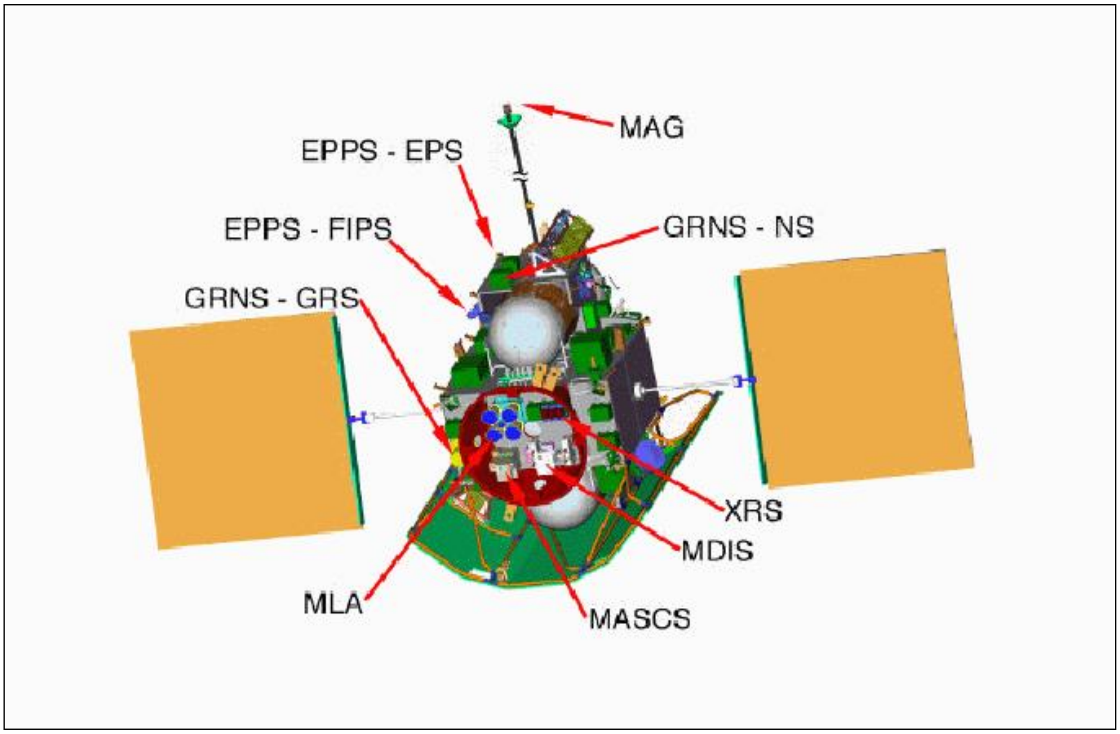
MESSENGER:

Software Interface Specification for the Derived Data Records of the Energetic Particle and Plasma Spectrometer

Version 1M



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Document Review

This document and the archive it describes have been through PDS Peer Review and have been accepted into the PDS archive.

George Ho, MESSENGER EPPS Instrument Scientist, has reviewed and approved this document.

Jim Raines, MESSENGER FIPS Instrument Scientist, has reviewed and approved this document.

Susan Ensor, MESSENGER Science Operations Center Lead, has reviewed and approved this document.

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Table 1 Revision History

Version	Author	Date	Description	Sections
1A	L. Nguyen	5/22/2012	Initial revision	All
1B	M. Gannon	5/25/2012	Minor updates from APL team review	All
1C	J. Raines M. Gannon	10/17/2012	Updates from the EPPS PDS Peer Review of the Sample Archive for DDR	All
1D	P. Bedini	1/29/2013	Editorial updates	All
1E	M. Reid	1/29/2013	Replaced text indicating a draft version of this document with approved & release version.	Document Review, pg. 2
1F	J. Raines M. Gannon	11/06/2013	Updates to incorporate new FIPS Advanced Products	
1G	G. Ho J. Raines S. Ensor	1/17/2014	Updates to DDR descriptions and applicable documents	1.2, 2, 5.2.1
1H	J. Raines M. Reid	6/13/2014	Added information about the FIPS Viewing Normalization products; fixed larger document formatting.	5.2.2, 5.3.4, 6.5, 6.8, 8.7, 8.8
1I	M. Reid	7/16/2014	Removed references to the FIPS Pixel FOV table. They were moved to the CDR SIS. Corrected document volume directory structure diagram.	5.2.2.6, 5.3, 6.5, 6.7, 8
1J	J. M. Raines M. Reid	11/19/2014	Modified to incorporate substitution of FIPS_ARRDIR product with FLUXMAP and addition of ERPCHANG product. Added ERPCHANG product. Removed FIPS_FOVPIX directory (FIPA_* files moved to Document Vol. CALIBRATION). Modifications to ROTSMO label. Formatting.	5.1.1, 5.2, 5.3.4, 6.8, 8.3, 8.7.

Version	Author	Date	Description	Sections
1K	J. M. Raines M. Gannon	1/27/2015	Edits to FIPS Flux Map and FIPS Pitch Angle product descriptions. Correction of minor typographical errors.	5.2.2.3, 5.2.2.5
1L	S. Ensor	1/16/2016	Final edits (partial)	All
1M	J. M. Raines M. Gannon	1/28/2016	Final edits	1.1.4 and others

1 Purpose and Scope of Document

1.1 Purpose

This document serves to provide users of the MErcury Surface, Space ENvironment, GEochemistry, and Ranging (MESSENGER) Energetic Particle and Plasma Spectrometer (EPPS) data products with a detailed description of the EPPS instrument, data product generation, validation, and storage. Note that the EPPS is made up of two instrument subsystems, the Fast Imaging Plasma Spectrometer (FIPS), and the Energetic Particle Spectrometer (EPS). The FIPS and EPS are described in individual sections within this document. They are referred to separately when necessary and referred to as the EPPS instrument when dealing with areas common to both instruments. The FIPS covers the lower energy range of particles and measures the mass per charge (m/q), energy per charge (E/q), and incoming direction of each charged particle. The EPS covers the higher energy range and measures mass, energy, and incoming direction of each particle. The MESSENGER EPPS data products are deliverables to the Planetary Data System (PDS) and the scientific community that it supports. All data formats are based on the PDS standard.

1.2 Scope

The EPPS science data are divided into two categories: Level 2 edited raw data (referred to as experiment data records or EDRs) and processed data (referred to as reduced data records or RDRs). RDRs are generated from EDRs, and represent data calibrated to a physical unit such as particle intensity (Level 3), resampled Level 4 data products, or derived Level 5 data products. RDRs consist of Calibrated Data Records (CDRs), Derived Data Records (DDRs), and Derived Analysis Products (DAPs). This Software Interface Specification (SIS) describes the EPPS DDR data products.

For EPS, DDRs consist of two products: pitch angle values, and pitch angle distribution spectrograms over selected ranges of energies for selected time periods. For FIPS, DDRs consist of seven products that provide data for spatial and temporal distributions of observed density for major ion species, and for selected ion species and time periods, energy spectra, pitch angle distributions, ion flux, density, temperature, and pressure, and viewing normalizations for each energy scan. The DDR data were delivered to the PDS as CODMAC (Committee on Data Management and Computation) Level 4 data. EPPS's DDRs are formatted to include standard PDS labels. A detailed description of all data products in the EPPS DDR follows.

In addition, this SIS describes the EPPS documentation volume, which contains products related to both the EDR- and RDR-level archives. The contents of the documentation volume enables one to conduct useful analysis of the DDRs. The documentation volume is described in greater detail in section 6.6.

2 Applicable Documents

The MESSENGER EPPS SIS is responsive to the following documents:

1. Planetary Data System Standards Reference, Feb 27, 2009, Version 3.8. JPL D-7669, Part-2.
2. MESSENGER Data Management and Archiving Plan. The Johns Hopkins University, APL. Document ID number 7384-9019
3. MESSENGER Mercury: Surface, Space Environment, Geochemistry, Ranging; A mission to Orbit and Explore the Planet Mercury, Concept Study, March 1999. Document ID number FG632/ 99-0479
4. [PLR] Appendix 7 to the discovery program Plan; Program Level Requirement for the MESSENGER Discovery project; June 20, 2001.

The following documents may be referenced for details on the EPPS instruments:

5. Livi et al. (The energetic particle spectrometer (EPS) on MESSENGER: Instrument description, characterization, and calibration, MESSENGER Project report, 2004)
6. Zurbuchen et al. (The Fast Ion Plasma Spectrometer (FIPS) calibration report, MESSENGER Project report, 2004)
7. Andrews et al. (The Energetic Particle and Plasma Spectrometer Instrument on the MESSENGER Spacecraft, Space Science Reviews Volume 131, Numbers 1-4, August 2007)
8. Raines et al. (Distribution and compositional variations of plasma ions in Mercury's space environment: The first three Mercury years of MESSENGER observations, Journal of Geophysical Research, 118, p1604-1619, 2013)
9. Gilbert et al. (Background noise in space-based time-of-flight sensors, Reviews of Scientific Instrumentation, in review, 2014)

10. Gershman et al. (Post-processing modeling and removal of background noise in space-based time-of-flight sensors, Deep Blue, 2013, http://hdl.handle.net/2027.42/100358)

11. Raines et al. (MESSENGER observations of the plasma environment near Mercury, Planetary and Space Science 59, p2004-2015, 2011)

12. Ho et al. (Spatial distribution and spectral characteristics of energetic electrons in Mercury's magnetosphere, *J. Geophys. Res.*, doi:10.1029/2012JA017983, 117, 2012)

13. Gershman et al. (Magnetic Flux Pile-up and Plasma Depletion in Mercury's Subsolar Magnetosheath, Journal of Geophysical Research: Space Physics, 118, p7181-7199, 2013)

14. Slavin et al. (MESSENGER Observations of Extreme Loading and Unloading of Mercury's Magnetic Tail, Science, 329, p665-668, 2010, doi: 10.1126/science.1188067)

3 Relationships with Other Interfaces

The EPPS DDR data products were stored at the MESSENGER Science Operations Center (SOC) during the MESSENGER mission. The data products were transferred to the PDS Planetary Plasma Interactions (PPI) Node according to the delivery schedule in section 7. The data in the DDR files is stored in PDS ASCII TABLE objects unless stated otherwise (section 5.2).

4 Roles and Responsibilities

The roles and responsibilities of the instrument teams, The Johns Hopkins University Applied Physics Laboratory (APL), Applied Coherent Technology Corporation (ACT), and the Planetary Data System (PDS), are discussed in sections 5.3.2 and 5.3.3.

5 Data Product Characteristics and Environment

5.1 Instrument Overview

5.1.1 FIPS Overview

The Fast Imaging Plasma Spectrometer (FIPS) measures the energy per charge (E/q), time-of-flight (TOF), and incident angles for plasma ions entering the sensor. Intensities, velocity distributions, and mass per charge (m/q) distributions are derived from these measurements and make up FIPS primary science data. These data are used to understand the kinetic properties, angular distributions, and composition of Mercury magnetospheric ions, and contribute to the characterization of the planetary magnetic field.

Ions measured by FIPS pass through an electrostatic analyzer (ESA), located at the entrance to the sensor; a post-acceleration chamber between the output of the ESA and the carbon foil; and a time-of-flight telescope. The ESA at the entrance to FIPS acts as a wide-angle lens for ions, with a 1.4 sr field of view. It allows only ions with a specific E/q band to enter through its output plane. This band is stepped through 64 values to complete one measurement cycle (scan), nominally from 0.046-13.3 keV/e. FIPS is normally operated in one of two stepping rates: one step per second (normal mode), or one step per 100 milliseconds (burst mode). When delays due to high-voltage ramp-ups are included, these result in cycle times of 64 sec and 8 sec, respectively. The operation of FIPS is highly configurable via table upload. The time spent in each step can, in principal, be set to arbitrary values, different for each step. Associated with each E/q step is a deflection voltage, a threshold, a settling time, and an integration (dwell) time.

Ions exit the output plane of the ESA and are then accelerated in the post acceleration chamber. This acceleration is done to give low-energy ions sufficient energy to penetrate the carbon foil. The acceleration also helps to reduce energy straggling and angular scattering – effects that cause degradation in mass resolution and imaging. When ions exit the carbon foil, secondary electrons are liberated. These electrons travel to the Start MCP (microchannel plate), providing a timing-start signal and incident angle information via impact location on a position-sensing anode. The ion then travels through the TOF chamber and strikes the Stop MCP, providing a timing-stop signal and allowing computation of TOF. From E/q and TOF, m/q can be computed. FIPS can measure species from H to Fe, 1-60 amu/e (or higher).

Individual ions are identified in FIPS data from their E/q and TOF measurements. A simple model is used to predict the TOF range expected for each ion as a function of E/q, referred to as the E/q-TOF track for that ion. This model includes the effects of energy lost upon passage through the carbon foil, as well delays due to electron flight time and electronic processing. All events with measured TOF within the predicted range for a particular ion are assigned to that ion. To improve signal to noise, E/q-TOF tracks for some ions are grouped together. In this dataset, H^+, He^+, and He^{2+} are assigned from their respective individual ion tracks. Two ion groups are defined: O^+ group (m/q = 16 – 20; including O^+ and water group ions) and Na^+ group (m/q = 21-30; including Na^+, Mg^+, and Si^+). Additional details concerning this process are given in [8].

FIPS uses a double coincidence technique to greatly reduce background noise. However, spurious double-coincidence counts still do occur. These counts come from two main sources: the extension of very high count proton measurements into other times of flight, and the release of small numbers ions from surface processes within the instrument [9]. While all major ion species reported here can be analyzed from the raw data, accuracy is significantly improved by removing these spurious counts. A detailed noise model and removal method has been developed [10] and is employed on the data in this work at the individual scan level.

After species are identified in E/q-TOF space and noise counts removed, the resulting counts for species s ($C_{i,s}$) at each measured $(E/q)_i$ are transformed to phase space density ($f_{i,s}$) in units of s^3 m^{-6}. Using the CDR fluxes ($J_{i,s}$) in sec^{-1} cm^{-2} sr^{-1}, this conversion is achieved using the following relationship:

$$f_{i,s} = J_{i,s} \frac{m_s}{v_{i,s}^2 C}$$

where $v_{i,s}$ is velocity, m_s is ion mass (in amu) and C is a unit conversion factor, 1.6022×10^{-20} $(cm^2\ s\ keV)^{-1}$.

The details of the conversion of counts to phase space density are provided in the EDR2CDR document, available in the CALIBRATION directory of the EPPS documentation volume.

Details of FIPS operations can be found in [7].

5.1.2 EPS Overview

EPS is a compact TOF telescope with two main components: a TOF section and a Solid State Detectors (SSD) array. The SSD array comprises six ion-implanted planar silicon detectors, each with four pixels (two dedicated to ion measurements and two to electron measurements) for a total of 24 SSD elements. Particles enter the system through a mechanical collimator that delimits the look direction into the instrument. Particles that pass through the collimator then transit through a thin, composite Start foil (polyimide + aluminum, 10 μg/cm^2) and onto the TOF region of the instrument.

