Juno

Software Interface Specification
JunoCam Standard Data Products

M. Caplinger
Malin Space Science Systems, Inc.

Approved by:

____
Candy Hansen, JunoCam Team Leader

____
Leslie Lipkaman, MSSS JunoCam Archiving Lead

____
Dave Gell, JSOC Manager

____
William Kurth, Juno Archivist

____
Sue Lavoie, PDS Imaging Node

Version 1.3, August 2016
(formatted August 31, 2016)

Juno

Software Interface Specification Junocam Global/Regional Map Image Standard Data Product

M. Caplinger
Malin Space Science Systems, Inc.

Approved by:

Candy Hansen, Junocam Team Leader

Leslie Lipkaman, MSSS Juno Archiving Lead

Dave Gell, JSOC Manager

William Kurth, Juno Archivist

Sue Lavoie, PDS Imaging Node

November 2013
(formatted November 14, 2013)

Change Log

DATE	SECTIONS CHANGED	DESCRIPTION OF CHANGES	REVISION
11/14/13	Initial Release, Version 1.0		
12/08/14	Signature Page, Change Log, 1.4.4, 2.1, 4.1, 4.2, 4.3, 4.3.2, Appendix A, B, C	Signature Page: added Change Log: added 1.4.4: section removed from V1.0, section numbers shifted 2.1: added section on Instrument Overview 4.1: updated DATA_SET_IDs 4.2: updated generic LBL file 4.3: updated keywords 4.3.2: expanded section Appendix A, B, C: added new appendices	1.1
07/31/15	Acronyms and Abbreviations, 1.1, 1.2, 1.3, 1.4, 2.3, 2.4, 4.1, 4.2, 4.3, 4.3.1.3, Appendix A, B, C	Acronyms and Abbreviations: added 1.1: updated acronyms 1.2 : updated acronym 1.3: added numbers for reference 1.4: section removed from V1.1, section numbers shifted 2.3: updated acronyms 2.4: updated acronym 4.1: updated section with peer review inputs, updated acronyms 4.2: changed section title, updated with peer review inputs 4.3: replaced generic LBL file with a real LBL file 4.4: section has been moved to table format in Appendix A 4.3.1.3: added section with peer review inputs Appendix A: new appendix (section 4.3 from V1.1) Appendix B: new appendix with peer review inputs Appendix C: updated appendix with peer review inputs (originally Appendix A in V1.1)	1.2
08/31/16	4.2, Appendix D	4.2: modified the PICNO structure to include 5 characters for the image index Appendix D: removed the Global Map SIS listing and files from the CATALOG, DATA, and DOCUMENT directories as this has not yet been peer reviewed and therefore will not be included in the volume	1.3

Contents

Acronyms and Abbreviations

CCD	Charged Coupled Device
CFDP	CSSDS File Delivery Protocol
CODMAC	Committee on Data Management and Computation
CSSDS	Consultative Committee for Space Data Systems
DSN	Deep Space Network
EDR	Experiment Data Record
EFB	Earth Flyby
ICD	Interface Control Document
ID	Identification
IOT	Instrument Operations Team
JNC	JunoCam
JPL	Jet Propulsion Laboratory
JSOC	Juno Science Operations Center
MOF	Mission Operations Facility
N/A	Not applicable
NASA	National Aeronautics and Space Administration
PDS	Planetary Data System
RDR	Reduced Data Record
SFDU	Standard Format Data Unit
SIS	Software Interface Specification
SPICE	Spacecraft, Planet, Instrument, C-matrix Events kernels
SQROOT	Square root
TBD	To be determined
UNK	Unknown

1. Introduction

1.1. Purpose
This document describes the format of the JunoCam Experiment Data Record (EDR) and Reduced Data Record (RDR) Planetary Data System (PDS) Data Products.

1.2. Scope
The format and content specifications in this Software Interface Specification (SIS) apply to all phases of the project for which this product is available.

1.3. Applicable Documents
This SIS is consistent with the following PDS documents:

1. Planetary Data System Standards Reference, Version 3.8, JPL D-7669, Part 2, February 27, 2009.
2. Planetary Science Data Dictionary Document, JPL D-7116, Rev. F, October 20, 2008.

Additionally, this SIS makes reference to the following documents for technical and background information:

3. JUNO Science Operations Center (JSOC) JSOC-IOT Interface Control Document, 12029.02-JSOC_IOT_ICD-01, Rev 4 Chg 0, October 2013.
4. Software Interface Specification JunoCam Global/Regional Map Image Standard Data Product, M. Caplinger, Version 1.0, November 14, 2013.
5. Juno Project Mission Plan, Revision B, JPL D-35556, 29 March 2011.

1.4. Functional Description

1.4.1. Data Content Summary
Each JunoCam standard data product is a single image contained in one file, in the raw image format as produced by the instrument. The EDR product has been depacketized, decompressed and reformatted with standard labels, but is otherwise "raw"; that is, as received from the instrument. The RDR product is similar, but has been corrected for instrument signature and converted to scaled radiance.

1.4.2. Source and Transfer Method
JunoCam products are produced by the \`junomakepds' program from the format internally used at the JunoCam Mission Operations Facility (MOF). This program reads a raw JunoCam image file, extracts various information from its headers, creates an image product (.IMG) with a formatted detached PDS label (.LBL).

