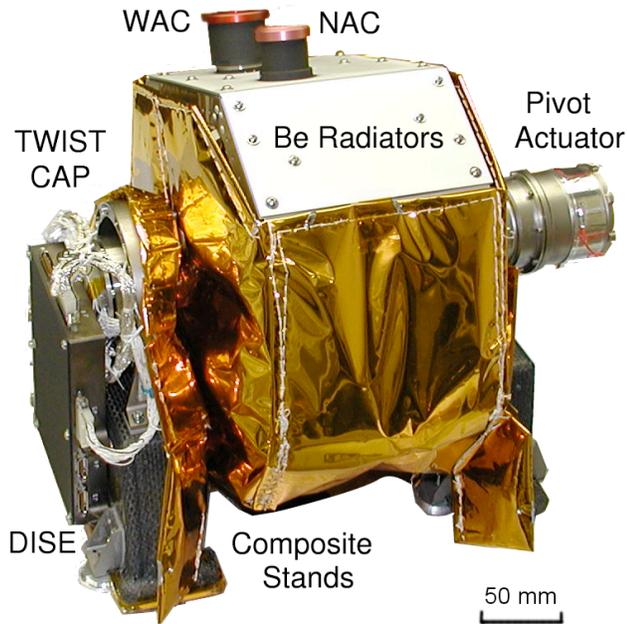


# MESSENGER

## Mercury Dual Imaging System (MDIS)

### Experimental Data Record (EDR)

### Software Interface Specification (SIS)



Version 2G

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## 1. Purpose And Scope Of Document

### 1.1 Purpose

This Software Interface Specification (SIS) describes the organization and contents of the MESSENGER MDIS Experimental Data Record (EDR) archive. There are two cameras onboard the MESSENGER spacecraft that will produce image data: a Wide Angle Camera (WAC) and Narrow Angle Camera (NAC) (Figure 1). The MDIS EDR Data products are

deliverable to the Planetary Data System (PDS) and the scientific community that it supports. All data formats are based on the PDS standard.

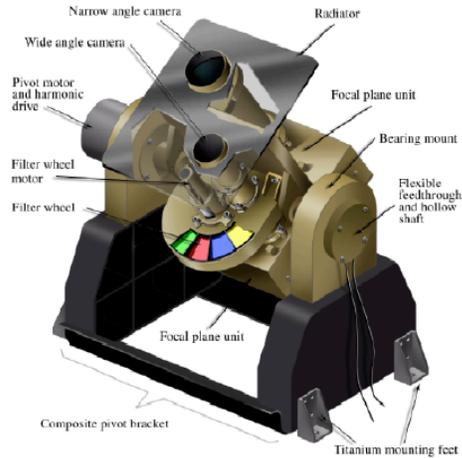


Figure 1: MDIS Instrument.

## 1.2 Scope

This specification is useful to those who wish to understand the format and content of the MDIS EDR image data products and ancillary support data. The SIS applies to the MDIS EDR data products produced during the course of MESSENGER mission operations, and preflight calibration.

## 2. Applicable Documents

The MDIS EDR SIS is responsive to the following Documents:

1. MESSENGER Mercury: Surface, Space Environment, Geochemistry, Ranging; A mission to Orbit and Explore the Planet Mercury, Concept Study, March 1999.
2. Planetary Data System Data Preparation Workbook, February 17, 1995, Version 3.1, JPL D-7669, Part 1.
3. Planetary Data System Standards Reference, July 24, 1995, Version 3.2. JPL D-7669, Part-2.
4. MESSENGER Data Management and Science Analysis Plan. The Johns Hopkins University, APL. 7384-9019, Revision A, 25 Sept 2006.
5. [PLR] Appendix 7 to the discovery program Plan; Program Level Requirement for the MESSENGER Discovery project; June 20, 2001.
6. MESSENGER Instrument DPU / MDIS Flight Software Specification, John Hayes. 7390-9041, Revision a, 26 Feb 2004. Describes the instrument flight software.
7. MDIS Compression Description, Pat Murphy. SRM-03-056, Aug. 25, 2003. Describes the MESSENGER Main Processor wavelet compression, sub-framing and binning flight software.
8. Hawkins, S. E., III, et al.: 1997, Multi-Spectral Imager on the Near Earth Asteroid Rendezvous mission, Space Sci. Rev., 82, 31-100.
9. Hansen, O. L.: 1974, Surface temperature and emissivity of Mercury, Astrophys. J. 190, 715-717.

### 3. Relationships with other Interfaces

The MDIS EDR data products are stored on hard disk and indexed in SQL (Structured Query Language) relational databases for rapid mission access. For delivery to PDS, the data products are placed into the directory structure specified in this document and are compressed into a “zip archive.” The zip archive preserves the data’s directory structure. The zip archive is transmitted to the Imaging PDS node via FTP. The data in the EDR files themselves will be stored in a PDS TABLE object.

The MDIS image files coming from the MESSENGER Solid State Recorder (SSR) can be in various states of data compression. Three of the compression methods are implemented within the instrument. These are: a 2X pixel binning, a 12 to 8 bit lookup table, which is a lossy compression type, and “FAST” which is a lossless compression type. Additionally, post processing, consisting of FAST decompression, wavelet compression and data subsetting can be applied using MESSENGER’s Main Processor (MP). These are: an Integer Wavelet Transform (IWT) compression algorithm (can be lossy or lossless), rectangular and jailbar frame subsetting, and 2X, 4X, or 8X pixel binning. (For more detail, see *Appendix B, MESSENGER Instrument DPU / MDIS Flight Software Specification*, and *MDIS Compression Description*).

## 4. Data Product Characteristics and Environment

### 4.1 Instrument Overview

The Wide Angle Camera (WAC) supports 12 band pass filters while the Narrow Angle Camera (NAC) is monochromatic. An overview of the MDIS camera is provided in the Appendix B – MDIS Instrument Overview. Table 3 in Appendix B summarizes relevant parameters for both the WA and NA cameras. The EDR format for each camera is identical.

### 4.2 Data Product Overview

There is one EDR product per MDIS image. The EDR product consists of a binary image file with an attached PDS label. The PDS label describes the format of the files, and has all of the parameters describing the state of the instrument when the image was exposed. The label also describes the post-processing options selected to be performed by the MESSENGER Main Processor (MP). In addition, the label has parameters derived from the instrument state such as viewing geometry, lighting, filter selections, etc. An MDIS EDR can consist of up to five sub-frames, reassembled into a full frame image. An EDR can also be a regularly spaced set of individual columns reassembled into a full frame image (jailbar mode). The image data have been uncompressed and reformatted with standard PDS labels, but are otherwise "raw".

Instrument parameters and other ancillary data will be archived in an INDEX file as part of the Archive Data Volume delivered to PDS. A label file will describe the contents and structure of the index file.

### 4.3 Data Processing

#### 4.3.1 Data Processing Level

For MESSENGER there is one archive for the WAC and NAC imagers. The archive includes level 2 (or above) CODMAC (Committee on Data Management and Computation) data, SPICE files, standard data products, relevant software, and documentation describing the generation of the products. Each product will have a unique file name across all MDIS data products and follow the file naming convention (see 5.1.4 File Naming Conventions).

#### 4.3.2 Data Product Generation

MESSENGER WA and NA image EDRs will be produced by the MESSENGER Science Operations Center (SOC) operated jointly by APL and ACT. The 'ACT/PIPE-MDIS2EDR' software ingestion engine converts the data to the proper PDS labeled format. The EDR data products are made available to the MESSENGER Science Team for initial evaluation and validation. At the end of the evaluation and validation period, the data are organized and stored in the directory structure described in section 5.1.5, *Directory Structure and Contents for Static Volumes*, along with fiduciary checksums for transmittal to the Imaging PDS node. The transmittal process is described in the next section, *Data Flow*. These products will be used for engineering support, direct science analysis, and construction of other science products.

The MDIS EDR data product contains image data in decompressed format. Decompression will result in a raw image that is not corrected for instrument signature, effects of spacecraft motion, or effects of imaging geometry.

#### 4.3.3 Data Flow and Transmittal to PDS Imaging Node

The MESSENGER Science Operation Center (SOC) operates under the auspices of the MESSENGER Project Scientist to plan data acquisition and generate and validate data archives. The SOC supports and works with the Mission Operations Center (MOC, located at and operated by JHU/APL), the Science Team, instrument scientists, and the PDS.

The SOC will be located at JHU/APL. The SOC will produce early versions of products that can be used by the science and instrument teams. Ideally they should be of the same type, content, and format as the final science products with default information for unknown data such as pointing and spacecraft housekeeping.

At the end of the evaluation and validation period, the data are organized and stored in the directory structure described in section 5.1.5, *Directory Structure and Contents for Static Volumes*, along with fiduciary checksums. This directory structure is compressed into a single "zip archive" file for transmittal to the Imaging PDS node. The zip archive preserves the directory structure internally so that when it is decompressed the original directory structure is recreated at the Imaging PDS node. The zip archive is transmitted to the Imaging PDS node via FTP to the URL specified by the node for receiving it.

#### 4.3.4 Transmittal Time Line

Several archive releases, as detailed in section 6, Archive Release Schedule to PDS, will be assembled and transmitted to PDS. Table 2, Schedule of Data Releases by Mission Phase, gives the date of each transmittal. At least two weeks before the deadline for transmittal, the zip archive file will be transmitted, via FTP, to the Imaging PDS node. At the same time, a letter of transmittal will be sent which provides an independent record of the fiduciary checksums provided in the archive file itself. Within several days of transmittal, the node will acknowledge receipt (but not verification) of the archive and letter of transmittal. If acknowledgement is not received, or if problems are reported, the MESSENGER SOC will immediately take corrective action to effect successful transmittal.

After transmittal, the Imaging PDS node will uncompress the zip archive file and independently calculate the fiduciary checksums for each file. The calculated checksums will be compared to the checksums in the transmittal letter to those recorded in the archive itself. The node will then perform any additional verification and validation of the data provided and will report any discrepancies or problems to the MESSENGER SOC. It is expected that the node will perform these checks and inspections in about two weeks. After inspection has been completed to the satisfaction of the Imaging PDS node, the node will issue to the MESSENGER SOC acknowledgement of successful receipt.

#### 4.3.5 Labeling and Identification

The label area of the data file conforms to PDS version 3.7 standards (PDS Standards Reference JPL D-7669). The purpose of the PDS label (see below) is to describe the measurement data and provide engineering and observation parameters. The images may consist of partial "sub-frames" of data overlaid into the full image frame instead of the entire 1024x1024 CCD. There are optional group objects for each of the present sub-frames.

EXAMPLE PDS LABEL FOR THE MDIS EDR

```

PDS_VERSION_ID      = PDS3

/**** FILE FORMAT ****/
RECORD_TYPE         = FIXED_LENGTH
RECORD_BYTES        = 1024
FILE_RECORDS        = 519

/**** POINTERS TO START BYTE OFFSET OF OBJECTS IN IMAGE FILE ****/
^IMAGE              = 8

/**** GENERAL DATA DESCRIPTION PARAMETERS ****/
MISSION_NAME        = "MESSENGER"
SPACECRAFT_NAME     = "MESSENGER"
INSTRUMENT_HOST_NAME = "MERCURY SURFACE, SPACE ENVIRONMENT,
                      GEOCHEMISTRY AND RANGING"
DATA_SET_ID         = "MESSENGER-X/CAL-MDIS-2-EDR-CRUISE1-V1.0"
DATA_QUALITY_ID     = "0000000000000000"
PRODUCT_ID          = "EW0001426431B"
SOURCE_PRODUCT_ID   = ("0001426431_IM1WV", "SPICEKERNEL1.BSP")
PRODUCER_INSTITUTION_NAME = "APPLIED COHERENT TECHNOLOGY"
SOFTWARE_NAME       = "mdis2edr"
SOFTWARE_VERSION_ID = 0.1
MISSION_PHASE_NAME  = "EARTH CRUISE"
TARGET_NAME         = MERCURY
SEQUENCE_TITLE      = 20040819_Checkout

/**** TIME PARAMETERS ****/
START_TIME          = 2004-08-19T18:13:19.414043
STOP_TIME           = 2004-08-19T18:13:19.415043
SPACECRAFT_CLOCK_START_COUNT = "1/0001426431:989000"
SPACECRAFT_CLOCK_STOP_COUNT = "1/0001426431:990000"
PRODUCT_CREATION_TIME = 2005-06-29T07:19:31

/**** INSTRUMENT ENGINEERING PARAMETERS ****/
INSTRUMENT_NAME     = "MERCURY DUAL-IMAGING SYSTEM WIDE-ANGLE
                      CAMERA"
INSTRUMENT_ID       = "MDIS-WAC"
FILTER_NAME         = "700 BW 600"
FILTER_NUMBER       = 2
CENTER_FILTER_WAVELENGTH = 700 <NM>
BANDWIDTH           = 600 <NM>
EXPOSURE_DURATION   = 1 <MS>
EXPOSURE_TYPE       = MANUAL
DETECTOR_TEMPERATURE = 4.4 <C>
FOCAL_PLANE_TEMPERATURE = 4.4 <C>
FILTER_TEMPERATURE  = 4.4 <C>
OPTICS_TEMPERATURE  = "N/A"

/**** INSTRUMENT RAW PARAMETERS ****/
MESS:MET_EXP        = 1426431
MESS:ATT_CLOCK_COUNT = 1426429
MESS:ATT_Q1          = -0.146701
MESS:ATT_Q2          = 0.439839
MESS:ATT_Q3          = 0.468664
MESS:ATT_Q4          = 0.751914
MESS:ATT_FLAG        = 7

