all pixels within the 1024×1024 image that are outside the 512×512 second window.

4.1.4.6. **SMART Nav Data Path**

The SMART Nav algorithm (Chen et al., 2018) is designed to autonomously navigate the spacecraft during its terminal approach to Dimorphos. It comprises image processing and guidance, navigation, and control (GNC) algorithms. Responsibility for navigation is handed over to the on-board SMART Nav algorithm 4 hours prior to impact. As part of this handoff, SMART Nav is initialized based on ground estimates of the current trajectory.

Images used by SMART Nav proceed through additional on-board processing steps performed on the FPGA (Bekker et al., 2021): thresholding, blobbing, and centroiding. Images enter the SMART Nav Data Path prior to the Window 2 step, still in their 1024×1024 plus header row form (after completing the binning step). Image processing results (centroids) are then used in the targeting module to identify and track the two asteroids; the targeting data is used in the GNC algorithms to autonomously keep the spacecraft on course.

In the thresholding step, each pixel is marked with a 1-bit flag (true/false) signifying whether the value is above a specified DN threshold value, defined by the FORETHRS keyword. This distinction is used to differentiate foreground pixels from background pixels, and is used in connected component analysis, known as blobbing and centroiding.

In the blobbing step, the thresholding flag of a pixel and its connected neighbors is checked to determine whether the pixel is part of the same “blob” as its neighbors, and an ID is assigned to the pixel. Pixels that belong to the same blob receive the same ID value. To reduce processing time downstream, very small blobs that are more likely to be the result of sensor noise than asteroids are discarded; the BLOBTHRS keyword states the maximum number of pixels for a blob to be discarded at this step (i.e., blobs that are smaller or equal to BLOBHRS are discarded; blobs that are larger are kept for further processing).

As the blobs are identified, feature data for each blob is computed. These data include the center coordinates (or centroid) of each blob (based on the information in the GCXSUM, GCYSUM, and GNPXLS keywords), along with the overall “intensity” of the blob (i.e., sum of all pixel

values in the blob, the GINTSM keywords), and the bounding box of the blob (not captured in a keyword). This information is then passed on to SMART Nav targeting, which is able to search through the list of centroids to locate the center of Didymos (DID_X and DID_Y) and, later, Dimorphos (the DIM_X and DIM_Y keywords). The center-point of the 512×512 Window 2 (as described in Section 4.1.4.5 above) is set by SMART Nav based on the computed location of Dimorphos from the previous image. The SNGROI_C and SNGROI_R keywords are based on this information.

4.1.5. Image Processing Slot

DRACO image processing firmware has two configuration “slots” that define the image processing pipeline. These two configuration slots (A/B) alternate as image frames are received from the FPE over the SERDES link. For the FPE, the slots are differentiated only by integration time and are referred to as integration time 1, corresponding to slot-A, and integration time 2, corresponding to slot-B. Image-A goes through the processing pipeline configured from slot-A settings, and Image-B goes through the processing pipeline configured from slot-B settings. The option to alternate settings is only available for global-shutter images. The baseline plan is to have slot-A and slot-B settings match. The keyword IMGSLLOT indicates which image processing mode slot was used to acquire a given image.

4.1.6. Observational Profile and Data Acquisition

The DART mission is divided into six main phases for the purpose of organizing DRACO data products: Pre-launch, Commissioning, Cruise, Approach, Terminal, and Final. The MPHASE keyword states the mission phase during which a given image was taken.

1. *Pre-launch phase*: The pre-launch mission phase refers to the period of software development and testing of the data processing pipeline, before launch. Data products generated during this phase include calibration files created during the ground testing of the instrument as well as data products created for peer review.
2. *Commissioning phase (2021-11-24 through 2021-12-21)*: The commissioning phase lasted for 27 days after launch. Images acquired during this phase include calibrations and functional testing for DRACO to ensure proper operations.
3. *Cruise phase (2021-12-22 through 2022-08-27 TBD)*: The cruise phase began after the commissioning phase and runs until the beginning of the approach phase. Images acquired during this phase are used for several purposes, including for optical navigation (OpNav), testing of SMART Nav algorithms, characterization of star tracker noise, and star calibrations to characterize distortion, responsivity, and stray light.
4. *Approach phase*: The approach phase begins when the Didymos system is first acquired by DRACO, ~ 30 days before impact, and extends until the Terminal phase begins. During this phase, DRACO acquires a long-range suite of observations where the Didymos system is mostly not resolvable to be used for OpNav and to extract light curves complementary to ground-based observations.
5. *Terminal phase*: The terminal phase begins with the initiation of DART's autonomous navigation, ~ 4 h prior to impact, and extends until the final phase begins. During this

phase, the separation between Didymos and Dimorphos can be resolved, and DRACO images support both autonomous navigation (via Smart Nav algorithms) and characterization of Didymos and Dimorphos. The final image to contain both members of the system will be acquired ~4 minutes before impact, at a scale of ~7 m. By the end of this phase, images will be obtained of Dimorphos that have a 2×2 binned pixel scale of ~3.5 m. The final image to contain any portion of Didymos will also occur around this time.

6. *Final phase:* The final phase comprises the last ~4 min of the DART mission. During this phase, all DRACO images will be devoted to characterization of Dimorphos, as autonomous navigation will have been completed. In the baseline trajectory at ~20 s prior to impact, DRACO achieves its requirement to image Dimorphos at a pixel scale of 66 cm. Higher-resolution images will continue to be acquired in the final seconds of the DART spacecraft operations, which end upon impact. Planned real-time Deep Space Network (DSN) coverage enables downlink of these images to Earth, including images acquired 7 s before impact (down to ~20-cm binned pixel scale) and earlier, and possibly including images acquired during the final 7 s.

DRACO images support several activities. The OBSTYPE keyword states the observation type for each image, which can make it easier for a user to find identify images of interest. Details about the valid OBSTYPE values are given in [Table 2](#). The TARGET keyword can be used to identify the main target of an observation sequence. Further information about these keywords can be found in [Table 8](#).

Table 2. Information about the valid OBSTYPE keyword values

OBSTYPE	Purpose
TERMINAL	Taken in the Terminal and Final mission phases
LIGHTCURVE	Taken to derive a lightcurve
STAR_CLUSTER	Images of stars taken for calibration purposes (e.g., geometric, radiometric, stray light)
STREAMING	Continuous stream of images transmitted directly to Earth for testing purposes
SMARTNAV_TEST	SMART Nav testing
OPNAV	Optical navigation
CALIBRATION	Calibration
DARK	Dark calibration
BIAS	Bias calibration
FUNCTIONAL_TEST	DRACO checkout
OTHER	Various
PARTIAL_HDR	Identifies images that are missing keywords in their fits headers (see Section 4.1.6.1 for more information)
BAD_IMAGE	Identifies images whose image data and FPE metadata are not reliable and should not be used for analysis (see Section 4.1.6.1 for more information)
LIGHTCURVE_REHEARSAL	Mission rehearsal of spacecraft operations; not a real lightcurve
OPNAV_REHEARSAL	Mission rehearsal of spacecraft operations; not a real opnav

TERMINAL_REHEARSAL	Mission rehearsal of spacecraft operations; not real terminal observations
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The imaging sequences acquired by DRACO over the course of the DART mission are detailed in Appendix 7.4.

4.1.6.1. Image Acquisition

DRACO images are acquired at a 1.04 Hz rate (0.962 seconds per image). The shutter mode (Section 4.1.2), gain (Section 4.1.3) and exposure time are defined for every imaging sequence. All DRACO images start out 2560 × 2160 pixels, are windowed to 2048 × 2048 pixels, and are 2 × 2 binned to 1024 × 1024 pixels (see also Sections 4.1.4.1 and 4.1.4.2). Table 3 lists the seven valid configurations for DRACO image processing to set the application of the on-board calibration table (Section 4.1.4.3), window 2 step (Section 4.1.4.5), and data playback (Section 4.1.4.4).

Table 3. Valid Configuration for DRACO Image Processing During Stream/Record

Image Type *	On-board Calibration Table	Window 2	Data Collection Mode	Final Image Size
TERMINAL, STREAMING, TERMINAL_REHEARSAL, SMARTNAV_TEST	On	512 × 512	Radio	512 × 512
SMARTNAV_TEST, STREAMING	Off	512 × 512	Radio	512 × 512
OTHER	Off	512 × 512	SSR	
LIGHTCURVES, BIAS, OPNAV_REHEARSAL, LIGHTCURVE REHEARSAL	Off	Bypass	Radio	1024 × 1024
SMARTNAV_TEST	On	Bypass	SSR	1024 × 1024
OPNAV, STAR_CLUSTER, DARK, BIAS, OPNAV_REHEARSAL, SMARTNAV_TEST	Off	Bypass	SSR	1024 × 1024

*All listed configurations were used during functional testing

Dropped images: Real-time downlink of 512 × 512 images (e.g., those from the Terminal and Final phases) occurs at ~0.90 Hz (1.107 seconds per image). Approximately 7 out of 8 (~87%) such images will make it to the ground as a result of the mismatch between this downlink rate and the 1.04 Hz imaging rate. The buffering scheme means that the latest image will always be downlinked. Real-time downlink of 1024 × 1024 images (e.g., lightcurve images) occurs at ~0.22 Hz (4.448 seconds per image). Approximately 1 out of five (~22%) such images will make it to the ground as a result of the mismatch between this downlink rate and the 1.04 Hz imaging

rate. There is no *a priori* way to know which images will be lost and which will be downlinked. No images are dropped when they are recorded to the SSR and played back at a later time.

Partial images: When DRACO is in streaming mode, the radio must be continually fed with either actual DRACO image data frames or idle frames. In idle mode, no image or data processing occurs. When the command is executed to begin or stop streaming DRACO images directly to the radio, it occurs mid-idle frame and results in a partial image. A keyword value `MISPCNT >0` (missing pixel count) indicates a partial image. Missing pixels are set to -32768 in raw images and 1E32 in calibrated images.

- The first image in a direct-to-radio (streamed) sequence will be missing the beginning portion of the data, including the DRACO header row (see Section 4.1.4), so fits keywords populated using this information are empty. Such an image will be labeled as `OBSTYPE=PARTIAL_HDR` and designated as `BADIMAGE=TRUE`. Such images should not be used for any analyses. Example: `dart_0376599992_26784_01_raw.fits`.
- The last image in a streamed sequence will be missing the end portion of the data. The header information will be present, so fits keywords can be populated and this image can be used for analysis. Example: `dart_0380603034_08537_01_raw.fits`.

Bad images: There are a few scenarios that result in DRACO images that should not be used for analysis. These images are identified using the keyword value `BADIMAGE=TRUE` in the fits header to alert users to the fact that the image data and FPE metadata are not reliable for that image. **Users should NOT use images with `BADIMAGE=TRUE` for any analyses.** The scenarios that result in a keyword value `BADIMAGE=TRUE` are:

- DRACO reconfiguration: For some imaging sequences, the DRACO detector is reconfigured during the observation to use a different imaging mode, gain setting, or exposure time. The first image or two acquired after the DRACO detector is reconfigured will have inaccurate image data and FPE metadata (e.g., the `IMGMOD`, `GAIN`, `EXPTIME`, and `TRUNC` keyword values will not match what was commanded). Example: `dart_0376162040_16925_01_raw.fits`. Lightcurve, terminal, and final images are not affected as DRACO is not reconfigured during these imaging sequences.
- DRACO misconfiguration: DRACO was misconfigured while acquiring images `dart_0376147120_43856_01_raw.fits` through `dart_0376161226_45633_01_raw.fits` on the first day of data acquisition (2021-12-02).
- Partial header: Images labeled with `OBSTYPE=PARTIAL_HDR` are missing the DRACO header row, so fits keywords populated using this information are empty. See “Partial images” description earlier in this section for more information and an example image name.
- Test pattern: The test pattern overwrites the DRACO header row (see Section 4.1.4), so fits keywords populated using this information are unreliable. Example: `dart_0376146984_05334_01_raw.fits`.

4.1.6.2. Image Flip

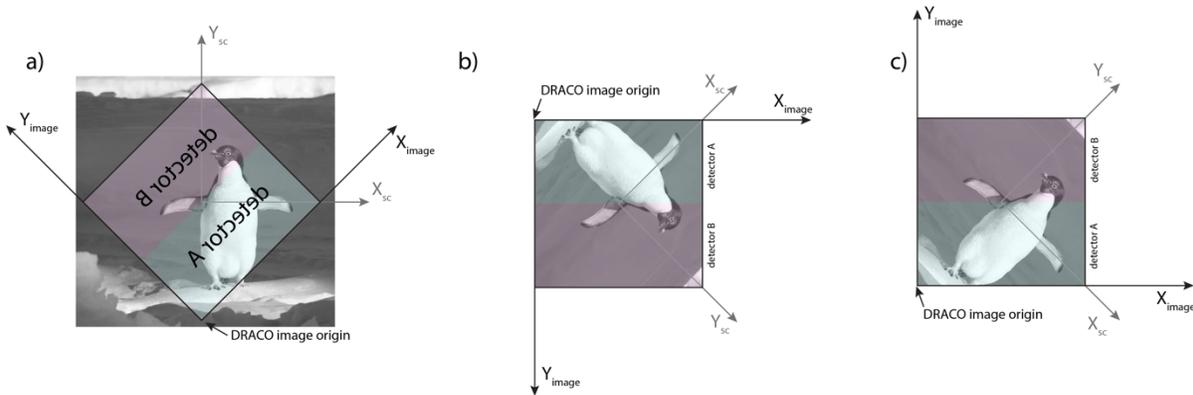


Figure 8. a) An example of a scene an observer looking out the DRACO boresight would see. The spacecraft and DRACO frames shown here are each oriented with respect to the scene, and not with respect to one another (see [Figure 3](#) for their mutual orientation). Detector A and B labels are purposefully backwards to illustrate that the view is looking out the DRACO boresight (i.e., looking through the back of the detector). The square image here corresponds to the central 2048x2048 pixels of the detector (Window 1, see [Figure 5](#)). B) The scene as it appears on the DRACO detector, or in the image when viewed with software that places the image origin at the upper left corner. The image is mirror flipped across the x axis from reality. C) The scene as it appears when viewed with software that places the image origin at the lower left corner. This view matches reality.

Different software may label the origin as (0,0) or (1,1). Different fits viewers may place the origin in a different position (e.g., upper left corner vs lower left corner). A DRACO image appears as it would if you were looking out the DRACO boresight when viewed with a fits viewer that places the origin at the lower left. SAO DS9 is an example of a program with this convention. Opening a DRACO image with a program where the origin is at the upper left (e.g., ImageJ, GraphicConverter) will flip the image vertically. The browse pngs included in the DRACO archive can be used to verify the correct orientation of a corresponding DRACO fits image. Software that utilizes the PDS4 XML to open and display the image will automatically display the image in the proper orientation due to the PDS4 Display dictionary keywords. [Figure 8](#) illustrates the relationship of the DRACO and spacecraft frames with respect to the scene an observer looking out the DRACO boresight would see, and how the image looks when displayed with software that places the image origin at the upper left ([Figure 8b](#), mirror flipped with respect to reality) or lower left ([Figure 8c](#), correctly oriented with respect to reality). The browse PNG files delivered as a part of the DRACO raw image (Section 4.3.2.1) and calibrated image (Section 4.3.2.2) collections can be used to verify the image display. The difference in response between the two halves of the detector in rolling shutter raw images can also be used to confirm the flip is correct (e.g., [Figure 6](#)).

4.2. Data Product Overview

This SIS describes the uncalibrated and calibrated image data acquired by DRACO. All DRACO images and their associated calibration files are 1024×1024 arrays formatted natively as binary Flexible Transport Image System (fits) files with a single header data unit (HDU), with the

exception of the radiometric lookup tables, which are comma separated value (csv) ASCII files. Metadata are captured in the headers (see Section 5.2 for a description of these metadata).