This data format is potentially used in three contexts: on the JunoCam web site, after archiving from the PDS, and as delivered to JSOC [Ref 3].

1.4.3. Recipients and Utilization

These products will be available to JunoCam team members, the Juno science community, the planetary science community, and any other interested parties. In general, there is no proprietary period for JunoCam data.

These products will be used for engineering support, direct science analysis, and/or the construction of other science products.

1.5. Assumptions and Constraints

Note that image products contain decompressed image data. The images are not corrected for the effects of spacecraft motion or imaging geometry. Although there is enough information in the header to do some processing, for more sophisticated processing ancillary files will be required. These ancillary files are not described in this document. Examples of ancillary files are calibration files, viewing geometry files (e.g., SPICE kernels), image index tables, etc.

2. Environment

2.1. Instrument Overview

JunoCam is a framing camera with a 1600x1200 pixel interline transfer CCD (Kodak KAI-2020M) with 7.4-micron square pixels illuminated by a single all-refractive 58-degree lens. A color filter array with four different bandpasses (visible red/green/blue and narrowband methane absorption at about 890 nm) is directly bonded to the CCD. A typical image consists of one to four "framelets", each 1648 pixels wide and 128 pixels high, in each of these bandpasses. The framelets can be optionally summed by 2x in both directions to improve their signal-to-noise ratio. Either Huffman (lossless) or Integer Cosine Transform (lossy) image data compression can be applied by software running in the spacecraft computer.

2.2. Hardware Characteristics and Limitations

2.2.1. Special Equipment and Device Interfaces

Interfaces to access either CD-ROM volumes or electronic file transfer are described elsewhere; for example, see the PDS Standards Reference [Ref 1].

2.2.2. Special Setup Requirements

No special setup requirements are needed.

2.3. Failure Protection, Detection, and Recovery

Raw instrument telemetry will be archived by the Jet Propulsion Laboratory (JPL) on a to be determined (TBD) archival medium. These archives and depacketized compressed image data will be archived at the JunoCam MOF.

2.4. End-of-File Conventions

End-of-file labeling shall comply with Standard Format Data Unit (SFDU) standards; specifically, fixed-size records are used. The header explicitly contains the record offset of each sub-element of the dataset, and the size of each sub-element can be computed from information in the header.

3. Access

3.1. Access Tools

Existing PDS image display programs can display these files.

3.2. Input/Output Protocols

None identified.

3.3. Timing and Sequencing Characteristics

None.

4. Data Product Overview

4.1. Data Processing Levels

This documentation recognizes both the National Aeronautics and Space Administration (NASA) data processing scheme and the "Committee on Data Management and Computation" (CODMAC) data level numbering system. The JunoCam instrument EDRs are "NASA Level 0" (CODMAC – Edited Level 2), while JunoCam instrument RDRs are "NASA Level 1A" (CODMAC – Calibrated Level 3). The following table presents a breakdown of the CODMAC and NASA data processing levels.

NASA	CODMAC	Description
Packet data	Raw - Level 1	Telemetry data stream as received at the ground station, with science and engineering data embedded.
Level 0	Edited - Level 2	Instrument science data (e.g., raw voltages, counts) at full resolution, time ordered, with duplicates and transmission errors removed.
Level 1A	Calibrated - Level 3	Level 0 data that have been located in space and may have been transformed (e.g., calibrated, rearranged) in a reversible manner and packaged with needed ancillary and auxiliary data (e.g., radiances with the calibration equations applied).
Level 1B	Resampled - Level 4	Irreversibly transformed (e.g., resampled, remapped, calibrated) values of the instrument measurements (e.g., radiances, magnetic field strength).
Level 1C	Derived - Level 5	Level 1A or 1B data that have been resampled and mapped onto uniform space-time grids. The data are calibrated (i.e., radiometrically corrected) and may have additional corrections applied (e.g., terrain correction).
Level 2	Derived - Level 5	Geophysical parameters, generally derived from Level 1 data, and located in space and time commensurate with instrument location, pointing, and sampling.
Level 3	Derived - Level 5	Geophysical parameters mapped onto uniform space-time grids.

JunoCam's DATA_SET_IDs for EDRs and RDRs contain references to both the CODMAC and NASA data processing levels. See Appendix A for more information.

4.2. File Naming Convention

Each product will have a file name of the form "<id>.IMG", where the ID is not to exceed 36 characters. The ID will start with an alphabetic character and will consist of only alphanumeric characters. Each file name will be unique across all JunoCam data product files.

File names will be of the form:

JNCT_YYYYDDD_OOFNNNNN_VXX.ZZZ

JNC: JunoCam
T: product type (E for EDR, R for RDR, and M for map product)
YYYY: year at the start of image acquisition
DDD: day-of-year at the start of image acquisition
OO: orbit number (or 00 for all cruise products)
F: filter combination specifier for the image (see Appendix B)
NNNNN: image index within that mission phase
V: version
XX: version number starting with "01"
ZZZ: file extension (can be IMG, LBL)

4.3. Structure and Organization

All JunoCam images must be a multiple of 16 pixels in both width and height. Images are broken up into sub-images (also called fragments), and each fragment is transmitted separately. Raw and predictively compressed images are reconstructed by concatenating all of their image fragments and then processing; transform compressed images are processed a fragment at a time.

