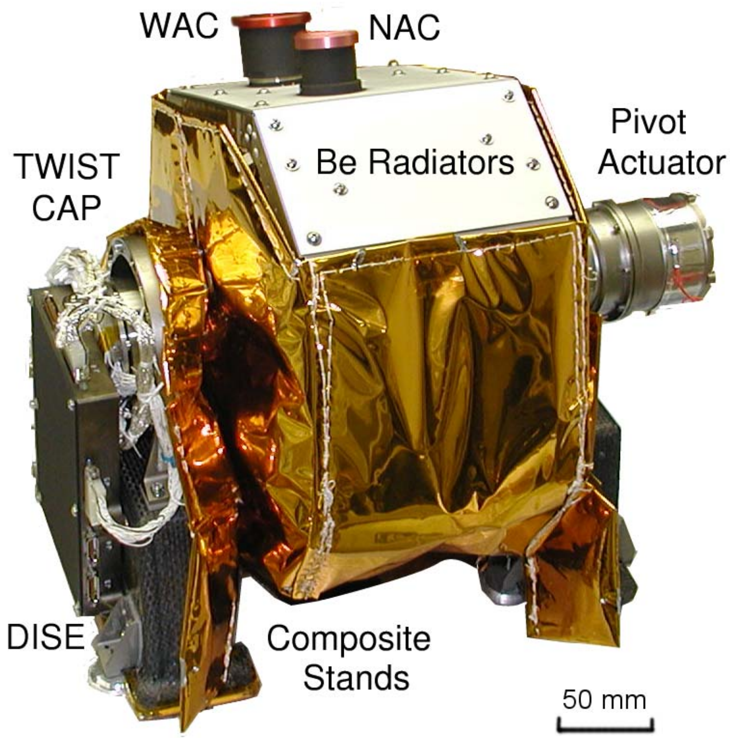
MESSENGER
Mercury Dual Imaging System (MDIS) Experimental Data Record (EDR) Software Interface Specification (SIS)



Version 2M

Christopher Hash
Raymond Espiritu
Erick Malaret
Applied Coherent Technology Corporation

Louise Prockter
Scott Murchie
Alan Mick
Johns Hopkins University Applied Physics Laboratory

Jennifer Ward
Washington University

DOCUMENT CHANGE LOG

Version	Date	Description	Sections affected
2J	UNK	Baseline for change log.	All
2L	1/8/10	Added keywords OBSERVATION_ID, MESS:IMG_ID LSB, MESS:IMG_ID_MSB, and MESS:PIV_POS_MOTOR to labels and index. Filled in values for various example label parameters that were previously shown as “N/A”. Revised index table to include SPACECRAFT_SOLAR_DISTANCE.	4.3.5, 5.1.6, 5.3
2M	1/13/10	Add PRODUCT_VERSION_ID to labels.	4.3.5, 5.3

TBD ITEMS

Section	Description
Appendix 7	TBD**.bpc:** Mercury orientation model using numerically integrated physical librations.

Table of Contents

Figures and Tables

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.

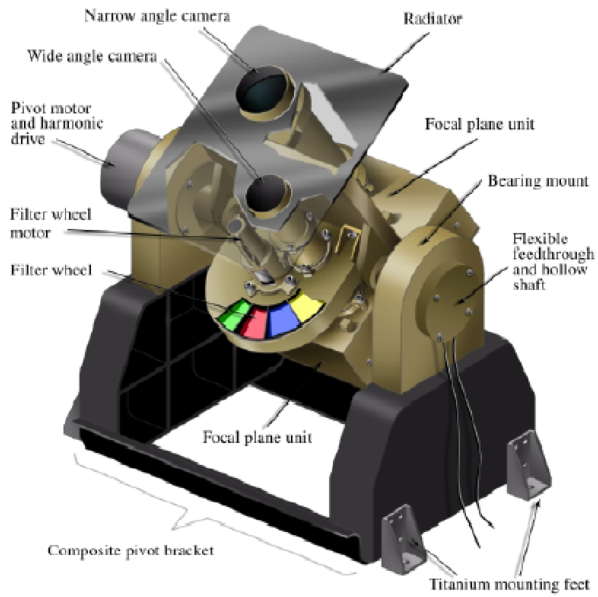


Figure 1: CAD rendering of MDIS instrument.

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: 2x2 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 (which 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 4 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 file, 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 is located at JHU/APL. The SOC produces early versions of products that can be used by the science and instrument teams. Ideally they are 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 3, 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 is sent which provides an independent record of the fiduciary checksums provided in the archive file itself. Within several days of transmittal, the node acknowledges receipt (but not verification) of the archive and letter of transmittal. If acknowledgement is not received, or if problems are reported, the MESSENGER SOC immediately takes corrective action to effect successful transmittal.

After transmittal, the Imaging PDS node uncompresses the zip archive file and independently calculates the fiduciary checksums for each file. The calculated checksums are compared to the checksums in the transmittal letter to those recorded in the archive itself. The node then performs any additional verification and validation of the data provided and reports any discrepancies or problems to the MESSENGER SOC. It is expected that the node performs these checks and inspections in about two weeks. After inspection has been completed to the satisfaction of the Imaging PDS node, the node issues 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 sub-frames present .

The keywords DARK_STRIP_MEAN, MINIMUM, MAXIMUM, MEAN, STANDARD_DEVIATION, SATURATED_PIXEL_COUNT, and MISSING_PIXELS were added to EDR labels beginning in September 2008 to provide additional information on image brightness levels and whether or not saturated pixels are present.

As a result of an August 2009 flight software update, all MDIS EDRs were regenerated and redelivered to PDS with Release 5 (see Table 3). The keywords OBSERVATION_ID, MESS:IMG_ID_LSB, MESS:IMG_ID_MSB, and MESS:PIV_POS_MOTOR were added to the EDR labels with this update. EDRs from Mercury Flyby 2 and earlier have values of "N/A" for these keywords. The keyword MESS:PIV_GOAL is set to "N/A" after Mercury Flyby 2.

EXAMPLE PDS LABEL FOR THE MDIS EDR

```
PDS_VERSION_ID       = PDS3

/*** FILE FORMAT ***/
RECORD_TYPE          = FIXED_LENGTH
RECORD_BYTES         = 512
FILE_RECORDS          = 0526
LABEL_RECORDS         = 0014

/*** POINTERS TO START BYTE OFFSET OF OBJECTS IN IMAGE FILE ***/
^IMAGE                = 0015

/*** GENERAL DATA DESCRIPTION PARAMETERS ***/
MISSION_NAME         = "MESSENGER"
INSTRUMENT_HOST_NAME = "MESSENGER"
DATA_SET_ID          = "MESS-E/V/H-MDIS-2-EDR-RAWDATA-V1.0"
DATA_QUALITY_ID      = "0000001000000000"
PRODUCT_ID           = "EN0131825260M"
PRODUCT_VERSION_ID   = "3"
SOURCE_PRODUCT_ID    = ("0131825260_IM6")
PRODUCER_INSTITUTION_NAME = "APPLIED COHERENT TECHNOLOGY CORPORATION"
SOFTWARE_NAME        = "MDIS2EDR"
SOFTWARE_VERSION_ID  = "0.7"
MISSION_PHASE_NAME   = "MERCURY 2 FLYBY"
TARGET_NAME          = "MERCURY"
SEQUENCE_NAME        = "08280_DEP_NAC_MOVIE_2"
OBSERVATION_ID       = "7436"

/*** TIME PARAMETERS ***/
START_TIME           = 2008-10-07T00:03:37.333598
STOP_TIME            = 2008-10-07T00:03:37.340598
SPACECRAFT_CLOCK_START_COUNT = "1/0131825260:983000"
SPACECRAFT_CLOCK_STOP_COUNT = "1/0131825260:990000"
PRODUCT_CREATION_TIME = 2009-12-14T21:41:07

/***  INSTRUMENT ENGINEERING PARAMETERS ***/
INSTRUMENT_NAME      = "MERCURY DUAL IMAGING SYSTEM NARROW ANGLE CAMERA"
INSTRUMENT_ID        = "MDIS-NAC"
FILTER_NAME          = "748 BP 53"
FILTER_NUMBER        = "N/A"
CENTER_FILTER_WAVELENGTH = 747.7 <NM>
BANDWIDTH            = 52.6 <NM>
EXPOSURE_DURATION    = 7 <MS>
EXPOSURE_TYPE        = AUTO
DETECTOR_TEMPERATURE = -42.82 <DEGC>
FOCAL_PLANE_TEMPERATURE = -30.81 <DEGC>
FILTER_TEMPERATURE   = "N/A"
OPTICS_TEMPERATURE   = -32.02 <DEGC>
```

```
/*** INSTRUMENT RAW PARAMETERS ***/
MESS:MET_EXP          = 131825260
MESS:IMG_ID_LSB       = "N/A"
MESS:IMG_ID_MSB       = "N/A"
MESS:ATT_CLOCK_COUNT = 131825258
MESS:ATT_Q1           = -0.51003933
MESS:ATT_Q2           = -0.68887365
MESS:ATT_Q3           = 0.26611212
MESS:ATT_Q4           = -0.44101849
MESS:ATT_FLAG         = 7
MESS:PIV_POS_MOTOR    = "N/A"
MESS:PIV_GOAL         = 9102
MESS:PIV_POS          = 9102
MESS:PIV_READ         = 13484
MESS:PIV_CAL          = -26758
MESS:FW_GOAL          = 11976
MESS:FW_POS           = 12108
MESS:FW_READ          = 12108
MESS:CCD_TEMP         = 1025
MESS:CAM_T1           = 464
MESS:CAM_T2           = 489
MESS:EXPOSURE         = 7
MESS:DPU_ID           = 0
MESS:IMAGER           = 1
MESS:SOURCE           = 0
MESS:FPU_BIN          = 1
MESS:COMP12_8         = 1
MESS:COMP_ALG         = 2
MESS:COMP_FST         = 1
MESS:TIME_PLS         = 2
MESS:LATCH_UP         = 0
MESS:EXP_MODE         = 1
MESS:PIV_STAT         = 3
MESS:PIV_MPEN         = 1
MESS:PIV_PV           = 1
MESS:PIV_RV           = 1
MESS:FW_PV            = 1
MESS:FW_RV            = 1
MESS:AEX_STAT         = 256
MESS:AEX_STHR         = 5
MESS:AEX_TGTB         = 2400
MESS:AEX_BACB         = 240
MESS:AEX_MAXE         = 14
MESS:AEX_MINE         = 1
MESS:DLNKPRIO         = 6
MESS:WVLRATIO         = 8
MESS:PIXELBIN         = 0
MESS:SUBFRAME         = 0
MESS:SUBF_X1          = 4
MESS:SUBF_Y1          = 0
MESS:SUBF_DX1         = 0
MESS:SUBF_DY1         = 0
MESS:SUBF_X2          = 4
MESS:SUBF_Y2          = 0
MESS:SUBF_DX2         = 0
MESS:SUBF_DY2         = 0
MESS:SUBF_X3          = 0
MESS:SUBF_Y3          = 0
MESS:SUBF_DX3         = 0
MESS:SUBF_DY3         = 0
MESS:SUBF_X4          = 0
MESS:SUBF_Y4          = 0
MESS:SUBF_DX4         = 0
MESS:SUBF_DY4         = 0
MESS:SUBF_X5          = 0
MESS:SUBF_Y5          = 0
MESS:SUBF_DX5         = 0
```

```
MESS:SUBF_DY5         = 0
MESS:CRITOPNV         = 0
MESS:JAILBARS         = 0
MESS:JB_X0            = 0
MESS:JB_X1            = 0
MESS:JB_SPACE         = 0

/*** GEOMETRY INFORMATION ***/
RIGHT_ASCENSION       = 344.01283 <DEG>
DECLINATION           = -13.92227 <DEG>
TWIST_ANGLE           = 25.74281 <DEG>
RA_DEC_REF_PIXEL      = (256.00000,256.00000)
RETICLE_POINT_RA      = (343.65971 <DEG>,345.03950 <DEG>,342.99108 <DEG>,
  344.37544 <DEG>)
RETICLE_POINT_DECLINATION = (-14.91941 <DEG>,-14.27452 <DEG>,-13.57603
<DEG>,
  -12.92987 <DEG>)

/*** TARGET PARAMETERS ***/
SC_TARGET_POSITION_VECTOR = (-272568.91257 <KM>,77584.66837
<KM>,69356.60711
  <KM>)
TARGET_CENTER_DISTANCE = 291759.37314 <KM>

/*** TARGET WITHIN SENSOR FOV ***/
SLANT_DISTANCE        = 289529.75439 <KM>
CENTER_LATITUDE       = -13.63951 <DEG>
CENTER_LONGITUDE      = 347.87151 <DEG>
HORIZONTAL_PIXEL_SCALE = 14763.37652 <M>
VERTICAL_PIXEL_SCALE = 14763.37652 <M>
SMEAR_MAGNITUDE       = 0.00008 <PIXELS>
SMEAR_AZIMUTH         = 4.16379 <DEG>
NORTH_AZIMUTH         = 94.23934 <DEG>
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 = -0.06832 <DEG>
SUB_SPACECRAFT_LONGITUDE = 328.04386 <DEG>
SPACECRAFT_ALTITUDE  = 289319.37314 <KM>
SUB_SPACECRAFT_AZIMUTH = 34.90611 <DEG>

/*** SPACECRAFT LOCATION ***/
SPACECRAFT_SOLAR_DISTANCE = 50501079.00038 <KM>
SC_SUN_POSITION_VECTOR = (48728210.88598 <KM>,13118668.10143 <KM>,
  1954735.60814 <KM>)
SC_SUN_VELOCITY_VECTOR = (26.57284 <KM/S>,-44.19584 <KM/S>,-26.36150
<KM/S>)

/*** VIEWING AND LIGHTING GEOMETRY (SUN ON TARGET) ***/
SOLAR_DISTANCE        = 50741510.93485 <KM>
SUB_SOLAR_AZIMUTH     = 138.53775 <DEG>
SUB_SOLAR_LATITUDE    = -0.01065 <DEG>
SUB_SOLAR_LONGITUDE   = 2.45546 <DEG>
INCIDENCE_ANGLE       = 19.86004 <DEG>
PHASE_ANGLE           = 34.57148 <DEG>
EMISSION_ANGLE        = 24.06508 <DEG>
LOCAL_HOUR_ANGLE      = 165.41605 <DEG>

/*** 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         = 8
  UNIT                = "N/A"
  DARK_STRIP_MEAN     = 8.965

/*** IMAGE STATISTICS OF  ***/
/*** THE EXPOSED CCD AREA ***/
  MINIMUM             = 8.000
  MAXIMUM             = 216.000
  MEAN                = 51.385
  STANDARD_DEVIATION = 60.462

/*** PIXEL COUNTS ***/
  SATURATED_PIXEL_COUNT = 0
  MISSING_PIXELS      = 0
END_OBJECT = IMAGE
END
```

