Juno
L-2 Data
Gravity Science Instrument
Archive Volume Software Interface Specification

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CHANGE LOG

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ACRONYMS AND ABBREVIATIONS

ASCII	American Standard Code for Information Interchange
DOY	Day of Year
DSN	Deep Space Network
GS	Gravity Science
GSI	Gravity Science Instrument
JPL	Jet Propulsion Laboratory
JUGR	Jupiter Gravity
NAIF	Navigation Ancillary Information Facility
NASA	National Aeronautics and Space Administration
PDS	Planetary Data System
RDA	Raw Data Archive
RDR	Reduced Data Record
RS	Radio Science
RSS	Radio Science Subsystem
PRRSG	Planetary Radar and Radio Sciences Group
SIS	Software Interface Specification

1. INTRODUCTION

1.1. Purpose and Scope

This Software Interface Specification (SIS) describes the format and content of the Juno Mission to Jupiter Gravity Science (GS) Reduced Data Record (RDR) Archive. The Juno Gravity Science RDR represents the archive of derived data from gravity science investigations conducted using the radio link between the Juno spacecraft and the Deep Space Network (DSN) tracking stations.

The archives are generated by the Juno Gravity Science Team and Juno Gravity Science Instrument Operations Teams. It is maintained and distributed by the Planetary Data System (PDS).

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

1.2. Content Overview

This archive contains data products derived from raw Juno Gravity Science tracking data. The radio observations were carried out using the Juno spacecraft and Earth-based receiving stations of the NASA Deep Space Network.

This SIS describes the format and content of the Juno GS RDR archive. The data are generated and assembled into archives by the Juno Gravity Science Team delivers the completed archive to PDS.

The specific data products included in this archive are:

- **Gravity field model coefficients (SHADR):** The spherical harmonic coefficients of the gravity field derived from the tracking data

1.3. References

[1] Asmar, S.W., Scott J. Bolton, Dustin R. Buccino, Timothy P. Cornish, William M. Folkner, Roberto Formaro, Luciano Iess, Andre P. Jongeling, Dorothy K. Lewis, Anthony P. Mittskus, Ryan Mukai Lorenzo Simone. *The Juno Gravity Science Instrument*. Simone Space Sci Rev (2017). doi:10.1007/s11214-017-0428-7

[2] Folkner, W. M., L. Iess, J. D. Anderson, S. W. Asmar, D. R. Buccino, D. Durante, M. Feldman, L. Gomez Casajus, M. Gregnanin, A. Milani, M. Parisi, R. S. Park, D. Serra, G. Tommei, P. Tortora, M. Zannoni, S. J. Bolton, J. E. P. Connerney, and S. M. Levin. *Jupiter gravity field estimated from the first two Juno orbits*, Geophysical Research Letters, 44, 4697-4700 (2017), doi:10.1002/2017GL073140

[3] L. Iess, W.M. Folkner, D. Durante, M. Parisi, Y. Kaspi, E.Galanti, T. Guillot, W.B. Hubbard, D.J. Stevenson, J.D. Anderson, D. R. Buccino, L. Casajus, A. Milani, R. Park, P. Racioppa, D. Serra, P. Tortora, M. Zannoni, H. Cao, R. Helled, J.I. Lunine, Y. Miguel, B. Militzer, S. Wahl, J.E.P. Connerney, S.M. Levin, and S.J. Bolton. *The Asymmetric Gravity Field of Jupiter*. Nature 555 (2018), pp. 220-222.

[4] Durante, D., M. Parisi, D. Serra, M. Zannoni, V. Notaro, P. Racioppa, D. R. Buccino et al. "*Jupiter's gravity field halfway through the Juno mission.*" Geophysical Research Letters 47, no. 4 (2020): e2019GL086572.

2. REDUCED DATA RECORD ARCHIVE OVERVIEW

2.1. Instrument Overview

The Juno telecommunications system operates at X-band and Ka-band to support the gravity science investigation at Jupiter. The X-band transponder onboard the spacecraft provides the primary communications and telemetry with the ground station. The Ka-band telemetry system is augmented with a Ka-band Translator (KaT) and downconverter enabling a two-way Ka-band radio science link to the Deep Space Network. The X-band and Ka-band systems can be operated simultaneously for dual X-up/X-down and Ka-up/Ka-down. The ground station uplinks a carrier to the spacecraft which the receiver acquires and tracks. The spacecraft then transmits a signal that is coherent with the received uplink signal. When no uplink signal is present, the downlink signal is referenced to the auxiliary oscillator. Data that are noncoherent contain too much Doppler noise to be useful for gravity science.