A JunoCam data product consists of one image with decompression applied. For each image file, a header (or label in PDS terminology) identifies various properties of the image and contains a file offset to the data portion of the image. In addition, each image product has two parts: the data product itself with the extension of "IMG" and a detached label with an extension of "LBL".

The following is a sample LBL for a JunoCam product from cruise:

```
PDS_VERSION_ID                = PDS3

/* FILE CHARACTERISTICS */

RECORD_TYPE                   = FIXED_LENGTH
RECORD_BYTES                  = 1648
FILE_RECORDS                  = 5120

/* POINTERS TO DATA OBJECTS */

^IMAGE                        = "JNCE_2013337_00R111_V01.IMG"

/* IDENTIFICATION DATA ELEMENTS */

FILE_NAME                     = "JNCE_2013337_00R111_V01.IMG"
SPACECRAFT_NAME               = JUNO
MISSION_PHASE_NAME            = "QUIET CRUISE"
TARGET_NAME                   = SPACE
INSTRUMENT_ID                 = "JNC"
INSTRUMENT_HOST_NAME          = "JUNO"
INSTRUMENT_NAME               = "JUNO EPO CAMERA"
PRODUCER_ID                   = JUNO_JUNOCAM_TEAM
DATA_SET_ID                   = "JUNO-J-JUNOCAM-2-EDR-L0-V1.0"
STANDARD_DATA_PRODUCT_ID      = "JUNOCAM-EDR"
PRODUCT_CREATION_TIME         = 2015-07-13T20:16:14
PRODUCT_VERSION_ID            = "1.0"
PRODUCT_ID                    = "JNCE_2013337_00R111_V01"
SOURCE_PRODUCT_ID             = "3D-090001006F-2013-337T14.00.01"
START_TIME                    = 2013-12-03T00:57:32.673
IMAGE_TIME                    = 2013-12-03T00:57:32.673
STOP_TIME                     = 2013-12-03T00:58:02.313
SPACECRAFT_CLOCK_START_COUNT  = "439304361:143"
SPACECRAFT_CLOCK_STOP_COUNT   = "N/A"

/* DESCRIPTIVE DATA ELEMENTS */

ORBIT_NUMBER                  = "N/A"
SOFTWARE_NAME                 = "JUNOMAKEPDS.PY 0.4"
PROCESSING_LEVEL_ID           = "2"
FOCAL_PLANE_TEMPERATURE       = 264.1 <K>
INTERFRAME_DELAY              = 0.741 <s>
```

```
SUB_SPACECRAFT_LATITUDE        = 0.0000
SUB_SPACECRAFT_LONGITUDE       = 0.0000
SPACECRAFT_ALTITUDE            = 0.0 <km>
SOLAR_DISTANCE                 = 2.0186e+08 <km>
SAMPLE_BIT_MODE_ID             = "SQROOT"
EXPOSURE_DURATION              = 512.000000 <ms>
JNO:TDI_STAGES_COUNT           = 80
SAMPLING_FACTOR                = 1
FILTER_NAME                    = ('RED')
COMPRESSION_TYPE               = "INTEGER COSINE TRANSFORM"
RATIONALE_DESC                 = "Cruise imaging"

/* DATA OBJECT DEFINITIONS */

OBJECT                         = IMAGE
  LINES                        = 5120
  LINE_SAMPLES                 = 1648
  SAMPLE_TYPE                  = UNSIGNED_INTEGER
  LINE_PREFIX_BYTES            = 0
  LINE_SUFFIX_BYTES            = 0
  SAMPLE_BITS                  = 8
  SAMPLE_BIT_MASK              = 2#11111111#
  MD5_CHECKSUM                 = "a95cf51ac55643e360647787baf13fe7"
END_OBJECT                     = IMAGE
END
```

4.4. Substructure Definition and Format

For JunoCam label file (.LBL) keyword definitions and valid values, see Appendix A.

4.3.1. Data Description Details

4.3.1.1. Filter order

Each JunoCam frame acquired has 128/summing factor lines of image data per selected filter. The image defined by this document is ordered as follows:

```
+------------------------------+
|     frame 1, band 1          +
+------------------------------+
|     frame 1, band 2          +
+-----------...----------------+
|     frame 1, band N          +
+------------------------------+
|     frame 2, band 1          +
+------------------------------+
|     frame 2, band 2          +
+-----------...----------------+
|     frame 2, band N          +
+-----------...----------------+
|     frame M, band 1          +
+------------------------------+
|     frame M, band 2          +
+-----------...----------------+
|     frame M, band N          +
+------------------------------+
```

This orders each frame by acquisition time and is the same order as the data produced by the instrument. This format has been chosen for simplicity at the expense of interpretability of display of the raw product; a simple reordering by band may be desirable for examination of the raw product, though most users will likely perform more complex geometric reprocessing.

4.3.1.2. Geometry

Note that JunoCam images are acquired and compressed in row-major order by increasing time. The arrangement of the CCD and optics in JunoCam, the spin and spin direction of the spacecraft, and its orbital motion somewhat complicates the mapping of pixel to surface feature. For easier geometric interpretation, a map-projected JunoCam product is also generated; this product is described in a companion document by Caplinger 2013 [Ref 4].