Electrons are released from the inner surface of the Start foil and focused to a well-defined region on an MCP to generate the START signal in a dedicated anode. The incident ions are not significantly affected by the electric fields of the focusing optics. After a 6 cm flight path, ions traverse the Stop foil, which is a polyimide + palladium (19 μg/cm²) composite foil. The secondary electrons released by the stop foil are steered to the MCP and generate the STOP signal. Electron trajectory simulations show that there is less than 2 ns dispersion in the transit time of the secondary electron from the foil to the MCP. Sub-nanosecond dispersion is required so as not to misidentify ion species. If both a START and STOP signal (double coincidence) are registered, then the time, t, for the particle to travel a known distance (d=6 cm) can be determined. For triple coincidence we must have the START, STOP, and also the energy measured (E_{meas}) by the SSDs. Using these measured parameters, we can calculate the mass (M) and the incident energy (E) of each ion using the following equations:

$$E_{true} = E_{meas} / \gamma$$

$$E_{ToF} = \beta E_{true}$$

$$M = 2(T / d)^2 E_{ToF} = 2(t / d)^2 (\beta E_{meas} / \gamma)$$

E_{true} takes into account the small energy loss of the ions passing through the stop foil, and the energy loss and pulse-height defect in the SSDs. E_{ToF} takes into account the even smaller energy loss or gain in the start foil, and may also include up to ~2.5 keV electrostatic pre-acceleration of ions that remain charged on exiting the start foil. If the energy of the incident particle is not large enough to trigger the SSD, then only t is measured and the pulse height of the start anode is used to discriminate whether it is a light (M~1 amu), or heavy (M > 1 amu) ion. At the same value of TOF, heavy ions have been shown to generate substantially more secondary electrons than do protons.

Besides composition measurements, the particle's angular direction can be determined. The pair of start and stop anodes provide the polar entrance angle of the incident particle. The polar angle of +80º to -80º is divided into six equal sectors (nominally 27º).

5.1.2.1 Electron measurements

Energetic electrons have higher penetration power than ions at the same energy. The SSDs dedicated to electron detection in EPS are covered by a thin layer (flashing) of 1μm of aluminum. This dead layer stops protons with energy less then ~250 keV; Electrons, on the other hand, lose less than 10 keV by the interaction with this dead layer. Electrons are identified in EPS by the presence of an energy signal. The TOF spectra collected in the adjacent SSD (without flashing) are used during ground data analysis for checking and correcting for the proton contamination.

“Calibration” for a particle instrument like EPS means determining the following:

1. Transfer function from counts into flux (physical units)
2. Characteristic of “Rate-out” versus “Rate-in”
3. Response to low energy and high energy particle background
4. Response to visible and ultraviolet light
5. Response to high magnetic field

All these functions need to be characterized and the relevant parameters need to be determined before flight.

5.1.2.2 Transfer Function

Flux, differential intensity, and phase space density

The number of particles N that traverse an area A during a time t can be characterized by the flux F [1/cm2/s]

$$N = A * t * F$$

or by the intensity I [1/cm2/s/sr]

$$N = A * t * \int I \cos(\hat{u})\, d\Omega$$

where Ω is solid angle and û is angle to the area normal. Here, the geometric characteristics of the sensor determine the limits on the integration.

Often used is the quantity differential intensity f [1/cm2/s/sr/keV], defined as the number of particles with energy between E and E+ΔE that traverse the area A during the time t, where

$$N(E)=f(E) * A * t * \Delta\Omega * \Delta E$$

In three dimensions, with θ being the polar angle and φ the azimuthal angle of a polar reference system:

$$d3N(E,\theta,\varphi)=f(E, \theta, \varphi) * A \cos(\hat{u}) * t * dE \cos\theta \, d\theta \, d\varphi$$

Note that f(E, θ, φ) is related to the phase-space density psd (number of particles in the configuration space element d3R and with velocity between v and v+ d3v) by the simple relationship in the non-relativistic limit (valid for ions measured by EPS but not for the higher energy electrons):

$$psd(s3/ cm6)=f(1/cm2/s/sr/keV) * m/v2$$

For relativistic particles, one generally utilizes momentum space rather than velocity space, and the corresponding expression is:

$$psd(s3/gm.cm6) = f(1/cm2/s/sr/keV) / p2$$

Where “p” is momentum.

Definition of sensor transfer function and geometric factor

The number of counts N of particles of mass m, in the energy band around mean energy E, angular band Δθ around mean polar direction θ, and angular band Δφ around the mean azimuthal direction φ, measured by the instrument during the time δt can be expressed as:

$$N(E, \theta, \varphi; m) = \delta t * \int\Delta E \int\Delta\theta \int\Delta\varphi \quad f(E, \theta, \varphi; m) * A \cos(\hat{u}) * dE \cos\theta \, d\theta \, d\varphi$$

If f(E, θ, φ) is a Dirac δ function (monoenergetic, infinitely narrow beam), then

$$N(E, \theta, \varphi; m) = \delta t * f(E, \theta, \varphi; m) * G(E, \theta, \varphi; m)$$

Where G(E, θ, φ; m) [cm2 sr keV] is the transfer function of the instrument.

In the other limit, when the flux is completely isotropic (all directions the same)

$$N(E; m) = \delta t * f(E; m) * GF(E; m)$$

GF is called geometric factor and represents a measure of the efficiency of the system (count rate/flux), and typically is a function of energy and species.

The goal of the calibration is to characterize the function G(E, θ, φ; m), so that from measurements of the count rates it is possible to constrain f(E, θ, φ; m). Note that an exact inversion of the integral is rarely possible, and we can compute only the coefficients of some tailored expansion of f(E, θ, φ; m), such as in spherical harmonics (Legendre polynomials). The accuracy of these coefficients depends on both the raster coverage of the measurements and on the calibration.

5.1.2.3 Collimator

The EPS collimator consists of four concentric half circular plates that have holes aligned with a common point of origin at the center of the EPS TOF telescope. The size and number of collimator holes define the geometric factor GF of the instrument. The many-holes collimator design minimizes the scattering of ions and electrons at the collimator while restricting the field-of-view (FOV) of the instrument.

GEANT4 simulation shows that the geometry factor for the total SSD area to be 0.016 cm2 sr. The simulation accounted for gaps between the detectors, but did not allow for the guard ring dead area between the large and small pixels or the losses in the two grids used to mount the thin foils. Hence, before grid losses, the total large pixel geometry factor is therefore GFSSD = 0.0152 cm2 sr, and the small pixels would be 0.0008 cm2 sr. The grid losses are actual blockages, so these should be included in the geometry factor. EPS used 40-lines-per-inch grids on the foils that are 86% transmissive. Therefore, for the 12 large pixels, we have a total geometry factor of 0.862x0.0152, or 0.011 cm2 sr, and each large pixel is 1/12 of that, or GFSSD-Large = 0.001 cm2 sr. For the 12 small pixels, we have a total geometry factor of 5.6x10-4 cm2 sr, or GFSSD-Small = 4.7x10-5 cm2 sr per pixel. The current simulation does not model the scattering of low energy ion and electron in the collimator; hence the current value of GFSSD is constant with energy and look direction. The instrument team may revise the value of GFSSD at a later time when we develop a further understanding of the instrument response as a function of direction, energy and species.

GFTOF for the Low Energy Ions (TOF-only) is roughly twice the SSD values, or ~0.03 cm2 sr. Note that the needed Transfer Factor G depends also on the counting efficiency εkj which depends, in turn, on species and instrument mode. However, these values were never conclusively determined. During the time of instrument check out shortly after launch, EPS's TOF section suffered a failure; subsequently, EPS lost its ability to measure ions by elemental mass species. All in-flight EPS data contains null TOF values, hence, EPS can now only measure

$$N(E) = \delta t * f(E) * GFSSD$$

GFSSD is now the geometric factor and represents a measure of the efficiency of the system (count rate/flux), and is constant with look direction, energy and species. This is the standard approximate conversion of count rate to intensity assuming the channel efficiency is part of the geometry factor. The shape of the energy spectrum also affects the response.

5.2 Data Product Overview

The DDR data products generated by the EPS and FIPS subsystems are described in this section. For all of the DDR products there is a detached PDS label file, which describes the contents of one data file. Each label file has the same base name as the data file it is describing, with the extension ".LBL" to denote a label file. The label file defines the start time and end of the observation, product creation time, and the structure of the ASCII tables. Each data file contains the data collected on a given Earth day.

5.2.1 EPS Data Products

The EPS portion of the data archive consists of tables of EPS pitch angle values and pitch angle distribution function spectrograms in the form of browse plots.

5.2.1.1 Pitch Angle Computation

The pitch angle is defined as the instantaneous angle between the particle flow direction and the measured in-situ magnetic field, with 0 degrees being where the particle is traveling along the field and 180 degrees where the particle is traveling in the opposite direction. Both vectors (the particle flow direction and the magnetic field) are measured in the spacecraft frame. The particle flow direction for each of the six EPS look directions is obtained by using the MESSENGER SPICE pointing kernels (c-kernels) and the EPS frame kernel. The magnetic field measurements are taken from MESSENGER Magnetometer (MAG) Level 1 1-second averaged data; see the MAG instrument DDR SIS.

5.2.1.2 Pitch Angles Product

The pitch angle value tables contain the pitch angle for each of the six look directions reported at the same cadence as the EPS LoRes Spectral rate measurements (see EPPS CDR SIS document). Each file thus has a one-to-one relationship with a corresponding LoRes spectral file. The pitch angle values are calculated using the odd-shaped channels. These hardware channels correspond to ions or electrons that are above the instrument threshold (nominally ~30 keV), and are not affected by prioritization in the instrument software. For a rapidly falling energy spectrum, these counts would be dominated at the lowest energies. These values should be used in conjunction with the rate channels for which intensity is computed. Constant normalization factors and background subtractions have been applied to these channels to offset any bias in the threshold setting. The formula used is Adjusted Value = Scaling * Raw Value + Offset. The constant scaling and offset values are given in Table 2.

5.2.1.3 Pitch Angle Distribution Spectrogram Browse Product

The pitch angle distribution shown in the pitch angle spectrogram browse plots is plotted using the pitch angle values and averaged accordingly.

We averaged the particle measurement in 120-second bins. Pitch angle bins are 22.5 degrees wide, and run from 0 to 180 degrees. For the pitch angle distribution spectrogram, the color scale is normalized to the maximum flux for the time interval covered by the current plot (i.e. the intensity color scale varies between plots). The events are selected based on the selection criteria as outlined by Ho et al. [JGR, 2012] on selecting events that are at least 10 times above the instrument background at the lowest energy channel 36-57 keV. Note: The pitch angle distribution spectrogram product is a one-time delivery.

Channel Name	Scaling	Offset
SHAPED_COUNTS D00	1.0412691533565521	15.11127820611
SHAPED_COUNTS D01	1	0
SHAPED_COUNTS D02	0.7014738321304321	10.141375184059143

SHAPED_COUNTS D03		
SHAPED_COUNTS D04	1.338530421257019	18.39651709794998
SHAPED_COUNTS D05	1.3527332693338394	7.795897737145424
SHAPED_COUNTS D06	1.4293411076068878	27.3230662047863
SHAPED_COUNTS D07	0.805070623755455	3.0807372108101845
SHAPED_COUNTS D08	0.9233275651931763	32.62595450878143
SHAPED_COUNTS D09	0.5404207110404968	-0.39973045140504837
SHAPED_COUNTS D10	0.31776440143585205	22.942654877901077
SHAPED_COUNTS D11	0.15649390034377575	-22.306587459519506

Table 2 Constant values used to adjust the count rate for the shaped channels. D01 is the channel to which all others were fit in order to arrive at these values, while D03 is unlike the others and cannot be fit, so it remains unadjusted.

5.2.2 FIPS Data Products

Except where noted below, these data products are derived from individual event (PHA) words, which have full angle and TOF information. Using PHA words enables the finest possible separation into ion species as well as distinguishing incident angles. Noise removal in *E/q* – TOF space is performed before accumulation for all ions except H^+, for which noise removal is not needed.

The orbital regions for which data is provided varies by product, as described below. Within these, data is provided for time steps whenever the instrument was operating in a nominal mode and when the data was of sufficient quality for scientific analysis. These conditions are met for the vast majority of times throughout the mission. In particular, many of these products are provided in regions determined by hand-picked or modeled bow shock and magnetopause boundaries. Boundary picking was done by the MAG team at a level of accuracy sufficient for the relatively low time resolution FIPS data (10s - 60s). Where these were not available, the model given by Slavin et al. [14] is used.

5.2.2.1 Differential Energy Flux Spectra

Differential energy flux spectra in units of $(keV/e)^{-1}$ sec^{-1} cm^{-2} sr^{-1} are provided for all 5 ion species throughout the entire magnetosphere and magnetosheath regions crossed by the spacecraft during each orbit. These spectra cover the full energy per charge range of FIPS, which ws 0.046 – 13.3 keV/e during most of the mission. See the FIPA_EYYYYDOY.DAT file for exact energy range. They are derived in a manner completely analogous to CDR differential energy flux spectra ($dJ_{i,s}/dE_i$) except that the total number of PHA event words for a given species at each *E/q* step is used in place of on-board accumulated count rates (except protons). See EPPS_FIPS_EDR2CDR.DOCX for more details. For protons, this product is derived from on-board accumulated rates just as for the CDR version, so that for ***protons only*** this product is a duplicate of the CDR version. This duplication is made to allow users to primarily use DDR data only in their scientific analysis.

$$\frac{dJ_{i,s}}{dE} = \frac{J_{i,s}}{(E/q)_i}$$

5.2.2.2 Observed Density

Observed density ($n_{obs,s}$, in cm^{-3}) for all ion species is provided for all 5 ion species throughout all orbit regions. This product serves to determine the spatial and temporal distribution of these ions and is the foundation DDR data product for FIPS. For protons, this product is derived from on-board accumulated rates rather than PHA event words, for much higher signal to noise ratio.

Observed densities are computed from differential energy flux spectra $J_{i,s}$ in two stages: First, $dJ_{i,s}/dE_i$ is converted to phase-space density ($f_{i,s}$, s^3 m^{-6})

$$f_{i,s} = 6.2414 \times 10^{19} \left(\frac{m_s}{v_{i,s}^2}\right)\left(\frac{dJ_{i,s}}{dE_i}\right)$$

Second, $f_{i,s}$ integrated over all velocities ($v_{i,s}$) and solid angle ($\Delta\Omega$) for a full scan to yield observed density ($n_{obs,s}$) for species s

$$n_{obs,s} = \sum_i f_{i,s} v_{i,x}^2 (Dv)_{i,s} (DW)$$

It is important to note that no correction has been made for limited field of view in this calculation. This correction requires knowledge of the true velocity distribution function in which the measured particles reside and is therefore beyond the scope of this data product. The net result is that nobs values reported are not in general equal to the ambient plasma density. More information about calculation of n_{obs} and the limited FIPS field of view can be found in [10, 11].

5.2.2.3 Angular Flux Maps

Integrated ion flux, $J_s(\theta,\phi)$, as a function of flow direction in MSO coordinates are provided for all 5 ion species throughout the entire magnetosphere and magnetosheath regions crossed by the spacecraft during each orbit. This product replaces the Arrival Direction Histogram (ARRDIR) product as it more a more useful representation of plasma behavior. Angular Flux Maps may be used in conjunction with pitch angle distributions to understand the location and motion of ions relative to Mercury. The discrete integration of phase space density (f) is performed over ion speed (v) in the standard way, leaving the two angular dimensions unchanged:

$$J_s(\theta, \phi) = \sum_i f_{i,s}\,(\theta, \phi) v_{i,s}^3 dv_i$$

Very low count rates can make this product difficult to interpret. For some ions, this situation is mitigated by summing over several, often many, FIPS scans until sufficient counts are available. In other cases, counts for a particular ion are so low the required number of counts would require summation over large regions of space, making the arrival directions again difficult to interpret. Therefore, these cases are not included in the data.

