

Magdalena Ridge Observatory 2.4-meter Telescope

Uncalibrated/Calibrated Data Product Software Interface Specification for Data Collected in Support of DART Mission

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Revision Log

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	William Ryan	Initial Release	05/22/21
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1 Purpose and Scope

The data products described by the Software Interface Specification (SIS) are the Magdalena Ridge Observatory (MRO) 2.4-meter Telescope Observatory uncalibrated and calibrated data products. MRO operates under the New Mexico Institute of Mining and Technology (NM Tech) and Eileen Ryan (Director, MRO 2.4-meter Telescope) and William Ryan (Faculty Researcher and Senior Telescope Scientist) produces these data products and will distribute them to the DART SOC for redistribution to the DART Investigation Team and the Planetary Data System (PDS).

The purpose of this document is to provide users of the data products with a detailed description of the product and a description of how it was generated, including data sources and destinations. The document is intended to provide enough information to enable users to read and understand the data products. The users for whom this document is intended are the scientists who will analyze the data, including those associated with the DART mission and those in the general planetary science community.

1.1 DART Mission Purpose and Goals

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

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

To achieve these objectives the DART spacecraft will intercept the secondary of the binary near-Earth asteroid 65803 Didymos. The primary member of the binary system will be referred to as Didymos and the secondary as Dimorphos. The system as a whole is also referred to as Didymos.

As part of the baseline level 1 Mission Investigation requirements the DART project shall obtain data, in collaboration with ground-based observations and data from another spacecraft to constrain the location and surface characteristics of the impact site and to allow the estimation of the dynamical changes in the Didymos system resulting from the DART impact and the coupling between the body rotation and the orbit.

1.2 MRO 2.4-meter Telescopic Observations

To interpret the deflection due to the DART impact, equally high-quality lightcurves of the Didymos system must be available from periods both prior to and following the DART impact. A contract has been established with NM Tech/MRO Observatory to acquire telescopic data in support of the DART mission. The telescopic data made available as part of this contract will be

archived by the DART project. Didymos and Dimorphos will be sufficiently far from the Earth and are sufficiently close together that they will not be resolved from one another, but instead will appear as a single point of light in these measurements. When Didymos is referred to below, it can be taken to be referring to the system as a whole rather than the primary body, unless otherwise specified.

The MRO 2.4-meter Telescope is a Ritchey-Chrétien telescope with a 2.4-meter mirror located in the Cibola National Forest in New Mexico, and owned and operated by New Mexico Institute of Mining and Technology. It will be used with an Andor iKon-L CCD camera (denoted as MRO2K) to obtain these data products. The data will include for each night of observation raw fits images, calibrated (flat field corrected, bias subtracted) versions of those images with associated calibration frames, data tables of measured Didymos photometry, and png files identifying the calibration stars used for photometric processing.

2 Applicable Documents and Constraints

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

1. Planetary Data System Standards Reference, Version 1.14.0.0, May 20, 2020
2. PDS4 Data Dictionary, Abridged, Version 1.14.0.0, Mar 23, 2020
3. PDS4 Information Model Specification, Version 1.14.0.0, Mar 23, 2020
4. FITS Standard document, version 4.0, July 22, 2016

This SIS is responsive to the following DART documents:

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

3 Relationships with Other Interfaces

The transfer of data from the MRO 2.4-meter Observatory to the DART SOC is described in the DART SOC/MRO ICD.

4 Data Product Characteristics and Environment

4.1 Instrument Overview

The visible-wavelength, direct-imaging CCD for the MRO 2.4-meter Telescope is an Andor iKon-L 936, and is identified as “MRO2K”. The MRO2K instrument is a 2048 x 2048 array with 13.5 μm^2 pixels combined to deliver a 27.6 x 27.6 mm active image area. The CCD is TE cooled down to -85°C. The camera is mounted on the Right Nasmyth port of the telescope. The camera’s shutter delay has measured via GPS to permit accurate exposure timing to better than 0.1 seconds. Further, the camera control computer is synched once per minute to a GPS coordinated Network Time Protocol (NTP) server to account for any hardware-induced errors.