```

MESS:PIV_GOAL	=	0
MESS:PIV_POS	=	1
MESS:PIV_READ	=	20652
MESS:PIV_CAL	=	-26758
MESS:FW_GOAL	=	11976
MESS:FW_POS	=	11980
MESS:FW_READ	=	11980
MESS:CCD_TEMP	=	1089
MESS:CAM_T1	=	487
MESS:CAM_T2	=	493
MESS:EXPOSURE	=	1
MESS:DPU_ID	=	0
MESS:IMAGER	=	0
MESS:SOURCE	=	0
MESS:FPU_BIN	=	0
MESS:COMPL2_8	=	0
MESS:COMP_ALG	=	0
MESS:COMP_FST	=	1
MESS:TIME_PLS	=	1
MESS:LATCH_UP	=	0
MESS:EXP_MODE	=	0
MESS:PIV_STAT	=	1
MESS:PIV_MPEN	=	0
MESS:PIV_PV	=	1
MESS:PIV_RV	=	1
MESS:FW_PV	=	1
MESS:FW_RV	=	1
MESS:AEX_STAT	=	256
MESS:AEX_STHR	=	0
MESS:AEX_TGTB	=	3000
MESS:AEX_BACB	=	240
MESS:AEX_MAXE	=	989
MESS:AEX_MINE	=	1
MESS:DLNKPRIO	=	1
MESS:WVLRTATIO	=	4
MESS:PIXELBIN	=	2
MESS:SUBFRAME	=	5
MESS:SUBF_X1	=	0
MESS:SUBF_Y1	=	0
MESS:SUBF_DX1	=	256
MESS:SUBF_DY1	=	256
MESS:SUBF_X2	=	768
MESS:SUBF_Y2	=	0
MESS:SUBF_DX2	=	256
MESS:SUBF_DY2	=	256
MESS:SUBF_X3	=	0
MESS:SUBF_Y3	=	768
MESS:SUBF_DX3	=	256
MESS:SUBF_DY3	=	256
MESS:SUBF_X4	=	768
MESS:SUBF_Y4	=	768
MESS:SUBF_DX4	=	256
MESS:SUBF_DY4	=	256
MESS:SUBF_X5	=	408
MESS:SUBF_Y5	=	408
MESS:SUBF_DX5	=	256
MESS:SUBF_DY5	=	256
MESS:CRITOPNV	=	0
MESS:JAILBARS	=	0

```

MESS:JB_X0           =           0
MESS:JB_X1           =           0
MESS:JB_SPACE        =           0

/*** GEOMETRY INFORMATION ***/
RIGHT_ASCENSION      = 44.4 <DEG>
DECLINATION          = 44.4 <DEG>
TWIST_ANGLE          = 44.4 <DEG>
RETICLE_POINT_RA     = (44.4,44.4,44.4, 44.4)
RETICLE_POINT_DECLINATION = (44.4, 44.4, 44.4, 44.4)

/*** TARGET PARAMETERS ***/
SC_TARGET_POSITION_VECTOR = (44.4, 44.4, 44.4)
TARGET_CENTER_DISTANCE = 44444.44 <KM>

/*** TARGET WITHIN SENSOR FOV ***/
SLANT_DISTANCE       = "N/A"
CENTER_LATITUDE      = "N/A"
CENTER_LONGITUDE     = "N/A"
HORIZONTAL_PIXEL_SCALE = "N/A"
VERTICAL_PIXEL_SCALE = "N/A"
SMEAR_MAGNITUDE      = "N/A"
SMEAR_AZIMUTH        = "N/A"
NORTH_AZIMUTH        = "N/A"
RETICLE_POINT_LATITUDE = ("N/A","N/A","N/A","N/A")
RETICLE_POINT_LONGITUDE = ("N/A","N/A","N/A","N/A")

/*** SPACECRAFT POSITION WITH RESPECT TO CENTRAL BODY ***/
SUB_SPACECRAFT_LATITUDE = "N/A"
SUB_SPACECRAFT_LONGITUDE = "N/A"
SPACECRAFT_ALTITUDE = "N/A"
SUB_SPACECRAFT_AZIMUTH = "N/A"

/*** SPACECRAFT LOCATION ***/
SPACECRAFT_SOLAR_DISTANCE = 4444444.4
SC_SUN_POSITION_VECTOR = (44.4,44.4,44.4)
SC_SUN_VELOCITY_VECTOR = (44.4,44.4,44.4)

/*** VIEWING AND LIGHTING GEOMETRY (SUN ON TARGET) ***/
SOLAR_DISTANCE       = "N/A"
SUB_SOLAR_AZIMUTH    = "N/A"
SUB_SOLAR_LATITUDE   = "N/A"
SUB_SOLAR_LONGITUDE  = "N/A"
INCIDENCE_ANGLE      = "N/A"
PHASE_ANGLE          = "N/A"
EMISSION_ANGLE       = "N/A"
LOCAL_HOUR_ANGLE     = "N/A"

/*** GEOMETRY FOR EACH SUBFRAME ***/
GROUP = SUBFRAME1_PARAMETERS
  RETICLE_POINT_LATITUDE = ("N/A","N/A","N/A","N/A")
  RETICLE_POINT_LONGITUDE = ("N/A","N/A","N/A","N/A")
END_GROUP = SUBFRAME1_PARAMETERS

GROUP = SUBFRAME2_PARAMETERS
  RETICLE_POINT_LATITUDE = ("N/A","N/A","N/A","N/A")
  RETICLE_POINT_LONGITUDE = ("N/A","N/A","N/A","N/A")
END_GROUP = SUBFRAME2_PARAMETERS

```

```

GROUP = SUBFRAME3_PARAMETERS
  RETICLE_POINT_LATITUDE = ("N/A", "N/A", "N/A", "N/A")
  RETICLE_POINT_LONGITUDE = ("N/A", "N/A", "N/A", "N/A")
END_GROUP = SUBFRAME3_PARAMETERS

GROUP = SUBFRAME4_PARAMETERS
  RETICLE_POINT_LATITUDE = ("N/A", "N/A", "N/A", "N/A")
  RETICLE_POINT_LONGITUDE = ("N/A", "N/A", "N/A", "N/A")
END_GROUP = SUBFRAME4_PARAMETERS

GROUP = SUBFRAME5_PARAMETERS
  RETICLE_POINT_LATITUDE = ("N/A", "N/A", "N/A", "N/A")
  RETICLE_POINT_LONGITUDE = ("N/A", "N/A", "N/A", "N/A")
END_GROUP = SUBFRAME5_PARAMETERS

OBJECT = IMAGE
  LINES = 512
  LINE_SAMPLES = 512
  SAMPLE_TYPE = MSB_UNSIGNED_INTEGER
  SAMPLE_BITS = 16
END_OBJECT = IMAGE
END

```

A reconstructed image (at any level of binning) can contain up to five sub-frames, plus the special dark strip sub-frame. Figure 2 shows 6 sub-frames (dark strip plus 5 image area sub-frames). See the MDIS Compression Description document [Murphy, Document 7 in the Applicable Documents list] for a detailed discussion of the treatment of the dark strip sub-frame. Also, Appendix B discusses the dark column layout and behavior.

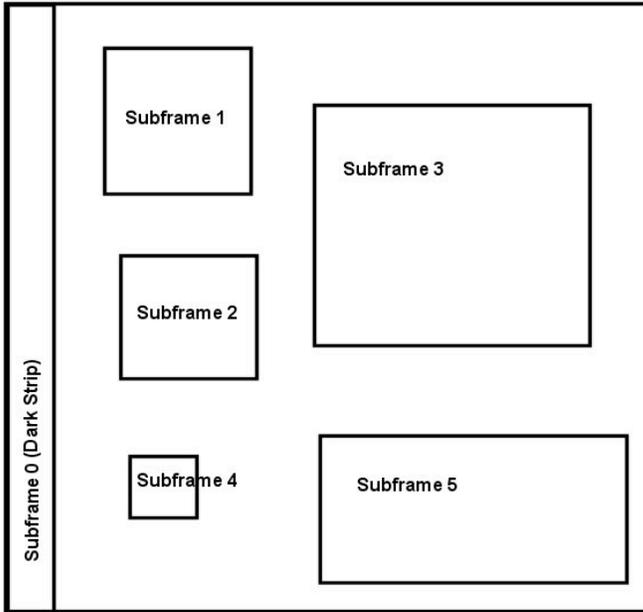


Figure 2 Reconstructed image with 5 subframes plus the dark strip subframe

#### 4.4 Standards Used in Generating Data Products

##### 4.4.1 PDS Standards

The MDIS EDR data products are constructed according to the data object concepts developed by the PDS. By adopting the PDS format, the MDIS EDRs are consistent in content and organization with other planetary image collections. In the PDS standard, the EDR image file is grouped into objects with PDS labels describing the objects. The MESSENGER MDIS EDR data products contains

1. *The PDS Label describing the EDR product*
2. *The Image data containing a reconstructed image where all the sub-image-frames have been decompressed and embedded into their original corresponding location in the focal plane array.*

##### 4.4.2 Coordinate Systems

The following bullet list outlines the computational assumptions for the geometric and viewing data provided in the PDS label. There are two coordinate systems in use: 1) the celestial reference system used for target and spacecraft position and velocity vectors, and camera pointing; and 2) the planetary coordinate system for geometry vectors and target location. The celestial coordinate system is J2000 (Mean of Earth equator and equinox of J2000). The planetary coordinate system is **planetographic** with respect to a reference ellipsoid (sphere with 2440 km radius).

###### COMPUTATIONAL ASSUMPTIONS

- The mid-point time of observation is used for the geometric element computations.
- Label parameters reflect observed, not true, geometry. Therefore, light-time and stellar aberration corrections are used as appropriate.
- The inertial reference frame is J2000 (also called EME2000).
- Target latitudes and longitudes are **planetographic**. The initial agreed upon Mercury ellipsoid is a sphere with a 2440 km radius.
- The "sub-point" of a body on a target is defined by the surface intercept of the body-to-target-center vector. This is not the closest point on the target to the body. This definition gives sub-point latitude and longitude that are independent of the target's reference ellipsoid.
- Distances are in km, speeds in km/sec, angles in degrees.
- Angular rates in degrees/sec, unless otherwise noted.
- Angle ranges are 0 to 360 degrees for azimuths and local hour angle. Longitudes range from 0 to 360 degrees (positive to the East). Latitudes range from -90 to 90 degrees.
- SPICE kernel files used in the geometric parameters are outlined in **Appendix A**.

##### 4.4.3 Data Storage Conventions

The data are organized following PDS standards and transferred to the PDS for distribution to the science community. Data will be stored under unique file names as defined in Section 5.1.4.

#### 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 Science Team, and the second will be overseen by the PDS, in coordination with the Science Team.

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 dataset provider: the SOC for Level 1 data, and the Science Team for higher-level data products, calibration data, and calibration algorithms. Once the liens are cleared, PDS will do a final validation prior to packaging and delivery.

The SOC will periodically report results of validation to the Science Steering Committee. If the volumes are approved for release by the Project, then the SOC will transfer the archives to the PDS. [MESSENGER Data Management and Science Analysis Plan].

### 5. Detailed Data Product Specifications

#### 5.1 Data Product Structure And Organization

Data that comprise the MESSENGER Image Archive are formatted according to the standards of the Planetary Data System standard, version 3.7 as documented in the PDS Standards Reference manual [JPL Document D-7669]. Archive-quality data sets include everything needed to understand and utilize the data. The raw images by themselves are insufficient for the science community to realize the full scientific potential of the data. Thus, the MESSENGER project is providing as part of the archive the ancillary data to perform radiometric, photometric, and cartographic processing. Additionally, a documentation set is provided to describe the data products, imaging instruments, and mission operations.

##### 5.1.1 Static and Dynamic Data volumes

The MESSENGER data sets are placed into static and dynamic categories. Static data sets, once produced and validated, are not subject to update or modification, except through errata updates. Dynamic data sets have the inherent property that they continue to evolve and improve as the knowledge of the mission parameters improve. These data sets are periodically updated or replaced with new versions, and are likely to be updated by post-mission data analysis programs. *Examples of static data sets* include the raw images; the ancillary data that describe the camera modes, and errata files that describe problems encountered during production of the data volumes. Once the raw images have been received, validated, and properly stored in an archive they will never change. Required changes to static data sets would have to be a redelivered version, or an errata update. Likewise, the camera modes, once properly recorded, will not change. *Examples of dynamic data sets* are calibration files for radiometric correction. As knowledge of the camera properties improve the calibration files will be updated and evolve to reflect the new knowledge. In the archive, the static and dynamic data sets are physically separated into different volumes. The static data set makes up virtually the entire archive volume set. The dynamic data sets (calibration files, and SPICE kernels) have modest storage requirements. Once the static volumes are created and validated, they would rarely need to be recreated or updated — a desirable quality for the volumes that

make up most of the archive. As the dynamic data sets are improved and updated, only the limited number of volumes dedicated to the dynamic data need to be redistributed.

### 5.1.2 Handling Errors

If errors in an archive volume are discovered, they are reported to the MESSENGER data processing facility. An ERRATA report file is maintained to track and document all discovered errors. At the conclusion of the production of the MESSENGER volume set, a final DVD is prepared that contains corrected versions of all problem files.

### 5.1.3 Geometric Elements

Geometric elements fully describe the viewing geometry of each observation. The geometric elements are organized according to the SPICE kernel concepts adopted by the Navigational Ancillary Information Facility (NAIF) at the Jet Propulsion Laboratory. SPICE is an acronym for **S**pacecraft, **P**lanet, **I**nstrument, **C**-matrix, and **E**vent kernels. (See <http://naif.jpl.nasa.gov>)

The SPICE kernel data set are archived on the dynamic data volumes that accompany the EDR data products. SPICE kernels evolve and improve as further analysis is done. The PDS data labels attached to the image data products are based on the most up-to-date SPICE information available at the time of product creation.

### 5.1.4 File Naming Conventions

The file names developed for this PDS archive are restricted to a maximum 27-character base name and 3 character extension name with a period separating the file and extension names. Also known as the "27.3" format, this is compliant with the ISO 9660 Level 2 specification (maximum of 31 characters), which is required by PDS. The MDIS EDR products will have a "13.3" format and thus remain within the specification parameters. Below is the detailed naming convention for this dataset.