Summing over multiple scans brings with it the need to normalize the arrival direction distributions for the amount of time that a particular incident angle could be observed. In normal operations, the MESSENGER spacecraft rotates around the spacecraft Y-axis (Y_{MSGR}) to optimize viewing for different instruments. FIPS orientation is fixed relative to the spacecraft, so that the FIPS FOV rotates with the MESSENGER spacecraft. This results in significant variation in observing time for look directions in MSO coordinates. These variations in observing time have been normalized out of the fluxes included in this data product. Despite this normalization, the finite sensitivity of FIPS can still result in reduced measured ion flux from arrival directions with low observing time. In practice, this does not usually affect the typically qualitative interpretation of these maps. The user could mitigate this effect by reducing the variability of observing time: Only flux from directions that are viewed within a fixed fraction (e.g. 0.1) of the maximum observation time for a given time accumulation could be included in arrival direction histograms. This restriction is not applied to delivered data from this data product.

The FLUXMAP data product is constructed and normalized as follows:

1. Two arrays representing a full 4π steradian FOV are created at the 10° native angle binning of FIPS. This results in an 18 x 36 element array for the polar and azimuthal angle bins, respectively. The first of these is used for the average flux, FLUX, while the second is used for the average measurement time, VIEWTIME.

    a. The FLUX matrix for each energy scan is created from PHAs as follows:

i. Find the rotation matrix, ROTMSO, (described below) for the day (YYYYDOY) and index which corresponds to the scan

ii. Form the unit velocity vector:

1. Convert the incident polar and azimuthal angles of the event from FIPS spherical coordinates to FIPS Cartesian coordinates. Use the usual manner for spherical to Cartesian conversion, using 1 for the r component.

2. Invert by multiplying all components by -1. This changes the FOV coordinates to flow direction.

iii. Rotate to MSO via multiplication by the ROTMSO.

iv. Convert the resultant MSO vector to spherical coordinates. Round angles down to the nearest 10°.

v. Add the flux value multiplied by the PHA solid angle into a temporary 18 x 36 matrix using the rounded-down angles.

vi. Convert entire FIPS spherical MCP map to MSO using the steps from (ii) for each coordinate pair. Round angles down to the nearest 10°.

vii. Add the MCP pixel solid angles into a second temporary 18 x 36 matrix using the rounded-down angles.

viii. Divide the temporary flux by the temporary solid angle,, element-by-element.

b. The VIEWTIME matrix for each energy scan is created as follows:

i. Calculate the average step measurement time for the scan

ii. Add that value into every element of the VIEWTIME matrix

iii. Set to 0 any matrix location for which the corresponding solid angle matrix value is 0 (this will remove unobserved locations from the result).

2. Sum FLUX and VIEWTIME over all accumulation scans

3. Form the properly normalized product by dividing (element by element) the FLUX (summed over scans) and VIEWTIME (summed over scans).

$$FLUXMAP = \frac{\sum FLUX}{\sum VIEWTIME}$$

5.2.2.4 Arrival Direction (Retired Product)

This product class was retired after the Mercury Orbit Year 2 mission phase. The Angular Flux Map products described in the previous section supersede it. Since the Arrival Direction products remain in version V1.0 of the data set in the FIPS DDR archive volume at the PDS, a description of them is retained in this document.

This product provides observed density as a function of arrival direction in the instrument frame (incident polar and azimuthal angle) in MSO coordinates for selected ions and regions around Mercury. The discrete integration of phase space density (f) is performed in the velocity dimension (v) only, leaving the two angular dimensions unchanged:

$$n_{obs,s}(\theta,\phi) = \sum_i f_{i,s}\,(\theta,\phi) v_{i,s}^2 dv_i$$

The above quantity, termed "observed density", is analogous to density in each angular bin formed only from the counts observed in that bin. It differs from that performed in the Angular Flux Map product by one power of v which introduced in that product to change from a density to a flux quantity.

The Arrival Direction Histogram product is identical in several ways to the Angular Flux Maps product that replaced it: It can be difficult to interpret due to very low count rates, a problem which is partially mitigated by summing over FIPS scans. This summing then requires proper normalization, performed in exactly the same manner as described in detail for Angular Flux Maps. This product may be used in conjunction with pitch angle distributions to understand the location and motion of ions relative to Mercury.

The ARRDIR data product is constructed and normalized exactly as described above for the Angular Flux Maps, with two exceptions (with the ARRDIR array replacing the FLUXMAP array):

1. The velocity vector must NOT be inverted by reversing the sign of each component.

2. Multiply the weight from each PHA is added into the ARRDIR array. It is ***not*** multiplied by the particle speed. (Modify step 2.b.iv. above.)

5.2.2.5 Pitch Angle Distributions

For an ion in the presence of a magnetic field, the angle between the velocity vector and the local magnetic field direction is referred to as pitch angle. For populations of plasma ions, pitch angle distribution histograms can be formed by counting the number of ions within a given pitch angle range (PCHANG data product). This histogram may also be separated into measured E/q bins, forming energy-resolved pitch angle distributions (ERPCHANG data product). Pitch angle distributions give information on the velocity of ions along magnetic field lines, character of velocity distributions and the general plasma environment. Care must be taken when interpreting pitch angle distributions in the instrument frame (such as these) when the plasma has a non-negligible bulk velocity. Both the PCHANG and ERPCHANG products are provided for all 5 ion species throughout the entire magnetosphere and magnetosheath regions crossed by the spacecraft during each orbit.

The pitch angle distribution for a given time period consists of a histogram of these angles in 10° bins for all the ion events (PHA words) in the time period. Energy-resolved pitch angle distributions are also separated into the native FIPS E/q stepping bins. Pitch angle distributions are provided for selected ions and time periods, when sufficient statistics exist to make the product meaningful for scientific studies.

The PCHANG data product is normalized as follows:

1. Two arrays representing pitch angles 0-180° are created at 10° binning, resulting in two 18-element arrays. The first of these is used for the average flux, FLUX, while the second is used for viewing normalization, VIEWTIME.
    a. The FLUX array for each energy scan is created from PHAs as follows:
        i. Find the rotation matrix, ROTMSO, (described below) for the day (YYYYDOY) and index which corresponds to the scan
        ii. Form the unit velocity vector:
            1. Convert the incident polar and azimuthal angles of the event from FIPS spherical coordinates to FIPS Cartesian coordinates. Use the

usual manner for spherical to Cartesian conversion, using 1 for the r component.

2. Invert by multiplying all components by -1. This changes the FOV coordinates to flow direction.

iii. Rotate to MSO via multiplication by the ROTMSO.

iv. Average the MAG CDR vectors (already in MSO) that fall within the FIPS scan time to one value

v. Calculate the angular separation between this vector and the average MAG vector. Round down angle to nearest 10°.

vi. Add the flux value multiplied by the PHA solid angle into a temporary 18 element array using the rounded-down angles.

vii. Convert entire FIPS spherical MCP map to MSO using the steps from (ii) for each coordinate pair. Round angles down to the nearest 10°.

viii. Calculate the angular separation between the MCP vectors and the average MAG vector. Round down angle to nearest 10°.

ix. Add the MCP pixel solid angles into a second temporary 18 element array using the rounded-down angles.

x. Divide the flux temp by the solid angle temp, element-by-element.

b. The VIEWTIME array for each energy scan is created as follows:

i. Calculate the average step measurement time for the scan

ii. Add that value into every element of the VIEWTIME array.

iii. Set to 0 any array location for which the corresponding solid angle array value is 0 (this will remove unobserved locations from the result).

2. Sum FLUX and VIEWTIME over all accumulation scans

3. Form the properly normalized product by dividing (element by element) the FLUX (summed over scans) and VIEWTIME (summed over scans).

$$PCHANG = \frac{\sum FLUX}{\sum VIEWTIME}$$

The ERPCHANG product is formed in an analogous fashion, with the additional separation by E/q step. In this case, the weighting value in the 'FLUX' numerator is average phase space density.

5.2.2.6 Kinetic Properties

Under several conditions, full number density, n, temperature, T, and pressure, P, can be calculated directly from counts. (In contrast, when these conditions are not fulfilled, only the partial, observed densities, described above in 5.2.2.2, can be determined.) The conditions are as follows:

1) There must be sufficient counts to produce a well-defined energy spectrum. When necessary, counts from multiple scans are summed to meet this criterion.

2) The plasma must be subsonic. That is,

$$\frac{v_b}{v_{th}} < 0.5$$

where v_b is the plasma bulk velocity and V_{th} is the plasma thermal velocity.

3) The plasma must be nearly isotropic. That is,

$$0.5 < T_{\perp} / T_{||} < 5$$

where $T_{\perp}$ is the plasma temperature perpendicular to the magnetic field and $T_{||}$ is the plasma temperature parallel to the magnetic field.

This data is provided where these assumptions are most likely to hold: a) throughout the magnetosphere and b) the dayside magnetosheath within a 45° cone angle around the X_{MSO} axis. Furthermore, the data are averaged over multiple FIPS scans so as to minimize the effect on the recovered n and T of transients (e.g. high speed flows) which violate the assumptions. **However**, for studies involving features near the time scale of the averaged data and/or inside the magnetosheath, **users are strongly cautioned** to evaluate the validity of the assumptions themselves. This is most easily done by comparing velocity distribution functions, computed from differential energy flux spectra and averaged to the same period as this data, to those formed from a non-drifting Maxwell-Boltzmann velocity distribution formed from the recovered n and T (with bulk speed of zero).

For protons, this product is derived from on-board accumulated rates rather than PHA event words, for much higher signal to noise ratio. Data is summed over multiple scans to increase signal to noise. Furthermore, this data is produced only those accumulations which exceed a minimum count level (20 counts). Extensive testing has shown that computing these products from PHA event words for ions heavier than protons is not practical at fixed time steps of the order of a few minutes. Therefore, these ions are not included in this product.

When these conditions are fulfilled, we compute n and v_{th} directly from measured velocity distribution functions (formed from differential energy flux spectra) using a numerical method of solving the system of moment equations [*Gershman et al.*, 2013]. T and P are then calculated using the usual relations:

$$T = m v_{th}^2 / k_b$$
$$P = n k_b T$$

where k_b is the Boltzmann constant. The units of the recovered plasma parameters are cm^{-3}, MK, and nPa for n, T, and P, respectively. The quoted uncertainties of these parameters are a function of only number of counts used to create each distribution, following Gershman et al., 2013. There are small additional uncertainties that result as the measured energy spectra approach the limits of conditions (2) and (3) above. These additional uncertainties are difficult to quantify and not included in the reported uncertainties.

5.2.2.7 Viewing Normalization

The FIPS Viewing Normalization data product contains a rotation matrix (ROTMSO) from FIPS cartesian to MSO coordinates, for each FIPS energy scan. This matrix can be used to rotate ion incident angles in CDR PHA data into MSO coordinates needed for producing normalized directional maps (e.g. FLUXMAP or PCHANG) for arbitrary time resolutions, in multiples of 10s.

5.3 Data Processing

5.3.1 Data Processing Level

There is one EPPS PDS Documentation Archive Volume and one EPPS PDS Data Archive Volume. The data volume contains level 4 CODMAC data products, also known as DDRs. Each product has a unique file name and conforms to the file naming convention in section 6.5. All DDR products were stored at the MESSENGER Science Operations Center (SOC) during the MESSENGER mission. Volumes were transferred to the PDS PPI Node following the procedure in section 5.3.3.

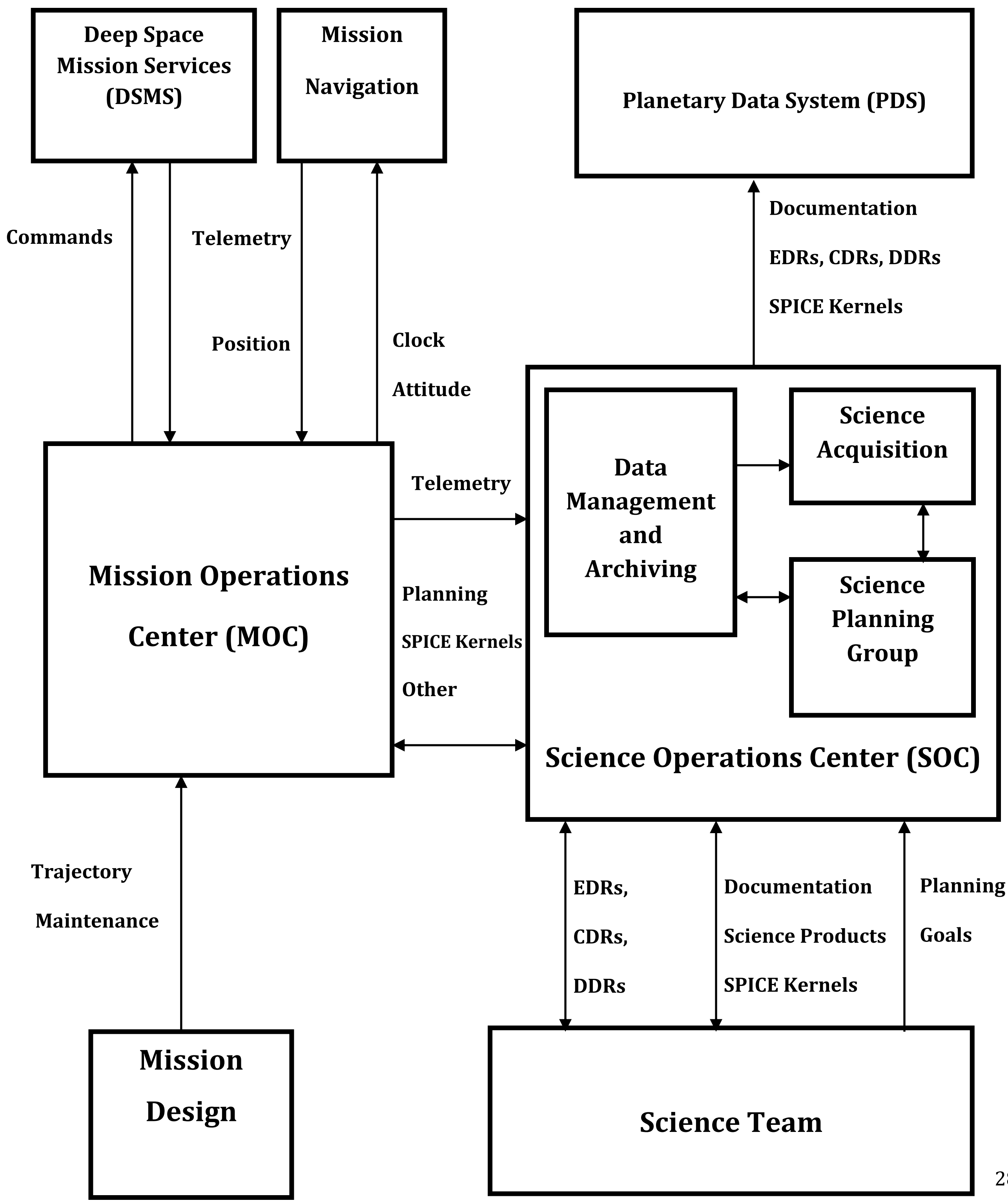
5.3.2 Data Product Generation

The EPPS DDR files were produced by the EPS and FIPS teams. A Java program derived from the MIDL (Mission Independent Data Layer) analysis software developed by APL was used to generate the DDRs. The FIPS data were produced using Interactive Data Language (IDL) software routines developed at the University of Michigan. The DDR data products were made available to the MESSENGER Science Team for initial evaluation and validation. At the end of the evaluation and validation period, the data were organized and stored in the directory structure described in section 6.8 for transfer to the PPI Node. The transmittal process is described in section, 5.3.3. An initial release of the documentation volume accompanied the initial release of the data volume. Thereafter, updates to the documentation volume were made with each data delivery to document the data quality for the delivery, changes to products including calibration updates, and other updates as appropriate. PDS provides public access to the data products through its online distribution system. These products support engineering analysis, direct science analysis, and construction of other science products.