A reconstructed image (at any level of binning) can contain up to five sub-frames, plus a special sub-frame dark strip for a masked dark strip at the edge of the CCD that measures a reference dark current. In an image that has not been binned, the dark strip is 4 columns wide, with a dimension of 4 sample x 1024 lines, so that the exposed part of the image is up to 1020 samples x 1024 lines. The value used for areas outside of the subframes and dark strip is zero. 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.

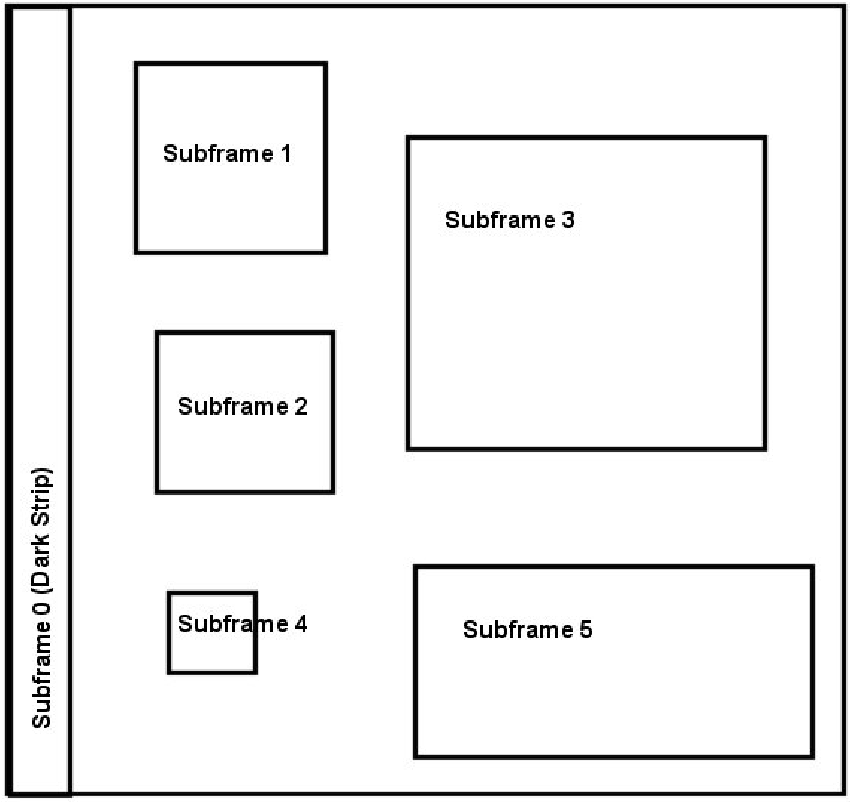


Figure 2 Reconstructed image with 5 subframes plus the dark strip subframe.

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 contain

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 **planetocentric** 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 **planetocentric.** 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.

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 EDR Naming Convention

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

```
X = E for 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,U) for
the WAC.  (See Table 5, 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.CAT: Description of the MDIS WAC camera for the PDS catalog.

MDIS_NAC_INST.CAT: 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.

TARGET.CAT: List of observation targets in the MDIS data set.

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.

INDEX.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 (Table 1). 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.

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

INDEX.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 fight 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.

Table 1. Index table entries.

VOLUME_ID	The identifier of the volume on which the product is stored
PATH_NAME	Path to directory containing file
FILE_NAME	Name of file in archive
PRODUCT_ID	A permanent, unique identifier assigned to a data product by its producer
OBSERVATION_ID	Image counter from header
DATA_QUALITY_ID	A data quality index is used to encode figures-of-merit into one parameter that is included in the label of each EDR
MISSION_PHASE_NAME	Provides the commonly-used identifiers of the MESSENGER Mission Phase
TARGET_NAME	Identifies the target
SEQUENCE_NAME	Identifies the imaging sequence name
PRODUCT_CREATION_TIME	The time in UTC when the EDR product was created
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)
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)
INSTRUMENT_ID	Abbreviated name or acronym which identifies the instrument as the WAC or NAC
FILTER_NUMBER	Provides the number of the WAC filter through which an image or measurement was acquired
CENTER_FILTER_WAVELENGTH	The mid point wavelength value between the minimum and maximum instrument filter wavelength values
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 exposure setting and 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
FOCAL_PLANE_TEMPERATURE	Indicates the temperature of the focal plane array in degrees Celsius at observation time. The conversion formula depends on the camera performing the observation
FILTER_TEMPERATURE	The temperature of the filter wheel
OPTICS_TEMPERATURE	The temperature of the NAC telescope
MESS:PIV_POS	Pivot position in units of 180deg/2^15. Note: these are the pivot position values being used to generate the MDIS pivot platform SPICE C-kernel
MESS:PIV_POS_MOTOR	Pivot position in motor steps
MESS:PIV_READ	Pivot reading from resolver
MESS:FPU_BIN	Identifies the image binning in FPU - 0=1x1, 1=2x2
MESS:COMP12_8	Identifies if 12 to 8 bit image compression is enabled or disabled. 0=disabled, 1=enabled
MESS:COMP_ALG	Identifies the 12 to 8 bit compression algorithm used
MESS:COMP_FST	Identifies if Fast image compression is disabled (=0) or enabled (=1)
MESS:WVLRATIO	Identifies the wavelet compression ratio
MESS:PIXELBIN	Identifies the MP software pixel binning
MESS:SUBFRAME	Identifies the number of subframes

RETICLE_POINT_RA_1	The right ascension of the principle points of the camera
RETICLE_POINT_RA_2	The right ascension of the principle points of the camera
RETICLE_POINT_RA_3	The right ascension of the principle points of the camera
RETICLE_POINT_RA_4	The right ascension of the principle points of the camera
RETICLE_POINT_DECLINATION_1	The declination of the principle points of the camera
RETICLE_POINT_DECLINATION_2	The declination of the principle points of the camera
RETICLE_POINT_DECLINATION_3	The declination of the principle points of the camera
RETICLE_POINT_DECLINATION_4	The declination of the principle points of the camera
SPACECRAFT_SOLAR_DISTANCE	Distance from spacecraft to the sun
SLANT_DISTANCE	Distance from spacecraft to the camera boresight intercept point on the surface in kilometers
CENTER_LATITUDE	Latitude at the center of the full image frame
CENTER_LONGITUDE	Longitude at the center of the full image frame
HORIZONTAL_PIXEL_SCALE	The scale of a pixel in the horizontal direction
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.)
RETICLE_POINT_LATITUDE_1	Latitudes of the surface intercept points of the principle points of the camera
RETICLE_POINT_LATITUDE_2	Latitudes of the surface intercept points of the principle points of the camera
RETICLE_POINT_LATITUDE_3	Latitudes of the surface intercept points of the principle points of the camera
RETICLE_POINT_LATITUDE_4	Latitudes of the surface intercept points of the principle points of the camera
RETICLE_POINT_LONGITUDE_1	Longitudes of the surface intercept points of the principle points of the camera
RETICLE_POINT_LONGITUDE_2	Longitudes of the surface intercept points of the principle points of the camera
RETICLE_POINT_LONGITUDE_3	Longitudes of the surface intercept points of the principle points of the camera
RETICLE_POINT_LONGITUDE_4	Longitudes of the surface intercept points of the principle points of the camera
SOLAR_DISTANCE	Distance from target body center to Sun
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 the epoch
SUB_SPACECRAFT_LATITUDE	Planetocentric latitude of spacecraft-to-body-center surface intercept vector
SUB_SPACECRAFT_LONGITUDE	Planetocentric longitude of spacecraft-to-body-center surface intercept vector
SPACECRAFT_ALTITUDE	Altitude of the spacecraft above a reference ellipsoid
SUB_SOLAR_LATITUDE	Planetocentric latitude of the apparent sub-solar point
SUB_SOLAR_LONGITUDE	Planetocentric latitude 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
PHASE_ANGLE	Provides a measure of the relationship between the instrument viewing position and incident illumination. Phase angle is measured at the target; it is the angle between a vector to the illumination source and a vector to the instrument

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
DARK_STRIP_MEAN	The mean DN in the CCD dark strip. This is a measure of the dark current even if the rest of the CCD is illuminated
MINIMUM	The lowest DN value within the exposed area of the CCD
MAXIMUM	The highest DN value within the exposed area of the CCD
MEAN	The arithmetic mean DN value within the exposed area of the CCD
STANDARD_DEVIATION	The standard deviation of the DN values within the exposed area of the CCD
SATURATED_PIXEL_COUNT	The number of pixels whose values indicate that the corresponding detector elements exceeded their linear response range. In the WAC (MESS:IMAGER=0) the 12-bit DN value where saturation occurs is approximately 3600; in the NAC (MESS:IMAGER=1) it is approximately 3400
MISSING_PIXELS	The number of pixels not downlinked, or absent from the total subframe area within the image, that have a null value of 0

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 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.LBL - 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
bining = 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 nomclature:

```
MDISWAC_bining_FLAT_FILnn_v.FIT where:
  bining = 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_FILnn_v.LBL.

Flat-field files for the NAC have the nomenclature:

```
MDISNAC_bining_FLAT_v.FIT where:
  bining = 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
  bining = 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.

LABEL_RECORDS
The number of physical label 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.

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 pivot position validity flag MESS:PIV_PV=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 two conditions:
(a) filter wheel position validity flag MESS:FW_PV=0=invalid,
(b) 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, by both MESS:FW_PV=1 (See Table 2).

Table 2. Filter wheel encoder positions

FILTER_NUMBER	MESS:FW_GOAL	Allowable (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 5 in Appendix B) It is M for the NAC.

PRODUCT_VERSION_ID
Ordinal number of the version of the label or EDR.

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, if present, 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_NAME
Identifies the imaging sequence name. Format: YYYYMMDD_Sequence_Name.

OBSERVATION_ID
Image counter from header.

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 expsoure. 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:TTTTTT
    - P = SPICE clock partition
    - S = first stage, spacecraft clock seconds
    - 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.

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.

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:
Temperature = -318.4553 + Raw * 0.2718

For NAC:
Temperature = -323.3669 + 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:
Temperature = -263.2584 + Raw * 0.5022

For NAC:
Temperature = -268.8441 + 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:

Temperature = -292.7603 + 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:

Temperature = -269.7180 + Raw * 0.4861

Where Raw is the raw counts in telemetry (MESS:CAM_T2).

Instrument raw parameters

MESS:MET_EXP
The mission-elapsed-time, or MET, in seconds since MESSENGER launch of the second during which an MDIS image completes its exposure.

MESS:IMG_ID_LSB
The 16 least-significant-bits of the 24-bit unique image identifier from the raw image header. This item is not available prior to an instrument software upload 2009-08-18 and will be set to N/A in images taken prior to that time.

MESS:IMG_ID_MSB
The 8 most-significant-bits of the 24-bit unique image identifier from the raw image header. This item is not available prior to an instrument software upload 2009-08-18 and will be set to N/A in images taken prior to that time.

MESS:ATT_CLOCK_COUNT

The mission-elapsed-time, or MET, in seconds since MESSENGER launch, of the second during which the spacecraft attitude measurement in the header of an MDIS image was acquired.

MESS:ATT_Q1
The roll value of the vector component of the attitude quaternion representing spacecraft attitude, in the header of an MDIS image.

MESS:ATT_Q2
The pitch value of the vector component of the attitude quaternion representing spacecraft attitude, in the header of an MDIS image.

MESS:ATT_Q3
The yaw value of the vector component of the attitude quaternion representing spacecraft attitude, in the header of an MDIS image.

MESS:ATT_Q4
The scalar component of the attitude quaternion representing spacecraft attitude, in the header of an MDIS image.

MESS:ATT_FLAG
Attitude quality flag for the spacecraft attitude quaternion in the header of an MDIS image:

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_POS_MOTOR
The actual position of the MDIS pivot during exposure of an MDIS image, in 150-microradian motor step units. This item is not available prior to 2009-08-18 and will be set to N/A.

MESS:PIV_GOAL
The commanded position of the MDIS pivot during exposure of an MDIS image, in increments of (180 DEGREES / (2**15)) with zero at nadir. -180 degrees is stowed. This item is not available after 2009-08-18 and will be set to N/A.

MESS:PIV_POS

The position of the MDIS pivot during exposure of an MDIS image, determined by counting steps of the pivot stepper motor, in increments of (360 DEGREES/(2**16)) with zero at nadir. -180 degrees is stowed.

MESS:PIV_READ
The position of the MDIS pivot during exposure of an MDIS image, determined from raw output of the pivot position resolver, in increments of (45 DEGREES / (2**16)). The resolver covers 45 degrees of motion; the resolver read-out values repeat eight times over the entire 360 degrees that an unconstrained platform could travel.

MESS:PIV_CAL
The offset in measured pivot position applied to MESS:PIV_POS and MESS:PIV_GOAL so that zero is as close as possible to true spacecraft nadir (+z axis). The correction is in increments of (180 DEGREES / (2**15)).

MESS:FW_GOAL
The goal position, in raw counts of the position resolver on the MDIS filter wheel. For each commanded filter number, the instrument software will try to place the filter wheel at the positions listed in Table 2. Actual position attained is reported in MESS:FW_POS.

MESS:FW_POS
The actual position, in raw counts of the position resolver on the MDIS filter wheel. For each commanded filter number, the instrument software will try to place the filter wheel at the positions listed in Table 2. Commanded position is reported in MESS:FW_GOAL. There is a tolerance of 240 resolver counts around MESS:FW_GOAL for MESS:FW_POS to indicate that the filter wheel is correctly positioned.

MESS:FW_READ
The raw value from the MDIS filter wheel resolver in resolver counts. It is used by the flight software to compute MESS:FW_POS. For each commanded filter number, the instrument software will try to place the filter wheel at the positions listed in Table 2. Commanded position is reported in MESS:FW_GOAL. There is a tolerance of 240 resolver counts around MESS:FW_GOAL for MESS:FW_POS to indicate that the filter wheel is correctly positioned.

MESS:CCD_TEMP
MDIS CCD temperature in raw counts. The conversion formula to degrees Celsius depends on the camera performing the observation:

For WAC:
Temperature = -318.4553 + Raw * 0.2718

For NAC:
Temperature = -323.3669 + Raw * 0.2737

Where Raw is the raw counts in telemetry (MESS:CCD_TEMP).

MESS:CAM_T1
The temperature of the focal plane array in raw counts at observation time. The conversion formula to degrees Celsius depends on the camera performing the observation:

For WAC:
Temperature = -263.2584 + Raw * 0.5022

For NAC:
Temperature = -268.8441 + Raw * 0.5130

Where Raw is the raw counts in telemetry (MESS:CAM_T1).

MESS:CAM_T2
Camera temperature 2 in raw counts. The meaning depends on whether it is being reported by the WAC or NAC. A single telemetry point is used to return the raw value of filter wheel temperature (WAC), FILTER_TEMPERATURE once converted to units of degrees Celsius, or the raw value of telescope temperature (NAC), OPTICS_TEMPERATURE once converted to units of degrees Celsius, depending on which camera is in use.