The specific DRACO data products described by this SIS are:

1. DRACO Raw Image Data – Images that have been reassembled from downlinked telemetry with complete image metadata including instrument settings, in units of DN. These images are stored as 32-bit fits files. See Section 5.2.1 for more details.
2. DRACO Calibrated Image Data – Images that have been corrected for bias, dark current, and flat field, and calibrated into physical units (that depend on whether the image contains a point source or extended source) by the DRACO calibration pipeline. These images are stored as 32-bit fits files. See Section 5.2.2 for more details.
3. DRACO Calibration Files – Files needed to process image data. These files are: on-board calibration table; bad pixel map; bias frames; dark current frames; flat field; radiometric lookup tables. These files are stored as 1024 × 1024, 32-bit fits files, except for the radiometric lookup tables, which are ASCII csv files. See Section 5.2.3 for more details.
4. DRACO Image Backplanes – Image cubes that include location, illumination, and geometric values for each pixel. These files are stored as 32-bit, 16-plane fits files. See Section 5.2.4 for more details.

4.3. Data Processing

All DRACO data processing is performed at the DART SOC. This section provides general information about data product content, format, size, and production rate. Specifics of the data processing pipeline can be found in Section 4.3.3 and data formats in Section 5.

4.3.1. Data Processing Level

Table 4 describes PDS4 data processing level of the DRACO data products covered by this SIS. The relationship to NASA and Committee on Data Management and Computation (CODMAC) data processing levels and definitions for both conventions are given in Appendix 7.3.

Table 4. DRACO Data Processing Levels

DRACO Data Product	NASA Product Level	PDS4 Data Processing Level	Unit	Description
Raw Images	Level-0	Raw	DN	Images reassembled from downlinked telemetry with complete image metadata including instrument settings, states, and geometry.
Calibrated Image	Level-1B	Calibrated	$W m^{-2} nm^{-1} sr^{-1}$ or unitless I/F	Images calibrated to physical units. The data are represented in radiance when keyword IOVERF = “SKIP” and in reflectance

				when IOVERF = "PERFORM".
Calibration Files	Level-4	Calibrated	various	Files needed to process image data. In this archive the calibration files are co-located with the Calibrated Data.
Image Backplanes	Level-4	Derived	various	Backplanes containing additional per-pixel information. See Table 5 for a list and description of the image backplanes.

4.3.2. Data Product Generation

4.3.2.1. Raw Images

DRACO image and housekeeping telemetry are received by the MOC from the DSN. The MOC reconstructs images from the raw telemetry and populates a suite of fits keywords, which includes information on DRACO mode, spacecraft attitude, SMART Nav threshold estimates of centroids, and records of any windowing, binning, and calibration done via the on-board image processing pipeline. The MOC stores the image in the fits file in 16-bit integer format and delivers it to the SOC. The SOC then converts the fits file such that the images are stored as 32-bit floats. This conversion is done to standardize the DRACO data products. The SOC also adds additional information, such as TARGET, MPHASE (mission phase), and OBSTYPE (observation type) to the fits header. If OBSTYPE is not TERMINAL or SMARTNAV_TEST, all SMART-Nav-related keywords should be ignored. See the DRACO Calibration Pipeline Description for additional details. The resultant fits header is defined in Section 5.2.1. Keyword values are directly derived from DRACO telemetry (including the DRACO header row), the GNC correlation packet, and some other spacecraft telemetry packets to which the MOC has direct access. Ground software requires that the GNC packets be time-stamped with the same image capture time as an image in order to correlate. However, the GNC correlation packet is generated at a 1 Hz rate, which is slightly slower than the DRACO 1.04 Hz imaging rate. Once every ~25 seconds, two images will be captured during the same second, but only one correlation packet will be generated in that second. Therefore, one in every ~26 images will not correlate with a GNC packet. When the packet is not available, the keywords derived from the GNC correlation packet will be left blank (see Section 5.2.1).

Smear and quaternion values are calculated independently onboard the spacecraft (ESTSC_Q*, SMEARIN*) and on the ground by the SOC (SOCQUAT*, SMERSIN*) so that this information is available even for images that do not correlate on the spacecraft (and therefore have blank values for ESTSC_Q* and SMEARIN*). The values of keywords calculated onboard the spacecraft and by the SOC will differ because the ESTSC_Q* and SMEARIN* keywords are computed from high-rate GNC data onboard the spacecraft, whereas SOCQUAT* and SMERSIN* are based on reconstructed SPICE kernels, which have a slower sample rate than the onboard GNC software. The smear-related keywords (SMEARIN*, SMERSIN*) are useful for

identifying images most affected by smear, but they do not perfectly correlate with the magnitude of smear in the image.

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

- A 32-bit fits file with one Header Data Unit (HDU) containing the metadata header fields and the data unit of the windowed array (1024 pixels x 1024 pixels). The data are represented as DN.
- A browse PNG created from the raw fits file. Pixel values indicating “outside of window” or “missing data” will be set to zero in the browse PNG. Note, the browse PNG files are oriented as the scene would appear to an observer looking out the DRACO boresight.

4.3.2.2. Calibrated Images

DRACO calibrated images have gone through the calibration pipeline at the SOC, as described in the DRACO Calibration Pipeline Description. The calibration pipeline appends 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: in-flight bias and dark current images; test patterns; images identified as BADIMAGE=TRUE (images taken around detector reconfigurations; images with images taken with a misconfigured instrument; partial headers; test patterns). Additional data needed to interpret the calibrated images, such as bias frames, dark current frames, and flat field, are included as part of the DRACO Calibrated Data Collection (see also Section 5.2.3).

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 (1024 pixels x 1024 pixels). The data are represented in radiance ($\text{W m}^{-2} \text{nm}^{-1} \text{sr}^{-1}$) when keyword IOVERF = “SKIP”. The data are represented in reflectance (I/F, unitless) when keyword IOVERF = “PERFORM”. The conversion to I/F is performed for Final Phase images only. 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 calibrated fits file. Pixel values indicating “outside of window” or “missing data” will be set to zero in the browse PNG. Note, the browse PNG files are oriented as the scene would appear to an observer looking out the DRACO boresight.

Calibrated images whose processing ends with a conversion to radiance will have “rad” added to their filename. Calibrated images whose processing ends with a conversion to I/F will have “iof” added to their filename. See the DRACO Calibration Pipeline Description Sections 4.4.7 and 4.4.8 for more information. Neither this document nor the DRACO Calibration Pipeline Description discuss at length calibration activities or results. These topics will be treated in papers by Fletcher et al. and Ernst et al., with expected publication dates in 2022 or 2023. Keywords in the calibrated image fits header (e.g., SATPXVAL, BADMASKV, OORADLUT, and IOVRFLAG) identify pixels to be cautious about when analyzing images (see [Table 8](#), [Table 9](#), and the DRACO Cheat Sheet at the beginning of this document).

4.3.2.3. Calibration Files

The following calibration files will be developed from in-flight and/or ground calibration data: on-board calibration table; bad pixel map; bias frames, dark frames; flat field; radiometric lookup

tables. Calibration files will be saved in fits file format with the exception of the radiometric lookup tables, which are in ASCII csv format.

A detailed description of the calibration files and the calibration process is found in the DRACO Calibration Pipeline Description document (see Section 2).

The calibration files will be included in the DRACO Calibrated Data collection.

4.3.2.4. Image Backplanes

Backplanes are generated only for images collected during the Final phase. A number of location, illumination, and geometric parameters have been calculated at each DRACO pixel center that intersects either Didymos or Dimorphos using spacecraft position and observational geometry derived from the respective highest-resolution Didymos and Dimorphos shape models that are archived with the PDS as part of the DART Shape Model Collection (to be delivered in Jan–Mar 2023) and described in the DART Derived Data Product Software Interface Specification document. The intersection of the shape model with a ray originating at the spacecraft in the pixel direction is found. That facet determines the plane for the backplane calculation. For images that contain both Didymos and Dimorphos, backplanes are calculated for each body independently: if the pixel intersects Didymos the backplane values are calculated in the Didymos body fixed frame; if the pixel intersects Dimorphos, they are in the Dimorphos body fixed frame.

Each of the DRACO backplane files is a 16-plane image cube in fits format. The planes of the cube contain the information detailed in [Table 5](#), calculated at the center of each pixel:

Table 5. Description of image backplanes

Plane Number	Plane Name	Description	Units
1	Pixel value	Pixel values of the calibrated image	I/F
2	X coordinate	X coordinate of the intercept with the surface of an asteroid in body-fixed reference frame	km
3	Y coordinate	Y coordinate of the intercept with the surface of an asteroid in body-fixed reference frame	km
4	Z coordinate	Z coordinate of the intercept with the surface of an asteroid in body-fixed reference frame	km
5	Latitude	Planetocentric latitude	degrees
6	Longitude	Planetocentric longitude	degrees east (0–360)

7	Radial distance	Radial distance from the asteroid center of figure	km
8	Solar incidence angle	Solar incidence angle	degrees
9	Emission angle	Emission angle	degrees
10	Solar phase angle	Solar phase angle	degrees
11	Horizontal pixel scale	Horizontal pixel scale measured from range to surface and shape	m
12	Vertical pixel scale	Vertical pixel scale measured from range to surface and shape	m
13	Surface slope	Average surface slope relative to gravity*	degrees
14	Elevation	Average elevation relative to gravity*	m
15	Gravitational acceleration	Average gravitational acceleration*	m s ⁻²
16	Gravitational potential	Average gravitational potential*	J kg ⁻¹

* The calculations for a given body take the gravitational pull of the other body into account.

The values used to populate Planes 13–16 were calculated using the method described by Werner and Scheeres (1997), using a constant density for Didymos of 2170 kg/cm³ (TBR, based on updates after measurements in flight) and a rotation rate of 7.7E-4 (TBR, see above) rad/s and for Dimorphos of 2170 kg/cm³ (TBR see above) and a rotation rate of 1.5E-4 (TBR, see above) rad/s. The gravitational potential was computed via integration. A reference gravitational potential equivalent to a “geoid” on Earth was obtained from the area-averaged root-mean-square of the gravitational potential. This reference potential provides the elevation on the surface of the asteroid once divided by the local magnitude of the gravitational acceleration. The density and rotation also provide via integration the magnitude and direction of the gravitational acceleration at the surface. The slope given is obtained by taking the inverse cosine of the dot product of the normal to each plate model facet with the vector describing the direction of the gravitational acceleration at the center of each plate model facet. For more information on these calculations, see the DART Derived Data Product Software Interface Specification document.

Each final Level-4 image backplane file is:

- A single HDU, 16-plane, 1024 (sample) × 1024 (line), 32-bit floating point fits file. The first plane of the fits file contains the calibrated image for which the backplanes are derived. The contents of the 16 planes are detailed in [Table 5](#). More details about these files can be found in Section 5.2.4.

These image backplane files may be read into the U.S. Geological Survey's Integrated Software for Imagers and Spectrometers (ISIS, version 3) using the command 'fits2isis' on the fits file. This command will generate an ISIS cube file that can be displayed using the 'qview' routine. To

open one of the backplane fits files in an image analysis package such as ENVI, set the header offset to the value stored in the XML label under <Header><object_length unit="byte">.

A planetocentric coordinate system is employed, which is body-centered, using the center of figure as the origin. A complete discussion of the coordinate systems and how they are deployed in the mission can be found in the DART Coordinate System for Didymos document.

4.3.3. Data Flow

The MOC reconstructs DRACO images from the raw telemetry and populates a suite of fits keywords. Additional fits headers are then added by the SOC (see also Section 4.3.2.1). Calibrated images are created by the DRACO Calibration Pipeline (see also Section 4.3.2.2). Derived products (image backplanes) are generated by the SOC (see also Section 4.3.2.4). 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 6). Raw, calibrated, and derived data products are stored at the SOC. These products, with the calibration files and associated documentation, are combined to form the DRACO collections within the DART Spacecraft Bundle, which is delivered to the Small Bodies Node (SBN) of the PDS. The full list of collections described in this SIS is: DRACO Raw Data Collection, DRACO Calibrated Data Collection, DRACO Derived Data Collection, and the Documentation collection specifically for the DRACO documentation. This archive provides one public access point to the DRACO data. The DRACO 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.

Figure 9 shows the DRACO data flow from raw telemetry to derived data products, and how the data are shared with the public.

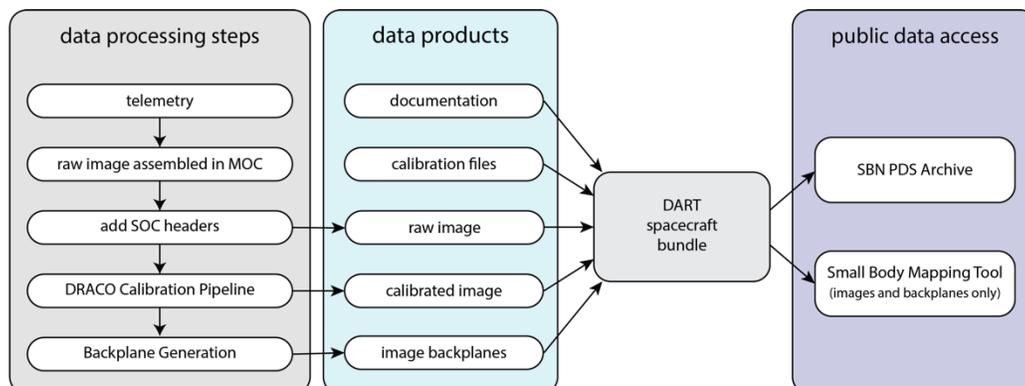


Figure 9. DRACO data processing flow diagram.

4.3.4. Labeling and identification

All DRACO data products are labeled 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 except that the label file has an .xml extension.

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

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

dart_SSSSSSSSSS_#####_<product type>.<extension>

The file name sections are described in Table 6.

Table 6. Definition of DRACO filename

File name section	Description
SSSSSSSSSS	10-digit value of IMGTMSEC (see Section 5.2.1 for keyword description)
SSSSS	5-digit value of IMGTM SUB (see Section 5.2.1 for keyword description)
##	two digit version number, e.g., “01”
<product type>	defines product as one of the following types: <ul style="list-style-type: none"> • raw • rad (calibrated image converted to radiance, see Section 4.3.2.2) • iof (calibrated image converted to I/F, see Section 4.3.2.2) • geo (backplanes)
<extension>	the file extension. “.fits” for fits file format, “.png” for PNG files.

The naming convention for the DRACO calibration files is shown in Table 7. For more information about these files, refer to the DRACO Calibration Pipeline Description Document.

Table 7. File formats and naming conventions of calibration inputs

Pipeline input	File format	File naming scheme
On-board calibration table	1024x1024 32-bit floating point fits (2x2 binned from 2048x2048 window1)	draco_onboardcaltable_date-of-creation.fits (e.g., draco_onboardcaltable_20200910.fits)
Bad pixel map	1024x1024 32-bit floating point fits (2x2 binned from 2048x2048 window1)	draco_bad_pixels_date-of-creation.fits (e.g., draco_bad_pixels_20200910.fits)
Bias frames	1024x1024 32-bit floating point fits (2x2 binned from 2048x2048 window1)	draco_bias_mode_gain_temperature_date-of-delivery.fits (e.g., draco_bias_global_1x_n20c_20210225.fits) (An “n” indicates a negative temperature value.)

Dark current frames (if able to be measured)	1024x1024 32-bit floating point fits (2x2 binned from 2048x2048)	draco_dark_mode_gain_temperature_date-of-delivery.fits (e.g., draco_dark_global_1x_10int_n20c_20210225.fits) (An "n" indicates a negative temperature value.)
Flat fields	1024x1024 32-bit floating point fits (2x2 binned from 2048x2048)	draco_flat_date-of-delivery.fits (e.g., draco_flat_20210225.fits)
Radiometric look-up tables	.csv	draco_lookup_mode_gain_date-of-delivery.csv (e.g., draco_lookup_global_1x_20210225.csv)

4.4. Standards used in Generating Data Products

4.4.1. PDS Standards

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

4.4.2. Time Standards

Time standards used by the DART mission conform to PDS time standards. All DRACO data products contain both the spacecraft clock time at the start of data acquisition and a conversion to UTC at the start of the data acquisition to facilitate comparison of data products.

