Mars Atmosphere and Volatile Evolution (MAVEN) Mission

Radio Occultation Science Experiment (ROSE)

PDS Archive

Software Interface Specification

Rev. 1.6

ROSE

03 May 2022

Prepared by

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MAVEN

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1 Introduction

This software interface specification (SIS) describes the format and content of the Radio Occultation Science Experiment (ROSE) Planetary Data System (PDS) data archive. It includes descriptions of the data products and associated metadata, and the archive format, content, and generation pipeline.

1.1 Distribution List

Table 1: Distribution list

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1.2 Document Change Log

Table 2: Document change log

Version	Change	Date	Affected portion
1.0	Initial draft	2017-Jul-20	All
1.1	Revisions based on initial PDS review	2017-Oct-16	All
1.2	Revisions based on delta PDS review	2018-Jan-26	All
1.3	Discussion of LGA observations; addition of OVW document; note deletion of ranging information from some DLF files	2019-Jan-16	1.2, 2, 5.2.1.3, 5.2.1.8
1.4	Deletion of erroneous mention of Earth Orientation Parameters file; addition of information related to DSN transition from RSR to OLR in 2019; change in PDS Program Manager from Morgan to Banks	2019-Jul-26	1.4, 2, 3.5, 4.1.1, 5.2.1.2, 5.2.1.7, 5.2.2.2
1.5	Addition of ROSE references	2020-Jul-27	2, 5.2.3.1

1.6	Discussion of change in appearance and production of BRO files	2022-May-03	3.5, 5.2.1.7

1.3 TBD Items

Table 3 lists items that are not yet finalized.

Table 3: List of TBD items

Item	Section(s)	Page(s)
Replace TBD in Transfer Manifest text	6.4, App F	

1.4 Abbreviations

Table 4: Abbreviations and their meanings

Abbreviation	Meaning
ACC	Accelerometer
ADC	Analog-to-digital Convertor
ASCII	American Standard Code for Information Interchange
Atmos	PDS Atmospheres Node (NMSU, Las Cruces, NM)
BRO	Browse
CCSDS	Consultative Committee for Space Data Systems
CDF	Common Data Format
CDR	Calibrated Data Record
CFDP	CCSDS File Delivery Protocol
CK	C-matrix Kernel (NAIF orientation data)
CODMAC	Committee on Data Management, Archiving, and Computing
CRC	Cyclic Redundancy Check
CU	University of Colorado (Boulder, CO)
DAP	Data Analysis Product
DECANSO	Deep Space Communications and Navigation Systems
DDR	Derived Data Record
DEM	Downlink Equipment Monitor
DLF	Downlink Frequency
DMAS	Data Management and Storage
DPF	Data Processing Facility

Abbreviation	Meaning
DSN	Deep Space Network
E&PO	Education and Public Outreach
EDP	Electron Density Profile
EDR	Experiment Data Record
ERT	Earth Received Time
EUV	Extreme Ultraviolet; also used for the EUV Monitor, part of LPW (LASP)
FEI	File Exchange Interface
FOV	Field of View
FTP	File Transfer Protocol
FUP	Uplink Frequency
GB	Gigabyte(s)
GSFC	Goddard Space Flight Center (Greenbelt, MD)
HGA	High Gain Antenna
HK	Housekeeping
HTML	Hypertext Markup Language
ICD	Interface Control Document
IDL	Interactive Data Language
IM	Information Model
ION	Ionosphere
ISO	International Standards Organization
IRAP	Institut de Recherche en Astrophysique et Planétologie
ITF	Instrument Team Facility
IUVS	Imaging Ultraviolet Spectrograph (LASP)
JPL	Jet Propulsion Laboratory (Pasadena, CA)
LASP	Laboratory for Atmosphere and Space Physics (CU)
LGA	Low-Gain Antenna
LID	Logical Identifier
LIDVID	Versioned Logical Identifer
LPW	Langmuir Probe and Waves instrument (LASP)
MAG	Magnetometer instrument (GSFC)

Abbreviation	Meaning
MAVEN	Mars Atmosphere and Volatile EvolutioN
MET	Mission Elapsed Time
MB	Megabyte(s)
MCP	Microchannel Plate
MD5	Message-Digest Algorithm 5
MOI	Mars Orbit Insertion
MOS	Mission Operations System
MSA	Mission Support Area
MSO	Mars-Sun-Orbit (reference frame)
NAIF	Navigation and Ancillary Information Facility (JPL)
NASA	National Aeronautics and Space Administration
NGIMS	Neutral Gas and Ion Mass Spectrometer (GSFC)
NMSU	New Mexico State University (Las Cruces, NM)
NSSDC	National Space Science Data Center (GSFC)
OLR	Open Loop Receiver
PAD	Pitch Angle Distribution
PCK	Planetary Constants Kernel (NAIF)
PDS	Planetary Data System
PDS4	Planetary Data System Version 4
PF	Particles and Fields (instruments)
PFDPU	Particles and Fields Data Processing Unit
POC	Payload Operations Center
PPI	PDS Planetary Plasma Interactions Node (UCLA)
RMP	Radiometric Predictions
ROSE	Radio Occultation Science Experiment
RS	Remote Sensing (instruments)
RSA	Radio Science Advisor (Dick Simpson, Stanford University)
RSR	Radio Science Receiver
RSSG	Radio Science Systems Group
SCET	Spacecraft Event Time

Abbreviation	Meaning
SCLK	Spacecraft Clock
SDC	Science Data Center (LASP)
SEP	Solar Energetic Particle instrument (SSL)
SFDU	Standard Formatted Data Unit
SIS	Software Interface Specification
SKY	Sky frequency
SOC	Science Operations Center (LASP)
SPE	Solar Particle Event
SPICE	Spacecraft, Planet, Instrument, C-matrix, and Events (NAIF data format)
SPK	Spacecraft and Planetary ephemeris Kernel (NAIF)
SSL	Space Sciences Laboratory (UCB)
STATIC	Supra-Thermal And Thermal Ion Composition instrument (SSL)
SWEA	Solar Wind Electron Analyzer (SSL)
SWIA	Solar Wind Ion Analyzer (SSL)
TBC	To Be Confirmed
TBD	To Be Determined
TNF	Tracking and Navigation Service Data File
TRO	Troposphere
UCB	University of California, Berkeley
UCLA	University of California, Los Angeles
UHF	Ultra-High Frequency
URN	Uniform Resource Name
USO	Ultrastable Oscillator
UTC	Coordinated Universal Time
UV	Ultraviolet
VID	Versioned Logical Identifier
WEA	Weather
XML	eXtensible Markup Language

1.5 Glossary

Archive – A place in which public records or historical documents are preserved; also the material preserved – often used in plural. The term may be capitalized when referring to all of PDS holdings – the PDS Archive.

Basic Product – The simplest product in PDS4; one or more data objects (and their description objects), which constitute (typically) a single observation, document, etc. The only PDS4 products that are *not* basic products are collection and bundle products.

Bundle Product – A list of related collections. For example, a bundle could list a collection of raw data obtained by an instrument during its mission lifetime, a collection of the calibration products associated with the instrument, and a collection of all documentation relevant to the first two collections.

Class – The set of attributes (including a name and identifier) which describes an item defined in the PDS Information Model. A class is generic – a template from which individual items may be constructed.

Collection Product – A list of closely related basic products of a single type (e.g. observational data, browse, documents, etc.). A collection is itself a product (because it is simply a list, with its label), but it is not a *basic* product.

Data Object – A generic term for an object that is described by a description object. Data objects include both digital and non-digital objects.

Description Object – An object that describes another object. As appropriate, it will have structural and descriptive components. In PDS4 a "description object" is a digital object – a string of bits with a predefined structure.

Digital Object – An object which consists of real electronically stored (digital) data.

Identifier – A unique character string by which a product, object, or other entity may be identified and located. Identifiers can be global, in which case they are unique across all of PDS (and its federation partners). A local identifier must be unique within a label.

Label – The aggregation of one or more description objects such that the aggregation describes a single PDS product. In the PDS4 implementation, labels are constructed using XML.

Logical Identifier (**LID**) – An identifier which identifies the set of all versions of a product.

Versioned Logical Identifier (LIDVID) – The concatenation of a logical identifier with a version identifier, providing a unique identifier for each version of product.

Manifest - A list of contents.

Metadata – Data about data – for example, a "description object" contains information (metadata) about an "object."

Non-Digital Object – An object which does not consist of digital data. Non-digital objects include both physical objects like instruments, spacecraft, and planets, and non-physical objects like missions, and institutions. Non-digital objects are labeled in PDS in order to define a unique identifier (LID) by which they may be referenced across the system.

Object – A single instance of a class defined in the PDS Information Model.

PDS Information Model – The set of rules governing the structure and content of PDS metadata. While the Information Model (IM) has been implemented in XML for PDS4, the model itself is implementation independent.

Product – One or more tagged objects (digital, non-digital, or both) grouped together and having a single PDS-unique identifier. In the PDS4 implementation, the descriptions are combined into a single XML label. Although it may be possible to locate individual objects within PDS (and to find specific bit strings within digital objects), PDS4 defines "products" to be the smallest granular unit of addressable data within its complete holdings.

Tagged Object – An entity categorized by the PDS Information Model, and described by a PDS label.

Registry – A data base that provides services for sharing content and metadata.

Repository – A place, room, or container where something is deposited or stored (often for safety).

XML – eXtensible Markup Language.

XML schema – The definition of an XML document, specifying required and optional XML elements, their order, and parent-child relationships.

1.6 MAVEN Mission Overview

The MAVEN mission was launched on an Atlas V on 18 November 2013. After a ten-month ballistic cruise phase, Mars orbit insertion occurred on 21 September 2014. MAVEN then transitioned into its science orbit at a 75° inclination, with a 4.5 hour period and periapsis altitude of 140-170 km (density corridor of 0.05-0.15 kg/km^3). During the primary mission, which lasted one Earth year, MAVEN's periapsis precessed over a wide range of latitude and local time as the spacecraft obtained detailed measurements of the upper atmosphere, ionosphere, planetary corona, solar wind, interplanetary/Mars magnetic fields, solar EUV and solar energetic particles. MAVEN also explored down to the homopause during a series of "deep-dip" campaigns that each lasted approximately five days, during which periapsis was lowered to an atmospheric density of 2 kg/km^3 (~125 km altitude) in order to sample the transition from the collisional lower atmosphere to the collisionless upper atmosphere. These campaigns were interspersed though the primary mission to sample different times of day and latitudes. After the completion of its primary mission, MAVEN began its extended mission, which also included deep-dip campaigns. As of November 2017, eight deep-dip campaigns have been conducted.

1.6.1 Mission Objectives

The primary science objectives of the MAVEN project are to provide a comprehensive picture of the present state of the upper atmosphere and ionosphere of Mars and the processes controlling them and to determine how loss of volatiles to outer space in the present epoch varies with changing solar conditions. Knowing how these processes respond to the Sun's energy inputs will enable scientists, for the first time, to reliably project processes backward in time to study atmosphere and volatile evolution. MAVEN was designed to deliver definitive answers to highpriority science questions about atmospheric loss (including water) to space that will greatly enhance our understanding of the climate history of Mars. Measurements made by MAVEN allow us to determine the role that escape to space has played in the evolution of the Mars atmosphere, an essential component of the quest to "follow the water" on Mars. MAVEN accomplishes this by achieving science objectives that answer three key science questions:

- What is the current state of the upper atmosphere and what processes control it?
- What is the escape rate at the present epoch and how does it relate to the controlling processes?
- What has the total loss to space been through time?

MAVEN was designed to achieve these objectives by measuring the structure, composition, and variability of the Martian upper atmosphere, so that it is able to separate the roles of different loss mechanisms for both neutrals and ions. MAVEN samples all relevant regions of the Martian atmosphere/ionosphere system – from the termination of the well-mixed portion of the atmosphere (the "homopause"), through the diffusive region and main ionosphere layer, up into the collisionless exosphere, and through the magnetosphere and into the solar wind and downstream tail of the planet where loss of neutrals and ionization occurs to space – at all relevant latitudes and local solar times. To allow a meaningful projection of escape back in time, measurements of escaping species are made simultaneously with measurements of the energy drivers and the controlling magnetic field over a range of solar conditions. Together with measurements of the isotope ratios of major species, which constrain the net loss to space over time, this approach was designed to allow thorough identification of the role that atmospheric escape plays today and to extrapolate to earlier epochs.

1.6.2 Payload

MAVEN will use the following science instruments to measure the Martian upper atmospheric and ionospheric properties, the magnetic field environment, the solar wind, and solar radiation and particle inputs:

- NGIMS Package:
  - Neutral Gas and Ion Mass Spectrometer (NGIMS) measures the composition, isotope ratios, and scale heights of thermal ions and neutrals.
- RS Package:
  - Imaging Ultraviolet Spectrograph (IUVS) remotely measures UV spectra in four modes: limb scans, planetary mapping, coronal mapping and stellar occultations. These measurements provide the global composition, isotope ratios, and structure of the upper atmosphere, ionosphere, and corona.
- PF Package:
  - Supra-Thermal and Thermal Ion Composition (STATIC) instrument measures the velocity distributions and mass composition of thermal and suprathermal ions from below escape energy to pickup ion energies.
  - Solar Energetic Particle (SEP) instrument measures the energy spectrum and angular distribution of solar energetic electrons (30 keV – 1 MeV) and ions (30 keV – 12 MeV).

  - Solar Wind Ion Analyzer (SWIA) measures solar wind and magnetosheath ion density, temperature, and bulk flow velocity. These measurements are used to determine the charge exchange rate and the solar wind dynamic pressure.
  - Solar Wind Electron Analyzer (SWEA) measures energy and angular distributions of 5 eV to 5 keV solar wind, magnetosheath, and auroral electrons, as well as ionospheric photoelectrons. These measurements are used to constrain the plasma environment, magnetic field topology and electron impact ionization rate.
  - Langmuir Probe and Waves (LPW) instrument measures the electron density and temperature and electric field in the Mars environment. The instrument includes an EUV Monitor that measures the EUV input into Mars atmosphere in three broadband energy channels.
  - Magnetometer (MAG) measures the vector magnetic field in all regions traversed by MAVEN in its orbit.
- Accelerometer:
  - Accelerometer (ACC) investigation measures the mass density and scale height of the upper atmosphere.
- Radio Science:
  - Radio Occultation Science Experiment (ROSE) investigation measures the electron density in the ionosphere of Mars.

1.7 SIS Content Overview

Section 2 describes the ROSE investigation. Section 3 gives an overview of data organization and data flow. Section 4 describes data archive generation, delivery, and validation. Section 5 describes the archive structure and archive production responsibilities. Section 6 describes the file formats used in the archive, including the data product record structures. Appendix A lists individuals involved in the generation of the archive. Appendix B describes the MAVEN science data file naming conventions. Appendices C, D, and E contain sample PDS product labels. Appendix F describes the PDS delivery format and conventions for ROSE.

1.8 Scope of this Document

The specifications in this SIS apply to all ROSE products submitted for archive to the Planetary Data System (PDS), for all phases of the MAVEN mission. This document includes descriptions of archive products that are produced by the ROSE team.

1.9 Applicable Documents

[1] Planetary Data System Data Provider's Handbook, Version 1.7.0, April 2017.

[2] Planetary Data System Standards Reference, Version 1.8.0, 21 March 2017.

[3] PDS4 Data Dictionary – Abridged, Version 1.8.0.0, 10 March 2017.

[4] Planetary Data System (PDS) PDS4 Information Model Specification, 1.8.0.0, 10 March 2017.

[5] Mars Atmosphere and Volatile Evolution (MAVEN) Science Data Management Plan, Rev. C, doc. no.MAVEN-SOPS-PLAN-0068.

1.10 Audience

This document serves both as a SIS and Interface Control Document (ICD). It describes both the archiving procedure and responsibilities, and data archive conventions and format. It is designed to be used both by the instrument teams in generating the archive, and by those wishing to understand the format and content of the ROSE PDS data bundles. Typically, these individuals would include scientists, data analysts, and software engineers.

2 ROSE Investigation Description

The Radio Occultation Science Experiment (ROSE) is a two-way, single-frequency (X-band) radio occultation experiment designed to measure electron density in the ionosphere of Mars. ROSE contains two elements – the spacecraft element and the ground element. The spacecraft element is the spacecraft communications system, particularly the radio transceiver and high gain antenna (HGA). The ground element is the Deep Space Network (DSN), particularly the 34m/70m radio antennas in California, Spain, and Australia, and their Radio Science Receivers (RSRs). The spacecraft communications system is similar to those used on Mars Reconnaissance Orbiter and Juno, which are described further in JPL Deep Space Communications and Navigation Systems Center of Excellence (DESCANSO) publications (https://descanso.jpl.nasa.gov/DPSummary/summary.html). The Deep Space Network is described further in the DSN Telecommunications Link Design Handbook (https://deepspace.jpl.nasa.gov/dsndocs/810-005/).

