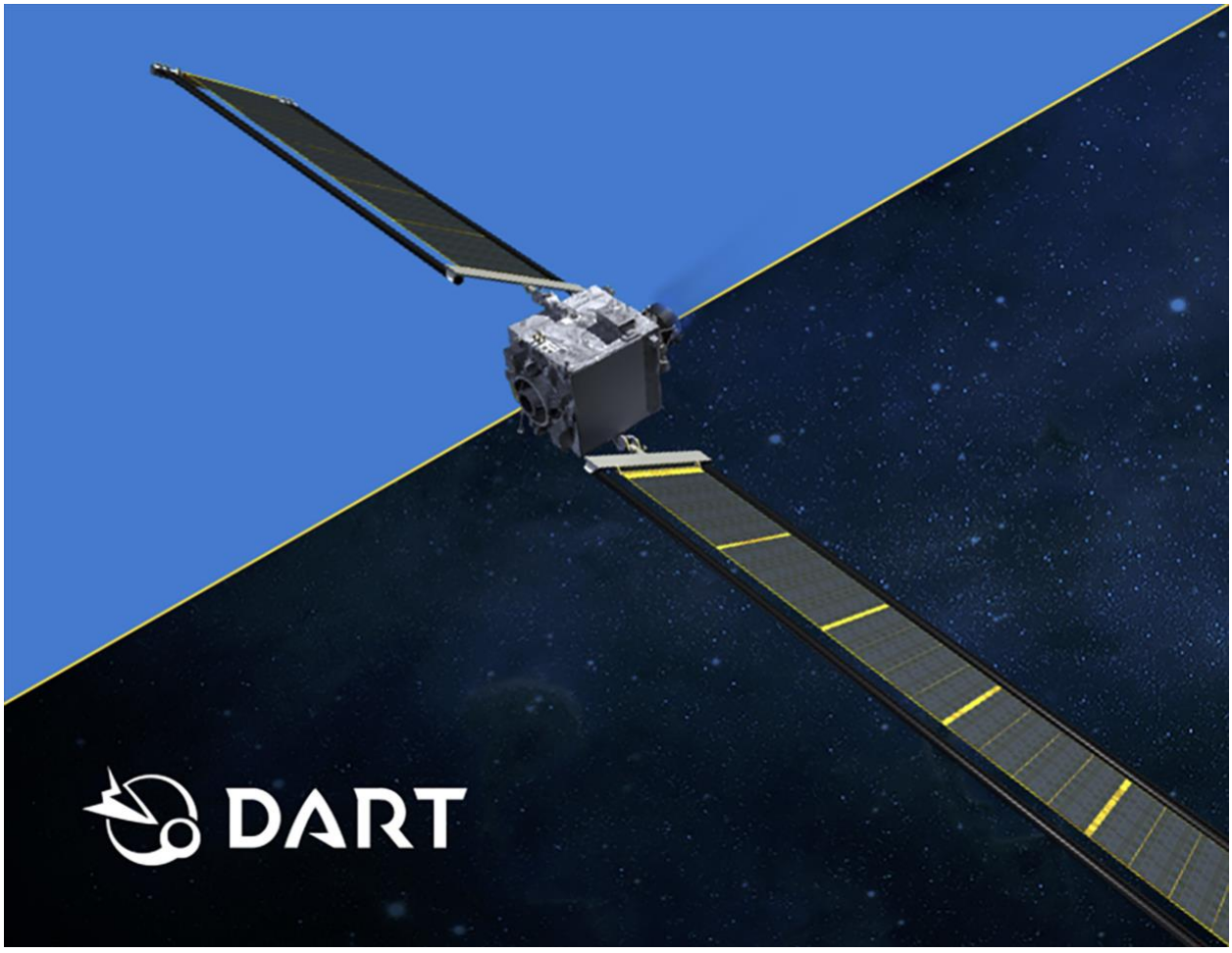
Radio Science Data Data ProductSoftware Interface Specification

Double Asteroid Redirection Test (DART)



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Revision Log

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0	O.S. Barnouin	Initial Draft	3/22/22
0.1	S. Chesley	Updates	3/31/22
0.1.1	O.S. Barnouin	Addressed Chesley's comments.	4/4/22
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0.3.4	R. Espiritu	Naming convention update	10/19/22
1.0	R. Espiritu	Initial PDS release	10/24/22

CONTENTS

1. Purpose and Scope

This Software Interface Specification (SIS) describes the Radio Science (RS) and Maneuver Acceleration Files (MAF) data collected by the Double Asteroid Redirection Test (DART) mission. The DART Science Operations Center (SOC) located at Johns Hopkins University Applied Physics Laboratory (JHU/APL) produces these products and distributes them to the DART Investigation Team (IT) and the Planetary Data System (PDS).