4.4.3. Coordinate Systems

All coordinate systems used by the DART 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 DART Coordinate System for Didymos document.

4.4.4. Data Storage Conventions

All DRACO data products with the exception of the radiometric lookup tables are stored natively as binary fits files and conform to the fits 3.0 standard. The radiometric lookup tables are stored as ASCII csv files.

4.5. Data Validation

Data validation falls into two types, validation of the science data and validation of the compliance of the archive with PDS archiving and distribution requirements. The first type of validation will be carried out by the SOC and the Investigation Team, and the second will be overseen by the PDS, in coordination with the SOC.

The formal validation of data content, adequacy of documentation, and adherence to PDS archiving and distribution standards is subject to an external peer review. The peer review will be scheduled and coordinated by the PDS. The peer review process may result in "liens," actions recommended by the reviewers or by PDS personnel to correct the archive. All liens must be resolved by the SOC. Once the liens are cleared, PDS will do a final validation prior to

packaging and delivery. When data are prepared for submission to PDS, the SOC will use PDS-provided validation tools to ensure conformance to PDS standards.

Continuous validation of the data products will be performed throughout the mission, as the Project will be utilizing the PDS4 data products as they are generated and the data do not exist in any form other than PDS4 data products.

5. Detailed Data Product Specifications

The following sections provide detailed data product specifications for the DRACO uncalibrated and calibrated data products.

5.1. Data Product Structure and Organization

The DRACO data archive is organized by processing level and then by mission phase. Mission phases are defined in Section 4.1.6.

All image data are 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 DRACO document collection for example labels for each type of DRACO data product. “DRACO Documentation” refers to the documentation used to describe the DRACO products. This includes, but is not limited to, the DRACO SIS, calibration pipeline description, and published papers.

The DRACO collection directory structure within the DART Spacecraft Bundle is as follows. The root directory of the bundle is “dart”. The folder containing the DRACO data collections is named “data_draco<processing level>”.

The “data_dracoraw” folder contains the data in the DRACO Raw Data Collection: raw fits file, browse PNG, and associated XML label.

The “data_dracocal” folder contains the data in the DRACO Calibrated Data Collection: calibrated fits file, browse PNG, and associated label. This collection also includes the calibration files and their associated labels.

The “data_dracoddp” folder contains the data in the DRACO Derived Data Collection: backplanes fits file and associated label.

There is also a “document_draco” folder to separate DRACO specific documentation from that of other upcoming collections, e.g., the Shape Model Collection.

```
/root
  /data_dracoraw/
  /data_dracocal/
  /data_dracoddp/
  /document_draco/
```

5.2. Data Format Descriptions

DRACO images are stored in the fits file format. These follow the fits Standard as referenced by Section 4.4.4. Pointing information and other ancillary information will be parsed from the fits header and stored in the PDS4 label associated with the fits file.

5.2.1. Raw Image Data

The Level-0 raw DRACO image format is a single HDU, 1024 (sample) × 1024 (line), 32-bit floating point fits file, 2×2 binned from the original 2048 × 2048 window1, in units of DN. Metadata contained in the fits header and mapping to class and attribute in the PDS4 .xml label structure is listed in Table 8. The Class.Attribute Name column is left blank for fits keywords not mapped to the .xml label.

Table 8. DRACO Level-0 Raw 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	DRACO images delivered to the SOC will always be 32 bit. Raw images are converted from the original 11- or 12-bit integer data. Calibrated images are the result of applying the calibration files, themselves in 32-bit floating point, to the raw images. Backplanes images include additional geometry data calculated as single-precision floats. All are stored in big-endian as per the FITS standard.	-32
	NAXIS = 2 / number of data axes	Number of axes; all DRACO images have 2 axes.	2
Axis_Array. sequence number	NAXIS1 = 1024 / length of data axis 1	Number of rows, all DRACO images have 1024 rows.	1024
Axis_Array. sequence number	NAXIS2 = 1024 / length of data axis 2	Number of columns, all DRACO images have 1024 columns.	1024
	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 raw it is the time fits is transformed to 32-bit float and keywords added. 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= 'DART' / spacecraft name	DRACO is on the spacecraft called DART.	DART
Observing_System_C omponent. name	INSTRUME= 'DRACO' / Instrument name	Name of instrument. Only one instrument, so always DRACO.	DRACO

Class.Attribute Name	Keyword and example	Description	Range of values
	APID= '333' / Application ID of science data	Application ID of science image data: the images themselves	333
	MISPCNT= '0' / The number of missing pixels.	Ground software will provide the number of missing pixels, not including areas that were not downlinked because of windowing.	0 to 1048576.
Special_Constants. missing_constant	MISPVAL = '-32768' / the value assigned to missing pixels	Ground software would use this pixel value to populate all pixels within a 1024x1024 image that are missing.	-32768
Special_Constants. not_applicable_constant	PXOUTWIN= '32767' / Value assigned to pixels outside window2	Ground software would use this pixel value to populate all pixels within a 1024x1024 image that are outside of the 512x512 second window (see WIN2X* and WIN2Y*).	32767
	IMGTMSEC= '298271898' / [sec] image time	Time the first bit of the image was read into the FPGA on the SBC, in spacecraft clock notation, as reported by GNC. This is also called the image capture time. Number is in integer seconds.	Time since t=0, as defined in the SCLK kernel. Left blank when not available.
	IMGTMSUB= '21314' / [subsec] image time, 16-bit subseconds	Time the first bit of the image was read into the FPGA on the SBC, in spacecraft clock notation, as reported by GNC. This is also called the image capture time. Number is subsecond clock ticks, where each tick represents 20 microseconds (1/50,000). In some images, the comments for IMGTMSEC and IMGTMSUB will differ slightly from what is listed here. This is because the value for this keyword can come from either the image data packet (if no GNC packet), or the GNC packet (overrides what was in the image data packet). The different comments make it obvious what the source of the value is. The value itself would be the same in either case, so the effect on the end user is negligible.	0 to 49999. Left blank when not available.

Class.Attribute Name	Keyword and example	Description	Range of values
	CORTMSEC= '298271898' / [sec] correlation time	Time when the first bit of the image was read into the FPGA on the SBC, in spacecraft clock notation. Number is in integer seconds. This correlation time is used by the MOC to correlate the image and housekeeping data.	Time since $t=0$, as defined in the SCLK kernel. Left blank when not available.
	CORTMSUB= '123' / [subsec] 8-bit subseconds	Subsecond when the first bit of the image was read into the FPGA on the SBC, in spacecraft clock notation. This correlation time is used by the MOC to correlate the image and housekeeping data. This subsecond tick represents 1/256 sec. Subsecond resolution is part of the DART-standard secondary header and is enough to uniquely identify and correlate the image and housekeeping data.	0 to 255. Left blank when not available.
	SN_SEC= '298271898' / [sec] SMART Nav time	Time when the image data is processed by SMART Nav, in spacecraft clock notation. Number is in integer seconds.	Time since $t=0$, as defined in the SCLK kernel. Left blank when not available. If OBSTYPE is not TERMINAL or SMARTNAV_TEST, all SMART-Nav-related keywords should be ignored.

Class.Attribute Name	Keyword and example	Description	Range of values
	SN_SUB= '21314' / [subsec] SMART Nav time 16-bit subseconds	Subsecond when the image data is processed by SMART Nav, in spacecraft clock notation. Number is subsecond clock ticks, where each tick represents 20 microseconds (1/50,000).	0 to 49999. Left blank when not available. If OBSTYPE is not TERMINAL or SMARTNAV_TEST, all SMART-Nav-related keywords should be ignored.
	FPE_SEC= '323548618' / [sec] MET first pixel arrives at SBC	32-bit MET seconds of when first pixel arrives at SBC as recorded in DRACO metadata. Should be consistent with IMGTMSEC.	Time since t=0, as defined in the SCLK kernel.
	FPE_SBSS= '25000' / [subsec] MET 16bit subsec first pxl arr. at SBC	16-bit MET subseconds of when first pixel arrives at SBC as recorded in DRACO metadata. Should be consistent with IMGTMSEC.	0 to 49999.
	FPE_EBSS='128' / [subsec] MET 8bit subsec first pxl arr. at SBC	8-bit MET subseconds of when first pixel arrives at SBC; LSB = 1/256 s, derived from 16-bit version (MSB-justified, 4-bits unused in pix 411). Should be consistent with CORTMSUB.	0 to 255.
	ESTAQSEC = '298271898' / [sec] est. latch time	Estimated Image Time of Validity, in integer seconds, computed <i>before</i> the image is actually acquired. Time at which GNC information is latched.	Time since t=0, as defined in the SCLK kernel. Left blank when not available.
	ESTAQSUB= '1234' / [subsec] est. latch time, 16-bit subseconds	Subsecond Estimated Image Time of Validity computed <i>before</i> the image is actually acquired. Time at which GNC information is latched. This subsecond tick represents 1/50000 sec.	0 to 49999. Left blank when not available.

Class.Attribute Name	Keyword and example	Description	Range of values
dart:acquisition_time	ACQTMSEC= '298271898' / [sec] image TOV	Image time of validity (TOV) in integer seconds, in spacecraft clock notation. This is the time for which the GNC attitude data is valid. In global imaging mode, this time is defined as the midpoint of the integration period, given by image capture time ([IMGTMSEC and IMGTMSEC]-[96.2 ms]-[EXPTIME/2]). In rolling imaging mode, this time is given by image capture time ([IMGTMSEC and IMGTMSEC]-[48.1 ms]-[EXPTIME/2]).	Time since t=0, as defined in the SCLK kernel. Left blank when not available.
	ACQTMSUB= '2345' / [subsec] image TOV	Image time of validity (TOV) subseconds, in spacecraft clock notation. Number is subsecond clock ticks, where each tick represents 20 microseconds (1/50,000).	0 to 49999. Left blank when not available.
	SNG_SEC= '298271898' / [sec] SNG state update time	The time at which the SMART Nav guidance (SNG) filter states were last updated, in integer seconds.	Time since t=0, as defined in the SCLK kernel. Left blank when not available. If OBSTYPE is not TERMINAL or SMARTNAV_TEST, all SMART-Nav-related keywords should be ignored.

Class.Attribute Name	Keyword and example	Description	Range of values
	SNG_SUB= '123' / [subsec] SNG state update time	The time at which the SMART Nav guidance (SNG) filter states were last updated, in subsecond clock ticks, where each tick represents 1/50,000 seconds.	0 to 49999. Left blank when not available. If OBSTYPE is not TERMINAL or SMARTNAV_TEST, all SMART-Nav-related keywords should be ignored.
	IMGMOD= 'ROLLING' / Imaging mode	Shutter mode used to acquire image.	"ROLLING" or "GLOBAL".
dart:exposure_time	EXPTIME = '9.0440878E-0002' / [sec] Exposure time	Image exposure time in seconds.	0 to 0.094 for global shutter mode. 0 to 10.15129 for rolling shutter mode.
	VIRTROWS = '20' / number of virtual rows	Virtual rows are added to the image to increase the exposure time beyond that implied by the number of lines in the detector. 20 is the default.	20 to 1080 for global shutter mode; 20 to 115000 for rolling shutter mode.
	GAIN= '1X' /Gain setting	Detector gain setting.	"1X", "2X", "10X", or "30X".
	IMGSLOT= 'A' /Processing slot used	Image processing mode slot used. The detector ping-pongs between A and B, alternating with every image.	"A" or "B".
	DATAMODE='RECORD' / Data collection mode	Describes whether the images were directly downlinked or recorded and played back.	"DOWNLINK" or "RECORD".
dart:test_pattern	TSTPTTRN = 'dis' /Test pattern mode	'dis' if the image is not a test pattern. Otherwise, the value corresponds to the test pattern used. STATHORZ is a static horizontal gradient, DYNAHORZ is a dynamic horizontal gradient (i.e., it changes from image to image), TWOBBOX is a two-box pattern, and FLAT is a uniform gray image.	"dis", "STATHORZ", , "DYNAHORZ", , "TWOBBOX", "FLAT"

Class.Attribute Name	Keyword and example	Description	Range of values
dart:binning	BINNING='ON' /Binning status	If binning is on or not.	"ON" or "OFF".
	WIN1XSTA = '0' / X origin of window 1	Column where first window starts. Window1 coordinates are with respect to a 2560 x 2161 image plus header row (the 2560 x 2160 image plus 2560 x 1 header row) and unbinned pixels. The first pixel of the image plus header row is coordinate 0,0.	0 to 511.
	WIN1XEND= '2047' / X end of window 1	Column where first window ends. Window1 coordinates are with respect to a 2560 x 2161 image plus header row (the 2560 x 2160 image plus 2560 x 1 header row) and unbinned pixels. The first pixel of the image plus header row is coordinate 0,0.	2047 to 2559.
	WIN1YSTA = '1' / Y origin of window 1	Row where first window starts. Window1 coordinates are with respect to a 2560 x 2161 image plus header row (the 2560 x 2160 image plus 2560 x 1 header row) and unbinned pixels. The first pixel of the image plus header row is coordinate 0,0.	1 to 113.
	WIN1YEND= '2048' / Y end of window 1	Row where first window ends. Window1 coordinates are with respect to a 2560 x 2161 image plus header row (the 2560 x 2160 image plus 2560 x 1 header row) and unbinned pixels. The first pixel of the image plus header row is coordinate 0,0.	2048 to 2160.
	WINDOWH = '512' / Height of the image	Height of the downlinked image. Will equal height of second window, when image is smaller than NAXIS1.	512 or 1024.
	WINDOWW = '512' / Width of the image.	Width of the downlinked image. Will equal second window width, when image is smaller than NAXIS2.	512 or 1024.
	WINDOWX = '1' / X origin of image	Column where downlinked image starts. The first pixel of the image plus header row is coordinate 0,0. Greater than 0 when window2 is applied.	0 to 512.

Class.Attribute Name	Keyword and example	Description	Range of values
	WINDOWY= '5' / Y origin of image	Row where downlinked image starts. The first pixel of the image plus header row is coordinate 0,0. Greater than 0 when window2 is applied.	0 to 512.
	SNGROI_C = '123' / pixel col start	Pixel column of the first pixel of the 512x512 image subwindow whose center corresponds to the S/C relative velocity to asteroid vector	0 to 512. Left blank when SMART Nav is not operating.
	SNGROI_R = '496' / pixel row start	Pixel row of the first pixel of the 512x512 image subwindow whose center corresponds to the S/C relative velocity to asteroid vector	0 to 512. Left blank when SMART Nav is not operating.
dart>window2_x_start	WIN2XSTA = '256' / X origin of window 2	Column where second window starts. Window 2 coordinates are with respect to a 1024 x 1025 image plus header row (the 1024 x 1024 image plus 1024 x 1 header row) following the window1 and/or binning process. The first pixel of the image plus header row is coordinate 0,0. Value should be same as WINDOWX but derived from different source. This keyword is populated but not meaningful when WINDOWH=1024.	0 to 512.
dart>window2_y_start	WIN2YSTA = '257' / Y origin of window 2	Row where second window starts. Window 2 coordinates are with respect to a 1024 x 1025 image plus header row (the 1024 x 1024 image plus 1024 x 1 header row) following the window1 and/or binning process. The first pixel of the image plus header row is coordinate 0,0. Value should be (WINDOWY+1) but derived from different source. This keyword is populated but not meaningful when WINDOWH=1024.	1 to 513.
	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".
dart:onboard_cal	CALIB= 'OFF' /Calibration status	Status of the on-board calibration table application.	"ON" or "OFF".

