Software Interface Specification

Voyager Jupiter
Radio Science
Raw Data Archive (REDR)

(restoration from Voyager Radio Science Team archives)

Prepared By

Richard Simpson

Version 1.0
3 November 2023

Change Log

Date	Sections Changed	Reason for Change	Revision
2023-11-03	All	New document	1.0

Contents

Acronyms and Abbreviations

ASCII	American Standard Code for Information Interchange
CCT	computer-compatible tape
CD-ROM	compact disc, read-only memory
DSN	NASA Deep Space Network
DSS	Deep Space Station (antenna and associated facilities)
GB	gigabyte
GHz	gigaHertz
HGA	high-gain antenna
JPL	Jet Propulsion Laboratory
LID	logical identifier
LIDVID	versioned logical identifier
MB	megabyte
NASA	National Aeronautics and Space Administration
NAIF	Navigation Ancillary Information Facility
OCC	occultation
ODA	Occultation Data Assembly
ODR	Original Data Record[1]
PDF	(Adobe Systems) Portable Data Format
PDS	Planetary Data System
PDS3	PDS Standards, version 3
PDS4	PDS Standards, version 4
POCA	Programmable Oscillator Control Assembly
RCP	right-circular polarization
RDA	Raw Data Archive
REDR	Reconstructed Data Record
RMS	Ring Moon Systems (PDS discipline node)
RS	radio science
RSS	Radio Science Subsystem
RSST	Radio Science Support Team
RST	Radio Science Team
S	S-band (a frequency near 2.3 GHz)
s/c	spacecraft
SCAT	scatter (as in ring scattering observations)
SETI	Search for Extra-Terrestrial Intelligence
SIS	Software Interface Specification
SPICE	information system produced by the NAIF Team
USO	ultra-stable oscillator

[1] The Original Data Record (ODR) is the output from DSN receivers used to acquire open-loop radio science data during Voyager encounters with Jupiter. It should not be confused with a 'processing level', also called ODR, and sometimes used by PDS.

VG, VGR	Voyager
VG1	Voyager 1
VG1J	Voyager 1 Jupiter
VG2	Voyager 2
VG2J	Voyager 2 Jupiter
VID	version identifier
X	X-band (a frequency near 8.4 GHz)
XML	eXtensible Markup Language

1 Introduction

1.1 Document Overview

This Software Interface Specification (SIS) describes the format and content of two bundles within the Voyager (VGR) Jupiter Radio Science (RS) Raw Data Archive (RDA) after restoration from original holdings of the Voyager Radio Science Team. The data are from radio science observations with the Voyager 1 spacecraft and NASA Deep Space Network (DSN) facilities near Madrid, Spain, (DSS-63) during the Jupiter encounter in March 1979 (VG1J) and with Voyager 2 and DSN facilities near Barstow, California, (DSS-14) during the Jupiter encounter in July 1979 (VG2J). The bundles conform to Planetary Data System standards version 4 (PDS4) [1]. The restorations to PDS4 were carried out in 2021-3 with support from the PDS Ring Moon Systems (RMS) node.

1.2 Data Overview

The two bundles are distinguished by spacecraft (Voyager 1 or 2). Bundle contents are summarized in Table 1.2-1. Within each bundle are several collections, summarized in Table 1.2-2. This document applies to both bundles. Investigations were occultations (OCC) targeting the neutral atmosphere and ionosphere [6, 7]. Searches for a ring signature and for an 'evolute flash' were conducted; neither was detected [8, 9]. The observing geometry is illustrated in Figure 1.2-1.

Table 1.2-1: Bundles within the Voyager Jupiter Radio Science Raw Data Archive

bundle_id	Investigations	Dates
voyager1_rss_jupiter_raw	OCC	1979-064
Voyager2_rss_jupiter_raw	OCC	1979-191

1.3 Experiment Overview

In each experiment the spacecraft transmitted an unmodulated carrier referenced to the output frequency of an on-board ultra-stable oscillator (USO). As the signal passed through Jupiter's atmosphere, it was refracted, absorbed, and/or scattered (Figure 1.2-1). Refraction may be interpreted in terms of the temperature and pressure in a neutral atmosphere or the electron density in an ionosphere. Changes in signal intensity may be attributed to refraction, diffraction, and/or presence of absorbing materials in the atmosphere. In the deep atmosphere, the spacecraft antenna pointing was offset to compensate for predicted refraction.

The raw data were outputs from receivers connected to the DSN antenna, which were digitally sampled and recorded (Figure 1.2-1). Two receivers were operated in parallel — at S-band (13 cm wavelength) and X-band (3.6 cm wavelength), both capturing the signal in right-circular polarization (RCP). The sample streams were combined with housekeeping data so that a single computer-compatible tape (CCT) held 200 seconds of Voyager 1 data or 400 seconds of Voyager 2 data.

Table 1.2-2: Collections within Voyager Jupiter RS RDA Bundles			
collection_id	**Product Contents**	**Number of Products**	
		VG1J	**VG2J**
data	8-bit samples of radio receiver output (binary and ASCII)	54	41
browse	Quick-look plots illustrating content of each ODR (in PDF/A format); tables of received signal strength and frequency	56	43
calib_freq	Estimates of USO frequency	1	1
context	References to context products, which are maintained elsewhere	0[2]	0[2]
geometry	Geometry files in non-SPICE formats, including spacecraft trajectory and antenna pointing reconstructions	4	4
document	Documents relevant to use of data files	3[2]	2[2]

