Dawn Mission to Vesta and Ceres
L-0 Data from Ceres
Gravity Science Instrument
Archive Volume Software Interface Specification

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CHANGE LOG

DATE	CHANGES	REASON	REVISION
06/29/15	Updated from Vesta to Ceres		2.0
03/02/16	Added references for multiple PDS deliveries for Ceres		2.1
02/24/17	Updated for final delivery		2.2
05/30/17	Updated for peer review		2.3
01/11/19	Updated for re-release (version 2.0) of Ceres raw dataset	XM2 data archival	3.0
02/26/19	Updated for peer review of XM2 data		3.1

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ACRONYMS AND ABBREVIATIONS

ASCII	American Standard Code for Information Interchange
CEGR	Ceres Gravity
CK	C-Kernel
DOM	Distributed Object Manager
DOY	Day of Year
DSC	Dawn Science Center
DSN	Deep Space Network
GS	Gravity Science
GSI	Gravity Science Instrument
HGA	High Gain Antenna
ION	Ionosphere (in reference to Ionosphere calibration files)
JPL	Jet Propulsion Laboratory
LGA	Low Gain Antenna
NAIF	Navigation Ancillary Information facility
NASA	National Aeronautics and Space Administration
ODF	Orbit Data File
PDS	Planetary Data System
RDA	Raw Data Archive
RS	Radio Science
RSS	Radio Science Subsystem
RSSG	Radio Science Systems Group
SCLK	Spacecraft Clock Kernel
SIS	Software Interface Specification
SFF	Small Forces File
SNR	Signal-to-Noise Ratio
TNF	Tracking and Navigation Service Data Files
TRO	Troposphere (in reference to Troposphere calibration files)
TSAC	Tracking System Analytic Calibration
VEGR	Vesta Gravity
WEA	Weather (in reference to DSN Weather files)

1. INTRODUCTION

1.1. Purpose and Scope

This Software Interface Specification (SIS) describes the format and content of the Dawn Mission to Vesta and Ceres (Dawn) Gravity Science (GS) Raw Data Archive (RDA) for the Ceres phase of the mission. The Dawn Ceres Gravity (CEGR) RDA represents the complete archive of raw data from gravity science investigations conducted using the radio link between the Dawn spacecraft and the Deep Space Network (DSN) tracking stations. The archive is generated by the Dawn Gravity Science Team and the Dawn Science Center (DSC). It is maintained and distributed by the Planetary Data System (PDS).

Gravity Science is a subset of Radio Science, and because of this, the terms Gravity Science (GS) and Radio Science (RS) are used interchangeably in this archive; as are the terms the Gravity Science Instrument (GSI) and Radio Science Subsystem (RSS).

1.2. Data Overview

This data set contains archival raw, partially processed, and ancillary/supporting gravity science data acquired during the Dawn mission while the spacecraft was in orbit around the asteroid Ceres. The radio observations were carried out using the Dawn spacecraft and Earth-based receiving stations of the NASA Deep Space Network. The data set was designed primarily to support generation of high-resolution gravity field models for Ceres. Of most interest are likely to be the Orbit Data Files in the ODF directory and Tracking and Navigation Files in the TNF directory, which provided the raw input to gravity investigations, as well as the ionospheric and tropospheric media calibration files in the ION and TRO directories, respectively.

The closed-loop system of the Deep Space Network used a phase-lock loop in the ground receiver to track the downlink signal from the Dawn spacecraft, reporting both amplitude and frequency at rates typically of 1-10 times per second. Closed-loop data are efficient for characterizing slowly changing signals and are the input to operational navigation and orbit-determination processes.

The data set includes two types of primary data, the TNF and the ODF. TNFs (Tracking and Navigation Service Data Files) are the output of the closed-loop receiver. Orbit Data Files (ODFs) are compressed versions of TNFs. ODFs are specifically targeted to spacecraft navigators and scientists interested in gravity fields.