For the WAC, this is temperature of the filter wheel. Thus, FILTER_TEMPERATURE is "N/A" if the NAC was used for the observation because the telemetry point will be a measurement of the NAC telescope temperature. For the WAC the conversion from raw counts to degrees

Celsius is:

T = -292.7603 + Raw * 0.5553

where Raw is the raw counts in MESS:CAM_T2.

For the NAC, this is temperature of the NAC telescope. Thus OPTICS_TEMPERATURE is "N/A" if the WAC was used for observation because the telemetry point will be a measurement of the WAC filter wheel temperature.

For the NAC the conversion from raw counts to degrees Celsius is:

T = -269.7180 + Raw * 0.4861

where Raw is the raw counts in telemetry (MESS:CAM_T2).

MESS:EXPOSURE
MDIS exposure time in milliseconds.

MESS:DPU_ID
The identified of the DPU used during acquisition of an MDIS image:

0 = DPU-A
1 = DPU-B.

MESS:IMAGER
Which of the two cameras was used during acquisition of an MDIS image:

0 = WAC
1 = NAC.

MESS:SOURCE
Source of an MDIS image, either a scene image from the CCD or one of two test patterns:

0 = CCD
1 = Test pattern
2 = Inverted test pattern.

MESS:FPU_BIN
On-chip image binning option for MDIS. Images may be taken either without on-chip binning or with 2x2 binning, which decreases the size of a full image from 1024x1024 pixels to 512x512 pixels. On-chip binning can be used to manage the size of raw images being stored on the spacecraft solid-state recorder, or to increase CCD sensitivity. If this option is used, sensitivity increases by about a factor of four but read noise is similar:

0 = 1x1 binning (none)
1 = 2x2 binning.

MESS:COMP12_8
12 to 8 bit image compression enabled or disabled. Which algorithm is used is specified by MESS:

0 = disabled (images are 12-bit)
1 = enabled (images are 8-bit).

MESS:COMP_ALG
12 to 8 bit compression algorithm (0-7) used to compress images from 12 to 8 bits. Whether this option is enabled is indicated by MESS:COMP12_8. The compression is implemented using one of eight lookup tables, which are optimized to the lower WAC CCD read noise and higher NAC read noise, light levels, and bias level (nominal or after inflight drift):

0 = Lo-noise hi-bias SNR proportional. Case: Either NAC or WAC, for nominal bias (all DNs greater than 12-bit 230). Formulation: Maps 12-bit DNs between bias and saturation into 8 bits, proportional to SNR. Information loss is spread evenly over dynamic range. Usage: Typical imaging with varied brightness.

1 = Lo-noise hi-bias DN-weighted SNR proportional. Case: Low-noise (WAC) CCD, bias nominal (all DNs greater than 12-bit 230). Formulation: Maps 12 bits between bias and saturation into 8 bits proportional to sliding scale. Information is preferentially retained at the low DN end. Usage: Faint objects. Saturates at a DN of 3000.

2 = Hi-noise hi-bias DN-weighted SNR proportional. Case: High-noise (NAC) CCD, bias nominal (all DNs greater than 12-bit 230). Formulation: Maps 12 bits between bias and saturation into 8 bits proportional to sliding scale. Information is preferentially retained at the low DN end. Usage: B/W, mostly low brightness.

3 = Lo-noise med-bias SNR proportional. Case: Either CCD, assuming bias has dropped tens DN (all DNs greater than 12-bit 180). Formulation: Maps 12-bit DNs between bias and saturation into 8 bits, proportional to SNR. Information loss is spread over dynamic range. Usage: Typical imaging, varied brightness.

4 = Lo-noise med-bias DN-weighted SNR proportional. Case: Lo-noise (WAC) CCD, assuming bias has dropped tens DN (all DNs greater than 12-bit 180). Formulation: Maps 12 bits between bias and saturation into 8 bits proportional to sliding scale. Information retained at low DN end. Usage: Faint objects. Saturates at a DN of 3000.

5 = Hi-noise med-bias DN-weighted SNR proportional. Case: High-noise (NAC) CCD, assuming bias has dropped tens DN (all DNs greater than 12-bit 180).

Formulation: Maps 12 bits between bias and saturation into 8 bits proportional to sliding scale. Information is retained preferentially at the low end of the DN range. Usage: B/W, mostly low brightness.

6 = Zero-bias SNR proportional. Case: Contingency; assuming bias decreased to near 0 from the nominal 230 12-bit DNs. Formulation: Maps 12-bit DNs between bias and saturation into 8 bits, proportional to SNR. Information loss is spread over the dynamic range. Usage: Typical imaging, varied brightness.

7 = Linear. Case: either CCD, bias or read noise. Formulation: Maps 12-bit DNs between the bias level and saturation linearly into 8-bit space. Usage: High brightness mapping; information loss greatest at low DNs, preserves information at high DNs.

MESS:COMP_FST
Status of lossless Fast compression of MDIS images. This is applied to images by the instrument itself. The images are first uncompressed on the solid-state recorder if lossy wavelet compression is applied:

0 = Fast disabled
1 = Fast enabled.

MESS:TIME_PLS
Source of the 1 Hz time pulse used in time-tagging MDIS images:

0 = Software
1 = Main Processor A (MP-A)
2 = Main Processor B (MP-B)
3 = Software.

MESS:LATCH_UP
Indicator if MDIS FPU is latched up. If the value is 1 then the image data are probably invalid.

0 = OK
1 = Latched.

MESS:EXP_MODE
Exposure time mode used for acquisition of an MDIS image. Manual exposure uses a pre-commanded exposure time. Autoexposure determines the exposure time from test images taken before the exposure, targeting a specific brightness value.

0 = Manual
1 = Automatic.

MESS:PIV_STAT
Pivot control state of MDIS.

A resolver provides a position reading of the pivot platform. The resolver only covers 45 degrees of motion; the resolver read-out values repeat eight times over the entire 360 degrees that an unconstrained platform could travel. The DPU software must determine in which of the eight octants the platform is located before the resolver reading is meaningful. The software combines the octant with the resolver reading to form a position that covers the entire 360 degrees.

To determine the octant the DPU software must be commanded to 'home' the platform. To home the pivot platform, the software drives the motor open loop backwards into the hard stop at -185 degrees. Then the software drives the motor forward, open loop, prepositioning it to -179 degrees. Until homing is completed, the pivot platform is considered 'lost' and all other pivot commands will remain pending.

This status item describes that state of the pivot in determining this position knowledge.

0 = Lost
1 = Searching
2 = Found
3 = OK.

MESS:PIV_MPEN
Status of main processor (MP) control of the MDIS pivot. If this is enabled, then the pivot goes to a position broadcast by the MP that points MDIS to nadir or some other aimpoint. If not enabled then a discrete pivot position is commanded.

0 = Disabled
1 = Enabled.