4.3.1.3. RDR processing flow

The RDR is produced by inverting the onboard 12-to-8-bit companding to yield linear data numbers of detector response (see 8-bit square root (SQROOT) value and 12-bit linear value companding tables in Appendix C). A flat field correction would also be done at this step, but this is not currently implemented as the instrument response is fairly uniform without it. For planetary targets, these values are then scaled such that a white surface at the solar distance at the time of imaging and with the commanded exposure time would have a pixel value of 10,000 data numbers.

For images of a black sky, however, this would result in a loss of dynamic range, since most pixel values would collapse to 1 or 2 data numbers. Therefore, for such images the RDR values simply represent the number of electrons at each pixel. Since the detector's full well capacity is about 30,000 electrons of signal, this value can be represented as a 16-bit integer.

4.3.2. Data loss considerations

Juno can use a version of the CSSDS File Delivery Protocol (CFDP) protocol to retransmit portions of data products that are dropped during initial transmission. This capability may not be employed at all times, however, and so it is possible that some JunoCam images will be affected by data loss.

A typical data loss is that of one or two packets due to uncorrectable bit errors caused by noise in the space-to-Earth communications path (rare), momentary loss of receiver lock caused by a transition between the one-way and two-way tracking modes, or loss in the Earth segment of the Deep Space Network (DSN).

For compressed images, a packet loss leads to loss of 'line sync' in the image. When a packet is lost from this compressed data stream, the decompression algorithm aligns itself to the next line by searching for the line counter. It then applies statistical testing to distinguish a valid line counter from a data pattern that coincidentally resembles a line counter. The effect of decompressing the data between the site of packet loss and the next valid line is the loss of one or more partial lines of data, which are zero-filled by the decompression software.

A second type of loss is that of tens or hundreds of packets caused by bad weather, hardware failure, operator error at the DSN stations, or mis-commanding of the telemetry playback on the spacecraft. For these errors in a compressed data stream, many lines of the image are lost, making it impossible to recover even the original downtrack size of the image.

4.4. Data Volume, Size, and Frequency Estimates

Data volume returned varies as a function of the available data rate; see the Juno Mission Plan [Ref 5] for more details.

5. PDS Archive Volume

5.1. Archive Structure

Every archive delivery contains data for a set period of time. These data are archived according to type, either EDR or RDR, and when in the mission they were acquired: cruise, Earth Flyby (EFB), or at Jupiter. Data collected at Jupiter will be archived by the date of acquisition.

In addition, there are several static directories and files that will also be delivered with each volume. The structure of these directories and corresponding files can be found in Appendix D.

6. Appendices

Appendix A – JunoCam Keywords, Definitions, and Valid Values & Entries

Keyword	Group	Definition	Valid Values
PDS_VERSION_ID		The PDS_version_id data element represents the version number of the PDS standards documents that is valid when a data product label is created. Values for the PDS_version_id are formed by appending the integer for the latest version number to the letters 'PDS'. Examples: PDS3, PDS4.	PDS3, N/A, NULL, UNK
	FILE CHARACTERISTICS		
RECORD_TYPE		The record_type element 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. For JunoCam products, nearly always FIXED_LENGTH.	FIXED_LENGTH, N/A, NULL, UNK
RECORD_BYTES		The record_bytes element indicates the number of bytes in a physical file record, including record terminators and separators.	integer, 0 to n, N/A, NULL, UNK

FILE_RECORDS		The file_records element indicates the number of physical file records, including both label records and data records. The last record will be padded with zeros if necessary.	integer, 0 to n, N/A, NULL, UNK
	POINTERS TO DATA OBJECTS		
^IMAGE		Pointer to the starting record of an image product. For JunoCam products, nearly always identical to FILE_NAME with the extension .IMG.	string (see section 4.2 of this document), N/A, NULL, UNK
	INDENTIFICATION DATA ELEMENTS		
FILE_NAME		The file_name element provides the location independent name of a file. It excludes node or volume location, directory path names, and version specification. For JunoCam products, extension is .IMG.	string (see section 4.2 of this document), N/A, NULL, UNK
SPACECRAFT_NAME		The spacecraft_name element provides the full, unabbreviated name of a spacecraft.	JUNO, N/A, NULL, UNK
MISSION_PHASE_NAME		The mission_phase_name element provides the commonly used identifier of a mission phase.	INNER CRUISE 1, INNER CRUISE 2, INNER CRUISE 3, QUIET CRUISE, CAPTURE ORBIT, PERIOD REDUCTION MANEUVER, ORBITS 1-2, SCIENCE ORBITS, DEORBIT, N/A, NULL, UNK

TARGET_NAME		The target_name element identifies a target. The target may be a planet, satellite, ring, region, feature, asteroid or comet.	CALLISTO, EARTH, EUROPA, GANYMEDE, IO, JUPITER, MOON, SPACE, N/A, NULL, UNK
INSTRUMENT_ID		The instrument_id element provides an abbreviated name or acronym, which identifies an instrument.	JNC, N/A, NULL, UNK
INSTRUMENT_HOST_NAME		The instrument_host_name element provides the full name of the host on which an instrument is based.	JUNO, N/A, NULL, UNK
INSTRUMENT_NAME		The instrument_name element provides the full name of an instrument.	JUNO EPO CAMERA, N/A, NULL, UNK
PRODUCER_ID		The producer_id element provides a short name or acronym for the producer or producing team/group of a dataset.	JUNO_JUNOCAM_TEAM, N/A, NULL, UNK
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. In most cases the data_set_id is an abbreviation of the data_set_name. Note: In the PDS, the values for both data_set_id and data_set_name are constructed according to standards outlined in the Standards Reference.	JUNO-J-JUNOCAM-2-EDR-L0-V1.0, JUNO-J-JUNOCAM-3-RDR-L1A-V1.0, N/A, NULL, UNK