A detailed overview of the ROSE investigation is Withers et al. (2020) The MAVEN Radio Occultation Science Experiment (ROSE). Space Sci Rev 216, 61. https://doi.org/10.1007/s11214-020-00687-6. ROSE data processing software are available in Withers et al. (2020) Correction to: The MAVEN Radio Occultation Science Experiment (ROSE). Space Sci Rev 216, 79 (2020). https://doi.org/10.1007/s11214-020-00714-6.

In 2019, the DSN upgraded from using Radio Science Receivers to using Open Loop Receivers. From the perspective of the ROSE investigation, this change had minimal impact. The text of this document generally reflects the early use of the Radio Science Receivers.

When MAVEN is occulted from view of Earth by Mars, the DSN transmits a carrier-only radio signal up to MAVEN at 7.2 GHz. This uplink signal is received by MAVEN, its frequency is multiplied by 880/749, and MAVEN transmits a carrier-only radio signal down to the DSN at 8.4 GHz. The downlinked radio signal is received at the DSN and recorded using the open-loop RSRs. Due to the occultation geometry, the radio signal passes through the ionosphere of Mars on its uplink and downlink legs. Refraction experienced as the radio signal passes through the ionosphere of Mars results in a mHz change in the frequency of the downlink radio signal received at the DSN. The difference between the observed frequency received at the DSN and the predicted frequency received at the DSN is called the frequency residual. It contains information about the electron density in the ionosphere of Mars. The JPL Radio Science Systems Group (RSSG), who operate the DSN's RSRs, determine time series of the frequency residual from the known transmitted uplink frequency, the observed received downlink frequency, and known trajectories of the DSN antenna and MAVEN spacecraft.

The time series of frequency residual is a critical ROSE data product from which ionospheric electron densities are determined. It is transferred from the RSSG to the Science Data Center (SDC) several weeks after the occultation. This delay occurs because the frequency residual cannot be reliably determined using the predicted trajectory of MAVEN during the occultation. An accurate reconstructed trajectory for MAVEN during the occultation is required, which takes several weeks. The determination of electron densities from frequency residuals is described in Section 5.2.3.1.

MAVEN has adopted this two-way mode because the spacecraft does not carry an ultrastable oscillator (USO). The frequency stability of radio transmissions generated by the actual MAVEN oscillator is insufficient for ionospheric contributions to the frequency residual to be measurable.

Hence the two-way mode is adopted in which the frequency stability of the radio signal is referenced to the highly stable oscillators located on the ground at the DSN sites. Some early test observations were conducted in one-way mode and the ROSE team may elect to conduct additional one-way observations in the future. As of November 2017, the only one-way observations occurred on 19 February 2016 (egress) and 23 February 2016 (egress).

MAVEN has adopted a single-frequency mode because MAVEN only transmits to or receives from Earth at X-band. MAVEN does not do so at S-band or Ka-band, and its UHF Electra package is not used for communications with Earth.

Note that no ROSE data are stored on MAVEN. The initial ROSE data products are those collected on the ground at the DSN. Consequently, there is no need to downlink any ROSE data products from MAVEN to Earth.

ROSE conducts occultations on both ingress (MAVEN disappearing from view as seen from Earth) and egress (MAVEN re-appearing into view as seen from Earth). Acquisition by MAVEN of the uplinked radio signal as MAVEN re-emerges from behind Mars does not occur immediately. It typically takes MAVEN tens of seconds after emerging from behind Mars to acquire the uplinked radio signal. In this case, the final ROSE electron density profile does not extend below the closest approach distance of the ray path at the time of signal acquisition. A representative value for this minimum altitude is 70 km. By contrast, observations ingress occultations extend down to the solid surface. Even though this minimum altitude of 70 km is below the detectable ionosphere, it affects the data processing. Anchoring the transition between neutral and ionospheric refractivities, which have opposite signs, at zero by applying a baseline correction to the frequency residuals is an important part of the generation of electron density profiles from frequency residuals. Consequently, generation of electron density profiles is more challenging for egress occultations than for ingress occultations.

In principle, it is desirable to start a ROSE occultation observation well before the predicted ingress occultation and end the observation well after the predicted egress occultation. That would provide long series of measurements before the ingress occultation that are unaffected by conditions in the ionosphere or atmosphere of Mars and a similar series after the egress occultation. These provide useful baselines for the analysis of the ionospheric measurements. Yet only a limited amount of DSN time is available to MAVEN each week, typically two 8-hour passes per week. The requirement that MAVEN downlink all its onboard data during these DSN communications passes limits the amount of time that can be devoted to each ROSE occultation observation. Infrequent DSN passes and an orbital periapsis within the variable upper atmosphere of Mars mean that the MAVEN trajectory predicted for an upcoming occultation at the time when the observing commands are transmitted from Earth to MAVEN is often somewhat inaccurate. That can lead to errors on the order of tens of seconds in the time of an occultation. Consequently, ROSE observations do not always extend to as high an altitude as is desirable.

ROSE was originally planned to conduct a two-way radio occultations using the spacecraft high-gain antenna with a carrier-only signal (i.e., telemetry off). As the ROSE team gained experience, other types of occultations were conducted. Possibilities include one-way or two-way (three-way occultations are essentially equivalent to two-way occultations); high-gain antenna or low-gain antenna; and carrier-only or telemetry on.

2.1 Science Objectives

ROSE measures vertical profiles of the electron density in the ionosphere of Mars with an accuracy on the order of 10^3 cm^{-3}, a vertical resolution on the order of 1 km, and a vertical range on the order of 100-500 km. With these measurements, ROSE (1) determines the vertical structure of plasma in the ionosphere and (2) identifies the density, altitude, and width of the ionospheric density peak.

2.2 Investigation Operation

During an occultation observation, the MAVEN HGA is pointed towards Earth and a DSN antenna is pointed towards Mars. No commands are uplinked from Earth to MAVEN and no telemetry is downlinked from MAVEN to Earth. Instead, a DSN antenna transmits a carrier-only radio signal with a precisely-known frequency up to MAVEN, where it is received by the HGA. The MAVEN radio transceiver multiplies the received frequency by a known factor of 880/749, then uses the HGA to transmit a carrier-only radio signal at this frequency back down to Earth, where it is received by a DSN antenna. Typically transmission from Earth and reception at Earth occur at the same DSN antenna. At the DSN station, the received radio signal is sent to an RSR. The RSR records the in-phase and quadrature components of the received radio signal from approximately 500 seconds before MAVEN is occulted by Mars until approximately 500 seconds after MAVEN emerges from occultation. The total duration of the RSR recording is on the order of one hour. The RSSG processes the data recorded by the RSR to generate time series of received frequency for ingress and egress. These typically have a time step of 0.5 seconds and duration of 500 seconds. The RSSG also uses the transmitted uplink frequencies, trajectories of MAVEN and the DSN antenna, and measurements of environmental conditions at and above the DSN station to generate a time series of the frequency that would have been received in the absence of refraction in the ionosphere and atmosphere of Mars. The RSSG then generates a time series of the frequency residual, which is the difference between the observed and predicted received frequencies. Earth Received Time (ERT) (UTC) is used as the time reference for the received frequency and the frequency residual.

2.3 Measured parameters

No measurements occur onboard MAVEN. On Earth, at the DSN station, an RSR records the in-phase and quadrature components of the received radio signal. Properties of the transmitted radio signal are also recorded.

2.4 Operational Modes

ROSE has one operational mode.

2.5 Operational Considerations

Occultations do not occur on every MAVEN orbit. Occultations only occur if the MAVEN orbit plane is aligned such that MAVEN goes behind Mars as viewed from Earth. For instance, if the

Earth-Mars line lies in MAVEN's orbital plane, then the orbit is edge-on and occultations occur. Conversely, if the Earth-Mars line is perpendicular to MAVEN's orbital plane, then the orbit is face-on and occultations do not occur. When occultations do occur, one ingress occultation opportunity and one egress occultation opportunity occur per orbit. As the orbital geometry changes only slightly from one orbit to the next, occultations typically occur on every orbit for a few months (an occultation season), then do not occur on any orbits for the next few months.

MAVEN typically has two 8-hour DSN passes each week, one on Tuesday and one on Friday. During occultation seasons, ROSE generally has the opportunity to observe one ingress and one egress occultation during each DSN pass. No ROSE observations are conducted around solar conjunction, when communications between Earth and MAVEN are severely disrupted, or around MAVEN's occasional Deep Dip campaigns, when enhanced atmospheric drag makes occultation times uncertain and when mission operations efforts are focused on specialized Deep Dip operations.

Not all occultation opportunities offer sufficient scientific value to merit the resources that would be required to observe them. For instance, an occultation opportunity may only survey the ionosphere up to 130 km altitude. An electron density profile obtained from that occultation opportunity would not cover most of the ionosphere. Furthermore, the lack of a high-altitude baseline would cause the electron density uncertainty to be significantly greater than usual. Alternatively, another occultation opportunity may survey a large range of solar zenith angles at ionospheric altitudes. The process by which electron density profiles are derived from radio occultation observations assumes that the solar zenith angle and other key environmental factors are uniform throughout the vertical extent of the observation. When this assumption is strongly violated, confidence in the validity of a derived electron density profile is low.

The ROSE team predicts the start and end dates of occultation seasons several months in advance using long-range orbit predictions. At this time, they also make a preliminary assessment of which upcoming occultations would be worth observing. This information is provided to the MAVEN mission operations team. Typically, occultations within a week or so of the start and end of an occultation season are less suitable than those in the middle. Several weeks prior to the start of an occultation season, the ROSE team uses updated orbit predictions to make an updated assessment of which upcoming occultations would be worth observing. This information is provided to the MAVEN mission operations team, who collaborate with the DSN and RSSG to conduct the planned occultation observations. Towards the end of the occultation season, the ROSE team similarly decides when occultation observations should cease. This assessment is made several weeks before the end of occultation observations.

2.6 Ground Calibration

Since ROSE was conceived after MAVEN was launched, no ROSE-specific ground calibration of the MAVEN communications system was conducted. The performance of the DSN and its dedicated radio science equipment, such as the RSRs, is routinely monitored and evaluated. No ROSE-specific calibration of the DSN has been conducted.

2.7 In-flight Calibration

No in-flight calibration for ROSE has been conducted or is planned. Derived electron density profiles will be compared against similar measurements from earlier radio occultation experiments and from relevant MAVEN instruments, such as LPW or NGIMS. This will validate the data processing pipeline.

3 Data Overview

This section provides a high level description of archive organization under the PDS4 Information Model (IM) as well as the flow of the data from the spacecraft through delivery to PDS. Unless specified elsewhere in this document, the MAVEN ROSE archive conforms to version 1.8.0.0 of the PDS4 IM [4] and version 1.0.3.0 of the MAVEN mission schema. A list of the XML schema and schematron documents associated with this archive is provided in Table 5 below.

Table 5: MAVEN ROSE archive schema and schematron

XML Document	Steward	Product LID
PDS Core Schema, v. 1.8.0.0	PDS	urn:nasa:pds:system_bundle:xml_schema:pds-xml_schema
PDS Core Schematron, v. 1.8.0.0	PDS	urn:nasa:pds:system_bundle:xml_schema:pds-xml_schema
MAVEN Mission Schema, v. 1.0.3.0	MAVEN	urn:nasa:pds:system_bundle:xml_schema:mvn-xml_schema
MAVEN Mission Schematron, v. 1.0.3.0	MAVEN	urn:nasa:pds:system_bundle:xml_schema:mvn-xml_schema

3.1 Data Processing Levels

A number of different systems may be used to describe data processing level. Table 6 provides a description of these levels along with the equivalent designations used in other systems.

Table 6: Data processing level designations

PDS4 processing level	PDS4 processing level description	MAVEN Processing Level	CODMAC Level	NASA Level
Raw	Original data from an instrument. If compression, reformatting, packetization, or other translation has been applied to facilitate data transmission or storage, those processes are reversed so that the archived data are in a PDS approved archive format.	0	2	1A
Reduced	Data that have been processed beyond the raw stage but are not yet entirely independent of the instrument.	1	2	1A
Calibrated	Data converted to physical units entirely independent of the instrument.	2	3	1B

PDS4 processing level	PDS4 processing level description	MAVEN Processing Level	CODMAC Level	NASA Level
Derived	Results that have been distilled from one or more calibrated data products (for example, maps, gravity or magnetic fields, or ring particle size distributions). Supplementary data, such as calibration tables or tables of viewing geometry, used to interpret observational data, should also be classified as “derived” data if not easily matched to one of the other three categories.	3	4	2

3.2 Products

A PDS product consists of one or more digital and/or non-digital objects, and an accompanying PDS label file. Labeled digital objects are data products (i.e., electronically stored files). Labeled non-digital objects are physical and conceptual entities which have been described by a PDS label. PDS labels provide identification and description information for labeled objects. The PDS label defines a Logical Identifier (LID) by which any PDS labeled product is referenced throughout the system. In PDS4 labels are XML formatted ASCII files. More information on the formatting of PDS labels is provided in Appendices C-E. More information on the usage of LIDs and the formation of MAVEN LIDs is provided in Section 5.1.

3.3 Product Organization

The highest level of organization for PDS archives is the bundle. A bundle is a list of one or more related collection products which may be of different types. A collection is a list of one or more related basic products. Figure 1 below illustrates these relationships.

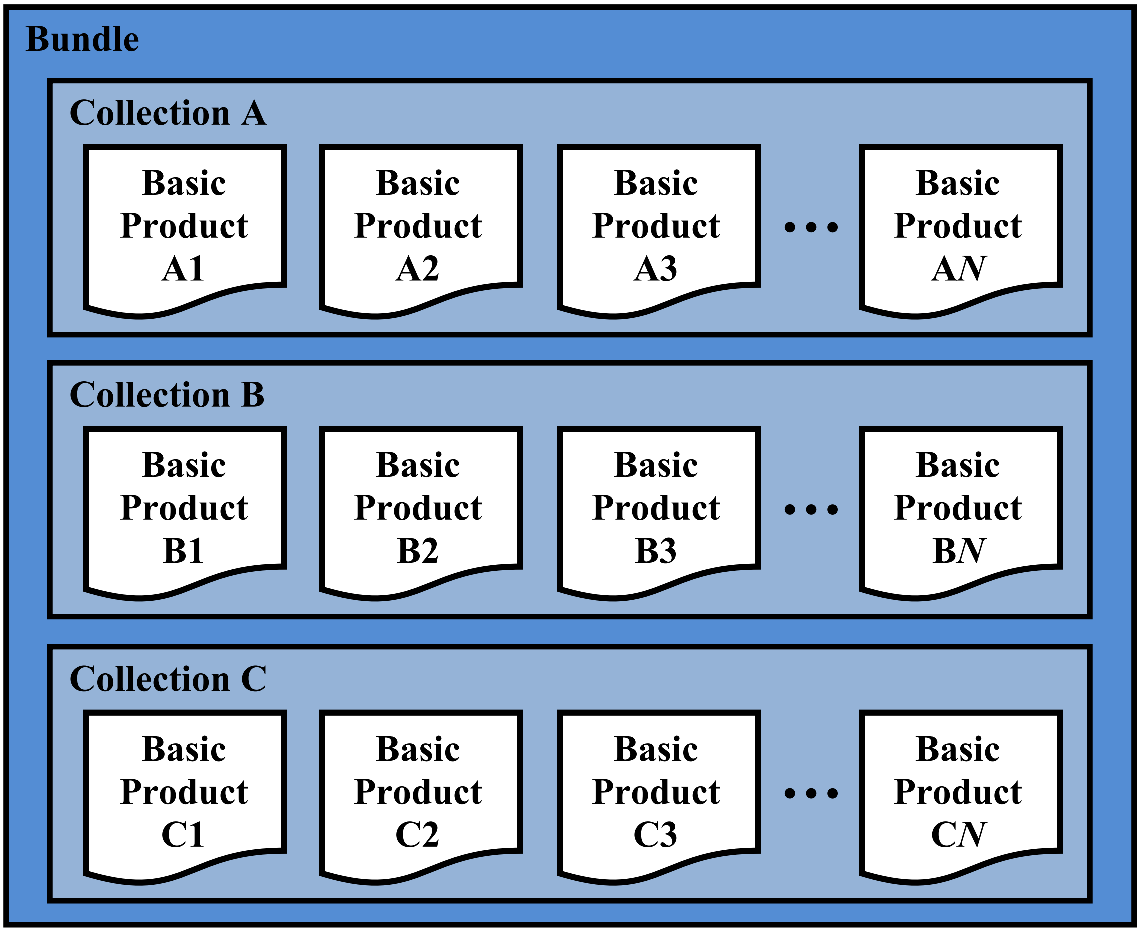

Figure 1: A graphical depiction of the relationship among bundles, collections, and basic products.