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

2. Applicable Documents and Constraints

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

1. Planetary Data System Standards Reference, Version 1.14.0, May 22, 2020
2. PDS4 Data Dictionary, Abridged, Version 1.14.0.0, March 23, 2020
3. PDS4 Information Model Specification, Version 1.14.0.0, March 23, 2020

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

1. DART Data Management and Archive Plan (DMAP), Rev C, 24 May 2021
2. TRK-2-34 DSN Tracking System Data Archival format, Rev. R, 03 June 2021
3. TRK-2-23 DSN Media Calibration Interface Rev. C, 05 March 2008
4. DART Coordinate System for Didymos and Dimorphos, March 2021
5. DRACO Uncalibrated/Calibrated Data Product SIS, March 2022

3. Relationships with Other Interfaces

Changes to the data products described in this SIS may affect the documents listed in Table 1. In the event of a conflict between the RS SIS and the DRACO DMAP, the DMAP takes precedence.

Table 1. Interface Relationships

Name	Type	Owner
DRACO Data Management and Archive Plan	Document	DART SOC

4. Data Product Characteristics and Environment

4.1. Radio Science Overview

The DART mission receives spacecraft tracking data from the Deep Space Network (DSN). These data are collected primarily from signals emitted by the high gain antenna (HGA) onboard the DART spacecraft. The scientifically useful RS data is collected in the last 30 days before DART's impact with the moon of Didymos, Dimorphos. It is in this phase of

the mission that DART first acquires the Didymos system visually, deploys the Italian Cubesat LICIACube (~10 days before impact) and finally impacts into Dimorphos. Both mission navigators and investigation team members working on radio science investigations use these data. The DART navigation and radio science teams receive DSN Tracking and Navigation File (trk-2-34) data, Media Calibration Files (Ionosphere Calibration Files, Troposphere Calibration File, trk-2-23), and Weather Files (trk-2-24) files via secure FTP. The files are all formatted in standard ways, documented in a series of Software Interface Specifications (SIS) noted in Table 1. The DSN SIS documents are not mission specific, they are applicable to all DSN produced data products. The DSN files are transferred to a secure area within the DART Mission Operations Center (MOC) data repository, and then made available to the investigation teams via the DART Science Operations Center (SOC). For the final PDS archive, DSN data files are retrieved from the SOC data repository and prepared for delivery by to the Planetary Data System who convert them into PDS 4 format.

Along with the DSN provided RS data, the DART mission also provides a small forces file, or Maneuver Acceleration File (MAF), that describe the thrusting undertaken by DART and aids in understanding science associated with the RS data. These files record the cumulative delta-v effect of attitude thruster firings over a specified time period(s). An estimate of mass loss due to usage is included in these MAF. These files were produced at the DART MOC from onboard telemetry and were then pulled to the DART SOC before delivery to the PDS. The original csv files were modified to be consistent with PDS4 standard.

The DART HGA is gimballed. It is the primary antenna of DART that provides most of the RS data collected during in last 30 days of the mission. The gimballed antenna allows for the final terminal pointing orientation, with solar array on the Sun, DRACO pointed at the asteroid, and the HGA at Earth. Safe mode utilizes the two low gain antennas (LGA) and a slow rotation around the NEXT-C-DRACO axis. The location of the HGA is shown in Figure 1. Additional information on the location of the HGA is given by the NAIF structure SPK for the DART spacecraft. Likewise, the locations of the thrusters discussed in the MAF files are shown in Figure 2. Additional data on the locations of the center of thrust is indicated in the NAIF structure SPK as well.