#### MDIS File Naming Convention

Format: "xc#####f.IMG"

**x** = **E** for EDR, or **C** for CDR

**c** = **W** or **N** for Wide or Narrow Angle camera

**#####** = Mission Elapsed Time (MET) counter taken from the image header (and same as original compressed filename from SSR) NOTE: this a spacecraft clock seconds counter, and the value in the filename corresponds to the LAST second of the exposure.

**f** = Filter wheel position (A,B,C,D,E,F,G,H,I,J,K,L,U) for the WAC. (See Table 4, Appendix B) It is M for the NAC, which has no filter wheel. It will be U if the position is unknown.

The following is an example file name with a description of the individual components:

**EW0014032676F.IMG**

This image:

- Is an EDR (**E**)
- Is from the WAC camera (**W**)
- Contained **0014032676** as the Mission Elapsed Time (MET) in its header.
- Used WAC filter wheel position 6 (**F**)

**5.1.5 Directory Structure And Contents For Static Volumes**

An MDIS archive volume will contain the following directories below the root:

- CATALOG
- DATA
- DOCUMENT
- INDEX

In addition, a volume may contain the following optional directories:

- LABEL
- BROWSE
- CALIB
- ERRATA
- GEOMETRY

**5.1.6 Directory Contents****<ROOT> DIRECTORY**

This is the top-level directory of a volume. The following are files contained in the root directory.

**AAREADME.TXT** - General information file. Provides users with an overview of the contents and organization of the associated volume, general instructions for its use, and contact information. This file contains the fiduciary checksums calculated for the files in the archive.

**VOLDESC.CAT** - PDS file containing the VOLUME object. This gives a high-level description of the contents of the volume. Information includes: production date, producer name and institution, volume ID, etc.

**ERRATA.TXT** - Text file for identifying and describing errors and/or anomalies found in the current volume, and possibly previous volumes of a set. Any known errors for the associated volume will be documented in this file.

**BROWSE DIRECTORY (OPTIONAL)**

The BROWSE directory contains synoptic versions of data products to help identify products of interest. The directory structure mirrors the DATA directory. The browse product for each EDR is a scaled (0-255) image stored in the Portable Network Graphics (PNG) format. The PNG images are resized from the original EDR image to 128x128 pixels. In addition there is single daily HTML file that contains each image and its key parameters for that day. There are detached labels for the PNG and the HTML files which describe the source EDRs and the scaling between raw data values and the PNG files.

BROWINFO.TXT: Describes the contents of this directory.

### CATALOG DIRECTORY

This subdirectory contains the catalog object files for the entire volume. The following files are included in the catalog subdirectory.

**CATINFO.TXT:** Identifies and describes the function of each file in the catalog directory.

**MISSION.CAT:** Description of the MESSENGER mission for the PDS catalog.

**INSTHOST.CAT:** Description of the MESSENGER spacecraft for the PDS catalog.

**MDIS\_WAC\_INST:** Description of the MDIS WAC camera for the PDS catalog.

**MDIS\_NAC\_INST:** Description of the MDIS NAC camera for the PDS catalog.

**MDIS\_EDR\_DS.CAT:** Description of MDIS EDR dataset for the PDS catalog.

**PERSON.CAT:** List of personnel associated with the MESSENGER PDS delivery for the PDS catalog.

**REF.CAT:** Catalog objects' citation list for the PDS catalog.

### DATA DIRECTORY

This is the top level directories for the EDR image data products.

**YYYY\_DOY:** These directories contain the EDRs for one day of the mission. YYYY is the year, and DOY is the day of year. An EDR's inclusion in a folder is determined by the UTC time of the start of the exposure. See section 5.1.4 for the file naming convention of the contained EDR images.

### DOCUMENT Directory

The DOCUMENT directory contains documentation to help the user understand and use the archive data.

**DOCINFO.TXT** - Description of the DOCUMENT directory

**VOLINFO.PDF** (OPTIONAL) - The files contain detailed descriptions of the MESSENGER mission, and the MDIS instrument.

**MDIS\_EDRSIS.PDF** - Contains the Software Interface Specification for the EDR data products.

**LDD directory** - Contains the local data dictionary catalog files.

## INDEX DIRECTORY

This subdirectory contains the indices for all data products on the volume. The following files are contained in the index subdirectory.

**INDXINFO.TXT** - Identifies and describes the function of each file in the index subdirectory. This includes a description of the structure and contents of each index table in the subdirectory AND usage notes.

**MDISINDEX.TAB** - The image index file is organized as a table: there is a row for each image on the volume; the columns contain parameters that describe the observation and camera states of the images. Information includes viewing geometry (such as latitude and longitude of the image center, sun and observation angles) and camera state information such as filter wheel position, spacecraft clock count, time of observation, image integration time, and camera modes.

**MDISINDEX.LBL** - Detached PDS label for MDISINDEX.TAB. The image index file is accompanied by a detached PDS label that describes its organization and contents.

**MDISINDEX.HDR** (OPTIONAL) - Header file, used for spread sheet applications. This file contains a single line that gives column names to each column in the MDISINDEX.TAB file.

**MISSEDINDEX.TAB** (OPTIONAL) - Table of missing images. Image file names in this directory were lost during the active flight projects due to a variety of problems including: incomplete or improper transmission to earth, or loss of image files lost between ground receiving station and mission operations center. Images listed in this directory cannot be recovered.

**MISSEDINDEX.HDR** (OPTIONAL) - Header file used for spread sheet applications for the image index file. This file contains a single line that gives heading names to each row in the index file.

**MISSEDINDEX.LBL** (OPTIONAL) - Detached PDS label that describes the MISSEDINDEX.TAB file.

**REDOINDEX.TAB** (OPTIONAL) - If an image could not be recovered from the telemetry archive before a volume was created, then this table contains a list of the image files that will be reprocessed for inclusion on the last volume. This file is identical in format to the MDISINDEX.TAB file.

**REDOINDEX.LBL** (OPTIONAL) - Detached label for REDOINDEX.TAB

**REDOINDEX.HDR** (OPTIONAL) - Header file used for spread sheet applications for the image index file. This file contains a single line that gives heading names to each row in the index file.

#### **LABEL Directory (OPTIONAL)**

This subdirectory contains additional PDS labels and label structure files that were not packaged with the data products or in the data subdirectories. The following file is included in the subdirectory.

**LABINFO.TXT:** Identifies and describes the function of each file in the label directory.

#### **CALIB Directory (OPTIONAL)**

This subdirectory contains files needed to reduce raw MDIS images (EDRs) to units of radiance or I/F. Files for needed for major corrections are arranged into subdirectories by correction type.

**CALINFO.TXT:** Contains descriptions of calibration files and directions for their application to MDIS EDRs.

**/LUT\_INVERT:** Contains the inverse lookup table required for inverting 8-bit images into their original 12-bit format. There are two files:

MDISLUTINV\_0.TAB - This file contains 8-bit values, and the 12-bit values to which they correspond. There is one set of 12-bit values for each of the eight available lookup tables in the instrument.

MDISLUTINV\_0.TAB - The label that describes the preceding file.

**/DARK\_MODEL:** Contains tables of coefficients needed to model the dark level in the NAC or WAC, with on-chip pixel binning turned on or not. There are tables of coefficients with the nomenclature:

MDIScam\_bining\_DARKMODEL\_v.TAB where:  
 cam = camera, NAC or WAC  
 binning = binning, NOTBIN or BINNED  
 v = version number, 0-9,a-z

Detached labels describing the tables have the nomenclature:

MDIScam\_bining\_DARKMODEL\_v.LBL

**/FLAT:** Contains flat-field images which correct for response variations from pixel to pixel and across the CCD. There separate files for each of the 12 WAC filters and for the NAC, with on-chip pixel binning turned on or not.

Flat-field files for the WAC have the nomenclature:

MDISWAC\_bining\_FLAT\_FILT\_nn\_v.FIT where:  
 binning = binning, NOTBIN or BINNED  
 nn = filter number, 1-12  
 v = version number, 0-9,a-z

Detached labels describing the images have the nomenclature:

MDISWAC\_bining\_FLAT\_FILT\_nn\_v.LBL.

Flat-field files for the NAC have the nomenclature:

MDISNAC\_bining\_FLAT\_v.FIT where:  
 binning = binning, NOTBIN or BINNED  
 v = version number, 0-9,a-z

and detached labels describing them have the nomenclature:

MDISNAC\_bining\_FLAT\_v.LBL.

**/RESPONSIVITY:** Contains tables of coefficients used to convert corrected DN to units of radiance. There are separate tables for the WAC and NAC, with on-chip pixel binning turned on or not. The tables have the nomenclature:

MDIScam\_bining\_RESP\_v.TAB where:  
 cam = camera, NAC or WAC  
 binning = binning, NOTBIN or BINNED  
 v = version number, 0-9,a-z

Each of the WAC tables has records for all of the filters. Detached labels describing the tables have the nomenclature:

MDIScam\_bining\_RESP\_v.LBL.

**/SOLAR:** Contains tables of solar irradiance used to convert radiance to units of I/F. There are separate tables for the WAC and NAC. The tables have the nomenclature:

MDIScam\_SOLAR\_v.TAB where:  
 cam = camera, NAC or WAC  
 v = version number, 0-9,a-z

The WAC table has records for all of the filters. Detached labels describing the tables have the nomenclature:

MDIScam\_SOLAR\_v.LBL.

**/SUPPORT:** Contains characterizations of the instrument that are not part of the calibration process per se, but were used to derive the calibration files that are used.

MDISLUTFWD\_0.TAB contains the onboard forward lookup tables used optionally to convert 12-bit to 8-bit images.

MDISLUTFWD\_0.LBL describes that file.

Bandpasses for each WAC filter and for the NAC are given in tables having the nomenclature

MDISBPWa.TAB where:  
 a = A through M for different filters:

DETECTOR,	FILTER #,	NAME,	LETTER IN FILENAME
WAC,	1,	700 BP 5 ,	A
WAC,	2,	700 BP 600,	B

WAC,	3,	480 BP 10 ,	C
WAC,	4,	560 BP 5 ,	D
WAC,	5,	630 BP 5 ,	E
WAC,	6,	430 BP 40 ,	F
WAC,	7,	750 BP 5 ,	G
WAC,	8,	950 BP 7 ,	H
WAC,	9,	1000 BP 15 ,	I
WAC,	10,	900 BP 5 ,	J
WAC,	11,	1020 BP 40 ,	K
WAC,	12,	830 BP 5 ,	L
NAC,	N/A,	N/A ,	M

**ERRATA Directory**

The ERRATA directory tree is reserved for the last volume in the static volume set of the archive. The tree stores data files that correct files of previous volumes that had errors. The directory tree maintains the same structure as on other volumes.

**GEOMETRY DIRECTORY (OPTIONAL)**

This subdirectory contains the files (e.g. SPICE kernels, etc) needed to describe the observation geometry for the data.

**GEOMINFO.TXT:** Identifies and describes the function of each file in the geometry subdirectory.

**5.2 Data Format Description**

Data is stored in a binary file format. A PDS IMAGE object is contained within each binary file in addition to a PDS label which describes the data. See section 5.3 for detailed label description, and section 4.3.4 for a sample label.

**5.3 Label and Header Descriptions**

The keywords are listed in the order in which they appear in the example label shown above in section 4.3.5 Labeling and Identification.

**PDS\_VERSION\_ID**

The version number of the PDS standards documents that is valid when a data product label is created. PDS3 is used for the MESSENGER Data products.

**File format parameters****RECORD\_TYPE**

The record format of a file.

**RECORD\_BYTES**

The number of bytes in a physical file record, including record terminators and separators.

**FILE\_RECORDS**

The number of physical file records, including both label records and data records.

**^IMAGE**

The pointer to the full image object. This object contains all the sub-frames which correspond to a given observation. The sub-frames are arrayed in their respective positions corresponding to a full frame observation. The value contains the starting record position in the file.

**General data description parameters****MISSION\_NAME**

Identifies the MESSENGER planetary mission.

**SPACECRAFT\_NAME**

Abbreviated name of the spacecraft.

**INSTRUMENT\_HOST\_NAME**

The full, unabbreviated name of the spacecraft.

**DATA\_SET\_ID**

Uniquely identifies the data sets available on the volume. The EDR collection is made up of a single data set.

**DATA\_QUALITY\_ID**

Used to encode figures-of-merit into one parameter that is included in the label of each EDR.

A data quality index is used to encode figures-of-merit into one parameter that is included in the label of each EDR. The 16-byte data quality index is interpreted as follows:

**Byte 0:** Image source is CCD.

- 1 = Image source is test pattern as indicated by  
MESS:SOURCE=1=Test pattern or  
MESS:SOURCE=2=Inverted test pattern.
- 0 = Image source is CCD as indicated by MESS:SOURCE=0=CCD.

**Byte 1:** Non-zero exposure time.

- 1 = Exposure time in ms as indicated by MESS:EXPOSURE equals 0 ms.
- 0 = Exposure time in ms as indicated by MESS:EXPOSURE is greater than 0 ms.

**Byte 2:** Presence of an excessive number of pixels at or approaching saturation.

As saturation is approached responsivity decreases, and signal becomes nonlinear with brightness for small sources. Saturation can be exceeded for very bright or large sources once pixel antiblooming is overwhelmed. The raw DN level indicative of the onset of saturation varies between the two CCDs. In the WAC (MESS:IMAGER=0) it is approximately 3600; in the NAC (MESS:IMAGER=1) it is approximately 3400. In autoexposure mode, the typical threshold for the allowable number of saturated pixels is 5 pixels. In manual exposure mode the number of saturated pixels is uncontrolled.

1 = There are > 5 pixels exceeding the DN indicating onset of saturation.  
 0 = There are < 5 pixels exceeding the DN indicating onset of saturation.