The CCD images are a 4.5 arc minute square field of view with 13.5-micron pixels. The unbinned detector provides a pixel scale of 0.13 arcsec/pixel. The chip is commonly binned at 2x2 (0.26 arcsec/pixel) or 4x4 (0.52 arcsec/pixel). The chip is linear up to 65k ADU at the default gain of 1.9 e-/ADU with a read noise is 3.5 ADU per pixel. The CCD quantum efficiency is 90% from 475-700 nm and dropping to ~50% at 400 and 900 nm.

Dual filter wheels in the CCD camera light path provide 12 filter slots. The facility filters currently available are Johnson-Cousins UBVRI, and a broad VR filter that provides >80% transmission from 500-700 nm.

4.2 Data Product Overview

The specific data products described by this SIS are:

1. Raw Image Data
2. Calibrated Image Data
3. Master Bias Data
4. Flat Frame Data
5. Reference Star Data
6. Photometry Tables

4.3 Data Processing

All data processing is performed at MRO. This section provides general information about data product content, format, and size.

4.3.1 Data Processing Level

The following table describes the delivered data products.

MRO 2.4m Product	PDS4 Data Processing Level	NASA Product Level	Description
Raw Image	Raw	Level-0	Raw images
Processed Image	Calibrated	Level-2	Processed Images
Master Bias	Calibrated	Level-2	Master Bias Frame
Master Dark Frame	Calibrated	Level-2	Master Dark Frame
Master Flat Frame	Calibrated	Level-2	Master Flat Frame
Reference Star	Calibrated	Level-2	PNGs of reference stars used photometric calibrations.
Photometry Tables	Calibrated	Level-2	Photometry/lightcurve tables

4.3.2 Data Product Generation

All MRO 2.4-meter Telescope data products are generated by MRO/NM Tech, and transferred to the DART SOC. The DART SOC then generates the PDS4 labels for each data collection.

4.4 Data Products

This section gives a more detailed description of each data product, including the process by which the product is generated. The data products are categorized according to their PDS4 data processing level.

4.4.1 Raw Image Data

Fits images are obtained with the MRO2K CCD camera at the MRO 2.4-meter Telescope. Raw image data includes sky frames of Didymos, comparison star fields, and standard star calibration fields. Images of comparison star fields will be identified in the XML label with an internal reference to the reference star PNG (Section 4.4.4.).

4.4.2 Calibrated Image Data

Calibrated sky frames that have been bias subtracted, dark subtracted, and flat field corrected. See section 4.4.6 for details of the Data Flow.

4.4.3 Master Bias and Flat Frame Data

Median combined stacks of bias, dark, and flat field images (which may or may not be acquired as part of the DART data collection initiative) are used to create master calibration frames and are archived by the MRO 2.4-meter Observatory. The application of these master frames to the raw data, e.g. bias subtraction, exposure-scaled dark subtraction, and division by the normalized flat field, result in the calibrated image data. Any master dark, bias, or flat field frames utilized in Didymos image calibration will be added to the DART archive.

4.4.4 Reference Star PNG

PNG images for each sky frame of comparison star fields where the comparison stars used in the photometric reductions are marked.

4.4.5 Photometry Table Data

ASCII summary table of the measured photometry of Didymos on each sky frame. The format of the table is specified in Section 5.1.2. The comparison star field used in the generation of the Photometry table data is identified in the XML label with an internal reference to the reference star PNG (Section 4.4.4).

4.4.6 Data Flow

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

Raw image data are processed in three steps: (1) a median combined master bias frame is subtracted from each sky image, (2) the exposure-scaled dark frame is then subtracted, and (3) a median combined, normalized flat field is divided into each sky frame. The *IRAF ccdproc* package is used to perform these tasks.

