Measurement & Instrumentation Systems
National Space Institute
Technical University of Denmark

Advanced Stellar Compass
JUNO
Software Interface Specification

Prepared for: NASA Planetary Data System

Prepared by: Space Instrumentation Group

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1.4	2024/07/30	1.2	Corrected JSOC abbreviation	T. Denver
		2.2, 2.4	Added description of interlaced mode and electronic shutter	
		2.5	Detailed description of radiation speckle and star apperance	
		3.1, 6.2.1, 6.2.3	Decreased PRODUCT_ID length	
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		6.1.2, 6.1.3 6.1.2, 6.2.2 6.1.3 6.2.2 6.2.2 6.2.3	Changed SCET to SCLK and removed epoch description DETECTOR_NAME -> _ID Detailed accummulation time for the raw radiation counts Added MISSION_PHASE_NAME, LINES, IMAGE_TIME and EXPOSURE_DURATION Deleted LABEL_RECORDS Added description of binary image header	
1.5	2024/11/13	1.5 2.4.1 3.1, 6.1.1, 6.2.1 6.1.2, 6.2.2 6.1.2, 6.2.2 6.1.2, 6.2.2 6.1.3 6.1.3 6.2.2 6.2.2 6.2.2	Added DOI to RD2 Added note on pulse height reporting JSOC file name convention Added PROCESSING_LEVEL_ID STANDARD_DATA_PRODUCT_ID Expanded ASC to “ADVANCED STELLAR COMPASS” Added processing description relative to RD2 Added seconds to calendar description Added MD5 for images Added PRODUCT_VERSION_ID Updated LINES = 581	T. Denver
1.6	2024/11/25	6.1.1 6.2.2	Removed PRODUCT_TYPE Added ORBIT_NUMBER Changed PRODUCT_TYPE to STANDARD_DATA_PRODUCT_ID	T. Denver

Table of Contents

1 Introduction

This software interface specification (SIS) describes the format and content of the ASC (Advanced Stellar Compass) Planetary Data System (PDS) data archive. It includes descriptions of the Standard Data Products and associated metadata, volume archive format, content, and generation pipeline.

1.1 Distribution list

Name	Organization	Email
TBD	TBD	TBD

1.2 Abbreviations

Abbreviation	Meaning
ASC	Advanced Stellar Compass
BBO	Big Bright Object
CCD	Charge Coupled Device
CHU	Camera Head Unit
DPU	Data Processing Unit
EDA	End of Data Acquisition
GSFC	Goddard Space Flight Center
JPL	Jet Propulsion Laboratory
JSOC	Juno Science Operations Center

1.3 Juno mission overview

Juno was launched on the first day of its launch window, 5 August 2011. The spacecraft used a ΔV-EGA trajectory consisting of deep space manoeuvres on 8 August 2012 and 14 September 2012 (ΔV) followed by an Earth gravity assist (EGA) on 9 October 2013. The spacecraft arrived at Jupiter on 5 July 2016 (UTC), using two 53-day capture orbits prior to commencing science operations for a prime mission comprising 34 high inclination, high eccentricity orbits of Jupiter. Instead of firing the engines a second time to get to the originally intended 14-day orbits, it was decided not to do so for health and safety reasons, and the spacecraft remained in the 53-day orbital periods (extending the 34-orbit prime mission duration from the original 1 year to 5 years). Juno is in a polar orbit (90° inclination) with a periapsis altitude of ~4200 km (following orbit insertion) and a semi-major axis of ~113RJ (1 RJ is one Jovian radius, ~71492 km). The primary science is acquired for ~6 hours, ~centered on each periapsis although field and particle data are acquired at low rates over the remaining portion of the orbit. Of the first 9 periapses, 4 were dedicated to microwave radiometry (MWR orbits) of Jupiter's deep atmosphere, 4 were dedicated to gravity measurements (GRAV orbits) to determine the structure of Jupiter's interior. Unfortunately, Juno went into Safe mode on its second orbit resulting in no perijove data. All orbits include field and particle measurements of the planet's auroral regions. Juno is spin stabilized with a rotation rate of 1 to 3 revolutions per minute (RPM). For the MWR orbits the spin axis is, usually, perpendicular to the orbit plane so that the radiometer fields of view pass through the nadir but is tilted for some orbits. For gravity passes, the spin axis is aligned to the Earth direction, allowing for Doppler measurements through the periapsis portion of the orbit. The orbital plane was initially very close to perpendicular to the Sun-Jupiter line but has evolved over the mission. Data acquired during the periapsis passes are recorded and played back over the subsequent apoapsis portion of the orbit.

Juno's instrument complement includes Gravity Science using the X and Ka bands to determine the structure of Jupiter's interior; a vector fluxgate magnetometer (FGM) to study the magnetic dynamo and interior of Jupiter as well as to explore the polar magnetosphere; and a microwave radiometer (MWR) experiment covering 6 wavelengths between 1.3 and 50 cm to perform deep atmospheric sounding and composition measurements. The instrument complement also includes a suite of field and particle instruments to study the polar magnetosphere and Jupiter's aurora. This suite includes an energetic particle detector (JEDI), a Jovian auroral (plasma) distributions experiment (JADE), a radio and plasma wave instrument (Waves), an ultraviolet spectrometer (UVS), and a Jupiter infrared auroral mapping instrument (JIRAM). JunoCam is a camera onboard Juno and was included for education and public outreach. While it is not a science instrument, the data is being archived in the PDS along with the other mission data.