**Byte 3:** Valid pivot position.

1 = Pivot position not valid, as indicated by either of two conditions:  
 (a) pivot position validity flag MESS:PIV\_PV=0=invalid,  
 or  
 (b) pivot reading validity flag MESS:PIV\_RV=0=invalid.  
 0 = Pivot position valid as indicated by both keywords having a value of 1=valid.

**Byte 4:** Filter wheel in position (WAC only; requires MESS:IMAGER=0, or else value of this byte = 0).

1 = Filter wheel not in position, as indicated by any of three conditions:  
 (a) filter wheel position validity flag MESS:FW\_PV=0=invalid,  
 (b) filter wheel reading validity flag MESS:FW\_RV=0=invalid, or  
 (c) an excessive difference between filter wheel resolver goal and actual position as given in table below.  
 0 = Filter wheel in position as indicated by an allowable difference between goal and position, and by both MESS:FW\_PV=1 and MESS:FW\_RV=1 (See Table 1).

Table 1. Filter wheel encoder positions

FILTER_NUMBER	MESS:FW_GOAL	Allowable (abs(MESS:FW_POS - MESS:FW_GOAL))
1	17376	+/- 240
2	11976	+/- 240
3	6492	+/- 240
4	1108	+/- 240
5	61104	+/- 240
6	55684	+/- 240
7	50148	+/- 240
8	44760	+/- 240
9	39256	+/- 240
10	33796	+/- 240
11	28252	+/- 240
12	22852	+/- 240

**Byte 5:** Quality of spacecraft attitude knowledge.

1 = Spacecraft attitude knowledge is bad (MESS:ATT\_FLAG is in the range 0-3).  
 0 = Spacecraft attitude knowledge is good (MESS:ATT\_FLAG is in the range 5-7).

**Byte 6:** CCD temperature range.

1 = CCD out of temperature range at which performance is well calibrated (MESS:CCD\_TEMP is outside a range of between 1042

and 1120, which for the WAC is -35C to -14 C, and for the NAC is -38C to -16C).  
 0 = CCD within well calibrated temperature range (MESS:CCD\_TEMP is within the stated range).

**Byte 7:** Completeness of data within the commanded selection of subframes or full frame.  
 Missing frames or portions of frames are indicated in an EDR with a value of 0 (this cannot be a valid data value).  
 1 = There are missing data (some pixels populated with 0).  
 0 = There are no missing data.

**Bytes 8-15:** spare.

**PRODUCT\_ID**

The permanent, unique identifier assigned to a data product by its producer. In the PDS, the value assigned to product\_id must be unique within its data set. The format is:

**Ec#####f**

**E** = EDR

**c** = W or N for Wide or Narrow Angle camera

**#####** = Mission Elapsed Time (MET) counter taken from the image header (and same as original compressed filename from SSR) NOTE: this a spacecraft clock seconds counter, and the value in the filename corresponds to the LAST second of the exposure.

**f** = Filter wheel position (A,B,C,D,E,F,G,H,I,J,K,L) for the WAC. (See Table 4 in Appendix B) It is M for the NAC.

**SOURCE\_PRODUCT\_ID**

This is a set of input files used as input to create this product. The first element is the original spacecraft solid state recorder (SSR) filename as downlinked. Additional elements are the SPICE kernels used to produce the ancillary data.

**PRODUCER\_INSTITUTION\_NAME**

The organization responsible for developing the CODMAC/level2 data products.

**SOFTWARE\_NAME**

The name of the software system that created the data products. The version number of the software is identified by the SOFTWARE\_VERSION\_ID keyword.

**SOFTWARE\_VERSION\_ID**

Version of the software used to generate the EDR products.

**MISSION\_PHASE\_NAME**

Provides the commonly-used identifiers of the MESSENGER Mission Phase. These are (From Memorandum SRP-03-2006 rev

14 April 2006, MESSENGER Mission Phase Definitions, R.L. McNutt, Jr):

EARTH CRUISE  
 EARTH FLYBY  
 VENUS 1 CRUISE  
 VENUS 1 FLYBY  
 VENUS 2 CRUISE  
 VENUS 2 FLYBY  
 MERCURY 1 CRUISE  
 MERCURY 1 FLYBY  
 MERCURY 2 CRUISE  
 MERCURY 2 FLYBY  
 MERCURY 3 CRUISE  
 MERCURY 3 FLYBY  
 MERCURY 4 CRUISE  
 MERCURY ORBIT

**TARGET\_NAME**

Identifies the target. (Such as: MERCURY, VENUS, EARTH, MOON, N/A).

**SEQUENCE\_TITLE**

Identifies the imaging sequence name. Format: YYYYMMDD\_Sequence\_Name.

**Time parameters**

**START\_TIME**

The UTC date and time for the start of the exposure.

**STOP\_TIME**

The UTC date and time for the end of the exposure.

**SPACECRAFT\_CLOCK\_START\_COUNT**

Clock count of the spacecraft computer at the start of the exposure. For MESSENGER, this is also known as the Mission Elapsed Time (MET). MESSENGER has a two stage clock. The clock partition is added to the beginning of the two stages. The three parts of this value are formatted as follows:

- P/SSSSSSSSSS:TTTTT
  - o P = SPICE clock partition
  - o S = first stage, spacecraft clock seconds
  - o T = second stage, spacecraft clock microseconds

**SPACECRAFT\_CLOCK\_STOP\_COUNT**

Clock count of the spacecraft computer at the end of the exposure. For MESSENGER, this is also known as the Mission Elapsed Time (MET). See **SPACECRAFT\_CLOCK\_START\_COUNT** for format.

**PRODUCT\_CREATION\_TIME**

The time in UTC when the EDR product was created.

**Instrument engineering parameters**

**INSTRUMENT\_NAME**

The FULL name of the instrument. Note that the associated INSTRUMENT\_ID element provides an abbreviated name or acronym for the instrument, which includes the camera that was being used.

**INSTRUMENT\_ID**

Abbreviated name or acronym which identifies the instrument. In this case it is either MDIS-WAC or MDIS-NAC (for the WIDE ANGLE CAMERA or NARROW ANGLE CAMERA).

**FILTER\_NAME**

Filter names are descriptive names of the filter used for the WAC camera. The NAC has no filter wheel so it is "N/A" for the NAC.

**FILTER\_NUMBER**

Provides the number of the WAC filter wheel through which an image or measurement was acquired. The NAC has no filter wheel so it is "N/A" for the NAC.

**CENTER\_FILTER\_WAVELENGTH**

The mid point wavelength value between the minimum and maximum instrument filter wavelength values. A table showing the relationship between filter number, center wavelength, and bandwidth can be found in Appendix B - MDIS Instrument Overview. The NAC has no filter wheel so it is "N/A" for the NAC.

**BANDWIDTH**

A measure of the spectral width of a filter (nanometers). For a root-mean-square detector this is the effective bandwidth of the filter i.e., the full width of an ideal square filter having a flat response over the bandwidth and zero response elsewhere. The NAC has no filter wheel so it is "N/A" for the NAC.

**EXPOSURE\_DURATION**

The exposure duration (integration time) of the image observation expressed in milliseconds.

**EXPOSURE\_TYPE**

The MDIS exposure setting. There are two settings - "AUTOMATIC" is the automatic exposure setting, and "MANUAL" is a manually commanded exposure setting.

**DETECTOR\_TEMPERATURE**

Temperature of the CCD in degrees Celsius at the time the observation was made. The conversion formula depends on the camera performing the observation:

For WAC:

$$\text{Temperature} = -318.4553 + \text{Raw} * 0.2718$$

For NAC:

$$\text{Temperature} = -323.3669 + \text{Raw} * 0.2737$$

Where Raw is the raw counts in telemetry (MESS:CCD\_TEMP).

**FOCAL\_PLANE\_TEMPERATURE**

The element indicates the temperature of the focal plane array in degrees Celsius at observation time. The conversion formula depends on the camera performing the observation:

For WAC:  
 $\text{Temperature} = -263.2584 + \text{Raw} * 0.5022$

For NAC:  
 $\text{Temperature} = -268.8441 + \text{Raw} * 0.5130$

Where Raw is the raw counts in telemetry (MESS:CAM\_T1).

#### **FILTER\_TEMPERATURE**

The temperature of the filter wheel. A single telemetry point is used to return the Filter Wheel or the Telescope temperature, depending on which camera is in use. Thus, this parameter is "N/A" if the NAC was used for the observation because the telemetry point will be a measurement of the NAC telescope temperature. The conversion from Raw counts to degrees Celsius is:

$\text{Temperature} = -292.7603 + \text{Raw} * 0.5553$

Where Raw is the raw counts in telemetry (MESS:CAM\_T2).

#### **OPTICS\_TEMPERATURE**

The temperature of the NAC telescope. A single telemetry point is used to return the Filter Wheel or the Telescope temperature, depending on which camera is in use. Thus this parameter is "N/A" if the WAC was used for observation because the telemetry point will be a measurement of the WAC filter wheel temperature. The conversion from Raw counts to degrees Celsius is:

$\text{Temperature} = -269.7180 + \text{Raw} * 0.4861$

Where Raw is the raw counts in telemetry (MESS:CAM\_T2).

### **Instrument raw parameters**

**NOTE: for all of the following "MESS:" items, more detailed information can be found in the MDIS/DPU Flight Software Specification document. These values are direct copies of the raw image headers created by the flight software.**

#### **MESS:MET\_EXP**

Exposure time-tag. Mission Elapsed Time (MET) counter from the image header. This represents the last tick of the spacecraft clock second counter before the end of the exposure.

#### **MESS:ATT\_CLOCK\_COUNT**

Attitude time-tag. Mission Elapsed Time (MET) counter from the image header representing the time of the quaternion values MESS:ATT\_Q1 through MESS:ATT\_Q4

Note: Use of this single quaternion per image is not recommended. They are provided with each image and described here for completeness, however a better source of spacecraft attitude samples is used to generate the MESSENGER Spacecraft SPICE C-kernels used to support science ops. These sources are described in the comments of the C-kernel. (See Appendix A)

**MESS:ATT\_Q1**

The roll value of the vector component of the attitude quaternion.

**MESS:ATT\_Q2**

The pitch value of the vector component of the attitude quaternion.

**MESS:ATT\_Q3**

The yaw value of the vector component of the attitude quaternion.

**MESS:ATT\_Q4**

The scalar component of the attitude quaternion.

The attitude quaternion  $q$  formed by MESS:ATT\_Q1 through \_Q4 should be interpreted such that  $V_{SC} = M(q) V_{J2000}$  where

$$M(q) = \begin{bmatrix} 1 - 2(q_2^2 + q_3^2) & 2(q_1q_2 + q_4q_3) & 2(q_1q_3 - q_4q_2) \\ 2(q_1q_2 - q_4q_3) & 1 - 2(q_1^2 + q_3^2) & 2(q_2q_3 + q_4q_1) \\ 2(q_1q_3 + q_4q_2) & 2(q_2q_3 - q_4q_1) & 1 - 2(q_1^2 + q_2^2) \end{bmatrix}$$

**MESS:ATT\_FLAG**

Attitude quality flag

7 = Attitude Knowledge OK (At least 1 Star Tracker is available and at least 50% of gyro data is valid)

6 = Attitude Knowledge OK (No Star Tracker is available but at least 50% of gyro data is valid)

5 = Attitude Knowledge OK (No Star Tracker is and between 10% and 50% of gyro data is valid -OR- At least 1 Star Tracker is valid and between 0% and 50% of gyro data valid)

4 = not a legal option

3 = Attitude Knowledge BAD (At least 1 Star Tracker is available and at least 50% of gyro data is valid)

2 = Attitude Knowledge BAD (No Star Tracker is available but at least 50% of gyro data is valid)

1 = Attitude Knowledge BAD (No Star Tracker is available and between 10% and 50% of gyro data is valid -OR- At least 1 Star Tracker is valid and between 0% and 50% of gyro data is valid)

0 = Attitude Knowledge BAD (No Star Tracker data fewer than 10% of gyro data valid)

**MESS:PIV\_GOAL**

Pivot goal (180°/12<sup>15</sup>)

**MESS:PIV\_POS**

Pivot position (180°/12<sup>15</sup>)

Note: these are the pivot position values being used to generate the MDIS pivot platform SPICE C-kernel. 0° is nadir, -180° is the stowed position.

**MESS:PIV\_READ**

Raw pivot reading from resolver (resolver counts). The pivot platform resolver only covers 45° of motion; the resolver read-out values repeat eight times over the entire 360° that an unconstrained platform could travel. This value is used along with dead-reckoning knowledge of which "octant" the platform is in to give the value in

**MESS:PIV\_POS**.

**MESS:PIV\_CAL**

Pivot calibration offset (180°/12<sup>15</sup>)

**MESS:FW\_GOAL**

Filter wheel goal (resolver counts)

**MESS:FW\_POS**

Filter wheel pos. (resolver counts) This is the flight software's computed absolute position of the filter wheel

**MESS:FW\_READ**

Filter wheel reading (resolver counts). This is a raw value from the filter wheel resolver. It is used by the flight software to compute **MESS:FW\_POS**.

**MESS:CCD\_TEMP**

CCD temperature in raw counts

**MESS:CAM\_T1**

Camera temperature #1 in raw counts

**MESS:CAM\_T2**

Camera temperature #2 in raw counts

**MESS:EXPOSURE**

Exposure time (0-9990ms)

**MESS:DPU\_ID**

DPU Identifier

0 = DPU-A

1 = DPU-B

**MESS:IMAGER**

WAC or NAC imager

0 = WAC

1 = NAC

**MESS:SOURCE**

Image Source  
0 = CCD  
1 = Test pattern  
2 = Inverted test pattern

**MESS:FPU\_BIN**

Select image binning in FPU  
0 = 1x1  
1 = 2x2

**MESS:COMP12\_8**

Enable/disable 12 to 8 bit image compression  
0 = disable  
1 = enable

**MESS:COMP\_ALG**

12 to 8 bit compression algorithm (0-7). See Appendix B for a plot of the 12-8 bit lookup tables.

