GRAIL

DATA PRODUCT
SOFTWARE INTERFACE SPECIFICATION

JPL D-76383

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Daniel Kahan

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FIGURES

TABLES

DOCUMENT CHANGE LOG

Change	Date (mm/dd/yy)	Affected Portions
Version 1.0 submitted for peer review.	09/21/12	All
Version 1.1 submitted for PDS release.	12/13/12	All
Version 1.2 initial team RDR review.	03/11/13	All
Version 1.3 release 2 updates.	06/11/13	All
Version 1.4 adjusted SHBDR file name. Submitted for RDR review.	06/18/13	4.2.6.3
Version 1.5 RDR peer review updates.	08/23/13	4.2.4, 7.3.4.1-7.3.4.4
Version 1.6 updated for Version 04 data.	04/01/14	All
Version 1.7 PDS release 5 updates.	06/18/14	4.2.6.3, 7.3.4.1
Version 1.8 PDS release 7 updates.	05/03/16	4.33, 8

1 Purpose and Scope of Document

This document provides a detailed description of data products at all levels for the Gravity Recovery and Interior Laboratory (GRAIL) Mission. The data products specified in this document are obtained from the science instruments and subsystems on board the twin GRAIL spacecraft; some include the results of ground data processing carried out by the GRAIL Science Data System (SDS). Also included are data products from the NASA Deep Space Network (DSN) and products that resulted from processing by GRAIL Science Team members at their home institutions.

The GRAIL Science Data System (SDS) is defined as the infrastructure at NASA's Jet Propulsion Laboratory (JPL) for the collection of all science and ancillary data relevant to the GRAIL mission. It includes hardware, software tools, procedures, and trained personnel. The SDS receives data from three sources (as described below) and carries out calibration, editing, and processing to produce NASA Level 1A and 1B GRAIL science data as described below.

The GRAIL archive comprises the following four separate volumes (also known as data sets):

GRAIL-L-LGRS-2-EDR-V1.0 – Raw science data, originating from spacecraft telemetry, in time order with duplicates and transmission errors removed. Also known as NASA Level 0 science data (NASA processing levels are described in section 2) and stored in this archive for historical purposes only. All Level 0 products have been processed to Level 1A by the GRAIL SDS.

GRAIL-L-LGRS-3-CDR-V1.0 – Calibrated and resampled engineering (e.g., star tracker data and timing) and science data acquired from the Lunar Gravity and Ranging System (LGRS). NASA Level 1A and 1B.

GRAIL-L-RSS-2-EDR-V1.0 – Raw Radio Science data acquired at the Deep Space Network.

GRAIL-L-LGRS-5-RDR-V1.0 – Lunar gravitational field, NASA Level 2 data. Includes SPICE geometry and navigation kernels created by the GRAIL SDS. SPICE is the ephemeris, orientation, and event information system developed by the Navigation and Ancillary Information Facility (NAIF) at NASA's JPL (see section 7.2).

The above data set identifiers (IDs) may be abbreviated as LGRS EDR, LGRS CDR, RSS EDR, and LGRS RDR in the sections that follow. The first digit in each data set ID refers to the CODMAC processing level (see section 2).

2 Definitions of Data Processing Levels

The GRAIL Science Data System (SDS) uses NASA processing levels, which are defined in Table 1. Data set IDs use the processing levels defined by the Committee on Data Management, Archiving, and Computation (CODMAC), which are also given in Table 1.

Table 1. Processing Levels

NASA	CODMAC	Description
Packet data	Raw - Level 1	Telemetry with data embedded.
Level 0	Edited - Level 2	Corrected for telemetry errors and split or decommutated according to instrument. Sometimes called Experimental Data Record (EDR). Data are also tagged with time and location of acquisition.
Level 1A	Calibrated - Level 3	Edited data that are still in units produced by instrument, but that have been corrected so that values are expressed in or are proportional to some physical unit such as radiance. No resampling, so original values can be recovered.
Level 1B	Resampled - Level 4	Data that have been resampled in the time or space domains in such a way that the original edited data cannot be reconstructed. Could be calibrated in addition to being resampled.
Level 2	Derived - Level 5	Derived results, as maps, reports, graphics, etc.
	Ancillary - Level 6	Non-science data needed to generate calibrated or resampled data sets. Consists of instrument gains and/or offsets, pointing information for scan platforms, etc.

3 Relationships with Other Interfaces

The descriptions of data products in this document are consistent with the corresponding descriptions in “dataset” catalog files in the CATALOG directory of each GRAIL volume. File/directory names are consistent with the conventions used in the GRAIL Archive Volume Software Interface Specification (SIS) [16].