1.4 Applicable documents

AD1. Planetary Data System Archive Preparation Guide, Version 1.1, JPL D-31224, 08/29/2006.
Planetary Data System Standards Reference, JPL D-7669, Part 2, Version 3.8, 02/27/2009.
Planetary Science Data Dictionary Document, Planetary Data System, JPL D-7116, Version 1r65, 02/2007

AD2. Juno Mission Operations Concept Document, JPL D-35531, Version Preliminary, 04/30/2007.
Juno Science Data Management and Archive Plan, Version Final, JPL D-34032, 08/26/2009.
The Juno Magnetic Field Investigation, Space Sci. Rev 213, 39–138, 10.1007/s11214-017-0334-z, 2017

AD3. Juno Science Management Plan, JPL D-34942,

1.5 Reference documents

RD1. Connerney, J. E. P., Benn, M., Bjarnø, J. B., Denver, T., Espley, J., Jørgensen, J. L., Jørgensen, P. S., Lawton, P., Malinnikova Bang, A., Merayo, J. M. G., Murphy, S., Odom, J., Oliversen, R., Schnurr, R., Sheppard, D., & Smith, E. J. (2017). The Juno Magnetic Field Investigation. *Space Science Reviews*, *213*(1-4), 39–138. https://doi.org/10.1007/s11214-017-0334-z

RD2. Denver, T., Sushkova, J., Jørgensen, J.L., Ghizoni, L., Herceg, M., Toldbo, C., Benn, M, Jørgensen, P.S., Fléron, R., Connerney, J.E.P, Becker, H.N., Bolton, S.J. (2024). The Juno ASC as an Energetic Particle Counter. *Space Sci Rev* *220*(86). https://doi.org/10.1007/s11214-024-01120-y

1.6 Audience

This document is useful to those wishing to understand the format and content of the ASC data product archive collection. Typically, these individuals would include planetary scientists, data analysts, or software engineers.

2 ASC instrument description

2.1 Science objectives

The primary role of the ASC instrument is of a functional nature. It was included as part of the magnetometer investigation (MAG = FGM + ASC) as an engineering instrument, to supply accurate attitude to the vector magnetometers at the end of the MAG boom and solar array panel. However, during cruise and the prime mission it was realized that data from the ASC camera heads has scientific value, namely the recorded images and indirect radiation measurements (particle hit counts).

2.2 Sensors

The Camera Head Unit (CHU) is a monochrome camera with a 19°x13.5° field of view and a 752x580 pixel CCD sensor operated interlaced using field integration. Captured images can be saved for future transfer to the spacecraft memory and then to the DSN. By nature, CCD sensors are affected by charged particles. When a particle traverses the active surface of the sensor it leaves an ionization trail spanning one or more pixels, known as *hotspots*. By quantifying the number of hotspots, an indirect measure of radiation can be extracted (related to the fluence of the effecting particles within the CCD integration period). The four ASC CHUs are located on the MAG boom of Juno, one pair on each magneto-optical bench, as can be seen in Figure 1. The camera heads are designated A, B, C, and D.

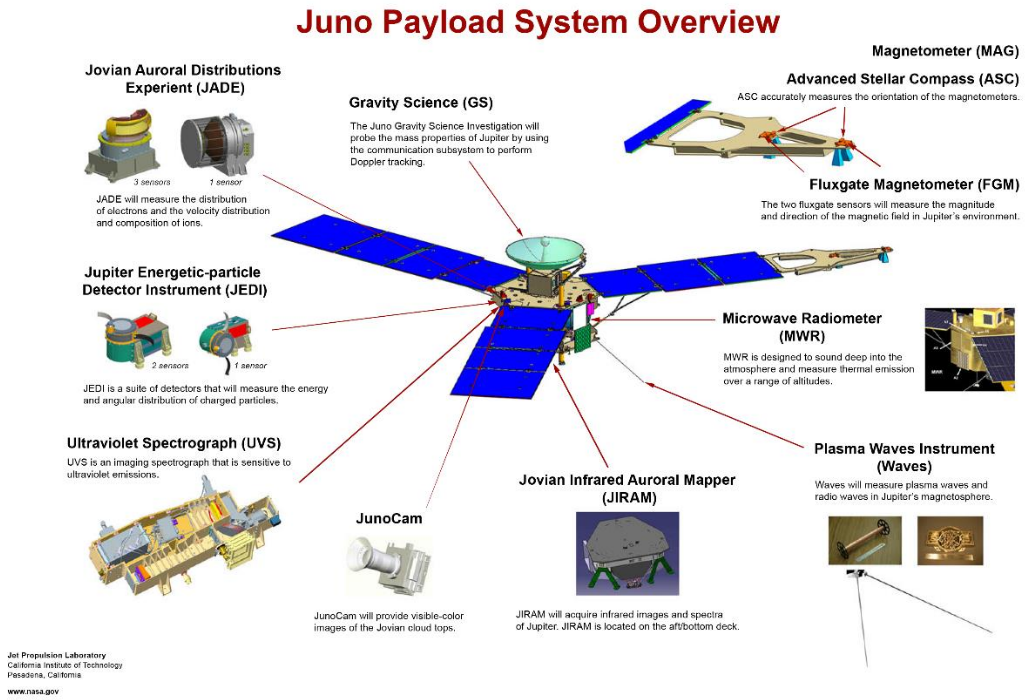

Figure 1. Juno Payloads overview

For more information, refer to RD1.

2.3 Electronics

The Data Processing Unit (DPU) holds the necessary electronics for ASC operations. In addition to handling communications and normal operation procedures (attitude determination etc.), other functionalities are included, such as quantifying the number of hotspots.

2.4 Measured Parameters

2.4.1 Radiation counts

The interline transfer type CCD consists of a photo-sensitive area (integration layer) and a readout layer - both are sensitive to energetic charged particle irradiation. The relative sensitivity has been established from ground calibrations (see section 2.6). When a charged particle, sufficiently energetic to pass through the electronics' mass shielding, traverses the CCD sensor's substrate, many electrons are liberated from the lattice structure and are captured within the CCD's charge wells. Consequently, when read out, the affected pixel(s) will have a false elevated photon count. This ionization is not damaging to the affected pixel(s). After being read out, the charge well will return to its nominal level and sensitivity to photons. The effect is therefore transient.

In the area of the image formed around the particle's interaction, the affected pixel will stand out with an elevated count. Since the interaction expresses itself as an isolated bright pixel, the formed image object will be referred to as a *hotspot* in this document. To differentiate between damaged pixels that continuously have elevated counts, these pixels may in some contexts be referred to as *transient hotspots*.