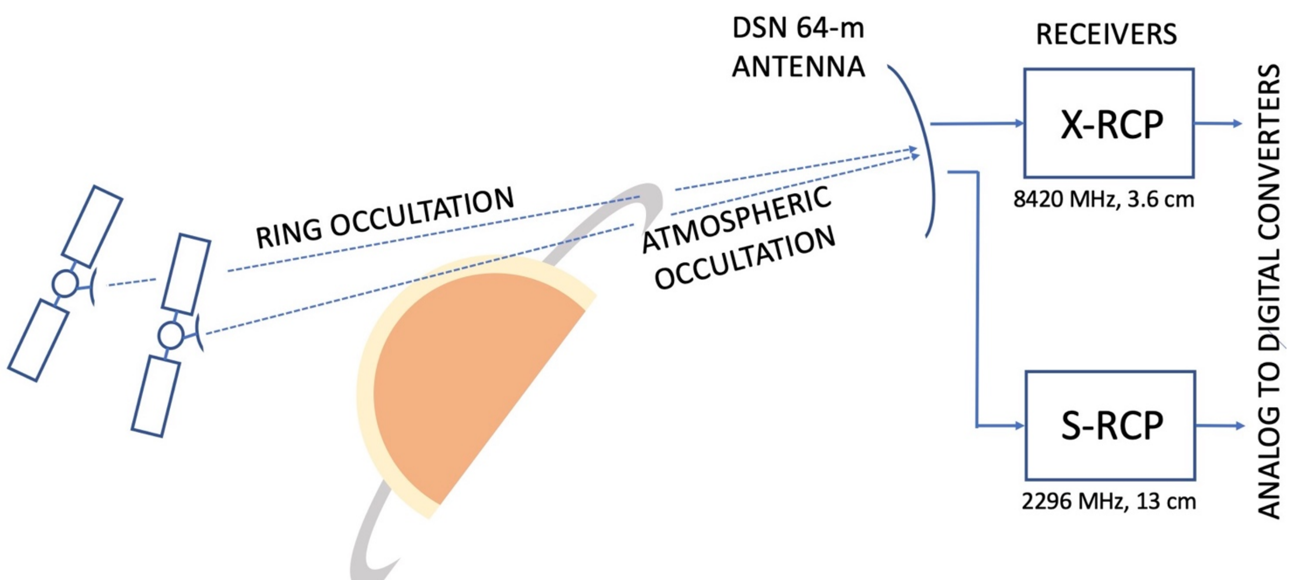

Figure 1.2-1. Observational geometry for data collection at Jupiter. As the spacecraft passed behind the planet, its S- and X-band signals were refracted by the atmosphere, causing an apparent Doppler shift at the receiving station. During occultation by Jupiter's rings, signal intensity might have been reduced and frequency might have been spread when scattered by ring particles; but neither was observed.

[2] Number includes only primary member products of the collection; additional, secondary, members are included by reference to products already archived elsewhere in PDS.

1.4 Example Data

Figure 1.4-1 is an example of partially processed S-RCP data from the Voyager 1 ingress occultation. For each raw data file in the *data* collection, there are two such four-panel plots in the *browse* collection (one plot for S-RCP and a second plot for X-RCP).

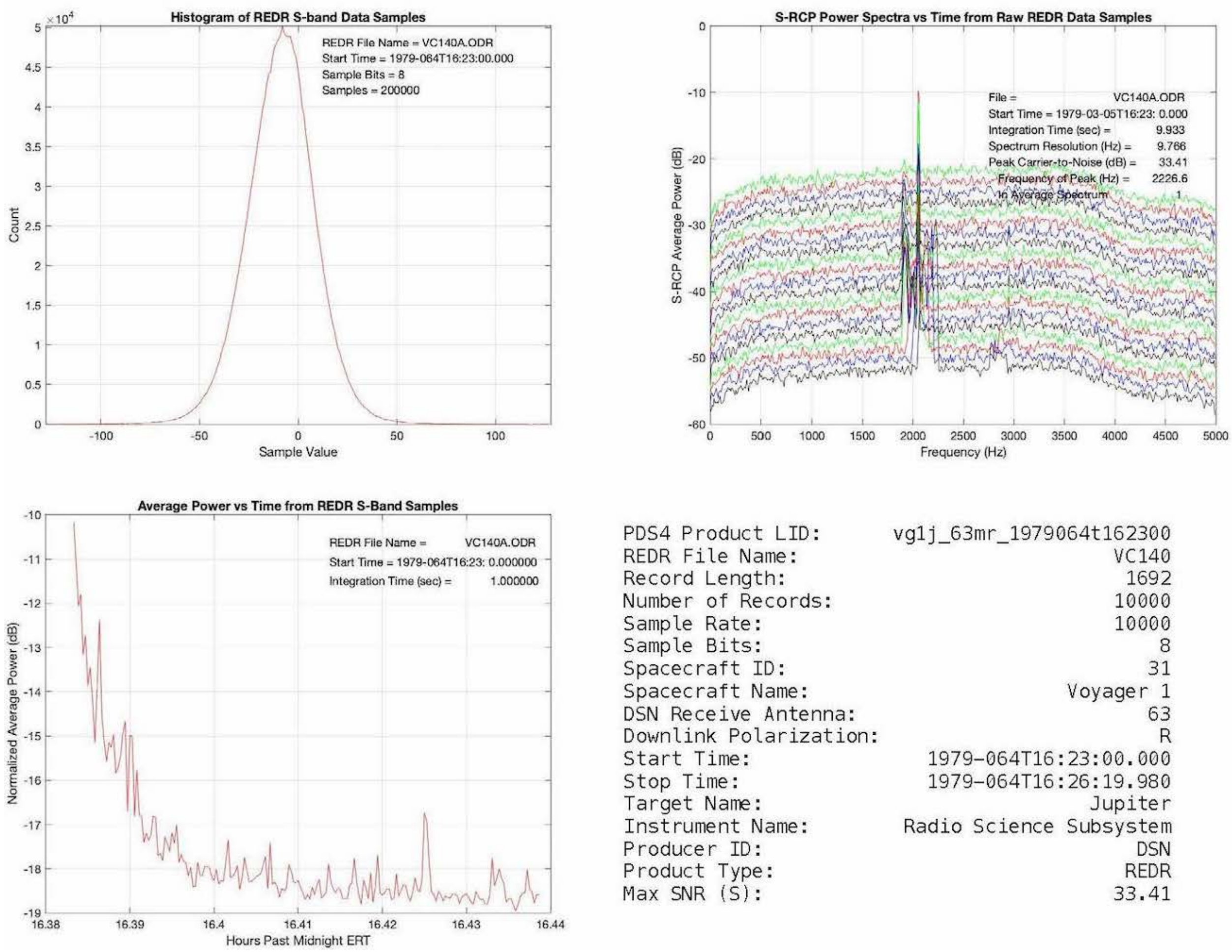

Figure 1.4-1: Example data from the beginning of the Voyager 1 S-RCP Jupiter ingress occultation. Upper left: histogram of raw data sample values. Lower left: Power versus time in sample values —one second averages of squared sample values after removal of the mean. Upper right: Power spectra (0-5 kHz); each trace is an average over 10 seconds. Time increases from bottom to top.

Raw data files have real 8-bit samples; sampling rate was 10000 samples per second at S-band and 30000 samples per second at X-band. The samples were interleaved and combined with housekeeping information in a single digital file of 10000 1692-byte records for Voyager 1 and 20000 1692-byte records for Voyager 2. Table 1.2-2 shows the total number of ODR products for each encounter.

1.5 Applicable Documents

This document references the following:

[1] PDS4 Information Model Specification, version 1.16.0.0, April 23, 2021 (https://pds.nasa.gov/datastandards/documents/im/current/index_1G00.html). See also Planetary Data System Standards Reference, JPL D-7669, Part 2, version 1.16.0, April 21, 2021 (https://pds.nasa.gov/datastandards/documents/sr/current/StdRef_1.16.0.pdf)

[2] REDR Formats for Voyager Radio Occultation Data from Jupiter (https://pds-geosciences.wustl.edu/radiosciencedocs/urn-nasa-pds-radiosci_documentation/dsn_redr/dsn_redr.2021-07-31.xml)

[3] Interpretation and Use of Binary REDR Data (https://pds-geosciences.wustl.edu/radiosciencedocs/urn-nasa-pds-radiosci_documentation/dsn_redr/redr_unpack.xml)

[4] Berman, A. L., and G. L. Tyler, Reconstruction of Downlink Frequency from Open-Loop Data, JPL IOM ALB-78-133, 22 November 1978. (https://pds-geosciences.wustl.edu/radiosciencedocs/urn-nasa-pds-radiosci_documentation/document/berman.1978.xml)

[5] Eshleman, V. R., G. L. Tyler, J. D. Anderson, G. Fjeldbo, G. S. Levy, G. E. Wood, and T. A. Croft, Radio Science Investigations with Voyager, *Space Science Reviews*, volume 21, Issue 2, pp. 207-232 (1977). doi: 10.1007/BF00200851.

