ShadowCam PDS Archive Software Interface Specification

Last Revised: 2023/03/01

ShadowCam SOC

1. Contents

2. Changelog

Date	Change	Affected Sections
2023/02/19	Initial Release	All
2023/02/29	Incorporated feedback from the PDS review panel	5.2, 5.3, 6.2, 6.3.2, 8

3. Acronyms and Abbreviations

- CDR - Calibrated Data Record, a PDS calibrated product
- COG - Cloud Optimized GeoTIFF, also works with non-map TIFFs
- CSV - Comma separated value text file
- DQI - Data quality ID
- DSN - Deep Space Network
- EDR - Experiment Data Record, a PDS raw product
- GIS - Geographic Information System
- IEEE - Institute of Electrical and Electronics Engineers
- KARI - Korea Aerospace Research Institute
- KPLO - Korea Pathfinder Lunar Orbiter
- LROC - Lunar Reconnaissance Orbiter Camera
- MET - Mission elapsed time
- NAIF - Navigation and Ancillary Information Facility, responsible for SPICE
- PDS - Planetary Data System
- PNG - Portable Network Graphics, a widely supported image standard
- PSR - Permanently shadowed region
- SCLK - Spacecraft clock kernel for SPICE
- SEU - Single event upset
- SIS - Software interface specification
- SOC - Science operations center
- SPICE - An Observation Geometry System for Space Science Missions
- TIFF - Tagged Image File Format, a widely supported image standard
- XML - eXtensible Markup Language

4. Introduction

4.1. Purpose and Scope

The primary objective of this Software Interface Specification (SIS) is to provide a comprehensive guide to the formats, labels, and directory structures of the ShadowCam Archive. This archive is a part of the Korea Pathfinder Lunar Orbiter (KPLO) mission flown by the Korea Aerospace Research Institute (KARI) and focuses on imaging the Moon's permanently shadowed regions (PSRs) larger than 10 kilometers with a nominal pixel scale of 1.7 meters. This archive conforms to NASA PDS 4 standards and includes ancillary products in standard Geographic Information System (GIS) formats when possible.

This document encompasses a basic overview of the ShadowCam instrument to provide context for the data collected. It also provides a detailed description of the various data products available in the archive, such as raw instrument data, calibrated data, and ancillary products like browse images, histogram data, smear maps, Cloud-Optimized GeoTIFFs (COGs), and map-projected products, along with information on their formats and naming schemes. Additionally, the SIS includes documentation of the data processing steps and label definitions. Completing the scope is a detailed explanation of the archive's directory structure and label descriptions, offering guidance on the organization of the data, file types, metadata standards, and the interpretive context provided by labels and metadata for each data product.

5. Instrument Overview

ShadowCam is designed to capture panchromatic high-resolution images inside lunar PSRs for the first time, building upon the heritage of the Lunar Reconnaissance Orbiter Camera (LROC) Narrow Angle Camera (NAC). This section provides a brief overview of the instrument's capabilities and features. For a comprehensive understanding of the ShadowCam instrument, readers are encouraged to refer to the ShadowCam Instrument and Investigation Overview [1].

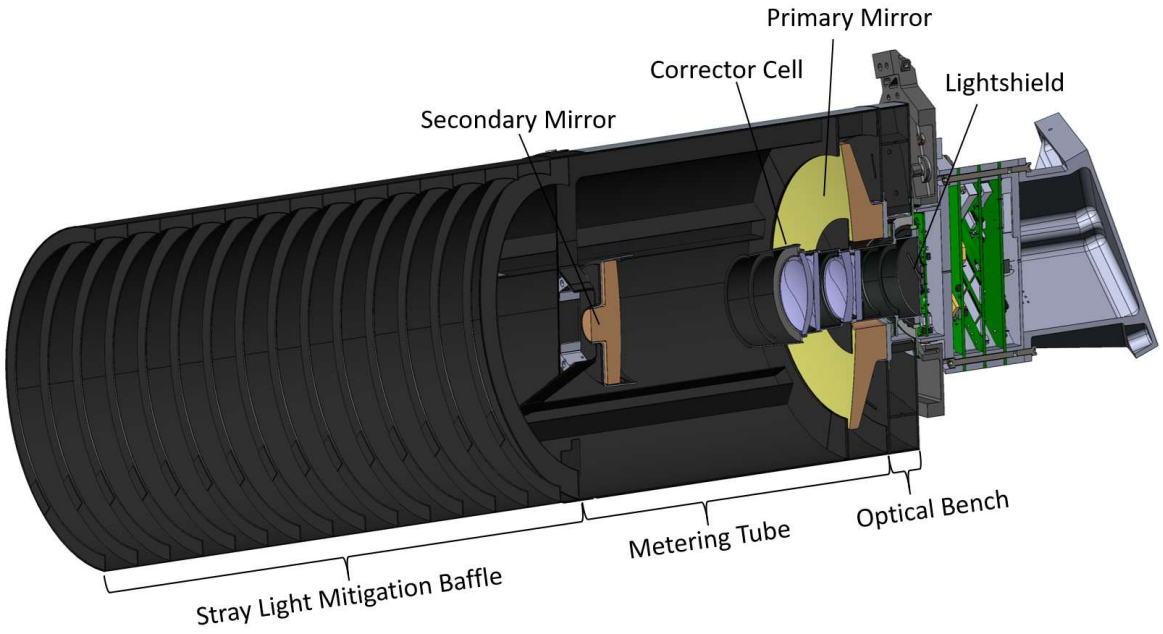

Figure 1: Diagram of the main components of ShadowCam

5.1. Design and Heritage

ShadowCam's design is heavily influenced by the LROC NAC, using the same telescope design but with modifications for stray light reduction (Figure 1). These modifications are crucial due to ShadowCam's specialized requirement for high sensitivity to image the Moon's PSRs.