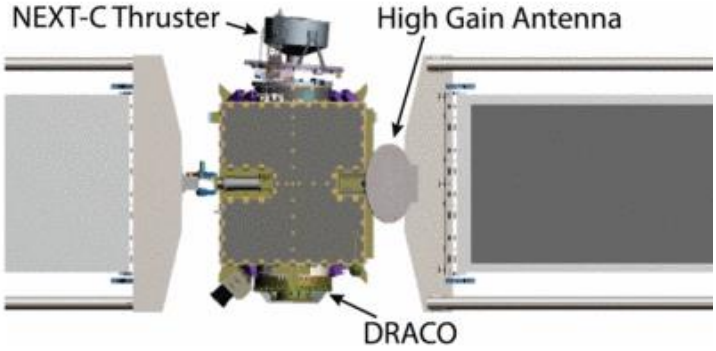

Figure 1. DART spacecraft showing location of the HGA.

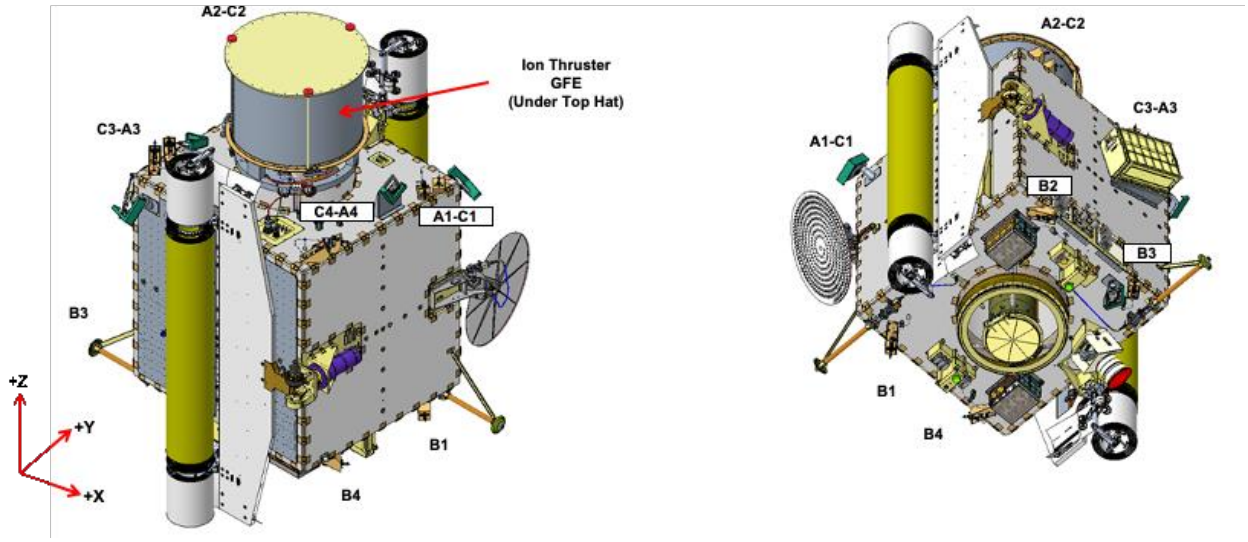

Figure 2. DART spacecraft indicating where the thrusters described in MAF and the NAIF structure SPK are located.

4.2. Data Product Overview

The specific data products described by this SIS are:

1. trk234 data products: these contain the DSN Tracking and Navigation Data. These are also known as trk-2-34 data.
2. trk223 data products: these contain the Ionosphere and Troposphere Calibration Data, These are also known as trk-2-23 data.
3. maf data products: these are the DART Maneuver Acceleration File (MAF) data

Details on the data products are provided in Section 5. References to SIS documents that describe the trk234 and trk223 data products are given in Section 5.2.1, Table 6.

4.3. Data Processing

All DART RS and MAF data are either generated by the DSN or by the DART MOC. The SOC collects and delivers these data to the PDS in PDS4 format.

4.3.1. Labeling and identification

All RS data products are labeled with PDS4 compliant detached XML labels. These labels describe the content and format of the associated data product. Labels and products are associated by file name with the label having the same name as the data product except that the label file has an .xml extension.

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

trk234 data products have the following naming convention:

dart_hga_tnf_yyyymmddThhmmss_v##.<extension>

The file name sections are described in Table .