[6] Eshleman, V. R., G. L. Tyler, G. E. Wood, G. F. Lindal, J. D. Anderson, G. S. Levy, and T. A. Croft, Radio Science with Voyager 1 at Jupiter: Preliminary Profiles of the Atmosphere and Ionosphere, *Science*, 204, pp. 976-978, 1979.

[7] Eshleman, V. R., G. L. Tyler, G. E. Wood, G. F. Lindal, J. D. Anderson, G. S. Levy, and T. A. Croft, Radio Science with Voyager at Jupiter: Initial Voyager 2 Results and a Voyager 1 Measure of the Io Torus, *Science*, 206, pp. 959-962, 1979.

[8] Tyler, G. L., E. A. Marouf, and G. E. Wood, Radio occultation of Jupiter's ring: bounds on optical depth and particle size and a comparison with infrared and optical results, *J. Geophys. Res*., 86, 8699-8703 (1981). doi 10.1029/JA086iA10p08699.

[9] Martin, J. M., G. L. Tyler, V. R. Eshleman, G. E. Wood, and G. F. Lindal, A Search for the Radio Occultation Flash at Jupiter, *J. Geophys. Res*., 86, pp. 8729-8732, 1981.

1.6 System Siting

1.6.1 Interface Location and Medium

The storage medium, including at least two backups, is determined by the PDS RMS Node. The user interface is through the PDS RMS web site (https://pds-rings.seti.org).

1.6.2 Data Sources, Destinations, and Transfer Methods

Bundles in the Voyager Jupiter RS RDA are aggregations of products generated by various elements of the DSN, the Voyager Project, the Voyager Radio Science Team (RST), the Voyager Radio Science Support Team (RSST), and others. The original data were delivered on CCTs to the Voyager RST at Stanford University, where they were maintained by Richard Simpson, an Associate Member of the RST. In 2020 he relocated to the SETI Institute, where he assembled the files into the PDS4 Voyager Jupiter RS RDA. All transfers during the final steps were electronic.

1.6.3 Generation Method and Frequency

The Voyager Jupiter RS RDA bundles have one primary observational data type — the Original Data Record (ODR), stored in the *data* collection (Table 1.2-2). In some documentation, the data acquisition system is called the Occultation Data Assembly (ODA) and the data are described as ODA records. Elsewhere, the Voyager Jupiter format is described as the REDR (Reconstructed Data Record) format.

The ODR format evolved over time; ODRs during the Voyager Jupiter era were quite different from ODRs during the Voyager Neptune era, when CCTs were being supplanted by electronic transfers. However, all ODRs were binary files. In the late 1970s and early 1980s they were often recorded on high-speed magnetic tape during data acquisition, then replayed at slower speed and copied to CCTs for delivery to science investigators.

Quick-look plots showing contents of the ODRs were originally generated by the Voyager Radio Science Team at Stanford. Those existed only as paper plots in the Jupiter era; new plots (such as Figure 1.4-1) have been generated as PDF/A-1b files for the PDS4 archive and are stored in the *browse* collection.

Estimates of the USO frequency at specific times during the mission for both Voyager 1 and Voyager 2 are included in the *calib_freq* collection as a memo in ASCII format. Receiver tuning at the DSN station was controlled by the Programmable Oscillator Control Assembly (POCA); the relationships among POCA values (included in the ODR records), the sky frequency, and the frequency observed in the sample output are described by a second memo [4].

Non-SPICE geometry files are in the *geometry* collection, which includes (1) one ASCII file with position and velocity data for selected targets with respect to the spacecraft and (2) a pair of files (one binary, one ASCII) with reconstructed high-gain antenna (HGA) pointing vectors, which are required to interpret radio occultation data in the deep atmosphere. SPICE geometry files may be found at https://naif.jpl.nasa.gov/naif/data_outer.html

The *document* collection includes files which describe the Voyager mission, the radio science operations plan, and the archive (this document). DSN document collections which describe radio science data formats that are mission independent — for example, [2]-[4] — are included as secondary members of the Voyager RS RDA collections.

1.7 Assumptions and Constraints

1.7.1 Usage Constraints

Access to Voyager RS RDA bundles is determined by PDS.

1.7.2 Documentation Conventions

1.7.2.1 Data Format Descriptions

Since formats vary widely among data/file types, users should consult product labels for details. Files containing receiver samples and housekeeping data are described by [2]; example conversions of binary to ASCII formats are given in [3].

1.7.2.3 Limits of This Document

This document applies only to PDS4 bundles containing Voyager radio science raw data collected during the Jupiter encounters.

2 Interface Characteristics

2.1 Hardware Characteristics and Limitations

2.1.1 Special Equipment and Device Interfaces

The PDS4 version of the Voyager Jupiter RS RDA is posted on the PDS/RMS web site. Users of the data must have access to systems which can connect with the web site.

2.1.2 Special Set-Up Requirements

None.

2.2 Volume and Size

Typical ODR data files are 16.92 MB for Voyager 1 and 33.84 MB for Voyager 2. ASCII files with S-band samples are slightly smaller than the parent ODR files (15.7 MB and 31.4 MB for Voyager 1 and Voyager 2, respectively). ASCII files with X-band samples are slightly smaller than three times the ODR sizes (47.1 MB and 94.2 MB, respectively). Other files are small by comparison. There are 54 ODRs in the Voyager 1 bundle, making the bundle volume approximately 4.4 GB. There are 41 ODRs in the Voyager 2 bundle, making that bundle approximately 6.8 GB.

2.3 Labeling and Identification

2.3.1 External Labels

There is no external labeling of the Voyager Jupiter RS RDA bundles; these archives are stored electronically on systems managed by the PDS RMS Node.

2.3.2 Internal Labels

Voyager Jupiter RS RDA bundles, collections, and products are identified by logical and version identifiers (LIDs and VIDs, respectively) constructed in accordance with PDS4 standards [1]. These identifiers are described further in Section 3 of this document.

2.4 Interface Medium Characteristics

The Voyager Jupiter RS RDA bundles are posted on the PDS RMS Node web site; the storage media and methods are determined by PDS/RMS.