MESS:PIV_PV
Validity flag for position of the MDIS pivot given in MESS:PIV_POS.

0 = invalid
1 = valid.

MESS:PIV_RV
Validity flag for reading of the MDIS pivot given in MESS:PIV_READ.

0 = invalid
1 = valid.

MESS:FW_PV
Validity flag for position of the MDIS filter wheel given in MESS:FW_POS.

0 = invalid
1 = valid.

MESS:FW_RV
Validity flag for reading of the MDIS filter wheel given in MESS:FW_READ.

0 = invalid
1 = valid.

MESS:AEX_STAT
The bin in a DPU histogram of image brightness used for MDIS automatic exposure time calculation.

In a test image that it analyzed to determine an exposure time using automatic exposure, DPU hardware generates a histogram of the image. The histogram is analyzed by the software to determine if the image is overexposed or underexposed, and the exposure time is adjusted accordingly by analyzing the histogram of raw DN values in different brightness bins. The background or dark current level (MESS:AEX_BACB) is taken into account an is assumed to be a constant value.

A threshold of number of pixels (MESS:AEX_STHR) is allowed to exceed a target brightness (MESS:AEX_TGTB). Starting with the maximum value, the number of pixels exceeding the target is counted, and the brightness of the histogram bin in which that threshold is reached (MESS:AEX_STAT) is reported. The exposure time is scaled back by the ratio of MESS:AEX_TGTB/MESS:AEX_STAT.

MESS:AEX_STHR
The number of pixels allowed to exceed target brightness during an MDIS automatic exposure time calculation.

In a test image that it analyzed to determine an exposure time using automatic exposure, DPU hardware generates a histogram of the image. The histogram is analyzed by the software to determine if the image is overexposed or underexposed, and the exposure time is adjusted accordingly by analyzing the histogram of raw DN values in different brightness bins. The background or dark current level (MESS:AEX_BACB) is taken into account an is assumed to be a constant value.

A threshold of number of pixels (MESS:AEX_STHR) is allowed to exceed a target brightness (MESS:AEX_TGTB). Starting with the maximum value, the number of pixels exceeding the target is counted, and the brightness of the histogram bin in which that threshold is reached (MESS:AEX_STAT) is reported. The exposure time is scaled back by the ratio of MESS:AEX_TGTB/MESS:AEX_STAT.

MESS:AEX_TGTB
The target brightness used for MDIS automatic exposure time calculation.

In a test image that it analyzed to determine an exposure time using automatic exposure, DPU hardware generates a histogram of the image. The histogram is analyzed by the software to determine if the image is overexposed or underexposed, and the exposure time is adjusted accordingly by analyzing the histogram of raw DN values in different brightness bins. The background or dark current level (MESS:AEX_BACB) is taken into account an is assumed to be a constant value.

A threshold of number of pixels (MESS:AEX_STHR) is allowed to exceed a target brightness (MESS:AEX_TGTB). Starting with the maximum value, the number of pixels exceeding the target is counted, and the brightness of the histogram bin in which that threshold is reached (MESS:AEX_STAT) is reported. The exposure time is scaled back by the ratio of MESS:AEX_TGTB/MESS:AEX_STAT.

MESS:AEX_BACB
The background brightness used for MDIS automatic exposure time calculation.

In a test image that it analyzed to determine an exposure time using automatic exposure, DPU hardware generates a histogram of the image. The histogram is analyzed by the software to determine if the image is overexposed or underexposed, and the exposure time is adjusted accordingly by analyzing the histogram of raw DN values in different brightness bins. The background or dark current level (MESS:AEX_BACB) is taken into account an is assumed to be a constant value.

A threshold of number of pixels (MESS:AEX_STHR) is allowed to exceed a target brightness (MESS:AEX_TGTB). Starting with the maximum value, the number of pixels exceeding the target is counted, and the brightness of the histogram bin in which that threshold is reached

(MESS:AEX_STAT) is reported. The exposure time is scaled back by the ratio of MESS:AEX_TGTB/MESS:AEX_STAT.

MESS:AEX_MAXE

The maximum allowable exposure time from an MDIS automatic exposure time calculation.

In a test image that it analyzed to determine an exposure time using automatic exposure, DPU hardware generates a histogram of the image. The histogram is analyzed by the software to determine if the image is overexposed or underexposed, and the exposure time is adjusted accordingly by analyzing the histogram of raw DN values in different brightness bins. The background or dark current level (MESS:AEX_BACB) is taken into account an is assumed to be a constant value.

A threshold of number of pixels (MESS:AEX_STHR) is allowed to exceed a target brightness (MESS:AEX_TGTB). Starting with the maximum value, the number of pixels exceeding the target is counted, and the brightness of the histogram bin in which that threshold is reached (MESS:AEX_STAT) is reported. The exposure time is scaled back by the ratio of MESS:AEX_TGTB/MESS:AEX_STAT.

MESS:AEX_MINE

The minimum allowable exposure time from an MDIS automatic exposure time calculation.

In a test image that it analyzed to determine an exposure time using automatic exposure, DPU hardware generates a histogram of the image. The histogram is analyzed by the software to determine if the image is overexposed or underexposed, and the exposure time is adjusted accordingly by analyzing the histogram of raw DN values in different brightness bins. The background or dark current level (MESS:AEX_BACB) is taken into account an is assumed to be a constant value.

A threshold of number of pixels (MESS:AEX_STHR) is allowed to exceed a target brightness (MESS:AEX_TGTB). Starting with the maximum value, the number of pixels exceeding the target is counted, and the brightness of the histogram bin in which that threshold is reached (MESS:AEX_STAT) is reported. The exposure time is scaled back by the ratio of MESS:AEX_TGTB/MESS:AEX_STAT.

MESS:DLNKPRIO

Priority for downlink of an MDIS image file from the MESSENGER spacecraft:

0 Priority #0 (highest)
1 Priority #1
.
.
9 Priority #9 (lowest).

MESS:WVLRATIO

Commanded (lossy) wavelet compression ratio for an MDIS image:

0: no wavelet compression (note: this expands an 8 or 12 bit image to 16 bits per pixel)
1: '1x' compression (actually lossless, with an indeterminate ratio)
2: 2x compression
3: 3x compression
.....
32: 32x compression.

MESS:PIXELBIN
Pixel binning done to MDIS images by the MESSENGER spacecraft main processor (MP). This is in addition to on-chip binning as described by MESS:FPU_BIN.

0 - no further binning
2 - 2x2 binning
4 - 4x4 binning
8 - 8x8 binning.

MESS:SUBFRAME