Table 2. Definition of RS filename

File name section	Description
dart_hga_tnf	Hardcoded string: "dart" is the DART mission, "hga", data is from the the high-gain antenna and this is a tracking and navigation file (tnf)
yyyymmdd	four digit year, two digit month, two digit day of first record in the data (UTC)
T	string character separating date from time
hhmmss	two digit hour, two digit minute, two digit second of first record in the data (UTC)
##	two digit version number, e.g., “01”
<extension>	"dat" for the binary data file, "xml" for the XML label

The maf data products have the following naming convention, with the definitions given in Table 3:

dart_rs_yyyy1_ddd1_yyyy2_ddd2_maf_##.<extension>

Table 3. Definition of maneuver acceleration files filename

File name section	Description
dart_rs	Hardcoded string: "dart" is the DART mission, "rs" is radio science
yyyy1	Four digit year (e.g., 2021) corresponding to the starttime of the first record in the csv (ephemeris time)
ddd1	Three digit day of year (e.g., 200 for July 19, 2021) corresponding to the starttime of the first record in the csv (ephemeris time)
yyyy2	Four digit year corresponding to the endtime of the last record in the csv (ephemeris time)
ddd2	Three digit day of year corresponding to the endtime of the last record in the csv (ephemeris time)
maf	"maf" - Manuever acceleration file
##	two digit version number, e.g., “01”
<extension>	"csv" for the comma delimited ASCII file, "xml" for the XML label

Several of the maf files have the same yyyy1, ddd1 but different yyyy2, ddd2. For example,

dart_rs_2022_257_2022_257_maf_01.csv

dart_rs_2022_257_2022_258_maf_01.csv.

This was caused by files generated at a faster cadence for some periods in the mission. Hence in the example above the 2022_257_2022_257 file only contained a subset of data for DOY 257, while the 2022_257_2022_258 file contains the full set of data for DOY 257. It is for this reason that the filename has to include both the start and end year and day of year.

The trk223 data products have the following naming convention, with the definitions given in Table 4:

dart_rs_yyyy_ddd_xxx_##.<extension>

Table 4. Definition of ionspheric calibration filename

File name section	Description
dart_rs	Hardcoded string: "dart" is the DART mission, "rs" is radio science
yyyy	four digit year of first record in the data
ddd	three digit day of year of first record in the data
xxx	three character string: "dop" indicates it is a doppler and range data file, "vlb" indicates it is a delta-differenced one-way ranging data file
##	two digit version number, e.g., “01”
<extension>	"csp" for the ASCII data file, "xml" for the XML label

4.4. Standards used in Generating Data Products

4.4.1. PDS Standards

All data products described in this SIS conform with PDS4 standards as described in the PDS Standards document noted in the Applicable Documents section of this SIS. trk234 data products (data and XML label) were generated from the original TRK-2-34 files using a software tool provided by the PDS Small Bodies Node (PDS-SBN). trk223 and maf data products are provided as-is by the DART mission. Prior to public release, all data products will have passed both a data product format PDS peer review to ensure compliance with applicable standards.

4.4.2. Time Standards

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

4.5. Data Validation

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

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

Continuous validation of the data products will be performed throughout the mission.

5. Detailed Data Product Specifications

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

5.1. Data Product Structure and Organization

The DART RS data archive is organized into the following data collections within the DART Spacecraft Bundle:

data_trk234 - This collection contains the trk234 data products

data_trk223 - This collection contains the trk223 data products

data_maf - This collection contains the maf data products

document_rs - This collection contains the documentation for the DART radio science data. Note that this collection name uniquely identifies it and separates it from other document collections that exist in the DART Spacecraft Bundle.

Below is the collection directory structure within the DART Spacecraft Bundle:

/root

/data_trk234

/data_trk223

/data_maf

/document_rs

5.2. Data Format Descriptions

DART trk-2-34 tracking data from the DSN were converted into trk234 PDS4 data products using the software tool provided by PDS-SBN. The software tool reorganized the original tracking data file, which was unsorted, such that it is sorted by record type. trl234 data are stored in binary format as one or more binary tables. trk223 data products are stored as 7-bit ASCII text. maf data products are stored as comma-delimited ASCII tables. All the radio science data products include PDS4 compliant labels.

5.2.1. Radio Science Tracking Data

The trk234 data products, aka the DSN Tracking and Navigation Files (trk-2-34) are natively formatted as a binary collection of approximately 18 different data record types. Not all data record types are present in each file. Each of the data record types can be described in a PDS4 XML label as a PDS4 Table_Binary object. The difficulty in labeling the natively formatted trk-2-34 files is that data records are not sorted by type, meaning that in a worst-case scenario, the PDS XML label would be required to have a Table_Binary specification for each data record in the trk-2-34 file, resulting in an XML label file that is hundreds of times larger in size than the data file. To remedy this unwieldy labeling result, the original trk-2-34 files (formatted according to the SIS referenced in Table 5), have been sorted by data record type.