Class.Attribute Name	Keyword and example	Description	Range of values
dart:badpix_invalidati on_mode	BADPIXMD= 'BYPASS' /Bad pixel invalidation mode	When BADPIXMD=USE, pixels identified by the bad pixel map are invalidated. When BADPIXMD=BYPASS, the bad pixel map is not used.	"USE" or "BYPASS".
Special_Constants. invalid_constant	SNAVFLAG= '4095' /Value SMART Nav uses to flag to bad pixels	Value assigned to bad pixels for SMART Nav purposes.	'4095'. Hardcoded.
	TARSTATE = 'PRECISIONLOCKED' / Targeting State	Current state of the targeting state machine.	"INITIAL", "LOCKING", "LOCKED", "PRECISION LOCKED". Left blank when not available. If OBSTYPE is not TERMINAL or SMARTNAV_ TEST, all SMART-Nav- related keywords should be ignored.
	DIDATRK = '1' /Didymos track ID	This is the track ID discriminated as Didymos in each iteration.	0 – 65535. Left blank when not available. If OBSTYPE is not TERMINAL or SMARTNAV_ TEST, all SMART-Nav- related keywords should be ignored.
	DIMOTK1 = '1' / Dimorphos Track ID 1	This is the track ID discriminated as Dimorphos in each iteration. In the Precision Locked Targeting state, Targeting could combine multiple tracks into its estimate	0 – 65535.
	DIMOTK2 = '1' / Dimorphos Track ID 2		Left blank when not available.
	DIMOTK3 = '1' / Dimorphos Track ID 3		

Class.Attribute Name	Keyword and example	Description	Range of values		
	DIMOTK4 = '1' / Dimorphos Track ID 4	of Dimorphos. If that happens, the track ID discriminated as Dimorphos with the highest total intensity is output here.	If OBSTYPE is not TERMINAL or SMARTNAV_TEST, all SMART-Nav-related keywords should be ignored.		
	DIMOTK5 = '1' / Dimorphos Track ID 5				
	DIMOTK6 = '1' / Dimorphos Track ID 6				
	DIMOTK7 = '1' / Dimorphos Track ID 7				
	DIMOTK8 = '1' / Dimorphos Track ID 8				
	DIMOTK9 = '1' / Dimorphos Track ID 9				
	DIMOTK10 = '1' / Dimorphos Track ID 10				
	DIMOTK11 = '1' / Dimorphos Track ID 11				
	DIMOTK12 = '1' / Dimorphos Track ID 12				
	DIMOTK13 = '1' / Dimorphos Track ID 13				
	DIMOTK14 = '1' / Dimorphos Track ID 14				
	DIMOTK15 = '1' / Dimorphos Track ID 15				
	DIMOTK16 = '1' / Dimorphos Track ID 16				
	DID_X = '780.22' / Est. col. position of Didymos centroid			Image coordinates of Didymos. This is the estimated column (DID_X) and row (DID_Y) positions of Didymos with respect to the 1024x1024 image.	0 to 1023. Left blank when not available. If OBSTYPE is not TERMINAL or SMARTNAV_TEST, all SMART-Nav-related keywords should be ignored.
	DID_Y = '780.22' / Est. row position of Didymos centroid				
	DIM_X = '780.22' / Est. col. position of Dimorphos centroid			Image coordinates of Dimorphos.	0 to 1023.

Class.Attribute Name	Keyword and example	Description	Range of values
	DIM_Y= '780.22' / Est. row position of Dimorphos centroid	This is the estimated column (DIM_X) and row (DIM_Y) position of Dimorphos, with respect to the 1024x1024 image.	Left blank when not available. If OBSTYPE is not TERMINAL or SMARTNAV_TEST, all SMART-Nav-related keywords should be ignored.
	GCXSUM1 = '1280' / Centroid 1 col sum	Centroid column sum. This is the sum of the column coordinate of each pixel in the centroid. The units are pixels. A value of 0 means there was no centroid in this slot during this iteration. This is because fewer than 16 centroids were identified in the image during this iteration.	0 to 536,346,624 Left blank when not available. If OBSTYPE is not TERMINAL or SMARTNAV_TEST, all SMART-Nav-related keywords should be ignored.
	GCXSUM2 = '1280' / Centroid 2 col sum		
	GCXSUM3 = '1280' / Centroid 3 col sum		
	GCXSUM4 = '1280' / Centroid 4 col sum		
	GCXSUM5 = '1280' / Centroid 5 col sum		
	GCXSUM6 = '1280' / Centroid 6 col sum		
	GCXSUM7 = '1280' / Centroid 7 col sum		
	GCXSUM8 = '1280' / Centroid 8 col sum		
	GCXSUM9 = '1280' / Centroid 9 col sum		
	GCXSUM10 = '1280' / Centroid 10 col sum		
	GCXSUM11 = '1280' / Centroid 11 col sum		
	GCXSUM12 = '1280' / Centroid 12 col sum		
	GCXSUM13 = '1280' / Centroid 13 col sum		
	GCXSUM14 = '1280' / Centroid 14 col sum		
	GCXSUM15 = '1280' / Centroid 15 col sum		
	GCXSUM16 = '1280' / Centroid 16 col sum		
	GCYSUM1 = '1280' / Centroid 1 row sum	Centroid row sum. This is the sum of the row coordinate of each pixel in the centroid. The units are pixels.	0 to 536,346,624 Left blank when not available.
	GCYSUM2 = '1280' / Centroid 2 row sum		
	GCYSUM3 = '1280' / Centroid 3 row sum		

Class.Attribute Name	Keyword and example	Description	Range of values		
	GCYSUM4 = '1280' / Centroid 4 row sum	A value of 0 means there was no centroid in this slot during this iteration. This is because fewer than 16 centroids were identified in the image during this iteration.	If OBSTYPE is not TERMINAL or SMARTNAV_TEST, all SMART-Nav-related keywords should be ignored.		
	GCYSUM5 = '1280' / Centroid 5 row sum				
	GCYSUM6 = '1280' / Centroid 6 row sum				
	GCYSUM7 = '1280' / Centroid 7 row sum				
	GCYSUM8 = '1280' / Centroid 8 row sum				
	GCYSUM9 = '1280' / Centroid 9 row sum				
	GCYSUM10 = '1280' / Centroid 10 row sum				
	GCYSUM11 = '1280' / Centroid 11 row sum				
	GCYSUM12 = '1280' / Centroid 12 row sum				
	GCYSUM13 = '1280' / Centroid 13 row sum				
	GCYSUM14 = '1280' / Centroid 14 row sum				
	GCYSUM15 = '1280' / Centroid 15 row sum				
	GCYSUM16 = '1280' / Centroid 16 row sum				
	GINTSM1 = '1280' / Centroid 1 intensity			Centroid intensity. The units are DN.	0 to 4,294,967,295
	GINTSM2 = '1280' / Centroid 2 intensity			A value of 0 means there was no centroid in this slot during this iteration. This is because fewer than 16 centroids were identified in the image during this iteration.	Left blank when not available. If OBSTYPE is not TERMINAL or SMARTNAV_TEST, all SMART-Nav-related keywords should be ignored.
	GINTSM3 = '1280' / Centroid 3 intensity				
	GINTSM4 = '1280' / Centroid 4 intensity				
	GINTSM5 = '1280' / Centroid 5 intensity				
	GINTSM6 = '1280' / Centroid 6 intensity				
	GINTSM7 = '1280' / Centroid 7 intensity				
	GINTSM8 = '1280' / Centroid 8 intensity				
	GINTSM9 = '1280' / Centroid 9 intensity				
	GINTSM10 = '1280' / Centroid 10 intensity				
	GINTSM11 = '1280' / Centroid 11 intensity				
	GINTSM12 = '1280' / Centroid 12 intensity				
	GINTSM13 = '1280' / Centroid 13 intensity				

Class.Attribute Name	Keyword and example	Description	Range of values
	GINTSM14 = '1280' / Centroid 14 intensity		
	GINTSM15 = '1280' / Centroid 15 intensity		
	GINTSM16 = '1280' / Centroid 16 intensity		
	GNPXLS1 = '1280' / Centroid 1 num. pixels	Number of pixels in centroid. The units are pixels.	0 to 1,048,576
	GNPXLS2 = '1280' / Centroid 2 num. pixels	A value of 0 means there was no centroid in this slot during this iteration. This is because fewer than 16 centroids were identified in the image during this iteration.	Left blank when not available. If OBSTYPE is not TERMINAL or SMARTNAV_TEST, all SMART-Nav-related keywords should be ignored.
	GNPXLS3 = '1280' / Centroid 3 num. pixels		
	GNPXLS4 = '1280' / Centroid 4 num. pixels		
	GNPXLS5 = '1280' / Centroid 5 num. pixels		
	GNPXLS6 = '1280' / Centroid 6 num. pixels		
	GNPXLS7 = '1280' / Centroid 7 num. pixels		
	GNPXLS8 = '1280' / Centroid 8 num. pixels		
	GNPXLS9 = '1280' / Centroid 9 num. pixels		
	GNPXLS10 = '1280' / Centroid 10 num. pixels		
	GNPXLS11 = '1280' / Centroid 11 num. pixels		
	GNPXLS12 = '1280' / Centroid 12 num. pixels		
	GNPXLS13 = '1280' / Centroid 13 num. pixels		
	GNPXLS14 = '1280' / Centroid 14 num. pixels		
	GNPXLS15 = '1280' / Centroid 15 num. pixels		
	GNPXLS16 = '1280' / Centroid 16 num. pixels		
	CNTKID1 = '1' / Centroid 1 track ID		
	CNTKID2 = '1' / Centroid 2 track ID		
	CNTKID3 = '1' / Centroid 3 track ID		
	CNTKID4 = '1' / Centroid 4 track ID		
	CNTKID5 = '1' / Centroid 5 track ID		
	CNTKID6 = '1' / Centroid 6 track ID		
	CNTKID7 = '1' / Centroid 7 track ID		

Class.Attribute Name	Keyword and example	Description	Range of values
	CNTKID8 = '1' / Centroid 8 track ID		keywords should be ignored.
	CNTKID9 = '1' / Centroid 9 track ID		
	CNTKID10 = '1' / Centroid 10 track ID		
	CNTKID11 = '1' / Centroid 11 track ID		
	CNTKID12 = '1' / Centroid 12 track ID		
	CNTKID13 = '1' / Centroid 13 track ID		
	CNTKID14 = '1' / Centroid 14 track ID		
	CNTKID15 = '1' / Centroid 15 track ID		
	CNTKID16 = '1' / Centroid 16 track ID		
	HYDRMSS = '8.6' / [kg] Remaining hydrazine mass	Hydrazine mass remaining in propellant tank.	0 to 50. Left blank when not available. If OBSTYPE is not TERMINAL or SMARTNAV_TEST, all SMART-Nav-related keywords should be ignored.
	SNTIAMAT = 'TRUE' / Targeting attitude matched	SMART Nav Targeting image attitude successfully matched. True/false flag that is true when an image has been matched to an attitude measurement successfully.	"TRUE" or "FALSE" Left blank when not available. If OBSTYPE is not TERMINAL or SMARTNAV_TEST, all SMART-Nav-related keywords should be ignored.

Class.Attribute Name	Keyword and example	Description	Range of values
	SNGDMAT = 'TRUE' / Guidance attitude matched	SMART Nav Guidance image attitude successfully matched. True/false flag that is true when an image has been matched to delta-V measurement successfully.	<p>"TRUE" or "FALSE"</p> <p>Left blank when not available.</p> <p>If OBSTYPE is not TERMINAL or SMARTNAV_TEST, all SMART-Nav-related keywords should be ignored.</p>
	TDVEST_X = '2.9' / [m/s] Terminal X deltaV est.	Terminal inertial DeltaV estimate in X direction.	<p>Full datatype range; 32-bit double (single precision)</p> <p>Left blank when not available.</p> <p>If OBSTYPE is not TERMINAL or SMARTNAV_TEST, all SMART-Nav-related keywords should be ignored.</p>

Class.Attribute Name	Keyword and example	Description	Range of values
	TDVEST_Y = '2.9' / [m/s] Terminal \bar{Y} deltaV est.	Terminal inertial DeltaV estimate in Y direction.	Full datatype range; 32-bit double (single precision) Left blank when not available. If OBSTYPE is not TERMINAL or SMARTNAV_TEST, all SMART-Nav-related keywords should be ignored.
	TDVEST_Z = '2.9' / [m/s] Terminal \bar{Z} deltaV est.	Terminal inertial DeltaV estimate in Z direction.	Full datatype range; 32-bit double (single precision) Left blank when not available. If OBSTYPE is not TERMINAL or SMARTNAV_TEST, all SMART-Nav-related keywords should be ignored.

Class.Attribute Name	Keyword and example	Description	Range of values
	SNFTEXE = 'TRUE' / SMART Nav guidance filter executing	SMART Nav Guidance filter executing. True/false flag that indicates whether the SMART Nav Guidance Filter is being executed.	"TRUE" or "FALSE" Left blank when not available. If OBSTYPE is not TERMINAL or SMARTNAV_TEST, all SMART-Nav-related keywords should be ignored.
	SNGSTAT = '0' / SN Guidance status flags in 8-bit LSB word	SMART Nav Guidance (SNG) status word with individual bits defining the following status: bit0 (LSB) – runFilterOff: if 1 then runFilter flag is True bit1 – imgTimeLTOEToLastImg: if 1 then image time is less than or equal to last image time bit2 – imgTimeOlderThanTol: if 1 then image time is older than tolerance bit3 – imgTimeGTOEToSCLK: if 1 then image time is greater than or equal to SCLK	0 to 255. If OBSTYPE is not TERMINAL or SMARTNAV_TEST, all SMART-Nav-related keywords should be ignored.
	BLOBTHRS = '5' / Minimum number of pixels used for a blob	Minimum number of pixels per blob threshold employed to compute centroid.	0 to $(2^{19} - 1)$.
	FORETHRS = '1' / DN Foreground threshold	Foreground threshold employed to compute centroid.	0 to $(2^{19} - 1)$.
	ESTSC_QA = '0.108080037674849' / SC quaternion in J2000 (q0)	Raw quaternion from S/C associated with ESTAQSEC and ESTAQSUB.	Left blank when not available.
	ESTSC_QX = '-0.674302095900066' / SC quaternion in J2000 (q1)	Raw quaternion from S/C associated with ESTAQSEC and ESTAQSUB.	Left blank when not available.
	ESTSC_QY = '-0.32453616895850' / SC quaternion in J2000 (q2)	Raw quaternion from S/C associated with predicted ESTAQSEC and ESTAQSUB.	Left blank when not available.
	ESTSC_QZ = '0.65445524213556' / SC quaternion in J2000 (q3)	Raw quaternion from S/C associated with predicted ESTAQSEC and ESTAQSUB.	Left blank when not available.

Class.Attribute Name	Keyword and example	Description	Range of values
	SMEARINX = '1.56559E-05' / [rad/sec] Angular rate about SC +X axis	Smear indicator. Windowed average angular rate about +X direction. Window duration is image integration time.	0 to 0.2. Left blank when not available.
	SMEARINY = '1.56559E-05' / [rad/sec] Angular rate about SC +Y axis	Smear indicator. Windowed average angular rate about +Y direction. Window duration is image integration time.	0 to 0.2. Left blank when not available.
	SMEARINZ = '1.56559E-05' / [rad/sec] Angular rate about SC +Z axis	Smear indicator. Windowed average angular rate about +Z direction. Window duration is image integration time.	0 to 0.2. Left blank when not available.
	ATT_VAL = '1' / Attitude flag	Flag indicating if the estimated attitude is considered valid. 1 = attitude valid; 0 = attitude not valid.	0 or 1. Left blank when not available.
	FRM_ID = '2' / Frame ID	Frame ID. The units are count.	0 to 4294967295. Left blank when not available.
dart:detector1_temp	DETTEMP1 = '18.333' / [degC] Detector temperature sensor 1	Detector 1 temperature.	
dart:detector2_temp	DETTEMP2 = '18.333' / [degC] Detector temperature sensor 2	Detector 2 temperature.	
dart:fpe_temp	FPETEMP = '21.111' / [degC] FPE board temperature	Temperature of FPE.	
dart:current_33va_supply	CURR33VA = '12.1' / [mA] Current for detector 3.3VA supply	Current for detector 3.3VA supply.	
dart:current_18vd_supply	CURR18VD = '7.14' / [mA] Current for detector 1.8VA supply	Current for detector 1.8VD supply.	
dart:current_33vd_supply	CURR33VD = '1.68' / [mA] Current for detector 3.3VD supply	Current for detector 3.3VD supply.	
	CURR33VP = '0.1' / [mA] Current for detector 3.3V pixel supply	Current for detector 3.3V pixel supply.	
dart:analog_reset_supply	ANRSTCUR = '7.01' / [mA] Current for detector analog reset supply	Current for detector analog reset supply.	
	REL_A_X = '0.123' / X SC Relative Inertial Position of Didymos	Position of Didymos relative to the spacecraft in the Vehicle Inertial Frame (VIF)	Left blank when not available.