4 Data Product Characteristics and Environment

4.1 Instrument Overview

Lockheed Martin built GRAIL-A and GRAIL-B as near-twins (Figure 1). Each satellite contains the following components:

1) Rectangular bus
2) Fixed solar panels
3) Titanium diaphragm fuel tank
4) Ultra stable oscillator (USO), which drives onboard LGRS clock and provides frequency reference for S-, X-, and Ka-Band radio systems
5) Attitude control system (ACS) [23], consisting of:
    a. Four reaction wheels to change attitude
    b. Inertial Measurement Unit (IMU) to measure the rate components of angular rotation
    c. Star Tracker to measure the absolute attitude
    d. Sun Sensor
    e. Eight thrusters, coupled to allow applications of torque
    f. Main engine
6) Ka-band carrier phase tracking inter-satellite receiver/transmitter

7) S-band inter-satellite Time Transfer System (TTS)
8) Two low-gain antennas (LGA) for S-band communication with the DSN
9) Two Radio Science Beacons (RSB), which transmit X-band carriers to the DSN

For the mechanical and optical properties of the spacecraft, see GRAILCOMPONENTS.TXT in the CALIB directory [11].

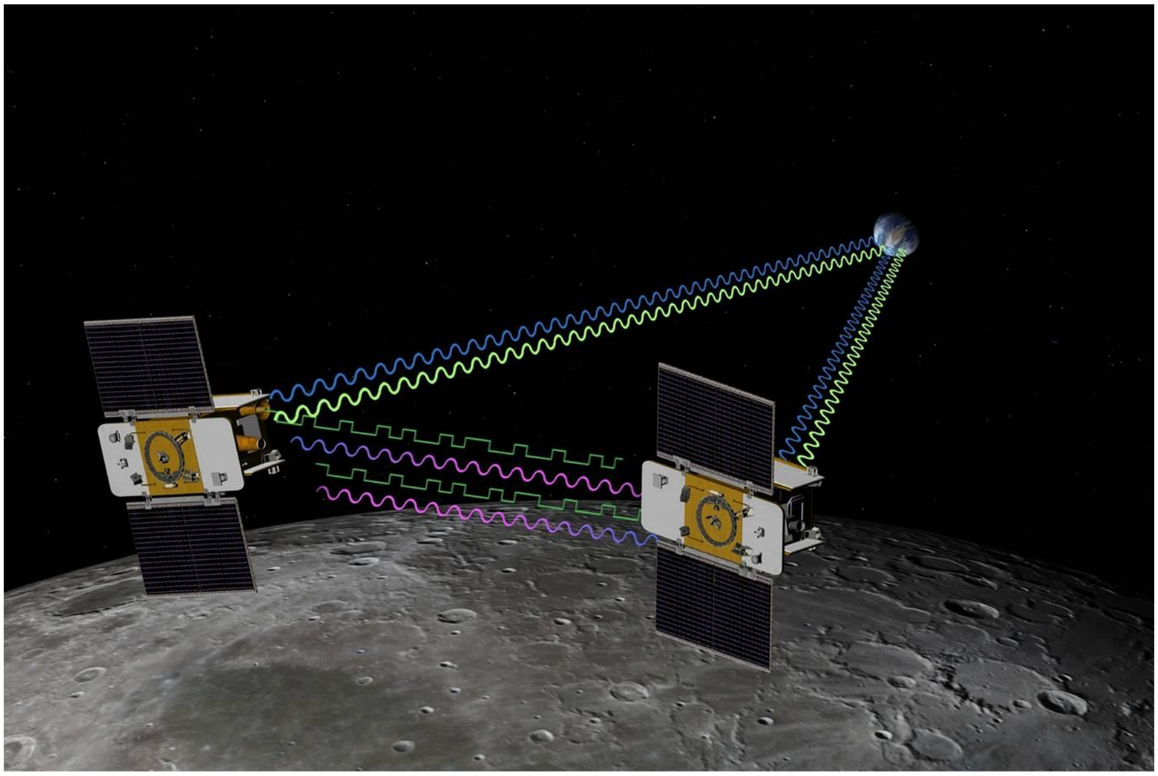

Figure 1: View of GRAIL satellites

There are two payload elements on each GRAIL orbiter: the Lunar Gravity Ranging System (LGRS) which is the science instrument, and the MoonKAM lunar imager which is used for education and public outreach. The LGRS is based on the instrument used for the Gravity Recovery and Climate Experiment (GRACE) mission [32], which has been mapping Earth's gravity since 2002. The LGRS is responsible for sending and receiving the signals needed to accurately and precisely measure the changes in range between the two orbiters. The LGRS consists of an Ultra-Stable Oscillator (USO), Microwave Assembly (MWA), a Time-Transfer Assembly (TTA), and the Gravity Recovery Processor Assembly (GPA). See Figure 2.