2.5 Backup and Duplicates

The entire content of each Voyager Jupiter RS RDA bundle is backed up following procedures developed by PDS/RMS in accordance with PDS policies.

3 Structure and Organization Overview

3.1 Logical Organization

The Voyager Jupiter RS RDA is organized into two bundles as specified in Table 1.2-1. Each bundle has six collections (Table 1.2-2). The members of collections are data products, each including its own label written in the eXtensible Markup Language (XML). The members of each collection are listed in a collection Inventory, which is accompanied by an XML label. The bundle has a label which lists the member collections, but there is no separate inventory file. Figure 3.1-1 illustrates the logical structure for the Voyager 1 Jupiter bundle. The logical structures for the Voyager 2 Jupiter bundle is identical except that the value for <bundle_id> in the upper left is voyager2_rss_jupiter_raw.

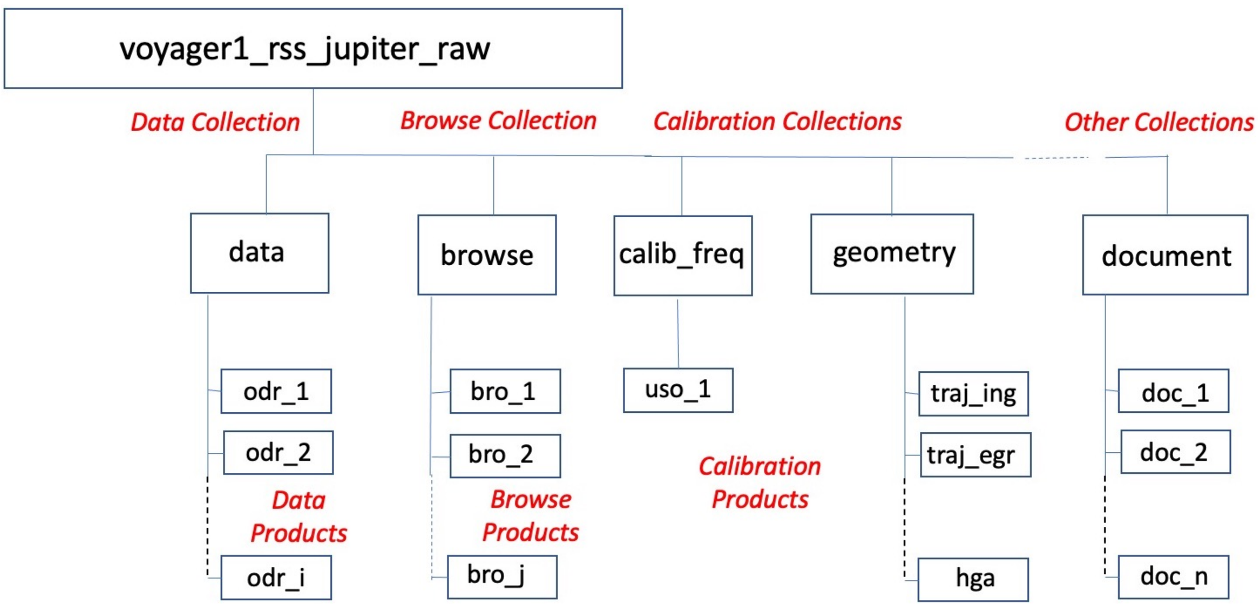

Figure 3-1.1. Logical structure of the Voyager 1 Jupiter bundle, which has one data collection, one browse collection, two calibration collections (frequency and geometry), one document collection, and one context collection (with only secondary members), which is not shown explicitly.

3.1.1 Bundles and Collections

The Logical Identifier (LID) for a bundle is constructed by appending the appropriate <bundle_id> from Table 1.2-1 to the PDS-specific root (`urn:nasa:pds`). Fields within the LID are delimited by ASCII colon characters. So long as the <bundle_id> value is unique within PDS, each bundle will be uniquely identified by its LID to all users of PDS and its archiving partners.

```
urn:nasa:pds:<bundle_id>
```

For example, the LID for the Voyager 1 bundle in Figure 3.1-1 is

```
urn:nasa:pds:voyager1_rss_jupiter_raw
```

Collection LIDs are constructed by appending <collection_id> (Table 1.2-2) to the bundle LID. Because the bundle LID is unique, it follows that the collection LIDs are also unique.

urn:nasa:pds:<bundle_id>:<collection_id>

For example, the collection LIDs for the data (ODR) and document collections in Figure 3.1-1 are:

```
urn:nasa:pds:voyager1_rss_jupiter_raw:data
urn:nasa:pds:voyager1_rss_jupiter_raw:document
```

3.1.2 Products

A product is one or more PDS4 data objects (*e.g.*, digital files) and an associated, detached PDS4 label, which is written in XML and describes the data object(s). Product LIDs are constructed by appending <product_id> to the collection LID. Because the collection LID is unique, it follows that the product LIDs are also unique.

urn:nasa:pds:<bundle_id>:<collection_id>:<product_id>

3.1.2.1 ODR and Browse Products

In the *data* collection, each product includes six files: the original binary ODR file, a file containing ASCII translations of each record header and trailer, a text file with terse titles for fields in the header/trailer file[3], a file containing ASCII translations of each record's S-band data samples, a file containing ASCII translations of each record's X-band data samples, and an XML label.

In the *browse* collection, each product includes a summary plot of the S-band data from the associated ODR product (in PDF/A-1b format), a summary plot of the X-band data (PDF/A-1b), and a PDS4 label.

Identifiers for data (ODR) and browse products have the form

```
vgnx_aabp_yyyydddthhmmss
```

where

n	= spacecraft number ("1" for Voyager 1, "2" for Voyager 2)
x	= target ("j" for Jupiter)
aa	= antenna number ("14" for DSS-14, "63" for DSS-63)
b	= band ("s" for S-band, "x" for X-band, "m" for both)
p	= polarization ("r" for RCP)
yyyy	= year
ddd	= day of year
hh	= hour

[3] The text file includes one record with field names and a second record with field formats.

```
mm    = minute
ss    = second
```

Examples of Voyager 1 Jupiter ODR and browse product LIDs derived from the same ODR are, respectively:

```
urn:nasa:pds:voyager1_rss_jupiter_raw:data:vg1j_63mr_1979064t161300
urn:nasa:pds:voyager1_rss_jupiter_raw:browse:vg1j_63mr_1979064t161300
```

Although the <`product_id`> is the same for both products, they have different LIDs because the <`collection_id`> values are distinct. The value for b (band) in both cases is "m" because each product contains both S-band and X-band data objects.