5.3.3 Data Flow

The MESSENGER SOC operates under the auspices of the MESSENGER Project Scientist to plan data acquisition, generate, and validate data archives. The SOC supports and works with the Mission Operations Center (MOC), the Science Team, instrument scientists, and the PDS.

Figure 1 MESSENGER data flow shows the flow of data within the MESSENGER project and out to PDS. The MOC handles raw data flow to and from the MESSENGER spacecraft and the SOC converts the raw telemetry into EDRs, which are subsequently converted into CDRs and DDRs by the Science Team. Documentation, CDRs, and DDRs are delivered to the PDS Planetary Plasma Interactions (PPI) node. All SPICE kernels used in CDR and DDR processing are delivered to the PDS Navigation and Ancillary Information (NAIF) node. The delivery process is detailed below.


Deep Space Mission Services (DSMS)
Mission Navigation
Planetary Data System (PDS)
Commands
Telemetry
Position
Clock
Attitude
Documentation
EDRs, CDRs, DDRs
SPICE Kernels
Data Management and Archiving
Science Acquisition
Science Planning Group
Science Operations Center (SOC)
Mission Operations Center (MOC)
Telemetry
Planning
SPICE Kernels
Other
Trajectory
Maintenance
EDRs,
CDRs,
DDRs
Documentation
Science Products
SPICE Kernels
Planning
Goals
Mission Design
Science Team

The MESSENGER SOC delivered data for the EPPS DDR data volume to the PDS PPI Node in standard product packages. Each package comprises data and ancillary data files, organized into directory structures consistent with the volume design described in section 6.8. The initial release contained the documents and required files for the EPPS documentation volume, organized into directory structures as described in section 6.7. Subsequent releases to the EPPS documentation volume contained updates as appropriate.

In preparation for delivery, the directory structure is compressed into a single "zip archive" file for transfer to the PDS node. The zip archive preserves the directory structure internally so that it can be recreated after delivery to the PDS node. Also included in the transfer is a checksum file created using the MD5 algorithm. This provides an independent method of verifying the integrity of the zip file after it has been sent. Within days of receipt of the delivery the PDS node acknowledges receipt of the archive and checksum file. If acknowledgement is not received, or if problems are reported, the MESSENGER SOC immediately takes corrective action to affect successful transfer. Delivery size determines the transfer mechanism: electronic or shipping a hard drive.

The PDS node uncompresses the zip archive file and checks for data integrity using the checksum file. The node performs any additional verification and validation of the data provided and reports any discrepancies or problems to the MESSENGER SOC. The node performs these checks within about two weeks from receipt of the delivery. After inspection has been completed to the satisfaction of the PDS node, the node issues an acknowledgement of successful receipt of the data to the MESSENGER SOC.

Following receipt of a data delivery the PDS node organizes the data into a PDS volume archive structure within its online data system. Newly delivered data are made available publicly from PDS once accompanying labels and other documentation have been validated.

5.3.4 Labeling and Identification

The PDS label conforms to PDS version 3.8 standards. For more information about this standard consult the PDS Standards Reference Document. The label is detached and in a separate PDS label file. The purpose of the PDS label is to describe the data product and provide ancillary information about the data product. There is a PDS label file for every EPPS DDR data file. There is one DATA_SET_ID assigned to the EPPS DDR data. The DDRs are further grouped into data products and are identified by the STANDARD_DATA_PRODUCT_ID keyword and the file naming convention, section 6.5. Example label file content is shown here for every DDR data product. Note that the data are contained within an ASCII table and the details of the table structure are described by an external ASCII format file (*.FMT). The columns in each format file are described separately in the Appendix.

5.3.4.1 EPS Pitch Angles Label

A sample EPS Pitch Angles DDR file label is shown below:

```
PDS_VERSION_ID             =  "PDS3"

/* ** FILE FORMAT ** */
FILE_RECORDS               =  5798
RECORD_TYPE                =  FIXED_LENGTH
RECORD_BYTES               =  167

/* ** GENERAL DATA DESCRIPTION PARAMETERS ** */
PRODUCT_ID                 =  "EPSP_A2012010DDR_V1"
PRODUCT_VERSION_ID         =  "V1"
PRODUCT_CREATION_TIME      =  2012-05-09T21:04:27
PRODUCT_TYPE               =  "DDR"
STANDARD_DATA_PRODUCT_ID   =  "EPS_PITCH_ANGLES_DDR"
SOFTWARE_NAME              =  "MIDLMessengerDDRGenerator"
SOFTWARE_VERSION_ID        =  "1.0"
INSTRUMENT_HOST_NAME       =  "MESSENGER"
INSTRUMENT_NAME            =  "ENERGETIC PARTICLE SPECTROMETER"
INSTRUMENT_ID              =  "EPS"
DATA_SET_ID                =  "MESS-E/V/H/SW-EPPS-3-EPS-DDR-V1.0"
DATA_SET_NAME              =  "MESSENGER E/V/H/SW EPPS CALIBRATED EPS DDR
V1.0"
MISSION_PHASE_NAME         =  "MERCURY ORBIT"
TARGET_NAME                =  "MERCURY"
START_TIME                 =  2012-010T00:00:49
STOP_TIME                  =  2012-010T23:59:45
```

```
SPACECRAFT_CLOCK_START_COUNT   = "234641115"
SPACECRAFT_CLOCK_STOP_COUNT   = "234727451"
^HEADER                    =  ("EPSP_A2012010DDR_V1.TAB", 1)
^ASCII_TABLE               =  ("EPSP_A2012010DDR_V1.TAB", 2)

OBJECT                     =  HEADER
  HEADER_TYPE                =  TEXT
  INTERCHANGE_FORMAT         =  "ASCII"
  RECORDS                    =  1
  BYTES                      =  167
  DESCRIPTION                  = "The first record of this
    file is the header section. The header contains column
    headings to improve usability."
END_OBJECT                 =  HEADER

OBJECT                     =  ASCII_TABLE
  COLUMNS                    =  7
  INTERCHANGE_FORMAT         =  ASCII
  ROW_BYTES                  =  167
  ROWS                       =  5798
  DESCRIPTION                = "
    This table contains Pitch Angles between the measured flow vector
    direction and the magnetic field for each of the 6 sectors of
    the MESSENGER EPS instrument. The complete column definitions are
    contained in an external file found in the LABEL directory of the
    archive volume. Additional details are contained in the DDR SIS
    document."
  NOTE                       =  "Data Quality: 0"
```

```
  ^STRUCTURE                = "EPS_PITCH_ANGLES.FMT"
END_OBJECT                  =  ASCII_TABLE

END
```

5.3.4.2 EPS Pitch Angle Spectrogram Label

A sample EPS Pitch Angle Spectrogram DDR file label is shown below:

```
PDS_VERSION_ID              =  "PDS3"

/* ** FILE FORMAT ** */
RECORD_TYPE                     = UNDEFINED
INTERCHANGE_FORMAT              = BINARY

/* ** GENERAL DATA DESCRIPTION PARAMETERS ** */
PRODUCT_ID                  =  "EPS_PAS_2012074205045_V1"
PRODUCT_VERSION_ID          =  "V1"
PRODUCT_CREATION_TIME       =  2012-05-09T17:00:00
PRODUCT_TYPE                =  "BROWSE"
STANDARD_DATA_PRODUCT_ID    =  "EPS_PITCH_ANGLE_SPECTROGRAM_DDR"
SOFTWARE_NAME               =  "MIDLMessengerDDRGenerator"
SOFTWARE_VERSION_ID         =  "1.0"
INSTRUMENT_HOST_NAME        =  "MESSENGER"
INSTRUMENT_NAME             =  "ENERGETIC PARTICLE SPECTROMETER"
INSTRUMENT_ID               =  "EPS"
DATA_SET_ID                 =  "MESS-E/V/H/SW-EPPS-3-EPS-DDR-V1.0"
 DATA_SET_NAME              =  "MESSENGER E/V/H/SW EPPS CALIBRATED EPS DDR V1.0"
MISSION_PHASE_NAME          =  "MERCURY ORBIT"
TARGET_NAME                 =  "MERCURY"
```

```
START_TIME                  =  2012-03-14T20:50:45
STOP_TIME                   =  2012-03-15T00:23:45
SPACECRAFT_CLOCK_START_COUNT   = "240245710"
SPACECRAFT_CLOCK_STOP_COUNT   = "240258490"

^DOCUMENT                 = "EPS_PAS_2012074205045_V1.PNG"
OBJECT                    = DOCUMENT
  DOCUMENT_NAME         = "EPS_PAS_2012074205045_V1"
  DOCUMENT_FORMAT       = PNG
  DOCUMENT_TOPIC_TYPE = "BROWSE IMAGE"
  INTERCHANGE_FORMAT  = BINARY
  PUBLICATION_DATE    = 2012-05-09T17:00:00
  SOURCE_PRODUCT_ID   = {
       "EPSL_R2012074EDR_V1.DAT",
       "MAGSC_SCIAVG12075_01_V00.TAB",
       "MAGSC_SCIAVG12074_01_V00.TAB",
       "EPSL_R2012075EDR_V1.DAT"
}
  LINES               = 400
  LINE_SAMPLES        = 850
  SAMPLE_TYPE         = MSB_UNSIGNED_INTEGER
  SAMPLE_BITS         = 8
  DESCRIPTION         = "PNG file containing a spectrogram representation of
the summation of the shaped count rates in detectors 0-10 except detector 3. The
counts are binned in time (120 s) and pitch angle (22.5 deg). Constant normalization
factors and background subtractions (see SIS for Table) have been applied to these
rates."
END_OBJECT            = DOCUMENT
END
```

5.3.4.3 FIPS Pitch Angles Label (PCHANG)

A sample FIPS Pitch Angles DDR file label is shown below:

```
PDS_VERSION_ID                 =  "PDS3"

/* ** FILE FORMAT ** */
FILE_RECORDS                   =  1350
RECORD_TYPE                    =  FIXED_LENGTH
RECORD_BYTES                   =  2799

/* ** GENERAL DATA DESCRIPTION PARAMETERS ** */
PRODUCT_ID                     =  "FIPS_PCHANG_2012001_DDR_V01"
PRODUCT_VERSION_ID             =  "V1"
PRODUCT_CREATION_TIME          =  2012-05-08T23:35:42
PRODUCT_TYPE                   =  "DDR"
STANDARD_DATA_PRODUCT_ID       =  "FIPS_PCHANG_DDR"
SOFTWARE_NAME                  =  "mfips_decode_pha.pro"
SOFTWARE_VERSION_ID            =  "1.0"
INSTRUMENT_HOST_NAME           =  "MESSENGER"
INSTRUMENT_NAME                =  "FAST IMAGING PLASMA SPECTROMETER"
INSTRUMENT_ID                  =  "FIPS"
DATA_SET_ID                    =  "MESS-E/V/H/SW-EPPS-3-FIPS-DDR-V2.0"
DATA_SET_NAME                  =  "MESSENGER E/V/H/SW EPPS CALIBRATED FIPS DDR
V2.0"
SOURCE_PRODUCT_ID              =  "FileByFile"
MISSION_PHASE_NAME             =  "MERCURY ORBIT"
TARGET_NAME                    =  "MERCURY"
START_TIME                     =  2012-01-01T00:00:00
```

```
STOP_TIME                      =  2012-01-01T23:59:59
SPACECRAFT_CLOCK_START_COUNT   =  "233863466"
SPACECRAFT_CLOCK_STOP_COUNT    =  "233949802"
^HEADER                        =  ("FIPS_PCHANG_2012001_DDR_V01.TAB", 1)
^ASCII_TABLE                   =  ("FIPS_PCHANG_2012001_DDR_V01.TAB", 4)

OBJECT                         =  HEADER
  HEADER_TYPE                    =  TEXT
  INTERCHANGE_FORMAT             =  "ASCII"
  RECORDS                        =  3
  BYTES                          =  8397
  DESCRIPTION                  = "The first 3 records of this
    file are the header section. The header contains column
    headings to improve usability."
END_OBJECT                     =  HEADER

OBJECT                         =  ASCII_TABLE
  COLUMNS                        =  3
  INTERCHANGE_FORMAT             =  ASCII
  ROW_BYTES                      =  2799
  ROWS                           =  1350
  DESCRIPTION                     = "
    This table contains FIPS Flux-Pitch angle histograms."
  ^STRUCTURE                     =  "FIPS_PCHANG_DDR.FMT"
END_OBJECT                     =  ASCII_TABLE

END
```

5.3.4.4 Energy-Resolved Pitch Angle Distributions (ERPCHANG) Label

A sample FIPS ERPCHANG DDR file label is shown below:

```
PDS_VERSION_ID                = "PDS3"


/* ** FILE FORMAT ** */

FILE_RECORDS                  = 5

RECORD_TYPE                   = FIXED_LENGTH

RECORD_BYTES                  = 16218


/* ** GENERAL DATA DESCRIPTION PARAMETERS ** */

PRODUCT_ID                    = "FIPS_ERPCHANG_2011174_V1"

PRODUCT_VERSION_ID            = "1"

PRODUCT_CREATION_TIME         = 2014-11-06T16:00:00

PRODUCT_TYPE                  = "DDR"

STANDARD_DATA_PRODUCT_ID      = "FIPS_ERPCHANG"

SOFTWARE_NAME                 = "MFIPS_DDR_SAMPLE.PRO"

SOFTWARE_VERSION_ID           = "0.1"

INSTRUMENT_HOST_NAME          = "MESSENGER"

INSTRUMENT_NAME               = "ENERGETIC PARTICLE AND PLASMA SPECTROMETER"

INSTRUMENT_ID                 = "EPPS"

DATA_SET_ID                   = "MESS-E/V/H/SW-EPPS-3-FIPS-DDR-V2.0"

DATA_SET_NAME                 = "MESSENGER E/V/H/SW EPPS CALIBRATED FIPS DDR
V2.0"

MISSION_PHASE_NAME            = "MERCURY ORBIT"

TARGET_NAME                   = "MERCURY"

START_TIME                    = 2011-06-23T10:45:40.419666

STOP_TIME                     = 2011-06-23T22:53:43.420605

SPACECRAFT_CLOCK_START_COUNT  = "1/217313408.800"
```

```
SPACECRAFT_CLOCK_STOP_COUNT   =  "1/217357091.000"

^HEADER                       =  ("FIPS_ERPCHANG_2011174_DDR_V01.TAB", 1)

^ASCII_TABLE                  =  ("FIPS_ERPCHANG_2011174_DDR_V01.TAB", 4)


OBJECT                        =  HEADER

  HEADER_TYPE                   =  TEXT

  INTERCHANGE_FORMAT            =  "ASCII"

  RECORDS                       =  3

  BYTES                         =  48654

  DESCRIPTION                 = "The first four records of this

    file are the header section. The header contains column

    headings to improve usability."

END_OBJECT                    =  HEADER



OBJECT                        =  ASCII_TABLE

  COLUMNS                       =  7

  INTERCHANGE_FORMAT            =  ASCII

  ROW_BYTES                     =  16218

  ROWS                          =  2

  DESCRIPTION                    = "

This table contains 2 dimensional pitch angle histograms as

described in EPPS DDR SIS."

  ^STRUCTURE                    =  "FIPS_ERPCHANG_DDR.FMT"

END_OBJECT                    =  ASCII_TABLE


END
```