All lightcurve observations of Didymos will be obtained with a Bessell R-band filter, with additional images using the Bessell V-band filter when needed for magnitude calibration purposes. Additional R and V images will be acquired for a comparison star and standard calibration fields. The photometry of Didymos and comparison stars will be performed using the *IRAF phot* package (Tody, D., *IRAF in the Nineties, in Astronomical Data Analysis Software and Systems II*, A.S.P. Conference Ser., Vol 52, eds. R.J. Hanisch, R.J.V. Brissenden, & J. Barnes, 173, 1993).

The instrumental magnitude of Didymos will be measured in each field. In addition, an ensemble of stars in each comparison field, as identified by the PNG image file described in Section 4.4.4, will also be measured. The comparison star field is observed multiple times in a night observing session and archived as raw image data. Note that after initial analysis, some stars will be assessed as inappropriate to be used as comparison stars based on inherent variability, etc., and will not be used in the final analysis. A temporally interpolated average magnitude of the comparison star fields is then subtracted from each Didymos instrumental magnitude resulting in a differential magnitude. If it is not feasible to perform further magnitude calibrations, the resulting magnitude is reported as “relative” as denoted in section 5.1.2. Ideally, additional observations of Landolt standard stars (Landolt, A.U. (1992), *Astronomical Journal* vol. 104, p. 340 and Landolt, A.U. (2009), *Astronomical Journal* vol. 137, p. 4186) will be obtained to derive Johnson-Cousins R- and V-band magnitudes of the comparison stars allowing the reporting of standard R-band magnitudes of Didymos. In this case, the magnitude will be reported according to Section 5.1.2 as “absolute”. Observations of sky fields containing Landolt standard stars are identified in the PDS4 label with target = "Sky". The OBJECT keyword of the fits header identifies the Landolt field observed.

4.4.7 Labeling and identification

Raw and Calibrated Images

Raw and processed images consist of a single fits file containing the raw image and an associated XML file. They are named according to the following convention.

<product type><yymmdd>.<image counter>.<ext>

where:

Filename Section	Description
<product type>	Image prefix: Defines product as one of the following types: <ul style="list-style-type: none">•m = raw•fm= processed
<yymmdd>	year, month, day of observing session in UT
<image counter>	Four-digit image counter for observing session, reset for each night of observation. Counter starts at 0001
<extension>	the file extension. “.fits” for fits file format, “.xml” for the PDS label.

Example: m210413.0036.fits is a raw image product for a 2021-04-13 observing session. It is the 36th image generated on that UT date. fm210413.0036.fits is the processed image product for a 2021-04-13 observing session. It is the 36th image generated on that UT date.

Comparison Star PNGs

For each comparison field image there is an associated PNG image of comparison stars used for the photometric solution: comp_<yymmdd>.png. A reference to the comparison star PNG is included in the XML label for each raw image file containing the comparison field image. A reference to the comparison star PNG is also included in the XML label for the photometry table.

Dark and Flat Field Frames

For each observing session the calibrated images are generated from the raw images using bias_<yymmdd>.fits, dark_<yymmdd>.fits, and flat_<filter>_<yymmdd>.fits calibration frames. <filter> in the master flat field name refers to the broadband filter in which the observations were obtained and can be either "r" or "v".

The master calibration files used to generate the calibrated image are recorded in the fits header. Note that master calibration files may not necessarily have been taken on the same night as a calibrated image file, and the same calibration files may potentially be used for more than one night. Master calibration files are stored in the nightly directory corresponding to the yymmdd in the master calibration filename.

Photometry Table

The photometry summary table is named according to the following convention:
mro_<yymmdd>_didymos_photometry.tab

where:

mro – refers to the MRO 2.4-meter Telescope
<yymmdd> is the year, month, day of the observing session in UTC.