Number of rectangular subframes within an MDIS image to be retained after image compression by the MESSENGER spacecraft main processor (MP). Subframes may overlap each other, and are defined in the original 1024x1024 pixel MDIS coordinate system before pixel binning as described by MESS:FPU_BIN and MESS:PIXELBIN. Either a full image may be specified, or up to five discrete regions within the full image. In all cases, the first four columns of the original 1024x1024 image, which are physically masked and serve as a dark current reference, are downlinked as subframe 0, even if the full image case is described. Within the subframes, pixel binning as described by MESS:FPU_BIN and MESS:PIXELBIN is performed.
0 - no subframes (full image)
1 - 1 subframe
2 - 2 subframes
3 - 3 subframes
4 - 4 subframes
5 - 5 subframes.

MESS:SUBF_X1
The zero-based starting column of the FIRST rectangular subframe within an MDIS image to be retained after image compression by the MESSENGER spacecraft main processor (MP). There may be up to five subframes per image as defined by MESS:SUBFRAME. Subframes are defined in the original 1024x1024 pixel MDIS coordinate system before pixel binning as described by MESS:FPU_BIN and MESS:PIXELBIN.

MESS:SUBF_Y1
The zero-based starting row of the FIRST rectangular subframe within an MDIS image to be retained after image compression by the MESSENGER spacecraft main processor (MP). There may be up to five subframes per image as defined by MESS:SUBFRAME. Subframes are defined in the original 1024x1024 pixel MDIS coordinate system before pixel binning as described by MESS:FPU_BIN and MESS:PIXELBIN.

MESS:SUBF_DX1
The number of columns in the FIRST rectangular subframe within an MDIS image to be retained after image compression by the MESSENGER spacecraft main processor (MP). There may be up to five subframes per image as defined by MESS:SUBFRAME. Subframes are defined in the original 1024x1024 pixel MDIS coordinate system before pixel binning as described by MESS:FPU_BIN and MESS:PIXELBIN.

MESS:SUBF_DY1
The number of rows in the FIRST rectangular subframe within an MDIS image to be retained after image compression by the MESSENGER spacecraft main processor (MP). There may be up to five subframes per image as defined by MESS:SUBFRAME. Subframes are defined in the original 1024x1024 pixel MDIS coordinate system before pixel binning as described by MESS:FPU_BIN and MESS:PIXELBIN.

MESS:SUBF_X2
The zero-based starting column of the SECOND rectangular subframe within an MDIS image to be retained after image compression by the MESSENGER spacecraft main processor (MP). There may be up to five subframes per image as defined by MESS:SUBFRAME. Subframes are defined in the original 1024x1024 pixel MDIS coordinate system before pixel binning as described by MESS:FPU_BIN and MESS:PIXELBIN.

MESS:SUBF_Y2
The zero-based starting row of the SECOND rectangular subframe within an MDIS image to be retained after image compression by the MESSENGER spacecraft main processor (MP). There may be up to five subframes per image as defined by MESS:SUBFRAME. Subframes are defined in the original 1024x1024 pixel MDIS coordinate system before pixel binning as described by MESS:FPU_BIN and MESS:PIXELBIN.

MESS:SUBF_DX2
The number of columns in the SECOND rectangular subframe within an MDIS image to be retained after image compression by the MESSENGER spacecraft main processor (MP). There may be up to five subframes per image as defined by MESS:SUBFRAME. Subframes are defined in the original 1024x1024 pixel MDIS coordinate system before pixel binning as described by MESS:FPU_BIN and MESS:PIXELBIN.

MESS:SUBF_DY2
The number of rows in the SECOND rectangular subframe within an MDIS image to be retained after image compression by the MESSENGER spacecraft main processor (MP). There may be up to five subframes per image as defined by MESS:SUBFRAME. Subframes are defined in the original 1024x1024 pixel MDIS coordinate system before pixel binning as described by MESS:FPU_BIN and MESS:PIXELBIN.

MESS:SUBF_X3
The zero-based starting column of the THIRD rectangular subframe within an MDIS image to be retained after image compression by the MESSENGER spacecraft main processor (MP). There may be up to five subframes per image as defined by MESS:SUBFRAME. Subframes are defined in the original 1024x1024 pixel MDIS coordinate system before pixel binning as described by MESS:FPU_BIN and MESS:PIXELBIN.

MESS:SUBF_Y3
The zero-based starting row of the THIRD rectangular subframe within an MDIS image to be retained after image compression by the MESSENGER spacecraft main processor (MP). There may be up to five subframes per image as defined by MESS:SUBFRAME. Subframes are defined in the original 1024x1024 pixel MDIS coordinate system before pixel binning as described by MESS:FPU_BIN and MESS:PIXELBIN.

MESS:SUBF_DX3
The number of columns in the THIRD rectangular subframe within an MDIS image to be retained after image compression by the MESSENGER spacecraft main processor (MP). There may be up to five subframes per image as defined by MESS:SUBFRAME. Subframes are defined in the original 1024x1024 pixel MDIS coordinate system before pixel binning as described by MESS:FPU_BIN and MESS:PIXELBIN.

MESS:SUBF_DY3
The number of rows in the THIRD rectangular subframe within an MDIS image to be retained after image compression by the MESSENGER

spacecraft main processor (MP). There may be up to five subframes per image as defined by MESS:SUBFRAME. Subframes are defined in the original 1024x1024 pixel MDIS coordinate system before pixel binning as described by MESS:FPU_BIN and MESS:PIXELBIN.

MESS:SUBF_X4
The zero-based starting column of the FOURTH rectangular subframe within an MDIS image to be retained after image compression by the MESSENGER spacecraft main processor (MP). There may be up to five subframes per image as defined by MESS:SUBFRAME. Subframes are defined in the original 1024x1024 pixel MDIS coordinate system before pixel binning as described by MESS:FPU_BIN and MESS:PIXELBIN.

MESS:SUBF_Y4
The zero-based starting row of the FOURTH rectangular subframe within an MDIS image to be retained after image compression by the MESSENGER spacecraft main processor (MP). There may be up to five subframes per image as defined by MESS:SUBFRAME. Subframes are defined in the original 1024x1024 pixel MDIS coordinate system before pixel binning as described by MESS:FPU_BIN and MESS:PIXELBIN.

MESS:SUBF_DX4
The number of columns in the FOURTH rectangular subframe within an MDIS image to be retained after image compression by the MESSENGER spacecraft main processor (MP). There may be up to five subframes per image as defined by MESS:SUBFRAME. Subframes are defined in the original 1024x1024 pixel MDIS coordinate system before pixel binning as described by MESS:FPU_BIN and MESS:PIXELBIN.

MESS:SUBF_DY4
The number of rows in the FOURTH rectangular subframe within an MDIS image to be retained after image compression by the MESSENGER spacecraft main processor (MP). There may be up to five subframes per image as defined by MESS:SUBFRAME. Subframes are defined in the original 1024x1024 pixel MDIS coordinate system before pixel binning as described by MESS:FPU_BIN and MESS:PIXELBIN.