STANDARD_DATA_PRODUCT_ID		The STANDARD_DATA_PRODUCT_ID element is used to link a data product (file) to a standard data product (collection of similar files) described within software interface specification document for a particular data set.	JUNOCAM-EDR, JUNOCAM-RDR, N/A, NULL, UNK
PRODUCT_CREATION_TIME		The product_creation_time element defines the UTC system format time when a product was created.	YYYY-MM-DDThh:mm:ss, N/A, NULL, UNK
PRODUCT_VERSION_ID		The first_product_id data element indicates the product_id that appears in the label of the first data product on an archive medium.	string, N/A, NULL, UNK
PRODUCT_ID		The product_id data element represents a permanent, unique identifier assigned to a data product by its producer. No extension is included.	string (see section 4.2 of this document), N/A, NULL, UNK
SOURCE_PRODUCT_ID		The source_product_id data element identifies a product used as input to create a new product. For JunoCam, format will be 3D-09nnnnnnnn-YYYY-DDDThh.mm.ss where n=8-most significant decimal digits of SCLK as ASCII-encoded hex, Y=year, D=doy of year, h=hour, m=minute, and s=second.	3D-09nnnnnnnn-YYYY-DDDThh.mm.ss, N/A, NULL, UNK
START_TIME		The start_time element 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. This time will be the start time of the first frame of a JunoCam image.	YYYY-MM-DDThh:mm:ss.fff, N/A, NULL, UNK

IMAGE_TIME		The image_time element provides the spacecraft event time at the time of frame acquisition. This should be represented in UTC system format. This time will be identical to START_TIME.	YYYY-MM-DDThh:mm:ss.fff, N/A, NULL, UNK
STOP_TIME		The stop_time element 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. This time will be the start time of the last frame of a JunoCam image.	YYYY-MM-DDThh:mm:ss.fff, N/A, NULL, UNK
SPACECRAFT_CLOCK_START_COUNT		The spacecraft_clock_start_count element provides the value of the spacecraft clock at the actual start of image acquisition. There may be small inconsistencies with START_TIME due to varying correlation between UTC and the spacecraft clock. For purposes of data analysis the spacecraft clock value should be used. The format of this field is compatible with the NAIF Toolkit software where s = seconds converted from the clock's coarse counter and m = seconds converted from the clock's fine counter.	sssssssss.mm[m], N/A, NULL, UNK

SPACECRAFT_CLOCK_STOP_COUNT		The spacecraft_clock_stop_count element provides the value of the spacecraft clock at the end of a time period of interest. For JunoCam, this value is not applicable because the timing of a JunoCam image, once started, is independent of the spacecraft clock.	N/A, NULL, UNK
	DESCRIPTIVE DATA ELEMENTS		
ORBIT_NUMBER		The orbit_number element identifies the number of the orbital revolution of the spacecraft around a target body. This value is N/A for cruise images.	string, N/A, NULL, UNK
SOFTWARE_NAME		The software_name element identifies data processing software such as a program or a program library.	string, N/A, NULL, UNK
PROCESSING_LEVEL_ID		The processing_level_id element identifies the processing level of a set of data according to the eight-level CODMAC standard. For JunoCam products, it will typically be 2 for EDR and 3 for RDR products.	2, 3, N/A, NULL, UNK
FOCAL_PLANE_TEMPERATURE		The focal_plane_temperature element provides the temperature of the focal plane array in degrees Kelvin at the start of image acquisition.	float, N/A, NULL, UNK
INTERFRAME_DELAY		The INTERFRAME_DELAY element provides the time between successive frames of an image, in seconds.	float, N/A, NULL, UNK

SUB_SPACECRAFT_LATITUDE		The sub_spacecraft_latitude element provides the latitude of the subspacecraft point. The subspacecraft point is that point on a body, which lies directly beneath the spacecraft. For an image of a planetary target, this is the latitude at the midpoint time of image acquisition.	float, -90.0000 to 90.0000, N/A, NULL, UNK
SUB_SPACECRAFT_LONGITUDE		The sub_spacecraft_longitude element provides the longitude of the subspacecraft point. The subspacecraft point is that point on a body's reference surface where a line from the spacecraft center to the body center intersects the surface. For an image of a planetary target, this is the longitude (System III for Jupiter) at the midpoint time of image acquisition.	float, 0.0000 to 360.0000, N/A, NULL, UNK
SPACECRAFT_ALTITUDE		The spacecraft_altitude element provides the distance from the spacecraft to a reference surface of the target body measured normal to that surface. For an image of a planetary target, this is the altitude at the midpoint time of image acquisition. Note that the amount of geometric information is intentionally made small because it is expected that complex processing using SPICE kernels will be needed to make full quantitative use of these data products.	float, N/A, NULL, UNK