Bundles and collections are logical structures, not necessarily tied to any physical directory structure or organization. Bundle and collection membership is established by a member inventory list. Bundle member inventory lists are provided in the bundle product labels themselves. Collection member inventory lists are provided in separate collection inventory table files. Sample bundle and collection labels are provided in Appendices C and D, respectively.

3.3.1 Collection and Basic Product Types

Collections are limited to a single type of basic products. The types of archive collections that are defined in PDS4 are listed in Table 7.

Table 7: Collection product types

Collection Type	Description
Browse	Contains products intended for data characterization, search, and viewing, and not for scientific research or publication.
Calibration	Contains data and files necessary for the calibration of basic products.
Context	Contains products which provide for the unique identification of objects which form the context for scientific observations (*e.g.* spacecraft, observatories, instruments, targets, etc.).
Document	Contains electronic document products which are part of the PDS Archive.
Data	Contains scientific data products intended for research and publication.
SPICE	Contains NAIF SPICE kernels.
XML_Schema	Contains XML schemas and related products which may be used for generating and validating PDS4 labels.

3.4 Bundle Products

The ROSE data archive is organized into three bundles. A description of the bundles is provided in Table 8, and a more detailed description of the contents and format is provided in Section 5.2.

Table 8: ROSE bundles

Bundle Logical Identifier	PDS4 Reduction Level	Description	Data Provider
urn:nasa:pds:maven.rose.raw	Raw	Raw data concerning the radio signal transmitted from Earth and the radio signal received at Earth.	RSSG
urn:nasa:pds:maven.rose.calibrated	Calibrated	Calibrated data in physical units, consisting of frequency transmitted from Earth and predicted and residual frequency received at Earth.	RSSG
urn:nasa:pds:maven.rose.derived	Derived	Vertical profile of electron density at Mars.	ROSE

3.5 Data Flow

This section describes only those portions of the MAVEN data flow that are directly connected to archiving for ROSE. The SIS documents for other MAVEN instruments provide further information on the MAVEN data flow.

Raw and calibrated data files are created by the RSSG, then transferred from the RSSG to the SDC by the RSSG. Open loop receiver output (either from an RSR or from an OLR in RSR format) are transferred from the SDC to the ROSE ITF at Boston University, where they are renamed to follow the MAVEN file naming convention and labeled. In parallel, the PDS Radio Science Advisor (RSA) downloads the RSR/OLR files, creates BRO files in PDF format, and forwards them to the ROSE ITF by e-mail where they are converted to PDF/A and labeled.

The SKY calibrated data files, which contain the frequency residuals, are transferred from the SDC to the ROSE ITF at Boston University by the ROSE ITF. From these files, derived data files (EDP) are generated by the ROSE ITF and transferred from the ROSE ITF to the SDC by the ROSE ITF. The generation of EDP files requires accompanying information on the MAVEN trajectory in the form of SPICE files. These SPICE files are created by the MAVEN team as a routine aspect of mission operations. The ROSE ITF obtains them from the SDC. Other necessary SPICE files are generic and therefore obtained from the JPL Navigation and Ancillary Information Facility by the ROSE ITF. The derived data files are transferred from the SDC to the PDS RSA by the PDS RSA and renamed and labeled; the labeled derived data files are transferred from the PDS RSA to the SDC by the PDS RSA.

The above description is applicable to the start of the MAVEN ROSE investigation. Over time, the responsibilities of the PDS RSA were assumed by the ROSE ITF (labels) and the RSSG (BRO files).

At regular intervals, batches of MAVEN data files are transferred from the SDC to the PDS PPI Node by the SDC. These files are then ingested into the PDS archives.

Once the file renaming and labeling software created by the PDS RSA is running smoothly, this software and the MAVEN ROSE archiving activities of the PDS RSA will be transferred to the ROSE ITF.

4 Archive Generation

The ROSE archive products are produced by the ROSE ITF and the RSSG, with support from the PDS Planetary Plasma Interactions (PPI) Node at the University of California, Los Angeles (UCLA), and the PDS Radio Science Advisor (Dick Simpson, Stanford University). The archive volume creation process described in this section sets out the roles and responsibilities of each of these groups. The assignment of tasks has been agreed upon by all parties. Archived data received by the PPI Node from the ROSE team are made available to PDS users electronically as soon as practicable but no later than two weeks after the delivery and validation of the data.

4.1 Data Processing and Production Pipeline

The following sections describe the process by which data products in the ROSE bundles listed in Table 8 are produced. All levels refer to MAVEN processing levels (Table 6).

The ROSE science data products that are delivered to the SDC will be stored by the SDC for the duration of the project, and will be made available to the MAVEN team. The SDC will deliver archival-quality science data products to the PDS for distribution to the public and long-term archiving in accordance with the ROSE-PDS SIS (this document).

The RSSG and ROSE ITF will routinely generate Level 0, Level 2, and Level 3 science data products and deliver them to the SDC. Final ROSE products will be delivered to the SDC as soon as they are complete, no later than needed to meet the PDS delivery schedule in Table 10. The typical data user is expected to be most interested in the Level 3 derived science data products that contain vertical profiles of electron density.

The ROSE ITF and associated data providers will deliver validated science data products and associated metadata for PDS archiving to the SDC two weeks prior to every PDS delivery deadline.

The ROSE ITF will also provide the SDC with data product descriptions, appropriate for use by the MAVEN science team in using MAVEN science data products and consistent with PDS metadata standards.

4.1.1 Raw Data Production Pipeline

Raw (Level 0) files include TNF and RSR data files and BRO browse files. The TNF and RSR data files concern the radio signal transmitted from Earth and the radio signal received at Earth. They are standard radio science data products that are in a binary format. The accompanying browse files summarize quick-look processing of the received radio signal. The RSSG will generate the raw data files from observations made by the DSN, then transfer them to the SDC.

For each DSN tracking pass during which an occultation was observed, one TNF file is archived. Given MAVEN's 5-hour orbit and the 8-hour duration of a typical DSN tracking pass, up to two pairs of ingress/egress occultations can be observed in a single tracking pass. Typically, one pair is observed, but two pairs have been observed on occasion (such as 23 May 2017). Usually, but not always, both ingress and egress occultations are observed. For example, an egress occultation might not be observed if it spanned only a limited range of altitudes. If either ingress or egress, but not both, are observed, then one RSR file is archived for that observation. If both ingress and egress occultations are observed, then either one or two RSR files are archived. In the case that one RSR file is archived, it will contain data for both ingress and egress. In the case that two RSR files are archived, the ingress occultation will be associated with the RSR that has the earlier start time. Due to the tendency to use a wider bandwidth to observe egress occultations, an egress-only RSR file is likely to have a larger file size per unit time than the corresponding ingress-only RSR file. Consequently, one TNF file may be associated with between one and four RSR files. One BRO file is archived for each RSR file.

4.1.2 Calibrated Data Production Pipeline

Calibrated (Level 2) files include DLF and WEA calibration files and FUP and SKY data files. The DLF calibration file contains frequency predictions and the WEA calibration file contains records of local meteorological conditions at the DSN sites. They are ASCII files. The FUP and SKY data files are ASCII tables that contain time series of the transmitted frequency (FUP) and the predicted and residual received frequency (SKY). The RSSG will generate the calibrated calibration and data files from raw data files, then transfer them to the SDC. The PDS RSA will rename the calibrated data files, create labels for calibrated data files, and transfer them to the SDC. Once this process is running smoothly, the activities of the PDS RSA will be assumed by the ROSE ITF.

One DLF file and one FUP file is archived for each DSN tracking pass on which an occultation was observed. One SKY file is archived for each ingress occultation observed and one SKY file is archived for each egress occultation observed. Thus one RSR file may be associated with one or two SKY files. Even when an RSR file has yielded one SKY file, the start/stop times of the RSR and SKY files are not the same. The SKY file contains data collected when the appropriate operational mode (e.g., two-way) was established, whereas the RSR file includes data collected before this was established, data collected when the spacecraft was behind the solid body of Mars, and data collected after the appropriate operational mode ended. WEA files are cumulative, containing up to one year of data, and site-specific (Goldstone, Madrid, Canberra).

4.1.3 Derived Data Production Pipeline

Derived (Level 3) files include ION and TRO calibration files and EDP data files. The ION and TRO calibration files model ionospheric (ION) and tropospheric (TRO) conditions at the DSN sites. They are ASCII files. The EDP data files are ASCII tables that contain vertical profiles of electron density in the ionosphere of Mars. The derived calibration files will follow the same pipeline as the calibrated calibration (WEA, Level 2) files.

The ROSE ITF will generate the derived data files from the SKY calibrated data files and SPICE kernels that contain the reconstructed trajectory of MAVEN, then transfer them to the SDC. The PDS RSA will create labels for derived data files, then transfer them to the SDC. Once this process is running smoothly, the activities of the PDS RSA will be assumed by the ROSE ITF.

ION and TRO files are cumulative, containing up to one month of data. For each SKY file, either zero or one EDP files are archived. There are several reasons why a given SKY file might not be accompanied by an associated EDP file. First, the altitude range covered by the SKY file might be insufficient for the generation of a satisfactory EDP file, which could be due to the observation start time being too late, the observation stop time being too soon, or the orbit geometry being such that an adequate range of altitudes was not accessible on that orbit. Second, application of the current data processing method to the frequency residuals in a given SKY file has not yielded an electron density profile that the ROSE ITF deemed satisfactory. Further details concerning which SKY files yielded EDP files is provided in the readme file present in this bundle.

4.2 Data Validation

4.2.1 Investigation Team Validation

All ROSE derived (Level 3) data products will be checked by the ROSE ITF for accuracy and integrity. Since occultations occur relatively infrequently, data products for every individual occultation can be examined directly.

4.2.2 MAVEN Science Team Validation

The MAVEN science team will work with the same ROSE products that will be archived in the PDS. If any calibration issues or other anomalies are noted, they will be addressed by the ROSE ITF.

4.2.3 PDS Peer Review

The PPI Node will conduct a full peer review of all of the data types that the ROSE team intends to archive. The review data will consist of fully formed bundles populated with candidate final versions of the data and other products and the associated metadata.

Table 9: MAVEN ROSE PDS review schedule

Date	Activity	Responsible Team
30 June 2017	Signed SIS deadline	ROSE ITF
30 June 2017	Sample data products due	RSSG, PDS RSA, ROSE ITF
July 2017 to August 2017	Preliminary PDS Peer Review (SIS, sample data files)	PDS
September 2017	Lien resolution	ROSE ITF
15 October 2017	Release #1: Data due to PDS	RSSG, PDS RSA, ROSE ITF
October 2017 to November 2017	PDS Delta Review	PDS
15 November 2017	Release #1: Public release	PDS

Reviews will include a preliminary delivery of sample products for validation and comment by PDS PPI and Engineering Node personnel and others. The ROSE ITF will then address the comments that arise from the preliminary review, and generate a full archive delivery that will undergo another review.

Reviewers will include MAVEN Project and ROSE team representatives, researchers from outside the MAVEN project, and PDS personnel from the PPI and Engineering Nodes.

Reviewers will examine the sample data products to determine whether the data meet the stated science objectives of the instrument and the needs of the scientific community and to verify that the accompanying metadata are accurate and complete. The peer review committee will identify any liens on the data that must be resolved before the data can be "certified" by PDS, a process by which data are made public as minor errors are corrected.

In addition to verifying the validity of the review data, this review will be used to verify that the data production pipeline by which the archive products are generated is robust. Additional deliveries made using this same pipeline will be validated at the PPI Node, but will not require additional external review.

As expertise with the experiment and data develops, the ROSE team may decide that changes to the structure or content of its archive products are warranted. Any changes to the archive products or to the data production pipeline will require an additional round of review to verify that the revised products still meet the original scientific and archival requirements or whether those criteria have been appropriately modified. Whether subsequent reviews require external reviewers will be decided on a case-by-case basis and will depend upon the nature of the changes. A comprehensive record of modifications to the archive structure and content is kept in the Modification_History object of the collection and bundle products.

4.3 Data Transfer Methods and Delivery Schedule

The SDC is responsible for delivering data products to the PDS for long-term archiving. While ITFs are primarily responsible for the design and generation of calibrated and derived data archives, the archival process is managed by the SDC.

The first PDS delivery is scheduled to occur in November 2017 and contain data products from occultation observations acquired 3 months before the delivery date or earlier. Subsequent deliveries will occur at three month intervals after the first delivery and will ensure that all data are delivered to the PDS within 6 months of collection.

If it becomes necessary to reprocess data which have already been delivered to the archive, the ITFs will reprocess the data and deliver them to the SDC for inclusion in the next archive delivery. A summary of this schedule is provided in Table 10 below.

Table 10: Archive bundle delivery schedule

Bundle Logical Identifier	First Delivery to PDS	Delivery Schedule	Estimated Delivery Size
urn:nasa:pds:maven.rose.raw	November 2017	Every 3 months	500 MB
urn:nasa:pds:maven.rose.calibrated	November 2017	Every 3 months	4 MB
urn:nasa:pds:maven.rose.derived	November 2017	Every 3 months	1 MB

Each delivery will comprise both data and ancillary data files organized into directory structures consistent with the archive design described in Section 5, and combined into a deliverable file(s) using file archive and compression software. When these files are unpacked at the PPI Node in the appropriate location, the constituent files will be organized into the archive structure.

Archive deliveries are made in the form of a "delivery package". Delivery packages include all of the data being transferred along with a transfer manifest, which helps to identify all of the products included in the delivery, and a checksum manifest which helps to ensure that integrity of the data is maintained through the delivery. The format of these files is described in Section 6.4.

Data are transferred electronically (using the *ssh* protocol) from the SDC to an agreed upon location within the PPI file system. PPI will provide the SDC a user account for this purpose. Each delivery package is made in the form of a compressed *tar* or *zip* archive. Only those files that have changed since the last delivery are included. The PPI operator will decompress the data, and verify that the archive is complete using the transfer and MD5 checksum manifests that were included in the delivery package. Archive delivery status will be tracked using a system defined by the PPI Node.

Following receipt of a data delivery, PPI will reorganize the data into its PDS archive structure within its online data system. PPI will also update any of the required files associated with a PDS archive as necessitated by the data reorganization. Newly delivered data are made available publicly through the PPI online system once accompanying labels and other documentation have been validated. It is anticipated that this validation process will require no more than fourteen working days from receipt of the data by PPI. However, the first few data deliveries may require more time for the PPI Node to process before the data are made publicly available.

4.4 Data Product and Archive Volume Size Estimates

ROSE data products consist of files that are specific either to one occultation or to an ingress/egress pair of occultations. Files vary in size depending on the duration of the observation, but the expected variation is a factor of a few.

4.5 Data Validation

Routine data deliveries to the PDS are validated at the PPI Node to ensure that the delivery meets PDS standards, and that the data conform to the SIS as approved in the peer review. As long as there are no changes to the data product formats, or data production pipeline, no additional external review will be conducted.

4.6 Backups and Duplicates

The PPI Node keeps three copies of each archive product. One copy is the primary online archive copy, another is an onsite backup copy, and the final copy is an off-site backup copy. Once the archive products are fully validated and approved for inclusion in the archive, copies of the products are sent to the National Space Science Data Center (NSSDC) for long-term archive in a NASA-approved deep-storage facility. The PPI Node may maintain additional copies of the archive products, either on or off-site as deemed necessary. The process for the dissemination and preservation of ROSE data is illustrated in Figure 2.