Three Deep Space Communications Complexes (DSCCs) comprise the DSN tracking network. The Goldstone DSCC (GDSCC) is located near Barstow, CA; the Canberra DSCC (CDSCC) is located near Canberra, Australia; and the Madrid DSCC (MDSCC) is located near Madrid, Spain. The complexes are strategically placed roughly 120 degrees in longitude apart to give continuous coverage of the sky. Each complex is equipped with several antennas, including at least one 70-m, 34-m High Efficiency (HEF), and 34-m Beam WaveGuide (BWG), and associated electronics, and operational systems.

Primary activity at each complex is radiation of commands to and reception of telemetry data from active spacecraft. Transmission and reception are possible in several radio-frequency bands, the most common being S-band (nominally a frequency of 2100-2300 MHz), X-band (7100-8500 MHz), and Ka-band (31800-32300 MHz). Transmitter output powers of up to 400 kW are available.

Ground stations have the ability to transmit coded and uncoded waveforms which can be echoed by distant spacecraft. Analysis of the received coding allows navigators to determine the distance to the spacecraft; analysis of Doppler shift on the carrier signal allows estimation of the line-of-sight spacecraft velocity. Range and Doppler measurements are used to calculate the spacecraft trajectory and to infer gravity fields of objects near the spacecraft.

Ground stations can record spacecraft signals that have propagated through or been scattered from target media. Measurements of signal parameters after wave interactions with surfaces, atmospheres, rings, and plasmas are used to infer physical and electrical properties of the target. The Deep Space Network is managed by the Jet Propulsion Laboratory of the California Institute of Technology for the U.S. National Aeronautics and Space Administration.

The radio tracking data are used to have better understanding of the magnitude and direction of Jupiter's gravity field. The analysis of the interplanetary tracking data (both range data and

VLBI) to Juno can be used to improve the modeling of the orbit of Jupiter in future versions of the solar system planetary ephemerides.

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

2.2. Data Product Overview

The derived data are stored in the DATA folder in two subdirectories. The RSDMAP files are binary files with detached PDS labels describing the format. The SHADR files are ASCII files with detached PDS labels describing the format. The table below describes the data products contained in these directories.

File	Abbrev.	File Type	Source of Files
Spherical Harmonics ASCII Data Record	SHADR	ASCII	Juno Gravity Science Team

2.2.1. Detailed Descriptions

Spherical Harmonics ASCII Data Record files

Spherical harmonic models are tables of coefficients GM, Cmn, and Smn. These can be used to represent gravitational potential of a celestial body, for example. ASCII (data type SHA) formatted spherical harmonics are defined. Each file contains two tables: a header table containing general parameters for the model (gravitational constant, its uncertainty, degree and order of the field, normalization state, reference longitude, and reference latitude); and a coefficients table (degree m, order n, coefficients Cmn and Smn, and their uncertainties).

ASCII spherical harmonic models are stored in the DATA/SHA directory with file names of the form GRV_JUGR_SHA_bbb_z_nnnn_YYYYMMDD_Vvv where:

```
'GRV'    indicates the file is a part of the Juno Gravity Science
         instrument
'_'      the underscore character is used to delimit information in
         the file name for clarity.
'JUGR'   indicates the file is a part of the Juno Gravity Science
         data set
'_'      the underscore character is used to delimit information in
         the file name for clarity.
'SHA'    denotes that this is an ASCII file of Spherical Harmonic
         coefficients
'_'      the underscore character is used to delimit information in
         the file name for clarity.
'bbb'    denotes the body the field is applicable for. variable width.
         valid bodies include:
                'JUP'  for Jupiter
                'GAN'  for Ganymede
                'EUR'  for Europa
                'IO'   for Io
'_'      the underscore character is used to delimit information in
         the file name for clarity.
```

```
'z'      indicates the normalization of the coefficients
                'U'    for UN-NORMALIZED
                'N'    for NORMALIZED
'_'      the underscore character is used to delimit information in
         the file name for clarity.
'nnnn'   is a variable-width descriptor of the gravity field
         specified by the data producer. This modifier is used
         to indicate the name of the gravity field model and producer.
'_'      the underscore character is used to delimit information in
         the file name for clarity.
'YYYY'   is the 4-digit gravity field publication year
'MM'     is the 2-digit gravity field publication month
'DD'     is the 2-digit gravity field publication day
'_'      the underscore character is used to delimit information in
         the file name for clarity.
'Vvv'    indicates the data product version number
                e.g. V01 = Version 01
'.TAB'  indicates the data is stored in tabular form.
```