Class.Attribute Name	Keyword and example	Description	Range of values
	REL_A_Y= '0.123'/ Y SC Relative Inertial Position of Didymos		If OBSTYPE is not TERMINAL or SMARTNAV_TEST, all SMART-Nav-related keywords should be ignored.
	REL_A_Z= '0.123'/ Z SC Relative Inertial Position of Didymos		
	REL_B_X= '0.123'/ X SC Relative Inertial Position of Dimorphos	Position of Dimorphos relative to the spacecraft in the VIF	Left blank when not available.
	REL_B_Y= '0.123' /Y SC Relative Inertial Position of Dimorphos		If OBSTYPE is not TERMINAL or SMARTNAV_TEST, all SMART-Nav-related keywords should be ignored.
	REL_B_Z= '0.123'/ SC Relative Z Inertial Position of Dimorphos		
	FSWNAM= 'DART_ONBOARD' /name of flight software	Name of onboard flight software.	Defined by FSW team
	FSWVER= '1.1.2' /flight software version tag	Version of flight software employed.	"X.X.X"
Target_Identification	TARGET = 'DIDYMOS' / Primary target object	Primary target object.	"DIDYMOS", "DIMORPHOS", "JUPITER_SYSTEM", "M1", "SKY", etc.
	SECTAR = 'NA' / Secondary target object	Secondary target object.	"DIDYMOS", "DIMORPHOS", "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".

Class.Attribute Name	Keyword and example	Description	Range of values
	COR.UTC='2018-08-25 12:34:56.000' / Est UTC (YYYY-MM-DD HH:MM:SS.000)	Estimated UTC, to second precision only, of the CORTMSEC and CORTMSUB using the SPICE SCLK kernel at the time of image receipt.	Time since $t=0$, as defined in the SCLK kernel. Left blank when not available.
	SCLKPATI='1' / SCLK partition	SCLK time partition.	
	SCLKNAME='DART_SCLK_0000.TSC' /SCLK file used for COR.UTC	Name of SCLK file used to compute COR.UTC.	
	ACQTM = '298271898:2345' / [sec:subsec] image TOV	Image time of validity (TOV) in integer seconds:subseconds. This concatenates the information in ACQTMSEC and ACQTMSUB, with a colon between the two.	Left blank when not available.
	ACQTM_ET = '717892158.7820001' / [sec] image TOV as ephemeris time	Image time of validity (TOV) as ephemeris time based on ACQTM.	Left blank when not available.

Class.Attribute Name	Keyword and example	Description	Range of values
dart:soc_acquisition_time	ACQTMSSOC = '298271898:2345' / [sec:subsec] SOC-calculated TOV	<p>Image time of validity (TOV) calculated by the Science Operations Center (SOC). The value before the colon is integer seconds in spacecraft clock notation. The value after the colon is subsecond clock ticks, where each tick represents 20 microseconds (1/50,000).</p> <p>This is the time for which the GNC attitude data is valid. In global imaging mode, this time is defined as the midpoint of the integration period, given by image capture time ([FPE_SEC and FPE_SBSS]-[96.2 ms]-[EXPTIME/2]). In rolling imaging mode, this time is given by image capture time ([FPE_SEC and FPE_SBSS]-[48.1 ms]-[EXPTIME/2]).</p> <p>The math is identical to the math for AQCTMSEC and ACQTMSSUB. However, the SOC calculates the image TOV based on FPE_SEC and FPE_SBSS, rather than IMGTMSEC and IMGTMSSUB. FPE_SEC and IMGTMSEC should be identical. IMGTMSSUB and FPE_SBSS should be identical. However, using FPE_SEC and FPE_SBSS allows the SOC to calculate image TOV even when an image does not correlate to information provided by the GNC system.</p>	Time since $t=0$, as defined in the SCLK kernel.
	ACQTMSET = '717892158.7820001' / [sec] ephemeris time from ACQTMSSOC	Image time of validity (TOV) as ephemeris time based on ACQTMSSOC	
	ACQ_UTC = '2022 OCT 01 10:28:09.600' / Image TOV in UTC from ACQTMSSOC	Image time of validity (TOV) in UTC based on ACQTMSSOC	
	ACQ_JDAT = '2459853.93702294' / Image TOV in Julian Ephemeris Date, ACQTMSSOC	Image time of validity (TOV) in Julian Ephemeris Date based on ACQTMSSOC	
dart:lineread	LINEREAD = '87.46666' / Readout time in microsec/line	Each line is read out at a 87.46666 microsecond clock rate.	87.46666

Class.Attribute Name	Keyword and example	Description	Range of values
dart:pix_delay	PIXDELAY = '33.3' / Delay between sequential pixels in line in ns	Each pixel is read out sequentially at a 33.3 ns clock rate.	33.3
dart>window2_x_end	WIN2XEND= '767' / X end of window 2	Column where second window ends. Window 2 coordinates are with respect to a 1024 x 1025 image plus header row (the 1024 x 1024 image plus 1024 x 1 header row) following the window1 and/or binning process. The first pixel of the image plus header row is coordinate 0,0. -1 if second windowing not applied.	-1 or 511 to 1023.
dart>window2_y_end	WIN2YEND= '768' / Y end of window 2	Row where second window ends. Window 2 coordinates are with respect to a 1024 x 1025 image plus header row (the 1024 x 1024 image plus 1024 x 1 header row) following the window1 and/or binning process. The first pixel of the image plus header row is coordinate 0,0.-1 if second windowing not applied.	-1 or 512 to 1024.
	CALFILE= 'DRACO_calibration_20210106.mat' / calibration file	Name of file provided by SMART Nav to the spacecraft for use when CALIB=ON.	DRACO_calibration_YYYYMMDD.mat
	SOCQUATA = '0.108080037674849' / SC quaternion in J2000 (q0) using ACQTMSOC	Spacecraft quaternion computed by the SOC using SPICE and ACQTMSOC.	
	SOCQUATX = '-0.674302095900066' / SC quaternion in J2000 (q1) using ACQTMSOC		
	SOCQUATY = '-0.32453616895850' / SC quaternion in J2000 (q2) using ACQTMSOC		
	SOCQUATZ = '0.65445524213556' / SC quaternion in J2000 (q3) using ACQTMSOC		
	SMERSINX = '1.56559E-05' / [rad/sec] Angular rate about SC +X axis		Smear indicator. Windowed average angular rate about +X direction. Window duration is image integration time. Computed by SOC, rather than GNC.

Class.Attribute Name	Keyword and example	Description	Range of values
	SMERSINY = '1.56559E-05' / [rad/sec] Angular rate about SC +Y axis	Smear indicator. Windowed average angular rate about +Y direction. Window duration is image integration time. Computed by SOC, rather than GNC.	0 to 0.2. Left blank when not available.
	SMERSINZ = '1.56559E-05' / [rad/sec] Angular rate about SC +Z axis	Smear indicator. Windowed average angular rate about +Z direction. Window duration is image integration time. Computed by SOC, rather than GNC.	0 to 0.2. Left blank when not available.
	BORERA = '326.459994' / [deg] Boresight right ascension	Boresight right ascension	0 to 360 degrees.
	BOREDEC = '-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.

Class.Attribute Name	Keyword and example	Description	Range of values
	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.

Class.Attribute Name	Keyword and example	Description	Range of values
	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.

Class.Attribute Name	Keyword and example	Description	Range of values
	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.

Class.Attribute Name	Keyword and example	Description	Range of values
	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.

Class.Attribute Name	Keyword and example	Description	Range of values
	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.
dart:bad_image	BADIMAGE = 'FALSE' / Bad image identifier	A flag describing whether an image should be analyzed by end data product users. If BADIMAGE = 'FALSE', then the image is valid and can be reliably used. If BADIMAGE = 'TRUE', then the metadata and image contain invalid information and should not be used in any analyses.	TRUE or FALSE See Section 4.1.6.1 for more details about this keyword.
dart:observation_type	OBSTYPE = 'TERMINAL' / Observation type	A keyword that describes the type of observation the DRACO image is associated with. This is a useful keyword for users to filter on to hone in on the specific images of interest.	See list in Table 2
geom:SPICE_Kernel_Identification	METAKRNL = 'current_2022052T16.tm' / metakernel used to compute SOC keywords	Name of metakernel used to compute SOC added keywords. The XML label identify the specific SPICE kernels using geom:SPICE_Kernel_Identification	
	SRCFILE = 'dart_0380520950_01511_01.fits' / original MOC fits file	Name of the original fits file received from the MOC. Used by the pipeline to track provenance between the PDS Data Product file and MOC original file, as the MOC version numbering system is independent of the PDS version number.	

5.2.2. Calibrated Image Data

The Level-2 calibrated DRACO image format is a single HDU, 1024 (sample) × 1024 (line), 32-bit floating point fits file, 2×2 binned from the original 2048 × 2048 window¹. These images have traveled through the DRACO Calibration Pipeline, which is described in detail in the DRACO Calibration Pipeline Description document. The data are represented in radiance ($\text{W m}^{-2} \text{nm}^{-1} \text{sr}^{-1}$) when keyword IOVERF = “SKIP”. The data are represented in reflectance (I/F, unitless) when keyword IOVERF = “PERFORM”. The conversion to I/F is performed for Final Phase images only. The metadata associated with these Level-2 calibrated images (Table 9) are appended as additional keywords to the fits header and XML label of the corresponding raw image. The Class.Attribute Name column is left blank for fits keywords not mapped to the .xml label.

Not all calibrated images will have all keywords listed below. If the DRACO Instrument Scientist determines that a particular step can be skipped, the pipeline does not add the names of the reference files that would be used in that step if it had been performed. Instead, the pipeline only shows the step as being skipped. For example, if the dark current correction step were not needed, then DARK_SUB = 'SKIP' and they keywords REFDARK1 and REFDARK2 would not be added to the fits header of the calibrated image.

Table 9. DRACO Level-2 Calibrated Image Appended Metadata

Class.Attribute Name	Keyword and example	Description	Range of values
dart:undo_onboard_cal	ONBRDCAL = ‘UNDONE’ / On-board cal table status	Indicates whether the on-board calibration table was removed (i.e., by adding it back) to the image. NA if the onboard cal table was not applied to the image.	UNDONE, NA
dart:bias_subtraction	BIAS_SUB = ‘PERFORM’ / Bias subtraction	Indicates whether the bias subtraction step was done	PERFORM, SKIP
dart:dark_subtraction	DARK_SUB = ‘PERFORM’ / Dark subtraction	Indicates whether the dark subtraction step was done	PERFORM, SKIP
dart:flatfield	FLATFIEL = ‘PERFORM’ / Flat fielding	Indicates whether the flat field was applied	PERFORM, SKIP
dart:radiance_conversion	RADIANCE = ‘PERFORM’ / Conversion to radiance	Indicates whether the conversion to radiance was applied	PERFORM, SKIP
dart:ioverf_conversion	IOVERF = ‘PERFORM’ / Conversion to I/F	Indicates whether the conversion to I/F was done	PERFORM, SKIP
	REFBADPX = ‘DRACO_bad_pixels_20200910.fits’ / bad pixel map file	Name of bad pixel map used to calibrate image.	Determined by file naming convention.
	BADMASKV = ‘-1E09’ / Value assigned to bad pixels	Pixel value assigned to bad pixels by the SOC	-1E09
	REFBIAS = ‘DRACO_bias_global_1x_n20C_20200910.fits’ / ref bias file	Name of bias file used.	Determined by file naming convention.
	REFDARK1 = ‘DRACO_dark_global_1x_n20C_20200910.fits’ / ref dark file	Name of first dark file used to interpolate temperature-dependent bias.	Determined by file naming convention.

	REFDARK2 = 'DRACO_dark_global_1x_n 15C_20200910.fits' / ref dark file	Name of second dark file used to interpolate temperature- dependent bias.	Determined by file naming convention.
	REFFLAT = 'DRACO_flat_global_1x_20 200910.fits)' / Flat field file	Name of flat field file used.	Determined by file naming convention.
	LUPTABLE = 'DRACO_lookup_global_1x _20200910.csv' / Look-up table	Name of look-up table used	Determined by file naming convention.
Special_Constants. not_applicable_constant	PXOUTWIN = '-1E10' / Value assigned to pixels outside window2	Keyword created by MOC; value updated by pipeline	-1E10
Special_Constants. missing_constant	MISPXVAL = '1E10' / Value assigned to missing pixels	Keyword created by MOC; value updated by pipeline	1E10
Special_Constants. high_instrument_saturation	SATPXVAL = '1E09' / Value assigned to saturated pixels	Pixel value assigned to saturated pixels by the SOC	1E09
	OORADLUT = '1E08' / Out of range of lookup table	Pixel value assigned to pixels that are not truly saturated but whose DN is too high to be reliably calibrated using the radiometric lookup tables	1E08
	IOVRFLAG = '-1E08' / negative before conversion to I/F	Pixel value assigned to pixels that are negative before conversion to I/F	-1E08
	PIVOTWL = '622' / pivot wavelength, nm	DRACO pivot wavelength	622
	RDIDYMOS = '4.11E8' / (e- /s)/[W/(m ² nm sr)]	Photometric keyword. Fixed value to be updated once flight instrument is tested.	4.11E8 Value may be updated periodically based on in- flight data. Assume the value in the fits file is the most-up-to- date value.
	F_SUN622 = '1.6784' / solar flux at 1 AU at 622 nm, W/(m ² nm)	Solar flux at 622 nm. Fixed value	1.6784

5.2.3. DRACO Calibration File Formats

DRACO has the following calibration files that will be developed from in-flight and/or ground calibration data: on-board calibration table; bad pixel map; bias; dark; flat field; radiometric lookup table. Calibration files will be saved in the formats listed in and described further in the DRACO Calibration Pipeline Description Document, which is included in the DRACO bundle document collection. In the event of a conflict between the DRACO SIS and the DRACO Calibration Pipeline Description, the pipeline description takes precedence.

The calibration pipeline inputs specified as fits files cover the same area as window1 on the DRACO detector and are 2×2 binned from 2048×2048 to 1024×1024 to match the DRACO images obtained in flight. The naming convention for the calibration input files is described in [Table 7](#).

5.2.3.1. On-board Calibration Table and Bad Pixel Map

On-board Calibration Table – The on-board calibration table is used as part of Small-body Maneuvering Autonomous Real-Time Navigation (SMART Nav) algorithm. It is essentially a bias subtraction that improves algorithm performance.

This file is formatted as a single HDU, 1024 (sample) × 1024 (line), 32-bit floating point fits file, 2×2 binned from the original 2048 × 2048 window1, in units of DN. Metadata contained in the fits header for the on-board calibration table are listed in [Table 10](#).

The on-board calibration table is not completely reversible, because the calibration table subtraction bottoms out at zero. Based on testing done up through 31 March 2022 by the DRACO and SMART Nav teams, approximately 0.8% of pixels will be affected by the calibration table. Roughly 70% of these (0.6% of all pixels in images to which the on-board calibration table is applied) may have DN = 0 after the on-board calibration table has been applied. In approximately 16% of such pixels (i.e., ~0.09% of the total pixels in the image), adding back the calibration table will overcorrect the image by one or a few DN. For example, if the original value in a pixel were 3 DN, but the calibration table value was 5 DN, the pixel value after the calibration table was applied would be 0 DN, not -2 DN. So, when the ground calibration pipeline adds back the on-board calibration table, the pixel value in that pixel would be 5 DN, rather than the correct value of 3 DN.

One cannot identify which pixels have been overcorrected; however, one can hone in on the subset of pixels that might have been overcorrected by comparing the locations of pixels where DN = 0 in the SMART Nav image and where DN > 0 in the on-board calibration table.