Counting the number of transient hotspots in an image provides an efficient means of deriving the surrounding particle flux for particles with energies above the mass shielding stopping power.

The measured hotspot count is telemetered as part of the periodic attitude telemetry that otherwise provides orientation quaternions to support the JUNO MAG investigation. Also, the telemetry only reports on count rate. I.e. the impacting particle spectral energy is not reported upon.

2.4.2 Images

The MicroASC instrument under normal operation captures and stores an image at a rate set by the integration time. These images however are discarded after they have been processed. The instrument has the capability to store captured images (one at a time), which can be exported and downlinked on demand. These images are made available in the data set in their original, uncompressed format as transmitted from the instrument. The gain settings for each captured image (determined automatically by the instrument's automatic gain control) and the integration time are present in each label file.

2.5 Operational Modes

For optimal attitude performance during periods of high radiation, the CCD integration time (shutter time) is decreased by using the built-in electronic shutter. The integration time is divided evently between the two image fields and does not alter the image cycle cadence. If the electronic shutter is not used, the CCD will integrate for the full integration cycle, half the time in each image field. All radiation count products available at PDS have been calibrated taking into account the integration time used for each image. Also, during times when stray light from Jupiter entered the CHU, the radiation count measurements are not accurate and will not correctly correspond the radiation environment at the given time. Thus, images with Jovian stray light are not included in the archived radiation count data set.

Finally, the sampling period depends on the distance from perijove. The data sets are collected at three different sampling rates: 7s, 1s and 0.25s. The most frequent sampling rate is used within a few hours from perijove passage. The middle sampling rate is available a few hours further out on both sides of perijove, and finally, the low sampling rate is used for the remainder of the JUNO orbit. The sampling rate is not expressed directly in the archived dataset but may easily be inferred from the time tag difference. The decimation is performed by suppressing individual samples from the telemetry. Hence, the sensitivity per sample is NOT dependent on this telemetry update rate.

Note on operational modes: Following PJ-35 (July 21, 2021) the camera heads providing input to the radiation monitoring activities had reached the radiation dose design limit. Following this dose limit, the camera heads exhibited a strong decrease in sensitivity, inhibiting use of the camera heads for star tracking. The low sensitivity state also impacts the apparent sensitivity to ionizing radiation due to a decreased effective cross-section. A calibration effort allowing linking between the nominal and the post dose limit response is on-going. Example star tracker source images from nominal and post dose limit period is shown in Figure 2

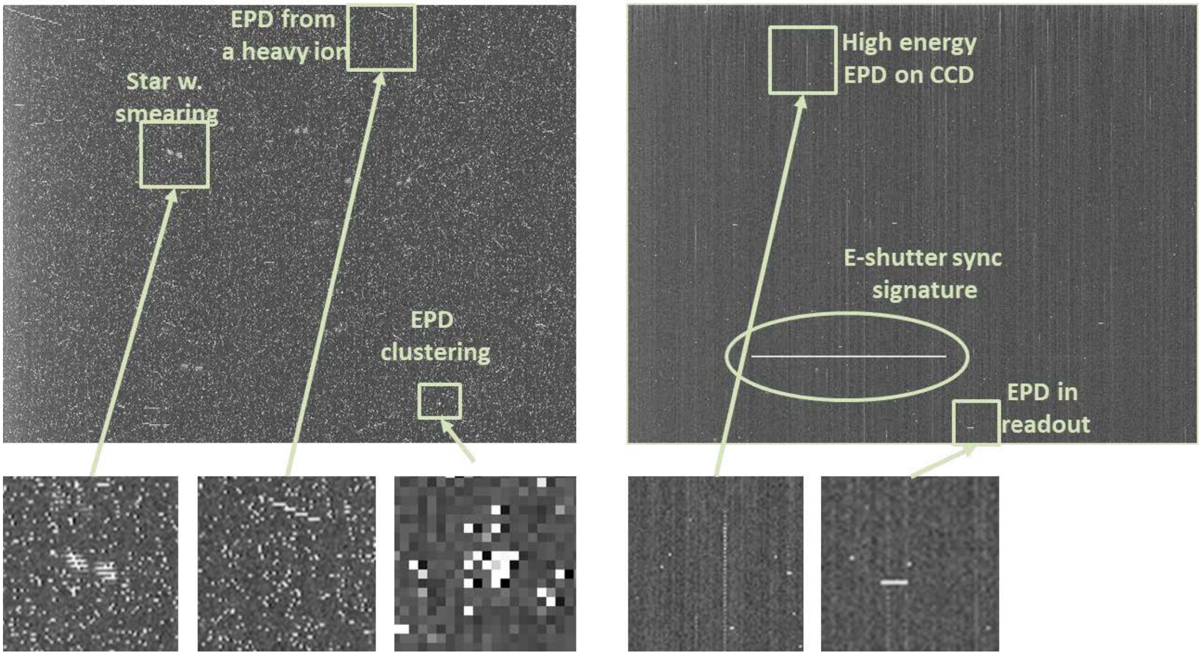

Figure 2: Star tracker source image from a heavy radiation region. (Left) before dose limit, showing stars, energetic particle detection (EPD) from heavy ions and multiple EPD on full CCD as background scatter. (Right) after dose limit, showing high energy interactions as vertical stripes (low charge transfer efficiency) and multiple EPD on horizontal readout registry as background scatter

While the nominal operation radiation products offer good sensitivity in the low to medium radiation flux regions, it tends to saturate in the high flux regions. The post dose limit products, on the other hand, do not tend to saturate in these regions making these products a valuable contribution to the mapping of the Jovian radiation environment.

2.6 Ground Calibration

2.6.1 Extrinsic Calibration

The instrument provides raw hotspot count as measured from the images, i.e., the number of charged particles that were sufficiently energetic to pass through the mass shielding. This physical mass shielding is from the mechanical structure of the CHU, additional shielding at selected directions, as well as the surrounding shielding provided by the spacecraft. Hence, the total mass shielding becomes strongly anisotropic leading to a directional dependent sensitivity.