SOLAR_DISTANCE		The solar_distance element provides the distance from the center of the sun to the center of a target body.	float, N/A, NULL, UNK
SAMPLE_BIT_MODE_ID		The SAMPLE_BIT_MODE_ID element identifies the type of pixel scaling performed. For JunoCam, this is applied to EDRs only. JunoCam digitizes pixels to 12 bits and then uses a lookup table to map pixels to 8 bits. This field identifies the table in use. Valid values are SQROOT and LUT1-LUT3. The contents of these companding tables are given in Appendix C. A note for RDRs: The original image (EDR) has a companding mode and the RDR, which is derived from the EDR, inherits that companding mode. The SQROOT companding mode, for example, is only applied to the EDR. However, the RDR, which is generated from the EDR, accounts for that companding mode and will carry that value forward in the keyword.	SQROOT, LUT1, LUT2, LUT3, N/A, NULL, UNK
EXPOSURE_DURATION		The exposure_duration element provides the value of the time interval between the opening and closing of an instrument aperture (such as a camera shutter). For JunoCam, this interval is per-frame exposure duration in milliseconds (including TDI, if any).	float, N/A, NULL, UNK

JNO:TDI_STAGES_COUNT		The TDI element provides the number of time delay and integration (TDI) stages used to increase the exposure time of a JunoCam observation.	integer, 1 to 255, N/A, NULL, UNK
SAMPLING_FACTOR		The sampling_factor element provides the value N, where every Nth data point was kept from the original data set by selection, averaging, or taking the median. JunoCam can do pixel averaging in the instrument before transmission. For JunoCam, this value will always be 1 or 2.	1, 2, N/A, NULL UNK
FILTER_NAME		The filter_name element provides the commonly-used name of the instrument filter through which an image or measurement was acquired or which is associated with a given instrument mode. This is a string array up to four values in length with nominal values of RED, GREEN, BLUE, and/or METHANE.	string array, N/A, NULL, UNK
COMPRESSION_TYPE		The compression_type element indicates the type of compression/encoding used for data that was subsequently decompressed/unencoded before storage.	INTEGER COSINE TRANSFORM, HUFFMAN, NONE, N/A, NULL, UNK

RATIONALE_DESC		The rationale_desc element describes the rationale for performing a particular observation. For some specific images, this string will contain a description of the image as actually received; for routine mapping operations, it will more likely be the goal of the image as targeted (which may not be met if the image missed its target significantly, image parameters were set inappropriately, etc.)	string, N/A, NULL, UNK
	DATA OBJECT DEFINTIONS		
LINES		The lines element indicates the total number of data instances along the vertical axis of an image, or, the number of lines in the decompressed image.	positive integer, N/A, NULL, UNK
LINE_SAMPLES		The line_samples element indicates the total number of data instances along the horizontal axis of an image, or, the number of samples per line in the decompressed image.	positive integer, N/A, NULL, UNK
SAMPLE_TYPE		The sample_type element indicates the data storage representation of sample value. For JunoCam, nearly always UNSIGNED_INTEGER.	UNSIGNED_INTEGER, N/A, NULL, UNK
LINE_PREFIX_BYTES		The line_prefix_bytes element indicates the number of non-image bytes at the beginning of each line. The value must represent an integral number of bytes. For JunoCam, field is always 0.	0, N/A, NULL, UNK

LINE_SUFFIX_BYTES		The line_suffix_bytes element indicates the number of non-image bytes at the end of each line. This value must be an integral number of bytes. For JunoCam, field is always 0.	0, N/A, NULL, UNK
SAMPLE_BITS		The sample_bits element indicates the stored number of bits, or units of binary information, contained in a line_sample value; for the JunoCam EDR product, always 8, and for the JunoCam RDR product, always 16. Additionally, for the RDR product, the pixel value is normalized such that a value of 10000 would be produced for a white Lambertian target with an incidence angle of 0 at a solar distance of the target at the time of imaging.	8, 16, N/A, NULL, UNK
SAMPLE_BIT_MASK		The sample_bit_mask element identifies the active bits in a sample; for EDR, always 2#11111111#, for RDR, always 2#1111111111111111#.	2#11111111#, 2#1111111111111111#, N/A, NULL, UNK
MD5_CHECKSUM		The MD5 algorithm takes as input a file (message) of arbitrary length and produces as output a 128-bit 'fingerprint' or 'message digest' of the input. This field will be used for data validation.	string, N/A, NULL, UNK

Appendix B – Filter Combinations

In a JunoCam product file name, F represents the filter combination specifier. The following table lists the filter letter and its corresponding combination.

Filter	Combination
A	All 4 filters (Red, Green, Blue, Methane)
B	Blue filter only
C	Three-color filters (Red, Green, Blue)
G	Green filter only
M	Methane filter only
R	Red filter only
T	Two-color filter (Red, Blue)

Appendix C – JunoCam Companding Tables

8-bit_SQROOT_Value	12-bit_Linear_Value
0	0
1	1
2	2
3	3
4	4
5	5
6	6
7	7
8	8
9	9
10	10
11	11
12	12
13	13
14	14
15	15
16	16
17	17
18	18
19	19
20	20
21	21
22	22
23	23
24	25
25	27
26	29
27	31
28	33
29	35
30	37
31	39
32	41
33	43
34	45