The calibration table is built by identifying two kinds of pixels: “hot pixels”, here defined as having a high bias value that is consistent across a multi-frame dataset (50 frames for pre-launch data), and “popcorn pixels” which have an intermittent high bias value. For consistently hot pixels, the high bias value is entered into the calibration table. For intermittent, popcorn pixels, the minimum bias value seen for that pixel over the multi-frame dataset is entered into the calibration table to reduce the frequency and severity of overcorrections discussed in the previous paragraph. It is possible that actual popcorn pixels exist that fluctuate with a longer time constant than that used in testing (50 seconds for pre-launch data), leading to misidentification either as a hot pixel and overcorrection in the calibration table, or as a good pixel and under-correction. The fits header includes keywords relating to how these two types of pixels are distinguished: popcorn pixels are identified as those whose standard deviation, over the multi-

frame dataset, is both larger than POPSTD in absolute terms and larger than POPFACTR times the value expected for a hot pixel due to electron shot noise. If a pixel does not meet the criteria for either a hot pixel or a popcorn pixel, then the on-board calibration table is set to 0 DN for those pixels.

Bad Pixel Map – To allow for the situation in which some pixels on the detector are deemed “bad” (i.e., responsivity abnormal enough to potentially affect SMART Nav performance), the pipeline contains an input file that specifies the locations of bad pixels. A value of 0 indicates that the pixel is good. A value of 1 means that the pixel was deemed bad. The header contains keywords that relate to determining how potential bad pixels are identified: pixels which, under dark frame conditions: have a very high bias value (larger than BADBIAS), or under illuminated conditions are much dimmer than surrounding pixels (have a relative photoresponse less than BADPR). For pre-launch testing, both dark and flat-field illuminated datasets are available, so the bad pixel map will be the union of the set of pixels with high bias and the sets of pixels with low photoresponse measured from each listed exposure time independently. For post-launch updates, flat-field illumination is not available, so any updates to the bad pixel map will be based only on the bias values from dark frames.

This file is formatted as a single HDU, 1024 (sample) × 1024 (line), 32-bit floating point fits file, 2×2 binned from the original 2048 × 2048 window1, and is unitless. Metadata contained in the fits header for the bad pixel map are listed in Table 10. The Class.Attribute Name column is left blank for fits keywords not mapped to the .xml label.

Table 10. DRACO File Metadata for On-board Calibration Table and Bad Pixel Map

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	Calibration inputs are always be 32-bit floating point files.	-32
	NAXIS = 2 / number of data axes	Number of axes; all DRACO images have 2 axes.	2
Axis_Array. sequence_number	NAXIS1 = 1024 / length of data axis 1	Number of rows, all DRACO images have 1024 rows.	1024
Axis_Array. sequence_number	NAXIS2 = 1024 / length of data axis 2	Number of columns, all DRACO images have 1024 columns.	1024
	EXTEND = T / FITS dataset may contain extensions	By default, set to T so that we can add extensions.	T
Modification_History. modification_date	DATE = '2018-08-25' / file creation date YYYY-MM-DD	Date file was created.	YYYY-MM-DD
Investigation_Area. name	MISSION = 'DART' / mission: DART	Name of mission.	"DART"
Observing_System. name	HOSTNAME= 'DART ' / spacecraft name	DRACO is on the spacecraft called DART.	"DART"
Observing_System_Co mponent.name	INSTRUME= 'DRACO ' / instrument name	Name of instrument.	"DRACO"
	ORIGIN = 'JHUAPL' / source of data product	Organization that created the file	"JHUAPL"

	CREATOR = 'CAROLYN SAWYER' / product author	Author of the file	The format is firstName lastName.
	DETECTOR = 'SN403' / detector name	Name of detector from which the images used to create the file were collected	"SN403"
	CALTYPE = 'CALTABLE' / calibration file type	Type of calibration file	"CALTABLE", "BADPIXEL MAP", "BIAS", "DARK", "FLATFIELD", "RADIOMETRIC"
dart:mission_phase	MPHASE = 'PRELAUNCH' / mission phase	Mission phase(s) during which the images used to create the input file were collected. A slash indicates data from multiple mission phases were used to create the file	"PRELAUNCH", "COMMISSIONING", "CRUISE", "APPROACH", "TERMINAL", "FINAL"
dart:imaging_mode	IMGMOD= 'GLOBAL' / imaging mode	Shutter mode of the images used to create the file	"GLOBAL". The calibration table and bad pixel map are only build from global shutter images, even though DRACO is capable of using both rolling and global shutter modes.
dart:gain	GAIN= '1X' /gain setting	Detector gain setting of the images used to create the file	"1X", "2X", "10X", or "30X"
dart:test_temp	TESTTEMP = -20 / [degC] nominal test temperature	Nominal temperature for the test sequence used to generate the calibration table	Unspecified
	SRCRTDIR = 'APLFSFRONTIER/PROJECT/AIDA/500 INSTRUMENT/DETECTOR/' / Top-level path	Top-level directory location of source images used to create the file	Unspecified
	DATASRC = 'TESTING/SN403 PTC/- 20C/20_09_14_10_28_44/' / Mid-level data path	Path to lowest-level folder containing both illuminated and dark data used to create the file, relative to SRCRTDIR	Unspecified

	DARKFRM = 'BIAS_FULL/GLOBAL/1X_BIAS_FULL/1' / Location of dark frames	Path to directory containing dark frames used to create the file, relative to DATASRC	Unspecified
	ILLUMFRM = 'FULL/GLOBAL/1X' / Location of illuminated frames	Path to directory containing illuminated frames used to create the file, relative to DATASRC	Unspecified
	LITTIMES = '100 500 1000' / [linetimes] exposure time for photoresponse	Exposure times of the illuminated images used to create the file, in units of linetime. This should be understood as a pointer to the datasets used within the ILLUMFRM folder – pre-launch testing included flat-field illuminated frames with a variety of integration times – rather than having direct significance. If N/A, no illuminated data were used.	1, 2, 4, 8, 16, 32, 64, 100, 150, 200, 250, 200, 250, 400, 450, 500, 550, 600 650, 700, 750, 800, 850, 900, 950, 1000, N/A
	GENVER = '4CEC7B2E' / Version of software used to create file	Version of software used to create the calibration table or bad pixel map, in the form of a Git repository commit hash	8-character short version of Git commit hash
	BADBIAS = 2048 / Bias limit for bad pixels	Bias in DN above which pixels are declared bad and included in the bad pixel map. The value of 2048 is convenient because, at half-saturated, it implies only half of the pixel's range is available to respond to light, making the post-calibration pixel likely to have poor photoresponse.	0 to 4095
	POPFACTR = 1.5 / Popcorn shot noise criterion	Factor above the expected shot noise used to declare a popcorn pixel. The expected standard deviation due to shot noise is calculated from the mean bias of the pixel. Then the actual standard deviation of each pixel is compared to POPFACTR times the expected shot noise, and pixels with a standard deviation greater than this product are treated as popcorn pixels.	1 to Inf

	POPSTD = 1 / Popcorn standard deviation criterion	Floor on allowed std values for a popcorn pixel. Because of discretization, it is difficult to estimate shot noise for pixels with few- or sub-DN mean bias. To avoid spuriously marking a large number of popcorn pixels, pixels which meet the POPFACTR criterion, but have an absolute standard deviation below this floor, are not treated as popcorn pixels in the on-board calibration table.	0 to 4095
	BADPR = 0.5 / Photoresponse criterion	Photoresponse to mark a bad pixel. Pixels are considered bad if they are much less responsive to light than their neighbors, potentially leading to a distorted blob and incorrect centroid. A criterion of 0.5 marks pixels that are less than half as bright as their neighbors under flat-field illumination conditions.	0 to 1
	OFFSTCOL = 256 / Window 1 column offset	Window 1 offset from left edge of frame. Window1 coordinates are with respect to a 2560 x 2161 image plus header row (the 2560 x 2160 image plus 2560 x 1 header row) and unbinned pixels. The first pixel of the image plus header row is coordinate 0,0.	0 to 512
	OFFSTROW = 57 / Window 1 row offset	Window 1 offset from origin of frame, incl. header. Window1 coordinates are with respect to a 2560 x 2161 image plus header row (the 2560 x 2160 image plus 2560 x 1 header row) and unbinned pixels. The first pixel of the image plus header row is coordinate 0,0.	1 to 113
Time_Coordinates. start_date_time	CALSTART = '2022-03-10T00:00:00' / file start time YYYY-MM-DDThh:mm:ss	UTC start time at which the calibration file is used in the pipeline. For the on-board calibration table and the bad pixel map, hh:mm:ss always set to 00:00:00.	YYYY-MM-DDThh:mm:ss

5.2.3.2. Bias Frames, Dark Current Frames, and Flat Field

Bias Frames – Bias frames remove the electronic readout noise present for a zero-length exposure time. One file exists per combination of shutter mode, gain state, and temperature used to calibrate flight data. This file is formatted as a single HDU, 1024 (sample) × 1024 (line), 32-

bit floating point fits file, 2×2 binned from the original 2048 × 2048 window1, in units of DN. Metadata contained in the fits header for the bias frame files are listed in [Table 11](#).

Dark Current Frames –Dark current frames correct for the accumulation of signal in a pixel in the absence of photons. One file exists per combination of shutter mode, gain state, and temperature used to calibrate flight data. This file is formatted as a single HDU, 1024 (sample) × 1024 (line), 32-bit floating point fits file, 2×2 binned from the original 2048 × 2048 window1, in units of DN/second. Metadata contained in the fits header for the dark current files are listed in [Table 11](#).

Flat Field – The flat field frame is used to normalize responsivity variations across the detector. This file is formatted as a single HDU, 1024 (sample) × 1024 (line), 32-bit floating point fits file, 2×2 binned from the original 2048 × 2048 window1, and is unitless. The flat field frames were all derived from ground calibration data; there are no opportunities to acquire flight data to produce updated flat field files. Metadata contained in the fits header for the flat field files are listed in [Table 11](#). The Class.Attribute Name column is left blank for fits keywords not mapped to the .xml label.

Table 11. DRACO File Metadata for Bias, Dark Current, and Flat Field Frames

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	Calibration inputs are always be 32-bit floating point files.	-32
	NAXIS = 2 / number of data axes	Number of axes; all DRACO images have 2 axes.	2
Axis_Array. sequence number	NAXIS1 = 1024 / length of data axis 1	Number of rows, all DRACO images have 1024 rows.	1024
Axis_Array. sequence number	NAXIS2 = 1024 / length of data axis 2	Number of columns, all DRACO images have 1024 columns.	1024
	EXTEND = T / FITS dataset may contain extensions	By default, set to T so that we can add extensions.	T
Modification_History. modification date	DATE = '2018-08-25' / file creation date YYYY-MM-DD	Date file was created.	YYYY-MM-DD
Investigation_Area. name	MISSION = 'DART' / mission: DART	Name of mission.	"DART"
Observing_System. name	HOSTNAME= 'DART' / spacecraft name	DRACO is on the spacecraft called DART.	"DART"
Observing_System_Co mponent.name	INSTRUME= 'DRACO' / instrument name	Name of instrument.	"DRACO"
	ORIGIN = 'JHUAPL' / source of data product	Organization that created the file	"JHUAPL"
	CREATOR = 'SYAU-YUN HSIEH' / product author	Author of the file	The format is firstName lastName.
	DETECTOR = 'SN403' / Detector name	Name of detector used to create the file	"SN403"

Class.Attribute Name	Keyword and example	Description	Range of values
	CALTYPE = 'BIAS' / calibration file type	Type of calibration file	"CALTABLE", "BADPIXEL MAP", "BIAS", "DARK", "FLATFIELD", "RADIOMETRIC"
dart:mission_phase	MPHASE = 'PRELAUNCH' / mission phase	Mission phase(s) during which the images used to create the input file were collected. A slash indicates data from multiple mission phases were used to create the file	"PRELAUNCH", "COMMISSIONING", "CRUISE", "APPROACH", "TERMINAL", "FINAL"
dart:imaging_mode	IMGMOD= 'ROLLING' / imaging mode	Shutter mode of the images used to create the file	"GLOBAL" or "ROLLING"
dart:gain	GAIN= '1X' /gain setting	Detector gain setting of the images used to create the file	"1X", "2X", "10X", or "30X"
dart:test_temp	TESTTEMP = '-20' / [degC] nominal test temperature	Nominal temperature for the test sequence used to generate the file	Unspecified
	BASEDIR = 'APLFSFRONTIER/' /Base path	Base-level directory location of source images used to create the file.	Unspecified
	TOPDIR = 'PROJECT/AIDA/500 INSTRUMENT/DETECTOR/' / Top-level path	Top-level directory location of source images used to create the file. N/A indicates that the pixel values in this file were set to zero (no correction) based on test results to date.	Unspecified
	MIDDIR = 'TESTING/SN403 PTC/- 20C/20_09_14_10_28_44/' / Mid-level path	Path to lowest-level folder containing both illuminated and dark data used to create the file, relative to TOPDIR. N/A indicates that the pixel values in this file were set to zero (no correction) based on test results to date.	Unspecified
	BOTDIR = 'BIAS_FULL/GLOBAL/1X_BIAS_FULL/1' / Bottom-level path	Path to directory containing dark frames used to create the file, relative to MIDDIR. N/A indicates that the pixel values in this file were set to zero (no correction) based on test results to date.	Unspecified

Class.Attribute Name	Keyword and example	Description	Range of values
	LITTIMES = '100 500 1000' / [linetime] exposure	Exposure of the images used to create the file, in units of linetime. A DRACO linetime is 87.467 us.	1 to 116059
	GENVER = '4CEC7B2E' / Version of software used to create file	Version of software used to create the calibration table or bad pixel map, in the form of a Git repository commit hash	8-character short version of Git commit hash
	OFFSTCOL = 256 / Window 1 column offset	Window 1 offset from left edge of frame. Window1 coordinates are with respect to a 2560 x 2161 image plus header row (the 2560 x 2160 image plus 2560 x 1 header row) and unbinned pixels. The first pixel of the image plus header row is coordinate 0,0.	0 to 512
	OFFSTROW = 57 / Window 1 row offset	Window 1 offset from origin of frame, incl. header. Window1 coordinates are with respect to a 2560 x 2161 image plus header row (the 2560 x 2160 image plus 2560 x 1 header row) and unbinned pixels. The first pixel of the image plus header row is coordinate 0,0.	1 to 113
Time_Coordinates. start_date_time	CALSTART = '2022-03-10T00:00:00' / file start time YYYY-MM-DDThh:mm:ss	UTC start time at which the calibration file is used in the pipeline.	YYYY-MM-DDThh:mm:ss

5.2.3.3. Radiometric Look-up Tables

Radiometric Look-up Tables – The radiometric lookup table defines the conversion from DN to electrons. The detector is sufficiently nonlinear that a lookup table is used instead of a linear function. Separate conversions exist for the two halves of the detector. One lookup table exists for each combination of shutter mode, gain state, and temperature that had adequate performance to generate a radiometric calibration. This file is formatted as CSV file. Each CSV line will consist of the following fields. The CSV file should be sorted by row start, then by DN.

- rowStart – start row (with respect to the 1024×1024, 2×2 binned image) for which this line in the lookup table applies
- rowEnd – end row for which this line applies (with respect to the 1024×1024, 2×2 binned image) for which this line in the lookup table applies
- DN – the DN value to be looked up.
- e – the electron value to use given the DN value

Example:

```
0, 511, 1, 25.111
0, 511, 2, 50.222
0, 511, 3, 73.333
```

Metadata contained in the csv header for the radiometric look-up tables are listed in [Table 12](#). The header rows in the CSV files are prefixed with "#" to distinguish them from the table data so the pipeline can parse the keywords and use them to fill out the .xml label. Hence the keywords in [Table 12](#) start with "#". The Class.Attribute Name column is left blank for keywords not mapped to the .xml label.