In September 2017, the Deep Space Network retired the TRK-2-18 ODF file format. It is replaced by only the TRK-2-34 TNF files. Before September 2017, all tracking data is stored in ODF format files. After September 2017, all tracking data is stored in TNF format files.

Typical users of these data might analyze range and Doppler measurements in ODFs to reconstruct the spacecraft trajectory. Relevant questions would include the measurement uncertainties in range and Doppler at different DSN antennas (typical Doppler uncertainty at 10 second integration time is 50 microns/sec, for further details see INST.CAT); the uncertainties could set constraints on any model of Ceres's gravity field developed later, for example.

1.3. Content Overview

This SIS describes the format and content of the Dawn GS RDA. There is minimal processing done of the data collected. This archive is delivered to the PDS via the DSC by the Gravity Science Team. The DSC delivers the completed archives to PDS with the DATA_SET_ID of *DAWN-A-RSS-CEGR-V2.0*.

Version 2.0 of this dataset adds the raw and ancillary/supporting radio science data from Dawn during the Extended Mission 2 (XM2) mission phase around Ceres. Gravity observations in the XM2 phase began on June 6, 2018. There were no gravity observations between the end of the prime mission in September 2017 and the start of XM2 in June 2018.

The following data are archived:

1. **ODF:** Orbit Data Files; contain the minimally processed output of the closed-loop receiver, including Doppler
2. **TNF:** Tracking and Navigation Files; contain the most verbose output of the closed-loop receiver, including Doppler and phase (available for XM2 phase only)
3. **APC:** Antenna Phase Center file; contains the times when the phase center changes due to selection of a low gain antenna (default is the high gain antenna)
4. **ION:** Ionosphere calibration files; contains historical and predicted Earth ionosphere conditions
5. **SCM:** Spacecraft mass report file; contain the spacecraft mass, center of mass, and propellant usage over time
6. **SFF:** Small forces files; contain spacecraft thruster firing data
7. **TRO:** Troposphere calibration files; contain historical and predicted Earth troposphere conditions
8. **WEA:** DSN weather files; contain the weather conditions at each tracking station

1.4. References

[1] Deep Space Network Telecommunications Link Design Handbook, JPL-E-810-005, Jet Propulsion Laboratory, Pasadena, CA, 2013.

[2] Park R.S., A.S. Konopliv, B.G. Bills, N. Rambaux, J.C. Castillo-Rogez, C.A. Raymond, A.T. Vaughan, A.I. Ermakov, M.T. Zuber, R.R. Fu, M.J. Toplis, C.T. Russell, A. Nathues and F. Preusker, *A partially differentiated interior for (1) Ceres deduced from its gravity field and shape*, Nature 537, 515-517, doi:10.1038/nature18955, 2016.

2. RAW DATA ARCHIVE OVERVIEW

2.1. Instrument Overview

The gravity science instrument utilizes the deep space transponder onboard the Dawn spacecraft and Doppler tracking equipment at the Deep Space Network to perform radio science investigations to determine the gravitational field of celestial bodies.

For the full description of the Gravity Science instrument, please refer to the INST.CAT and DATASET.CAT files in the CATALOG directory.

2.2. Data Product Overview

The ODFs and TNFs are binary files with detached PDS labels. The ancillary data products (APC, ION, SCM, SFF, TRO, and WEA) are ASCII files. The table below describes the data products contained in these directories.

File	Abbrev.	File Type	Average File Size	Generation Frequency	Source of Files
Orbit Data File	ODF	Binary	100K	Per request	DSN/OSCARX
Tracking and Navigation File	TNF	Binary	20M	Once per pass	DSN/OSCARX
Antenna Phase Center files	APC	ASCII	4K	Once	Dawn Gravity Team
Ionosphere Calibration files	ION	ASCII	24K	Monthly	TSAC/OSCARX
Spacecraft Mass Report	SCM	ASCII	8K	Per request	Dawn DOM
Small Forces Files	SFF	ASCII	2.5M	Per mission phase	Dawn DOM
Troposphere Calibration files	TRO	ASCII	150K	Monthly	TSAC/OSCARX
DSN Weather files	WEA	ASCII	1.1M	Weekly	TSAC/OSCARX

2.2.1. Detailed Descriptions

Unless otherwise noted, the abbreviations '*yyyy*' indicate the year, and '*ddd*' indicate the day of year. In a series, such as '*yyyy_ddd_yyyy_ddd*', the first date ('*yyyy_ddd*') indicates the starting date and the second date indicates the end date that the file is applicable for. If only one sequence of dates is provided, it is the applicable start time of the file.