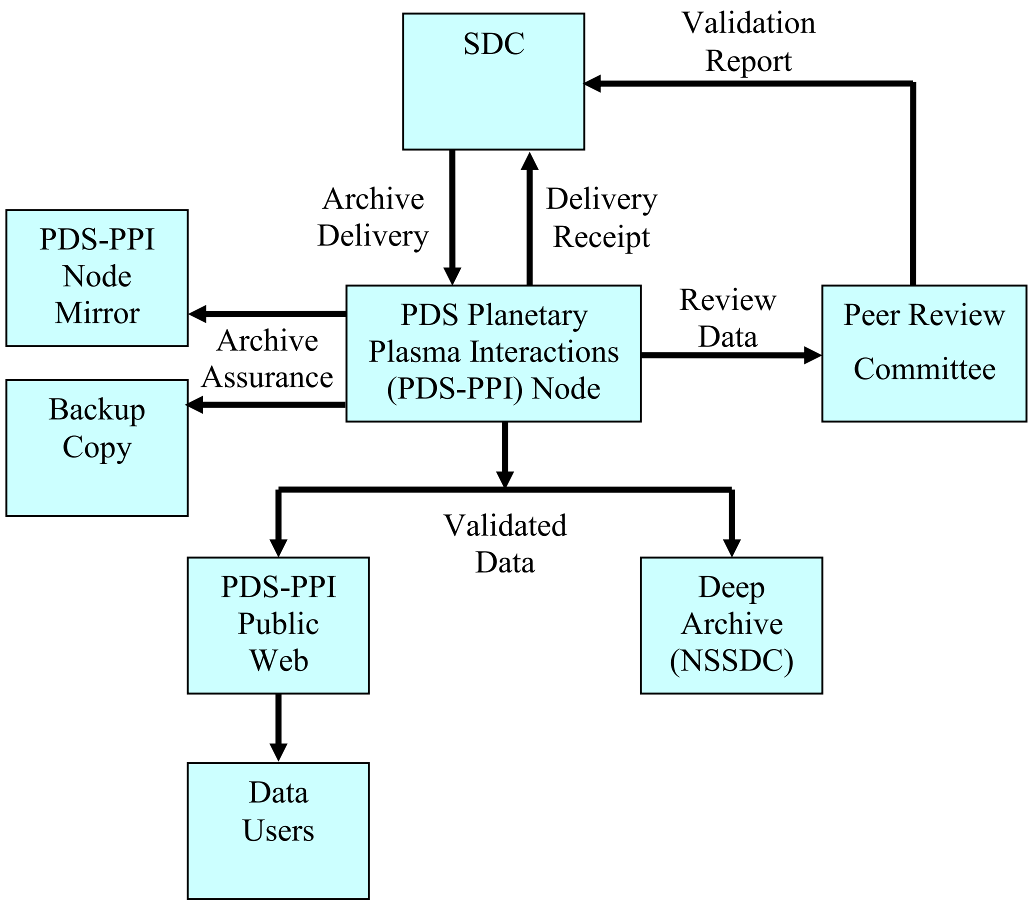

Figure 2: Duplication and dissemination of ROSE archive products at PDS/PPI.

5 Archive Organization and Naming

This section describes the basic organization of a ROSE bundle, and the naming conventions used for the product logical identifiers, and bundle, collection, and basic product filenames.

5.1 Logical Identifiers

Every product in PDS is assigned an identifier which allows it to be uniquely identified across the system. This identifier is referred to as a Logical Identifier or LID. A LIDVID (Versioned Logical Identifier) includes product version information, and allows different versions of a specific product to be referenced uniquely. A product's LID and VID are defined as separate attributes in the product label. LIDs and VIDs are assigned by the entity generating the labels and are formed according to the conventions described in Sections 5.1.1 and 5.1.2 below. The uniqueness of a product's LIDVID may be verified using the PDS Registry and Harvest tools.

5.1.1 LID Formation

LIDs take the form of a Uniform Resource Name (URN). LIDs are restricted to ASCII lower case letters, digits, dash, underscore, and period. Colons are also used, but only to separate prescribed components of the LID. Within one of these prescribed components dash, underscore, or period are used as separators. LIDs are limited in length to 255 characters.

MAVEN ROSE LIDs are formed according to the following conventions:

- Bundle LIDs are formed by appending a bundle specific ID to the MAVEN ROSE base ID:

  urn:nasa:pds:maven.rose.<bundle ID>

  Since all PDS bundle LIDs are constructed this way, the combination of maven.rose. .<bundle ID> must be unique across all bundles archived with the PDS.

- Collection LIDs are formed by appending a collection specific ID to the collection's parent bundle LID:

  urn:nasa:pds:maven.rose.<bundle ID>:<collection ID>

  Since the collection LID is based on the bundle LID, which is unique across PDS, the only additional condition is that the collection ID must be unique across the bundle. Collection IDs correspond to the collection type (e.g. "browse", "data", "document", etc.). Additional descriptive information may be appended to the collection type (e.g. "data-raw", "data-calibrated", etc.) to ensure that multiple collections of the same type within a single bundle have unique LIDs.

- Basic product LIDs are formed by appending a product specific ID to the product's parent collection LID:

  urn:nasa:pds:maven.rose.<bundle ID>:<collection ID>:<product ID>

  Since the product LID is based on the collection LID, which is unique across PDS, the only additional condition is that the product ID must be unique across the collection.

The ROSE bundle LIDs are urn:nasa.pds:maven.rose.raw, urn:nasa.pds:maven.rose.calibrated, and urn:nasa.pds:maven.rose.derived. Collection LIDs are listed in Tables 11, 12, and 14. Product LIDs for a given collection are given in the portion of section 5.2 that describes that collection.

5.1.2 VID Formation

Product version ID's consist of major and minor components separated by a "." (M.n). Both components of the VID are integer values. The major component is initialized to a value of "1", and the minor component is initialized to a value of "0". The minor component resets to "0" when the major component is incremented.

5.2 ROSE Archive Contents

The ROSE archive includes three bundles: rose.raw, rose.calibrated, and rose.derived. The rose.raw bundle contains raw (Level 0) data files and other files that are naturally associated with them. The other files are not necessarily raw Level 0 files. The rose.calibrated bundle contains calibrated (Level 2) data files. The rose.derived bundle contains derived (Level 3) data files. The following sections describe the contents of each of these bundles in greater detail.

5.2.1 rose.raw Bundle

The rose.raw bundle contains four types of collections: data, calibration, browse, and document. The two data collections contain raw data concerning the radio signal transmitted from Earth and the radio signal received at Earth. The four calibration collections contain a prediction for the frequency of the radio signal received at Earth and information on the effects of Earth's ionosphere, troposphere, and weather on the experiment. The one browse collection contains browse plots that provide an overview of received data. The one document collection contains documents that describe this bundle. This bundle contains eight collections as listed in Table 11.

Table 11: Collections in the rose.raw bundle

Collection LID	Description
urn:nasa.pds:maven.rose.raw:data.tnf	Radiometric data associated with the radio signal transmitted from Earth. Tracking and Navigation Service Data File (TNF) formatted as DSN Tracking System Data Archival Format TRK-2-34.

Collection LID	Description
urn:nasa.pds:maven.rose.raw:data.rsr	Radiometric data associated with the radio signal received at Earth by an open-loop receiver. Radio Science Receiver Data File formatted as DSN Radio Science Receiver Standard Formatted Data Unit.
urn:nasa.pds:maven.rose.raw:calibration.dlf	Predicted frequency of the radio signal received at Earth.
urn:nasa.pds:maven.rose.raw:calibration.ion	Ionospheric calibration (ION) files that provide information concerning conditions in Earth's ionosphere along the line of sight between the DSN antenna and MAVEN
urn:nasa.pds:maven.rose.raw:calibration.tro	Tropospheric calibration (TRO) files that provide information concerning conditions in Earth's troposphere along the line of sight between the DSN antenna and MAVEN
urn:nasa.pds:maven.rose.raw:calibration.wea	DSN Weather (WEA) files that provide information concerning weather conditions at the DSN station
urn:nasa.pds:maven.rose.raw:browse.bro	Browse plots (BRO) that provide an overview of received data
urn:nasa.pds:maven.rose.raw:document	Documents that describe the raw Science Data Bundle

5.2.1.1 rose.raw:data.tnf Data Collection

TNF data files capture radiometric tracking data for delivery to navigation and radio science users from the Telecommunications Services at JPL. The format and content of the TNF data product is documented in DSN document 820-013, TRK-2-34 (DSN Tracking System Data Archival Format). This document is included in the ROSE raw document collection.

TNF data files typically cover the full duration of a DSN tracking pass. In most tracking passes, one ingress/egress occultation pair is observed. However, in some tracking passes, two ingress/egress occultation pairs are observed. In both cases, only one TNF data file is archived for the tracking pass.

Files in this data collection were provided by the RSSG and are classified as MAVEN Level 0. They are binary files. As outlined in Appendix B, the file naming convention is:

mvn_rse_l0_tnf_<YYYY><MM><DD> T<hh><mm><ss>_v<xx>_r<yy>.dat

The Product LID for this file is:

mvn_rse_l0_tnf_<YYYY><MM><DD> t<hh><mm><ss>

5.2.1.2 rose.raw:data.rsr Data Collection

RSR data files contain data recorded by a Radio Science Receiver (RSR). This is a computer-controlled open loop receiver that digitally records a spacecraft signal through the use of an analog to digital converter (ADC) and up to four digital filter sub-channels. The digital samples from each sub-channel are stored to disk in one second records in real time. In near real time the one second records are partitioned and formatted into a sequence of RSR Standard Format Data Units (SFDUs). Included in each RSR SFDU are the ancillary data necessary to reconstruct the signal represented by the recorded data samples. Data from one of the four sub-channels is forwarded by the RSSG to the SDC for ROSE analysis. The format and content of the RSR data product is documented in DSN document 820-013, 0159-Science (Radio Science Receiver Standard Formatted Data Unit (SFDU)). This document is included in the ROSE raw document collection.

A given ingress/egress pair of occultations is recorded in either one or two RSR data files. If two RSR data files are archived for an ingress/egress pair of occultations, then ingress frequency residuals were obtained from the RSR data file with the earlier start time and egress frequency residuals were obtained from the RSR data file with the later start time. If two RSR data files are archived, then the egress RSR file usually has a larger bandwidth than the corresponding ingress RSR file. This leads to a larger file size per unit time for the egress RSR file than the ingress RSR file.

In 2019, the DSN upgraded from using Radio Science Receivers to using Open Loop Receivers. From the perspective of the ROSE investigation, this change had minimal impact. The text of this document generally reflects the early use of the Radio Science Receivers. Data recorded on Open Loop Receivers are formatted as if recorded on a Radio Science Receiver. Hence an RSR data file may contain data recorded on an Open Loop Receiver.

Files in this data collection were generated by the RSSG and are classified as MAVEN Level 0. They are binary files. As outlined in Appendix B, the file naming convention is:

mvn_rse_l0_rsr_<YYYY><MM><DD> T<hh><mm><ss>_v<xx>_r<yy>.dat

The Product LID for this file is:

mvn_rse_l0_rsr_<YYYY><MM><DD> t<hh><mm><ss>

5.2.1.3 rose.raw:calibration.dlf Calibration Collection

DLF calibration files contain frequency predictions for radio science observations. A DLF data file is generated as a subset of a Downlink Equipment Monitor (DEM) file with Radio Metric Predictions (RMP). These DLF files contain the predicted frequency of the radio signal received at Earth excluding the effects of refraction in the ionosphere and atmosphere of Mars. The format and content of the DLF data product is documented in an ad hoc revision of DSN document 820-013, 0159-Science (Radio Science Receiver Standard Formatted Data Unit (SFDU)) that was previously used by Mars Reconnaissance Orbiter. This document is included in the ROSE raw document collection. If ranging observations occurred during the period covered by a DLF file, then this information was deleted from the DLF file prior to archiving. As of January 2019, this affected low-gain antenna observations only.

One DLF file is archived for each DSN tracking pass on which an occultation was observed.

Files in this data collection were generated by the RSSG and are classified as MAVEN Level 2. They are ASCII files. As outlined in Appendix B, the file naming convention is:

mvn_rse_l2_dlf_<YYYY><MM><DD> T<hh><mm><ss>_v<xx>_r<yy>.tab

The Product LID for this file is:

mvn_rse_l2_dlf_<YYYY><MM><DD> t<hh><mm><ss>

5.2.1.4 rose.raw:calibration.ion Calibration Collection

Ionospheric (ION) calibration files document and predict Earth ionospheric conditions. The format and content of the ION data product is documented in DSN document 820-013, TRK-2-23 (Media Calibration Data Interface). This document is included in the ROSE raw document collection.

ION files are cumulative, containing up to one month of data.

Files in this data collection were collected and forwarded by the RSSG and are classified as MAVEN Level 3. They are ASCII files. As outlined in Appendix B, the file naming convention is:

mvn_rse_l3_ion_<YYYY><MM><DD> T<hh><mm><ss>_v<xx>_r<yy>.txt

The Product LID for this file is:

mvn_rse_l3_ion_<YYYY><MM><DD> t<hh><mm><ss>

5.2.1.5 rose.raw:calibration.tro Calibration Collection

Tropospheric Calibration (TRO) files document and predict Earth tropospheric conditions. The format and content of the TRO data product is documented in DSN document 820-013, TRK-2-23 (Media Calibration Data Interface). This document is included in the ROSE raw document collection.

TRO files are cumulative, containing up to one month of data.

Files in this data collection were collected and forwarded by the RSSG and are classified as MAVEN Level 3. They are ASCII files. As outlined in Appendix B, the file naming convention is:

mvn_rse_l3_tro_<YYYY><MM><DD> T<hh><mm><ss>_v<xx>_r<yy>.txt

The Product LID for this file is:

mvn_rse_l3_tro_<YYYY><MM><DD> t<hh><mm><ss>

5.2.1.6 rose.raw:calibration.wea Calibration Collection

Weather (WEA) calibration files record local meteorological conditions at the DSN sites. Conditions at Goldstone (Deep Space Communications Complex 10), Canberra (Deep Space

Communications Complex 40), and Madrid (Deep Space Communications Complex 60) are reported in separate files. The format and content of the WEA data product is documented in DSN document 820-013, TRK-2-24 (Weather Data Interface). This document is included in the ROSE raw document collection.

WEA files are cumulative, containing up to one year of data, and site-specific (Goldstone, Madrid, Canberra).

Files in this data collection were generated by the RSSG and are classified as MAVEN Level 2. They are ASCII files. As outlined in Appendix B, the file naming convention is:

mvn_rse_l2_w<aa>_<YYYY><MM><DD> T<hh><mm><ss>_v<xx>_r<yy>.tab

where <aa> is 10 for Goldstone, 40 for Canberra, and 60 for Madrid.

The Product LID for this file is:

mvn_rse_l2_w<aa>_<YYYY><MM><DD> t<hh><mm><ss>

where <aa> is 10 for Goldstone, 40 for Canberra, and 60 for Madrid.

5.2.1.7 rose.raw:browse.bro Browse Collection

Browse (BRO) files are composite PDF files summarizing quick-look processing of received data. Each PDF file is sized to fit on a single 8.5 x 11 inch page. Browse files show time series of the power and power spectrum of the received signal. They also summarize key characteristics of the received data, including start time, stop time, sampling rate, and DSN antenna. Browse files may be helpful in quickly scanning data to determine which files are suitable for closer study.

One BRO file is archived for each RSR file.

In 2019, the DSN upgraded from using Radio Science Receivers to using Open Loop Receivers. Note that the histogram included in a BRO file based upon Open Loop Receiver data may appear filled, which is unusual. This occurs when the granularity of the histogram is too fine for the data samples used. This issue was addressed by software updates for the Open Loop Receiver, so should only affect measurements from the first half of 2019.

The appearance and production of files in this data collection changed on 14 November 2021. For observations prior to this date, BRO files were generated by the PDS Radio Science Advisor, Dick Simpson (Stanford University). After this date, they were generated by the PDS Radio Science Subnode (JPL). Files in this data collection are classified as MAVEN Level 0. They are binary files. The file naming convention is:

mvn_rse_l0_bro_<YYYY><MM><DD> T<hh><mm><ss>_v<xx>_r<yy>.pdf

The Product LID for this file is:

mvn_rse_l0_bro_<YYYY><MM><DD> t<hh><mm><ss>

5.2.1.8 rose.raw:document Document Collection

The rose.raw:document collection contains documents which are useful for understanding and using ROSE data products. The SIS, TNF, RSR, ION/TRO, and WEA documents are PDF/A files, which are binary files. The ad hoc 0159 document that describes the DLF data files and the OVW document are ASCII text. Table 12 contains a list of the documents included in this collection, along with the LID, and responsible group. Following this a brief description of each document is also provided.

Table 12: Documents in the rose.raw:document collection

Document Name	LID	Responsibility
MAVEN ROSE Archive SIS	urn:nasa:pds:maven.rose.raw:document:sis	ROSE Team
TRK-2-34 (TNF)	urn:nasa:pds:maven.rose:raw.document:tnf	RSSG
0159 (RSR)	urn:nasa:pds:maven.rose:raw.document:rsr	RSSG
Ad hoc 0159 (DLF)	urn:nasa:pds:maven.rose:raw.document:dlf	RSSG
TRK-2-23 (ION, TRO)	urn:nasa:pds:maven.rose:raw.document:med	RSSG
TRK-2-24 (WEA)	urn:nasa:pds:maven.rose:raw.document:wea	RSSG
Overview (OVW)	urn:nasa:pds:maven.rose:raw.document:ovw	ROSE Team

MAVEN ROSE Archive SIS – describes the format and content of the ROSE PDS data archive, including descriptions of the data products and associated metadata, and the archive format, content, and generation pipeline (this document)

TRK-2-23 (TNF) – describes the format of TNF files

0159 – describes the format of RSR files

Ad hoc 0159 – describes the format of DLF files

TRK-2-23 – describes the format of ION and TRO files, collectively known as media calibration files (MED)

TRK-2-24 – describes the format of WEA files

Overview – describes key characteristics of observations, particularly whether a given observation used a one-way or two-way method, used the MAVEN high-gain antenna or low-gain antenna, and involved a carrier-only signal or a signal with telemetry

5.2.2 rose.calibrated Bundle

The rose.calibrated bundle contains two types of collections: data and calibration. The one data collection contains time series of the predicted and residual frequency received at Earth in physical units. The one calibration collection contains time series of the frequency transmitted from Earth in physical units. This bundle contains two collections as listed in Table 13.