Example: mro_220813_didymos_photometry.tab

4.5 Standards used in Generating Data Products

4.5.1 PDS Standards

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

4.5.2 Time Standards

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

4.5.3 Coordinate Systems

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

4.5.4 Data Storage Conventions

All raw fits files store the image data as MSB 16-bit integers. All processed fits files and the master calibration files store the image data as 32-bit floats. The photometry table is stored as UTF-8 ASCII.

4.6 Data Validation

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

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

resolved by the SOC. Once the liens are cleared, PDS will do a final validation prior to packaging and delivery. When data are prepared for submission to PDS, the SOC will use PDS-provided validation tools to ensure conformance to PDS standards.

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

5 Detailed Data Product Specifications

The following sections provide detailed data product specifications for the MRO data products.

5.1 Data Product Structure and Organization

The highest level of organization for a PDS archive is the bundle. A bundle is a set of one or more related collections which may be of different types. A collection is a set of one or more related basic products which are all of the same type. Bundles and collections are logical structures, not necessarily tied to any physical directory structure or organization.

A unique identifier is assigned to each PDS4 product. This is known as the logical identifier, or LID. All LIDs consist of a series of colon-separated segments. The complete rules for formulating LIDs are in the PDS4 Standards Reference. An example of the LID structure is shown below:

```
urn:nasa:pds:{BundleID}:{CollectionID}:{ProductID}
```

The bundle XML label stops at the {BundleID}. Each collection label stops at {CollectionID}. Products within a collection contain all segments. The LID allows each data product to be uniquely identified, even if the filenames are the same, as in the case of the Master Bias and Master Flat Field products (see Section 4.4.7).

The MRO PDS archive is part of the DART Telescopic Observation Bundle, as outlined in the DART DMAP. There will be specific MRO collections: MRO Raw Data Collection, MRO Calibrated Data Collection, and MRO Derived Data Collection. Documentation such as the SIS is organized in the Bundle Document collection.

The MRO data collections will be stored in a directory tree organized by collection, then by date of observation.. This structure allows a user to navigate first by processing level desired, then to the specific observing date, and finally browse the data product types.

The planned directory structure for the MRO data collections is shown below. The “data_mroraw” folder contains the raw FITS files and their associated XML labels. The “data_mrocal” folder contains the calibrated fits file, reference star PNGs, and master calibration fits files used to calibrate the data. MRO light curve data associated with the observation is

contained in the derived data product folder, “data_mroddp”. "data_mroraw", "data_mrocal", and "data_mroddp" are also the values for the {CollectionID} in the LID naming convention.

Example:

```
root/
  document_mro/
  data_mroraw/
    mro_yymmdd
  data_mrocal/
    mro_yymmdd
  data_mroddp/
    mro_yymmdd
```

where “mro” refers to the MRO 2.4-meter Telescope and “yymmdd” is the UT YearMonthDay of the observation.

A separate “document_mro” folder will be created under the bundle root folder. This will distinguish documentation specific to the MRO data collection from other telescopic data collections.

5.1.1 Image Fits Files

Image data products are stored in the FITS file format with a detached PDS label. The detached PDS labels are PDS4 compliant XML labels that describe the contents of the image file and record the significant portions of the FITS header for data processing and interpretation. The following table describes the format and content of the FITS header. The Class.Attribute Name column shows the mapping of the fits keyword to the class and attribute in the PDS4 XML label. Blank Class.Attribute fields indicate where the metadata only exists in the fits keyword.