MESS:SUBF_X5
The zero-based starting column of the FIFTH rectangular subframe within an MDIS image to be retained after image compression by the MESSENGER spacecraft main processor (MP). There may be up to five subframes per image as defined by MESS:SUBFRAME. Subframes are defined in the original 1024x1024 pixel MDIS coordinate system before pixel binning as described by MESS:FPU_BIN and MESS:PIXELBIN.

MESS:SUBF_Y5
The zero-based starting row of the FIFTH rectangular subframe within an MDIS image to be retained after image compression by the MESSENGER spacecraft main processor (MP). There may be up to five subframes per image as defined by MESS:SUBFRAME. Subframes are defined in the original 1024x1024 pixel MDIS coordinate system before pixel binning as described by MESS:FPU_BIN and MESS:PIXELBIN.

MESS:SUBF_DX5
The number of columns in the FIFTH rectangular subframe within an MDIS image to be retained after image compression by the MESSENGER spacecraft main processor (MP). There may be up to five subframes per image as defined by MESS:SUBFRAME. Subframes are defined in the original 1024x1024 pixel MDIS coordinate system before pixel binning as described by MESS:FPU_BIN and MESS:PIXELBIN.

MESS:SUBF_DY5
The number of rows in the FIFTH rectangular subframe within an MDIS image to be retained after image compression by the MESSENGER spacecraft main processor (MP). There may be up to five subframes per image as defined by MESS:SUBFRAME. Subframes are defined in the original 1024x1024 pixel MDIS coordinate system before pixel binning as described by MESS:FPU_BIN and MESS:PIXELBIN.

MESS:CRITOPNV
When true, this indicates that the MDIS 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
When true, this indicates that an MDIS image is subsampled by jailbars, a subset of all the image columns that are downlinked to save data volume in optical navigation images. The start column, stop column, and column spacing are indicated by MESS:JB_X0, MESS:JB_X1, and MESS:JB_SPACE respectively. Jailbars are defined in the original 1024x1024 pixel MDIS coordinate system before pixel binning as described by MESS:FPU_BIN and MESS:PIXELBIN.

MESS:JB_X0
The start column for jailbars in an MDIS image, a subset of all the image columns that are downlinked to save data volume in optical navigation images. Jailbars are defined in the original 1024x1024 pixel MDIS coordinate system before pixel binning as described by MESS:FPU_BIN and MESS:PIXELBIN.

MESS:JB_X1
The stop column for jailbars in an MDIS image, a subset of all the image columns that are downlinked to save data volume in optical navigation images. Jailbars are defined in the original 1024x1024 pixel MDIS coordinate system before pixel binning as described by MESS:FPU_BIN and MESS:PIXELBIN.

MESS:JB_SPACE
The column spacing for jailbars in an MDIS image, a subset of all the image columns that are downlinked to save data volume in optical navigation images. Jailbars are defined in the original 1024x1024 pixel MDIS coordinate system before pixel binning as described by MESS:FPU_BIN and MESS:PIXELBIN.

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-CELESTIAL_NORTH_CLOCK_ANGLE) mod 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 clock-wise 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
Analogs 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.

UNIT
The physical units in which the image data are encoded; inapplicable to EDRs in which data are in units of data number, or DN.

DARK_STRIP_MEAN
The mean DN in the CCD dark strip. This is a measure of the dark current even if the rest of the CCD is illuminated

Image statistics of the exposed area of the CCD

MINIMUM
The lowest DN value within the exposed area of the CCD.

MAXIMUM
The highest DN value within the exposed area of the CCD.

MEAN
The arithmetic mean DN value within the exposed area of the CCD.

STANDARD_DEVIATION
The standard deviation of the DN values within the exposed area of the CCD.

Number of pixels having values that cannot be calibrated

SATURATED_PIXEL_COUNT
The number of pixels whose DN values indicate that the corresponding detector elements exceeded their linear response range. In the WAC (MESS:IMAGER=0) the 12-bit DN value where saturation occurs is approximately 3600; in the NAC (MESS:IMAGER=1) it is approximately 3400.

MISSING_PIXELS
The number of pixels not downlinked, or absent from the total subframe area within the image, that have a null value of 0.

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 may be defined in the MDIS RDR SIS.

The principal 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.

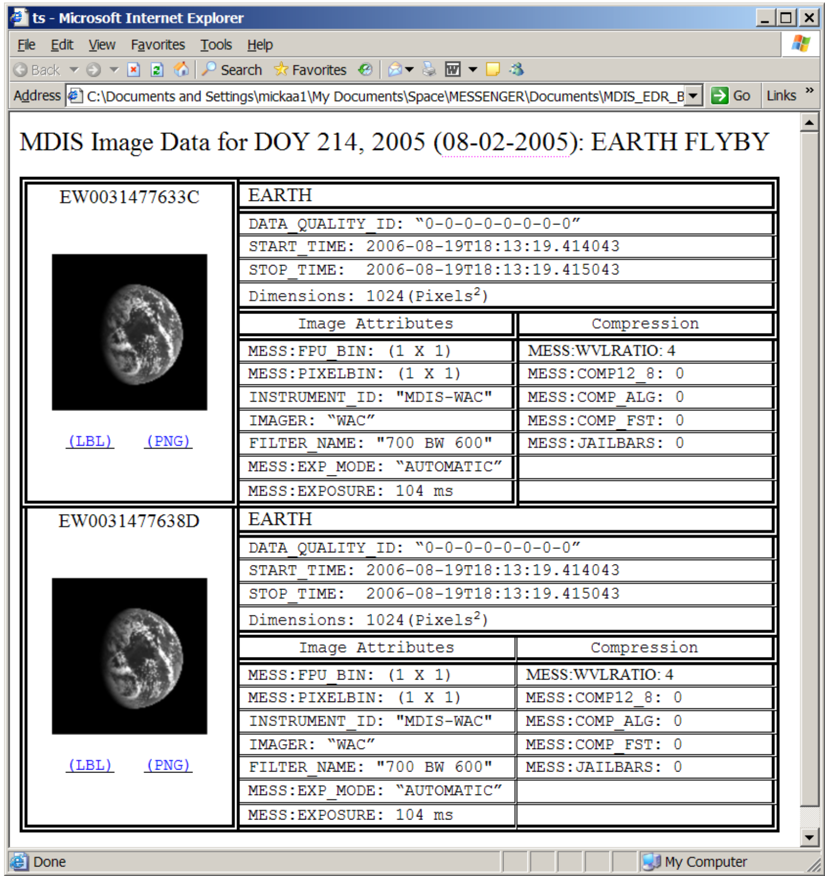


Figure 3: Example prototype EDR browse page.

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 3.

Table 3. Schedule of EDR releases by mission phase.

Milestone	Date	Release	Rel. Date*	Products
Launch (L)	08/03/04	Release 1 L + 6 months	Done	On-ground calibration data
Earth Flyby (EF)	08/02/05	-	-	-
Venus Flyby 2 (VF2)	06/05/07	Release 2 VF2 + 6 months	12/15/07	EDRs from EF and VF2 SPICE files used in processing data
Mercury Flyby 1 (MF1)	01/14/08	Release 3 MF1 + 6 months	7/15/08	EDRs from MF1 Calibration files Re-processed EDRs (if needed) SPICE files used in processing data
Mercury Flyby 2 (MF2)	10/06/08	Release 4 MF2 + 6 months	4/15/09	EDRs from MF2 Re-processed EDRs (if needed) Calibration files SPICE files used in processing data
Mercury Flyby 3 (MF3)	09/29/09	Release 5 MF3 + 6 months	3/15/10	EDRs from MF3 Re-processed EDRs (if needed) Calibration files SPICE files used in processing data
Mercury Orbit Insertion (MOI)	03/18/11	Release 6 MOI + 6 months	9/15/11	EDRs for first 2 months of orbital operations Calibration files Re-processed EDRs (if needed) SPICE files used in processing data
Orbital 1	09/18/11	Release 7 MOI + 12 months	3/15/12	EDRs for months 3-6 of orbital operations Calibration files Re-processed EDRs (if needed) SPICE files used in processing data
Orbital 2 (EOO)	03/18/12	Release 8 EOO + 6 months	9/15/12	EDRs for months 7-12 of orbital operations Re-processed EDRs (if needed) Calibration files from all instruments SPICE files used in processing data
End Of Mission (EOM)	03/18/13	Release 9 EOM	3/15/13	Re-processed EDRs (if needed) Final calibration files SPICE files used in processing data Engineering data

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.

msgr_20040803_YYYYMMDD_odNNNsc.xsp:
MESSENGER spacecraft merged reference & reconstructed trajectory file.

msgrYYYYMMDD.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.

msgr_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_mdis_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_mdis_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_mdis_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.