5.2. Sensor and Image Capture

The core of ShadowCam's imaging capability lies in its Time Delay Integration (TDI) sensor, which operates across six channels. Each channel is structured, comprising two lead-in pixels, eight bias pixels, 512 scene pixels, and two lead-out pixels. This configuration results in a raw image width of 3,144 pixels, with the scene width being 3,072 pixels.

The lead-in/out and bias pixels are sometimes collectively called “overscan” pixels, but they are functionally different types of non-scene pixels. The lead-in/out pixels are transition pixels between the TDI line readout and the serial shift registers and contain no useful information for calibration. The bias pixels, however, are valuable for calibration as they are active imaging pixels that are completely shielded from light.

5.3. TDI Operation

At every beta 0 crossing, KPLO performs a 180° yaw flip to optimize sunlight on the solar panel. To accommodate this, the ShadowCam TDI can operate in both directions. The TDI sensor used is a CCD with 128 stages, but a light mask on the sensor effectively reduces it to 32 stages. This light mask is slightly in front of the focal plane, so a slight defocus at the point of the mask causes light to affect more than 32 stages, but the effective accumulation of signal is equal to 32 stages of TDI.

A critical operational aspect of TDI operation is setting the line rate. This rate is adjusted primarily to minimize smear across the scene as the TDI moves over the surface. In most scenarios, the line rate is determined based on the median optimal line rate for the shadowed areas within the scene. ShadowCam saturates with any amount of direct illumination from the Sun, so only shadowed areas are considered. This optimal line rate for the TDI is calculated in 100-meter bins, considering spacecraft altitude, local topography, and ground speed. In some instances, the line rate may be specifically optimized to meet particular scientific objectives, deviating from the nominal calculation (Figure 2).

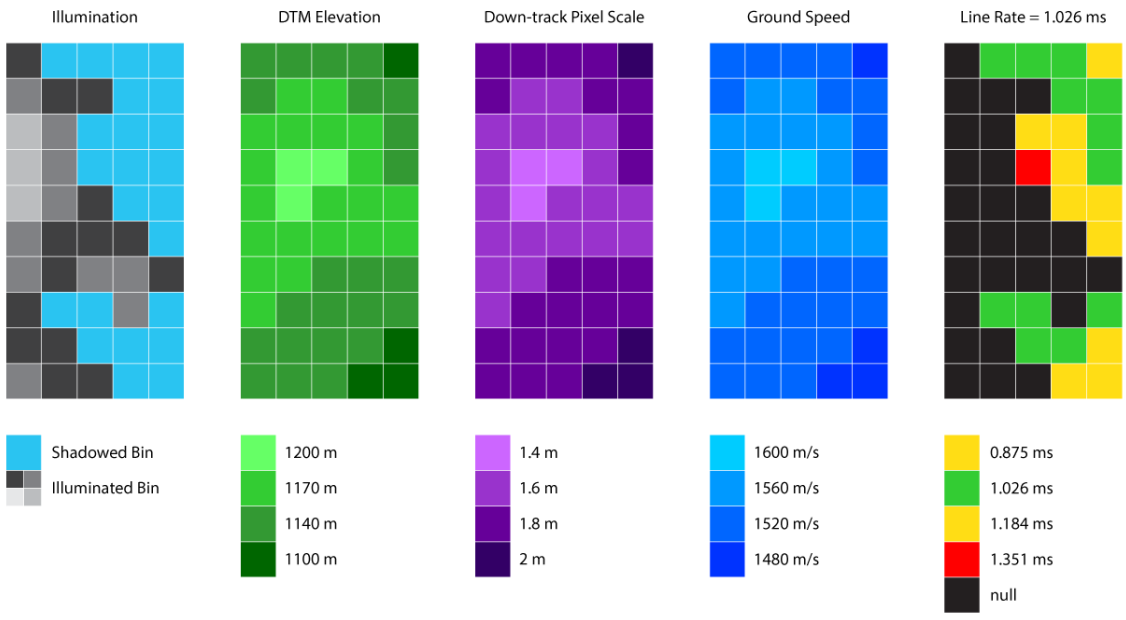

Figure 2: Artist's representation of how the line rate is calculated for each bin.

6. Data Product Overview

The ShadowCam data archive includes raw products, calibrated products, and an assortment of derived ancillary products to provide additional context or convenience when using the dataset. Due to the long history of the LROC mission, the LROC heritage of ShadowCam, and the utility of combining the LROC and ShadowCam datasets, the image names are based on the LROC archive. The raw ShadowCam products are equivalent to LROC Experiment Data Records (EDR), and the calibrated ShadowCam products are equivalent to LROC Calibrated Data Records (CDR). This document will use the PDS 4 terminology, but it's important to know the correlation with the LROC EDRs and CDRs. The ancillary products accompanying the primary dataset are "derived products" as defined by the PDS 4 standards.