Table 13: Collections in the rose.calibrated bundle

Collection LID	Description

Collection LID	Description
urn:nasa.pds:maven.rose.calibrated:calibration.fup	Time series of frequency transmitted from Earth
urn:nasa.pds:maven.rose.calibrated:data.sky	Time series of predicted and residual frequency received at Earth

5.2.2.1 rose.calibrated:calibration.fup Calibration Collection

FUP files contain a time series of the transmitted frequency. The radiometric properties of the radio signal transmitted from Earth to MAVEN are provided in raw TNF data files. For many applications, the transmitted frequency is the most useful of those properties. This data collection contains a time series of the transmitted frequency based on the accompanying raw TNF data file.

The quantities ETTYEAR, ETTDOY, and ETTSEC provide the UTC time when the radio signal is transmitted from Earth (Earth transmission time, ETT). ETTYEAR is an integer that states the year, ETTDOY is an integer that states the day of year, and ETTSEC is a number that states the number of seconds past midnight. The quantity DFUPDT provides the rate of change of frequency. The quantity FUP provides frequency. It is a number that states the frequency of the radio signal transmitted from Earth.

One FUP file is archived for each DSN tracking pass on which an occultation was observed.

Files in this data collection were generated by the RSSG and are classified as MAVEN Level 2. They are ASCII files. As outlined in Appendix B, the file naming convention is:

mvn_rse_l2_fup_<YYYY><MM><DD>T<hh><mm><ss>_v<xx>_r<yy>.tab

The Product LID for this file is:

mvn_rse_l2_fup_<YYYY><MM><DD> t<hh><mm><ss>

5.2.2.2 rose.calibrated:data.sky Data Collection

SKY files contain a time series of the frequency residual. The radiometric properties of the radio signal received at Earth from MAVEN are provided in raw RSR data files. For many applications, the received frequency is the most useful of those properties. More specifically, two components of the received frequency: the received frequency at Earth predicted in the absence of refraction at Mars (predicted sky frequency) and the change in the received frequency at Earth due to refraction at Mars (frequency residual). The actual received frequency is the sum of these two components. The actual received frequency is found from the raw RSR data file. The predicted sky frequency is found from the time series of frequency transmitted from Earth, the frequency multiplier (880/749) imposed onboard MAVEN, the reconstructed trajectories of the DSN antenna and the MAVEN spacecraft, and corrections for the effects of Earth's environment and general relativity. The transmitted frequency is obtained from the rose.calibrated:data:fup data file, the frequency multiplier is a fixed property of the MAVEN communications system, the trajectories are obtained from the reconstructed SPICE kernels for the relevant objects, and corrections for the effects of Earth's environment are obtained from the rose.derived:calibration:ion, rose.derived:calibration:tro, and rose.derived:calibration:wea data files.

The quantities ERTYEAR, ERTDOY, and ERTSEC provide the UTC time when the radio signal is received at Earth (Earth received time, ERT). ERTYEAR is an integer that states the year, ERTDOY is an integer that states the day of year, and ERTSEC is a number that states the number of seconds past midnight. The quantity FSKY is a number that provides the predicted sky frequency and the quantity FRESID is a number that provides the frequency residual. The actual received frequency is the sum of FSKY and FRESID.

One SKY file is archived for each ingress occultation observed and one SKY file is archived for each egress occultation observed. Thus one RSR file may be associated with one or two SKY files.

Files in this data collection were generated by the RSSG and are classified as MAVEN Level 2. They are ASCII files. As outlined in Appendix B, the file naming convention is:

mvn_rse_l2_sky_<YYYY><MM><DD> T<hh><mm><ss>_v<xx>_r<yy>.tab

The Product LID for this file is:

mvn_rse_l2_sky_<YYYY><MM><DD> t<hh><mm><ss>

5.2.3 rose.derived Bundle

The rose.derived bundle contains vertical profiles of electron density. This bundle contains one collection as listed in Table 14.

Table 14: Collections in the rose.derived bundle

Collection LID	Description
urn:nasa.pds:maven.rose.derived:data.edp	Vertical profile of electron density and related information

5.2.3.1 rose.derived:data.edp Data Collection

EDP files contain the electron density profile. The frequency residual is non-zero due to refraction in the ionosphere and atmosphere of Mars. A vertical profile of electron density in the ionosphere of Mars can be determined from a time series of frequency residuals during an occultation. Ionospheric electron density profiles were first measured using this method by Mariner 4 in 1965, and implementations of this method have been discussed extensively in the literature. A detailed technical description of how the ROSE team has implemented this method is Withers and Moore (2020) How to process radio occultation data: 2. From time series of two-way, single-frequency frequency residuals to vertical profiles of ionospheric properties. Radio Science, 55, doi:10.1029/2019RS007046. ROSE data processing software are available in Withers et al. (2020) Correction to: The MAVEN Radio Occultation Science Experiment (ROSE). Space Sci Rev 216, 79 (2020). https://doi.org/10.1007/s11214-020-00714-6. The method is summarized here.

The time series of frequency residuals is inspected. Data points that are clearly erroneous are either deleted or replaced. Data points at the high altitude end of the time series can be erroneous due to effects associated with changes in the operations of the communications system as the occultation observations begin or end. Points at the high altitude end of the time series that are clear outliers are deleted. Data points at the low altitude end of the time series can be erroneous due to effects associated with diffraction of the signal by the surface of Mars. Points at the low altitude end of the time series that are clearly distinct from the general trend in the data are deleted. Data points elsewhere in the time series that are clearly inconsistent with the surrounding portion of the time series are replaced by an average of adjacent points.

A linear baseline correction is applied to the time series of frequency residuals. This ensures that the frequency residual is consistent with zero for ray paths whose closest approach to Mars is above the ionosphere. It also ensures that the resultant electron densities are consistent with zero at altitudes above the ionosphere and at the transition near 80 km altitude between refractivity due to plasma and neutrals, which have opposite signs. This correction accounts for errors in the trajectory information used to generate the frequency residuals and for unmodeled effects of Earth's neutral atmosphere, Earth's ionosphere, and the solar wind.

Due to refraction of the radio signal as it passes up and down through the atmosphere and ionosphere of Mars, the ray paths differ from those that they would have if the solid body of Mars were surrounded by vacuum. Those differences in the ray paths can be described by a set of angles. The first angle is the angle between the actual direction of propagation of the uplink signal at the transmitter (Earth) and the vacuum direction. Similarly, the second angle concerns the direction of propagation of the uplink signal at the receiver (spacecraft), the third angle concerns the downlink signal at the transmitter (spacecraft), and the fourth angle concerns the downlink signal at the receiver (Earth). These four unknown angles are related to the measured frequency residual and known positions and velocities by three equations, Equations A1, A2, and A3 of Jenkins et al. (1994), "Radio occultation studies of the Venus atmosphere with the Magellan spacecraft: 2. Results from the October 1991 experiments", Icarus, 110, 79-94. A fourth equation is required in order to determine the set of four angles for a given radio ray given a measured frequency residual and other known quantities. Since the ionosphere is the primary focus of these MAVEN observations, we assume that all refraction is caused by plasma. In this case, the ratio of the total bending angle of the uplink ray to the total bending angle of the downlink ray is equal to the square of the turn-around ratio in the frequency (880/749). This gives the required fourth equation. With the frequency residual and these four equations, the four angles, the total bending angles on the uplink and downlink paths, and the uplink and downlink impact parameters can be found. The ionospheric refractivity as a function of radial distance can be derived from the downlink bending angle and the average of the uplink and downlink impact parameters using the standard Abel transform (Equation 20 of Withers et al. (2014), "How to process radio occultation data: 1. From time series of frequency residuals to vertical profiles of atmospheric and ionospheric properties", Planetary and Space Science, 101, 77-88). Electron density is found from refractivity using Equation 23 of this article. The archived electron densities are accompanied by 1-sigma uncertainties. The same uncertainty is assigned to all altitudes in a profile. It is calculated as the root-mean-square of the electron density at high altitudes above the ionosphere. Specifically, above 400 km. If the electron density profile does not extend above 400 km, then a default value of 5×10^9 m^{-3} is adopted. This is on the order of uncertainties from other profiles, but larger than their average value.

One key point should be noted. The reported electron density profiles often include negative values between the surface and roughly 80 km altitude. The magnitudes of these values tend to increase exponentially with decreasing altitude. These are not realistic electron densities. Instead, they reflect a deliberate design decision for the data processing pipeline. In other experiments, the full refractivity profile is typically separated into a low-altitude region with positive refractivity due to the neutral atmosphere and a high-altitude region with negative refractivity due to the ionosphere. Refractivity is then converted into electron or neutral number density using the appropriate conversion factors. For ROSE, by contrast, refractivities at all altitudes have been assumed to be caused by plasma as outlined above. Since the refractivity of the neutral atmosphere has the opposite sign from the refractivity of the ionosphere, the derived profile includes erroneous negative electron densities at low altitudes. Derived electron densities are deliberately archived for all altitudes, not merely those where the electron densities exceed their uncertainty. Data users are encouraged to pay attention to derived electron densities at very high altitudes and at the transition near 80 km altitude between ionospheric effects and neutral atmospheric effects: these can be used to establish the confidence that should be placed on ionospheric features of interest to the data user.

Although neutral atmospheric profiles can be derived from archived frequency residuals, the ROSE team has not generated neutral atmospheric profiles. The current focus of the investigation is the ionosphere and the data processing method described above is not appropriate for the neutral atmosphere. Specifically, the assumed relationship between uplink and downlink bending angles that closes the set of equations is valid for the ionosphere, but invalid for the neutral atmosphere. Users who wish to generate neutral atmospheric profiles should start from the frequency residuals. The reported refractivity profiles are not appropriate for conversion into neutral atmospheric profiles.

This data collection contains two distinct types of information. First, information specific to the time and place where the downlink ray has a closest approach distance to Mars of 3550 km. This radial distance is a representative ionospheric altitude. Quantities that are representative of the entire occultation are reported as this type of information, such as date, latitude, and longitude. Second, information that is expressed as a function of radial distance. Quantities such as electron density and its uncertainty are reported as this type of information.

Closest approach distances are found for each Earth received time in the time series of frequency residuals. Quantities appropriate for the ray whose closest approach distance is closest to 3550 km are reported. When the vertical extent of the occultation encompasses this altitude, the closest approach distance of the relevant ray is generally within 1 km of 3550 km. However, some occultation observations started or stopped at inconvenient times, with the result that the reported values come from a ray with a closest approach distance that could be hundreds of km above 3550 km. These cases can be identified by inspection of the vertical extent of the reported profiles.

The first type of information is presented as follows. All information specific to 3550 km have the suffix “3550”. The quantity UTCTIME3550 provides time. It is a string that states the UTC time at Mars when the downlink ray has closest approach distance of 3550 km. The quantity AREOCENTRICLAT3550 provides latitude. It is a number that states the areocentric latitude of the downlink ray at time UTCTIME3550. The quantity AREOCENTRICLON3550 provides longitude. It is a number that states the areocentric longitude of the downlink ray at time UTCTIME3550. The quantity SZA3550 provides solar zenith angle. It is a number that states the solar zenith angle of the downlink ray at time UTCTIME3550. The quantity LTST3550 provides local true solar time. It is a number that states the local true solar time of the downlink ray at time UTCTIME3550. The quantity LS3550 provides the areocentric longitude of the Sun, a measure of season, or Ls. It is a number that states the areocentric longitude of the Sun at time UTCTIME3550. The quantity NXFLAG identifies whether this is an ingress or egress occultation. It is an integer that is 0 for an ingress occultation and 1 for an egress occultation. The quantity BSPFILENAME provides the name of the SPICE trajectory kernel used to derive electron densities from frequency residuals. It is a string. Data users may acquire this file from other areas of the MAVEN data archive. The quantity UPLINKBAND identifies the band used for the uplink radio signal. It is a string where "X" denotes X-band and "0" denotes a one-way occultation that does not have an uplink signal. For all two-way occultations, this quantity is "X". The quantity UPLINKANTENNA identifies the DSN antenna used for uplink. It is an integer for two-way occultations. For one-way occultations that do not have an uplink signal, it is "00". The quantity DOWNLINKBAND identifies the band used for the downlink radio signal. It is a string where "X" denotes X-band. The quantity DOWNLINKANTENNA identifies the DSN antenna used for downlink. It is an integer. The quantity MSOX3550 provides the x-coordinate of position in the MSO reference frame. It is a number that states the x-coordinate in the MSO reference frame of the downlink ray at time UTCTIME3550. The quantity MSOY3550 provides the y-coordinate of position in the MSO reference frame. It is a number that states the y-coordinate in the MSO reference frame of the downlink ray at time UTCTIME3550. The quantity MSOZ3550 provides the z-coordinate of position in the MSO reference frame. It is a number that states the z-coordinate in the MSO reference frame of the downlink ray at time UTCTIME3550. The quantity MSOLAT3550 provides latitude in the MSO reference frame. It is a number that states the latitude in the MSO reference frame of the downlink ray at time UTCTIME3550. The quantity MSOLON3550 provides longitude in the MSO reference frame. It is a number that states the longitude in the MSO reference frame of the downlink ray at time UTCTIME3550. The MSO reference frame is defined in the SPICE MAVEN frames kernel.

The second type of information is presented as follows. The quantity RADIUS provides the radial distances for the vertical profile of electron density. It is a number that states the distance from the center of mass of Mars. The quantity ALTITUDEMOLA provides the altitudes for the vertical profile. It is a number that states the altitude relative to the MOLA areoid. ALTITUDEMOLA is derived from RADIUS. The radius of the MOLA areoid at AREOCENTRICLAT3550 and AREOCENTRICLON3550 is found from the 4 pixel per degree MOLA Mission Experiment Gridded Data Record (MEGDR) that is available online at http://pds-geosciences.wustl.edu/missions/mgs/megdr.html. This areoid radius is subtracted from all values of RADIUS for this occultation to give ALTITUDEMOLA. The quantities NELEC and SNELEC provide the electron densities and their 1-sigma uncertainties for the vertical profile. They are numbers. The process of determining a vertical profile of electron density from a time series of frequency residuals generates a set of intermediate data products that may be useful to some users. Hence they are provided here. The quantity BENDINGANGLEDOWN provides the bending angle of the downlink ray. It is a number. The quantity IMPACTPARAMDOWN provides the impact parameter of the downlink ray. It is a number. REFRACTIVITYDOWN provides the refractivity, defined as the refractive index minus one, at radial distance RADIUS and the frequency of the downlink ray. It is a number. The quantities ERTYEAR, ERTDOY, and ERTSEC provide the UTC time at which the downlink ray was received at Earth (Earth received time, ERT). ERTYEAR is an integer that states the year, ERTDOY is an integer that states the day of year, and ERTSEC is a number that states the number of seconds past midnight. The quantity ERTDATETIME provides the same Earth received time in a date/time format. It is a string. The quantity OCCTIME provides the UTC time at which the downlink ray has its closest approach to Mars. It is a string. The quantity OCCAREOCENTRICLAT provides the areocentric latitude of the downlink ray at its closest approach to Mars. It is a number. The quantity OCCAREOCENTRICLON provides the areocentric longitude of the downlink ray at its closest approach to Mars. It is a number. The quantity OCCSZA provides the solar zenith angle of the downlink ray at its closest approach to Mars. It is a number. The quantity OCCLTST provides the local true solar time of the downlink ray at its closest approach to Mars. It is a number. The quantity OCCLS provides the areocentric longitude of the Sun at time OCCTIME. It is a number. The quantity OCCFRESID provides the original frequency residual for this ray. This quantity is also reported in the associated SKY file. It is a number. The quantity OCCFRESIDADJ provides the frequency residual for this ray after the baseline correction. This quantity is used to derive the electron density. It is a number. The quantity IMPACTPARAMAVERAGE provides the mean of the impact parameters of the downlink ray and its associated uplink ray. This quantity is used to derive the electron density. It is a number. The quantity OCCMSOX provides the x-coordinate in the MSO reference frame of the downlink ray at its closest approach to Mars. It is a number. The quantity OCCMSOY provides the y-coordinate in the MSO reference frame of the downlink ray at its closest approach to Mars. It is a number. The quantity OCCMSOZ in the MSO reference frame provides the z-coordinate of the downlink ray at its closest approach to Mars. It is a number. The quantity OCCMSOLAT provides the latitude in the MSO reference frame of the downlink ray at its closest approach to Mars. It is a number. The quantity OCCMSOLON provides the longitude in the MSO reference frame of the downlink ray at its closest approach to Mars. It is a number.