In addition to the plot products, each *browse* collection also includes a pair of tables containing estimates of received signal strength and frequency. There is one table for ingress and a second table for egress. The Voyager 1 LIDs for the tables are, respectively:

```
urn:nasa:pds:voyager1_rss_jupiter_raw:browse:vg1_radio_ing
urn:nasa:pds:voyager1_rss_jupiter_raw:browse:vg1_radio_egr
```

3.1.2.2 Frequency Calibration Products

There is one product in the *calib_freq* collection; its Voyager 1 LID is:

```
urn:nasa:pds:voyager1_rss_jupiter_raw:calib_freq:vgr_uso
```

The Voyager 2 product has the same LID except for the bundle_id:

```
urn:nasa:pds:voyager2_rss_jupiter_raw:calib_freq:vgr_uso
```

3.1.2.3 Geometry Products

Logical identifiers for products in the Voyager 1 *geometry* collection are as follows:

```
urn:nasa:pds:voyager1_rss_jupiter_raw:geometry:vg1_traj_ing
urn:nasa:pds:voyager1_rss_jupiter_raw:geometry:vg1_traj_egr
urn:nasa:pds:voyager1_rss_jupiter_raw:geometry:vh008a
urn:nasa:pds:voyager1_rss_jupiter_raw:geometry:vh008b
```

The first two products are non-SPICE trajectory reconstructions for ingress and egress, respectively. The second two are high-gain antenna pointing reconstructions in ASCII and binary formats, respectively.

For Voyager 2 the corresponding LIDs are

```
urn:nasa:pds:voyager2_rss_jupiter_raw:geometry:vg2_traj_ing
urn:nasa:pds:voyager2_rss_jupiter_raw:geometry:vg2_traj_egr
urn:nasa:pds:voyager2_rss_jupiter_raw:geometry:vu001a
urn:nasa:pds:voyager2_rss_jupiter_raw:geometry:vu001b
```

3.1.2.4 Document Products

Logical identifiers for primary members of the Voyager 1 *document* collection are as follows:

urn:nasa:pds:voyager1_rss_jupiter_raw:document:mission (mission overview)
urn:nasa:pds:voyager1_rss_jupiter_raw:document:vg1j_hga (HGA pointing)
urn:nasa:pds:voyager1_rss_jupiter_raw:document:sis_vgr_rs (this document)

The Voyager 2 *document* collection includes the mission overview and the archive volume SIS; but there is no document describing the high-gain antenna pointing reconstruction. The LIDs are:

urn:nasa:pds:voyager2_rss_jupiter_raw:document:mission (mission overview)
urn:nasa:pds:voyager2_rss_jupiter_raw:document:sis_vgr_rs (this document)

The *document* collection also includes several products which are physically not included in the Voyager Jupiter RS RDA. They are listed in the collection_document.csv file as secondary members and can be found at
https://pds-geosciences.wustl.edu/radiosciencedocs/urn-nasa-pds-radiosci_documentation/

3.1.3 Versioning

A version identifier (VID) may be appended to a logical identifier to specify one of several versions of the same bundle, collection, or product [1]. The combination is called a versioned identifier (LIDVID). LIDVIDs are used to locate specific products within PDS; every version of every product within PDS has a unique LIDVID. VIDs are separated from LIDs by a double colon (“::”) and have the form M.n where M and n are integers. All versions are 1.0 in the initial release of Voyager Jupiter RS RDA bundles. Example LIDVIDs are shown below:

urn:nasa:pds:voyager1_rss_jupiter_raw:calib_freq:vgr_uso::1.0
urn:nasa:pds:voyager1_rss_jupiter_raw:document:sis_vgr_rs::1.0
urn:nasa:pds:voyager1_rss_jupiter_raw:data::1.0 (collection LIDVID)
urn:nasa:pds:voyager2_rss_jupiter_raw::1.0 (bundle LIDVID)

3.1.4 Labels

Each digital data object is accompanied by a PDS4 label, which describes the data object and is written in XML. In many cases in the Voyager Jupiter RS RDA a single label will describe multiple data objects. In a few cases (*e.g.*, the Bundle product), the label may exist by itself since the data object is either 'physical' or 'conceptual'. A typical label includes sections which identify the associated data file(s) (by file name, version identifier, modification history, time and/or spatial coverage, etc.), provide references to other relevant information (journal articles, observing system, target description, etc.), and describe the format of the file(s) at the bit level, if necessary. PDS4 labels are digital files in their own right; their file names are the <product_id> as described above with the extension ".xml" appended.

3.2 Physical Organization

3.2.1 File Naming and Conversions

Both within this document and within the archive itself bundle, collection, and product file names (including both digital data objects and their labels) are lower case.

File names are of the form "`filename.ext`" where the base "`filename`" contains up to 27 characters and "`ext`" contains 3-4 characters. The allowable characters for PDS file names are "a-z", "0-9", and the underscore "_". Extensions are "`dat`" for binary files, "`tab`" for tables with fixed-length records, "`txt`" for text files, and "`pdf`" for PDF/A document and browse files. Other extensions (*e.g.,* "docx") are available for document files.

In addition to the various data files and their labels identified in the sections below, each collection has a collection Inventory file (collection*.csv) and label (collection*.xml).

3.2.1.1. ODR and Browse Product File Names

Base file names are constructed according to the procedure outlined in Section 3.1.2.1; the base file name is followed by an ASCII period "." and a file name extension. The value for b (band) in the base file name is "s" if the file contains only S-band data, "x" if the file contains only X-band data, or "m" if the file contains data for both bands. File name extensions in these two collections are listed below. Header files (including the file with field names) and label files use "m" for band.

`dat`	original binary ODR file
`hdr`	file containing ASCII translations of ODR header and trailer records
`pdf`	PDF/A-1b file with 4-panel browse plots
`tab`	file containing ASCII translations of receiver sample values from an ODR, or an ASCII table of receiver signal strength and frequency values in a browse collection
`txt`	text file with terse field names to accompany the `hdr` file
`xml`	PDS4 label file

For example, the following six files constitute one PDS4 product:

vc134a.odr	original ODR file (binary)
vg1j_63mr_1979064t123001.hdr	header/trailer data (ASCII)
vg1j_63sr_1979064t123001.tab	S-band receiver samples (ASCII)

vg1j_63xr_1979064t123001.tab	X-band receiver samples (ASCII)
vg1j_63mr_1979064t123001.xml	PDS4 XML label (ASCII)
vg1j_63mr_1979064t123001.txt	field headers for hdr file (ASCII)

3.2.1.2 Frequency Calibration Product File Names

Each product in the *calib_freq* collection is a digital data object paired with a PDS4 label. The file name pair for the product in the *calib_freq* collection is:

```
vgr_uso.txt   vgr_uso.xml
```

3.2.1.3 Geometry Product File Names

Each product in the *geometry* collection is a digital data object paired with a PDS4 label. File name pairs for the trajectory and HGA products in the Voyager 1 *geometry* collection are:

```
vg1_traj_ing.tab   vg1_traj_ing.xml
vg1_traj_egr.tab   vg1_traj_egr.xml
      vh008a.tab   vh008a.xml
      vh008b.tab.  vh008b.xml
```

3.2.1.4 Document Product File Names

Each product in the *document* directory is a PDS4 label plus one or more digital data objects. For example, the mission description document includes a label plus the document in two formats. The three file names are:

```
mission.pdf   mission.txt   mission.xml
```

3.2.2 File Conversions

Binary files can be difficult to read; this is particularly true when the binary format is no longer supported on contemporary platforms. Voyager Jupiter ODRs used ‘packed’ formats to minimize storage requirements; reconstructions of Voyager high-gain antenna pointing were delivered using Univac 36-bit binary integers.