35	47
36	49
37	51
38	53
39	55
40	57
41	59
42	61
43	63
44	67
45	71
46	75
47	79
48	83
49	87
50	91
51	95
52	99
53	103
54	107
55	111
56	115
57	119
58	123
59	127
60	131
61	135
62	139
63	143
64	147
65	151
66	155
67	159
68	163
69	167
70	171
71	175
72	179
73	183
74	187
75	191
76	195
77	199
78	203
79	207
80	211
81	215
82	219
83	223
84	227
85	231
86	235
87	239
88	243
89	247
90	255
91	263
92	271

93	279
94	287
95	295
96	303
97	311
98	319
99	327
100	335
101	343
102	351
103	359
104	367
105	375
106	383
107	391
108	399
109	407
110	415
111	423
112	431
113	439
114	447
115	455
116	463
117	471
118	479
119	487
120	495
121	503
122	511
123	519
124	527
125	535
126	543
127	551
128	559
129	567
130	575
131	583
132	591
133	599
134	607
135	615
136	623
137	631
138	639
139	647
140	655
141	663
142	671
143	679
144	687
145	695
146	703
147	711
148	719
149	727
150	735

151	743
152	751
153	759
154	767
155	775
156	783
157	791
158	799
159	807
160	815
161	823
162	831
163	839
164	847
165	855
166	863
167	871
168	879
169	887
170	895
171	903
172	911
173	919
174	927
175	935
176	943
177	951
178	959
179	967
180	975
181	983
182	991
183	999
184	1007
185	1023
186	1039
187	1055
188	1071
189	1087
190	1103
191	1119
192	1135
193	1151
194	1167
195	1183
196	1199
197	1215
198	1231
199	1247
200	1263
201	1279
202	1295
203	1311
204	1327
205	1343
206	1359
207	1375
208	1391

209	1407
210	1439
211	1471
212	1503
213	1535
214	1567
215	1599
216	1631
217	1663
218	1695
219	1727
220	1759
221	1791
222	1823
223	1855
224	1887
225	1919
226	1951
227	1983
228	2015
229	2047
230	2079
231	2111
232	2143
233	2175
234	2207
235	2239
236	2271
237	2303
238	2335
239	2367
240	2399
241	2431
242	2463
243	2495
244	2527
245	2559
246	2591
247	2623
248	2655
249	2687
250	2719
251	2751
252	2783
253	2815
254	2847
255	2879

LUT1 (Linear Inverse 1)

```
  0,   1,   2,   3,   4,   5,   6,   7,   8,   9,  10,  11,  12,  13,  14,  15,
 16,  17,  18,  19,  20,  21,  22,  23,  24,  25,  26,  27,  28,  29,  30,  31,
 32,  33,  34,  35,  36,  37,  38,  39,  40,  41,  42,  43,  44,  45,  46,  47,
 48,  49,  50,  51,  52,  53,  54,  55,  56,  57,  58,  59,  60,  61,  62,  63,
 64,  65,  66,  67,  68,  69,  70,  71,  72,  73,  74,  75,  76,  77,  78,  79,
 80,  81,  82,  83,  84,  85,  86,  87,  88,  89,  90,  91,  92,  93,  94,  95,
 96,  97,  98,  99, 100, 101, 102, 103, 104, 105, 106, 107, 108, 109, 110, 111,
112, 113, 114, 115, 116, 117, 118, 119, 120, 121, 122, 123, 124, 125, 126, 127,
128, 129, 130, 131, 132, 133, 134, 135, 136, 137, 138, 139, 140, 141, 142, 143,
144, 145, 146, 147, 148, 149, 150, 151, 152, 153, 154, 155, 156, 157, 158, 159,
160, 161, 162, 163, 164, 165, 166, 167, 168, 169, 170, 171, 172, 173, 174, 175,
176, 177, 178, 179, 180, 181, 182, 183, 184, 185, 186, 187, 188, 189, 190, 191,
192, 193, 194, 195, 196, 197, 198, 199, 200, 201, 202, 203, 204, 205, 206, 207,
208, 209, 210, 211, 212, 213, 214, 215, 216, 217, 218, 219, 220, 221, 222, 223,
224, 225, 226, 227, 228, 229, 230, 231, 232, 233, 234, 235, 236, 237, 238, 239,
240, 241, 242, 243, 244, 245, 246, 247, 248, 249, 250, 251, 252, 253, 254, 255
```