6.1. Raw Products

The raw product is released as an 8-bit ISIS cube. The raw 12-bit instrument data is companded (Appendix - Companding Details) into 8-bit data and interleaved by channel into two memory banks within the instrument. The raw product deinterleaves the data so each row is in the correct pixel order, but otherwise, it has the raw 8-bit values unchanged from the instrument, including all lead-in and bias columns for an image width of 3,144 pixels. The ISIS header allows these data products to be directly used by ISIS as well as any PDS-compliant image viewer while providing key information in the form of the embedded ISIS label in the event the image file gets separated from the detached XML label.

Each raw product comes with three ancillary products to help view or evaluate the data without downloading or processing the original file.

- Browse Image - scaled-down image with the largest dimension of 1,000 pixels in PNG format.
- Full-resolution COG - pyramidal product in TIFF format complying with the COG standard without the geographic header to allow fast browsing via web-based tools.
- Histogram - CSV-formatted histogram data with a bin for each 8-bit DN.

6.2. Calibrated Products

The calibrated product is released as a 32-bit ISIS cube. The raw product is decompanded (Appendix - Companding Details) into 12-bit DNs. Then, the calibration steps defined in the ShadowCam calibration paper [2] are applied, with the resulting pixel units being in radiance units of $W/m^2/sr/\mu m$. The non-scene columns are removed

in this process, resulting in an image width of 3,072 pixels. The ISIS header allows these data products to be directly used by ISIS as well as any PDS-compliant image viewer while providing key information in the form of the embedded ISIS label in the event the image file gets separated from the detached XML label.

Each calibrated product comes with three ancillary products to help view or evaluate the data without downloading or processing the original file.

- Browse Image - scaled-down image with the largest dimension of 1,000 pixels in PNG format.
- Full-resolution COG - pyramidal product in a 32-bit TIFF format complying with the COG standard without the geographic header to allow fast browsing via web-based tools.
- Histogram - CSV-formatted histogram data with the values divided into 256 bins.

6.3. Ancillary

There are two additional types of ancillary products generated for each observation entirely on the Moon's surface. These products are not generated for any non-Moon observations or for limb views.

6.3.1. Smear Map

Smear maps are based on the same software used to calculate line rate information when targeting ShadowCam. The same 100-meter bins are calculated using the definitive SPICE rather than the predictive SPICE used when planning (Figure 2). Each bin's line rate is converted to the number of pixels of smear for that bin. Note that this calculates only the downtrack smear. This number may be positive or negative depending on whether the line rate is too high or too low. In most cases, the absolute value of the smear is all that is needed to understand the local smear, but the sign is preserved in this product for any analysis that may need it. The smear maps are released in two varieties and two formats. The first variety is a shadowed smear map where only shadowed bins have a smear value. This form is often the most useful since ShadowCam is saturated in directly-illuminated areas. In cases where smear values over the entire scene are needed, a full smear map is also generated. These two smear map varieties are released as both ISIS cubes and COGs. In both cases, map projection information is included, and the data format is 32-bit.

6.3.2. Map Projected

Map-projected products are included for all on-Moon observations for the convenience of data users. Notably, no fine-tuning, control networks, or other techniques have been

applied to these products. They are the raw output using the ISIS ShadowCam camera model, so ground accuracy may vary.

The map projection uses a topography file selected based on the area to get the best-available data selected from SLDEM, LOLA 60 m, or LOLA 30 m. Images with a center latitude between plus or minus 65° are projected in equirectangular with a latitude of true scale at the image center. Images closer to the poles are projected in polar stereographic with a longitude of true origin and latitude of true scale at the image center, to orient the map more upright and minimize scale distortion. The resolution of the map-projected products is based on the pixel scale at the image center projected onto the selected topography source.

These map-projected products are released in COG format to support ease of use in both GIS and web-based applications. For each observation, two versions are created.

- 8-bit stretched COG - a stretched product resulting from a 0.5% contrast stretch of non-saturated pixels with 0 as a NODATA value.
- 32-bit COG - contains the 32-bit calibrated radiance values with ISIS special pixel values converted to NODATA values.

6.4. Naming

The root name of all single-observation products is based on the observation target, an approximate mission elapsed time (MET) in seconds, and the letter ‘S’ to help differentiate ShadowCam products from LROC NAC products’ ‘L’ or ‘R’ when included in the same project. Products directly related to the raw product or calibrated product will also get an ‘E’ or a ‘C’ to designate that. The ‘E’ meaning raw is a holdover from LROC heritage EDR terminology, so products within the same project will be named consistently. The observation target letter can be one of ‘M,’ ‘E,’ ‘S,’ or ‘C’ to designate targets of Moon, Earth, Star, or non-Moon Calibration. Note that for the name, the MET is calculated without consideration for any commanding delays, timing offsets, or SCLK corrections and is solely based on the execution time plus the preroll time.