3.2.2.1 ODR Conversions

A typical ODR file has 10000 (VG1J) or 20000 (VG2J) binary records. Each record includes a 12-byte header, followed by 200 8-bit samples of receiver output from each of four analog-to-digital converters (800 total samples), followed by an 80-byte trailer. The receiver samples are stored in groups of four — the first from the S-band receiver, the next three from the X-band receiver. As part of the PDS4 archiving task, the headers and trailers from each ODR were extracted and written to an ASCII file. The binary data samples were converted to ASCII and were written to a pair of separate files (one for S-band, one for X-band), each with 20 samples per line. The original binary format of the ODR is described in [2]. Conversion to ASCII is described in [3]; the conversion document is accompanied by an example.

Browse products were derived from the S-band and X-band ASCII files of receiver samples. There is one four-panel summary plot (*e.g.,* Figure 1.4-1) from the S-band samples and a separate plot from the X-band samples. A single PDS4 label file describes the pair of plots.

3.2.2.1 HGA Pointing Reconstruction Conversions

High-gain antenna (HGA) pointing reconstructions were delivered to the Voyager Radio Science Team in Univac binary format (18 36-bit integers per record); the final reconstruction was converted to ASCII for this archive.

3.2.3 Directories

PDS4 products are stored in directory structures determined by the PDS/RMS node. The PDS4 Registry can locate bundles, collections, and products as needed by users. No further information can be provided here.

4 Support Staff and Cognizant Personnel

4.1 Planetary Data System

Richard A. Simpson
PDS Radio Science Adviser
radiosci@att.net

5 Errata and User Notes

The following errors/anomalies apply to the PDS4 archive. Notes of possible use, prompted by the peer review of the PDS4 bundles, have been added in section 5.4.

5.1 Bad or Missing Data

5.1.1 Unreadable Records

While Voyager Jupiter data were held at Stanford, the binary data were transferred from magnetic tape to CD-ROM for better long-term storage. When a record could not be read from tape, the CD-ROM file was terminated, and a new file was started with the first readable record after the error. For example, records 69 and 70 could not be read from tape VC139; the file VC139A was created with 68 records, and the file VC139B became the continuation and had 9930 records. During creation of the PDS4 archive, two replacement records were fabricated, then inserted between VC139A and VC139B. The restored VC139X appears in this archive with 10000 records, two of which are dummy records. Values in header and trailer fields of the replacement records were adjusted for continuous transitions; the value in field 6 of the binary file (field 3 of the ASCII header/trailer file) was set to '2' in replacement records. Sample values from the receivers were set to zero. Table 5.1.1-1 lists Voyager 1 products with replacement records. There were no replacement records in the Voyager 2 files.

Table 5.1.1-1: Listing of Files with Replacement Records (in time order)

Tape ID	Fabricated Record(s)	PDS4 LID
VC139	69, 70	vg1j_63mr_1979064t161940
VC146	276, 470	vg1j_63mr_1979064t164300
VC169	9875, 9876	vg1j_63mr_1979064t175940
VC170	5672, 5673	vg1j_63mr_1979064t180300

5.1.2 Tape/File Naming Variations

Tapes delivered to the Voyager Radio Science Team were labeled VCnnn (Voyager 1) and VPnnn (Voyager 2), as described above and as used in Appendices A and B. Suffixes were added to identify variations on the original files. These modified names may appear within the archive (especially in panels of browse plots). Users may use the root (VCnnn or VPnnn) to determine origins. Within the PDS4 archive, products and files are identified as described in Section 3 of this document.

5.1.3 Duplicate and Missing Files

The CD-ROM files in Table 5.1.3-1 contain identical data; the reason(s) for duplication are not known. Only one copy of these data (from VC149) has been included in the PDS4 archive.

Table 5.1.3-1: Listing of Tapes/Files with Duplicate Records

Tape ID	Duplicate Record(s)	PDS4 LID
VC149	All	vg1j_63mr_1979064t165300
VC150	All	vg1j_63mr_1979064t165300
VC151	All	vg1j_63mr_1979064t165300
VC152	All	vg1j_63mr_1979064t165300
VC153	All	vg1j_63mr_1979064t165300

The following time period is not covered by any Voyager 1 tape or CD-ROM file. The reason for the gap is not known. There are no known gaps in the Voyager 2 data.

Table 5.1.3-2: Data Gaps

Data Gap	Notes
179-064T16:53:29 to 1979-064T17:09:40	There may have been a tape copying error in the time between 1979-064T16:53:00 and 1979-064T17:09:40. Five tapes covered the first 29 seconds (Table 5.1.2-1) and none covered the remaining 971 seconds. This gap is more than 20 minutes after the ground station lost the Voyager 1 signal in the deep atmosphere.

5.2 Buffer delays

Because of buffering in the recording process, samples may be delayed by 1-2 sample positions (a few microseconds) compared with the record time tag in ODR files.

Similarly, POCA readings are delayed 1-2 seconds compared to time tags.

No corrections for buffer delays have been applied during the archiving process.

5.3 Truncations for Creating Browse Products

In four cases, the file was temporarily truncated to an even number of seconds to allow generation of the browse product (VC145, VC149, VP095, and VP096). The original file (with all records) is retained in the *data* collection.

5.4 User Notes

The following notes have been added following peer review of the PDS4 bundles. They are suggestions, based on limited knowledge of the people involved in the restoration. They should not be considered definitive since the correct answers have been lost in the passage of time.

5.4.1 Receiver Operation

Open loop receiver operation is described in [4]. For example, the DSS 63 VG1J data start at 12:30:01 UTC. If the S-band transmitted frequency was

$$f_{tx} = (3/11)* 8414995272.53 = 2.29499871069e9$$

(from `calib_freq:vgr_uso.txt` in this archive), then the expected baseband frequency in the samples should be [4]

$$f_b = f_{tx} - 48*f_{po} - 3e8 = 730.37 \text{ Hz}$$

where

$$f_{po} = 4.15624579232e+07 \text{ Hz}$$

is 'commanded_frequency' in the first row of `data/vg1j_63mr_1979064r123001.tab` in this archive. The value of f_{tx} used here is the best estimate for Voyager 1 at Titan. Refining the estimate to correct for drift since the Jupiter encounter and then incorporating Doppler effects, timing/frequency errors, and other calibrations is well beyond the scope of this restoration effort. Nonetheless, $f_b = 730.37$ Hz is only ~1300 Hz different from the signal position in `browse/vg1j_63sr_1979064r123001.jpg`.