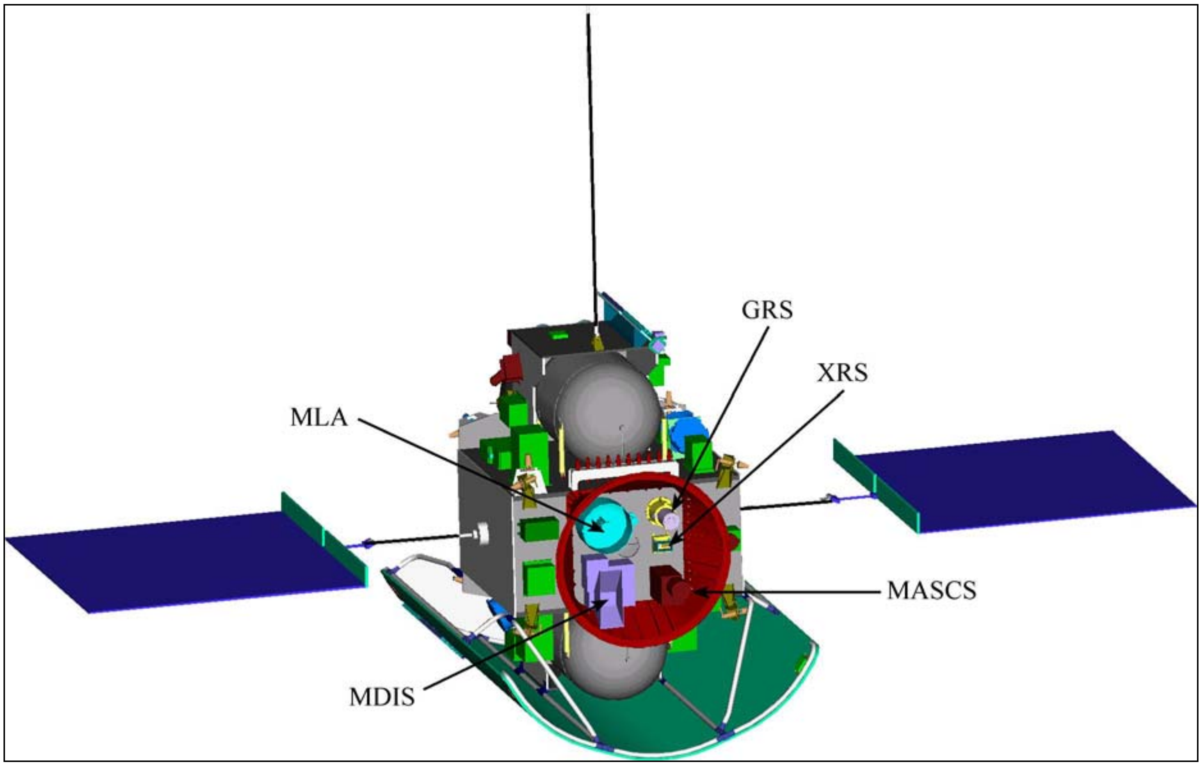


Figure 4: MESSENGER instrument deck showing instrument accommodation.

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°C to -10°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 (~240°) 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 -185º and 55º. 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 up to 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.

There are two alternative measures of pivot position: by counting motor steps following homing, as described above, or by using the position returned from a pivot position resolver.

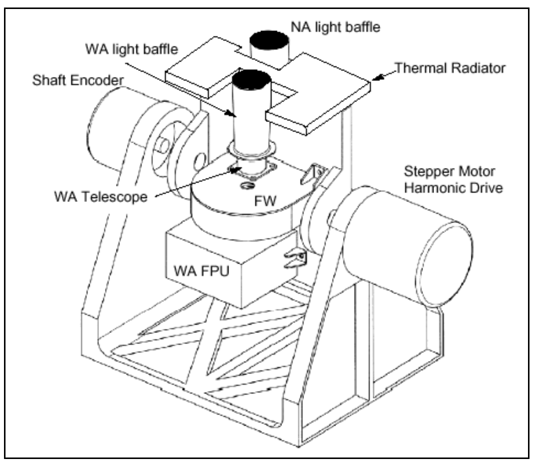


Figure 5. MDIS design.

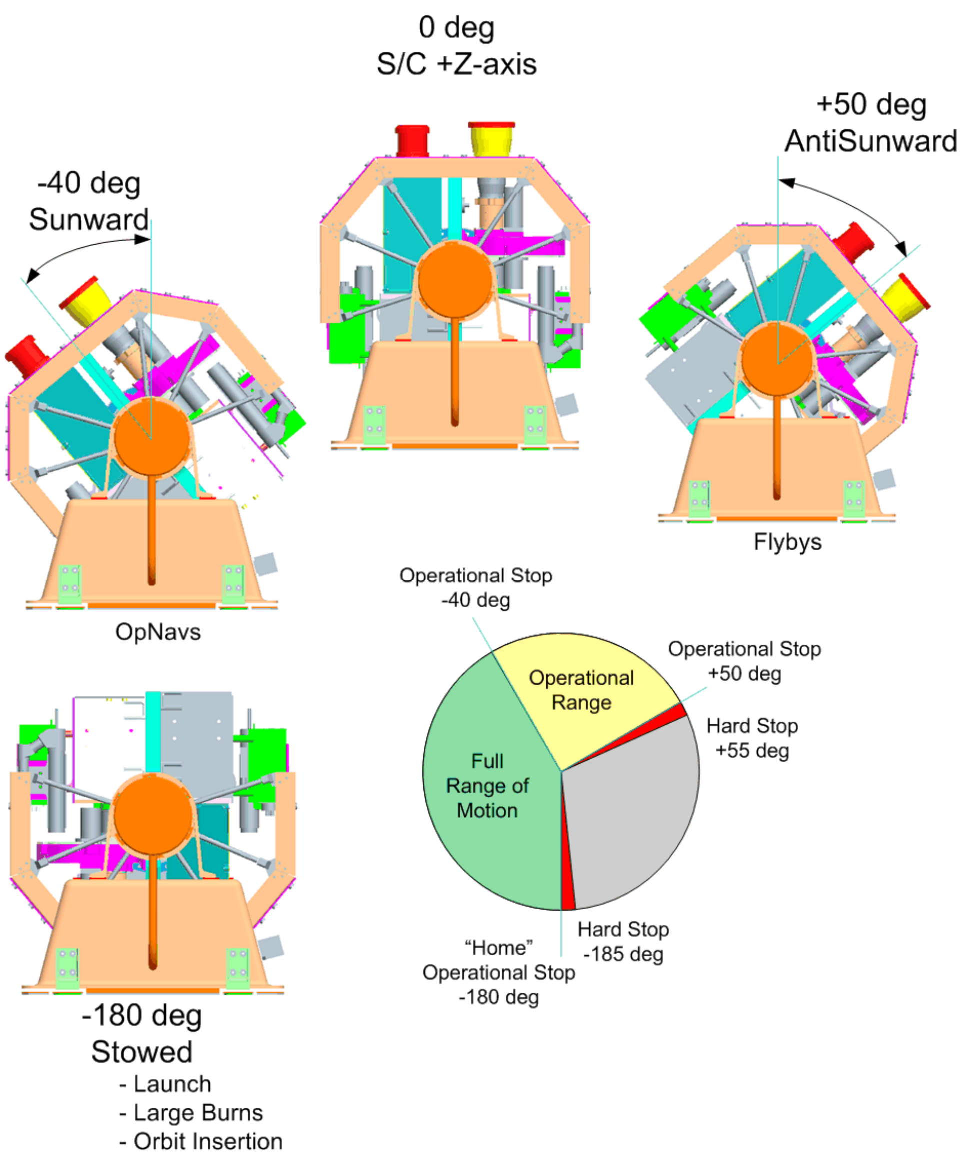


Figure 6: Range of motion of the MDIS pivot platform. Operational range is -40° sunward to +50° antisunward (planetward). When stowed, the sensitive first optic of each telescope is protected.

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 and using the spacecraft main processor (MP). At the focal plane, 2×2 binning is available on-chip to reduce the 1024×1024 images to 512×512 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 (≤ 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 1024×1024 images per day (or 330 512×512 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 ~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.

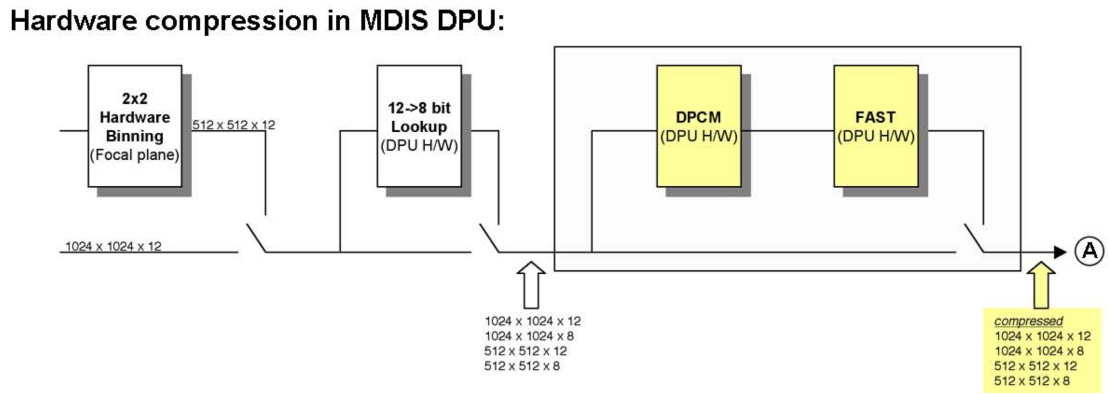


Figure 7a MDIS/DPU real-time compression flowchart

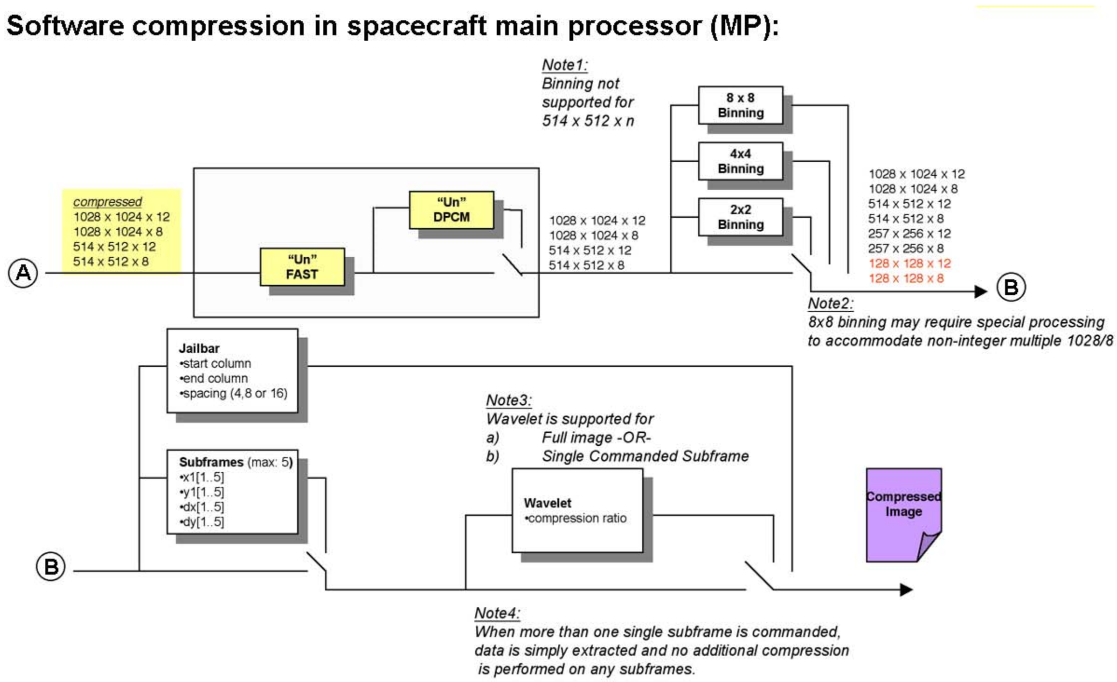


Figure 7b MESSENGER Main Processor (MP) image post-processing compression flowchart.

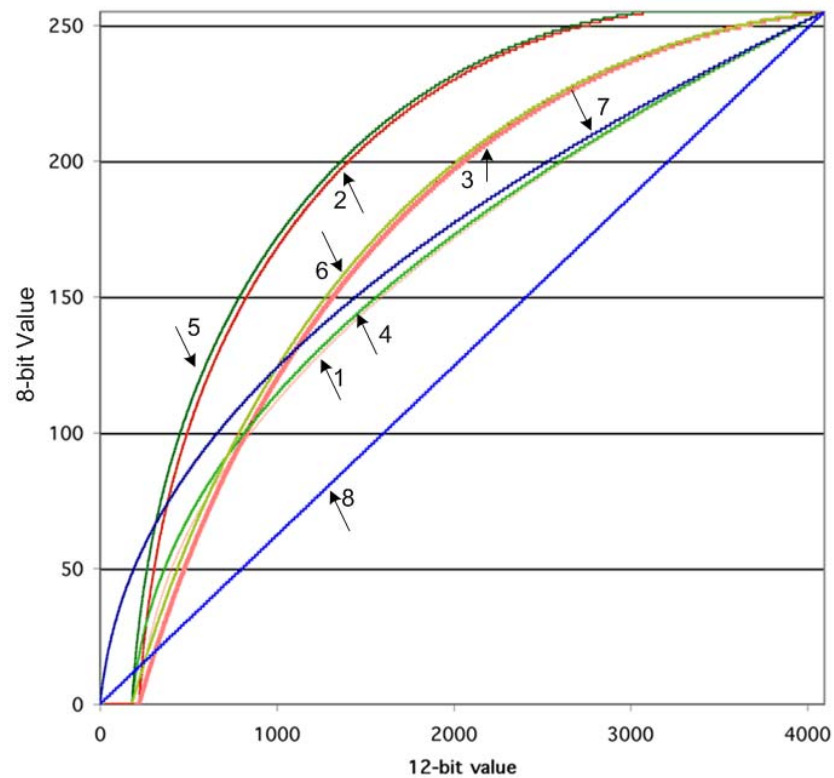


Figure 8. Mapping of 12 bits to 8 bits will be accomplished using onboard look-up tables. The tables are designed to preferentially preserve information at different DN ranges, and they can accommodate a nominal detector dark level as well as one that has changed with time. (1) Low noise, hight bias 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. (5) Low noise, medium bias DN-weighted SNR proportional. Usage: Faint objects. (6) High noise, medium bias DN-weighted SNR proportional. Usage: B/W mostly low 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 (Figure 9). This computation has two distinct steps. The first step computes a new exposure time based on the brightness of a test 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 2×2 binned image. If the brightest histogram value (except for a commandable number of allowable saturated pixels) 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, allowable number of saturated pixels, 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 (actually, the expected brightness in DN/s) 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.

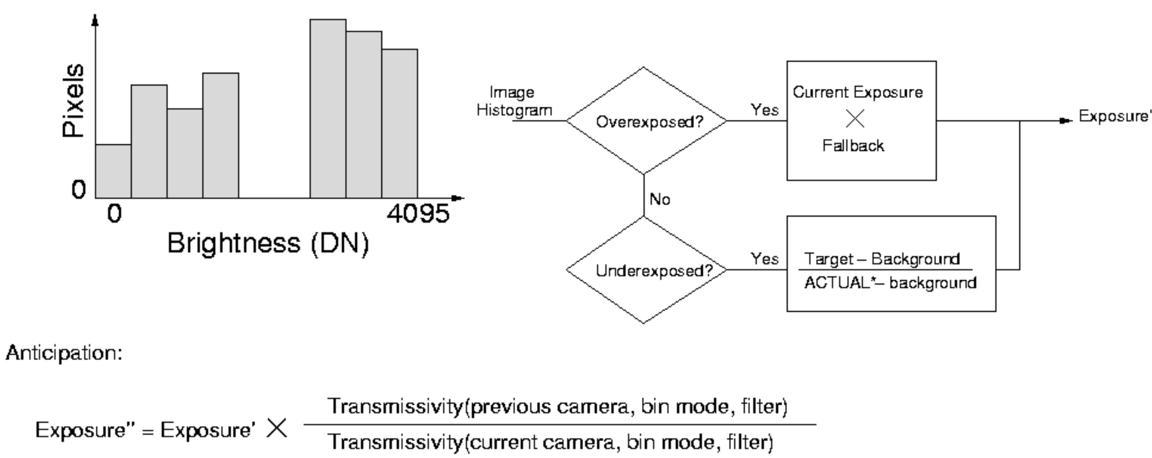


Figure 9. Autoexposure algorithm decision tree. A 64-bin histogram is computed in hardware for each image. If an image is determined to be underexposed, the actual exposure is computed as Actual = minimum brightness such that the sum of the pixels above this brightness < saturation threshold.

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^2. 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^2 (Table 4). 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.

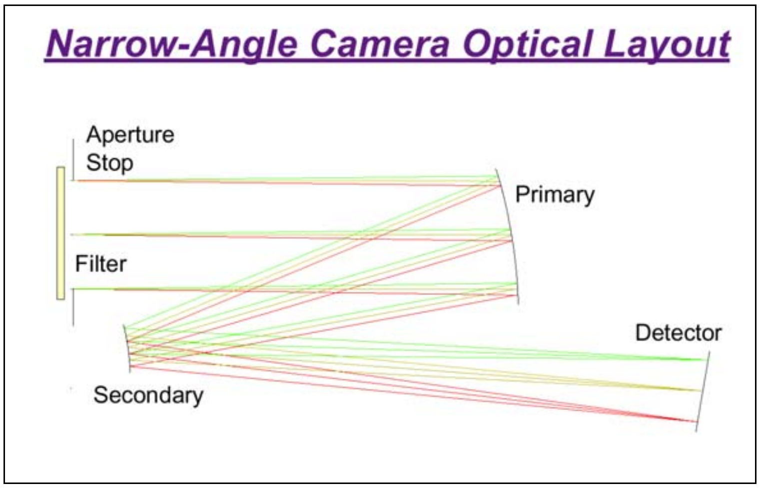


Figure 10. NAC optical layout.

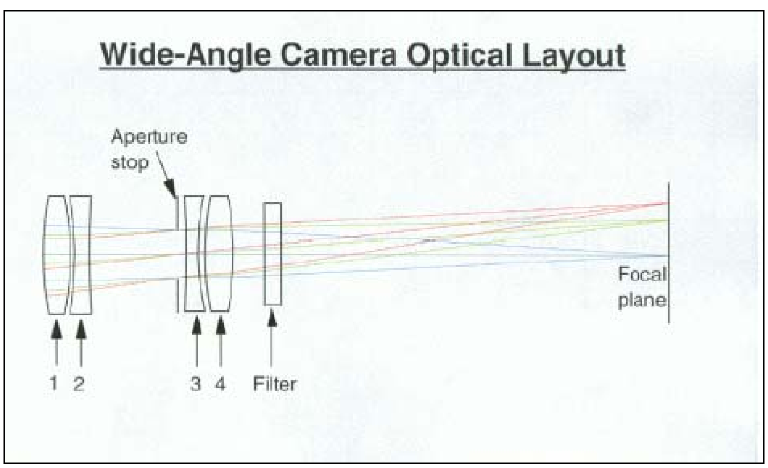


Figure 11. WAC optical layout.

Table 4: MDIS specifications

	Narrow Angle	**Wide Angle**
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†	1 s	
Spectral filters	1	12 positions
Spectral range	725–775 nm	395–1040 nm
Focal length	550 mm	78 mm
Collecting area	462 mm²	48 mm²
NAC-WAC coalignment knowledge	0.01 deg (179 urad)	
Spacecraft pointing knowledge	0.1 deg (1.75 mrad)	
Spacecraft knowledge	0.02 deg (350 μrad)	
Detector-TH7888A	CCD 1024×1024, 14-μm pixels	
IFOV	26 μrad	179 μrad
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	

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

Filters

The WAC camera utilizes a twelve position filter wheel with band passes between 430 and 1020 nm, including a broadband navigation filter centered at 750 nm. The NAC is a broadband BW imager with sensitivity across the range 725 – 775 nm. Other than the image dimensions, the data products of each camera are identically formatted. Table 4 shows the design-level focal length, collecting area, and field of view for each camera. Table 5 shows the calibrated filter wavelength and bandwidth parameters.

Table 5. WAC filters specifications; wavelength and width measured at -26° C, focal lengths and scale changes based on instrument design.

Filter Number	Filter Filename letter	Wavelength (Flight) (nm)	Width (Flight) (nm)	Total Thickness (mm)	Focal length (mm)	Scale change (%)
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	4.93	78.535	0.372
12	L	828.4	5.2	5.60	78.308	0.082

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 ≥ 7× 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 <<35-µm 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 were used to redetermine the flat field post-launch.

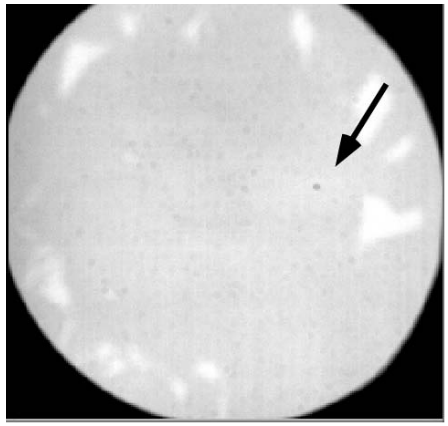


Figure 12: Non-uniformity due to dust particles is visible in integrating sphere images acquired through the quartz window in the OCF chamber door of the calibration facility.

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 (Figure 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. Binned images are sampled from a part of the CCD that is offset 8 unbinned pixels (4 binned pixels) in the direction of increasing sample number in the image. This difference in pointing is accounted for in the SPICE frames kernel.

As a result of this shift, in binned mode, 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.

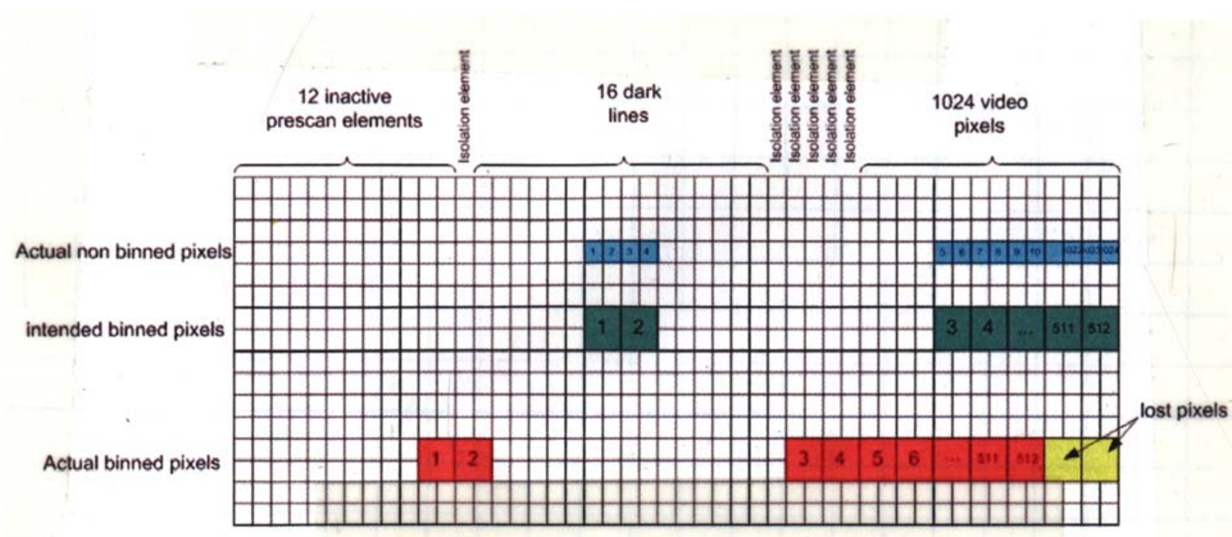


Figure 13. Pixels intended for dark columns, and actual pixels used in binned images for WAC and NAC.

Appendix C - Data Archive Terms

Definition of Terms:

Archive	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.
Archive volume, archive volume set	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.
Data Product	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.
Data Set	An accumulation of data products. A data set together with supporting documentation and ancillary files is an archive.
Experiment Data Records	NASA Level 0 data for a given instrument; raw data. Same as CODMAC level2.
Reduced data records	Science data that have been processed from raw data to CODMAC level 3 and above. See Table for definitions of processing levels.
Standard data product	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

CODMAC Level	Proc. Type	Data Processing Level Description
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). 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). 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

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

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