At time of writing, work is ongoing establishing an absolute/extrinsic calibration supported by Total Ionizing Dose (TID) signature matching with an on-ground radiated specimen.

2.6.2 Intrinsic Calibration

The image sensor is an interline transfer CCD. Such devices consist of:

- A photosensitive part (the integration layer)
- A masked part (the readout layer)

Both physical layers are sensitive to ionizing radiation with their own sensitivity.

The radiation counts telemetered from the instrument are subject to several calibration activities including:

- Saturation: The particle counting is aborted if too many stellar candidate objects are identified.
- Trailing: The ionization trail of a particle may not be confined to a single image pixel but may extend to neighbouring pixels. This may lead to incorrect classification as a stellar candidate object.
- Clustering: Particle interactions in neighbouring pixels will be reported as a single interaction. The probability of an incorrect count increases with higher radiation flux.
- Electronic shutter usage: During some operational modes, the built-in electronic shutter is used to reduce the electron accumulation. The electronic shutter works by flushing the integration layer for electrons at a fixed time before the transport to the readout layer is commanded. The effective integration period is then from the time of flushing to the time of transport to the integration layer. During the integration layer flushing, all signals from radiation impacts are flushed in this layer as well. The net radiation count will be equal to the counts accumulated from the integration layer during the effective integration period + the counts accumulated from the read layer during the entire read out cycle.

Note:

- All particle count data is calibrated/adjusted per the description above.
- All particle images are NOT adjusted, and the apparent particle signatures reflect the original observation.

2.7 Inflight Calibration

No in-flight calibration has been performed.

3 Data Set Overview

3.1 Data sets

The ASC data archive is divided into two *Data Sets*, the basic description of which can be seen in Table 1.

Table 1. Data Sets

Data Set ID	CODMAC level	Data Product ID
JNO-J-ASC-2-IMG-V1.0	2	P0
JNO-J-ASC-3-RAD-V1.0	3	P1

The data products of each data sets are detailed in Table 2. The following format are used:

- *pj* : Peri-jove number in the format PJ### (e.g. "PJ011")
- *date* : Date of acquisition in the format YYYYDDDTHHMMSS (e.g. "2018038T190221")
- *chuid* : ID of the CHU used (e.g. "CHUD")
- *ver* : Version of the product release (e.g. "V01")

Table 2. Data Products

Data Product ID	Key / Physical Parameters	Inputs	Format	Description	Filename Format
P0	Captured image	ASC raw telemetry packets	binary	Uncompressed binary data of the captured images	ASC_IMG_L2_ *pj_date_chuid_ver*
P1	Rad count	ASC raw telemetry packets	ASCII	CSV file of count information timeseries	ASC_RAD_L3_ *pj_date_chuid_ver*

Since in the prime mission phase, the primary role of the ASC instrument was of a functional nature (section 2.1), there were no plans, or funding, to archive prime mission data. Only the dataset acquired during the extended mission (i.e., acquired after August 1, 2021) is archived in the PDS. Since the camera heads acquired their radiation dose design limit prior to the start of the extended mission, degrading the image quality of the instrument, mostly radiation data and very few images are archived in the PDS. Lastly the orbital period of the Juno spacecraft decreased down to ~34 days during the extended mission from the prime missions ~53 days.

3.2 Data Flow

Figure 3 depicts the flow of the data from the spacecraft through the various stages to the PDS node.

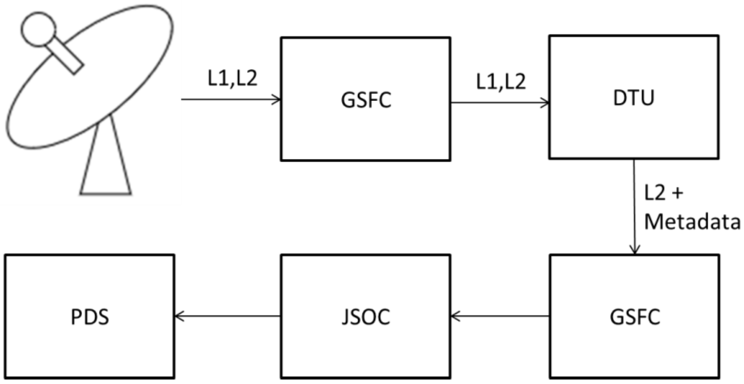

Figure 3. Data flow to PDS node

3.3 Data Processing and Production Pipeline

3.3.1 CODMAC Level 2 Data Production Pipeline

Figure 4 depicts the radiation count data pipeline processes that starts with the raw telemetry data received and transforms the data into the final product submitted to the PDS node.

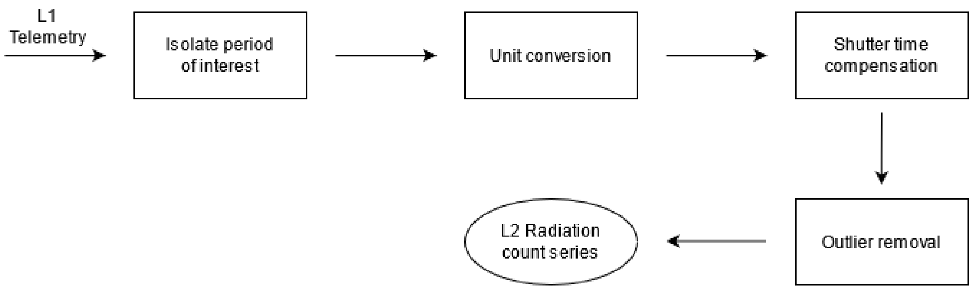

Figure 4. Radiation count data pipeline

Figure 5 depicts the image data pipeline which processes the images received and transforms them into the final product submitted to the PDS node.

Figure 5. Image product data pipeline

3.4 Data validation

3.4.1 Instrument Team Validation

The ASC team checks the incoming data for outliers and subsequently discards them.