The full collection of files for an observation with a root name of M002429524S would be as follows:

- M002429524SE.cub
- M002429524SE.xml
- M002429524SE_browse.png
- M002429524SE_browse.xml
- M002429524SE_cog.tif
- M002429524SE_cog.xml

- M002429524SE_hist.csv
- M002429524SE_hist.xml

- M002429524SC.cub
- M002429524SC.xml
- M002429524SC_cog.tif
- M002429524SC_cog.xml
- M002429524SC_hist.csv
- M002429524SC_hist.xml
- M002429524SC_browse.png
- M002429524SC_browse.xml

- M002429524S_smear_full_cog.tif
- M002429524S_smear_full_cog.xml
- M002429524S_smear_full.cub
- M002429524S_smear_full.xml
- M002429524S_smear_shadowed_cog.tif
- M002429524S_smear_shadowed_cog.xml
- M002429524S_smear_shadowed.cub
- M002429524S_smear_shadowed.xml

- M002429524S_map_raw.tif
- M002429524S_map_raw.xml
- M002429524S_map_stretched.tif
- M002429524S_map_stretched.xml

7. Data Processing

The ShadowCam Science Operations Center (SOC) at Arizona State University performs all data processing for ShadowCam. The processing pipelines consist of multiple individual procedures for each step in the process, and provisions exist for reprocessing in the event of newer SPICE, updated calibration, or other potential causes for the data to change.

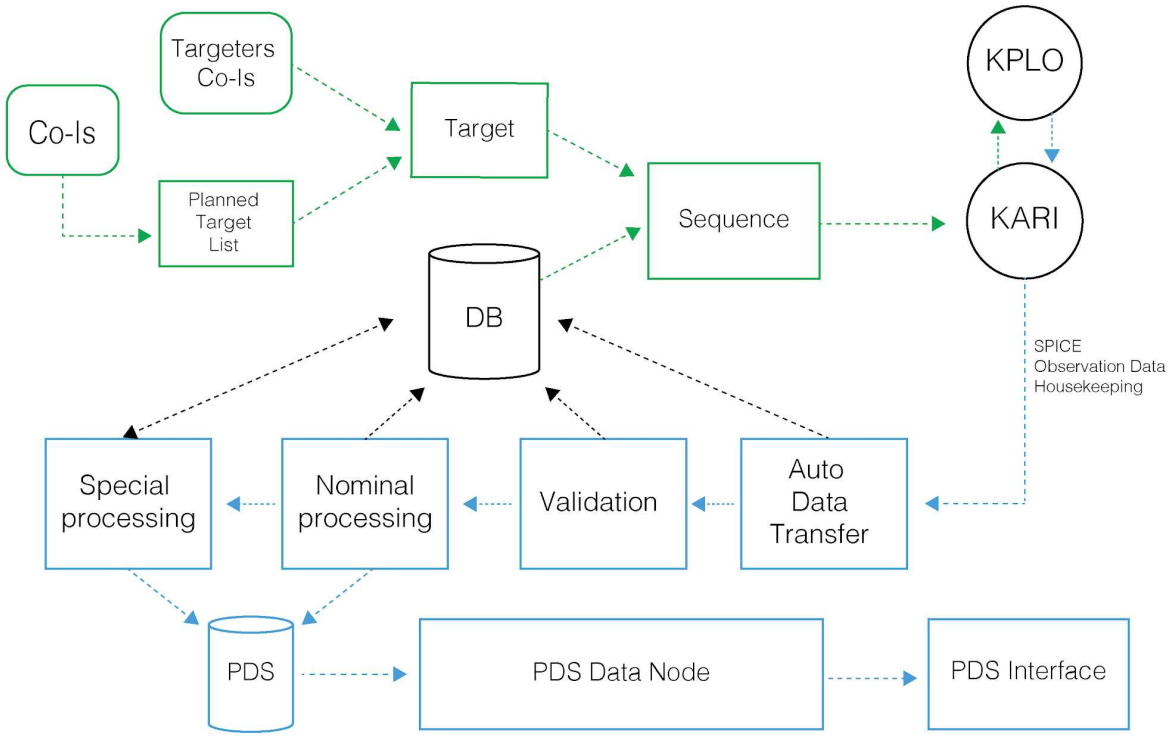

Figure 3: ShadowCam operations flow chart from target selection through PDS release.

The raw instrument files are downlinked by KARI using both KARI and DSN ground stations. These instrument files contain companded instrument data. The six channels are interleaved, and the resulting data is split between two segments within the ShadowCam memory. Multiple observations can be taken on the instrument as long as they all fit in the buffer space, and those observations are then read out in a single instrument file.

There is no checksum or other error correction/detection on the actual image data, so it is possible for single event upsets (SEUs) to corrupt a portion of the data. This corruption can affect a single pixel value or a chunk of data, depending on the nature of the SEU. Additionally, in most cases, packets are not retransmitted if they are lost during transmission to the ground, which can leave gaps in the data. The data quality ID (DQI) flags for missing data (entire 1 MiB blocks missing), undersaturated (possible individual downlink frames missing), and corruption detection (automatically-detected offset in bias columns indicating an SEU) can help evaluate if an observation is intact or if some amount of corruption or missing data is present. Most of the missing data and

corruption issues occurred during January and the first half of February 2023, with the error rate being significantly lower after that time frame.