For the raw image file: (example image m210413.0036.fits)

Class.Attribute Name	Keyword and example	Description
n/a	SIMPLE = T	FITS standard
element_array.data_type	BITPIX = 16	8 unassigned int, 16 & 32 int, -32 & -64 real
axes	NAXIS = 2	number of data axes
axis_array.sequence number	NAXIS1 = 512	fastest changing axis
axis_array.sequence number	NAXIS2 = 512	next to fastest changing axis
	BSCALE = 1.0000000000000000	physical = BZERO + BSCALE*array_value
element_array.value_offset	BZERO = 32768.000000000000	physical = BZERO + BSCALE*array_value
Time_Coordinates.start_date_time	DATE-OBS='2021-04-13T09:34:19.42'	YYYY-MM-DDThh:mm:ss observation start, UTC
img:exposure_duration	EXPTIME= 3.0000000000000000	Exposure time in seconds

	SET-TEMP=-85.00000000000000	CCD temperature setpoint (degC)
	CCD-TEMP=-85.087997436523438	CCD temperature at start of exposure (degC)
	XPIXSZ=54.00000000000000	Pixel Width in microns (after binning)
	YPIXSZ=54.00000000000000	Pixel Height in microns (after binning)
	XBINNING=4	Binning factor in width
	YBINNING=4	Binning factor in height
	XORGSUBF=0	Subframe X position in binned pixels
	YORGSUBF=0	Subframe Y position in binned pixels
	IMAGETYP='object'	Image type (object, flat, dark, etc)
Target Identification.name	OBJECT='c5eg822'	Target Object
	TELESCOP='MRO 2.4-meter'	telescope name
	INSTRUME='MRO2K'	instrument name
	OBSERVER='Bill Ryan'	Observer(s)
	NOTES=' '	Usually blank. Otherwise contains notes about the observation
	FILENAME='m210413.0036.fits'	Original fits filename
	PROJID='evr_neo'	Project ID
	RA='13:12:05.86'	right ascension at Equinox [hh:mm:ss.ss]
	DEC='49:09:34.84'	declination at Equinox [deg:mm:ss.ss]
	EQUINOX=2000.0	Equinox of coordinates of coordinates
	AIRMASS='1.19146'	Airmass at beginning of exposure
	TELALT='57.03257'	Telescope altitude (deg)
	TELAZ='309.38178'	Telescope azimuth (deg)
	FOCUS='0.515158'	Telescope focus position (microns)
	PA='102.084584'	Parallactic angle. This is the angle in deg formed at the on-sky location of a given object by the intersection of arcs drawn from the object to zenith and from the object to the celestial pole. (deg)
	FILTER='2 1'	Filter wheel positions
	WINDVEL='22.0'	Wind speed (kph)
	WINDGUST='29.2'	Wind gust (kph)
	WINDDIR='243.0'	Wind direction (deg E of N)

The master calibration fits files have the same header as the raw fits images with the following exceptions:

Class.Attribute Name	Keyword and example	Description
	NCOMBINE	Number of images used to create master calibration image
	DARKTIME	Effective exposure time of master calibration frame

For the processed image file: (example image Fm210413.0036.fits)

Class.Attribute Name	Keyword and example	Description
n/a	SIMPLE = T	FITS standard
element array.data type	BITPIX = -32	Bits per pixel
axes	NAXIS = 2	Number of data axes
axis array.sequence number	NAXIS1 = 512	Axis length
axis array.sequence number	NAXIS2 = 512	Axis length
	EXTEND = F	File may contain extensions
	ORIGIN = 'NOAO-IRAF FITS Image Kernel July 2003'	FITS file originator
modification_date	DATE = '2021-04-13T09:35:28'	Date FITS file was generated
	IRAF-TLM = 2021-04-13T09:35:40'	Time of last modification
Time_Coordinates.start_date_time	DATE-OBS = '2021-04-13T09:34:19.42'	YYYY-MM-DDThh:mm:ss observation start, UTC
img:exposure_duration	EXPTIME = 3.0000000000000000	Exposure time in seconds
	SET_TEMP = -85.0000000000000000	CCD temperature setpoint (degC)
	CCD-TEMP = -85.087997436523438	CCD temperature at start of exposure (degC)
	XPIXSZ = 54.0000000000000000	Pixel Width in microns (after binning)
	YPIXSZ = 54.0000000000000000	Pixel Height in microns (after binning)
	XBINNING = 4	Binning factor in width