LUT2 (Linear Inverse 8)

```
   0,    8,   16,   24,   32,   40,   48,   56,   64,   72,   80,   88,   96,
 104,  112,  120,  128,  136,  144,  152,  160,  168,  176,  184,  192,  200,
 208,  216,  224,  232,  240,  248,  256,  264,  272,  280,  288,  296,  304,
 312,  320,  328,  336,  344,  352,  360,  368,  376,  384,  392,  400,  408,
 416,  424,  432,  440,  448,  456,  464,  472,  480,  488,  496,  504,  512,
 520,  528,  536,  544,  552,  560,  568,  576,  584,  592,  600,  608,  616,
 624,  632,  640,  648,  656,  664,  672,  680,  688,  696,  704,  712,  720,
 728,  736,  744,  752,  760,  768,  776,  784,  792,  800,  808,  816,  824,
 832,  840,  848,  856,  864,  872,  880,  888,  896,  904,  912,  920,  928,
 936,  944,  952,  960,  968,  976,  984,  992, 1000, 1008, 1016, 1024, 1032,
1040, 1048, 1056, 1064, 1072, 1080, 1088, 1096, 1104, 1112, 1120, 1128, 1136,
1144, 1152, 1160, 1168, 1176, 1184, 1192, 1200, 1208, 1216, 1224, 1232, 1240,
1248, 1256, 1264, 1272, 1280, 1288, 1296, 1304, 1312, 1320, 1328, 1336, 1344,
1352, 1360, 1368, 1376, 1384, 1392, 1400, 1408, 1416, 1424, 1432, 1440, 1448,
1456, 1464, 1472, 1480, 1488, 1496, 1504, 1512, 1520, 1528, 1536, 1544, 1552,
1560, 1568, 1576, 1584, 1592, 1600, 1608, 1616, 1624, 1632, 1640, 1648, 1656,
1664, 1672, 1680, 1688, 1696, 1704, 1712, 1720, 1728, 1736, 1744, 1752, 1760,
1768, 1776, 1784, 1792, 1800, 1808, 1816, 1824, 1832, 1840, 1848, 1856, 1864,
1872, 1880, 1888, 1896, 1904, 1912, 1920, 1928, 1936, 1944, 1952, 1960, 1968,
1976, 1984, 1992, 2000, 2008, 2016, 2024, 2032, 2040
```

LUT3 (Linear Inverse 16)

```
   0,   16,   32,   48,   64,   80,   96,  112,  128,  144,  160,  176,  192,
 208,  224,  240,  256,  272,  288,  304,  320,  336,  352,  368,  384,  400,
 416,  432,  448,  464,  480,  496,  512,  528,  544,  560,  576,  592,  608,
 624,  640,  656,  672,  688,  704,  720,  736,  752,  768,  784,  800,  816,
 832,  848,  864,  880,  896,  912,  928,  944,  960,  976,  992, 1008, 1024,
1040, 1056, 1072, 1088, 1104, 1120, 1136, 1152, 1168, 1184, 1200, 1216, 1232,
1248, 1264, 1280, 1296, 1312, 1328, 1344, 1360, 1376, 1392, 1408, 1424, 1440,
1456, 1472, 1488, 1504, 1520, 1536, 1552, 1568, 1584, 1600, 1616, 1632, 1648,
1664, 1680, 1696, 1712, 1728, 1744, 1760, 1776, 1792, 1808, 1824, 1840, 1856,
1872, 1888, 1904, 1920, 1936, 1952, 1968, 1984, 2000, 2016, 2032, 2048, 2064,
2080, 2096, 2112, 2128, 2144, 2160, 2176, 2192, 2208, 2224, 2240, 2256, 2272,
2288, 2304, 2320, 2336, 2352, 2368, 2384, 2400, 2416, 2432, 2448, 2464, 2480,
2496, 2512, 2528, 2544, 2560, 2576, 2592, 2608, 2624, 2640, 2656, 2672, 2688,
2704, 2720, 2736, 2752, 2768, 2784, 2800, 2816, 2832, 2848, 2864, 2880, 2896,
2912, 2928, 2944, 2960, 2976, 2992, 3008, 3024, 3040, 3056, 3072, 3088, 3104,
3120, 3136, 3152, 3168, 3184, 3200, 3216, 3232, 3248, 3264, 3280, 3296, 3312,
3328, 3344, 3360, 3376, 3392, 3408, 3424, 3440, 3456, 3472, 3488, 3504, 3520,
3536, 3552, 3568, 3584, 3600, 3616, 3632, 3648, 3664, 3680, 3696, 3712, 3728,
3744, 3760, 3776, 3792, 3808, 3824, 3840, 3856, 3872, 3888, 3904, 3920, 3936,
3952, 3968, 3984, 4000, 4016, 4032, 4048, 4064, 4080
```

Appendix D – Archive Volume Structure

The following is the PDS directory structure for the JunoCam archive volume.

```
| -- AAREADME.TXT
| -- CATALOG
     | -- CATINFO.TXT
     | -- DSMAP.CAT
     | -- JNC_EDR_IMG_DS.CAT
     | -- JNC_GLOBAL_MAP_DS.CAT
     | -- JNC_INST.CAT
     | -- JNC_PERSON.CAT
     | -- JNC_RDR_IMG_DS.CAT
     | -- JNC_REF.CAT
     | -- JUNO_INSTHOST.CAT
     | -- JUNO_MISSION.CAT
     | -- JUNO_REF.CAT
| -- DATA
     | -- EDR
           | -- CRUISE
           | -- EFB
           | -- JUPITER
                | -- ORBIT_##
     | -- RDR
           | -- CRUISE
           | -- EFB
           | -- JUPITER
                | -- ORBIT_##
     | -- GLOBAL_MAPS
| -- DOCUMENT
     | -- DOCINFO.TXT
     | -- JUNO_JNC_EDR_RDR_DPSIS.HTM
     | -- JUNO_JNC_EDR_RDR_DPSIS.LBL
     | -- JUNO_JNC_EDR_RDR_DPSIS.PDF
     | -- JUNO_JNC_GLOBAL_MAP_SIS.HTM
     | -- JUNO_JNC_GLOBAL_MAP_SIS.LBL
     | -- JUNO_JNC_GLOBAL_MAP_SIS.PDF
| -- ERRATA.TXT
| -- INDEX*
| -- VOLDESC.CAT
```

* Directory and subsequent files will be provided by JSOC.