Rows within an EDP file are organized by RADIUS, which increases from the start to the end of the file. Consequently, ingress EDP files have late times at the start of the file and early times at the end of the file, whereas egress EDP files have early times at the start of the file and late times at the end of the file.

Multiple coordinate systems have been used at Mars. This data archive primarily uses radial distance, areocentric latitude, and areocentric longitude. Altitude is derived from radial distance as described above. Data users should ensure that these coordinates are used correctly.

For each SKY file, either zero or one EDP files are archived. There are several reasons why a given SKY file might not be accompanied by an associated EDP file. First, the altitude range covered by the SKY file might be insufficient for the generation of a satisfactory EDP file, which could be due to the observation start time being too late, the observation stop time being too soon, or the orbit geometry being such that an adequate range of altitudes was not accessible on that orbit. Second, application of the current data processing method to the frequency residuals in a given SKY file has not yielded an electron density profile that the ROSE ITF deemed satisfactory. Further details concerning which SKY files yielded EDP files is provided in the readme file present in this bundle.

Files in this data collection were generated by the ROSE ITF and are classified as MAVEN Level 3. They are ASCII files. The file naming convention is:

mvn_rse_l3_edp_<YYYY><MM><DD> T<hh><mm><ss>_v<xx>_r<yy>.tab

The Product LID for this file is:

mvn_rse_l3_edp_<YYYY><MM><DD> t<hh><mm><ss>

6 Archive Product Formats

Data that comprise the ROSE archives are formatted in accordance with PDS specifications, see *Planetary Science Data Dictionary* [4], *PDS Data Provider's Handbook* [2], and *PDS Standards Reference* [3]. This section provides details on the formats used for each of the products included in the archive.

6.1 Data File Formats

This section describes the format and record structure of each of the data file types.

6.1.1 Structure of Files in the rose.raw Bundle

rose.raw:data.tnf (TNF) and rose.raw:data.rsr (RSR) files will be archived as PDS4 Table_Binary objects. They are binary files. The contents of the ROSE TNF and RSR files are described by documents in the ROSE raw document collection and by their PDS4 labels. Users of TNF files should note that records delivered originally by the DSN were in time order, with records for different TNF data types interleaved. Retaining that structure would have made the PDS label many times larger than the data file itself. To keep the size of the label manageable, the original file was sorted so that all records of a single TNF data type are together. The blocks of homogeneous records were then concatenated – TNF data type 0, followed by TNF data type 1, ... followed by TNF data type 17. When there were no records of a given TNF data type, that block was omitted. Within each block, the records remain in time order. The label is still long, since each block is a Table_Binary with many records containing many fields. But there will never be more than 18 blocks and never more than 18 Table_Binary definitions. The document referenced here correctly describes the record formats. Note, however, that the records are no longer in absolute time order. They are in time order within each block and the blocks are ordered by TNF data type.

rose.raw:data.dlf (DLF) files will be archived as one or more PDS4 Table_Character objects stored contiguously in a single file. Each table contains frequencies for one of several operational modes (one-way, two-way, or three-way). They are ASCII files. The contents of the ROSE DLF files are described by documents in the ROSE raw document collection and by their PDS4 labels.

rose.raw:calibration.ion (ION) and rose.raw:calibration.tro (TRO) files will be archived as PDS4 Table_Delimited objects. They are ASCII files. The contents of the ROSE ION and TRO files are described by documents in the ROSE raw document collection and by their PDS4 labels.

Rose.raw:calibration.w<aa> (WEA) files will be archived as PDS4 Table_Character objects where "aa" set to "10" denotes Goldstone, "40" denotes Canberra, and "60" denotes Madrid. They are ASCII files. The contents of the ROSE WEA files are described by documents in the ROSE raw document collection and by their PDS4 labels.

rose.raw:browse.bro (BRO) files will be archived with the PDS in PDF/A format. They are binary files.

6.1.2 Structure of Files in the rose.calibrated Bundle

rose.calibrated:calibration.fup (FUP) and rose.calibrated:data.sky (SKY) files will be archived with the PDS as fixed-width ASCII (Table_Character) files. They are ASCII files. The contents of these files are described in Tables 15-16 below.

Table 15: Contents for rose:calibrated:calibration.fup files

Field Name	Data Type	Description
ETTYEAR	ASCII_Integer	Year of UTC time when radio signal was transmitted from Earth (Earth transmit time, ETT) [year]
ETTDOY	ASCII_Integer	Day of year (DOY) of UTC time when radio signal was transmitted from Earth (Earth transmit time, ETT) [day]
ETTSEC	ASCII_Real	Seconds past midnight of UTC time when radio signal was transmitted from Earth (Earth transmit time, ETT) [second]
DFUPDT	ASCII_Real	Rate of change of the frequency of the signal transmitted from Earth at ETTYEAR, ETTDOY, ETTSEC [Hz/s]
FUP	ASCII_Real	Frequency of signal transmitted from Earth at ETTYEAR, ETTDOY, and ETTSEC [Hz].

Table 16: Contents for rose:calibrated:data.sky files

Field Name	Data Type	Description
ERTYEAR	ASCII_Integer	Year of UTC time when radio signal was received at Earth (Earth receive time, ERT) [year]
ERTDOY	ASCII_Integer	Day of year (DOY) of UTC time when radio signal was received at Earth (Earth receive time, ERT) [day]
ERTSEC	ASCII_Real	Seconds past midnight of UTC time when radio signal was received at Earth (Earth receive time, ERT) [second]
FSKY	ASCII_Real	Predicted sky frequency; the received frequency at Earth predicted in the absence of refraction at Mars [Hz]
FRESID	ASCII_Real	Frequency residual; the change in received frequency at Earth due to refraction at Mars. The actual received frequency at Earth is the sum of FSKY and FRESID. [Hz]

6.1.3 Structure of Files in the rose.derived Bundle

rose.derived:data.edp (EDP) files will be archived as a pair of PDS4 Table_Character objects stored contiguously in a single file. They are ASCII files. The contents of these files are described in Table 17 below. The first table has one record; the second table has many records.

Table 17: Contents for rose.derived:data.edp files

Field Name (first table)	Data Type	Description
UTCTIME3550	ASCII_String	UTC time at Mars when downlink ray has closest approach distance of 3550 km (one element per file)
AREOCENTRICLAT3550	ASCII_Real	Areocentric latitude of closest approach point of downlink ray at time UTCTIME3550 [degrees north] (one element per file)
AREOCENTRICLON3550	ASCII_Real	Areocentric longitude of closest approach point of downlink ray at time UTCTIME3550 [degrees east] (one element per file)
SZA3550	ASCII_Real	Solar zenith angle of closest approach point of downlink ray at time UTCTIME3550 [degrees] (one element per file)
LTST3550	ASCII_Real	Local true solar time of closest approach point of downlink ray at time UTCTIME3550 [hours] (one element per file)
LS3550	ASCII_Real	Areocentric longitude of the Sun (Ls) at time UTCTIME3550 [degrees] (one element per file)
NXFLAG	ASCII_Integer	0 if ingress occultation, 1 if egress occultation [dimensionless] (one element per file)
BSPFILENAME	ASCII_String	SPICE trajectory kernel (one element per file)
UPLINKBAND	ASCII_String	Band used for uplink radio signal, X for X-band, 0 if no uplink signal
UPLINKANTENNA	ASCII_Integer	Identifier of DSN antenna used for uplink radio signal, 00 if no uplink signal
DOWNLINKBAND	ASCII_String	Band used for downlink radio signal, X for X-band
DOWNLINKANTENNA	ASCII_Integer	Identifier of DSN antenna used for downlink radio signal

MSOX3550	ASCII_Real	X-coordinate in the MSO reference frame of closest approach point of downlink ray at time UTCTIME3550 [km] (one element per file)
MSOY3550	ASCII_Real	Y-coordinate in the MSO reference frame of closest approach point of downlink ray at time UTCTIME3550 [km] (one element per file)
MSOZ3550	ASCII_Real	Z-coordinate in the MSO reference frame of closest approach point of downlink ray at time UTCTIME3550 [km] (one element per file)
MSOLAT3550	ASCII_Real	Latitude in the MSO reference frame of closest approach point of downlink ray at time UTCTIME3550 [degrees north] (one element per file)
MSOLON3550	ASCII_Real	Longitude in the MSO reference frame of closest approach point of downlink ray at time UTCTIME3550 [degrees east] (one element per file)
Field Name (second table)	**Data Type**	**Description**
RADIUS	ASCII_Real	Radial distance [km]
ALTITUDEMOLA	ASCII_Real	Altitude with respect to MOLA areoid [km]
NELEC	ASCII_Real	Electron density [m^{-3}]
SNELEC	ASCII_Real	1-sigma uncertainty in electron density [m^{-3}]
BENDINGANGLEDOWN	ASCII_Real	Bending angle of downlink ray [radians]
IMPACTPARAMDOWN	ASCII_Real	Impact parameter of downlink ray [km]
REFRACTIVITYDOWN	ASCII_Real	Refractivity at radial distance RADIUS and frequency of downlink ray [dimensionless]
ERTYEAR	ASCII_Integer	Year of UTC time when radio signal was received at Earth (Earth receive time, ERT) [year]
ERTDOY	ASCII_Integer	Day of year (DOY) of UTC time when radio signal was received at Earth (Earth receive time, ERT) [day]
ERTSEC	ASCII_Real	Seconds past midnight of UTC time when radio signal was received at Earth (Earth receive time, ERT) [second]
ERTDATETIME	ASCII_String	Date/time representation of UTC time when radio signal was received at Earth (Earth receive time)
OCCTIME	ASCII_String	UTC time at which the downlink ray has its closest approach to Mars

OCCAREOCENTRICLAT	ASCII_Real	Areocentric latitude of the downlink ray at its closest approach to Mars [degrees north]
OCCAREOCENTRICLON	ASCII_Real	Areocentric longitude of the downlink ray at its closest approach to Mars [degrees east]
OCCSZA	ASCII_Real	Solar zenith angle of the downlink ray at its closest approach to Mars [degrees]
OCCLTST	ASCII_Real	Local true solar time of the downlink ray at its closest approach to Mars [hours]
OCCLS	ASCII_Real	Areocentric longitude of the Sun at time OCCTIME [degrees]
OCCFRESID	ASCII_Real	Original frequency residual for this ray, also reported in the associated SKY file [Hz]
OCCFRESIDADJ	ASCII_Real	Frequency residual for this ray after the baseline correction [Hz]
IMPACTPARAMAVERAGE	ASCII_Real	Mean of the impact parameters of the downlink ray and its associated uplink ray [km]
OCCMSOX	ASCII_Real	X-coordinate in the MSO reference frame of the downlink ray at its closest approach to Mars [km]
OCCMSOY	ASCII_Real	Y-coordinate in the MSO reference frame of the downlink ray at its closest approach to Mars [km]
OCCMSOZ	ASCII_Real	Z-coordinate in the MSO reference frame of the downlink ray at its closest approach to Mars [km]
OCCMSOLAT	ASCII_Real	Latitude in the MSO reference frame of the downlink ray at its closest approach to Mars [degrees north]
OCCMSOLON	ASCII_Real	Longitude in the MSO reference frame of the downlink ray at its closest approach to Mars [degrees east]

6.2 Document Product File Formats

Documents are provided in either Adobe Acrobat PDF/A or plain ASCII text format. Other versions of the document (including HTML, Microsoft Word, etc.) may be included as well.

6.3 PDS Labels

PDS labels are ASCII text files written, in the eXtensible Markup Language (XML). All product labels are detached from the digital files (if any) containing the data objects they describe (except Product_Bundle). There is one label for every product. Each product, however, may contain one or more data objects. The data objects of a given product may all reside in a single file, or they may be stored in multiple separate files. PDS4 label files must end with the file extension ".xml".

The structure of PDS label files is governed by the XML documents described in Section 6.3.1.

6.3.1 XML Documents

For MAVEN ROSE, PDS labels will conform to the PDS master schema based upon the version of the PDS Information Model specified in Table 5 for structure, and the version of the PDS schematron specified in Table 5 for content. By use of an XML editor these documents may be used to validate the structure and content of the product labels. A list of the XML documents associated with this archive is included in the XML_Schema collection section for each bundle.

Examples of PDS labels required for the ROSE archive are shown in Appendix C (bundle products), Appendix D (collection products), and Appendix E (data products).

6.4 Delivery Package

Data transfers from the SDC to the PDS are accomplished using delivery packages. Delivery packages include the following required elements:

1. The package which consists of a compressed bundle of the products being transferred.
2. A transfer manifest which maps each product's LIDVID to the physical location of the product label in the package after uncompression.
3. A checksum manifest which lists the MD5 checksum of each file included in the package after uncompression.

ROSE archive delivery packages (including the transfer and checksum manifests) for delivery to PDS are produced at the MAVEN SDC.

6.4.1 The Package

The directory structure used for the delivery package is described in Appendix F. Delivery packages are compressed using tar/gzip and are transferred electronically using the ssh protocol.

6.4.2 Transfer Manifest

TBD

6.4.3 Checksum Manifest

The checksum manifest contains an MD5 checksum for every file included as part of the delivery package. This includes both the PDS product labels and the files containing the digital objects which they describe. The format used for a checksum manifest is the standard output generated by the md5deep utility. Details of the structure of the checksum manifest are provided in Appendix F.

The checksum manifest is external to the delivery package, and is not an archive product. As a result, it does not require a PDS label.

Appendix A Support Staff and Cognizant People

Table 18: Archive support staff

ROSE team			
Name	**Address**	**Phone**	**Email**
Paul Withers	Center for Space Physics, 725 Commonwealth Avenue, Boston, MA 02215, USA	+1 617 353 1531	withers@bu.edu
Marianna Felici	Center for Space Physics, 725 Commonwealth Avenue, Boston, MA 02215, USA	+1 617 353 5990	mfelici@bu.edu

UCLA			
Name	**Address**	**Phone**	**Email**
Steven Joy PPI Operations Manager	IGPP, University of California 405 Hilgard Avenue Los Angeles, CA 90095-1567 USA	+1 310 825 3506	sjoy@igpp.ucla.edu
Joseph Mafi PPI Data Engineer	IGPP, University of California 405 Hilgard Avenue Los Angeles, CA 90095-1567 USA	+1 310 206 6073	jmafi@igpp.ucla.edu

Appendix B Naming Conventions for MAVEN Science Data Files

This section describes the naming convention used for science data files for the MAVEN mission.

Raw (MAVEN Level 0):

mvn_<inst>_<grouping>_l0_< YYYY><MM><DD>_v<xxx>.dat

with the exception of ROSE MAVEN Level 0 data, which follow the naming convention used for higher levels. The nominal Level 0 convention is not appropriate for ROSE because there may be multiple instances of a given type of ROSE raw file on a single day.

Level 1, 2, 3+:

mvn_<inst>_<level>_<descriptor>_<YYYY><MM><DD>T<hh><mm><ss>_v<xx>_r<yy>.<ext>

Table 19: File naming convention code descriptions

Code	Description
<inst>	3-letter instrument ID
<grouping>	Three-letter code: options are all, svy, and arc for all data, survey data, and archive data respectively. Primarily for PF to divide their survey and archive data at Level 0.
<YYYY>	4-digit year
<MM>	2-digit month, *e.g.* 01, 12
<DD>	2-digit day of month, *e.g.* 02, 31
<hh>	2-digit hour, separated from the date by T. OPTIONAL.
<mm>	2-digit minute. OPTIONAL.
<ss>	2-digit second. OPTIONAL.
v<xx>	3-digit (L0) or 2-digit (L1+) major revision number: For Level 0 data: increments whenever Level 0 data are reprocessed, typically to complete partial days or to fill in data gaps. For Level 1, 2, 3+ data: increments with a significant change in the processing algorithm or instrument calibration parameters. Typically triggers reprocessing of the entire data set.
r<yy>	2-digit minor revision number: increments whenever the data are regenerated without a change to the major revision. This can occur for a variety of reasons, typically to fill in missing science data or to apply new or updated ancillary data, such as SPICE kernels.
<descriptor>	A description of the data. Defined by the creator of the dataset. There are no underscores in the value.
<ext>	File type extension: fits, txt, cdf, png
<level>	A code indicating the MAVEN processing level of the data (valid values: l1, l2, l3). See Section 3.1, Table 6, for level definitions.