5.3.4.5 FIPS Energy Spectra Label

A sample FIPS Energy Spectra DDR file label is shown below:

```
PDS_VERSION_ID                 =  "PDS3"

/* ** FILE FORMAT ** */
FILE_RECORDS                   =  1350
RECORD_TYPE                    =  FIXED_LENGTH
RECORD_BYTES                   =  4824

/* ** GENERAL DATA DESCRIPTION PARAMETERS ** */
PRODUCT_ID                     =  "FIPS_ESPEC_2012001_DDR_V01"
PRODUCT_VERSION_ID             =  "V1"
PRODUCT_CREATION_TIME          =  2012-05-08T23:35:41
PRODUCT_TYPE                   =  "DDR"
STANDARD_DATA_PRODUCT_ID       =  "FIPS_ESPEC_DDR"
SOFTWARE_NAME                  =  "mfips_decode_pha.pro"
SOFTWARE_VERSION_ID            =  "1.0"
INSTRUMENT_HOST_NAME           =  "MESSENGER"
INSTRUMENT_NAME                =  "FAST IMAGING PLASMA SPECTROMETER"
INSTRUMENT_ID                  =  "FIPS"
DATA_SET_ID                    =  "MESS-E/V/H/SW-EPPS-3-FIPS-DDR-V2.0"
DATA_SET_NAME                  =  "MESSENGER E/V/H/SW EPPS CALIBRATED FIPS DDR
V2.0"
SOURCE_PRODUCT_ID              =  "FileByFile"
MISSION_PHASE_NAME             =  "MERCURY ORBIT"
TARGET_NAME                    =  "MERCURY"
START_TIME                     =  2012-01-01T00:00:00
```

```
STOP_TIME                      =  2012-01-01T23:59:59
SPACECRAFT_CLOCK_START_COUNT   =  "233863466"
SPACECRAFT_CLOCK_STOP_COUNT    =  "233949802"
^HEADER                        =  ("FIPS_ESPEC_2012001_DDR_V01.TAB", 1)
^ASCII_TABLE                   =  ("FIPS_ESPEC_2012001_DDR_V01.TAB", 4)

OBJECT                         =  HEADER
  HEADER_TYPE                    =  TEXT
  INTERCHANGE_FORMAT             =  "ASCII"
  RECORDS                        =  3
  BYTES                          =  19094472
  DESCRIPTION                  = "The first 3 records of this
    file are the header section. The header contains column
    headings to improve usability."
END_OBJECT                     =  HEADER

OBJECT                         =  ASCII_TABLE
  COLUMNS                        =  7
  INTERCHANGE_FORMAT             =  ASCII
  ROW_BYTES                      =  4824
  ROWS                           =  1350
  DESCRIPTION                     = "
    This table contains FIPS energy spectra for selected ion species."
  ^STRUCTURE                     =  "FIPS_ESPEC_DDR.FMT"
END_OBJECT                     =  ASCII_TABLE

END
```

5.3.4.6 FIPS Observed Density Label

A sample FIPS Observed Density DDR file label is shown below:

```
PDS_VERSION_ID                = "PDS3"

/* ** FILE FORMAT ** */
FILE_RECORDS                  = 1350
RECORD_TYPE                   = FIXED_LENGTH
RECORD_BYTES                  = 216

/* ** GENERAL DATA DESCRIPTION PARAMETERS ** */
PRODUCT_ID                    = "FIPS_NOBS_2012001_DDR_V01"
PRODUCT_VERSION_ID            = "V1"
PRODUCT_CREATION_TIME         = 2012-05-08T23:35:42
PRODUCT_TYPE                  = "DDR"
STANDARD_DATA_PRODUCT_ID      = "FIPS_NOBS_DDR"
SOFTWARE_NAME                 = "mfips_decode_pha.pro"
SOFTWARE_VERSION_ID           = "1.0"
INSTRUMENT_HOST_NAME          = "MESSENGER"
INSTRUMENT_NAME               = "FAST IMAGING PLASMA SPECTROMETER"
INSTRUMENT_ID                 = "FIPS"
DATA_SET_ID                   = "MESS-E/V/H/SW-EPPS-3-FIPS-DDR-V2.0"
DATA_SET_NAME                 = "MESSENGER E/V/H/SW EPPS CALIBRATED FIPS DDR
V2.0"
SOURCE_PRODUCT_ID             = "FileByFile"
MISSION_PHASE_NAME            = "MERCURY ORBIT"
TARGET_NAME                   = "MERCURY"
START_TIME                    = 2012-01-01T00:00:00
```

```
STOP_TIME                       =  2012-01-01T23:59:59
SPACECRAFT_CLOCK_START_COUNT    =  "233863466"
SPACECRAFT_CLOCK_STOP_COUNT     =  "233949802"
^HEADER                         =  ("FIPS_NOBS_2012001_DDR_V01.TAB", 1)
^ASCII_TABLE                    =  ("FIPS_NOBS_2012001_DDR_V01.TAB", 4)

OBJECT                          =  HEADER
  HEADER_TYPE                     =  TEXT
  INTERCHANGE_FORMAT              =  "ASCII"
  RECORDS                         =  3
  BYTES                           =  648
  DESCRIPTION                   = "The first 3 records of this
    file are the header section. The header contains column
    headings to improve usability."
END_OBJECT                      =  HEADER

OBJECT                          =  ASCII_TABLE
  COLUMNS                         =  20
  INTERCHANGE_FORMAT              =  ASCII
  ROW_BYTES                       =  216
  ROWS                            =  1350
  DESCRIPTION                      = "
    This table contains FIPS differential energy intensities for selected ion
species."
  ^STRUCTURE                      =  "FIPS_NOBS_DDR.FMT"
END_OBJECT                      =  ASCII_TABLE

END
```

5.3.4.7 FIPS Arrival Direction Label (Retired Product)

A sample FIPS Arrival Direction DDR file label is shown below:

```
PDS_VERSION_ID                 =  "PDS3"

/* ** FILE FORMAT ** */
FILE_RECORDS                   =  42
RECORD_TYPE                    =  FIXED_LENGTH
RECORD_BYTES                   =  9158

/* ** GENERAL DATA DESCRIPTION PARAMETERS ** */
PRODUCT_ID                     =  "FIPS_ARRDIR_2012054_DDR_V01"
PRODUCT_VERSION_ID             =  "01"
PRODUCT_CREATION_TIME          =  2013-06-04T21:22:22
PRODUCT_TYPE                   =  "DDR"
STANDARD_DATA_PRODUCT_ID       =  "FIPS_ARRDIR_DDR"
SOFTWARE_NAME                  =  "mfips_ddr_sample.pro"
SOFTWARE_VERSION_ID            =  "0.1"
INSTRUMENT_HOST_NAME           =  "MESSENGER"
INSTRUMENT_NAME                =  "FAST IMAGING PLASMA SPECTROMETER"
INSTRUMENT_ID                  =  "FIPS"
DATA_SET_ID                    =  "MESS-E/V/H/SW-EPPS-3-FIPS-DDR-V1.0"
DATA_SET_NAME                  =  "MESSENGER E/V/H/SW EPPS CALIBRATED FIPS DDR
V1.0"
SOURCE_PRODUCT_ID              =  "FileByFile"
MISSION_PHASE_NAME             =  "MERCURY ORBIT"
TARGET_NAME                    =  "MERCURY"
```

```
SPACECRAFT_CLOCK_START_COUNT  =  "1/238523075.000"
START_TIME                    =  2012-02-23T22:20:08.845
SPACECRAFT_CLOCK_STOP_COUNT   =  "1/238524872.000"
STOP_TIME                     =  2012-02-23T22:50:05.845
^HEADER                       =  ("FIPS_ARRDIR_2012054_DDR_V01.TAB", 1)
^ASCII_TABLE                  =  ("FIPS_ARRDIR_2012054_DDR_V01.TAB", 4)

OBJECT                        =  HEADER
  HEADER_TYPE                   =  TEXT
  INTERCHANGE_FORMAT            =  "ASCII"
  RECORDS                       =  3
  BYTES                         =  9158
  DESCRIPTION                 = "The first three records of this
    file are the header section. The header contains column
    headings to improve usability."
END_OBJECT                    =  HEADER


OBJECT                        =  ASCII_TABLE
  COLUMNS                       =  7
  INTERCHANGE_FORMAT            =  ASCII
  ROW_BYTES                     =  9158
  ROWS                          =  39
  DESCRIPTION                    = "
This table contains FIPS ion flux as a function of arrival
direction which have been accumulated in time enough to be
meaningfully interpreted."
  ^STRUCTURE                    =  "FIPS_ARRDIR_DDR.FMT"
```

```
END_OBJECT                   =  ASCII_TABLE

END
```

5.3.4.8 FIPS Angular Flux Map Label

A sample FIPS Angular Flux Map DDR file label is shown below:

```
PDS_VERSION_ID               =  "PDS3"

/* ** FILE FORMAT ** */
FILE_RECORDS                 =  5
RECORD_TYPE                  =  FIXED_LENGTH
RECORD_BYTES                 =  9162

/* ** GENERAL DATA DESCRIPTION PARAMETERS ** */
PRODUCT_ID                   =  "FIPS_FLUXMAP_2011174_V1"
PRODUCT_VERSION_ID           =  "1"
PRODUCT_CREATION_TIME        =  2014-11-06T16:00:00
PRODUCT_TYPE                 =  "DDR"
STANDARD_DATA_PRODUCT_ID     =  "FIPS_FLUXMAP"
SOFTWARE_NAME                =  "MFIPS_DDR_SAMPLE.PRO"
SOFTWARE_VERSION_ID          =  "0.1"
INSTRUMENT_HOST_NAME         =  "MESSENGER"
INSTRUMENT_NAME              =  "ENERGETIC PARTICLE AND PLASMA SPECTROMETER"
INSTRUMENT_ID                =  "EPPS"
DATA_SET_ID                  =  "MESS-E/V/H/SW-EPPS-3-FIPS-DDR-V2.0"
DATA_SET_NAME                =  "MESSENGER E/V/H/SW EPPS CALIBRATED FIPS DDR
V2.0"
MISSION_PHASE_NAME           =  "MERCURY ORBIT"
```

```
TARGET_NAME                    =  "MERCURY"
START_TIME                     =  2011-06-23T10:45:40.420458
STOP_TIME                      =  2011-06-23T22:53:43.420605
SPACECRAFT_CLOCK_START_COUNT   =  "1/217313408.800"
SPACECRAFT_CLOCK_STOP_COUNT    =  "1/217357091.000"
^HEADER                        =  ("FIPS_FLUXMAP_2011174_DDR_V01.TAB", 1)
^ASCII_TABLE                   =  ("FIPS_FLUXMAP_2011174_DDR_V01.TAB", 4)

OBJECT                         =  HEADER
  HEADER_TYPE                    =  TEXT
  INTERCHANGE_FORMAT             =  "ASCII"
  RECORDS                        =  3
  BYTES                          =  27486
  DESCRIPTION                  = "The first four records of this
    file are the header section. The header contains column
    headings to improve usability."
END_OBJECT                     =  HEADER


OBJECT                         =  ASCII_TABLE
  COLUMNS                        =  7
  INTERCHANGE_FORMAT             =  ASCII
  ROW_BYTES                      =  9162
  ROWS                           =  2
  DESCRIPTION                     = "
This table contains angular flux map data as
described in EPPS DDR SIS."
  ^STRUCTURE                     =  "FIPS_FLUXMAP_DDR.FMT"
```

```
END_OBJECT                    =  ASCII_TABLE

END
```

5.3.4.9 FIPS Kinetic Properties Label

A sample FIPS Kinetic Properties DDR file label is shown below:

```
PDS_VERSION_ID                =  "PDS3"

/* ** FILE FORMAT ** */
FILE_RECORDS                  =  42
RECORD_TYPE                   =  FIXED_LENGTH
RECORD_BYTES                  =  176

/* ** GENERAL DATA DESCRIPTION PARAMETERS ** */
PRODUCT_ID                    =  "FIPS_NTP_2012054_DDR_V01"
PRODUCT_VERSION_ID            =  "01"
PRODUCT_CREATION_TIME         =  2013-06-04T21:22:22
PRODUCT_TYPE                  =  "DDR"
STANDARD_DATA_PRODUCT_ID      =  "FIPS_NTP_DDR"
SOFTWARE_NAME                 =  "mfips_ddr_sample.pro"
SOFTWARE_VERSION_ID           =  "0.1"
INSTRUMENT_HOST_NAME          =  "MESSENGER"
INSTRUMENT_NAME               =  "FAST IMAGING PLASMA SPECTROMETER"
INSTRUMENT_ID                 =  "FIPS"
DATA_SET_ID                   =  "MESS-E/V/H/SW-EPPS-3-FIPS-DDR-V2.0"
DATA_SET_NAME                 =  "MESSENGER E/V/H/SW EPPS CALIBRATED FIPS DDR
V2.0"
SOURCE_PRODUCT_ID             =  "FileByFile"
MISSION_PHASE_NAME            =  "MERCURY ORBIT"
```

```
TARGET_NAME                     =  "MERCURY"
SPACECRAFT_CLOCK_START_COUNT    =  "1/238523075.000"
START_TIME                      =  2012-02-23T22:20:08.845
SPACECRAFT_CLOCK_STOP_COUNT     =  "1/238524872.000"
STOP_TIME                       =  2012-02-23T22:50:05.845
^HEADER                         =  ("FIPS_NTP_2012054_DDR_V01.TAB", 1)
^ASCII_TABLE                    =  ("FIPS_NTP_2012054_DDR_V01.TAB", 4)

OBJECT                          =  HEADER
  HEADER_TYPE                     =  TEXT
  INTERCHANGE_FORMAT              =  "ASCII"
  RECORDS                         =  3
  BYTES                           =  176
  DESCRIPTION                   = "
This table contains FIPS ion number densities and temperatures,
as well as the pressure calculated from their product.
Quantities are calculated after sufficient time accumulation
to allow meaningful interpretation."
END_OBJECT                      =  HEADER


OBJECT                          =  ASCII_TABLE
  COLUMNS                         =  13
  INTERCHANGE_FORMAT              =  ASCII
  ROW_BYTES                       =  176
  ROWS                            =  39
  DESCRIPTION                       = "
    This table contains FIPS NTP values."
```

```
  ^STRUCTURE                          =  "FIPS_NTP_DDR.FMT"

END_OBJECT                          =  ASCII_TABLE


END
```