Table 12. DRACO File Metadata for Radiometric Look-up Tables

Class.Attribute Name	Keyword and example	Description	Range of values
Modification_History.modification_date	#DATE= '2018-08-25'/ file creation date YYYY-MM-DD	Date file was created.	YYYY-MM-DD
Investigation_Area.name	#MISSION = 'DART' / mission: DART	Name of mission.	"DART"
Observing_System.name	#HOSTNAME= 'DART ' / spacecraft name	DRACO is on the spacecraft called DART.	"DART"
Observing_System_Component.name	#INSTRUME= 'DRACO ' / instrument name	Name of instrument.	"DRACO"
	#ORIGIN = 'JHUAPL' / source of data product	Organization that created the data product	"JHUAPL"
	#CREATOR = 'Andy Cheng' / product author	Author of the file	The format is firstName lastName.
	#DETECTOR = 'SN403' / detector name	Name of detector used to create the file	"SN403"
	#CALTYPE = 'RADIOMETRIC' / calibration file type	Type of calibration file	"CALTABLE", "BADPIXEL MAP", "BIAS", "DARK", "FLATFIELD", "RADIOMETRIC"
dart:mission_phase	#MPHASE = 'PRELAUNCH' / mission phase during which data used to create lookup table were collected	Mission phase(s) during which the images used to create the input file were collected. A slash indicates data from multiple mission phases were used to create the file	"PRELAUNCH", "COMMISSIONING", "CRUISE", "APPROACH", "TERMINAL", "FINAL"
dart:imaging_mode	#IMGMOD= 'GLOBAL' / imaging mode	Shutter mode of the images used to create the file	"GLOBAL" or "ROLLING"
dart:gain	#GAIN= '1X' /gain setting	Detector gain setting of the images used to create the file	"1X", "2X", "10X", or "30X"
dart:test_temp	#TESTTEMP = 18.333 / [degC] nominal test temperature	Nominal temperature for the test sequence used to generate the file	Unspecified
	#DATASRC = 'APLFSFRONTIER/PROJECT/AIDA/500	Complete path to data used to create the file	Unspecified

	INSTRUMENT/DETECTOR/' / path to lowest-level directory that still contains all data used to create the table		
	#LITTIMES = '16 32 64 100 150 200 250 200 250 400 450 500 550 600 650 700 750 800 850 900 950 1000' / [linetime], exposure	Exposure of the images used to create the file, in units of linetime. A DRACO linetime is 87.467 us.	1 to 116059
	#GENVER = 'DRACO_lookup_generator_v2 0201214.xlsx' / Version of software used to create file	Version of software used to create the radiometric look-up table, in the form of a file name	File name
	#OFFSTCOL = 256 / Window 1 column offset	Window 1 offset from left edge of frame. Window1 coordinates are with respect to a 2560 x 2161 image plus header row (the 2560 x 2160 image plus 2560 x 1 header row) and unbinned pixels. The first pixel of the image plus header row is coordinate 0,0.	0 to 512
	#OFFSTROW = 57 / Window 1 row offset	Window 1 offset from origin of frame, incl. header. Window1 coordinates are with respect to a 2560 x 2161 image plus header row (the 2560 x 2160 image plus 2560 x 1 header row) and unbinned pixels. The first pixel of the image plus header row is coordinate 0,0.	1 to 113
Time_Coordinates. start_date_time	#CALSTART = '2022-03- 10T00:00:00' / file start time YYYY-MM-DDThh:mm:ss	UTC start time at which the calibration file is used in the pipeline.	YYYY-MM- DDThh:mm:ss
	#Data structure	Alerts the user that the following header row contains the table column names	
	#rowStart, rowEnd, DN, electrons	Column names for the radiometric lookup table	

5.2.4. Derived Image Data with Geometry Backplanes

The Level-4 derived DRACO image with geometry backplanes format is a single HDU, 16-plane, 1024 (sample) × 1024 (line), 32-bit floating point fits file. The first plane of the fits file contains the calibrated image for which the backplanes are derived. These derived data products are generated only for Final phase images (those acquired in the final ~4 minutes before impact, see Section 4.1.6). Valid backplane values are generated only for pixels that intercept the surface of Dimorphos or Didymos. Pixels that intercept space are set to -999 (see GEOINVAL keyword). Pixels outside of the original 512 × 512 image (window 2) retain their PXOUTWIN = -1E32 values (see PXOUTWIN keyword in Table 9). The metadata associated with these Level-4 derived products (Table 13) are appended as additional keywords to the fits header and XML label of the corresponding calibrated image. The Class.Attribute Name column is left blank for fits keywords not mapped to the .xml label.

Table 13. DRACO Level-4 Derived Image with Geometry Backplanes Appended Metadata

Class.Attribute Name	Keyword and example	Description	Range of values
	GENVER = '2021-09-18T02:12:00' / Version of software used to create file	Version of software used to create the geometry backplanes. Format is YYYY-MM-DDTHH:MM:SS in UTC.	
	SHAPREF1 = 'g_06650mm_rdr_obj_dida_0000n00000_v001.obj' / Used shape model	Shape model used to calculate the backplanes for pixels that intersect with Didymos	See DART derived products SIS for shape model naming scheme. Example: g_06650mm_rdr_obj_dida_0000n0000_v001.obj

Class.Attribute Name	Keyword and example	Description	Range of values
	SHAPREF2 = 'g_06650mm_rdr_obj_did b_0000n00000_v001.obj' / Used shape model	Shape model used to calculate the backplanes for pixels that intersect with Dimorphos	See DART derived products SIS for shape model naming scheme. Example: g_06650mm_rdr_obj_did_b_0000n00000_v001.obj
Special_Constants. invalid_constant	GEOINVAL = '-999' / Value assigned to pixels without valid intercepts	Value assigned to pixels that do not have valid intercepts for computing backplanes	-999
Array_2D_Image. local_identifier = ioverf	PLANE1 = 'Pixel value' / [I/F]	Pixel values of the calibrated FITS image, in I/F	See calibrated data product
Array_2D_Image. local_identifier = xcoord	PLANE2 = 'X coordinate of pixel center' / [km]	X coordinate (km) of the intercept with the surface of the asteroid in body-fixed reference frame	0 to 1
Array_2D_Image. local_identifier = ycoord	PLANE3 = 'Y coordinate of pixel center' / [km]	Y coordinate (km) of the intercept with the surface of the asteroid in body-fixed reference frame	0 to 1
Array_2D_Image. local_identifier = zcoord	PLANE4 = 'Z coordinate of pixel center' / [km]	Z coordinate (km) of the intercept with the surface of the asteroid in body-fixed reference frame	0 to 1
Array_2D_Image. local_identifier = latitude	PLANE5 = 'Planetocentric latitude of pixel center' / [deg]	Planetocentric latitude (degrees) of pixel center	-90 to 90
Array_2D_Image. local_identifier = longitude	PLANE6 = 'Planetocentric East longitude of pixel center' / [deg]	Planetocentric longitude (degrees east) of pixel center	0 to 360
Array_2D_Image. local_identifier = radius	PLANE7 = 'Radial distance from asteroid center to pixel center' / [km]	Radial distance (km) from the asteroid center of figure to pixel center	0 to 1
Array_2D_Image.	PLANE8 = 'Solar incidence angle' / [deg]	Solar incidence angle (degrees)	0 to 180

Class.Attribute Name	Keyword and example	Description	Range of values
local_identifier = incidence			
Array_2D_Image. local_identifier = emission	PLANE9 = 'Emission angle' / [deg]	Emission angle (degrees)	0 to 180
Array_2D_Image. local_identifier = phase	PLANE10 = 'Solar phase angle' / [deg]	Solar phase angle (degrees)	0 to 180 degrees
Array_2D_Image. local_identifier = horizpixscale	PLANE11 = 'Horizontal pixel scale' / [m]	Horizontal pixel scale (meters) measured from range to surface and shape	0.1 to 100 m
Array_2D_Image. local_identifier = vertpixscale	PLANE12 = 'Vertical pixel scale' / [m]	Vertical pixel scale (meters) measured from range to surface and shape	0.1 to 100 m
Array_2D_Image. local_identifier = slope	PLANE13 = 'Slope' / [deg]	Average surface slope relative to gravity (degrees)	0 to 180 degrees
Array_2D_Image. local_identifier = elevation	PLANE14 = 'Elevation' / [m]	Average elevation relative to gravity (meters)	-10 to 10 m
Array_2D_Image. local_identifier = gravacc	PLANE15 = 'Gravitational acceleration' / [m/s ²]	Average gravitational acceleration (meters/[s ²])	0 to 6.0E-5 m.s ²
Array_2D_Image. local_identifier = gravpot	PLANE16 = 'Gravitational potential' / [J/kg]	Average gravitational potential (J/kg)	0 to -0.01 J/kg

5.3. Label and Header Descriptions

All DRACO 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 “draco” folder of the bundle document collection in a sub-directory named “example_labels”. There are example labels for each type of DRACO data product.

5.3.1. Image Time Keywords

DRACO images contain several fits keywords that describe different times associated with the image. [Table 8](#) in the DRACO SIS describes each time-related keyword individually. In some cases, keywords provide redundant information. This redundancy can occur for three reasons. First, in some cases different subsystems on the spacecraft report the time of the same event, and verifying that these times are consistent is a check on data quality. Second, in some cases the SOC computes keywords that provide time information in other formats for the convenience of the data user (e.g., ephemeris time and UTC, in addition to MET). Third, some images will not have certain time keywords populated because occasionally GNC telemetry and DRACO images

fail to correlate. So, the SOC computes several redundant time-related keywords so that the key times are available for each image.

This section contains additional information about how the time keywords relate and which time keywords(s) are likely to be of interest to most end users of DRACO images. Most of the time keywords describe two events (Figure 10). The first event is the image time of validity, which is defined as the midpoint of the integration period. The second event is the image capture time, which is defined as the time that the first bit of the first pixel of an image arrives at the spacecraft SBC. The image time of validity is the time of interest to most end users of DRACO images. The attitude information in the fits header is correct at the image time of validity.

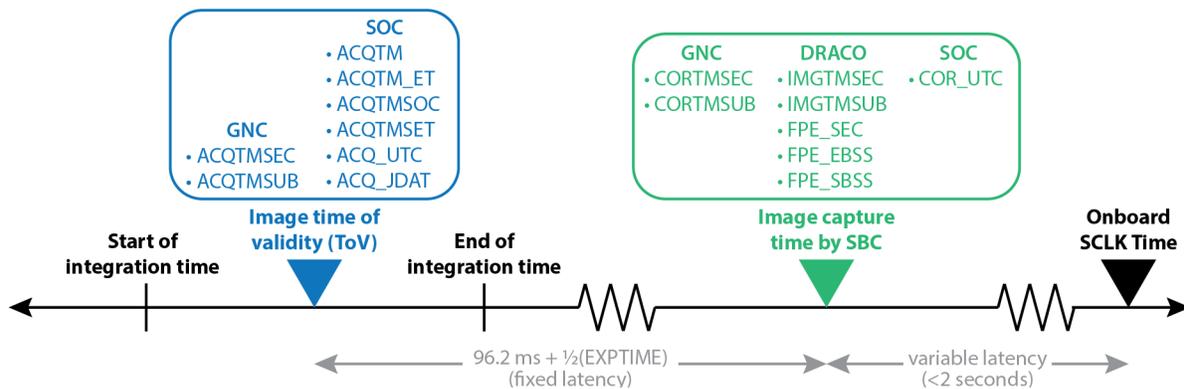


Figure 10. Keywords corresponding to the image time of validity (left box, in blue) and the image capture time (right box, in green) and the sources of each keyword. Some keywords come from GNC, some are calculated by the SOC, and others come from the DRACO FPE. The image time of validity is the time of interest to most end users of DRACO images.

Table 14 lists the keywords that provide the image time of validity. All of these keywords start with ACQTM. The various ACQTM* keywords report the time of validity in different formats or from different sources. Every DRACO image will have a valid value for ACQTMSOC and ACQTMSET. However, some images will lack values for ACQTMSEC, ACQTMSUB, ACQTM, and ACQTM_ET because GNC telemetry and DRACO images are generated at different rates.

Table 14. Image time of validity keywords.

Name	Source	Additional notes
ACQTMSEC	GNC	Computed by GNC onboard the spacecraft. Limited to images for which GNC and DRACO telemetry successfully correlate.
ACQTMSUB	GNC	
ACQTM	SOC	The SOC concatenates ACQTMSEC and ACQTMSUB and computes ACQTM_ET, when ACQTMSEC and ACQTMSUB are available, otherwise left blank.
ACQTM_ET	SOC	
ACQTMSOC	SOC	The SOC computes this using the same formula as GNC. Keyword available for all images.
ACQTMSET	SOC	The SOC computes this using SPICE based on ACQTMSOC.
ACQ_UTC	SOC	Keywords available for all images.

ACQ_JDAT	SOC	
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Table 15 lists the keywords that record the time when the first pixel of a DRACO image arrives at the SBC. These times are recorded in different formats, to different precisions, or from different sources, depending on the keyword. These times are not likely to be of use to most end users of DRACO images.

Table 15. Image capture time keywords.

Name	Source	Additional notes
CORTMSEC	GNC	Computed by GNC onboard the spacecraft. Limited to images for which GNC and DRACO telemetry successfully correlate.
CORTMSUB	GNC	
IMGTMSEC	DRACO	Reported by the DRACO focal plane electronics. Limited to images for which GNC and DRACO telemetry successfully correlate.
IMGTMSUB	DRACO	
FPE_SEC	DRACO	These keywords values are also provided by the DRACO focal plane electronics; however, they are downlinked in a different packet from IMGTMSEC and IMGTMSUB such that these keywords are available with every image, rather than only for images in which GNC and DRACO telemetry successfully correlate.
FPE_EBSS	DRACO	
FPE_SBSS	DRACO	
COR.UTC	SOC	The SOC computes this using SPICE based on COR.UTC, whenever COR.UTC is available.

The following keywords record estimated times used to latch GNC telemetry to DRACO images on the spacecraft and should not be used by end users of the DRACO images. These estimated times are computed before the image is acquired:

- ESTAQSEC
- ESTAQSUB

The following keywords record times relevant to SMART Nav processing and should not be used by end users of the DRACO images:

- SN_SEC
- SN_SUB
- SNG_SEC
- SNG_SUB

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 archive can be viewed with any PDS4 compatible software utility. DRACO 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.

7. Appendices

7.1. List of Acronyms and Abbreviations

Acronym or Abbreviation	Definition
APL	Applied Physics Laboratory
ASCII	American Standard Code for Information Interchange
CAD	Computer Aided Design
CDR	Calibrated Data Record
CMOS	Complementary Metal–Oxide–Semiconductor
CODMAC	Committee on Data Management and Computation
CSV	comma separated value
DAP	Derived Analysis Product
DART	Double Asteroid Redirection Test
DDP	Derived Data Product
DMAP	Data Management and Archive Plan
DN	Digital Numbers
DRACO	Didymos Reconnaissance and Asteroid Camera for OpNav
DSN	Deep Space Network
EDR	Experiment Data Record
FITS	Flexible Image Transport System
FPE	Focal Plane Electronics
FPGA	Field Programmable Gate Array
GNC	Guidance, Navigation, and Control
HDU	Header Data Unit
IAU	International Astronomical Union
IFOV	Instantaneous Field of View
IT	Investigation Team
LORRI	Long Range Reconnaissance Imager
MOC	Mission Operations Center
NASA	National Aeronautics and Space Administration
OpNav	Optical Navigation
OTA	optical telescope assembly
PDS	Planetary Data System
PLM	Product Lifecycle Management System
PNG	Portable Network Graphics
ROI	Region of Interest
RTS	Random Telegraph Signal
SBC	Single Board Computer
SBMT	Small Body Mapping Tool
SERDES	Serializer/Deserializer
SBN	Small Bodies Node
SIS	Software Interface Specification
SMART Nav	Small-Body Maneuvering Autonomous Real-Time Navigation

SNR	Signal to Noise
SOC	Science Operations Center
SRAM	Static Random-Access Memory
SSR	Solid State Recorder
TOV	Time of Validity
UTC	Coordinated Universal Time
XML	Extensible Markup Language

7.2. References

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7.3. Definitions of Data Processing Levels

Table 16 shows the comparison of DART, NASA and CODMAC data processing levels.