Orbit Data File

The ODF is a minimally processed output of the closed-loop receiver. It contains the most important information (range, Doppler and frequency ramps) needed by spacecraft investigators, and investigators interested in determining gravity fields. Each ODF is accompanied by a full PDS label which describes both the content and format of the associated file. ODF data fields include:

- Narrowband spacecraft VLBI, Doppler mode (cycles)
- Narrowband spacecraft VLBI, phase mode (cycles)
- Narrowband quasar VLBI, Doppler mode (cycles)
- Narrowband quasar VLBI, phase mode (cycles)
- Wideband spacecraft VLBI (nanoseconds)
- Wideband quasar VLBI (nanoseconds)
- One-way Doppler (Hertz)
- Two-way Doppler (Hertz)
- Three-way Doppler (Hertz)
- One-way total count phase (cycles)

- Two-way total count phase (cycles)
- Three-way total count phase (cycles)
- PRA planetary operational discrete spectrum range (range units)
- SRA planetary operational discrete spectrum range (range units)
- RE(GSTDN) range (nanoseconds)
- Azimuth angle (degrees)
- Elevation angle (degrees)
- Hour angle (degrees)
- Declination angle (degrees)

ODFs are abstracted from subsets of TNF data, the uncompressed output of the closed-loop receiver at the Deep Space Network. A full PDS label accompanies each ODF file and gives a bit level description of the content and format.

ODFs are stored in the ODF directory. ODFs contain the output of the closed-loop tracking system of the Deep Space Network. File names are of the form *DAWNCEGRyyyy_ddd_hhmmXuuwVn.ODF* where 'DAWNCEGR' identifies the mission and the data set; 'yyyy' is the four-digit year, 'ddd' is the three-digit day-of-year, 'hh' is the two-digit hour, and 'mm' is the two-digit minute at the beginning of the file; 'X' indicates an X-Band uplink ('N' denotes no uplink); 'uu' indicates the uplink station (set to 'NN' for no uplink or 'MM' for two or more uplinking stations during the time interval covered), 'w' indicates the downlink mode ('1', '2', '3', or 'M' for 1-way, 2-way, 3-way, or 'multiple', respectively), and 'Vn' indicates the version number of the file. The ODF label has file name *DAWNCEGRyyyy_ddd_hhmmXuuwVn.LBL*. The typical ODF contains about 100 Kbytes.

Tracking and Navigation File

In September 2017, the Deep Space Network retired the TRK-2-18 ODF file format. It is replaced by only the TRK-2-34 TNF files. Before September 2017, all tracking data is stored in ODF format files. After September 2017, all tracking data is stored in TNF format files.

TNFs contain the most primitive (and most voluminous) output from the closed-loop radio science system; they are stored in the TNF directory. File names are of the form *DAWNCEGRyyyy_ddd_hhmmXuuwVn.TNF* where 'DAWNCEGR' identifies the mission and the data set; 'yyyy' is the four-digit year, 'ddd' is the three-digit day-of-year, 'hh' is the two-digit hour, and 'mm' is the two-digit minute at the beginning of the file; 'X' indicates an X-Band uplink ('N' denotes no uplink); 'uu' indicates the uplink station (set to 'NN' for no uplink or 'MM' for two or more uplinking stations during the time interval covered), 'w' indicates the downlink mode ('1', '2', '3', or 'M' for 1-way, 2-way, 3-way, or 'multiple', respectively), and 'Vn' indicates the version number of the file. Dates and times in the file name are UTC. The TNF label has file name *DAWNCEGRyyyy_ddd_hhmmXuuwVn.LBL*. The typical TNF contains about 20 Mbytes.