5.3.4.10 FIPS Viewing Normalization Products Labels

5.3.4.10.1 FIPS Cartesian to MSO Coordinates Rotation Matrix (ROTMSO)

```
PDS_VERSION_ID                      =  "PDS3"


/* ** FILE FORMAT ** */

FILE_RECORDS                        =  1303

RECORD_TYPE                         =  FIXED_LENGTH

RECORD_BYTES                        =  195


/* ** GENERAL DATA DESCRIPTION PARAMETERS ** */

PRODUCT_ID                          =  "FIPS_ROTMSO_2010001_DDR_V01"

PRODUCT_VERSION_ID                  =  "01"

PRODUCT_CREATION_TIME               =  2014-06-04T10:00:00

PRODUCT_TYPE                        =  "DDR"

STANDARD_DATA_PRODUCT_ID            =  "FIPS_ROTMSO_DDR"

SOFTWARE_NAME                       =  "MFIPS_DDR_SAMPLE.PRO"

SOFTWARE_VERSION_ID                 =  "0.1"

INSTRUMENT_HOST_NAME                =  "MESSENGER"

INSTRUMENT_NAME                     =  "ENERGETIC PARTICLE AND PLASMA SPECTROMETER"

INSTRUMENT_ID                       =  "EPPS"

DATA_SET_ID                         =  "MESS-E/V/H/SW-EPPS-3-FIPS-DDR-V2.0"

DATA_SET_NAME                       =  "MESSENGER E/V/H/SW EPPS CALIBRATED FIPS DDR
V2.0"

MISSION_PHASE_NAME                  =  "MERCURY 4 CRUISE"
```

```
TARGET_NAME                    =  "MERCURY"
SPACECRAFT_CLOCK_START_COUNT   =  "1/170791497.000"
START_TIME                     =  2010-01-01T00:00:23.676
SPACECRAFT_CLOCK_STOP_COUNT    =  "1/170877732.000"
STOP_TIME                      =  2010-01-01T23:57:38.677
^HEADER                        =  ("FIPS_ROTMSO_2010001_DDR_V01.TAB", 1)
^ASCII_TABLE                   =  ("FIPS_ROTMSO_2010001_DDR_V01.TAB", 4)

OBJECT                         =  HEADER
  HEADER_TYPE                    =  TEXT
  INTERCHANGE_FORMAT             =  "ASCII"
  RECORDS                        =  3
  BYTES                          =  585
  DESCRIPTION                  = "The first three records of this
    file are the header section. The header contains column
    headings to improve usability."
END_OBJECT                     =  HEADER


OBJECT                         =  ASCII_TABLE
  COLUMNS                        =  5
  INTERCHANGE_FORMAT             =  ASCII
  ROW_BYTES                      =  195
  ROWS                           =  1300
  DESCRIPTION                     = "
This table contains rotation matrix from FIPS cartesian
 to MSO for each energy scan."
  ^STRUCTURE                     =  "FIPS_ROTMSO_DDR.FMT"
```

```
END_OBJECT                    =  ASCII_TABLE

END
```

5.4 Standards Used in Generating Data Products

5.4.1 PDS Standards

The EPPS DDR data products are constructed according to the data object concepts developed by the PDS. By adopting the PDS format, the data products are consistent in content and organization with other planetary data collections. In the PDS standard, the DDR data file is grouped into objects with PDS labels describing the objects. Each DDR data product consists of two files:

- A data file containing an ASCII table object (the primary data), in fixed field format. ASCII table objects are in either comma separated value (CSV) format (EPS) or are whitespace delimited (FIPS). This makes the ASCII data extremely easy to read by many commercial off-the-shelf programs. The one exception is the EPS Pitch Angle Spectrogram, which is a binary PNG file.

- A label file which serves as a high-level description of the parameters of which correspond to the data file. The label file contains a pointer to an external format file, which details the structure of the table object in the data file.

5.4.2 Time Standards

One of the time fields in the FIPS table objects references the Mission Elapsed Time (MET). This MET is the spacecraft time in integer seconds that is transmitted to MESSENGER subsystems by the Integrated Electronics Module (IEM). MET = 0 is on August 3, 2004, at 05:59:16 UTC (coordinated universal time), which is 1000 seconds prior to the MESSENGER launch. Relativistic effects and circumstances occurring during the mission would result in MET not being a true account of seconds since launch. Following a planned spacecraft clock reset in early 2013, partition numbers (1/, or 2/) were added to product labels to disambiguate MET seconds after the spacecraft clock reset (if partition number is not present, SPICE defaults to partition 1/). For these reasons the MESSENGER spacecraft clock coefficients file is archived at the PDS NAIF Node. This file is used in conjunction with the leap seconds kernel file in order to calculate the conversion between MET and UTC.

The conversion is easily done through the use of SPICE kernels and the CHRONOS Utility. CHRONOS is a utility included with the SPICE package that is distributed by the PDS NAIF node. The SPICE kernels are files that contain the information needed to perform the conversion. Two SPICE kernels are required. One is the Leap Seconds Kernel (LSK) and the other is the MESSENGER Spacecraft

Clock Kernel (SCLK). The SCLK file is used by CHRONOS to convert between spacecraft clock time and ephemeris time, while the LSK file is used to convert from ephemeris time to UTC time. The CHRONOS utility is self-documenting and the SPICE package itself contains full documentation on each of the utilities (including CHRONOS) and how they are used.

EPPS DDR data is time-tagged with spacecraft event time (SCET) in the following UTC format: CCYY-DDDTHH:MM:SS.sss. This format represents a concatenation of the conventional date and time expressions with the two parts separated by the letter T:

CC - century (00-99)

YY - year (00-99)

DDD - day of year (001-366)

T - date/time separator

HH - hour (00-23)

MM - minute (00-59)

SS - second (00-59)

sss - fractions of second (000-999)

5.4.3 Coordinate Systems

There are two coordinate systems in use in the EPPS DDR data products: 1) the Mercury-centric Solar Orbital (MSO, defined in the MESSENGER SPICE Dynamic Frames Kernel) used for spacecraft position vectors; and 2) the FIPS Spherical coordinate system, used for FIPS incident angles since it represents natural coordinates for the sensor. The latter is a spherical version of the FIPS Cartesian coordinate system (FIPS_CART), which is defined in the MESSENGER SPICE Frames Kernel. FIPS Spherical coordinates (FIPS_SPH) consist of a radius (r), zenith angle (theta) and azimuthal angle (phi). The zenith angle is defined as the angle between the vector and the z axis in the FIPS Cartesian coordinate system. It ranges from 0 to 180 degrees. The azimuthal angle ranges from 0 to 360 degrees and is defined as the angle between the vector and the x axis in the FIPS Cartesian coordinate system. The radius is defined as usual as the magnitude of the FIPS Cartesian vector.

5.4.4 Data Storage Conventions

The data are organized following PDS standards and stored on hard disk at the MESSENGER SOC. The SOC transfers data to PDS as detailed in section 5.3.3. After verification of the data transfer PDS provides public access to MESSENGER science data products through its online data distribution system.

5.5 Data Validation

The EPPS DDR data archive volume set includes all data acquired during the MESSENGER mission. The archive validation procedure described in this section applies to data products generated during all post launch phases of the mission. To be clear, there is one and only one documentation volume and one and only one EPPS data archive volume created over the whole mission. Release dates are stated in the schedule in section 7. Updates to the data volume occurred according to the same schedule. Updates to the documentation volume occurred according to this schedule and at the discretion of the EPPS team.

PDS standards recommend that all data included in the formal archive be validated through a peer-review process. This process is designed to ensure that both the data and documentation are of sufficient quality to be useful to future generations of scientists. The process is presented as several steps, most of which occur in the PDS peer review. This peer review is conducted before any volumes are produced and released to PDS.

The peer review panel consists of members of the EPPS team, the PPI node of PDS, and at least one outside scientist actively working in the field of energetic particles research. The PDS personnel are responsible for validating that the volumes are fully compliant with PDS standards. The instrument team and outside reviewer(s) are responsible for verifying the content of the data set, the completeness of the documentation, and the usability of the data in its archive format.

The peer review validates the documentation and data archive volumes. First the panel reviews this document and verifies that the volumes and DDRs produced to this specification will be useful. The peer review also validates the EPPS DDR data in a two step process. The first step consists of reviewing a sample data set for compliance with the PDS standards. The sample data set is delivered and reviewed in conjunction with delivery and review of this SIS document. The second step is examination of the data to ensure usability and completeness. The PDS personnel are responsible for validating that the DDR data set is fully compliant with PDS standards. The instrument team and the outside science reviewer(s) are responsible for verifying the content of the data set, the completeness of the documentation, and the usability of the data in its archive format.

Any deficiencies in the archive data or documentation volumes are recorded as liens against the product by the review panel. The sample data set is created using software provided by APL and the University of Michigan. Once the sample data are validated, and all liens placed against the product or product generation software are resolved, the same software will be used to generate subsequent data products in an automated fashion.

During automated production, the data file content is spot checked by members of the EPPS team. “Quick look” products generated by software provided by ACT and the EPPS team are produced routinely and examined by members of the team. In addition, the data are actively used by team members to perform their analysis. Any discrepancies in the data noted during these activities will be investigated. If the discrepancy is a data error, the response depends on the source of the error. If the error is in the software producing the data product, the error is corrected and the data affected is reproduced, replacing the data file. If there is a correctable error in a data file, the file is replaced. If an error in a data file is uncorrectable, the error is described in the cumulative errata file included in the archive volume. The structure of data files and labels will be spot checked by the PPI node for compliance with PDS standards and this SIS.

6 Detailed Data Product Specification

6.1 Data Product Structure and Organization

The MESSENGER EPPS DDR data products are archived at the PDS PPI Node. The automated production and release of DDRs lends itself to the regular release schedule outlined in section 7. If errors are discovered the data are replaced with corrected DDRs on the next scheduled delivery date.

Calibration tables and calibration procedures are required to properly analyze DDRs. These ancillary data are archived at the PDS PPI Node as part of the EPPS documentation volume. The documentation volume is referenced by all EPPS data archive volumes. The documentation volume therefore includes the EPPS EDR SIS, the EPPS CDR SIS, and the EPPS DDR SIS in addition to the calibration tables, calibration procedures, and other documents applicable to the data archive volumes. A first release of the EPPS documentation volume accompanied the initial release of the EPPS EDR data archive. An update to the EPPS documentation volume will accompany the initial release of the DDR data archive. After the initial releases of the DDR level documentation there were updates to the documentation volume to document data quality and as needed for product and calibration updates.

6.2 Handling Errors

The possibility exists that errors may be introduced into the archive even with validation procedures applied to the archive volumes. An ERRATA report file is maintained to track and document all discovered uncorrectable errors that may occur during the mission. Correctable errors, such as revised DDRs or DDRs that were missing from a previous PDS delivery are provided at the next scheduled PDS delivery or at the final delivery date (schedule in section 7). PDS then replaces the outdated files with the revised DDR files in the data directories of the archive volume. File revisions are also recorded in the data product label keywords PRODUCT_VERSION_ID and PRODUCT_CREATION_TIME, which can be used in addition to ERRATA.TXT to detect updates. The ERRATA report file is archived in the ROOT directory of the EPPS DDR data volume.

6.3 Data Format Description

Data are stored in ASCII table format. A detached PDS label file provides a detailed description of the structure of each table.

6.4 Label and Header Descriptions

The following are the keyword definitions for the detached PDS label file, which accompanies the instrument data file. The detached PDS label file has the same name as the data file it describes, except for the extension .LBL to distinguish it as a label file.

PDS_VERSION_ID

Represents the version number of the PDS standards documents that is valid when a data product label is created. PDS3 is used for the MESSENGER data products.

FILE_RECORDS

Indicates the number of physical file records, including both label records and data records.

RECORD_TYPE

Indicates the record format of a file. Note: In the PDS, when record_type is used in a detached label file it always describes its corresponding detached data file, not the label file itself. The use of record_type along with other file-related data elements is fully described in the PDS Standards Reference.

RECORD_BYTES

Indicates the number of bytes in a physical file record, including record terminators and separators. Note: In the PDS, the use of record_bytes, along with other file-related data elements is fully described in the Standards Reference.

PRODUCT_ID

Represents a permanent, unique identifier assigned to a data product by its producer.

PRODUCT_CREATION_TIME

Defines the UTC system format time when a product was created.

PRODUCT_VERSION_ID

Identifies the version of an individual product within a data set.

Example: 1.0, 2.0, 3.0.

Product_version_id is incremented if a given DDR has to be regenerated and sent to PDS to replace a previously submitted DDR.

PRODUCT_TYPE

Identifies the type or category of a product within a data set.

STANDARD_DATA_PRODUCT_ID

Used to link an EPPS DDR file to one of the 12 types of EPPS data products defined within the EPPS DDR SIS.

SOFTWARE_NAME

Identifies the data processing software used to convert from CDR into DDR products.

SOFTWARE_VERSION_ID

Indicates the version of the data processing software used to generate the DDR products.

MD5_CHECKSUM

Used to verify the successful electronic transfer of the DDR from the SOC to the PDS-PPI Node.

INSTRUMENT_HOST_NAME

The full name of the host on which an instrument is based. In this case it is the MESSENGER spacecraft.

INSTRUMENT_NAME

Provides the full name of the instrument.

INSTRUMENT_ID

Provides an abbreviated name or acronym which identifies an instrument.

DATA_SET_ID

The data_set_id element is a unique alphanumeric identifier for a data set or a data product. The data_set_id value for a given data set or product is constructed according to flight project naming conventions. There is only one data_set_id for the EPPS DDRs.

MISSION_PHASE_NAME

Provides the commonly used identifier of a mission phase.

TARGET_NAME

The target_name element identifies a target. The target may be a planet, satellite, ring, region, feature, asteroid or comet.

START_TIME

Provides the date and time of the beginning of an event or observation (whether it be a spacecraft, ground-based, or system event) in UTC system format.

STOP_TIME

Provides the date and time of the end of an observation or event (whether it be a spacecraft, ground-based, or system event) in UTC system format.

SPACECRAFT_CLOCK_START_COUNT

Provides the value of the spacecraft clock at the beginning of a time period of interest.

SPACECRAFT_CLOCK_STOP_COUNT

Provides the value of the spacecraft clock at the end of a time period of interest.

^TABLE

Pointer to the DDR file, which contains the data in ASCII table format. The structure of the data file is defined in a referenced format file.

OBJECT

Specifies that the DDR is a PDS TABLE object. This object contains its own elements, which are defined below. NOTE: the end of the object definition is always marked with an END_OBJECT line.

COLUMNS

Identifies the number of columns (fields) in the table.

INTERCHANGE_FORMAT

This element specifies that the table is in ASCII format.

ROW_BYTES

Specifies the number of bytes for each row in the table.

ROWS

Identifies the number of rows (records) in the table.