The ShadowCam pipelines catalog all the received files and process the base products accordingly. These base products include the instrument files, SPICE kernels, and housekeeping data. Once all the prerequisite files have arrived, the pipelines update the final data quality flags and process the raw and calibrated products for PDS. After the pipeline generates each PDS product, a follow-up procedure ensures that each product is individually validated. The PDS validation tool maintained by the PDS engineering node performs this validation. This step helps ensure that data validation issues are discovered well before publication.

7.1. Standards Used in Generating Data Products

7.2. PDS Standards

The ShadowCam data products conform to the NASA Planetary Data System standards for version 4 of PDS.

7.3. Time Standards

The raw and calibrated products comply with the PDS standards for Universal Coordinate Time (UTC) and spacecraft time in the labels. The KPLO spacecraft time has a resolution of 0.125 seconds per tick and is used only to represent the execution times of the observations, which must fall at the start of a second onboard the spacecraft. All other times are represented in UTC.

Time conversion from spacecraft time to UTC is performed using the NAIF SPICE toolkit and the SCLK kernels provided by KARI for KPLO.

7.4. COG

Convenient products for viewing large data in GIS and web-based tools are available in the COG format as defined by www.cogeo.org. This standard is based on the widely supported GeoTIFF format with only internal structure changes to facilitate direct cloud-based usage of these files without downloading the entire data product. These files are fully compatible with any system capable of reading GeoTIFFs.

8. Directory Structure

```
- /
| - bundle.xml
|
```

```
| - calibration
| | - collection_calibration.csv
| | - collection_calibration.xml
| |
| | - dark_subtract_intercept.csv
| | - dark_subtract_intercept.xml
| | - dark_subtract_slope.csv
| | - dark_subtract_slope.xml
| | - flat_field.csv
| | - flat_field.xml
| | - gain_factors.csv
| | - gain_factors.xml
| | - radience.csv
| | - radience.xml
|
| - document
| | - collection_document.csv
| | - collection_document.xml
| |
| | - archsis.pdf
| | - archsis.xml
| | - calibration-jass-40-4-173.pdf
| | - calibration-jass-40-4-173.xml
| | - instrument_overview-jass-40-4-149.pdf
| | - instrument_overview-jass-40-4-149.xml
|
| - observation
| | - collection_observation.csv
| | - collection_observation.xml
| |
| | - year
| | | - doy
| | | | - image_name
| | | | | - {image_name}E.cub
| | | | | - {image_name}E.xml
| | | | | - {image_name}E_browse.png
| | | | | - {image_name}E_browse.xml
| | | | | - {image_name}E_cog.tif
| | | | | - {image_name}E_cog.xml
```

```
| | | | | - {image_name}E_hist.csv
| | | | | - {image_name}E_hist.xml
| | | | | - {image_name}C.cub
| | | | | - {image_name}C.xml
| | | | | - {image_name}C_cog.tif
| | | | | - {image_name}C_cog.xml
| | | | | - {image_name}C_hist.csv
| | | | | - {image_name}C_hist.xml
| | | | | - {image_name}C_browse.png
| | | | | - {image_name}C_browse.xml
| | | | | - {image_name}_smear_full_cog.tif
| | | | | - {image_name}_smear_full_cog.xml
| | | | | - {image_name}_smear_full.cub
| | | | | - {image_name}_smear_full.xml
| | | | | - {image_name}_smear_shadowed_cog.tif
| | | | | - {image_name}_smear_shadowed_cog.xml
| | | | | - {image_name}_smear_shadowed.cub
| | | | | - {image_name}_smear_shadowed.xml
| | | | | - {image_name}_map_raw.tif
| | | | | - {image_name}_map_raw.xml
| | | | | - {image_name}_map_stretched.tif
| | | | | - {image_name}_map_stretched.xml
```