Note that 'commanded frequency' is related to 'synthesizer count' at $t+n$ seconds (O_{t+n}) and 'sweep rate' (SR) by [2]

$$f_{po} = 4e+07 + [(O_{t+n} - O_t - 0.5*SR*n^2)/n]$$

Appendix A Tape/File Index – Voyager 1 at Jupiter

The table below lists Voyager 1 Jupiter radio science raw data files in chronological order. Except as noted, each file contained 10000 records, covering 200 seconds.

The columns give (left to right):

YYYY Earth receive time at start time of the file (UTC year)
DDD Earth receive time at start time of the file (UTC day of year)
HH Earth receive time at start time of the file (UTC hour)
MM Earth receive time at start time of the file (UTC minute)
SS Earth receive time at start time of the file (UTC second)
SECS Earth receive time at start time of the file (UTC cumulative seconds since 0^h UTC)
TAPE Identifier of the computer-compatible tape delivered to the Voyager Radio Science Team.
DD DSN ground station recording the radio science data
B Frequency band of the data in the file ("S" for 13 cm, "X" for 3.5 cm, "M" for both)
P Polarization of the data in the file ("R" for right circular, RCP; "L" for left circular, LCP)
S/C Spacecraft ("VG1" for Voyager 1, "VG2" for Voyager 2)
T Target ("J" for Jupiter)
LID Logical identifier for the PDS4 archive, constructed in the form
vgnx_aabp_yyyydddthhmmss
where
n = spacecraft number ("1" for Voyager 1, "2" for Voyager 2)
x = target ("j" for Jupiter)
aa = antenna number ("14" for DSS-14, "63" for DSS-63)
b = band ("s" for S-band, "x" for X-band, "m" for both)
p = polarization ("r" for RCP. "l" for LCP)
yyyy = year ("1979")
ddd = day of year
hh = hour
mm = minute
ss = second

YYYY	DDD	HH	MM	SS	SECS	TAPE	DD	B	P	S/C	T	LID	NOTES
1979	064	12	30	01	45001	VC193	63	M	R	VG1	J	vg1j_63mr_1979064t123001	Pre-encounter test
1979	064	12	33	21	45201	VC194	63	M	R	VG1	J	vg1j_63mr_1979064t123321	Pre-encounter test
1979	064	12	36	41	45401	VC195	63	M	R	VG1	J	vg1j_63mr_1979064t123641	Pre-encounter test; 9930 records
1979	064	16	03	00	57780	VC134	63	M	R	VG1	J	vg1j_63mr_1979064t160300	
1979	064	16	06	20	57980	VC135	63	M	R	VG1	J	vg1j_63mr_1979064t160620	
1979	064	16	09	40	58180	VC136	63	M	R	VG1	J	vg1j_63mr_1979064t160940	
1979	064	16	13	00	58380	VC137	63	M	R	VG1	J	vg1j_63mr_1979064t161300	
1979	064	16	16	20	58580	VC138	63	M	R	VG1	J	vg1j_63mr_1979064t161620	
1979	064	16	19	40	58780	VC139	63	M	R	VG1	J	vg1j_63mr_1979064t161940	Replacement records at 69, 70
1979	064	16	23	00	58980	VC140	63	M	R	VG1	J	vg1j_63mr_1979064t162300	
1979	064	16	26	20	59180	VC141	63	M	R	VG1	J	vg1j_63mr_1979064t162620	
1979	064	16	29	40	59380	VC142	63	M	R	VG1	J	vg1j_63mr_1979064t162940	
1979	064	16	33	00	59580	VC143	63	M	R	VG1	J	vg1j_63mr_1979064t163300	
1979	064	16	36	20	59780	VC144	63	M	R	VG1	J	vg1j_63mr_1979064t163620	
1979	064	16	39	40	59980	VC145	63	M	R	VG1	J	vg1j_63mr_1979064t163940	
1979	064	16	43	00	60180	VC146	63	M	R	VG1	J	vg1j_63mr_1979064t164300	Replacement records at 276, 470
1979	064	16	46	20	60380	VC147	63	M	R	VG1	J	vg1j_63mr_1979064t164620	
1979	064	16	49	40	60580	VC148	63	M	R	VG1	J	vg1j_63mr_1979064t164940	
1979	064	16	53	00	60780	VC149	63	M	R	VG1	J	vg1j_63mr_1979064t165300	1448 records
GAP IN COVERAGE													
1979	064	17	09	40	61780	VC154	63	M	R	VG1	J	vg1j_63mr_1979064t170940	
1979	064	17	13	00	61980	VC155	63	M	R	VG1	J	vg1j_63mr_1979064t171300	
1979	064	17	16	20	62180	VC156	63	M	R	VG1	J	vg1j_63mr_1979064t171620	
1979	064	17	19	40	62380	VC157	63	M	R	VG1	J	vg1j_63mr_1979064t171940	
1979	064	17	23	00	62580	VC158	63	M	R	VG1	J	vg1j_63mr_1979064t172300	
1979	064	17	26	20	62780	VC159	63	M	R	VG1	J	vg1j_63mr_1979064t172620	
1979	064	17	29	40	62980	VC160	63	M	R	VG1	J	vg1j_63mr_1979064t172940	
1979	064	17	33	00	63180	VC161	63	M	R	VG1	J	vg1j_63mr_1979064t173300	
1979	064	17	36	20	63380	VC162	63	M	R	VG1	J	vg1j_63mr_1979064t173620	
1979	064	17	39	40	63580	VC163	63	M	R	VG1	J	vg1j_63mr_1979064t173940	
1979	064	17	43	00	63780	VC164	63	M	R	VG1	J	vg1j_63mr_1979064t174300	

Appendix A (continued; page 3 of 3)