^STRUCTURE

This is a pointer to the external file which provides the structure definition for the table object.

The following describes the keywords used to describe the PDS Table Object. These keywords are contained in the FORMAT (.FMT) files for each DDR data product.

COLUMN_NUMBER

Identifies the location of the column within the larger data object (such as a table). For tables consisting of rows (I= 1, N) and columns (j = 1, M) the column_number is the j-th index of any row.

NAME

Indicates a literal value representing the common term used to identify an element or object. NOTE: in the PDS data dictionary, name is restricted to 30 characters and must conform to PDS nomenclature standards.

BYTES

Specifies the number of bytes allocated for this particular column element.

DATA_TYPE

Specifies the internal representation and/or mathematical properties of the value being stored in this column.

START_BYTE

Identifies the location of the first byte of the particular column, counting from 1.

ITEMS

Defines the number of multiple, identical occurrences of a single object. Used mainly in columns containing spectral or histogram data.

ITEM_BYTES

The size in bytes of individual items in a column. ITEMS * ITEM_BYTES should equal the value in the BYTES column.

The format file contains the full text for describing each column of the table. See Appendices for a listing of each field in the individual format files.

6.5 File Naming Conventions

The file names developed for PDS data volumes are restricted to a maximum 36-character file name and a 3-character extension name with a period separating the file and extension names.

The general form of the EPPS EPS file name for pitch angle data is "EPSP_AyyyydddDDR_V#.TAB" where

EPS	Instrument name
P_A	Pitch Angle
yyyy	Four digit year
ddd	Three digit day of year
DDR	CODMAC processing level
V#	Version number

The general form of the EPPS EPS file name for pitch angle spectrograms is

"EPS_PAS_ yyyydddhhmmss_V#.PNG" where

EPS	Instrument name
PAS	Pitch Angle Spectrogram

yyyy	Four digit year
ddd	Three digit day of year
hhmmss	Hour, minute, second
V#	Version number
PNG	Portable Network Graphics file extension

The date in the file name is the start time of the data contained in the file.

The general form of the EPPS FIPS file name for DDRs is “FIPS_<TYPE>_yyyyddd_DDR_V#.TAB” where

FIPS	Instrument name
<TYPE>	Refers to the type of data contained in the file. Possible values are
	ESPEC - Energy Spectra
	NOBS – Observed Density
	PCHANG – Pitch Angle
	ERPCHANG – Energy-Resolved Pitch Angle
	ARRDIR – Arrival Direction
	FLUXMAP – Angular Flux Map
	NTP – Kinetic Properties
	ROTMSO – Viewing Normalization rotation matrix to MSO
yyyy	Four digit year
ddd	Three digit day of year
DDR	CODMAC processing level
V#	Version number

For all EPPS data, the initial version number is "V1" (EPS and FIPS_FOVPIX) or "V01" (all other FIPS). The version number increments for each successive version of the DDR product that is produced. A new version of the DDR product may be produced as a result of an error in the product or as a result of errors discovered in the product generation process.

For all EPPS data except the EPS Pitch Angle Spectrogram:

TAB	the file extension is dependent on the file type
	.TAB, EPS and FIPS Instrument Data in ASCII table
	.LBL, Detached PDS label file

6.6 Archive Volume and File Size

Two archive volumes are created to archive both the EPPS DDR data and the documentation, which is needed to analyze the DDRs. The first volume is the EPPS Documentation Volume, having volume ID MESSEPPS_DOC. This documentation volume contains products related to the EPPS EDR, CDR, and DDR data archives including:

1. All required PDS catalog files for the EDR, CDR, and DDR archives.
2. The EDR, CDR, and DDR SIS documents.
3. The Space Sciences Review (SSR) instrument paper once copyright permission is obtained. This may not be included in the initial release for copyright reasons.
4. The EPPS calibration report.
5. The EPPS calibration procedures document.
6. Calibration tables.
7. Other documents considered useful by the MESSENGER project or the EPPS team.

The data archive volume, designated the EPPS Data Archive Volume and having volume ID MESSEPPS_DDR, contains the DDR data and required files for conforming to PDS volume archive standards. This includes the index files, AAREADME.TXT file, etc. The approximate data archive volume size is 11 GB.

6.7 Directory Structure and Contents for EPPS Documentation Volume

The following illustration shows the directory structure overview for the EPPS documentation volume.

```
                         <ROOT>

       ______________________|_____________________

      |                      |                     |

<CALIBRATION>           <DOCUMENT>           <CATALOG>

                             |

              _______________|_______________

              |              |              |

          <EDR_SIS>      <CDR_SIS>      <DDR_SIS>
```

Figure 2 Documentation Volume Structure

6.7.1 Directory Contents

<ROOT> Directory

This is the top-level volume directory. The following are files contained in the root directory.

AAREADME.TXT - General information file. Provides users with an overview of the contents and organization of the associated volume, general instructions for its use, and contact information.

VOLDESC.CAT - PDS file containing the VOLUME object. This gives a high-level description of the contents of the volume. Information includes: production date, producer name and institution, volume ID, etc.

ERRATA.TXT - Text file for identifying and describing errors and/or anomalies found in the current volume, and possibly previous volumes of a set. Any known errors for the associated volume are documented in this file.

<CALIBRATION> Directory

This contains the calibration tables needed to analyze the EPPS CDR data. The calibration tables are in ASCII format. Format files for the calibration tables are also located here, as are the following files.

CALINFO.TXT – Brief description of the directory contents and naming conventions.

EPPS_*_EDR2CDR.PDF: Describes the procedure used to convert EDRs to CDRs for each instrument, (as indicated by the * text).

FIP*.TAB: The FIPS energy per charge tables.

<CATALOG> Directory

This subdirectory contains the catalog object files for the entire volume. The following files are included in the catalog subdirectory.

CATINFO.TXT: Identifies and describes the function of each file in the catalog directory.

EPPS*DATASET.CAT: Describes the general content of the EDR data set for each instrument (as indicated by the * text) and includes information about the duration of the mission and the person or group responsible for producing the data.

EPPS*DATASET_CDR.CAT: Describes the general content of the CDR data set for each instrument (as indicated by the * text) and includes information about the duration of the mission and the person or group responsible for producing the data.

EPPS*DATASET_DDR.CAT: Describes the general content of the DDR data set for each instrument (as indicated by the * text) and includes information about the duration of the mission and the person or group responsible for producing the data.

INSTRUMENT.CAT: Describes physical attributes of the EPPS instrument and provides relevant references to published literature.

INSTHOST.CAT: Describes the MESSENGER spacecraft.

MISSION.CAT: Describes the scientific goals and objectives of the MESSENGER program. It also identifies key people and institutions.

PERSON.CAT: Lists and provides contact information for the people involved in the MESSENGER mission, including those involved with EPPS.

REF.CAT: Provides references to scientific papers and other publications of interest to those using the data, both for EPPS and the mission as a whole.

< DOCUMENT > Directory

This subdirectory contains the documentation that is needed in order to understand and analyze the EDR, CDR, and DDR data volumes. The documents are separated into individual subdirectories according to the document type. The document types are not restricted to the four shown in the graphical depiction of the directory structure. There are additional document types as needed to categorize each document. The following file is included in the subdirectory.

DOCINFO.TXT: Identifies and describes the function of each file in the DOCUMENT directory.

6.8 Directory Structure and Contents for EPPS Data Volume

```
                                <ROOT>

        ___________________________|__________________________

       |                      |                  |             |

    <DATA>               <GEOMETRY>          <INDEX>       <LABEL>

       |

     __|________________________________________________________________

     |             |        |        |       |      |     |       |    |

<EPS_PITCH_ANGLES> |   <FIPS_PCHANG>   |   <FIPS_NOBS> |  <FIPS_NTP> |    |

  |                |           <FIPS_ESPEC>            |             |    |

  | <EPS_PITCH_ANGLES_SPECTROGRAM>       <FIPS_ARRDIR>  <FIPS_ROTMSO>     |

  |                                          __________________________|

  |                                          |               |

  |                                  <FIPS_ERPCHANG>   <FIPS_FLUXMAP>

 _|_______________

|        |        |

<2008>   <2009>   <2010> ...

           |
```

```
       ___|____________
      |        |        |
    <JAN>    <FEB>    <MAR>
```

Figure 3 Data Volume Directory Structure

6.8.1 Directory Contents

<ROOT> Directory

This is the top-level directory of a volume. The following are files contained in the root directory.

AAREADME.TXT - General information file. Provides users with an overview of the contents and organization of the associated volume, general instructions for its use, and contact information.

VOLDESC.CAT - PDS file containing the VOLUME object. This gives a high-level description of the contents of the volume. Information includes: production date, producer name and institution, volume ID, etc.

ERRATA.TXT - Text file for identifying and describing errors and/or anomalies found in the current volume, and possibly previous volumes of a set. Any known errors for the associated volume are documented in this file. This includes revised DDRs meant to replace DDRs in a previous PDS delivery.

<DATA> Directory

This top level directory contains the subdirectories corresponding to the seven data products (section 5.2) and supporting products. The directories are further subdivided into YEAR and MONTH directories. The FIPS_FOVPIX directory contains the Pixel Field Of View ancillary products.

<GEOMETRY> Directory

This subdirectory contains information about the files (e.g. SPICE kernels, etc) needed to describe the observation geometry for the data.

GEOMINFO.TXT : Identifies and describes the SPICE kernels that a user must have in order to determine observation geometry for the data. The SPICE kernel files are archived with the PDS NAIF node.

<INDEX> Directory

This subdirectory contains the indices for all data products on the volume. The following files are contained in the index subdirectory.

INDXINFO.TXT – Identifies and describes the function of each file in the index subdirectory. This includes a description of the structure and contents of each index table in the subdirectory AND usage notes.

INDEX.TAB - The DDR index file is organized as a table: there is one entry for each of the data files included in the EPPS data set; the columns contain parameters that describe the observation and instrument and spacecraft parameters. These parameters include state information, such as integration time, spacecraft clock count, time of observation, and instrument modes.

INDEX.LBL - Detached PDS label for INDEX.TAB. It contains the INDEX_TABLE object which identifies and describes the columns of the EPPS index table.

MD5.TAB - The MD5 checksum file that contains MD5 hash values for every file in the volume.

MD5.LBL - Detached PDS label for MD5.TAB.

<LABEL> Directory

This subdirectory contains the "label fragments" (i.e., the *.FMT files) for all data products on the volume. These format files describe the table and data objects which store the data.

7 Archive Release Schedule to PDS

The MESSENGER EPPS data and volume archives were transferred from the SOC to the PDS PPI Node using the process detailed in section 5.3.3. The SPICE kernels were transferred to the NAIF node. The transfer took place according to the schedule in [2].

8 Appendices

8.1 EPS_PITCH_ANGLES.FMT Table Columns

The following are the columns as defined by the EPS_PITCH_ANGLES.FMT structure file. This file defines the ASCII table containing the EPS pitch angle data. The archive volume is optimized by defining the table structure once and providing a reference to it in the PDS label file. The columns are numbered according to their column order in the table. Data Type refers to the PDS standards data type for a particular column in the table.

Table 3 EPS_ PITCH_ANGLES.FMT Columns

Length (bytes)	Data Type	Column Name	Summary (see full text for column description)
21	TIME	TIME	Spacecraft event time (UTC) for this data record.
22	ASCII_REAL	PITCH_ANGLE_S0	Pitch angle (degrees) for sector 0.
22	ASCII_ REAL	PITCH_ANGLE_S1	Pitch angle (degrees) for sector 1.
22	ASCII_ REAL	PITCH_ANGLE_S2	Pitch angle (degrees) for sector 2.
22	ASCII_ REAL	PITCH_ANGLE_S3	Pitch angle (degrees) for sector 3.
22	ASCII_ REAL	PITCH_ANGLE_S4	Pitch angle (degrees) for sector 4.
22	ASCII_ REAL	PITCH_ANGLE_S5	Pitch angle (degrees) for sector 5.

8.2 FIPS_PCHANG_DDR.FMT Table Columns

The following are the columns as defined by the FIPS_ PCHANG_DDR.FMT structure file. This file defines the ASCII table containing the FIPS pitch angle data. The archive volume is optimized by defining the table structure once and providing a reference to it in the PDS label file. The columns are numbered according to their column order in the table. Data Type refers to the PDS standards data type for a particular column in the table.

The INDEX field values are unique for a given day and may be used to match data in this file to that in the other FIPS DDR files for the same day. This fact is used to avoid data duplication: Universal Time (UTC) and MESSENGER positions are given only in the FIPS_NOBS_DDR file.

Table 4 FIPS_PCHANG_DDR.FMT

Length (bytes)	Data Type	Field Name	Summary (see full text for column description)
7	ASCII Integer	INDEX	Unique identifier for the current data sample.
14	ASCII Real	MET	Mission Elapsed Time in seconds.
554	ASCII Real	H_PA	H+ flux-pitch angle histogram. Pitch angle range = 0 - 180 inclusive, where 0 is parallel to magnetic field. Binsize is 5 degrees.
554	ASCII Real	HE2_PA	He2+ flux-pitch angle histogram. Pitch angle range = 0 - 180 inclusive, where 0 is parallel to magnetic field. Binsize is 5 degrees.
554	ASCII Real	HE_PA	He+ flux-pitch angle histogram. Pitch angle range = 0 - 180 inclusive, where 0 is parallel to magnetic field. Binsize is 5 degrees.
554	ASCII Real	NAGROUP_PA	Na+ group flux-pitch angle histogram. Pitch angle range = 0 - 180 inclusive, where 0 is parallel to magnetic field. Binsize is 5 degrees.
554	ASCII Real	OGROUP_PA	O+ group flux-pitch angle histogram. Pitch angle range = 0 - 180 inclusive, where 0 is parallel to magnetic field. Binsize is 5 degrees.

8.3 FIPS_ERPCHANG_DDR.FMT Table Columns

The following are the columns as defined by the FIPS_ ERPCHANG_DDR.FMT structure file. This file defines the ASCII table containing the FIPS energy-resolved pitch angle data. The archive volume is optimized by defining the table structure once and providing a reference to it in the PDS label file. The columns are numbered according to their column order in the table. Data Type refers to the PDS standards data type for a particular column in the table.

The START_INDEX and STOP_INDEX field values are unique for a given day and may be used to match data in this file to that in the other FIPS DDR files for the same day. This fact is used to avoid data duplication: Universal Time (UTC) and MESSENGER positions are given only in the FIPS_NOBS_DDR file.

Table 5 FIPS_ERPCHANG_DDR.FMT

Length (bytes)	Data Type	Field Name	Summary (see full text for column description)
14	ASCII Integer	START_INDEX	Unique identifier for the start of the current sample range.
14	ASCII Integer	STOP_INDEX	Unique identifier for the end of the current sample range.
14	ASCII Real	START_MET	Mission Elapsed Time in seconds at the beginning of the accumulation.
14	ASCII Real	STOP_MET	Mission Elapsed Time in seconds at the end of the accumulation.
16	CHARACTER	TIME_RESL	Time resolution label.
16	CHARACTER	ION	Ion group label.
1152	ASCII Real	ERPCHANG	2D matrix (Pitch angle, DSHV step). Pitch angle range: 0 - 180 inclusive divided over 10 degree bins. Matrix is ordered by sequential 64 element pitch angle vectors (elements 0-63 are pitch angle 0, DSHV steps 0 to 63; elements 64-127 are pitch angle 10, steps 0 to 63; and so on).