9. Label Descriptions

The PDS labels for each product conform with the PDS data dictionary specified. The following mission and instrument-specific labels are used for ShadowCam data.

```
       <kplo:KPLO_Parameters>
        <!-- parameters for all KPLO products -->
        <kplo:product_version_id>v1.1</kplo:product_version_id>
        <kplo:mission_phase_name>nominal</kplo:mission_phase_name>
        <kplo:producer_institution_name>ARIZONA STATE
UNIVERSITY</kplo:producer_institution_name>

        <kplo:SHADOWCAM_Parameters>
          <!-- Parameters specific to SHADOWCAM -->
          <kplo:rationale_desc>Lovelace E and Hermite</kplo:rationale_desc>
          <kplo:data_quality_id>0</kplo:data_quality_id>
          <kplo:data_quality_desc>
            The DATA_QUALITY_ID is set to an 8-bit value that encodes the
following data quality information
            for the observation. For each bit a value of 0 means FALSE and a
```

```
value of 1 means TRUE. More
            information about the data quality ID can be found in the
SHADOWCAM Archive SIS, section 3.3 'Label
            and Header Descriptions'.
            Bit 1: Temperature of focal plane array is out of bounds.
            Bit 2: Unused
            Bit 3: Threshold for under-saturated pixels is reached.
            Bit 4: Observation is missing telemetry packets.
            Bit 5: SPICE information is bad or missing.
            Bit 6: Observation or housekeeping information is bad or missing.
            Bit 7: Corruption detected.
            Bit 8: Spare.
          </kplo:data_quality_desc>
          <kplo:dqi_corruption_detected>false</kplo:dqi_corruption_detected>
          <kplo:dqi_fpa_out_of_bounds>false</kplo:dqi_fpa_out_of_bounds>
          <kplo:dqi_under_saturated>false</kplo:dqi_under_saturated>
          <kplo:dqi_missing_data>false</kplo:dqi_missing_data>
          <kplo:dqi_missing_spice>false</kplo:dqi_missing_spice>
          <kplo:dqi_uncalibratable>false</kplo:dqi_uncalibratable>

          <!-- SHADOWCAM specific attributes -->

<kplo:execution_spacecraft_time>1206:1096104</kplo:execution_spacecraft_time>

<kplo:execution_time>2023-02-13T02:03:33.000000Z</kplo:execution_time>
          <kplo:start_time_offset unit="s">1.8842228</kplo:start_time_offset>
          <kplo:preroll_time>2023-02-13T02:03:33.799755Z</kplo:preroll_time>
          <!-- SHADOWCAM environment attributes -->
          <kplo:temperature_fpa_a unit="degC">8.13</kplo:temperature_fpa_a>
          <kplo:temperature_fpa_b unit="degC">10.95</kplo:temperature_fpa_b>
          <kplo:temperature_fpga unit="degC">8.14</kplo:temperature_fpga>
          <kplo:temperature_telescope
unit="degC">19.39</kplo:temperature_telescope>
          <!-- SHADOWCAM imaging attributes -->
          <kplo:line_rate_ms unit="ms">1.05905</kplo:line_rate_ms>
          <kplo:line_rate_code>303</kplo:line_rate_code>
          <kplo:klines>83</kplo:klines>
          <kplo:preroll_lines>1024</kplo:preroll_lines>
          <kplo:bterm1>0</kplo:bterm1>
          <kplo:bterm2>8</kplo:bterm2>
          <kplo:bterm3>25</kplo:bterm3>
          <kplo:bterm4>59</kplo:bterm4>
          <kplo:bterm5>128</kplo:bterm5>
          <kplo:xterm0>0</kplo:xterm0>
          <kplo:xterm1>32</kplo:xterm1>
          <kplo:xterm2>136</kplo:xterm2>
          <kplo:xterm3>544</kplo:xterm3>
          <kplo:xterm4>2208</kplo:xterm4>
```

```
      <kplo:mode_test>false</kplo:mode_test>
      <kplo:tdi_direction>B</kplo:tdi_direction>
      <kplo:gain_ch0>48</kplo:gain_ch0>
      <kplo:gain_ch1>48</kplo:gain_ch1>
      <kplo:gain_ch2>48</kplo:gain_ch2>
      <kplo:gain_ch3>38</kplo:gain_ch3>
      <kplo:gain_ch4>38</kplo:gain_ch4>
      <kplo:gain_ch5>38</kplo:gain_ch5>
      <kplo:offset_ch0>0</kplo:offset_ch0>
      <kplo:offset_ch1>-6</kplo:offset_ch1>
      <kplo:offset_ch2>-5</kplo:offset_ch2>
      <kplo:offset_ch3>1</kplo:offset_ch3>
      <kplo:offset_ch4>-3</kplo:offset_ch4>
      <kplo:offset_ch5>-6</kplo:offset_ch5>
      <kplo:bias_spread>31</kplo:bias_spread>
      <kplo:bias_spread_ch0>23</kplo:bias_spread_ch0>
      <kplo:bias_spread_ch1>23</kplo:bias_spread_ch1>
      <kplo:bias_spread_ch2>25</kplo:bias_spread_ch2>
      <kplo:bias_spread_ch3>19</kplo:bias_spread_ch3>
      <kplo:bias_spread_ch4>18</kplo:bias_spread_ch4>
      <kplo:bias_spread_ch5>17</kplo:bias_spread_ch5>
    </kplo:SHADOWCAM_Parameters>
  </kplo:KPLO_Parameters>
```

Figure 4: Sample mission/instrument section of a ShadowCam PDS label.

- kplo:bias_spread - Difference between the max and min bias 12-bit DN value for the whole image.
- kplo:bias_spread_ch0 - Difference between the max and min bias 12-bit DN value for channel 0.
- kplo:bias_spread_ch1 - Difference between the max and min bias 12-bit DN value for channel 1.
- kplo:bias_spread_ch2 - Difference between the max and min bias 12-bit DN value for channel 2.
- kplo:bias_spread_ch3 - Difference between the max and min bias 12-bit DN value for channel 3.
- kplo:bias_spread_ch4 - Difference between the max and min bias 12-bit DN value for channel 4.
- kplo:bias_spread_ch5 - Difference between the max and min bias 12-bit DN value for channel 5.
- kplo:bterm1 - Term for the companding table as described in the appendix.
- kplo:bterm2 - Term for the companding table as described in the appendix.
- kplo:bterm3 - Term for the companding table as described in the appendix.
- kplo:bterm4 - Term for the companding table as described in the appendix.