Table 5. DSN Data Product SIS References

Data Product	SIS Reference	Availability
trk234	TRK 2-34 DSN Tracking System Data Archival Format, DSN No. 820-013, TRK-2-34, Rev N. JPL D-76488. November 7, 2013.	https://pds-geosciences.wustl.edu/radiosciencedocs/urn-nasa-pds-radiosci_documentation/dsn_trk-2-34/dsn_trk-2-34.2021-06-03.pdf
trk223	TRK 2-23 Media Calibration Interface, DSN No. 820-013, TRK-2-23, Rev C. JPL D-16765. March 5, 2008.	https://pds-geosciences.wustl.edu/radiosciencedocs/urn-nasa-pds-radiosci_documentation/dsn_trk-2-23/dsn_trk-2-23.2008-03-05.pdf

The DART trk234 tracking data product were converted from their original PDS3 compliant format using a software tool provided by the PDS-SBN. The trk223 data files are unchanged from their original format as they are ASCII, and accepted by PDS4 as-is.

5.2.1. Maneuver Acceleration File

The maf data product describes the attitude correction thrusts undertaken by DART. The files include a header (Table 6) and an ascii table (Table 7). The comma delimited (csv) file has variable width columns. The following describe what is captured in the files. The locations of the thrusters are indicated in Figure 2, and in the NAIF structure SPK file for the DART spacecraft.

Table 6. MAF Header data

Keyword	Example	Definition
MISSION_NAME	DART	Name of mission.
EVENT_NAME	TCM_1C	String specifying if a specific event is contained in the time-span of the file
PRODUCER_ID	JHU/APL	File producer
FILE_TYPE	SFF	Type of file
START_TIME	2021-12-12 21:56:59.283 (ET)	Ephemeris time when event began. Also known as Terrestrial Dynamic Barycenter (TDB
QUAT_CONVENTION	SPICE ([QS Q1 Q2 Q3])	Defines quaternion convention used
QUAT_FORMAT	J2000_TO_BODY	Describes the frame of the quaternion convention.
DV_FRAME	J2000	Frame in which delta-V was applied
DV_UNITS	m/s	Units of delta-V
DTIME_UNITS	s	Units of time employed
DMASS_UNITS	kg	Units of mass employed to describe mass changes

THR_DUR_UNITS	msec	Units of thrust duration.
PROPMASS_UNITS	kg	Mass of propellant remaining
PROPPRESS_UNITS	Pa	Pressure of propellant
TOTAL_SC_MASS_UNITS	kg	Total spacecraft mass.
STARTTIME/ENDTIME_TIMEZONE	ET	Time zone used for describing time.

Table 7. MAF Table data

Keyword	**Example**	**Definition**
INDEX	1	Number of record
RecType	P	P for predicted and R for reconstructed.
INBURN	0	Flag to indicate if a N2H4 maneuver is occurring
STARTTIME	2021-12-12 21:56:59.283	Start time of record in the specified STARTTIME/ENDTIME_TIMEZONE
ENDTIME	2021-12-12 21:57:59.383	End time of record in the specified STARTTIME/ENDTIME_TIMEZONE
DTIME	0.1	Duration of record (in seconds)
DMASS	0	Change in mass over the record duration
DVX	0	Accumulated change in velocity in the DV_FRAME X direction
DVY	0	Accumulated change in velocity in the DV_FRAME Y direction
DVZ	0	Accumulated change in velocity in the DV_FRAME Z direction
QUAT_S	0.53625804862	Scalar component of quaternion entry as defined in QUAT_FORMAT
QUAT_1	0.81891616198	First vector component of quaternion defined in QUAT_FORMAT
QUAT_2	-0.03273896529	Second vector component of quaternion defined in QUAT_FORMAT
QUAT_3	0.20182117107	Third vector component of quaternion defined in QUAT_FORMAT
PROP_MODE	1	Flag to indicate if electric propulsion is active. A value of 1 means N2H4 only. A value of 2 means that NEXT-C is activated.