4 Archive volume generation

The ASC Standard Data Record archive collection is produced by the Technical University of Denmark (DTU) in cooperation with NASA Goddard Space Flight Center (GSFC) and the support of JSOC and the PDS Node. The archive volume creation process described in this section sets out the roles and responsibilities of each of these groups. The assignment of tasks has been agreed upon by all parties. Archived data received by the PDS Node will be made electronically available to PDS users as soon as practicable but no later than **TBD.** PDS recommends that data users recheck PDS data holdings periodically to determine whether previously acquired data products have been updated or replaced.

4.1 Data transfer methods and delivery schedule

The data products will be sent electronically by the GSFC IOT via secure File Transport Protocol (SFTP) to JSOC and placed in directories that mirror the archive organization. Only those files that have changed since the last delivery will be included. JSOC subsequently transfers data products to the PDS discipline node.

Following receipt of a data delivery, the PDS node (Planetary Plasma Interactions – PPI) will organize the data into PDS archive volume structure within its online data system. PPI or JSOC will generate all of the required files associated with a PDS archive volume (index file, readme files, etc.)

The data will be delivered adhering to the plan in the Juno Project Science Data Management Plan with the caveat that ASC will have non-synchronous delivery schedules until the archiving pipeline is established and can sync up to this schedule. Each package will comprise both data and ancillary data files organized into directory structures consistent with the volume design described in Section 5, and combined into a deliverable file(s) using file archive and compression software. When these files are unpacked at the PDS Node in the appropriate location, the constituent files will be organized into the archive volume structure.

4.2 Data product and archive volume size estimates

A set of data files will be generated for each perijove, with an approximate total uncompressed size of 10Mb.

4.3 Backups and duplicates

All data provided to the PDS node will backed up and archived by DTU.

5 Archive volume contents

This section describes the contents of the ASC standard product archive collection volumes, including the file names, file contents, file types, and the organizations responsible for providing the files. The directory structure is shown in Figure 6.

```
ROOT
  |-----CATALOG
  |-----DATA
          |-----PJxxx

  |-----DOCUMENT
  |-----EXTRAS
  |-----INDEX
```

Figure 6. Archive Volume directory structure

5.1 Root directory

The following files are contained in the root directory and are produced by the PDS discipline node. Except for the hypertext file and its label, all these files are required by the PDS Archive Volume organization standards.

Table 3. Root directory contents

File	Description	Responsible
AAREADME.TXT	This file completely describes the volume organization and contents (PDS label attached)	PDS Node
ERRATA.TXT	A text file containing a cumulative listing of comments and updates concerning all ASC standard products on all ASC volumes in the volume set published to date	ASC Team
VOLDESC.CAT	A description of the contents of this volume in a PDS format readable by both humans and computers	PDS Node

5.2 INDEX directory

The following files: INDXINFO.TXT, INDEX.TAB, and INDEX.LBL, are contained in the index directory and are required by the PDS volume standards. The INDEX.TAB file contains a listing of all data products on the archive volume. The index tables include both required and optional columns. They are produced in the following manner. PDS will generate the INDXINFO.TXT file and will be responsible for any needed updates. JSOC will automatically generate the INDEX.TAB and INDEX.LBL files along with each PDS archive volume delivery. The PDS node will update the INDEX.TAB and INDEX.LBL when more files get added to a volume.

Table 4. INDEX directory contents

File	Description	Responsible
INDXINFO.TXT	A description of the contents of this directory	JSOC/PDS
INDEX.LBL	A PDS detached label that describes INDEX.TAB	JSOC/PDS
INDEX.TAB	A table listing all ASC data products on this volume	JSOC/PDS

5.3 DOCUMENT directory

The document directory contains documentation that is considered to be either necessary or simply useful for users to understand the archive data set. These documents are not necessarily appropriate for inclusion in the PDS catalog. Documents may be included in multiple forms (ASCII, PDF, MS Word, Hypertext Markup Language (HTML) with image file pointers, etc.). While PDS standards require that any documentation deemed required for use of the data be available in some ASCII format this requirement has been waived for the Juno mission. Clean HTML is acceptable as ASCII formats in addition to plain text. The following files are contained in the DOCUMENT directory and are produced or collected by the PDS discipline node.

Table 5. DOCUMENT directory contents

File	Description	Responsible
DOCINFO.TXT	A description of the contents of this directory	PDS Node
VOLSIS.LBL	A PDS detached label that describes VOLSIS.PDF	PDS Node
VOLSIS.PDF	A document describing the format and content of the ASC PDS archive (this document)	ASC Team

5.4 CATALOG directory

The completed PDS catalog files in the catalog directory provide a top-level understanding of the Juno mission and its data products.

Each file in the catalog directory contains an individual PDS catalog object. These objects provide a top-level understanding of the Juno mission, the instrument and its data products. The data set catalog files will be provided by the instrument team, and the CATINFO.TXT by the PDS discipline node.

Table 6. CATALOG directory contents

File	Description	Responsible
CATINFO.TXT	A description of the contents of this directory	PDS Node
MISSION.CAT	PDS mission catalog description of the Juno Mission	Juno Project
INSTHOST.CAT	PDS instrument host (spacecraft) catalog description of the Juno spacecraft	Juno Project
JNO_ASC_INST.CAT	PDS instrument catalog description of the ASC instrument	ASC Team
JNO_ASC_IMG_DS.CAT	PDS data set catalog description of the ASC IMG data set	ASC Team
JNO_ASC_RAD_DS.CAT	PDS data set catalog description of the ASC RAD data set	ASC Team
JNO_ASC_REF.CAT	PDS reference catalog description listing ASC-related references mentioned in other catalog files or otherwise relevant to the archive	ASC Team
PROJREF.CAT	PDS reference catalog description listing Juno project related references mentioned in other catalog files or otherwise relevant to the archive	Juno Project
JNO_ASC_PERSON.CAT	PDS personnel catalog description containing a list of persons involved	ASC Team

5.5 DATA directory

5.5.1 Contents

The DATA directory contains the data files produced by the ASC team. These files contain the raw images captured, and the radiation counts converted to ASCII and organized into time sequences, time tagged. The data products are organized in a subdirectory structure based on the perijove passage number and the time of acquisition.