**MESS:COMP\_FST**

Enable/disable Fast image compression  
0 = Disable  
1 = Enable

**MESS:TIME\_PLS**

1 Hz time pulse source  
0 = Software  
1 = Main Processor A (MP-A)  
2 = Main Processor B (MP-B)  
3 = Software

**MESS:LATCH\_UP**

FPU latchup indicator  
0 = Ok  
1 = Latched

**MESS:EXP\_MODE**

Exposure mode  
0 = Manual  
1 = Automatic

**MESS:PIV\_STAT**

Pivot Control State  
0 = Lost  
1 = Search  
2 = Found  
3 = Ok

**MESS:PIV\_MPEN**

Pivot controlled by MP  
0 = Disable  
1 = Enable

**MESS:PIV\_PV**

Pivot position validity flag  
0 = invalid  
1 = valid

**MESS:PIV\_RV**

Pivot reading validity flag  
0 = invalid  
1 = valid

**MESS:FW\_PV**

Filter wheel position validity flag  
0 = invalid  
1 = valid

**MESS:FW\_RV**

Filter wheel reading validity flag  
0 = invalid  
1 = valid

**MESS:AEX\_STAT**

"Mode" of histogram used for automatic exposure calculation  
(0-4095)

**MESS:AEX\_STHR**

Automatic exposure saturation threshold  
(0-65535) (number of pixels)

**MESS:AEX\_TGTB**

Automatic exposure target brightness  
(0-4095)

**MESS:AEX\_BACB**

Automatic exposure background/noise brightness  
(0-4095)

**MESS:AEX\_MAXE**

Maximum automatic exposure time  
(0 - 989 ms)

**MESS:AEX\_MINE**

Minimum automatic exposure time  
(0 - 989 ms)

**MESS:DLNKPRIO**

Priority that compressed file will be downlinked  
0 - Priority #0 (*highest*)  
1 - Priority #1  
.  
.  
9 - Priority #9 (*lowest*)

**MESS:WVLRATIO**

Wavelet Compression Ratio  
0 - No Wavelet  
1 - 1x compression (*lossless*)

2 - 2x compression  
3 - 3x compression  
.  
.  
32 - 32x compression

**MESS:PIXELBIN**

MP Software Pixel Binning  
0 - No Binning  
2 - 2x2 Binning  
4 - 4x4 Binning  
8 - 8x8 Binning

**MESS:SUBFRAME**

Subframe  
0 - No subframe  
1 - One subframe  
.  
.  
5 - Five subframes

**MESS:SUBF\_X1**

Subframe #1 Start Col(0-1023)

**MESS:SUBF\_Y1**

Subframe #1 Start Row(0-1023)

**MESS:SUBF\_DX1**

Subframe #1 Width(0-1024)

**MESS:SUBF\_DY1**

Subframe #1 Height(0-1024)

**MESS:SUBF\_X2**

Subframe #2 Start Col(0-1023)

**MESS:SUBF\_Y2**

Subframe #2 Start Row(0-1023)

**MESS:SUBF\_DX2**

Subframe #2 Width(0-1024)

**MESS:SUBF\_DY2**

Subframe #2 Height(0-1024)

**MESS:SUBF\_X3**

Subframe #3 Start Col(0-1023)

**MESS:SUBF\_Y3**

Subframe #3 Start Row(0-1023)

**MESS:SUBF\_DX3**

Subframe #3 Width(0-1024)

**MESS:SUBF\_DY3**

Subframe #3 Height(0-1024)

**MESS:SUBF\_X4**

Subframe #4 Start Col(0-1023)

**MESS:SUBF\_Y4**

Subframe #4 Start Row(0-1023)

**MESS:SUBF\_DX4**

Subframe #4 Width(0-1024)

**MESS:SUBF\_DY4**

Subframe #4 Height(0-1024)

**MESS:SUBF\_X5**

Subframe #5 Start Col(0-1023)

**MESS:SUBF\_Y5**

Subframe #5 Start Row(0-1023)

**MESS:SUBF\_DX5**

Subframe #5 Width(0-1024)

**MESS:SUBF\_DY5**

Subframe #5 Height(0-1024)

**MESS:CRITOPNV**

When true, indicates that the image is a critical optical navigation image and will be compressed by the MESSENGER Main Processor (MP) before other images. (Normally, the MP compresses images in the order that they are received)

0 = False

1 = True

**MESS:JAILBARS**

Jailbars (vertical only)

0 = No jailbar

1 = Enable Jailbars

**MESS:JB\_X0**

Start Jailbar Column(0-1023)

**MESS:JB\_X1**

Stop Jailbar Column(0-1023)

**MESS:JB\_SPACE**

Jailbar Intercolumn Spacing

**Geometry information**

**RIGHT\_ASCENSION**

The right ascension of the camera boresight. The values are specified relative to the J2000 inertial reference frame.

**DECLINATION**

The declination of the camera boresight. The values are specified relative to the J2000 inertial reference frame.

**TWIST\_ANGLE**

The angle of rotation about an optical axis relative to celestial coordinates. It is defined as  $(180 - \text{CELESTIAL\_NORTH\_CLOCK\_ANGLE}) \bmod 360$ . Where **CELESTIAL\_NORTH\_CLOCK\_ANGLE** is the direction of celestial north at the center of an image. It is measured from the 'upward' direction, clockwise to the direction toward celestial north (declination = +90 degrees), when the image is displayed left to right and top to bottom. The epoch of the celestial coordinate system is J2000.

**RETICLE\_POINT\_RA**

The right ascension of the principle points of the camera. Note: For MESSENGER the principle points are defined as the upper left pixel of the camera (line 1, sample 1), the upper right pixel (line 1, last sample), lower left (last line, sample 1), and lower right (last line, last sample).

**RETICLE\_POINT\_DECLINATION**

The declination of the principle points of the camera. For MESSENGER the principle points are defined as in **RETICLE\_POINT\_RA**.

**Target parameters****SC\_TARGET\_POSITION\_VECTOR**

X, Y, Z components of the position vector from observer to target center expressed in J2000 coordinates, and corrected for light time and stellar aberration, evaluated at epoch at which the image was taken. Units are expressed in kilometers.

**TARGET\_CENTER\_DISTANCE**

Distance between the spacecraft and the center of the named target in kilometers.

**Target within sensor field of view parameters**

**NOTE:** Any value computed below which requires the shape of Mercury (ellipsoid radii) as an input, will use values dictated by the science team, and updated during the course of the mission. A MESSENGER SPICE PCK kernel will be used to define any updated Mercury constants.

**SLANT\_DISTANCE**

Distance from spacecraft to the camera boresight intercept point on the surface in kilometers.

**CENTER\_LATITUDE****CENTER\_LONGITUDE**

Latitude and longitude at the center of the full image frame.

**HORIZONTAL\_PIXEL\_SCALE**

The horizontal picture scale.

**VERTICAL\_PIXEL\_SCALE**

The vertical picture scale.

**SMEAR\_MAGNITUDE**

Norm of velocity vector of camera boresight intercept point projected on the target, multiplied by the exposure duration with the scale of the image factored to obtain the smear in pixels. Spacecraft rotation is taken into account. (Units are in pixels.)

**SMEAR\_AZIMUTH**

Azimuth of smear velocity vector. The reference line for the angle extends from the center of the image to the right edge of the image. The angle increases in the clockwise direction. The angle is measured to the "image" of the smear velocity vector in the camera's focal plane. This image is computed by orthogonal projection of the smear vector onto the image plane and then applying transformations to orient the result properly with respect to the image. The specific transformations to be performed are given by the camera's I-kernel.

**NORTH\_AZIMUTH**

Analogous to smear azimuth, but applies to the target north pole direction vector.

**RETICLE\_POINT\_LATITUDE****RETICLE\_POINT\_LONGITUDE**

Latitudes and longitudes of the surface intercept points of the principle points of the camera. (see RETICLE\_POINT\_RA for definition of the reticule points for MESSENGER. The units are expressed in degrees.

**Spacecraft position with respect to target****SUB\_SPACECRAFT\_LATITUDE****SUB\_SPACECRAFT\_LONGITUDE**

Planetocentric latitude and longitude of spacecraft-to-body-center surface intercept vector. These parameters and the SPACECRAFT\_ALTITUDE, SUB\_SPACECRAFT\_AZIMUTH parameters described below are relative to the central body for which the spacecraft is orbiting and not the target of the observation.

**SPACECRAFT\_ALTITUDE**

Altitude of the spacecraft above a reference ellipsoid. Distance is measured to closest point on ellipsoid.

**SUB\_SPACECRAFT\_AZIMUTH**

Azimuth angle of sub-spacecraft point in image. Method of measurement is the same as for SMEAR\_AZIMUTH.

**Spacecraft Location****SPACECRAFT\_SOLAR\_DISTANCE**

Analogous to TARGET\_CENTER\_DISTANCE but Sun replaces target body in computation.

**SC\_SUN\_POSITION\_VECTOR**

X, Y, Z components of the position vector from observer to sun, center expressed in J2000 coordinates and corrected for light time and stellar aberration, evaluated at epoch at which image was taken. Units are kilometers.

**SC\_SUN\_VELOCITY\_VECTOR**

x-, y-, and z- components of velocity vector of sun relative to the observer, expressed in J2000 coordinates, and corrected for light time, evaluated at epoch at which image was taken. Units are kilometers per second.

**Viewing and lighting geometry****SOLAR\_DISTANCE**

Distance from target body center to Sun. The Sun position used is that described above.

**SUB\_SOLAR\_AZIMUTH**

Azimuth of the apparent sub-solar point, as seen by the spacecraft. This point is the surface intercept of the target-center-to-Sun vector, evaluated at the camera epoch minus one-way light time from target to spacecraft at that epoch spacecraft at that epoch.

Azimuth is measured as described above. Target body position relative to the spacecraft is corrected for light-time and stellar aberration. Target body orientation is corrected for light-time.

**SUB\_SOLAR\_LATITUDE****SUB\_SOLAR\_LONGITUDE**

Planetocentric latitude and longitude of the apparent sub-solar point.

**INCIDENCE\_ANGLE**

Provides a measure of the lighting condition at the intercept point. Incidence angle is the angle between the local vertical at the intercept point (surface) and a vector from the intercept point to the sun. The incidence\_angle varies from 0 degrees when the intercept point coincides with the sub\_solar point to 90 degrees when the intercept point is at the terminator (i.e., in the shadowed or dark portion of the target body). Thus, higher values of incidence\_angle indicate the existence of a greater number of surface shadows.

**PHASE\_ANGLE**

Provides a measure of the relationship between the instrument viewing position and incident illumination (such as solar light). Phase\_angle is measured at the target; it is the angle between a vector to the illumination source and a vector to the instrument. If not specified, the target is assumed to be at the center of the instrument field of view. If illumination is from behind the instrument, phase\_angle will be small.

**EMISSION\_ANGLE**

Provides the value of the angle between the surface normal vector at the intercept point and a vector from the intercept point to the spacecraft. The emission\_angle varies from 0 degrees when the spacecraft is viewing the subspacecraft point (nadir viewing) to 90 degrees when the intercept is tangent to the surface of the target body. Thus, higher values of emission\_angle indicate more oblique viewing of the target.

#### **LOCAL\_HOUR\_ANGLE**

Angle from the negative of the target-body-to-Sun vector to the projection of the negative of the spacecraft-to-target vector onto the target's instantaneous orbital plane. Both vectors are computed as in the sub-spacecraft point computation. The angle is measured in a counterclockwise direction when viewed from North of the ecliptic plane.

### **Geometry for each sub-frame**

#### **GROUP = SUBFRAME# PARAMETERS**

##### **RETICLE\_POINT\_LATITUDE**

##### **RETICLE\_POINT\_LONGITUDE**

These are the latitude and longitude points of the corners of each subframe. The corner points in order are upper left pixel of the subframe (line 1, sample 1), the upper right pixel (line 1, last sample), lower left (last line, sample 1), and lower right (last line, last sample).

### **IMAGE Object**

#### **LINES**

Total number of data instances along the vertical axis of an image.

Note: In PDS label convention; the number of lines is stored in a 32-bit integer field. The minimum value of 0 indicates no data received. For compressed images this value represents the total number of data instances along the vertical axis once the image has been uncompressed.

#### **LINE\_SAMPLES**

Total number of data instances along the horizontal axis of an image. For compressed images the keyword value is the for the total number of data instances along the horizontal axis once the image has been uncompressed.

#### **SAMPLE\_TYPE**

Data storage representation of the sample value.

#### **SAMPLE\_BITS**

Stored number of bits, or units of binary information, contained in a line\_sample value.

**5.4 MDIS Browse Data Products**

Browse products are synoptic versions of data products to help identify products of interest. There may be browse products for all levels of data reduction; in this document only the browse product for the MDIS EDRs is defined. Browse data products for higher levels of data reduction will be defined in the MDIS RDR SIS.

The principle browse product for each EDR is a scaled (0-255), median DN value image, stored in the Portable Network Graphics (PNG) format. The dimensions of the PNG file are scaled to 128 X 128 regardless of the original image's dimensions. This image is referred to as a "thumbnail." A detached label to the PNG file describes the source EDR and the scaling between its raw data values and the PNG file.

If subframing was specified, the full EDR image contains the subframes with fill values in those areas that are not within a subframe's boundary. This is reflected in the thumbnail for the EDR image; there is *not* a separate thumbnail for each subframe.

In addition to the thumbnails there is an HTML file for each day (based on the source EDR files location: archival year, doy in UTC), that displays the thumbnails and gives the key parameters for all the EDR's (images) collected during that day. For each EDR links are provided to the thumbnail's PNG file and to its detached label. Figure 3 shows an example browse page.