Unlike the ODF files, the TNF files do not have a complete data label but rather a minimal label. This is due to the complicated nature of the data format. The format of these TNF data are described in detail in the TNFSIS.LBL document in the DOCUMENT directory.

Antenna Phase Center files

Antenna Phase Center files were produced by the JPL Dawn Gravity Science Team. The Dawn spacecraft utilizes four antennas during operations (1 high gain antenna and 3 low gain antennas). The Antenna Phase Center files contain the start times and stop times when any of the low gain antennas were being used. During times not specified in these files, the high gain antenna was being used. The original sources of these data are the Dawn Sequence of Events (SOE) files. APC files are ASCII files. File names have the form *DAWNCEGR_yyyy_ddd_yyyy_ddd.APC*. The accompanying PDS label (with name *DAWNCEGR_yyyy_ddd_yyyy_ddd.LBL*) describes the content and structure of the file.

Ionosphere Calibration files

Ionosphere Calibration files are ASCII files produced by the Tracking System Analytic Calibration (TSAC) Group at JPL. They provide historical and predicted Earth ionospheric conditions. File names have the form *DAWNCEGR_yyyy_ddd_yyyy_ddd.ION.* Each ION file is accompanied by a PDS minimal label with file name *DAWNCEGR_yyyy_ddd_yyyy_ddd.LBL*. Typical file size is 24 KB. Format and content of the files are described by *TRK_2-23_REVC_L5* in the DOCUMENT directory.

Spacecraft Mass Report

Spacecraft Mass History files were produced by the Dawn Spacecraft Team. They contain the estimates of the spacecraft mass, center of mass, and propellant usage. These are ASCII files of variable length records. File names have the form *DAWNCEGR_yyyy_ddd.SCM*, where yyyy_ddd is the applicable start time of the file. Files are accompanied by a PDS label describing the format of the data. Typical file size is 8 KB. The accompanying PDS label describes the content and structure of the file.

Small Forces Files

Small Forces Files were created from the Dawn spacecraft engineering telemetry stream. These are ASCII files of variable length records. File names have the form *DAWNCEGR_yyyy_ddd_yyyy_ddd.SFF*. Each SFF file is accompanied by a PDS minimal label with file name *DAWNCEGR_yyyy_ddd_yyyy_ddd.LBL*. Typical file sizes are 2.5 MB. File content and structure are defined by *NAV018-SFF-JPL.DOC* in the DOCUMENT directory.

Troposphere Calibration files

Troposphere Calibration files are ASCII files produced monthly by the Tracking System Analytic Calibration (TSAC) Group at JPL. They provide historical and predicted Earth tropospheric conditions. File names have the form *DAWNCEGR_yyyy_ddd_yyyy_ddd.TRO*. Each TRO file is accompanied by a PDS minimal label with file name *DAWNCEGR_yyyy_ddd_yyyy_ddd.LBL*. Typical file size is 150 KB. Format and content of the files are described by *TRK_2-23_REVC_L5* in the DOCUMENT directory.

DSN Weather files

DSN Weather files were produced by the Tracking System Analytic Calibration (TSAC) Group at JPL. Files give weather calibration information for DSN complexes. These are ASCII files of variable length records. File names have the form *DAWNCEGR_yyyy_ddd_yyyy_ddd_ss.WEA*, where 'ss' is the DSN complex where weather data were acquired. WEA files are typically

released weekly and contain all weather data for the complex since 1 January. Only files covering the entire years of 2011 and 2012 are included in the archive. Each WEA file is accompanied by a PDS minimal label with file name *DAWNCEGR_yyyy_ddd_yyyy_ddd_ss.LBL*. The files grow at the rate of approximately 90 KB per month. Format and content of the files are described by T2_24_L5 in the DOCUMENT directory.