Each data product in the archive volume is accompanied by a corresponding PDS label file. Text documents have attached PDS labels and data files detached labels, present in the same directory as the data product and with the same name, but LBL file extension.

6 Detailed Interface Specifications

6.1 Radiation Counts

The radiation count data is confined to the orbital period, where JUNO is in proximity to Jupiter. The data span a period from 24h before to 24h after the perijove, i.e. spanning a total of 48h. Before forwarding the data to PDS, the following pre-processing is performed:

- Filtering: Data samples that are impaired by other operation, e.g. saturation or incorrectly set dark level clamping, are suppressed from the dataset
- Calibration: The radiation count data is converted to engineering units, calibrated for count statistics effect, shutter usage etc.
- Flux calibration: The engineering count units are converted to external omni-directional flux by compensating for sensor sensitivity and shielding attenuation.

6.1.1 Labelling and Identification

One radiation count data product is produced for each perijove passage and is contained within a single ASCII file. An associated label file describes details of the radiation count product. The naming of the radiation count file is described below. The naming of the label file is the name of the radiation count file with the extension replaced by an ".LBL" file extension.

The naming of each radiation count product follows the format:

`ASC_RAD_L3_`*`pj_date_chuid_ver`*`.TAB`

- *pj*: The perijove ID at which the image was acquired in the format `PJ###`
- *time:* Time of the perijove passage in the format `yyyydddThhmmss`
- *chuid*: ID of the CHU used for the acquisition (e.g. "CHUD")
- *ver*: The version number of the product (e.g. "V01")

An example radiation count product name is:

`ASC_RAD_L3_PJ001_2016240T125044_CHUD_V01.TAB`

- *pj*: The perijove ID at which the image was acquired (PJ1)
- *date*: The time of the perijove passage (2016/doy240)
- *chuid*: ID of the CHU used for the acquisition (CHUD)
- *ver*: The version of the product (version 1.0)

6.1.2 Label File Specifications

```
PDS_VERSION_ID              : The PDS version used - always set to "PDS3"
DATA_SET_ID                 : Always set to "JNO-J-ASC-3-RAD-V1.0"
STANDARD_DATA_PRODUCT_ID    : Always set to "ASC_RAD"

PRODUCT_ID                  : Base name of the data file
PROCESSING_LEVEL_ID         : Always set to "3"
PRODUCT_VERSION_ID          : Revision number of the product, starting from "01"
PRODUCT_CREATION_TIME       : Timestamp of the product creation
MD5_CHECKSUM                : MD5 checksum of the dataset

RECORD_TYPE                 : Always set to "FIXED_LENGTH"
RECORD_BYTES                : Number of bytes/record. always set to "69"
FILE_RECORDS                : The number of records in the radiation count file

ORBIT NUMBER                : The orbit number of Juno about Jupiter starting from JOI
SPACECRAFT_CLOCK_START_COUNT : Spacecraft time of the first count measurement
SPACECRAFT_CLOCK_STOP_COUNT : Spacecraft time of the last count measurement
```

```
START_TIME                 : UTC timestamp of the first count measurement
STOP_TIME                  : UTC timestamp of the last count measurement

/* Observation description */
INSTRUMENT_HOST_NAME       : Name of the spacecraft – always "JUNO"
INSTRUMENT_NAME            : Name of the instrument used – always "ADVANCED STELLAR
                             COMPASS"
DETECTOR_ID                : Name of the CHU (CHUA, CHUB, CHUC or CHUD)
MISSION_PHASE_NAME         : Name of the mission phase ("PRIME MISSION" or
                           "EXTENDED MISSION")
TARGET_NAME                : Always set to "JUPITER"

TABLE                      : Name of the data file

OBJECT                     : Always set to TABLE
  INTERCHANGE_FORMAT       : Data file is always "ASCII"
  ROWS                     : Number of radiation count measurements in the file
  COLUMNS                  : Number of columns – always set to "8"
  ROW_BYTES                : Number of bytes per row – always set to "69"

DESCRIPTION                : "This product consists of records (or rows, lines)
                              of ASC rad count data. Each record of the file contains
                              the SCLK timestamp, rad count, BBO (big bright object)
                              flag, number of stellar candidate objects, electronic
                              shutter compensation, un-calibrated rad count, UTC
                              timestamp and omni-directional flux"

OBJECT                = COLUMN
  NAME                = SCLK_TIME
  DATA_TYPE           = ASCII_REAL
  START_BYTE          = 1
  BYTES               = 14
  DESCRIPTION         = "The SCLK time in seconds w. millisecond
                         resolution of the data sample"
END_OBJECT            = COLUMN

 OBJECT               = COLUMN
  NAME                = RADIATION_COUNTS
  DATA_TYPE           = ASCII_INTEGER
  START_BYTE          = 17
  BYTES               = 5
  DESCRIPTION         = "The calibrated radiation count"
END_OBJECT            = COLUMN

OBJECT                = COLUMN
  NAME                = BBO_FLAG
  DATA_TYPE           = ASCII_INTEGER
  START_BYTE          = 24
  BYTES               = 1
  DESCRIPTION         = "Indicating presence of a big luminous object
                         within the field of view
                           0 : No BBO was present in the source image
                           1 : At least one BBO was present"
 END_OBJECT           = COLUMN

OBJECT                = COLUMN
  NAME                = OBJECT_COUNT
  DATA_TYPE           = ASCII_INTEGER
  START_BYTE          = 27
  BYTES               = 3
  DESCRIPTION         = "Number of stellar candidate objects
                         identified in the image"
 END_OBJECT           = COLUMN

OBJECT                = COLUMN
  NAME                = SHUTTER_COMPENSATION
  DATA_TYPE           = ASCII_REAL
```

```
  START_BYTE         = 32
  BYTES              = 4
  DESCRIPTION        = "The applied correction for electronic shutter
                        usage"
 END_OBJECT          = COLUMN

OBJECT               = COLUMN
  NAME               = RADIATION_COUNT_RAW
  DATA_TYPE          = ASCII_INTEGER
  START_BYTE         = 38
  BYTES              = 5
  DESCRIPTION        = "The raw uncalibrated radiation count as telemetered"
 END_OBJECT          = COLUMN

 OBJECT              = COLUMN
  NAME               = UTC_TIME
  DATA_TYPE          = ASCII_REAL
  START_BYTE         = 44
  BYTES              = 14
  DESCRIPTION        = "The UTC time in seconds w. millisecond
                        resolution of the data sample"
END_OBJECT           = COLUMN

 OBJECT              = COLUMN
  NAME               = OMNI-DIRECTIONAL FLUX
  DATA_TYPE          = ASCII_INTEGER
  START_BYTE         = 59
  BYTES              = 10
  DESCRIPTION        = "The calibrated radiation count"
END_OBJECT           = COLUMN

END_OBJECT = TABLE
END
```