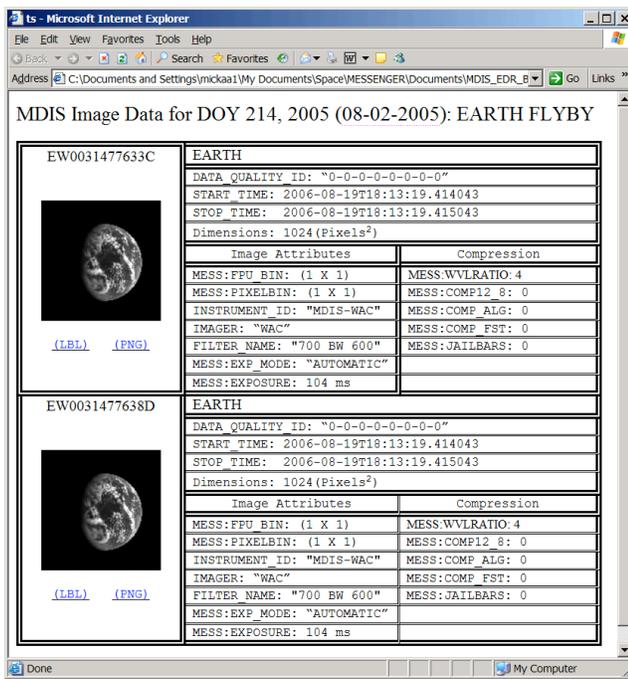


Figure 3: Example Browse Page

## **6. Archive Release Schedule to PDS**

The MDIS EDR archive will be transferred from the SOC to the Planetary Data System (PDS) imaging node using the established data transfer protocols. The details of transfer are specified in section 4.3.3. The transfer will take place according to the schedule in Table 2.

← Raymond Espiritu 6/23/06 4:50 PM  
Formatted: Bullets and Numbering

**Table 2. Schedule of Data Releases by Mission Phase**

<b>Mission Phase</b>	<b>Dates</b>	<b>Products Acquired</b>	<b>Release Schedule</b>	<b>Latest Release Date</b>
Launch	July 30, 2004	On-ground calibration data	Launch + 6 months	January 29, 2005
Earth-Moon flyby	July 29, 2005	EDRs	VF2 + 6 months	December 4, 2007
		In-flight calibration data	MF2 + 6 months	April 16, 2009
Venus flyby 1 (VF1)	October 24, 2006	EDRs	VF2 + 6 months	December 4, 2007
		In-flight calibration data	MF2 + 6 months	April 16, 2009
Venus flyby 2 (VF2)	June 5, 2007	EDRs	VF2 + 6 months	December 4, 2007
		In-flight calibration data	MF2 + 6 months	April 16, 2009
Mercury flyby 1 (MF1)	January 14, 2008	EDRs	MF2 + 6 months	April 16, 2009
		In-flight calibration data	MF2 + 6 months	April 16, 2009
Mercury flyby 2 (MF2)	October 6, 2008	EDRs	MF2 + 6 months	April 16, 2009
		In-flight calibration data	MF2 + 6 months	April 16, 2009
Mercury flyby 3 (MF3)	September 29, 2009	EDRs	MF3 + 6 months	March 29, 2010
		In-flight calibration data	EOM + 6 months	September, 18, 2012
Mercury orbit insertion (MOI)	March 18, 2011			
Mapping	March 18, 2011– March 18, 2012	EDRs	EOM + 6 months	September, 18, 2012
		CDRs, DDPs, DAPs	EOM + 12 months	March 18, 2013
		Final cal. algorithm	EOM + 12 months	March 18, 2013
End of mission (EOM)	March 18, 2012			

## 7. Appendices

### Appendix A - SPICE Kernel Files Used In MESSENGER Data Products

The following SPICE kernel files are used as inputs to generate the geometric quantities found in the PDS image labels and the Image Index files (MDISINDX.TAB) archived in this volume set. Improvements to some of these fundamental ancillary data will be made as further analysis of MESSENGER data continues, so the geometric quantities found in the labels should not be used for precision science data analyses.

#### General NAIF Kernels

##### naif0008.tls:

NAIF leapseconds kernel file, used for converting between Universal Time Coordinated (UTC) and Barycentric Dynamical Time (TDB, also called Ephemeris Time, or ET).

##### de405.bsp:

JPL planetary and Mercury ephemeris file, in SPICE SPK format.

##### pck00008.tpc:

Planetary constants kernel file, in the SPICE PCK format.

#### MESSENGER Science Derived Kernels

##### TBD.bpc:

Mercury orientation model using numerically integrated physical librations.

#### MESSENGER Spacecraft Kernels

##### messenger\_XXX.tsc:

MESSENGER spacecraft clock coefficients file, in SPICE SCLK format. Created by MESSENGER MOPS. XXX = Version counter.

##### msg\_20040803\_YYYYMMDD\_odNNNsc.xsp:

MESSENGER spacecraft merged reference & reconstructed trajectory file.

##### msg\_YYYYMMDD.bc:

High rate MESSENGER spacecraft orientation C-kernel. Created from 32-bit quaternion data. Created by MESSENGER Mission operations (MOPS). If unavailable, see below spacecraft C-kernel using quaternions (16-bit) bracketing MDIS exposures.

##### msg\_vXXX.tf:

MESSENGER spacecraft frame definitions kernel. This frame kernel contains the MESSENGER spacecraft, science instruments, and communication antennae frame definitions. XXX = version number.

**MDIS Specific Kernels****MMMMMMMMMM\_mdiss\_atthist.bc:**

High rate spacecraft orientation C-kernel Created from 16-bit quaternion data, synchronized to bracket MDIS images. Created by MESSENGER Science Operations Center (SOC). MMMMMMMMMM = MET from attitude history filename downlinked from recorder.

**SMMMMMMMMM\_EMMMMMMMMM\_mdiss\_pivot.bc:**

MDIS Pivot platform C-kernel. Created from pivot platform position values (MESS:PIV\_POS) from headers of each MDIS image. Created by MESSENGER SOC. SMMMMMMMMM\_EMMMMMMMMM = Start and end of coverage (MET from image headers).

**msgr\_mdiss\_vXXX.ti:**

MDIS instrument kernel. Contains the following instrument geometric parameters: focal length, focal plane dimension, pixel size, and the coefficient of radially symmetric optical distortion. XXX = version number.

### Appendix B - MDIS Instrument Overview

Most of the instruments are fixed-mounted (Figure 4), so that coverage of Mercury is obtained by spacecraft motion over the planet. The imaging system uses a pivot platform to accommodate flyby imaging and optical Navigation as well as imaging during the orbital phase.

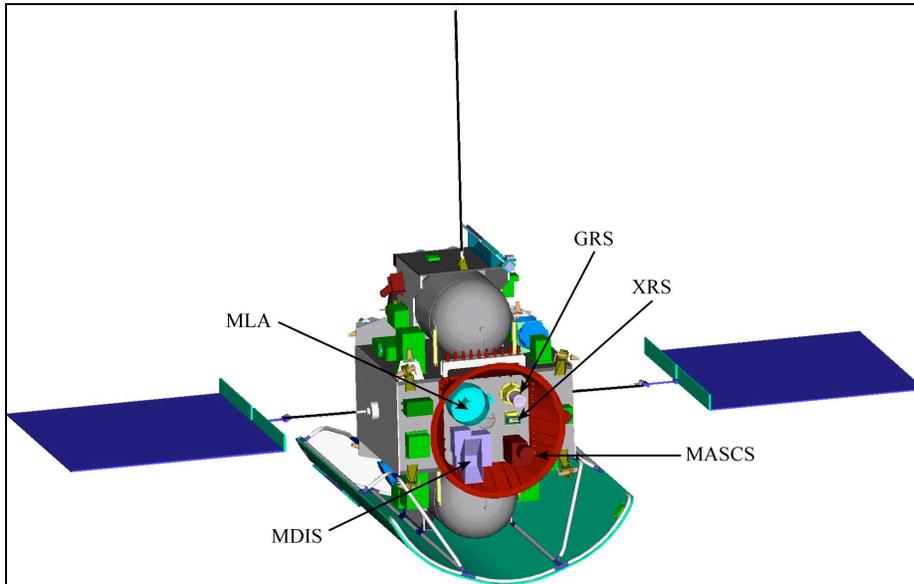


Figure 4: Instrument Deck

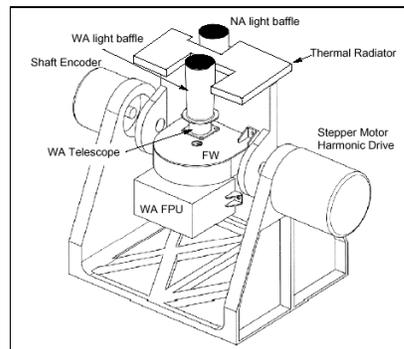
The full MDIS instrument includes the pivoting dual camera system as well as the two redundant external DPUs. The dual camera assembly without the DPUs is usually simply referred to as “MDIS.” The overall design and look of the MDIS, shown in Figure 5, was driven by mass limitations, the severe thermal environment, and the requirement for a large field-of-regard needed for optical navigation and off-nadir pointing. The total mass of MDIS is 8.32 kg, including flight blankets, harness to DPU + thermal gasket.

On the pivot platform are the multispectral WAC and the monochrome NAC. A passive thermal design maintains the CCD detectors in the WAC and NAC within their operating temperature range of  $-45^{\circ}\text{C}$  to  $-10^{\circ}\text{C}$ . Only one DPU may be active at a time, and due to thermal constraints only one camera will operate at a time; however, observations with the two cameras can be interleaved at 5-s intervals. A separate electronics assembly accommodates switching between the various modes of operating with the redundant DPUs. The pivot platform has a large range of motion ( $\sim 240^{\circ}$ ) to allow the cameras to be “tucked away” to protect the optics from contamination.

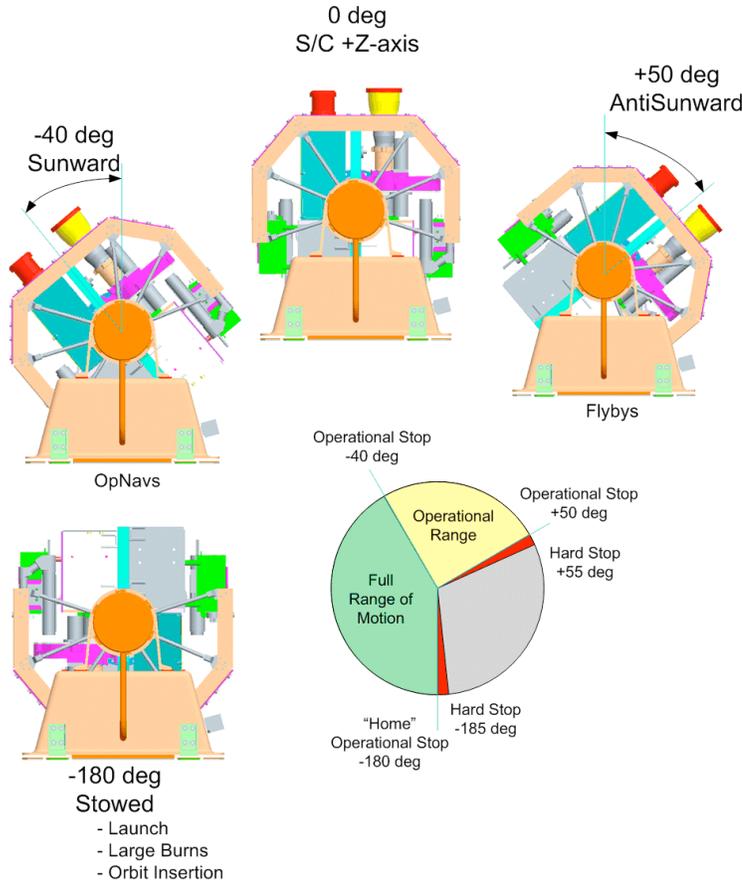
### ***Pivot Mechanism***

The MDIS pivot platform is controlled by a stepping motor (Fig. 5). The motor phases are controlled directly by the DPU software to move the platform. The phase pattern can be adjusted by software to move the platform forwards or backwards. The pivot platform's range of motion is mechanically constrained by "hard" stops. The range of motion is further constrained by "soft" stops applied by the software. The nominal allowed range is shown in Fig. 6. The total range of motion of MDIS is about 240°, limited by hard mechanical stops in the pivot motor. The hard stops are fixed at -185° and 55°. The pivot motor drive-train provides precision rotation over the 90° operational range of motion (Figure 6) about the spacecraft +Z axis.

The MDIS pivot actuator is capable of accurately stepping in intervals of 0.01° (~150 μrad) per step. Pointing knowledge is determined by first "homing" the instrument, which is accomplished by driving the actuator into one of the mechanical hard stops for a period of time sufficient to ensure the orientation of the instrument if it had been previously stopped at the opposite extreme of travel. The rotational speed of the pivot platform is 1.1°/s. Once the location of the pivot actuator is known, the flight software retains this knowledge and subsequent pointing commands are achieved by counting pulses (steps) to the motor.



**Figure 5. MDIS Design.**



**Figure 6: Range of motion of the MDIS pivot platform. Operational range is  $-40^{\circ}$  Sunward to  $+50^{\circ}$  antisunward (planetward). When stowed, the sensitive first optic of each telescope is protected.**

### ***MDIS Data Compression***

The MESSENGER mission requires compression to meet its science objectives within the available downlink. Figure 7 summarizes the compression options available to MDIS at the instrument level using the spacecraft main processor (MP). At the focal plane,  $2 \times 2$  binning is available on-chip to reduce the  $1024 \times 1024$  images to  $512 \times 512$  format, 12-bit data number (DN) levels can be converted to 8 bits, and data can be compressed losslessly. The strategy for DPU image compression is to acquire all monochrome data in 8-bit mode, and color data in 12-bit mode, and to compress all data losslessly to conserve recorder space. After data are written to the recorder, they can be uncompressed and recompressed by the MP more aggressively using any of several options: additional pixel-binning, subframing, and lossy

compression using an integer wavelet transform. The strategy for MP compression is that all data except flyby color imaging will be wavelet compressed, typically 8:1 for monochrome data and to a lower ratio ( $\leq 4:1$ ) for orbital color data. Color imaging but not monochrome imaging may be further pixel-binned. For the special case of optical navigation images, there is a "jailbar" option that saves selected lines of an image at a fixed interval for optical navigation images of Mercury during flyby approaches.