	YBINNING = 4	Binning factor in height
	XORGSUBF = 0	Subframe X position in binned pixels
	YORGSUBF = 0	Subframe Y position in binned pixels
	IMAGETYP = 'object'	image type (object, flat, dark, etc)
Target Identification.name	OBJECT = 'c5eg882'	Target object
	TELESCOP='MRO 2.4-meter'	telescope name
	INSTRUME='MRO2K'	instrument name
	OBSERVER = 'Bill Ryan'	Observer(s)
	NOTES=' '	Usually blank. Otherwise contains notes about the observation
	FILENAME='m210413.0036.fits'	Original fits filename
	PROJID='evr neo'	Project ID
	RA='13:12:05.86'	right ascension at equinox [hh:mm:ss.ss]
	DEC='49:09:34.84'	declination at equinox [deg:hh:mm:ss.ss]
	EQUINOX=2000.0	Epoch of Equinox of RA and DEC
	AIRMASS='1.19146'	Airmass at beginning of exposure
	TELALT='57.03257'	Telescope altitude (meters)
	TELAZ='309.38178'	Telescope azimuth (deg)
	FOCUS='0.515158'	Telescope focus (microns)
	PA='102.084584'	Parallactic angle. This is the angle in deg formed at the on-sky location of a given object by the intersection of arcs drawn from the object to zenith and from the object to the celestial pole. (deg)
	FILTER='2 1'	Filter wheel positions
	WINDVEL='22.0'	Wind speed (kph)
	WINDGUST='29.2'	Wind gust (kph)
	WINDDIR='243.0'	Wind direction (deg E of N)
	PROCHIST = 'Processed with clean2k.cl'	processing history
	PROCBIAS = 'bias_210412'	master bias file used to generate calibrated image

	PROCDARK = 'dark_210412'	master dark file used to generate calibrated image
	PROCFLAT = 'flat_r_210412'	master flat file used to generate calibrated image
	COMMENT= ' '	comment lines generated as a result of processing

5.1.2 Photometry ASCII table files

Photometry data are reported in ASCII files with two sections – an informational header and the photometry data itself. Header lines are denoted with an ASCII '#' with entries specified as follows.

Field	Description and Possible values
Observers	Observer names (string)
Facility	Facility name (string)
Instrument	Instrument name (string)
UTDate	UT Date (string)
Object	Object name (string)
CompField	Image file name identifying comparison stars measured (string)
CompStarsUsed	Comparison stars used in final computation (Numeric list)
Filter	Filter used (V,R,g,r,etc)
Magband	Magnitude band of reported data (V,R,g,r, etc)
CIBand	Color index used in calibration (B-V,V-R,g-r, etc or None)
CITarget	Color index used for target (Float; 0 if CIBand = None)
LTCorrection	Light time correction (True/False)
ReducedMag	Magnitude corrected for distance (True/False)
MagType	Magnitude type reported (Absolute or Relative)
ExpJD	Exposure time reported (Start or Mid)

The photometry data are stored as a PDS4 ASCII fixed-width table according to the following formats. Note that Field Location uses the PDS4 definition, which is the location, in bytes, of the first character in the field and that location counting begins at one, not zero. Note that the astronomical magnitude and sigma error values are unitless.

Field	Field Number	Description	Field Location (Bytes)	Length (Bytes)
julian date	1	Julian date of the exposure midtime	1	17
mag	2	Target Magnitude	18	8
sig	3	1-sigma error on the apparent magnitude	26	5

5.2 Label and Header Descriptions

All MRO 2.4-meter observatory data products contain time and date information that can be used to sort and correlate data products.

6 Applicable Software

6.1 Utility Programs

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

6.2 Applicable PDS Software Tools

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

6.3 Software Distribution and Update Procedures

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