6.1.3 Data File Specifications

The radiation count data files are organized as comma-separated, fixed width ASCII files. Each record is described in one row and the number of file rows marks the number of radiation count samples. A brief description of the rows is given in the table below:

#	Byte range	Type	Name	Description
1	1-14	ASCII_REAL	SCLK_TIME	Spacecraft clock in decimal seconds.
2	17-21	ASCII_INTEGER	RADIATION_COUNT	The calibrated, shutter compensated, radiation count. The count values are calibrated to counts as reaching the CCD per image cycle (250ms).
3	24-24	ASCII_INTEGER	BBO_FLAG	Indicating presence of a bright luminous object in the field of view at the time of acquisition. 0 means no BBO, 1 means BBO.
4	27-29	ASCII_INTEGER	OBJECT_COUNT	Number of stellar candidates identified in the image.
5	32-35	ASCII_REAL	SHUTTER_COMPENSATION	The measured count depends on the use of electronic shutter. This field indicates the level of compensation applied for the engineering count values (#2)
6	38-42	ASCII_INTEGER	RADIATION_COUNT_RAW	The raw radiation count as telemetered by the instrument in the given 250ms duration image cycle
7	44-57	ASCII_REAL	UTC_TIME	UTC time in decimal seconds. The time epoch is seconds since Jan 1st, 2000 at noon.
8	59-68	ASCII_INTEGER	OMNIDIRECTION_FLUX	The external omni-directional flux in [particles/cm^2/s], within the energy sensitivity range of the sensor.

Calibration

The calibration of the radiation data products follows largely the processing flow described in RD2 with the following deviations:

- The order of compensation steps (RD2 Fig 2) has been altered to:
  Saturation Compensation -> Trailing Compensation -> Cluster Compensation -> …
- The saturation compensation function (RD2 Equation 4) is changed to:

$$SCC(EPDC) = \begin{cases} 4.5 \cdot 10^{-14} EPDC^4 + 3.0 \cdot 10^{-6} EPDC^2 + 10.5 & , no\ shutter \\ 4.2 \cdot 10^{-15} EPDC^4 + 3.3 \cdot 10^{-6} EPDC^2 + 10.5 & , shutter \end{cases}$$

For a further details of the omni-directional flux calibration and dependability of the available data field, please refer to RD2.

Converting SCLK Seconds Since Epoch to Calendar Format

The timestamp for each sample (UTC_TIME) is given as seconds since epoch (J2000). If a calendar format is required, use the following sequence of spice functions to convert the spacecraft clock (SCLK_TIME):

1. `cspice_scs2e` converts
   - from seconds:fraction seconds as string
   - to ephemeries time
2. `cspice_et2utc` converts
   - from ephemeries time
   - to UTC

In MATLAB, convertion from spacecraft clock (*sclk*) to utc calendar format (*utc*) can be performed using the following code:

```
% Generate a string version of SCLK
sclk_str = [num2str(floor(sclk)) ':' num2str(round((sclk-floor(sclk))*2^16))];

% Convert Juno SCLK to Ephemeris Time
JUNO_ID = -61999;
et = cspice_scs2e(JUNO_ID, sclk_str);

% Convert ephemeries time to ISO calendar format
utc = cspice_et2utc(et, 'ISOC', 6);
```

6.1.4 Data Loss Considerations

After data is received at the DSN from the Juno spacecraft the spacecraft team and the IOT check loss of data by looking for missing packet numbers. If any are found, the missing data retransmission commands are sent to the spacecraft. If this process is unsuccessful, the individual lost measurement points are simply not available in the data set. The net loss will be a slight discontinuity in the radiation count data set.

6.1.5 Volume, Size and Frequency Estimates

The data volume is variable and depends on the spacecraft/Jupiter/Sun geometry, presence of Jovian satellites etc. A typical dataset spans 48h and contains in the order of 100,000 radiation count data samples. The data volume is this ~100,000 records x 43 bytes/record = 4-5Mbytes. One such volume is available for each perijove passage.

The sample frequency depends on the spacecraft time distance from perijove and varies between 1/7Hz, 1Hz and 4Hz, with highest frequency close to perijove.

6.2 Images

6.2.1 Labelling and Identification

Each image data product is contained within a single binary file. An associated label file describes details of the image data product. The naming of the image file is described below. The naming of the label file is the name of the image file with an ".LBL" file extension.

The labelling of each image product follows the format:

`ASC_IMG_L2_`*`pj_date_chuid_ver.DAT`*

- *`pj`*: The perijove ID at which the image was acquired in the format `PJ###`
- *`time:`* Time of the image acquisition in the format `yyyydddThhmmss`
- *`chuid`*: ID of the CHU used for the acquisition (e.g. "CHUD")
- *`ver`*: The version number of the product (e.g. "V01")

An example image name is:

`ASC_IMG_L2_PJ011_2018037T180709_CHUD_V01`

- *`pj`*: The perijove ID at which the image was acquired (PJ11)
- *`date`*: Time of image acquisition (2018/037 18:07:09)
- *`chuid`*: ID of the CHU used for the acquisition (CHUD)
- *`ver`*: The version of the image product (Version 1)