- kplo:bterm5 - Term for the companding table as described in the appendix.
- kplo:data_quality_desc - Describes how to interpret the data_quality_id field.
- kplo:data_quality_id - LROC-style data quality ID bitmask with minimal differences between ShadowCam and LROC definitions. See data_quality_desc for details. The individual boolean fields are likely easier to use for new software.
- kplo:dqi_corruption_detected - The corruption detection algorithm found a strong likelihood of image corruption somewhere in the observation. This is often localized to a small area, leaving most of the image usable.
- kplo:dqi_fpa_out_of_bounds - The focal plane temperature was outside of the nominal operational limits. The calibration of the image is likely to not be as good in this case.
- kplo:dqi_missing_data - One or more 1 MiB data blocks are missing from the image. Due to interleaving, this typically results in a pattern of 4 pixels present 4 pixels missing.
- kplo:dqi_missing_spice - SPICE was unavailable for this observation.
- kplo:dqi_uncalibratable - This observation could not be calibrated.
- kplo:dqi_under_saturated - One or more 0 DN values are present in the companded 8-bit DN.
- kplo:execution_spacecraft_time - The spacecraft time of when the image command was executed. Use this time with the SCLK kernel and add the start_time_offset value for the most accurate image start.
- kplo:execution_time - The UTC time and date at the execution of the image acquisition command. Add the start time offset to this time to get the start of the image data. Use the spacecraft clock version of the time with an SCLK kernel for the most accurate timing.
- kplo:gain_ch0 - The analog front end gain for channel 0.
- kplo:gain_ch1 - The analog front end gain for channel 1.
- kplo:gain_ch2 - The analog front end gain for channel 2.
- kplo:gain_ch3 - The analog front end gain for channel 3.
- kplo:gain_ch4 - The analog front end gain for channel 4.
- kplo:gain_ch5 - The analog front end gain for channel 5.
- kplo:klines - The number of 1024-line image chunks commanded (includes preroll).
- kplo:line_rate_code - The TDI line rate code commanded. The line time in seconds can be computed from the commanded line rate using the expression 50e-9*(12*524+(lr*(48+1)+46)), where lr is the commanded line rate (0-4095).
- kplo:line_rate_ms - The TDI line rate in milliseconds, the effective exposure time is multiplied by 32 for the number of TDI stages.

- kplo:mission_phase_name - The mission phase when this observation was collected.
- kplo:mode_test - The instrument was commanded in test mode, resulting in a gradient rather than image data.
- kplo:offset_ch0 - The analog front end offset for channel 0.
- kplo:offset_ch1 - The analog front end offset for channel 1.
- kplo:offset_ch2 - The analog front end offset for channel 2.
- kplo:offset_ch3 - The analog front end offset for channel 3.
- kplo:offset_ch4 - The analog front end offset for channel 4.
- kplo:offset_ch5 - The analog front end offset for channel 5.
- kplo:preroll_lines - The number of image lines dropped to initialize the TDI sensor. Typically, this is a minimum of 256.
- kplo:preroll_time - The UTC time and date at the start of the image acquisition, corresponding to the acquisition of preroll_lines at the given exposure prior to the actual image acquisition.
- kplo:producer_institution_name - The producer_institution_name attribute identifies a university, research center, NASA center, or other institution associated with the production of a data product.
- kplo:product_version_id - A version specifier to differentiate how the data was processed.
- kplo:rationale_desc - Any available commentary on the goal of the observation. This is created at planning time, and specific instrument and spacecraft performance may impact if the resulting image meets the original goal or not.
- kplo:start_time_offset - The time in seconds between the execution time and the start of image data. Use this with execution_spacecraft_time and the KPLO SCLK kernel to get the best available start of the image data.
- kplo:tdi_direction - The TDI direction of the sensor (A or B). This must match the flight direction of the spacecraft except for calibration images.
- kplo:temperature_fpa_a unit="degC" - The temperature of the ‘A’ sensor adjacent to the focal plane. This sensor is located on the heat strap going to the radiator and is the primary temperature used for calibration.
- kplo:temperature_fpa_b unit="degC" - The temperature of the ‘B’ sensor adjacent to the focal plane. This sensor is on the opposite side of the TDI sensor from ‘A’, but is not on the copper strap.
- kplo:temperature_fpga unit="degC" - The temperature reported on the electronics board adjacent to the FPGA.
- kplo:temperature_telescope unit="degC" - The temperature reported from the metering structure of the telescope.
- kplo:xterm0 - Term for the companding table as described in the appendix.

- kplo:xterm1 - Term for the companding table as described in the appendix.
- kplo:xterm2 - Term for the companding table as described in the appendix.
- kplo:xterm3 - Term for the companding table as described in the appendix.
- kplo:xterm4 - Term for the companding table as described in the appendix.