2.3. Data Processing

Data processing is performed by various groups and organizations at the Jet Propulsion Lab and the Deep Space Network. For details on each individual type, refer to the appropriate document in the DOCUMENT directory of this archive.

2.4. Software

No software is included in this archive. The SPICE toolkit provides useful tools and algorithms for data processing of this type and is located at the NAIF PDS node naif.jpl.nasa.gov.

2.5. File Naming Conventions

See Section 2.2.1 for file naming conventions in the description of each file type.

2.6. Data Product Labels

Every file in this archive is accompanied by a PDS label. The label is either attached (embedded in the file) or detached (separate file with same name except for extension '.LBL'). All data files in the ANCILLARY and ODF directory have detached PDS labels. Depending on the file type, the detached label may provide the content and structure of the file. Labels are structured in the PDS *KEYWORD=VALUE* fashion. A description of the keywords may be found on the web at http://pds.nasa.gov/tools/ddlookup/data_dictionary_lookup.cfm.

2.7. Standard Keyword Values

The Dawn Gravity Science RDA uses the following standard keywords and values, consistent across the archive:

Keyword	Dawn Standard Values
DATA_SET_ID	*DAWN-A-RSS-1-CEGR-V2.0*
DATA_SET_NAME	*"DAWN CERES RAW GRAVITY SCIENCE V2.0"*
INSTRUMENT_HOST_ID	*DAWN*
INSTRUMENT_HOST_NAME	*DAWN*
INSTRUMENT_ID	*RSS*
INSTRUMENT_NAME	*GRAVITY SCIENCE INSTRUMENT*
INSTRUMENT_TYPE	*RADIO SCIENCE*
MISSION_NAME	*DAWN MISSION TO VESTA AND CERES*
TARGET_NAME	*1 CERES, 4 VESTA*
VOLUME_ID	*DWNCGRS_0*
VOLUME_SERIES_NAME	*DAWN*
VOLUME_SET_ID	*USA_NASA_PDS_DWNCGRS_0*
VOLUME_SET_NAME	*"DAWN MISSION TO CERES RAW GRAVITY OBSERVATIONS"*
VOLUME_VERSION_ID	*VERSION 2*

3. ARCHIVE ORGANIZATION

The Dawn Gravity Science Raw Data Archive for Ceres has the following directories:

- Root directory
  - ANCILLARY
    - APC
    - ION
    - SCM
    - SFF
    - TRO
    - WEA
  - CATALOG
  - DOCUMENT
  - INDEX
  - ODF
  - TNF

The contents of the directories are described below.

3.1. Root Directory

This directory is the core directory on which the rest of the archive is built. It contains the following files:

1. AAREADME.TXT: Human readable description of the archive contents
2. ERRATA.TXT: Human readable list of corrections and other comments regarding the archive
3. VOLDESC.CAT: Description of the contents of the volume

3.2. ANCILLARY Directory

The ANCILLARY directory contains data that are useful in the analysis of the primary data, the ODF files. It contains the following subdirectories and file types:

Directory	File Type	Contents
APC	Antenna Phase Center	Antenna phase center times and PDS label
ION	Ionosphere Calibration	Ionosphere calibration files and PDS labels
SCM	Spacecraft Mass Report	Spacecraft mass history and PDS labels
SFF	Small Forces Files	Small forces files and PDS labels
TRO	Troposphere Calibration	Troposphere calibration files and PDS labels
WEA	DSN Weather files	Weather records from the DSN and PDS labels

3.3. CATALOG Directory

This directory contains descriptions of the dataset, mission, instrument, and spacecraft. They are all ASCII stream files. It contains the following files:

1. CATINFO.TXT: Description of the directory

2. DATASET.CAT: Overview of the RDA
3. INST.CAT: Overview of the Gravity Science Instrument
4. DAWNINSTHOST.CAT: Overview of the Dawn spacecraft
5. DAWNMISSION.CAT: Overview of the Dawn Mission to Vesta and Ceres
6. PERSON.CAT: Contributors to the archive and contact information
7. REF.CAT: References for the archive