CONTROL_MODE	#	String specifying the GNC control mode. Valid entries are: default (1), safe (2), terminal (3), tcm (4), opnav (5), detumble (6), thrustarc (7), hga (8), spare1 (9), spare2 (10).
THR_A1_DUR	0.0	Number of pulses of thruster A1 during record duration.
THR_A2_DUR	0.0	Number of pulses of thruster A2 during record duration
THR_A3_DUR	0.0	Number of pulses of thruster A3 during record duration.
THR_A4_DUR	0.0	Number of pulses of thruster A4 during record duration.
THR_B1_DUR	0.0	Number of pulses of thruster B1 during record duration.
THR_B2_DUR	0.0	Number of pulses of thruster B2 during record duration.
THR_B3_DUR	0.0	Number of pulses of thruster B3 during record duration.
THR_B4_DUR	0.0	Number of pulses of thruster B4 during record duration.
THR_C1_DUR	0.0	Number of pulses of thruster C1 during record duration
THR_C2_DUR	0.0	Number of pulses of thruster C2 during record duration
THR_C3_DUR	0.0	Number of pulses of thruster C3 during record duration
THR_C4_DUR	0.0	Number of pulses of thruster C4 during record duration
PROP_MASS	49.0	The mass of N2H4 propellant at the end of the record
PROP_PRESSURE	2386894.830070	The pressure of the N2H4 propellant at the end of the record.
TOTAL_SC_MASS	588.734600	The total spacecraft mass at the end of the record

6. Applicable Software

6.1. Utility Programs

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

6.2. Applicable PDS Software Tools

Data products found in the DART archive can be viewed with any PDS4 compatible software utility.

6.3. Software Distribution and Update Procedures

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

7. Appendices

7.1. List of Acronyms and Abbreviations

Acronym or Abbreviation	Definition
JHU/APL	John Hopkins UniversityApplied Physics Laboratory
ASCII	American Standard Code for Information Interchange
CODMAC	Committee on Data Management and Computation
CSV	comma separated value
DART	Double Asteroid Redirection Test
DMAP	Data Management and Archive Plan
DRACO	Didymos Reconnaissance and Asteroid Camera for OpNav
DSN	Deep Space Network
MAF	Maneuver Acceleration File
MOC	Mission Operations Center
NASA	National Aeronautics and Space Administration
PDS	Planetary Data System
SBN	Small Bodies Node
SIS	Software Interface Specification
UTC	Coordinated Universal Time
XML	Extensible Markup Language

7.2. Definitions of Data Processing Levels

Table 8 shows the comparison of DART, NASA and CODMAC data processing levels.

Table 8. Definition of data processing levels for science data (RS, PDS4, NASA & CODMAC)

RS	PDS4	NASA	CODMAC	Description
	Packet Data	Packet Data	Raw Level 1	Telemetry data stream as received at the ground station, with science and engineering data embedded.
trk234 - DSN Tracking and Navigation Data trk223 - Ionosphere and troposphere calibration data	Raw Data	Level 0	Edited Level 2	Instrument science data (e.g., raw voltages, counts) at full resolution, time ordered, with duplicates and transmission errors removed. Prior to PDS4, referred to as Experiment Data Records (EDRs).
	Partially Processed Data	Level 1A	Calibrated Level 3	NASA Level 0 data that have been located in space and may have been transformed (e.g., calibrated, rearranged) in a reversible manner and packaged with needed ancillary and auxiliary data (e.g., radiances with the calibration equations applied). Prior to PDS4, referred to as Calibrated Data Records (CDRs) and in some cases Derived Data Products (DDPs).
	Calibrated Data	Level 1B	Resampled Level 4	Irreversibly transformed (e.g., resampled, remapped, calibrated) values of the instrument measurements (e.g., radiances, magnetic field strength). Prior to PDS4, referred to as either Derived Data Products (DDPs) or Derived Analysis Products (DAPs).
	Derived Data	Level 2	Derived Level 5	Geophysical parameters, generally derived from NASA Level 1 (CODMAC level 3 and 4) data, and located in space and time commensurate with instrument location, pointing, and sampling. Prior to PDS4, referred to as Derived Analysis Products (DAPs).
		Level 3	Derived Level 5	Geophysical parameters mapped onto uniform space-time grids. Prior to PDS4, referred as derived analysis products (DAPs).
maf - maneuver acceleration file		Level 4	Ancillary Data Level 6	Non-science data needed to generate calibrated or resampled data sets and consisting of instrument gains, and offsets, spacecraft positions, target information, pointing information for scan platforms, etc.