Compression performance was extensively modeled prior to launch. The 12-to-8 bit look-up tables have been designed to preferentially retain information at low, medium, or high 12-bit DN values, for a nominal detector bias or for one that has decreased with time (Figure 8). Compression ratios to be used for flight have been based on a study of the magnitude and spatial coherence of compression artifacts using NEAR images. For expected loading of the main processor, simulations have shown that the MP can compress the equivalent of 82 full  $1024 \times 1024$  images per day (or 330  $512 \times 512$  images per day). The actual number of images has also been simulated, based on orbital trajectory simulations and the imaging plan described below. The MP image compression capabilities are consistent with the mission-average number of images per day. However, on days when lighting is favorable for global mapping, a peak of  $\sim 260$  images per day may be expected, requiring on-chip binning of most of the data on peak days. The full implications for average imaging resolution are still being assessed.

Hardware compression in MDIS DPU:

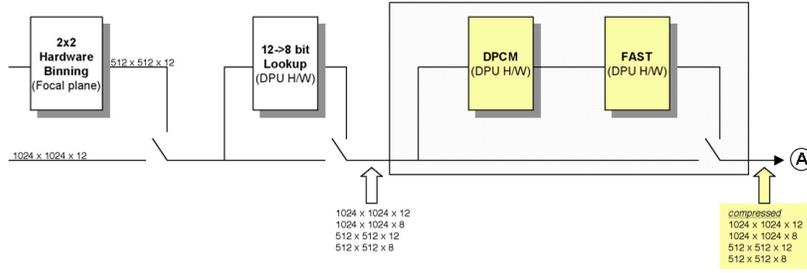


Figure 7a MDIS/DPU Real-time Compression flowchart

Software compression in spacecraft main processor (MP):

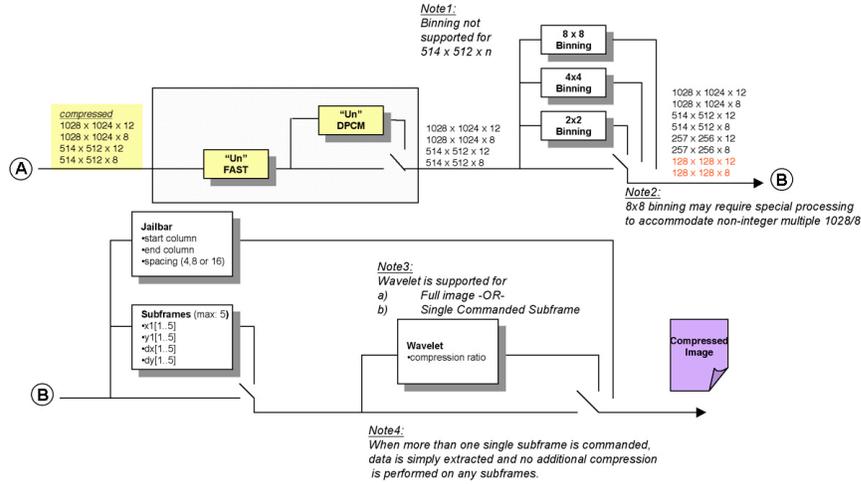
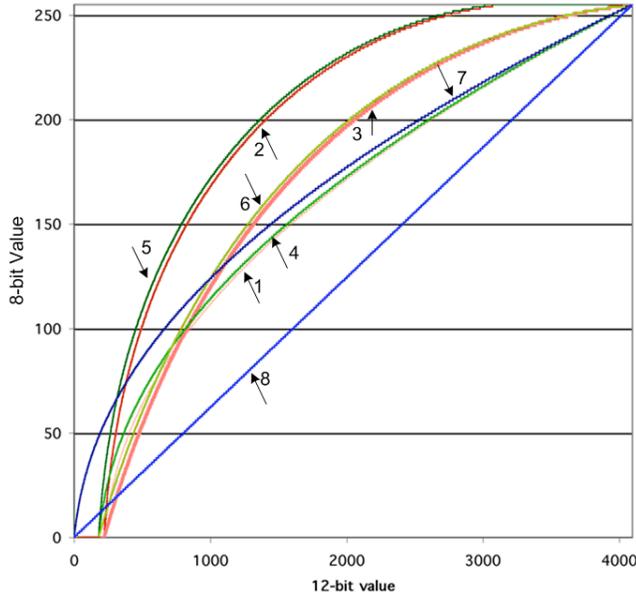


Figure 7b MESSENGER Main Processor (MP) image post-processing compression flowchart



**Figure 8.** Mapping of 12 bits to 8 bits will be accomplished using onboard look-up tables. The tables are designed to preferentially preserve information at different DN ranges, and they can accommodate a nominal detector dark level as well as one that has changed with time. (1) Low noise, high bias SNR proportional. Usage: Typical imaging with varied brightness. (2) Low noise, high bias DN-weighted SNR proportional. Usage: Faint object imaging. (3) High noise, high bias DN-weighted SNR proportional. Usage: B/W, low brightnesses. (4) Low noise, medium bias SNR proportional. Usage: Faint objects. (5) Low noise, medium bias DN-weighted SNR proportional. Usage: B/W mostly low brightness. (6) High noise, medium bias DN-weighted SNR proportional. Usage: Typical imaging, varied brightness. (7) Zero-bias SNR proportional. Usage: Typical imaging, varied brightness. (8) Linear. Usage: High brightness mapping, preserves high DN information.

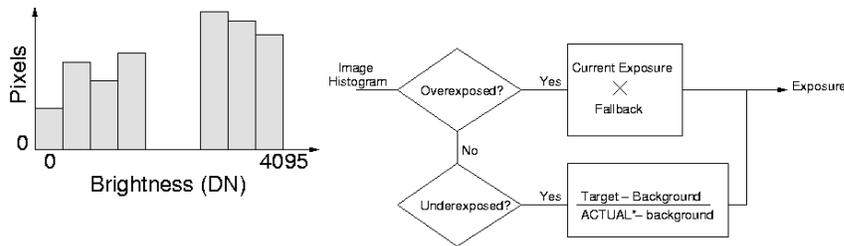
### ***Exposure Control***

The exposure time of images can be set manually by command or automatically by the software. In manual mode, a full 10-s range of exposure times is available. In automatic mode, the exposure time of the next image is computed by the DPU software (Fig. 9). This computation has two distinct steps. The first step computes a new exposure time based on the brightness of a previous image. The second step anticipates filter wheel motions and adjusts the computed exposure time accordingly.

During the read stage of the image pipeline, the hardware generates a histogram of the image. The histogram is analyzed by the software to determine if the image is overexposed or underexposed. First, the histogram is scaled by a factor of four if it comes from a  $2 \times 2$  binned image. If the brightest histogram value exceeds a saturation threshold, the image is considered overexposed and the exposure time is scaled back. Otherwise the image is considered underexposed. Histogram values are accumulated starting from the brightest bin

down towards the dimmest bin, until the saturation threshold is exceeded. The brightness value that causes the sum to exceed the threshold is the actual image brightness. The exposure time is scaled by the ratio of the commanded target brightness to the actual brightness, after a background brightness is removed. The algorithm is characterized by uploadable parameters for the saturation threshold, overexposure fallback, and background brightness.

The algorithm described so far compensates for changes in scene brightness and filter wheel changes. The next step adjusts the exposure time further if the imager, binning mode, or filter selected for the next exposure does not match what was used in the test exposure. The exposure time is scaled by the ratio of the transmissivity of the old setup to the transmissivity of the new setup. An uploadable table of transmissivities for the WAC filters and for the NAC imager in either binning mode are used. Finally, the computed exposure time is forced to fall within an uploadable range but is always less than 1 second.



Anticipation:

$$\text{Exposure}'' = \text{Exposure}' \times \frac{\text{Transmissivity}(\text{previous camera, bin mode, filter})}{\text{Transmissivity}(\text{current camera, bin mode, filter})}$$

**Figure 9. Autoexposure algorithm decision tree. A 64-bin histogram is computed in hardware for each image. If an image is determined to be underexposed, the actual exposure is computed as Actual = minimum brightness such that the sum of the pixels above this brightness < saturation threshold.**

### Optical Design

The NAC (Figure 10) is an off-axis reflective telescope with a 550-mm focal length and a collecting area of 462 mm<sup>2</sup>. The NAC focal plane is identical to the WAC's, providing a 25-μrad IFOV. The NAC has a single medium-band filter (100 nm wide), centered at 750 nm to match to the corresponding WAC filter for monochrome imaging.

The WAC (Figure 11) consists of a 4-element refractive telescope having a focal length of 78 mm and a collecting area of 48 mm<sup>2</sup> (Table 5). The detector located at the focal plane is an Atmel (Thomson) TH7888A frame-transfer CCD with a 1024×1024 format and 14-μm pitch detector elements that provide a 179-μrad pixel (instantaneous) field-of-view (IFOV). A 12-position filter wheel provides color imaging over the spectral range of the CCD detector.

Eleven spectral filters spanning the range from 395 to 1040 nm are defined to cover wavelengths diagnostic of different potential surface materials. The twelfth position is a broadband filter for optical navigation. The filters are arranged on the filter wheel in such a way as to provide complementary passbands (e.g., for 3-color imaging, 4-color imaging) in adjacent positions.

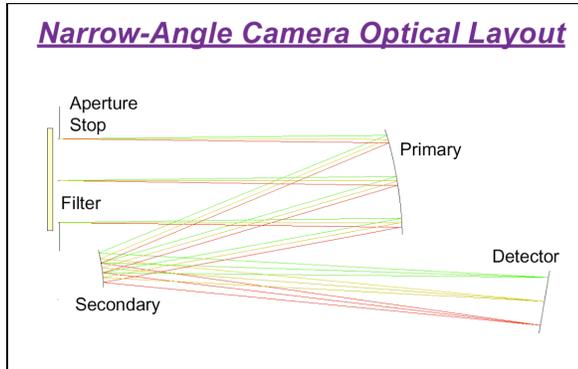


Figure 10. NAC optical layout

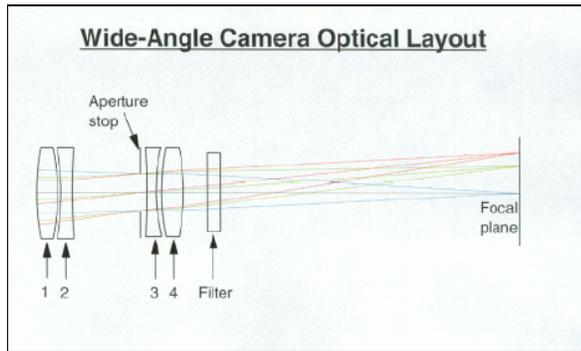


Figure 11. WAC optical layout.

	<b>Narrow Angle</b>	<b>Wide Angle</b>
Field of view	1.5° × 1.5°	10.5° × 10.5°
Pivot range (observational)	-40° to +50° (Sunward)      (Planetward)	
Exposure time	1 ms to ~10 s	
Frame transfer time	<4 ms	
Image readout time <sup>†</sup>	1 s	
Spectral filters	1	12 positions
Spectral range	700–800 nm	395–1040 nm
Focal length	550 mm	78 mm
Collecting area	462 mm <sup>2</sup>	48 mm <sup>2</sup>
NAC-WAC coalignment knowledge	0.01 deg (179 $\mu$ rad)	
Spacecraft pointing knowledge	0.1 deg (1.75 mrad)	
Spacecraft knowledge	0.02 deg (350 $\mu$ rad)	
Detector-TH7888A	CCD 1024×1024, 14- $\mu$ m pixels	
IFOV	26 $\mu$ rad	179 $\mu$ rad
Pixel FOV	5.1 m at 200-km altitude	35.8m at 200-km altitude
Quantization	12-bits per pixel	
Compression	Lossless, multi-resolution lossy, 12-to-n bits	

<sup>†</sup>Transfer to DPU; transfer from DPU to SSR limited to 3 Mbps (4 s to transfer 1024×1024 image).

**Table 3: MDIS specifications**

### ***Filters***

The WAC camera utilizes a twelve position filter wheel with band passes between 415 and 1020 nm, including a broadband navigation filter centered at 750 nm. The NAC is a broadband BW imager with sensitivity across the range 650 – 850 nm. Other than the image dimensions, the data products of each camera are identically formatted. Table 3 shows the focal length, collecting area, and field of view for each camera. Table 4, in section 5.2 above, shows the filter wheel position and bandwidth parameters.

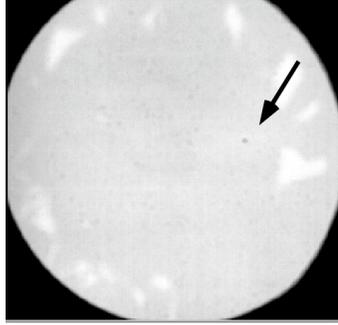
Filter	Filter	Wavelength	Width	Total	Focal	Scale
Number	Filename	(Flight)	(Flight)	Thickness	length	change
	letter	(nm)	(nm)	(mm)	(mm)	(%)
1	A	698.8	5.3	6.00	78.218	-0.104
2	B	700	600.0	6.00	78.163	-0.104
3	C	479.9	10.1	6.30	77.987	-0.329
4	D	558.9	5.8	6.30	78.023	-0.283
5	E	628.8	5.5	6.20	78.109	-0.173
6	F	433.2	18.1	6.00	78.075	-0.216
7	G	748.7	5.1	5.90	78.218	-0.033
8	H	947.0	6.2	5.20	78.449	0.262
9	I	996.2	14.3	5.00	78.510	0.340
10	J	898.8	5.1	5.35	78.390	0.186
11	K	1012.6	33.3 0	4.93	78.535	0.372
12	L	828.4	5.2	5.60	78.308	0.082

Table 4. WAC Filters Specifications – Wavelength and Width Measured at -26° C.