10. References

[1] Robinson MS, Brylow SM, Caplinger MA, Carter LM, Clark MJ, Denevi BW, Estes NM, Humm DC, Mahanti P, Peckham DA, Ravine MA, Schaffner JA, Speyerer EJ, Wagner RV. ShadowCam Instrument and Investigation Overview. J. Astron. Space Sci. 2023;40(4):149-171. https://doi.org/10.5140/JASS.2023.40.4.149

[2] Humm DC, Kinczyk MJ, Brylow SM, Wagner RV, Speyerer EJ, Estes NM, Mahanti P, Boyd AK, Robinson MS. Calibration of ShadowCam. J. Astron. Space Sci. 2023;40(4):173-197. https://doi.org/10.5140/JASS.2023.40.4.173

11. Appendix - Companding Details

ShadowCam uses a piecewise linear transfer function to compand the 12-bit instrument data into the 8-bit data sent to the ground in the instrument files. A series of terms are included in each ShadowCam command that controls the companding, which is also present in the raw and calibrated PDS labels. Six tables were defined for use with ShadowCam (Table 1), with the “square root” (Figure 5) and the “painless lin1” (Figure 6) tables being the most commonly used for nominal and calibration images, respectively. It is possible that additional companding tables may be defined and used for ShadowCam in flight, and the terms in the PDS labels will always represent the actual companding terms used for that image.

The piecewise linear transfer function logic operates as follows:

```
if pixin < xterm0 then
    pix <= pixin(7 downto 0);
elsif pixin < xterm1 then
    pix <= pixin/2+bterm1;
elsif pixin < xterm2 then
    pix <= pixin/4+bterm2;
elsif pixin < xterm3 then
    pix <= pixin/8+bterm3;
elsif pixin < xterm4 then
    pix <= pixin/16+bterm4;
else
```

```
    pix <= pixin/32+bterm5;
end if;
```

Description	xterm0	xterm1	xterm2	xterm3	xterm4	bterm1	bterm2	bterm3	bterm4	bterm5
square root	0	32	136	544	2208	0	8	25	59	128
lin1	511	0	0	0	0	0	0	0	0	0
lin16	0	0	0	0	4088	0	0	0	0	128
low signal	0	64	424	536	800	0	16	69	103	128
painless lin1	112	0	0	320	0	0	0	98	0	128
high signal	0	0	0	448	3200	0	0	0	28	128

Table 1: Predefined companding table terms for ShadowCam

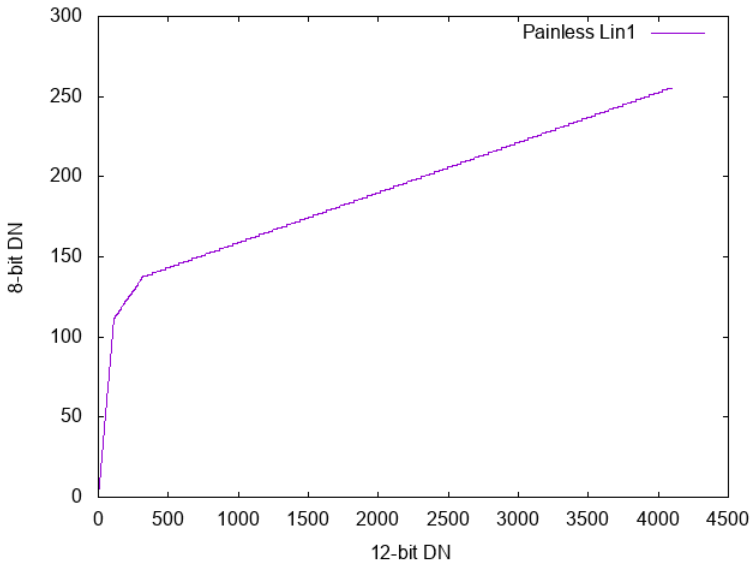

Figure 5: 12-bit to 8-bit transfer curve of the painless lin1 companding table.

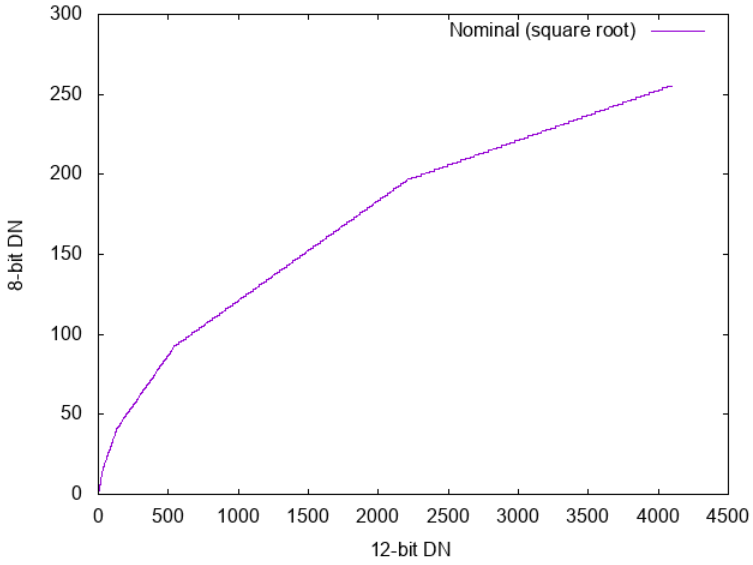

Figure 6: The square root companding table's 12-bit to 8-bit transfer curve.