The optional T<hh><mm><ss> field is used for ROSE occultations. All elements of this field are present. The field indicates the start time of the data contained in the file. If omitted, the data within the file span one UT day, with times ranging from 00:00:00 to 23:59:59 UTC (or 23:59:60 when a leap second occurs). Data do not necessarily start at 00:00:00 or end at 23:59:59 (or 23:59:60 when a leap second occurs), and data gaps may occur within the file.

Table 20: File naming convention instrument codes

Instrument name	<instrument>
IUVS	iuv
NGIMS	ngi
LPW	lpw
MAG	mag
SEP	sep
SWIA	swi
SWEA	swe
STATIC	sta
PF package	pfp
ACC	acc
ROSE	rse

Appendix C Sample Bundle Product Label

This section provides a sample bundle product label.
(bundle_maven_rose_calibrated_1.0.xml)


```
<?xml version="1.0" encoding="UTF-8"?>
<?xml-model href="http://pds.nasa.gov/pds4/pds/v1/PDS4_PDS_1900.sch"
  schematypens="http://purl.oclc.org/dsdl/schematron"?>
<Product_Bundle
  xmlns="http://pds.nasa.gov/pds4/pds/v1"
  xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
  xsi:schemaLocation="
    http://pds.nasa.gov/pds4/pds/v1
    http://pds.nasa.gov/pds4/pds/v1/PDS4_PDS_1900.xsd
  ">
  <Identification_Area>
    <logical_identifier>urn:nasa:pds:maven.rose.calibrated</logical_identifier>
    <version_id>1.0</version_id>
    <title>MAVEN ROSE Calibrated Data Bundle</title>
    <information_model_version>1.9.0.0</information_model_version>
    <product_class>Product_Bundle</product_class>
    <Citation_Information>
      <publication_year>2017</publication_year>
      <description>
        This bundle contains the predicted and residual frequency received at Earth, and
        transmitted from Earth.
      </description>
    </Citation_Information>
    <Modification_History>
      <Modification_Detail>
        <modification_date>2017-11-28</modification_date>
        <version_id>1.0</version_id>
        <description>
          This is the initial release of the MAVEN ROSE calibrated data bundle. Coverage
includes
          2016-02-19 to 2017-06-27.
        </description>
      </Modification_Detail>
    </Modification_History>
  </Identification_Area>
  <Context_Area>
    <Time_Coordinates>
      <start_date_time>2016-02-19T15:10:35.000Z</start_date_time>
      <stop_date_time>2017-06-27T22:07:07.000Z</stop_date_time>
    </Time_Coordinates>
    <Primary_Result_Summary>
```

```
      <purpose>Science</purpose>
      <processing_level>Calibrated</processing_level>
      <Science_Facets>
        <domain>Ionosphere</domain>
        <discipline_name>Particles</discipline_name>
        <facet1>Electrons</facet1>
      </Science_Facets>
    </Primary_Result_Summary>
    <Investigation_Area>
      <name>Mars Atmosphere and Volatile EvolutioN Mission</name>
      <type>Mission</type>
      <Internal_Reference>
        <lid_reference>urn:nasa:pds:context:investigation:mission.maven</lid_reference>
        <reference_type>bundle_to_investigation</reference_type>
      </Internal_Reference>
    </Investigation_Area>
    <Observing_System>
      <Observing_System_Component>
        <name>MAVEN</name>
        <type>Spacecraft</type>
        <Internal_Reference>

<lid_reference>urn:nasa:pds:context:instrument_host:spacecraft.maven</lid_reference>
          <reference_type>is_instrument_host</reference_type>
        </Internal_Reference>
      </Observing_System_Component>
      <Observing_System_Component>
        <name>Radio Science Instrument</name>
        <type>Instrument</type>
        <Internal_Reference>
          <lid_reference>urn:nasa:pds:context:instrument:rss.maven</lid_reference>
          <reference_type>is_instrument</reference_type>
        </Internal_Reference>
      </Observing_System_Component>
    </Observing_System>
    <Target_Identification>
      <name>Mars</name>
      <type>Planet</type>
      <Internal_Reference>
        <lid_reference>urn:nasa:pds:context:target:planet.mars</lid_reference>
        <reference_type>bundle_to_target</reference_type>
      </Internal_Reference>
    </Target_Identification>
  </Context_Area>
  <Reference_List>
  </Reference_List>
```

```
  <Bundle>
    <bundle_type>Archive</bundle_type>
    <description>
      This bundle contains the predicted and residual frequency received at Earth, and
      transmitted from Earth.
    </description>
  </Bundle>
  <File_Area_Text>
    <File>
      <file_name>readme_maven_rose_calibrated_1.0.txt</file_name>
      <local_identifier>readme</local_identifier>
      <creation_date_time>2017-11-22T23:06:34</creation_date_time>
      <md5_checksum>5cff5385ea680037ac707a271b43680e</md5_checksum>
      <comment>
        This file contains a brief overview of the MAVEN ROSE calibrated data bundle.
      </comment>
    </File>
    <Stream_Text>
      <name>readme_maven_rose_calibrated_1.0.txt</name>
      <offset unit="byte">0</offset>
      <object_length unit="byte">4696</object_length>
      <parsing_standard_id>7-Bit ASCII Text</parsing_standard_id>
      <description>
        This file contains a brief overview of the MAVEN ROSE calibrated data bundle.
      </description>
      <record_delimiter>Carriage-Return Line-Feed</record_delimiter>
    </Stream_Text>
  </File_Area_Text>
  <Bundle_Member_Entry>
    <lidvid_reference>urn:nasa:pds:maven.rose.calibrated:data.sky::1.0</lidvid_reference>
    <member_status>Primary</member_status>
    <reference_type>bundle_has_data_collection</reference_type>
  </Bundle_Member_Entry>
  <Bundle_Member_Entry>

<lidvid_reference>urn:nasa:pds:maven.rose.calibrated:calibration.fup::1.0</lidvid_reference>
    <member_status>Primary</member_status>
    <reference_type>bundle_has_calibration_collection</reference_type>
  </Bundle_Member_Entry>
  <Bundle_Member_Entry>
    <lidvid_reference>urn:nasa:pds:maven.rose.calibrated:document::1.0</lidvid_reference>
    <member_status>Primary</member_status>
    <reference_type>bundle_has_document_collection</reference_type>
  </Bundle_Member_Entry>
</Product_Bundle>
```

Appendix D Sample Collection Product Label

This section provides a sample collection product label.
(collection_maven_rose_calibrated_l2_sky_1.0.xml)


```xml
<?xml version="1.0" encoding="UTF-8"?>
<?xml-model href="http://pds.nasa.gov/pds4/pds/v1/PDS4_PDS_1900.sch"
  schematypens="http://purl.oclc.org/dsdl/schematron"?>

<Product_Collection
  xmlns="http://pds.nasa.gov/pds4/pds/v1"
  xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
  xmlns:mvn="http://pds.nasa.gov/pds4/mission/mvn/v1"
  xsi:schemaLocation="
    http://pds.nasa.gov/pds4/pds/v1
    http://pds.nasa.gov/pds4/pds/v1/PDS4_PDS_1900.xsd
   ">
  <Identification_Area>
    <logical_identifier>urn:nasa:pds:maven.rose.calibrated:data.sky</logical_identifier>
    <version_id>1.0</version_id>
    <title>MAVEN ROSE Sky and Resudual Frequencies Data Collection</title>
    <information_model_version>1.9.0.0</information_model_version>
    <product_class>Product_Collection</product_class>
    <Citation_Information>
      <publication_year>2017</publication_year>
      <description>
        Time series of predicted and residual frequency received at Earth.
      </description>
    </Citation_Information>
    <Modification_History>
      <Modification_Detail>
        <modification_date>2017-11-28</modification_date>
        <version_id>1.0</version_id>
        <description>MAVEN ROSE initial release</description>
      </Modification_Detail>
    </Modification_History>
  </Identification_Area>
  <Context_Area>
    <Time_Coordinates>
      <start_date_time>2016-02-19T21:30:00.250Z</start_date_time>
      <stop_date_time>2017-06-27T19:32:06.750Z</stop_date_time>
    </Time_Coordinates>
    <Primary_Result_Summary>
      <purpose>Science</purpose>
      <processing_level>Calibrated</processing_level>
      <Science_Facets>
```

```
        <domain>Magnetosphere</domain>
        <discipline_name>Radio Science</discipline_name>
      </Science_Facets>
    </Primary_Result_Summary>
    <Investigation_Area>
      <name>Mars Atmosphere and Volatile EvolutioN Mission</name>
      <type>Mission</type>
      <Internal_Reference>
        <lid_reference>urn:nasa:pds:context:investigation:mission.maven</lid_reference>
        <reference_type>collection_to_investigation</reference_type>
      </Internal_Reference>
    </Investigation_Area>
    <Observing_System>
      <Observing_System_Component>
        <name>MAVEN</name>
        <type>Spacecraft</type>
        <Internal_Reference>

<lid_reference>urn:nasa:pds:context:instrument_host:spacecraft.maven</lid_reference>
          <reference_type>is_instrument_host</reference_type>
        </Internal_Reference>
      </Observing_System_Component>
      <Observing_System_Component>
        <name>Radio Science Instrument</name>
        <type>Instrument</type>
        <Internal_Reference>
          <lid_reference>urn:nasa:pds:context:instrument:rss.maven</lid_reference>
          <reference_type>is_instrument</reference_type>
        </Internal_Reference>
      </Observing_System_Component>
    </Observing_System>
    <Target_Identification>
      <name>Mars</name>
      <type>Planet</type>
      <Internal_Reference>
        <lid_reference>urn:nasa:pds:context:target:planet.mars</lid_reference>
        <reference_type>collection_to_target</reference_type>
      </Internal_Reference>
    </Target_Identification>
  </Context_Area>
  <Reference_List>

  </Reference_List>
  <Collection>
    <collection_type>Data</collection_type>
    <description>
```

```
      Time series of predicted and residual frequency received at Earth.
    </description>
  </Collection>
  <File_Area_Inventory>
    <File>
      <file_name>collection_maven_rose_calibrated_l2_sky_1.0.csv</file_name>
      <creation_date_time>2017-11-28T22:01:54</creation_date_time>
      <file_size unit="byte">7636</file_size>
      <md5_checksum>7f6b005d00fd627784a8da179a9844e5</md5_checksum>
    </File>
    <Inventory>
      <offset unit="byte">0</offset>
      <parsing_standard_id>PDS DSV 1</parsing_standard_id>
      <records>92</records>
      <record_delimiter>Carriage-Return Line-Feed</record_delimiter>
      <field_delimiter>Comma</field_delimiter>
      <Record_Delimited>
        <fields>2</fields>
        <groups>0</groups>
        <maximum_record_length unit="byte">257</maximum_record_length>
        <Field_Delimited>
          <name>Member Status</name>
          <field_number>1</field_number>
          <data_type>ASCII_String</data_type>
          <maximum_field_length unit="byte">1</maximum_field_length>
        </Field_Delimited>
        <Field_Delimited>
          <name>LIDVID_LID</name>
          <field_number>2</field_number>
          <data_type>ASCII_LIDVID_LID</data_type>
          <maximum_field_length unit="byte">255</maximum_field_length>
        </Field_Delimited>
      </Record_Delimited>
      <reference_type>inventory_has_member_product</reference_type>
    </Inventory>
  </File_Area_Inventory>
</Product_Collection>
```

Appendix E Sample Data Product Label

This section provides a sample data product label
(mvn_rse_l3_edp_20160705T213726_v01_r01.xml)


```
<?xml version="1.0" encoding="UTF-8"?>
<?xml-model href="https://pds.nasa.gov/pds4/pds/v1/PDS4_PDS_1800.sch"
  schematypens="http://purl.oclc.org/dsdl/schematron"?>
<Product_Observational
  xmlns="http://pds.nasa.gov/pds4/pds/v1"
  xmlns:pds="http://pds.nasa.gov/pds4/pds/v1"
  xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
  xsi:schemaLocation="
    http://pds.nasa.gov/pds4/pds/v1
    https://pds.nasa.gov/pds4/pds/v1/PDS4_PDS_1800.xsd">
     <Identification_Area>

<logical_identifier>urn:nasa:pds:maven.rose.derived:data.edp:mvn_rse_l3_edp_20160705t2137
26</logical_identifier>
          <version_id>1.1</version_id>
          <title>MAVEN ROSE Electron Density Profile</title>
          <information_model_version>1.8.0.0</information_model_version>
          <product_class>Product_Observational</product_class>
          <Citation_Information>
               <author_list>Paul Withers</author_list>
               <publication_year>2018</publication_year>
               <description>MAVEN ROSE Electron Density Profile</description>
          </Citation_Information>
          <Modification_History>
               <Modification_Detail>
                    <modification_date>2017-10-09</modification_date>
                    <version_id>1.0</version_id>
                    <description>Initial version</description>
               </Modification_Detail>
               <Modification_Detail>
                    <modification_date>2018-01-23</modification_date>
                    <version_id>1.1</version_id>
                    <description>Added five MSO parameters to both tables in data
file</description>
               </Modification_Detail>
          </Modification_History>
     </Identification_Area>
     <Observation_Area>
          <Time_Coordinates>
               <start_date_time>2016-07-05T21:37:26.107Z</start_date_time>
               <stop_date_time>2016-07-05T21:50:57.087Z</stop_date_time>
```

```
        </Time_Coordinates>
        <Primary_Result_Summary>
            <purpose>Science</purpose>
            <processing_level>Derived</processing_level>
            <description>MAVEN ROSE electron density profile</description>
        </Primary_Result_Summary>
        <Investigation_Area>
            <name>Mars Atmosphere And Volatile EvolutioN Mission</name>
            <type>Mission</type>
            <Internal_Reference>

<lid_reference>urn:nasa:pds:context:investigation:mission.maven</lid_reference>
                <reference_type>data_to_investigation</reference_type>
            </Internal_Reference>
        </Investigation_Area>
        <Observing_System>
            <Observing_System_Component>
                <name>MAVEN</name>
                <type>Spacecraft</type>
                <Internal_Reference>

<lid_reference>urn:nasa:pds:context:instrument_host:spacecraft.maven</lid_reference>
                    <reference_type>is_instrument_host</reference_type>
                </Internal_Reference>
            </Observing_System_Component>
            <Observing_System_Component>
                <name>RSE</name>
                <type>Instrument</type>
                <Internal_Reference>
                    <lid_reference>urn:nasa:pds:context:instrument:rss.maven</lid_reference>
                    <reference_type>is_instrument</reference_type>
                </Internal_Reference>
            </Observing_System_Component>
        </Observing_System>
        <Target_Identification>
            <name>Mars</name>
            <type>Planet</type>
            <Internal_Reference>
                <lid_reference>urn:nasa:pds:context:target:planet.mars</lid_reference>
                <reference_type>data_to_target</reference_type>
            </Internal_Reference>
        </Target_Identification>
    </Observation_Area>
    <File_Area_Observational>
        <File>
            <file_name>mvn_rse_l3_edp_20160705T213726_v01_r01.tab</file_name>
```

```
            <creation_date_time>2018-01-23T14:10:52</creation_date_time>
            <file_size unit="byte">795760</file_size>
            <md5_checksum>1107bdf293480fc5e97cf3e1fc923a32</md5_checksum>
        </File>
        <Table_Character>
            <name>MAVEN ROSE Occultation Header Table</name>
            <offset unit="byte">0</offset>
            <records>1</records>
            <description>A one record table with observing conditions at the data point closest
to radius 3550 km</description>
            <record_delimiter>Carriage-Return Line-Feed</record_delimiter>
            <Record_Character>
                <fields>17</fields>
                <groups>0</groups>
                <record_length unit="byte">490</record_length>
                <Field_Character>
                    <name>UTCTIME3550</name>
                    <field_number>1</field_number>
                    <field_location unit="byte">2</field_location>
                    <data_type>ASCII_Date_Time_YMD</data_type>
                    <field_length unit="byte">23</field_length>
                    <description>UTC at Mars when downlink ray has closest approach distance
of 3550 km</description>
                </Field_Character>
                <Field_Character>
                    <name>AREOCENTRICLAT3550</name>
                    <field_number>2</field_number>
                    <field_location unit="byte">25</field_location>
                    <data_type>ASCII_Real</data_type>
                    <field_length unit="byte">20</field_length>
                    <field_format>%20.6e</field_format>
                    <unit>degree</unit>
                    <description>Areocentric north latitude of closest approach point of
downlink ray at time UTCTIME3550</description>
                </Field_Character>
                <Field_Character>
                    <name>AREOCENTRICLON3550</name>
                    <field_number>3</field_number>
                    <field_location unit="byte">45</field_location>
                    <data_type>ASCII_Real</data_type>
                    <field_length unit="byte">20</field_length>
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                    <unit>degree</unit>
                    <description>Areocentric east longitude of closest approach point of
downlink ray at time UTCTIME3550</description>
                </Field_Character>
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<Field_Character>
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<data_type>ASCII_Real</data_type>
<field_length unit="byte">20</field_length>
<field_format>%20.6e</field_format>
<unit>degree</unit>
<description>Solar zenith angle of closest approach point of downlink ray at time UTCTIME3550</description>
</Field_Character>
<Field_Character>
<name>LTST3550</name>
<field_number>5</field_number>
<field_location unit="byte">85</field_location>
<data_type>ASCII_Real</data_type>
<field_length unit="byte">20</field_length>
<field_format>%20.6e</field_format>
<unit>hour</unit>
<description>Local true solar time of closest approach point of downlink ray at time UTCTIME3550</description>
</Field_Character>
<Field_Character>
<name>LS3550</name>
<field_number>6</field_number>
<field_location unit="byte">105</field_location>
<data_type>ASCII_Real</data_type>
<field_length unit="byte">20</field_length>
<field_format>%20.6e</field_format>
<unit>degree</unit>
<description>Areocentric east longitude of the Sun (Ls) at time UTCTIME3550</description>
</Field_Character>
<Field_Character>
<name>NXFLAG</name>
<field_number>7</field_number>
<field_location unit="byte">140</field_location>
<data_type>ASCII_Integer</data_type>
<field_length unit="byte">1</field_length>
<field_format>%1d</field_format>
<description>Occultation direction flag: 0 if ingress occultation, 1 if egress occultation</description>
</Field_Character>
<Field_Character>
<name>BSPFILENAME</name>
<field_number>8</field_number>