Each SHADR file is accompanied by a detached PDS label; that label is a file in its own right, having the name but with the '.LBL' extension. The label file contains *IMPORTANT* information on the use of the gravity field coefficients stored in the data file.

2.3. Data Processing

Data processing is performed by the Juno Gravity Science Team. The raw radio tracking data are input into an orbit determination software such as JPL's Mission Design and Navigation Toolkit Environment (MONTE), which filters the data in a least-squares method to solve for parameters, including spherical harmonic coefficients describing the gravity field. For an overview of the method, see Reference [2], [3], or [4] in Section 1.3.

2.4. Software

No software is included in this archive.

The SPICE toolkit provides useful tools and algorithms for ancillary data processing that could help in the use of these products of and is located at the NAIF PDS node naif.jpl.nasa.gov.

The MONTE orbit determination software used to compute the gravitational fields can be licensed. Details are available on the MONTE website montepy.jpl.nasa.gov.

2.5. File Naming Conventions

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

2.6. Data Product Labels

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

2.7. Standard Keyword Values

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

Keyword	Standard Values
DATA_SET_ID	JUNO-J-RSS-5-JUGR-V1.0
DATA_SET_NAME	JUNO DERIVED RADIO SCIENCE GRAVITY DATA V1.0
INSTRUMENT_HOST_ID	JUNO
INSTRUMENT_HOST_NAME	JUNO
INSTRUMENT_ID	RSS
INSTRUMENT_NAME	GRAVITY SCIENCE INSTRUMENT
INSTRUMENT_TYPE	RADIO SCIENCE
MISSION_NAME	JUNO
TARGET_NAME	JUPITER
VOLUME_ID	JNOGRV_0002
VOLUME_SERIES_NAME	JUNO
VOLUME_SET_ID	USA_NASA_PDS_JUNO_RSS_L2
VOLUME_SET_NAME	JUNO GRAVITY SCIENCE INSTRUMENT DERIVED L-2 DATA
VOLUME_VERSION_ID	VERSION 1

3. ARCHIVE ORGANIZATION

The data archive the following directories:

- Root directory
  - CATALOG
  - DOCUMENT
  - DATA
    - SHADR
  - INDEX

The contents of the directories are described below.

3.1. Root Directory

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

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

3.2. CATALOG Directory

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

1. CATINFO.TXT: Description of the directory

2. DATASET.CAT: Overview of the RDA
3. INST.CAT: Overview of the Gravity Science Instrument
4. INSTHOST.CAT: Overview of the Juno spacecraft
5. MISSION.CAT: Overview of the Juno mission
6. PERSON.CAT: Contributors to the archive and contact information
7. REF.CAT: References for the archive

3.3. DOCUMENT Directory

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

Filename	Format	Description
DOCINFO.TXT	text	Description of the directory
JUNO_GRAV_RDR_SIS	Word, PDF, html	This document
SHADR	ASCII	Description of the contents and format of the Spherical Harmonic ASCII data record files

3.4. INDEX Directory

This directory contains the following files:

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

3.5. DATA Directory

The DATA directory contains the primary data. It contains the following subdirectories and file types:

Directory	File Type	Contents
SHADR	Spherical Harmonics ASCII Data Record	Contains the spherical harmonic coefficients of the gravity field of the specified body

4. RELEVANT DATA ARCHIVED AT OTHER SITES

4.1. NAIF Node

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

Relevant to gravity science are the following types:

- **CK:** Spacecraft and solar array attitude orientation files
- **FK:** Reference frame specification

- **SCLK:** Conversion between spacecraft time and ephemeris time
- **SPK:** Spacecraft and Planetary ephemeris data

The NAIF Node is located at:

- naif.jpl.nasa.gov/pub/naif/

5. PERSONNEL

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6. ACKNOWLEDGMENTS

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