8.4 FIPS_ESPEC_DDR.FMT Table Columns

The following are the columns as defined by the FIPS_ ESPEC _DDR.FMT structure file. This file defines the ASCII table containing the FIPS energy spectra data. The archive volume is optimized by defining the table structure once and providing a reference to it in the PDS label file. The columns are numbered according to their column order in the table. Data Type refers to the PDS standards data type for a particular column in the table.

The INDEX field values are unique for a given day and may be used to match data in this file to that in the other two FIPS DDR files for the same day. This fact is used to avoid data duplication: Universal Time (UTC) and MESSENGER positions are given only in the FIPS_NOBS_DDR file.

Table 6 FIPS_ ESPEC_DDR.FMT Columns

Length (bytes)	**Data Type**	**Field Name**	**Summary (see full text for column description)**
7	ASCII Integer	INDEX	Unique identifier for the current data sample.
14	ASCII Real	MET	Mission Elapsed Time in seconds.
959	ASCII Real	H	H+ flux per e/q in 1/(cm^2 s kV).
959	ASCII Real	HE2	He2+ flux per e/q in 1/(cm^2 s kV).
959	ASCII Real	HE	He+ flux per e/q in 1/(cm^2 s kV).
959	ASCII Real	NA_GROUP	Na+ group flux per e/q in 1/(cm^2 s kV).
959	ASCII Real	O_GROUP	O+ group flux per e/q in 1/(cm^2 s kV).

8.5 FIPS_NOBS_DDR.FMT Table Columns

The following are the columns as defined by the FIPS_NOBS_DDR.FMT structure file. This file defines the ASCII table containing the FIPS observed density data. The archive volume is optimized by defining the table structure once and providing a reference to it in the PDS label file. The columns are numbered according to their column order in the table. Data Type refers to the PDS standards data type for a particular column in the table.

The INDEX field values are unique for a given day and may be used to match data in this file to that in the other two FIPS DDR files for the same day. This fact is used to avoid data duplication: Universal Time (UTC) and MESSENGER positions are given only this file.

Table 7 FIPS_NOBS_DDR.FMT Columns

Length (bytes)	Data Type	Field Name	Summary (see full text for column description)
7	ASCII Integer	INDEX	Unique identifier for the current data sample.
14	ASCII Real	MET	Mission Elapsed Time in seconds.
7	ASCII Real	ACCUM	Accumulation time for the current data sample.
15	ASCII Real	YFR	Time at end of the accumulation in floating point year.
8	ASCII Real	DOYFR	Time at end of the accumulation in floating point day of year.
5	ASCII Integer	HOURS	Hour at the end of the accumulation.
7	ASCII Integer	MINUTES	Minute at the end of the accumulation.
7	ASCII Real	SECONDS	Second at the end of the accumulation.
10	ASCII Real	MSOX	MESSENGER X-coordinate in MSGR_MSO frame in km.
10	ASCII Real	MSOY	MESSENGER Y-coordinate in MSGR_MSO frame in km.
10	ASCII Real	MSOZ	MESSENGER Z-coordinate in MSGR_MSO frame in km.
6	ASCII Real	LAT	MESSENGER position in Mercury latitude in degrees.
6	ASCII Real	MLT	MESSENGER position in magnetic local time in hour fraction.
9	ASCII Real	ALT	MESSENGER altitude in km.
14	ASCII Real	H	H+ observed density in cm-3.
14	ASCII Real	HE2	He2+ observed density in cm-3.
14	ASCII Real	HE	He+ observed density in cm-3.

14	ASCII Real	NA	Na+ observed density in cm-3.
14	ASCII Real	O	O+ observed density in cm-3.
4	ASCII Integer	QUAL	Data quality flag (0=good, 1=bad).

8.6 FIPS_ARRDIR_DDR.FMT Table Columns

The following are the columns as defined by the FIPS_ARRDIR_DDR.FMT structure file. This file defines the ASCII table containing the FIPS arrival direction data. The archive volume is optimized by defining the table structure once and providing a reference to it in the PDS label file. The columns are numbered according to their column order in the table. Data Type refers to the PDS standards data type for a particular column in the table.

The START_INDEX and STOP_INDEX field values are unique for a given day and may be used to match data in this file to that in the other FIPS DDR files for the same day. For example, the START_INDEX corresponds to the INDEX for the first line in the FIPS NOBS data used for this accumulation. The STOP_INDEX corresponds to the last line. This fact is used to avoid data duplication: Universal Time (UTC) and MESSENGER positions are given only this file.

Table 8 FIPS_ARRDIR_DDR.FMT Columns

Length (bytes)	**Data Type**	**Field Name**	**Summary (see full text for column description)**
14	ASCII Integer	START_INDEX	Unique identifier for the start of the current sample range.
14	ASCII Integer	STOP_INDEX	Unique identifier for the end of the current sample range.
14	ASCII Real	START_MET	Mission Elapsed Time at the beginning of the accumulation.
14	ASCII Real	STOP_MET	Mission Elapsed Time at the end of the accumulation.
14	ASCII	TIME_RESL	String label for time resolution of current line.
14	ASCII	ION	Name of ion or ion group.

9072	ASCII Real	DIRECTIONAL_FLUX	Ion flux as a function of arrival direction. Units: (cm^2 s keV/keV sr)^-1.

8.7 FIPS_FLUXMAP_DDR.FMT Table Columns

The following are the columns as defined by the FIPS_FLUXMAP_DDR.FMT structure file. This file defines the ASCII table containing the FIPS arrival direction data. The archive volume is optimized by defining the table structure once and providing a reference to it in the PDS label file. The columns are numbered according to their column order in the table. Data Type refers to the PDS standards data type for a particular column in the table.

The START_INDEX and STOP_INDEX field values are unique for a given day and may be used to match data in this file to that in the other FIPS DDR files for the same day. For example, the START_INDEX corresponds to the INDEX for the first line in the FIPS NOBS data used for this accumulation. The STOP_INDEX corresponds to the last line. This fact is used to avoid data duplication: Universal Time (UTC) and MESSENGER positions are given only this file.

Table 9 FIPS_FLUXMAP_DDR.FMT Columns

Length (bytes)	**Data Type**	**Field Name**	**Summary (see full text for column description)**
14	ASCII Integer	START_INDEX	Unique identifier for the start of the current sample range.
14	ASCII Integer	STOP_INDEX	Unique identifier for the end of the current sample range.
14	ASCII Real	START_MET	Mission Elapsed Time at the beginning of the accumulation.
14	ASCII Real	STOP_MET	Mission Elapsed Time at the end of the accumulation.
14	ASCII	TIME_RESL	String label for time resolution of current line.
14	ASCII	ION	Name of ion or ion group.
9072	ASCII Real	DIRECTIONAL_FLUX	Ion flux as a function of arrival direction. Units: (cm^2 s keV/keV sr)^-1.

8.8 FIPS_NTP_DDR.FMT Table Columns

The following are the columns as defined by the FIPS_NTP_DDR.FMT structure file. This file defines the ASCII table containing the FIPS arrival direction data. The archive volume is optimized by defining the table structure once and providing a reference to it in the PDS label file. The columns are numbered according to their column order in the table. Data Type refers to the PDS standards data type for a particular column in the table.

The START_INDEX and STOP_INDEX field values are unique for a given day and may be used to match data in this file to that in the other FIPS DDR files for the same day. For example, the START_INDEX corresponds to the INDEX for the first line in the FIPS NOBS data used for this accumulation. The STOP_INDEX corresponds to the last line. This fact is used to avoid data duplication: Universal Time (UTC) and MESSENGER positions are given only this file.

Table 10 FIPS_NTP_DDR.FMT Columns

Length (bytes)	**Data Type**	**Field Name**	**Summary (see full text for column description)**
14	ASCII Integer	START_INDEX	Unique identifier for the start of the current sample range.
14	ASCII Integer	STOP_INDEX	Unique identifier for the end of the current sample range.
14	ASCII Real	START_MET	Mission Elapsed Time at the beginning of the accumulation.
14	ASCII Real	STOP_MET	Mission Elapsed Time at the end of the accumulation.
14	ASCII	TIME_RESL	String label for time resolution of current line.
14	ASCII	ION	Name of ion or ion group.
14	ASCII Real	N	Ion number density in units of cm^-3.
14	ASCII Real	T	Ion temperature in units of MK.
14	ASCII Real	P	Ion pressure in units of nPa.

14	ASCII Real	N_ERR	Error in ion number density in units of cm^-3.
14	ASCII Real	T_ERR	Error in ion temperature in units of MK.
14	ASCII Real	P_ERR	Error in ion pressure in units of nPa..
6	ASCII Integer	QUAL	Quality Flag. 0=Good; non-0=Bad. Non-zero flag values TBD.

8.9 FIPS_ROTMSO_DDR.FMT Table Columns

The following are the columns as defined by the FIPS_ROTMSO_DDR.FMT structure file. This file defines the ASCII table containing the FIPS Cartesian to MSO rotation matrix definition. The archive volume is optimized by defining the table structure once and providing a reference to it in the PDS label file. The columns are numbered according to their column order in the table. Data Type refers to the PDS standards data type for a particular column in the table.

The INDEX field values are unique for a given day and may be used to match data in this file to that in the other two FIPS DDR files for the same day. This fact is used to avoid data duplication: Universal Time (UTC) and MESSENGER positions are given only this file.

Table 11 FIPS_ROTMSO_DDR.FMT Columns

Length (bytes)	**Data Type**	**Field Name**	**Summary (see full text for column description)**
11	ASCII Integer	INDEX	Unique identifier for the current data sample.
20	ASCII Real	MET	Mission Elapsed Time at the end of the corresponding FIPS scan.
54	ASCII Real	MATRIX_ROW_0	FIPS FOV to MSGR MSO rotation matrix row 0.
54	ASCII Real	MATRIX_ROW_1	FIPS FOV to MSGR MSO rotation matrix row 1.
54	ASCII Real	MATRIX_ROW_2	FIPS FOV to MSGR MSO rotation matrix row 2.

8.10 SPICE Kernel Files Used in MESSENGER Data Products

The following SPICE kernel files were used to compute the UTC time and any geometric quantities found in the PDS labels. Kernel files were generated throughout the mission with a file naming convention specified by the MESSENGER project.

*.bsp:

MESSENGER spacecraft ephemeris file. Also known as the Planetary Spacecraft Ephemeris Kernel (SPK) file.

*.bc:

MESSENGER spacecraft orientation file. Also known as the Attitude C-Kernel (CK) file.

*.tf:

MESSENGER reference frame file. Also known as the Frames Kernel. Contains the MESSENGER spacecraft, science instrument, and communications antennae frame definitions.

*.ti:

MESSENGER instrument kernel (I-kernel). Contains references to mounting alignment, operation modes, and timing as well as internal and field of view geometry for the EPPS.

*.tsc:

MESSENGER spacecraft clock coefficients file. Also known as the Spacecraft Clock Kernel (SCLK) file.

*.tpc:

Planetary constants file. Also known as the Planetary Constants Kernel (PcK) file.

*.tls:

NAIF leapseconds kernel file. Used in conjunction with the SCLK kernel to convert between Universal Time Coordinated (UTC) and MESSENGER Mission Elapsed Time (MET). Also called the Leap Seconds Kernel (LSK) file.

8.11 CODMAC/NASA Definition of Processing Levels

CODMAC/NASA Definition of processing levels for science data sets

CODMAC Level	Proc. Type	Data Processing Level Description
1	Raw Data	Telemetry data stream as received at the ground station, with science and engineering data embedded. Corresponds to NASA packet data.
2	Edited Data	Instrument science data (e.g. raw voltages, counts) at full resolution, time ordered, with duplicates and transmission errors removed. Referred to in the MESSENGER program as Experiment Data Records (EDRs). Corresponds to NASA Level 0 data.
3	Calibrated Data	Edited data that are still in units produced by instrument, but have transformed (e.g. calibrated, rearranged) in a reversible manner and packaged with needed ancillary and auxiliary data (e.g. radiances with calibration equations applied). Referred to in the MESSENGER Program as Calibrated Data Records (CDRs). In some cases these also qualify as derived data products (DDRs). Corresponds to NASA Level 1A.
4	Resampled data	Irreversibly transformed (e.g. resampled, remapped, calibrated) values of the instrument measurements (e.g. radiances, magnetic field strength). Referred to in the MESSENGER program as either derived data products (DDPs) or derived analysis products (DAPs). Corresponds to NASA Level 1B.
5	Derived Data	Derived results such as maps, reports, graphics, etc. Corresponds to NASA Levels 2 through 5

CODMAC Level	Proc. Type	Data Processing Level Description
6	Ancillary Data	Non-Science data needed to generate calibrated or resampled data sets. Consists of instrument gains, offsets; pointing information for scan platforms, etc.
7	Corrective Data	Other science data needed to interpret space-borne data sets. May include ground based data observations such as soil type or ocean buoy measurements of wind drift.
8	User Description	Description of why the data were required, any peculiarities associated with the data sets, and enough documentation to allow secondary user to extract information from the data.

The above is based on the national research council committee on data management and computation (CODMAC) data levels.

8.12 MESSENGER Glossary and Acronym List

ACT Applied Coherent Technology Corporation

AMU Atomic Mass Unit

APL The Johns Hopkins University Applied Physics Laboratory

ASCII American Standard Code for Information Interchange

CDR Calibrated Data Record

CK Attitude C-Kernel (SPICE)

CODMAC Committee on Data Management and Computation

DAP Derived Analysis Products

DDP Derived Data Products

EDR Experiment Data Records

EPPS Energetic Particle and Plasma Spectrometer

EPS Energetic Particle Spectrometer

ESA	Electrostatic Analyzer
FIFO	First In, First out. An electronic component that stores and retrieves information following a first-in-first-out discipline.
FIPS	Fast Imaging Plasma Spectrometer
FOV	Field-of-View
FSW	Flight Software
FTP	File Transfer protocol
GEANT4	GEometry ANd Tracking software toolkit
GF	Geometric Factor
I2C	Inter-Integrated Circuit
JPL	Jet Propulsion Laboratory
IEM	Integrated Electronic Module
LSB	Least Significant Bit
LSK	Leapseconds Kernel (SPICE)
MCP	Micro-channel Plate
MESSENGER	MErcury Surface, Space ENvironment, GEochemistry, and Ranging
MET	Mission Elapsed Time
MIDL	Mission Independent Data Layer
MSO	Mercury-centric Solar Orbital
NAIF	Navigation and Ancillary Information Facility
NASA	National Aeronautics and Space Administration
PCK	Planetary Constant Kernel (SPICE)
PDS	Planetary Data System
PHA	Pulse Height Analysis
PPI	Planetary Plasma Interactions PDS Node

RDR	Reduced Data Record
SCLK	Space Clock Kernel (SPICE)
SOC	Science Operations Center
SPICE	Spacecraft, Planet, Instrument, C-matrix Events, refers to the kernel files and NAIF software used to generate viewing geometry.
SPK	Spacecraft and Planets Kernel (SPICE)
SSD	Solid-State Detector
SSR	Space Sciences Review
TOF	Time of Flight
UTC	Coordinated Universal Time