```
          <field_location unit="byte">151</field_location>
          <data_type>ASCII_String</data_type>
          <field_length unit="byte">30</field_length>
          <field_format>%40s</field_format>
          <description>The name of the SPK file used in processing</description>
        </Field_Character>
        <Field_Character>
          <name>UPLINKBAND</name>
          <field_number>9</field_number>
          <field_location unit="byte">190</field_location>
          <data_type>ASCII_String</data_type>
          <field_length unit="byte">1</field_length>
          <field_format>%1s</field_format>
          <description>
            The Band identifier for uplink:  X denotes X-Band.  0 indicates no uplink.
          </description>
        </Field_Character>
        <Field_Character>
          <name>UPLINKANTENNA</name>
          <field_number>10</field_number>
          <field_location unit="byte">199</field_location>
          <data_type>ASCII_Integer</data_type>
          <field_length unit="byte">2</field_length>
          <field_format>%2d</field_format>
          <description>Identifier for the DSN antenna used for uplink;  00  if there was
no uplink</description>
        </Field_Character>
        <Field_Character>
          <name>DOWNLINKBAND</name>
          <field_number>11</field_number>
          <field_location unit="byte">210</field_location>
          <data_type>ASCII_String</data_type>
          <field_length unit="byte">1</field_length>
          <field_format>%1s</field_format>
          <description>The Band identifier for downlink: X denotes X-
Band</description>
        </Field_Character>
        <Field_Character>
          <name>DOWNLINKANTENNA</name>
          <field_number>12</field_number>
          <field_location unit="byte">219</field_location>
          <data_type>ASCII_Integer</data_type>
          <field_length unit="byte">2</field_length>
          <field_format>%2d</field_format>
          <description>Identifier for the DSN antenna used for downlink</description>
        </Field_Character>
```

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            <Field_Character>
                <name>MSOX3550</name>
                <field_number>13</field_number>
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                <field_length unit="byte">20</field_length>
                <field_format>%20.6e</field_format>
                <unit>km</unit>
                <description>X-coordinate in the MSO reference frame of the closest
approach point of the downlink ray at time UTCTIME3550</description>
            </Field_Character>
            <Field_Character>
                <name>MSOY3550</name>
                <field_number>14</field_number>
                <field_location unit="byte">241</field_location>
                <data_type>ASCII_Real</data_type>
                <field_length unit="byte">20</field_length>
                <field_format>%20.6e</field_format>
                <unit>km</unit>
                <description>Y-coordinate in the MSO reference frame of the closest
approach point of the downlink ray at time UTCTIME3550</description>
            </Field_Character>
            <Field_Character>
                <name>MSOZ3550</name>
                <field_number>15</field_number>
                <field_location unit="byte">261</field_location>
                <data_type>ASCII_Real</data_type>
                <field_length unit="byte">20</field_length>
                <field_format>%20.6e</field_format>
                <unit>km</unit>
                <description>Z-coordinate in the MSO reference frame of the closest
approach point of the downlink ray at time UTCTIME3550</description>
            </Field_Character>
            <Field_Character>
                <name>MSOLAT3550</name>
                <field_number>16</field_number>
                <field_location unit="byte">281</field_location>
                <data_type>ASCII_Real</data_type>
                <field_length unit="byte">20</field_length>
                <field_format>%20.6e</field_format>
                <unit>degree</unit>
                <description>North latitude in the MSO reference frame of the closest
approach point of the downlink ray at time UTCTIME3550</description>
            </Field_Character>
            <Field_Character>
                <name>MSOLON3550</name>
```

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                <field_number>17</field_number>
                <field_location unit="byte">301</field_location>
                <data_type>ASCII_Real</data_type>
                <field_length unit="byte">20</field_length>
                <field_format>%20.6e</field_format>
                <unit>degree</unit>
                <description>East longitude in the MSO reference frame of the closest
approach point of the downlink ray at time UTCTIME3550</description>
            </Field_Character>
        </Record_Character>
    </Table_Character>
    <Table_Character>
        <name>MAVEN ROSE Electron Density Profile</name>
        <offset unit="byte">390</offset>
        <records>1623</records>
        <description>Electron density profile versus radial distance</description>
        <record_delimiter>Carriage-Return Line-Feed</record_delimiter>
        <Record_Character>
            <fields>25</fields>
            <groups>0</groups>
            <record_length unit="byte">490</record_length>
            <Field_Character>
                <name>RADIUS</name>
                <field_number>1</field_number>
                <field_location unit="byte">1</field_location>
                <data_type>ASCII_Real</data_type>
                <field_length unit="byte">20</field_length>
                <field_format>%20.6e</field_format>
                <unit>km</unit>
                <description>Radial distance</description>
            </Field_Character>
            <Field_Character>
                <name>ALTITUDEMOLA</name>
                <field_number>2</field_number>
                <field_location unit="byte">21</field_location>
                <data_type>ASCII_Real</data_type>
                <field_length unit="byte">20</field_length>
                <field_format>%20.6e</field_format>
                <unit>km</unit>
                <description>Altitude with respect to MOLA areoid</description>
            </Field_Character>
            <Field_Character>
                <name>NELEC</name>
                <field_number>3</field_number>
                <field_location unit="byte">41</field_location>
                <data_type>ASCII_Real</data_type>
```

```
            <field_length unit="byte">20</field_length>
            <field_format>%20.6e</field_format>
            <unit>1/m**3</unit>
            <description>Electron density</description>
        </Field_Character>
        <Field_Character>
            <name>SNELEC</name>
            <field_number>4</field_number>
            <field_location unit="byte">61</field_location>
            <data_type>ASCII_Real</data_type>
            <field_length unit="byte">20</field_length>
            <field_format>%20.6e</field_format>
            <unit>1/m**3</unit>
            <description>One-sigma uncertainty in NELEC</description>
        </Field_Character>
        <Field_Character>
            <name>BENDINGANGLEDOWN</name>
            <field_number>5</field_number>
            <field_location unit="byte">81</field_location>
            <data_type>ASCII_Real</data_type>
            <field_length unit="byte">20</field_length>
            <field_format>%20.6e</field_format>
            <unit>radian</unit>
            <description>Bending angle of downlink ray</description>
        </Field_Character>
        <Field_Character>
            <name>IMPACTPARAMDOWN</name>
            <field_number>6</field_number>
            <field_location unit="byte">101</field_location>
            <data_type>ASCII_Real</data_type>
            <field_length unit="byte">20</field_length>
            <field_format>%20.6e</field_format>
            <unit>km</unit>
            <description>Impact parameter of downlink ray</description>
        </Field_Character>
        <Field_Character>
            <name>REFRACTIVITYDOWN</name>
            <field_number>7</field_number>
            <field_location unit="byte">121</field_location>
            <data_type>ASCII_Real</data_type>
            <field_length unit="byte">20</field_length>
            <field_format>%20.6e</field_format>
            <description>Refractivity at RADIUS and at the frequency of the downlink
ray</description>
        </Field_Character>
        <Field_Character>
```

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                    <name>ERTYEAR</name>
                    <field_number>8</field_number>
                    <field_location unit="byte">147</field_location>
                    <data_type>ASCII_Integer</data_type>
                    <field_length unit="byte">4</field_length>
                    <field_format>%4d</field_format>
                    <unit>year</unit>
                    <description>Earth Receive Time of the occultation measurement
(year)</description>
                </Field_Character>
                <Field_Character>
                    <name>ERTDOY</name>
                    <field_number>9</field_number>
                    <field_location unit="byte">158</field_location>
                    <data_type>ASCII_Integer</data_type>
                    <field_length unit="byte">3</field_length>
                    <field_format>%3d</field_format>
                    <unit>day</unit>
                    <description>Earth Receive Time of the occultation measurement (day of
year)</description>
                </Field_Character>
                <Field_Character>
                    <name>ERTSEC</name>
                    <field_number>10</field_number>
                    <field_location unit="byte">169</field_location>
                    <data_type>ASCII_Real</data_type>
                    <field_length unit="byte">12</field_length>
                    <field_format>%12.6f</field_format>
                    <unit>second</unit>
                    <description>Earth Receive Time of the occultation measurement
(seconds)</description>
                </Field_Character>
                <Field_Character>
                    <name>ERTDATETIME</name>
                    <field_number>11</field_number>
                    <field_location unit="byte">182</field_location>
                    <data_type>ASCII_Date_Time_YMD</data_type>
                    <field_length unit="byte">23</field_length>
                    <field_format>%23s</field_format>
                    <description>Earth Receive Time of the occultation measurement (date/time
format)</description>
                </Field_Character>
                <Field_Character>
                    <name>OCCTIME</name>
                    <field_number>12</field_number>
                    <field_location unit="byte">206</field_location>
```

```
                    <data_type>ASCII_Date_Time_YMD</data_type>
                    <field_length unit="byte">23</field_length>
                    <field_format>%23s</field_format>
                    <description>Date and time of the occultation measurement at
Mars</description>
                </Field_Character>
                <Field_Character>
                    <name>OCCAREOCENTRICLAT</name>
                    <field_number>13</field_number>
                    <field_location unit="byte">229</field_location>
                    <data_type>ASCII_Real</data_type>
                    <field_length unit="byte">20</field_length>
                    <field_format>%20.6e</field_format>
                    <unit>degree</unit>
                    <description>Areocentric north latitude of the ray path closest approach
point</description>
                </Field_Character>
                <Field_Character>
                    <name>OCCAREOCENTRICLON</name>
                    <field_number>14</field_number>
                    <field_location unit="byte">249</field_location>
                    <data_type>ASCII_Real</data_type>
                    <field_length unit="byte">20</field_length>
                    <field_format>%20.6e</field_format>
                    <unit>degree</unit>
                    <description>Areocentric east longitude of the ray path closest approach
point</description>
                </Field_Character>
                <Field_Character>
                    <name>OCCSZA</name>
                    <field_number>15</field_number>
                    <field_location unit="byte">269</field_location>
                    <data_type>ASCII_Real</data_type>
                    <field_length unit="byte">20</field_length>
                    <field_format>%20.6e</field_format>
                    <unit>degree</unit>
                    <description>Solar zenith angle at the ray path closest approach
point</description>
                </Field_Character>
                <Field_Character>
                    <name>OCCLTST</name>
                    <field_number>16</field_number>
                    <field_location unit="byte">289</field_location>
                    <data_type>ASCII_Real</data_type>
                    <field_length unit="byte">20</field_length>
                    <field_format>%20.6e</field_format>
```

<unit>hour</unit>
<description>Local true solar time at the ray path closest approach
point</description>
</Field_Character>
<Field_Character>
<name>OCCLS</name>
<field_number>17</field_number>
<field_location unit="byte">309</field_location>
<data_type>ASCII_Real</data_type>
<field_length unit="byte">20</field_length>
<field_format>%20.6e</field_format>
<unit>degree</unit>
<description>
The angle between the Mars-Sun line at the observation time
and the Mars-Sun line at Mars vernal equinox.
</description>
</Field_Character>
<Field_Character>
<name>OCCFRESID</name>
<field_number>18</field_number>
<field_location unit="byte">329</field_location>
<data_type>ASCII_Real</data_type>
<field_length unit="byte">20</field_length>
<field_format>%20.6e</field_format>
<unit>hertz</unit>
<description>Frequency residual from the archived RSSG residual
file</description>
</Field_Character>
<Field_Character>
<name>OCCFRESIDADJ</name>
<field_number>19</field_number>
<field_location unit="byte">349</field_location>
<data_type>ASCII_Real</data_type>
<field_length unit="byte">20</field_length>
<field_format>%20.6e</field_format>
<unit>hertz</unit>
<description>Frequency residual after baseline correction</description>
</Field_Character>
<Field_Character>
<name>IMPACTPARAMAVERAGE</name>
<field_number>20</field_number>
<field_location unit="byte">369</field_location>
<data_type>ASCII_Real</data_type>
<field_length unit="byte">20</field_length>
<field_format>%20.6e</field_format>
<unit>km</unit>

<description>Average of up and down impact parameters</description>
</Field_Character>
<Field_Character>
<name>OCCMSOX</name>
<field_number>21</field_number>
<field_location unit="byte">389</field_location>
<data_type>ASCII_Real</data_type>
<field_length unit="byte">20</field_length>
<field_format>%20.6e</field_format>
<unit>km</unit>
<description>X-coordinate in the MSO reference frame of the downlink ray at it closest approach to Mars</description>
</Field_Character>
<Field_Character>
<name>OCCMSOY</name>
<field_number>22</field_number>
<field_location unit="byte">409</field_location>
<data_type>ASCII_Real</data_type>
<field_length unit="byte">20</field_length>
<field_format>%20.6e</field_format>
<unit>km</unit>
<description>Y-coordinate in the MSO reference frame of the downlink ray at it closest approach to Mars</description>
</Field_Character>
<Field_Character>
<name>OCCMSOZ</name>
<field_number>23</field_number>
<field_location unit="byte">429</field_location>
<data_type>ASCII_Real</data_type>
<field_length unit="byte">20</field_length>
<field_format>%20.6e</field_format>
<unit>km</unit>
<description>Z-coordinate in the MSO reference frame of the downlink ray at it closest approach to Mars</description>
</Field_Character>
<Field_Character>
<name>OCCMSOLAT</name>
<field_number>24</field_number>
<field_location unit="byte">449</field_location>
<data_type>ASCII_Real</data_type>
<field_length unit="byte">20</field_length>
<field_format>%20.6e</field_format>
<unit>degree</unit>
<description>North latitude in the MSO reference frame of the downlink ray at it closest approach to Mars</description>
</Field_Character>

```
                <Field_Character>
                    <name>OCCMSOLON</name>
                    <field_number>25</field_number>
                    <field_location unit="byte">469</field_location>
                    <data_type>ASCII_Real</data_type>
                    <field_length unit="byte">20</field_length>
                    <field_format>%20.6e</field_format>
                    <unit>degree</unit>
                    <description>East longitude in the MSO reference frame of the downlink ray
at it closest approach to Mars</description>
                </Field_Character>
            </Record_Character>
        </Table_Character>
    </File_Area_Observational>
</Product_Observational>
```

Appendix F PDS Delivery Package Manifest File Record Structures

The delivery package includes an MD5 checksum manifest. When delivered as part of a data delivery, this file is not a PDS archive product, and does not require a PDS label file. The format of this file is described below.

F.1 Transfer Manifest Directory Structure

TBD

F.2 MD5 Checksum Manifest Record Structure

The checksum manifest consists of two fields: a 32 character hexadecimal (using lowercase letters) MD5, and a file specification from the root directory of the unzipped delivery package to every file included in the package. The file specification uses forward slashes ("/") as path delimiters. The two fields are separated by two spaces. Manifest records may be of variable length. This is the standard output format for a variety of MD5 checksum tools (*e.g*. md5deep, etc.).