Table 16. Definition of data processing levels for science data (DART/DRACO, PDS4, NASA & CODMAC)

DRACO	PDS4	NASA	CODMAC	Description
	Packet Data	Packet Data	Raw Level 1	Telemetry data stream as received at the ground station, with science and engineering data embedded.
Raw Images	Raw Data	Level 0	Edited Level 2	Instrument science data (e.g., raw voltages, counts) at full resolution, time ordered, with duplicates and transmission errors removed. Prior to PDS4, referred to as Experiment Data Records (EDRs).
	Partially Processed Data	Level 1A	Calibrated Level 3	NASA Level 0 data that have been located in space and may have been transformed (e.g., calibrated, rearranged) in a reversible manner and packaged with needed ancillary and auxiliary data (e.g., radiances with the calibration equations applied). Prior to PDS4, referred to as Calibrated Data Records (CDRs) and in some cases Derived Data Products (DDPs).
Calibrated Images and Calibration Files	Calibrated Data	Level 1B	Resampled Level 4	Irreversibly transformed (e.g., resampled, remapped, calibrated) values of the instrument measurements (e.g., radiances, magnetic field strength). Prior to PDS4, referred to as either Derived Data Products (DDPs) or Derived Analysis Products (DAPs). Note that for this archive, the Calibration Files are co-located with the Calibrated Data in the Calibrated Data Collection even though they technically would be categorized as Level-4 NASA processed data.
	Derived Data	Level 2	Derived Level 5	Geophysical parameters, generally derived from NASA Level 1 (CODMAC level 3 and 4) data, and located in space and time commensurate with instrument location, pointing, and sampling. Prior to PDS4, referred to as Derived Analysis Products (DAPs).
		Level 3	Derived Level 5	Geophysical parameters mapped onto uniform space-time grids. Prior to PDS4, referred as derived analysis products (DAPs).
Image Backplanes		Level 4	Ancillary Data Level 6	Non-science data needed to generate calibrated or resampled data sets and consisting of instrument gains, and offsets, spacecraft positions, target information, pointing information for scan platforms, etc.

7.4. DRACO Imaging Sequences

Date (UTC)	Sequence Purpose	Images Acquired	Image Size	Of Interest	First image name	Last image name	First image UTC	Data quality note
2-Dec-21	DRACO Functional Testing (test pattern)	517	512x512 & 1024x1024		dart_0376144597_01640_01_raw.fits	dart_0376146984_05334_01_raw.fits	2021-12-02T12:36:35.874	Test patterns overwrite some header info. Do not trust values
2-Dec-21	DRACO Functional Testing (detector)	349	512x512 & 1024x1024		dart_0376161307_39654_01_raw.fits	dart_0376161568_31622_01_raw.fits	2021-12-02T17:15:06.643	ACQTM* values have errors up to 200 ms
2-Dec-21	Darks with door closed	744	1024x1024	Taken in rolling & global shutter; 4 gain states; 3 exposure times	dart_0376162835_37980_01_raw.fits	dart_0376165300_35035_01_raw.fits	2021-12-02T17:40:34.610	ACQTM* values have errors up to 200 ms
2-Dec-21	Bias with door closed	248	1024x1024	Taken in rolling & global shutter; 4 gain states; 1-INT exposure time	dart_0376165355_43668_01_raw.fits	dart_0376165992_35718_01_raw.fits	2021-12-02T18:22:34.725	ACQTM* values have errors up to 200 ms
2-Dec-21	DRACO images taken under misconfiguration (detector functionals + dark/bias)	5026	512x512 & 1024x1024	DO NOT USE THESE IMAGES	dart_0376147120_43856_01_raw.fits	dart_0376161226_45633_01_raw.fits	2021-12-02T13:18:39.719	DO NOT USE THESE IMAGES
7-Dec-21	Door open check / first light	64	512x512 & 1024x1024	First light; stars (hard to see in global 1x images); DRACO was not yet thermally stable; psf will improve	dart_0376581511_26840_01_raw.fits	dart_0376581842_38108_01_raw.fits	2021-12-07T13:58:30.600	ACQTM* values have errors up to 200 ms
7-Dec-21	Real-time DRACO stream downlink test 1 / DRACO - star tracker calibration	12945	1024x1024	Taken in rolling; 30x gain; 90 ms exposure time	dart_0376582665_26505_01_raw.fits	dart_0376597108_23394_01_raw.fits	2021-12-07T14:17:44.594	ACQTM* values have errors up to 200 ms
7-Dec-21	Darks 1 with door open	744	1024x1024	Taken in rolling & global shutter; 4 gain states; 3 exposure times	dart_0376597454_26050_01_raw.fits	dart_0376599915_25330_01_raw.fits	2021-12-07T18:24:13.592	ACQTM* values have errors up to 200 ms
7-Dec-21	Bias 1 with door open	254	1024x1024	Taken in rolling & global shutter; 4 gain states; 1-INT exposure time	dart_0376599992_26784_01_raw.fits	dart_0376600795_13809_01_raw.fits	2021-12-07T19:06:31.608	ACQTM* values have errors up to 200 ms

Date (UTC)	Sequence Purpose	Images Acquired	Image Size	Of Interest	First image name	Last image name	First image UTC	Data quality note
10-Dec-21	Star Cluster Cal A (M38) (geometric & radiometric cal)	4076	1024x1024	(1) Mosaic taken in global shutter at 13 positions to move the center of M38 around the FOV at 13 locations. At each location image with 4 gain/exposure time combinations. (2) Long series of rolling shutter images taken in 30x gain with 3 exposure times - all centered on M38.	dart_0376844404_15273_01_raw.fits	dart_0376848329_02856_01_raw.fits	2021-12-10T15:00:03.503	
10-Dec-21	Bias characterization	37	1024x1024	Taken in rolling; 30x gain; 1-INT exposure time	dart_0376848329_46228_01_raw.fits	dart_0376848364_05292_01_raw.fits	2021-12-10T16:05:29.124	
21-Dec-21	DRACO with high rate star tracker data streaming test (M34)	12905	512x512	Taken in rolling; 30x gain; 90 ms exposure time	dart_0377785801_14751_01_raw.fits	dart_0377800199_46780_01_raw.fits	2021-12-21T12:30:00.878	
21-Dec-21	Bias characterization	34	1024x1024	Taken in rolling; 30x gain; 1-INT exposure time	dart_0377800261_13512_01_raw.fits	dart_0377800407_31267_01_raw.fits	2021-12-21T16:31:00.906	
22-Jan-22	MR1: Lightcurve rehearsal	9436	1024x1024	Part of Mission Rehearsal #1; Taken in rolling; 30x gain; 90 ms exposure time; loose pointing to bright star Gamma Cancri (in real light curve, Didymos will not leave FOV)	dart_0380533439_15992_01_raw.fits	dart_0380581643_05072_01_raw.fits	2022-01-22T07:44:00.000	Gamma Cancri is saturated
22-Jan-22	MR1: Bias characterization	88	1024x1024	Part of Mission Rehearsal #1; Taken in rolling; 30x gain; 1-INT exposure time; tight pointing to bright star Gamma Cancri	dart_0380581647_16927_01_raw.fits	dart_0380582034_20462_01_raw.fits	2022-01-22T21:07:28.437	Gamma Cancri can be seen in stretched images
22-Jan-22	MR1: OpNav rehearsal (1/2)	270	1024x1024		dart_0380520839_15051_01_raw.fits	dart_0380522034_10674_01_raw.fits	2022-01-22T04:14:00.368	Gamma Cancri is saturated
22-Jan-22	MR1: OpNav rehearsal (2/2)	75	1024x1024	Part of Mission Rehearsal #1; Taken in rolling; 30x gain; 90 ms exposure time; tight pointing to bright star Gamma Cancri	dart_0380583835_22233_01_raw.fits	dart_0380584150_15047_01_raw.fits	2022-01-22T21:43:56.544	Gamma Cancri is saturated
22-Jan-22	MR1: Ground streaming test rehearsal part 1	1607	512x512	Part of Mission Rehearsal #1; Taken in global; 1x gain; 90 ms exposure time; loose pointing to bright star Gamma Cancri	dart_0380582038_13034_01_raw.fits	dart_0380583833_49997_01_raw.fits	2022-01-22T21:13:59.359	
22-Jan-22	MR1: Ground streaming test rehearsal part 2	11784	512x512	Part of Mission Rehearsal #1; Taken in global; 1x gain; 90 ms exposure time; loose pointing to bright star Gamma Cancri	dart_0380585059_36266_01_raw.fits	dart_0380598297_08565_01_raw.fits	2022-01-22T22:04:20.825	
23-Jan-22	MR1: OpNav rehearsal (1/5)	270	1024x1024	Part of Mission Rehearsal #1; Taken in rolling; 30x gain; 90 ms	dart_0380601839_12878_01_raw.fits	dart_0380603034_08537_01_raw.fits	2022-01-23T02:44:00.366	Gamma Cancri is saturated

Date (UTC)	Sequence Purpose	Images Acquired	Image Size	Of Interest	First image name	Last image name	First image UTC	Data quality note
				exposure time; tight pointing to bright star Gamma Cancri				
23-Jan-22	MR1: OpNav rehearsal (2/5)	270	1024x1024	Part of Mission Rehearsal #1; Taken in rolling; 30x gain; 90 ms exposure time; tight pointing to bright star Gamma Cancri	dart_0380623439_17317_01_raw.fits	dart_0380624634_12933_01_raw.fits	2022-01-23T08:44:00.466	Gamma Cancri is saturated
23-Jan-22	MR1: OpNav rehearsal (3/5)	271	1024x1024	Part of Mission Rehearsal #1; Taken in rolling; 30x gain; 90 ms exposure time; tight pointing to bright star Gamma Cancri	dart_0380646839_15646_01_raw.fits	dart_0380648039_01975_01_raw.fits	2022-01-23T15:14:00.444	Gamma Cancri is saturated
23-Jan-22	MR1: OpNav rehearsal (4/5)	270	1024x1024	Part of Mission Rehearsal #1; Taken in rolling; 30x gain; 90 ms exposure time; tight pointing to bright star Gamma Cancri	dart_0380659439_16576_01_raw.fits	dart_0380660634_12192_01_raw.fits	2022-01-23T18:44:00.469	Gamma Cancri is saturated
23-Jan-22	MR1: OpNav rehearsal (5/5)	271	1024x1024	Part of Mission Rehearsal #1; Taken in rolling; 30x gain; 90 ms exposure time; tight pointing to bright star Gamma Cancri	dart_0380675639_15039_01_raw.fits	dart_0380676839_01373_01_raw.fits	2022-01-23T23:14:00.447	Gamma Cancri is saturated
23-Jan-22	MR1: Bias characterization (1/2)	34	1024x1024	Part of Mission Rehearsal #1; Taken in rolling; 30x gain; 1-INT exposure time; tight pointing to bright star Gamma Cancri	dart_0380648043_18644_01_raw.fits	dart_0380648190_34541_01_raw.fits	2022-01-23T15:34:04.505	Gamma Cancri can be seen in stretched images
23-Jan-22	MR1: Bias characterization (2/2)	34	1024x1024	Part of Mission Rehearsal #1; Taken in rolling; 30x gain; 1-INT exposure time; tight pointing to bright star Gamma Cancri	dart_0380676843_18041_01_raw.fits	dart_0380676990_33939_01_raw.fits	2022-01-23T23:34:04.507	Gamma Cancri can be seen in stretched images
24-Jan-22	MR1: OpNav rehearsal (1/4)	270	1024x1024	Part of Mission Rehearsal #1; Taken in rolling; 30x gain; 90 ms exposure time; tight pointing to bright star Gamma Cancri	dart_0380691839_13499_01_raw.fits	dart_0380693034_09107_01_raw.fits	2022-01-24T03:44:00.424	Gamma Cancri is saturated
24-Jan-22	MR1: OpNav rehearsal (2/4)	270	1024x1024	Part of Mission Rehearsal #1; Taken in rolling; 30x gain; 90 ms exposure time; tight pointing to bright star Gamma Cancri	dart_0380699039_13314_01_raw.fits	dart_0380700234_08928_01_raw.fits	2022-01-24T05:44:00.424	Gamma Cancri is saturated
24-Jan-22	MR1: OpNav rehearsal (3/4)	270	1024x1024	Part of Mission Rehearsal #1; Taken in rolling; 30x gain; 90 ms exposure time; tight pointing to bright star Gamma Cancri	dart_0380706239_13177_01_raw.fits	dart_0380707434_08800_01_raw.fits	2022-01-24T07:44:00.425	Gamma Cancri is saturated
24-Jan-22	MR1: OpNav rehearsal (4/4)	271	1024x1024	Part of Mission Rehearsal #1; Taken in rolling; 30x gain; 90 ms exposure time; tight pointing to bright star Gamma Cancri	dart_0380713439_13063_01_raw.fits	dart_0380714638_49400_01_raw.fits	2022-01-24T09:44:00.427	Gamma Cancri is saturated
24-Jan-22	MR1: Bias characterization	34	1024x1024	Part of Mission Rehearsal #1; Taken in rolling; 30x gain; 1-INT exposure time; tight pointing to bright star Gamma Cancri	dart_0380714643_16069_01_raw.fits	dart_0380714790_31967_01_raw.fits	2022-01-24T10:04:04.487	Gamma Cancri can be seen in stretched images

Date (UTC)	Sequence Purpose	Images Acquired	Image Size	Of Interest	First image name	Last image name	First image UTC	Data quality note
24-Jan-22	MR1: Terminal rehearsal	1244	512x512	Part of Mission Rehearsal #1; Taken in global; 1x gain; 90 ms exposure time; tight pointing to bright star Gamma Cancri	dart_0380741450_28269_01.raw.fits	dart_0380742837_04441_01.raw.fits	2022-01-24T17:30:51.745	Window 2 fixed in center of detector (will move in real terminal)
04-Mar-22	TCM support	10000	512x512 & 1024x1024	Taken to support the trajectory correction maneuver (TCM)	dart_0384115798_13363_01.raw.fits	dart_0384127189_45327_01.raw.fits	2022-03-04T18:50:01.071	Images have high smear because acquired during TCM
04-Mar-22	Bias characterization	30	1024x1024		dart_0384127194_21614_01.raw.fits	dart_0384127345_30094_01.raw.fits	2022-03-04 21:59:57.334	
31-Mar-22	SMARTNav Testing	4836	512x512	Taken in rolling; 30x; 90 ms exposure time	dart_0386444696_13099_01.raw.fits	dart_0386450091_08956_01.raw.fits	2022-03-31 17:45:00.343	SMART-Nav-related keywords (see Table 8) for this dataset should be ignored. There was an issue with the population of these keywords during this test.
31-Mar-22	Bias characterization	37	1024x1024	Taken in rolling; 30x gain; 1-INT exposure time	dart_0386450092_21571_01.raw.fits	dart_0386450238_39326_01.raw.fits	2022-03-31 19:14:56.515	First four images in this sequence are 512x512
31-Mar-22	Bias characterization	34	1024x1024	Taken in global; 1x; 1-INT exposure time	dart_0386450243_20427_01.raw.fits	dart_0386450389_38179_01.raw.fits	2022-03-31 19:17:27.492	
31-Mar-22	SMARTNav Testing	34	1024x1024	Taken in global; 1x; 90 ms exposure time	dart_0386450394_19280_01.raw.fits	dart_0386450540_37033_01.raw.fits	2022-03-31 19:19:58.469	SMART-Nav-related keywords (see Table 8) for this dataset should be ignored. There was an issue with the population of these keywords during this test.
27-Apr-22	Star Tracker Terminal Sky Calibration 1	16259	512x512	Taken in rolling; 30x; 90 ms exposure time	dart_0388772995_13450_01.raw.fits	dart_0388788649_24947_01.raw.fits	2022-04-27 16:30:00.628	
27-Apr-22	Bias characterization	158	1024x1024	Taken in rolling; 30x; 1-INT exposure time	dart_0388789254_18537_01.raw.fits	dart_0388789405_27019_01.raw.fits	2022-04-27 21:00:59.783	