1979	064	17	46	20	63980	VC165	63	M	R	VG1	J	vg1j_63mr_1979064t174620	
1979	064	17	49	40	64180	VC166	63	M	R	VG1	J	vg1j_63mr_1979064t174940	
1979	064	17	53	00	64380	VC167	63	M	R	VG1	J	vg1j_63mr_1979064t175300	
1979	064	17	56	20	64580	VC168	63	M	R	VG1	J	vg1j_63mr_1979064t175620	
1979	064	17	59	40	64780	VC169	63	M	R	VG1	J	vg1j_63mr_1979064t175940	Replacement records at 9875, 9876
1979	064	18	03	00	64980	VC170	63	M	R	VG1	J	vg1j_63mr_1979064t180300	Replacement records at 5672, 5673
1979	064	18	06	20	65180	VC171	63	M	R	VG1	J	vg1j_63mr_1979064t180620	
1979	064	18	09	40	65380	VC172	63	M	R	VG1	J	vg1j_63mr_1979064t180940	
1979	064	18	13	00	65580	VC173	63	M	R	VG1	J	vg1j_63mr_1979064t181300	
1979	064	18	16	20	65780	VC174	63	M	R	VG1	J	vg1j_63mr_1979064t181620	
1979	064	18	19	40	65980	VC175	63	M	R	VG1	J	vg1j_63mr_1979064t181940	
1979	064	18	23	00	66180	VC198	63	M	R	VG1	J	vg1j_63mr_1979064t182300	
1979	064	18	26	20	66380	VC199	63	M	R	VG1	J	vg1j_63mr_1979064t182620	
1979	064	18	29	40	66580	VC178	63	M	R	VG1	J	vg1j_63mr_1979064t182940	
1979	064	18	33	00	66780	VC179	63	M	R	VG1	J	vg1j_63mr_1979064t183300	
1979	064	18	36	20	66980	VC180	63	M	R	VG1	J	vg1j_63mr_1979064t183620	
1979	064	18	39	40	67180	VC181	63	M	R	VG1	J	vg1j_63mr_1979064t183940	
1979	064	18	43	00	67380	VC182	63	M	R	VG1	J	vg1j_63mr_1979064t184300	
1979	064	18	46	20	67580	VC183	63	M	R	VG1	J	vg1j_63mr_1979064t184620	
1979	064	18	49	40	67780	VC184	63	M	R	VG1	J	vg1j_63mr_1979064t184940	
1979	064	18	53	00	67980	VC185	63	M	R	VG1	J	vg1j_63mr_1979064t185300	
1979	064	18	56	20	68180	VC186	63	M	R	VG1	J	vg1j_63mr_1979064t185620	
1979	064	18	59	40	68380	VC187	63	M	R	VG1	J	vg1j_63mr_1979064t185940	
1979	064	19	03	00	68580	VC188	63	M	R	VG1	J	vg1j_63mr_1979064t190300	

Appendix B Tape/File Index – Voyager 2 at Jupiter

The table below lists Voyager 2 Jupiter radio science raw data files in chronological order. Except as noted, each file contained 20000 records, covering 400 seconds. See Appendix A for column definitions.

YYYY	DDD	HH	MM	SS	SECS	TAPE	DD	B	P	S/C	T	LID	NOTES
1979	191	13	17	27	47847	VP095	14	M	R	VG2	J	vg2j_14mr_1979191t131727	Pre-encounter tests
1979	191	13	24	07	48247	VP096	14	M	R	VG2	J	vg2j_14mr_1979191t132407	Pre-encounter tests; 4970 records
1979	191	19	50	57	71457	VP097	14	M	R	VG2	J	vg2j_14mr_1979191t195057	
1979	191	19	57	37	71857	VP098	14	M	R	VG2	J	vg2j_14mr_1979191t195737	
1979	191	20	04	17	72257	VP099	14	M	R	VG2	J	vg2j_14mr_1979191t200417	
1979	191	20	10	57	72657	VP100	14	M	R	VG2	J	vg2j_14mr_1979191t201057	
1979	191	20	17	37	73057	VP101	14	M	R	VG2	J	vg2j_14mr_1979191t201737	
1979	191	20	24	17	73457	VP102	14	M	R	VG2	J	vg2j_14mr_1979191t202417	
1979	191	20	30	57	73857	VP103	14	M	R	VG2	J	vg2j_14mr_1979191t203057	
1979	191	20	37	37	74257	VP104	14	M	R	VG2	J	vg2j_14mr_1979191t203737	
1979	191	20	44	17	74657	VP105	14	M	R	VG2	J	vg2j_14mr_1979191t204417	
1979	191	20	50	57	75057	VP106	14	M	R	VG2	J	vg2j_14mr_1979191t205057	
1979	191	20	57	37	75457	VP107	14	M	R	VG2	J	vg2j_14mr_1979191t205737	
1979	191	21	04	17	75857	VP108	14	M	R	VG2	J	vg2j_14mr_1979191t210417	
1979	191	21	10	57	76257	VP109	14	M	R	VG2	J	vg2j_14mr_1979191t211057	
1979	191	21	17	37	76657	VP158	14	M	R	VG2	J	vg2j_14mr_1979191t211737	
1979	191	21	24	17	77057	VP159	14	M	R	VG2	J	vg2j_14mr_1979191t212417	
1979	191	21	30	57	77457	VP093	14	M	R	VG2	J	vg2j_14mr_1979191t213057	
1979	191	21	37	37	77857	VP111	14	M	R	VG2	J	vg2j_14mr_1979191t213737	
1979	191	21	44	17	78257	VP112	14	M	R	VG2	J	vg2j_14mr_1979191t214417	
1979	191	21	50	57	78657	VP160	14	M	R	VG2	J	vg2j_14mr_1979191t215057	
1979	191	21	57	37	79057	VP114	14	M	R	VG2	J	vg2j_14mr_1979191t215737	
1979	191	22	04	17	79457	VP115	14	M	R	VG2	J	vg2j_14mr_1979191t220417	
1979	191	22	10	57	79857	VP116	14	M	R	VG2	J	vg2j_14mr_1979191t221057	
1979	191	22	17	37	80257	VP117	14	M	R	VG2	J	vg2j_14mr_1979191t221737	
1979	191	22	24	17	80657	VP118	14	M	R	VG2	J	vg2j_14mr_1979191t222417	
1979	191	22	30	57	81057	VP119	14	M	R	VG2	J	vg2j_14mr_1979191t223057	
1979	191	22	37	37	81457	VP120	14	M	R	VG2	J	vg2j_14mr_1979191t223737	

Appendix B (continued; page 2 of 2)

1979	191	22	44	17	81857	VP121	14	M	R	VG2	J	vg2j_14mr_1979191t224417	
1979	191	22	50	57	82257	VP122	14	M	R	VG2	J	vg2j_14mr_1979191t225057	
1979	191	22	57	37	82657	VP123	14	M	R	VG2	J	vg2j_14mr_1979191t225737	
1979	191	23	04	17	83057	VP124	14	M	R	VG2	J	vg2j_14mr_1979191t230417	
1979	191	23	10	57	83457	VP125	14	M	R	VG2	J	vg2j_14mr_1979191t231057	
1979	191	23	17	37	83857	VP126	14	M	R	VG2	J	vg2j_14mr_1979191t231737	
1979	191	23	24	17	84257	VP127	14	M	R	VG2	J	vg2j_14mr_1979191t232417	
1979	191	23	30	57	84657	VP128	14	M	R	VG2	J	vg2j_14mr_1979191t233057	
1979	191	23	37	37	85057	VP129	14	M	R	VG2	J	vg2j_14mr_1979191t233737	
1979	191	23	44	17	85457	VP130	14	M	R	VG2	J	vg2j_14mr_1979191t234417	
1979	191	23	50	57	85857	VP131	14	M	R	VG2	J	vg2j_14mr_1979191t235057	
1979	191	23	57	37	86257	VP132	14	M	R	VG2	J	vg2j_14mr_1979191t235737	
1979	192	00	04	17	00257	VP133	14	M	R	VG2	J	vg2j_14mr_1979192t000417	