For WAC spectral filters, bandpass widths were selected to provide required SNR in exposure times sufficiently short to prevent linear smear by along-track motion, yet sufficiently long (>7 ms) to avoid excessive artifacts from removal of frame transfer smear during ground processing. SNR is not an issue, as sufficient light is available for SNRs >200, but saturation is a concern at low phase angles. At the same time, both cameras must be sufficiently sensitive to provide star images for optical navigation. When imaging Mercury against a star background, at least three stars must be visible per image at  $\geq 7\times$  noise.

### ***Flat field non-uniformity***

Response uniformity, or flat field, is a measure of pixel-to-pixel variations in responsivity. One significant non-uniformity in the data noted during ground calibration is that of dark spots scattered across the FOV of both imagers. The darker spots scattered across WAC images are fixed with respect to the CCD regardless of filter wheel setting, though their intensities do vary slightly with filter. The sizes of the spots are consistent with shadows of  $\ll 35\text{-}\mu\text{m}$  dust on the CCD window, and their number density is consistent with the standards for a class-10,000 clean room in which the camera was assembled. Also consistent with this hypothesis, following instrument vibration during environmental testing, the locations of several spots changed. With the exception of a single particle (arrow, Figure 12) the dust spots do not significantly affect the DN levels. Given this result, it is likely that the spots themselves will move as the instrument is subjected to the vibrations of launch and flight. Images of the Venus cloud tops acquired during the second Venus flyby will be used to redetermine the flat field post-launch.



**Figure 12: Non-uniformity due to dust particles is visible in integrating sphere images acquired through the quartz window in the OCF chamber door of the calibration facility.**

To reduce noise in the derived flat field to approximately  $10^{-3}$ , ~10 images have to be averaged together per filter, camera, and binning mode. When the images are dark-subtracted, desmeared, averaged, and normalized to the image mean, the relative DN levels are nearly identical on a pixel-by-pixel basis. Since the data are in good quantitative agreement regardless of physical temperature, the flight flat-fields are derived from room-temperature, door-open images. Full-frame and binned flat field values are normalized to unity in the central part of the images used for responsivity determinations, so that updates to responsivity from non-field-filling sources and to flat field from field-filling sources can be decoupled.

### ***Dark columns***

Dark models for MDIS images are created using (a) dark images (usually acquired with MDIS stowed against the spacecraft deck) or (b) columns lying outside of the CCD's active area. In the full-frame mode for either the WAC or NAC, the first four columns of each image are taken from a region of the CCD that is never exposed to light and, thus, represents a dark level that is purely a function of bias and dark current. The dark columns are separated from the image section by five isolation columns to avoid diffusion of signal from the active area. When the image is read out, these four columns are mapped into the first four imaging columns, so the resulting image is a square 1024 by 1024 pixels, with the first four columns replaced with the sampled dark columns. The four dark columns behave identically to the scene as a function of row, exposure time, and temperature to within 0.26 DN.

In the binned mode for both cameras, true dark columns are unavailable. However, the second column of a binned image provides a lower response than a column in the active image area. This lower-response column does show a temperature- and exposure-time response that can be modeled, making it a functional "dark." Therefore, the dark column model simply uses the second column of an image (binned or full-frame) to be a representative of the dark strip properties.

Given the nature of the binned "dark" columns, it is tempting to rely on the dark current model exclusively, rather than dark current calibration images. However, the dark strips, even for binned data, serve as an indicator of the variations of the CCD's response to radiation, and,

as such, a means to calibrate the changes in the behavior of the CCD with time. Thus, both dark models will be periodically re-evaluated en route to Mercury and during the orbital phase of the mission.

### ***Pixel shift due to pixel binning***

In the normal mode without binning for either the WAC or NAC, the first four columns of each image are taken from a region of the CCD that is never exposed to light and, thus, represents a dark level that is purely a function of bias and dark current. The dark columns are separated from the image section by five isolation columns to avoid diffusion of signal from the active area (Fig. 13). When the image is read-out, these four columns are mapped into the first four imaging columns, so the resulting image is a square 1024 by 1024 pixels, with four dark columns. The four dark columns behave identically to the scene as a function of row, exposure time, and temperature to within 0.26 DN. However for the binned modes of both cameras, an error in programming the Actel field-programmable gate arrays (FPGAs) that execute the binning resulted in a different sampling of the CCDs.

In binned mode, the offset to the isolated dark columns was miscalculated, and the first of the two dark columns is actually derived from an inactive portion of the CCD. The second dark column is an average of an inactive column and the first dark column in the dark strip. This sampled dark column is not one of the four read out for the unbinned images, but it does show a temperature- and exposure-time response that can be modeled, making it a functional "dark" column albeit with lower response. So, for the dark level from dark column model, the second column (binned or not-binned) was taken to be representative of the dark strip properties and used accordingly.

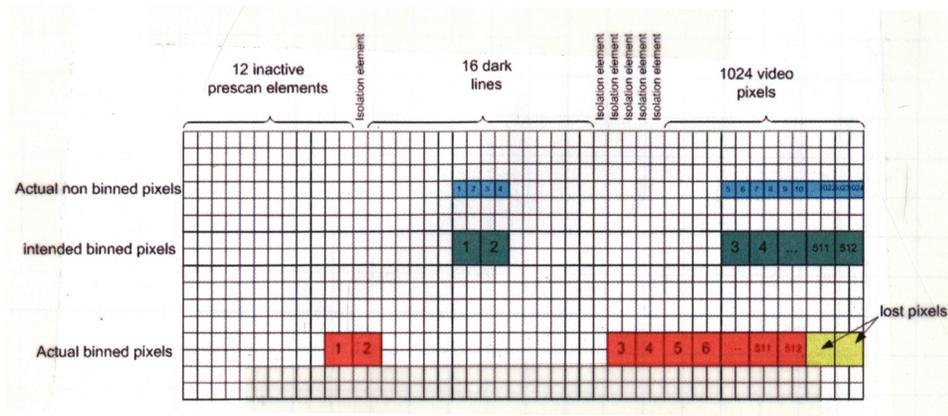


Figure 13. Pixels intended for dark columns, and actual pixels used in binned images for WAC and NAC.



**Appendix C - Data Archive Terms****Definition of Terms:**

<b>Archive</b>	An archive consists of one or more data sets along with all the documentation and ancillary information needed to understand and use the data. An archive is a logical construct independent of the medium on which it is stored.
<b>Archive volume, archive volume set</b>	A volume is a unit of medium on which data products are stored; for example, one DVD. An archive volume is a volume containing all or part of an archive; that is, data products plus documentation and ancillary files. When an archive spans multiple volumes, they are called an archive volume set. Usually the documentation and some ancillary files are repeated on each volume of the set, so that a single volume can be used alone.
<b>Data Product</b>	A labeled grouping of data resulting from a scientific observation, usually stored in one file. A product label identifies, describes, and defines the structure of the data. An example of a data product is a planetary image, a spectrum table, or a time series table.
<b>Data Set</b>	An accumulation of data products. A data set together with supporting documentation and ancillary files is an archive.
<b>Experiment Data Records</b>	NASA Level 0 data for a given instrument; raw data. Same as CODMAC level2.
<b>Reduced data records</b>	Science data that have been processed from raw data to CODMAC level 3 and above. See Table for definitions of processing levels.
<b>Standard data product</b>	A data product defined during the proposal and selection process and that is contractually promised by the PI as part of the investigation. Standard data products are generated in a predefined way, using well-understood procedures, and processed in "pipeline" fashion.

**Appendix D - CODMAC and NASA Data Levels**

**CODMAC/NASA Definition of processing levels for science data sets**

<b>CODMAC Level</b>	<b>Proc. Type</b>	<b>Data Processing Level Description</b>
1	Raw Data	Telemetry data stream as received at the ground station, with science and engineering data embedded. Corresponds to NASA packet data.
2	Edited Data	Instrument science data (e.g. raw voltages, counts) at full resolution, time ordered, with duplicates and transmission errors removed. Referred to in the MESSENGER program as Experimental Data Records (EDRs). Corresponds to NASA Level 0 data.
3	Calibrated Data	Edited data that are still in units produced by instrument, but have transformed (e.g. calibrated, rearranged) in a reversible manner and packaged with needed ancillary and auxiliary data (e.g. radiances with calibration equations applied). Referred to in the MESSENGER Program as Calibrated Data Records (CDRs). In some cases these also qualify as derived data products (DDRs). Corresponds to NASA Level 1A.
4	Resampled data	Irreversibly transformed (e.g. resampled, remapped, calibrated) values of the instrument measurements (e.g. radiances, magnetic field strength). Referred to in the MESSENGER program as either derived data products (DDPs) or derived analysis products (DAPs). Corresponds to NASA Level 1B.
5	Derived Data	Derived results such as maps, reports, graphics, etc. Corresponds to NASA Levels 2 through 5
6	Ancillary Data	Non-Science data needed to generate calibrated or resampled data sets. Consists of instrument gains, offsets; pointing information for scan platforms, etc.
7	Corrective Data	Other science data needed to interpret space-borne data sets. May include ground based data observations such as soil type or ocean buoy measurements of wind drift.
8	User Description	Description of why the data were required, any peculiarities associated with the data sets, and enough documentation to allow secondary user to extract information from the data.

The above is based on the national research council committee on data management and computation (CODMAC) data levels.

**Appendix E - Acronyms**

<b>ACT</b>	Applied Coherent technology Corporation
<b>AGC</b>	Automatic Gain Control
<b>AIAA</b>	American Institute of Aeronautics and Astronautics
<b>AM</b>	Atmosphere and Magnetosphere Group
<b>APL</b>	The Johns Hopkins University Applied Physics Laboratory
<b>ASCII</b>	American Standard Code for Information Interchange
<b>ATDF</b>	Archival Tracking Data File
<b>B-frame</b>	Body Frame
<b>C&amp;DH</b>	Command and Data Handler
<b>CA</b>	Closest Approach
<b>CAS</b>	Canned Activity sequence
<b>CCD</b>	Charged-Coupled Device
<b>CCSDS</b>	Consultative Committee for Space Data Systems
<b>CDF</b>	Common Data Format
<b>CFDP</b>	CCSDS File Delivery Protocol
<b>CK</b>	Camera Kernel (SPICE)
<b>CLCW</b>	Command Link Control Word
<b>CLTU</b>	Command Link Transfer Unit
<b>CoDMAC</b>	Committee on Data Management and Computation
<b>Co-I</b>	Co-Investigator
<b>COP</b>	Command Operation Procedure
<b>CUCC</b>	CSDS Unsegmented Time Code
<b>DPU</b>	Data Processing Unit
<b>EDR</b>	Experimental Data Records
<b>EK</b>	Event Kernel
<b>EPPS</b>	Energetic Particle and Plasma Spectrometer
<b>ET</b>	Ephemeris Time
<b>FIPS</b>	Fast Imaging Plasma Spectrometer
<b>FITS</b>	Flexible Image Transport System
<b>FOP</b>	Frame Operation Procedure
<b>FOV</b>	Field-of-View
<b>FPA</b>	Focal Plane Assembly
<b>FTP</b>	File Transfer protocol
<b>GC</b>	Geochemistry Group
<b>GP</b>	Geophysics Group
<b>GRNS</b>	Gamma-ray and Neutron Spectrometer
<b>GSFC</b>	Goddard Space Flight Center
<b>I&amp;T</b>	Integration and Test
<b>I2C</b>	Inter-Integrated Circuit
<b>IEM</b>	Integrated Electronic Module
<b>IK</b>	Instrument Measurement Kernel (SPICE)
<b>IMU</b>	Inertial Measurement unit
<b>ISI</b>	Integral Systems Incorporated (EPOCH)
<b>LSK</b>	Leapseconds Kernel (SPICE)
<b>MAG</b>	Magnetometer
<b>MASCS</b>	Mercury Atmospheric and Surface Composition Spectrometer
<b>MCP</b>	Monitor and Control Processor (DSN station)
<b>MDIS</b>	Mercury Dual Imaging System
<b>MESSENGER</b>	MErcury, Surface, Space ENvironment, Geochemistry, and Ranging
<b>MET</b>	Mission Elapsed Time
<b>MIA</b>	Monitor Interface Assembly (DSN station)
<b>NAIF</b>	Navigation and Ancillary Information Facility
<b>NASA</b>	Navigation Aeronautics and Space Administration
<b>NEAR</b>	The Near Earth Asteroid Rendezvous mission
<b>NSSDC</b>	National Space Science Data Center
<b>ODF</b>	Orbit Data File
<b>ODL</b>	Object Description Language
<b>OWLT</b>	One-Way Light Time
<b>PCK</b>	Planetary Constant Kernel (SPICE)

<b>PDR</b>	Preliminary Design Review
<b>PDR</b>	Packetized Data Records
<b>PDS</b>	Planetary Data System
<b>SCET</b>	Space Craft Event Time
<b>SCLK</b>	Space Clock Kernel (SPICE)
<b>SCPS</b>	Space Communication Protocol Standards
<b>SFDU</b>	Standard Formatted Data Unit
<b>SPICE</b>	Spacecraft, Planet, Instrument, C-matrix Events
<b>SPK</b>	Spacecraft and Planets Kernel (SPICE)
<b>TDB</b>	Barycentric Dynamical Time, the same as ET in the SPICE system
<b>TDT</b>	Terrestrial Dynamical Time
<b>TMOD</b>	Telecommunications and Mission Operations Directorate
<b>USN</b>	Universal Space Net
<b>UTC</b>	Coordinated Universal Time
<b>VC</b>	Virtual Channel