3.4. DOCUMENT Directory

This directory contains the corresponding documentation to help the end user use and interpret the data included in this archive. The following documents are included:

Filename	Format	Description
DOCINFO.TXT	text	Description of the directory
Dawn_Ceres_Grav_SIS	Word, PDF, HTML	This document
T2-18-L5	HTML, PDF	Description of the Orbit Data Files (ODF) and binary format
TRK-2-23-RevC-L5	HTML, PDF	Description of the DSN Media Calibration files (ION, TRO)
T2-24-L5	HTML, PDF	Description of the DSN Weather files (WEA)
DAWN_SFF_SIS	HTML, PDF	Description of the Small Forces Files (SFF)
TNFSIS	text, PDF	Description of the Tracking and Navigation Files (TNF) and binary format

3.5. INDEX Directory

This directory contains the following files:

1. INDEXINFO.TXT: Description of the directory
2. INDEX.LBL: Detached label describing INDEX.TAB
3. INDEX.TAB: Table listing all data products in the RDA

3.6. ODF Directory

The ODF directory contains the binary Orbit Data Files, one of the primary data types, for the Dawn Ceres Gravity Science RDA. Each is accompanied by a detached PDS label describing the format of the ODF file. For more details, see Section 2.2.1 of this document.

3.1. TNF Directory

The TNF directory contains the binary Tracking and Navigation Files, one of the primary data types, for the Dawn Ceres Gravity Science RDA. Each is accompanied by a minimal detached PDS label. For more details, see Section 2.2.1 of this document.

4. RELEVANT DATA ARCHIVED AT OTHER SITES

4.1. NAIF Node

The Navigation and Ancillary Information Facility (NAIF) is the navigation node of the PDS. NAIF provides the archives for spacecraft navigation, attitude, events, clock conversion, and planetary ephemerides for most NASA missions. Additionally, NAIF provides the SPICE toolkit, containing useful algorithms to utilize and manipulate data NAIF provide.

Relevant to gravity science are the following types:

- **CK:** Spacecraft and solar array attitude orientation files
- **EK:** Spacecraft events kernel
- **FK:** Reference frame specification
- **SCLK:** Conversion between spacecraft time and ephemeris time
- **SPK:** Spacecraft and Planetary ephemeris data

The NAIF PDS archive for Dawn is located at:

- naif.jpl.nasa.gov/pub/naif/pds/data/dawn-m_a-spice-6-v1.0/

4.2. Optical Navigation Data – Small Bodies Node

The PDS Small Bodies Node (SBN), the location of this archive, also hosts the data from the Dawn Framing Camera 2 (FC2) instrument. The Dawn FC2 archives include the optical navigation data, which aids the analysis of the DSN radiometric tracking data contained in this archive.

The PDS Small Bodies Node is located at:

- sbn.psi.edu/

The Framing Camera 2 imaging data may be easily located via the following URL:

- https://sbn.psi.edu/pds/resource/dwncfc2.html

5. PERSONNEL

- Ryan S. Park, Chair of the Dawn Gravity Science Working Group, NASA Jet Propulsion Lab
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7. APPENDIX

7.1. Spacecraft Antenna Locations

The Dawn spacecraft has four antennas onboard the spacecraft. In the spacecraft-fixed frame, the phase centers are:

Body ID	X-component (meters)	Y-component (meters)	Z-component (meters)
PLUS_X_HGA	1.22	0.00	1.58
PLUS_X_LGA	0.99	0.45	0.33
PLUS_Z_LGA	0.26	-0.43	2.29
MINUS_Z_LGA	0.45	0.45	-0.01

7.2. Deep Space Network Antenna Locations

The Deep Space Network has multiple antennas at three sites in Goldstone, California, United States; Canberra, Australia; and Madrid, Spain. Station locations are documented in *[DSN810-5]* (see references in CATALOG/REF.CAT). The locations are also available in CATALOG/INST.CAT.