6.2.2 Label File Specifications

The label files are in ASCII text and contain one property per line. The following property indicators are defined:

```
PDS_VERSION_ID            : The PDS version used - always set to "PDS3"

RECORD_TYPE               : Always set to "FIXED_LENGTH"
RECORD_BYTES              : The number of bytes per record, always "436194"
FILE_RECORDS              : The number of records in each file, always "1"
LINES                     : The number of lines, always "581"
^IMAGE_HEADER             : A pointer to the image header part, "filename"
^IMAGE                    : A pointer to the image data part, "("filename",
                            35 <BYTES>)"

DATA_SET_ID               : Always "JNO-J-ASC-2-IMG-V1.0"
PRODUCT_ID                : Base name of data file
STANDARD_DATA_PRODUCT_ID  : Always set to "ASC_IMG"
PROCESSING_LEVEL_ID       : Always set to "2"
PRODUCT_VERSION_ID        : Revision number of the product, starting from "01"
INSTRUMENT_HOST_NAME      : Name of the spacecraft, always "JUNO"
TARGET_NAME               : Name of the target body, always "JUPITER"
START_TIME                : UTC timestamp of the image acquisition
STOP_TIME                 : UTC timestamp of the image acquisition
SPACECRAFT_CLOCK_START_COUNT : Spacecraft time of the image acquisition
SPACECRAFT_CLOCK_STOP_COUNT : Spacecraft time of the image acquisition
IMAGE_TIME                : Time of center of integration
EXPOSURE_DURATION         : Total duration of the image exposure in seconds
PRODUCT_CREATION_TIME     : Timestamp of the product creation
MD5_CHECKSUM              : MD5 checksum of the image file
```

```
ORBIT_NUMBER              : The orbit number at which the image was acquired
INSTRUMENT_NAME           : Name of the instrument (always "ADVANCED STELLAR
                            COMPASS")
DETECTOR_ID               : Name of the camera head (e.g. "CHUD")
MISSION_PHASE_NAME        : Name of the mission phase ("PRIME MISSION" or
                            "EXTENDED MISSION")

/* DESCRIPTION OF OBJECTS CONTAINED IN FILE */

OBJECT = IMAGE_HEADER
      BYTES               : Size of the image header, always "34"
      RECORDS             : Number of records in the image header, always "1"
      HEADER_TYPE         : The structure used for the header, always "CUSTOM"
      INTERCHANGE_FORMAT  : Format used for data organization, always "BINARY"
END_OBJECT = IMAGE_HEADER

OBJECT = IMAGE
      LINES               : The number of rows in the image, always "580"
      LINE_SAMPLES        : The number of columns in the image, always "752"
      SAMPLE_TYPE         : The type of the pixel data, always "UNSIGNED_INTEGER"
      SAMPLE_BITS         : The number of bits per pixel data, always "8"
END_OBJECT = IMAGE

END
```

6.2.3 Data File Specifications

The data files are structured as binary data files. The image data is preceded by a custom binary header of 34 bytes. Following the header, the image data is given row-wise, starting from upper left corner moving right. The binary data file organization:

Byte offset (counting from 0)	**Contents**	**Details**
0 – 13	34 byte custom image header	ASC setup data irrelevant for radiation count
14-17		Offset of image data start (uint32)
18-21		Offset of image data end (uint32)
22-23		SCLK timestamp 1/65536 fraction of seconds (uint16)
24-27		SCLK timestamp seconds (uint32)
28-29		Height of image field in pixels = 290 (uint16)
30-31		Width of image field in pixels = 752 (uint16)
32-33		Number of fields/image -1 = 1
34 – 785	Image data	Image row 0 data, starting from left
786 – 1,537		Image row 1 data, starting from left
…		…
435,442 - 436,193		Image row 579 data, starting from left

Note that all header fields are given in little Endian format, i.e. with the least significant byte first and the most significant byte last.

The image data may by read into a 2D array in MATLAB using the following instructions:

```
fileid=fopen(filename, 'rb');
fseek(fileid, 34, 'bof');
imgdata=fread(fileid, [752 580], 'uint8')';
fclose(fileid);
```

And viewed in MATLAB using the following instructions:

```
figure;
image(imgdata);
contrast=6;
colormap(gray(256/contrast));
```

Opening the example file (ASC_IMG_2022-08-17T110005_PJ044_v1_CHUD.DAT) in MATLAB will display the image shown in Figure 7.

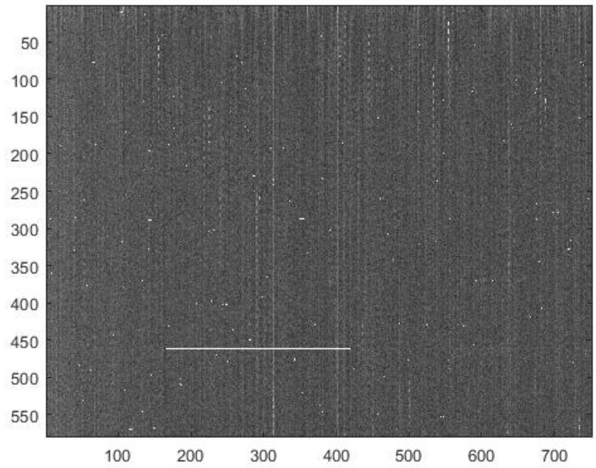

Figure 7: Example image file opened in MATLAB and showed with a contrast of 6

6.2.4 Data Loss Considerations

After data is received at the DSN from the Juno spacecraft the spacecraft team and the IOT check loss of data by looking for missing packet numbers. If any are found, the missing data retransmission commands are sent to the spacecraft. If this process is unsuccessful, the image will be discarded by DTU in the reviewing process, before passing on to GSFC. Hence, no image product available on PDS will exhibit data loss.

6.2.5 Volume, Size and Frequency Estimates

The volume of all image data products are identical (436,194 bytes)

Each image is manually requested via commands sent by the spacecraft to the ASC subsystem. They are typically acquired close to Jupiter (within ±24h of the perijove passage). The number of image acquisition commands in the timeline varies but will typically be in the range 10-30 per orbit.

Appendix A. Support staff and cognizant persons

Technical University of Denmark – DTU Space

- Associate Professor Troelz Denver
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