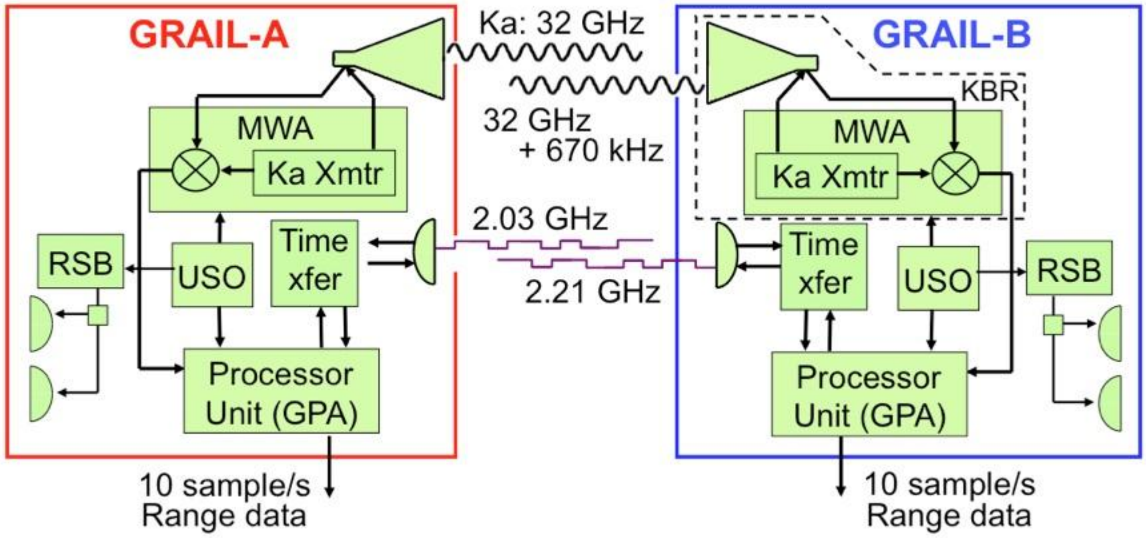

Figure 2: Payload Block Diagram [26]

The USO provides a steady reference signal that is used by all of the instrument subsystems. Within the LGRS, the USO provides the reference frequency for the MWA and the TTA. The MWA converts the USO reference signal to the Ka-band frequency, which is transmitted to the other orbiter.

The function of the TTA is to provide a two-way time-transfer link between the spacecraft to both synchronize and measure the clock offset between the two LGRS clocks. The TTA generates an S-band signal from the USO reference frequency and sends a GPS-like ranging code to the other spacecraft. The GPA combines all the inputs received from the MWA and TTA to produce the radiometric data that are downlinked to the Deep Space Network. In addition to acquiring the inter-spacecraft measurements, the LGRS also provides a one-way signal to the DSN based on the USO, which is transmitted via the X-band Radio Science Beacon (RSB). The steady-state drift of the USO is measured via the one-way Doppler data provided by the RSB.

4.2 Data Product Overview

The scientific goals of the GRAIL project are achieved by measuring the lunar gravitational attraction on the two spacecraft; GRAIL's instrumentation is specifically designed to sense this through relative motion between the two spacecraft and with DSN stations on Earth. The GRAIL payload on each spacecraft consists of a single science instrument called the Lunar Gravity Ranging System (LGRS), a Ka-band ranging system that determines the precise instantaneous relative range-rate of the two spacecraft. Also, as part of the LGRS, the GRAIL investigation requires a radio link from each spacecraft's Radio Science Beacon to the stations of the NASA Deep Space Network (DSN).

The rest of this section gives an overview of the data products and the measurements GRAIL provides. Product name suffixes indicate NASA processing level. For example, the Level 1A S-band product is named SBR1A, and the Level 1B S-band product is SBR1B.

The Algorithm Theoretical Basis Document (ATBD) [15] in the DOCUMENT directory contains a detailed description of the processing flow from EDR to CDR as implemented by the GRAIL SDS.

4.2.1 LGRS EDR (NASA Level 0 Products)

The GRAIL SDS receives science packets and engineering data from the JPL Ground Data System (GDS) (Figure 3). The LGRS EDR data set contains the raw data in time order with duplicates and transmission errors removed. These data are archived mainly for completeness, as they are immediately processed to Level 1A and/or 1B (the LGRS CDR data set) by the SDS. There are twelve product types in the LGRS EDR data set:

- **DTC00** - Time Correlation Data Record File (DRF) (ASCII) – Clock correlation among RTC, BTC, and the 1-per-second pulse associated with LGRS time. See section 4.2.2.1.
- **EHK00** - Spacecraft Engineering Housekeeping data, including temperature sensor data for locations near the LGRS instrumentation (ASCII)
- **LTB00** - LGRS Time Bias of the Lunar Gravity Ranging System in BTC time (ASCII). Accumulated list of biases over the complete mission. Biases apply to the LGRS time tag of both spacecraft
- **MAS00** - Satellite Mass Data (ASCII). Accumulated list of center of mass and spacecraft mass over the complete mission.
- **S7200** - Engineering SFDU ID #72 (binary)
- **S7300** - Science SFDU ID #73 (binary)
- **SAE00** - Solar Array Eclipse data, including solar array short circuit currents and open circuit voltages, to identify eclipse events for spacecraft ephemeris models (ASCII)
- **SCA00** - Star Tracker Data. Including attitudes from an on-board Kalman filter that processes Star Tracker attitude data and Inertial Measurement Unit (IMU) angular rotation data (ASCII)
- **STC00** - Time Correlation SFDU (binary)
- **TDE00** - measured time correlation between LGRS time and UTC, using Time Transfer System (TTS) S-Band ranging collected at DSS-24 (ASCII)
- **THR00** - Thruster Activation Data, including time tags, counts of cumulative work cycles for each thruster, recent thruster ‘on’ time, and cumulative thruster ‘on’ time (ASCII)
- **WRS00** – Wheel Rotational Speed data, including time tags, measures rotational wheel speed of each of four reaction wheels as determined by a digital tachometer (ASCII)

The SFDU products — S7200, S7300, and STC00 — are binary and contain (besides the appropriate headers) the unscaled, binary encoded instrument communication packets. For information on extracting the SFDU data contents. see the following in the DOCUMENT directory:

0161_TELECOMM_L5_8.TXT [8]
0171_TELECOMM_NJPL_L5.TXT [20]
090_REVC_1.TXT [1], and
0172_TELECOMM_CHDO_REVE_L5.TXT [35]

Each telemetry packet generated by the LGRS flight software is wrapped inside a packet called a BlackJack Protocol Frame, which ensures the integrity of the data; Blackjack was inherited from the predecessor Gravity Recovery and Climate Experiment (GRACE) terrestrial gravity mission. The documents GPA_TD_D_71987_REVE.TXT [14] and BLACKJACKDLP.TXT [12] in the DOCUMENT directory describe the format of the Blackjack binary data for processing to Level 1A.

The remaining nine LGRS EDR product types are in ASCII format.

4.2.2 LGRS CDR (NASA Level 1A and Level 1B Products)

The LGRS CDR data set contains (calibrated and resampled) Level 1A and 1B science data from the Lunar Gravity Ranging System. All forty-three LGRS CDR file types are in ASCII format. Most of the file types apply to both spacecraft separately. A few apply to both spacecraft together, as they are indicative of a relationship between the two.

4.2.2.1 Timing [17]

GRAIL timing (discussed further in section 4.3.2) requires coordination of three clocks on each satellite, and two time standards:

1. LGRS: Lunar Gravity Ranging System clock. Very stable clock for on-board Ka-band ranging (KBR), X-band (RSB), and S-band (TTS) instruments. Driven by an Ultra-Stable Oscillator (USO). Set to 0 when booted. Produces a pulse per second (pps) signal. LGRS time starts at 0 seconds when powered on. The SDS adds a bias to LGRS time to create an approximate UTC time tag. This time will be referred to as LGRS + bias.
2. BTC: Base Time Clock. On-board satellite clock, comparable in stability to a wristwatch. Roughly synced to UTC at launch time.
3. RTC: Real Time Clock. Flight software clock. Set to 0 when booted. Relatively unstable clock.
4. UTC: Coordinated Universal Time.
5. TDB: Barycentric Dynamical Time.

Seven Level 1A products establish the relationships among the clocks:
TC11A: LGRS to BTC, approximated by flight software.
TC21A: LGRS to BTC. more accurate mapping than TC11A, from BTC clock cycle counts.
TC31A: BTC to RTC.
TC41A: LGRS to RTC.
TC51A: RTC to UTC.
TC61A: UTC to TDB. One product applies to both spacecraft.
CLK1A: TDB toLGRS.

An approximation of the relativistic time correction from TDB to on-board satellite proper time is calculated in the **REL1A** product, treating the moon as a point mass, based on [17]:

$$\frac{d\tau}{dt} = 1 - \frac{U}{c^2} - \frac{1}{2}\frac{v^2}{c^2} + L$$

where τ = proper time, t = coordinate time, U = gravitational potential, v = velocity, and L is a constant offset (1.550520e-8).

Measurements from the S-band time transfer system (TTS) are processed to produce **DEL1A**, which lists inter-satellite LGRS clock offset between spacecraft by TDB time.

Radio Science Receivers (RSR), located at DSN sites and discussed in section 4.2.3, record X-band Radio Science Beacon (RSB) signals. Since the LGRS clock drives the RSB, LGRS frequency at TDB can be estimated for **USO1A**.

A **PPS1A** product is also created, listing the LGRS time of PPS signals.
A least squares fit to DEL1A, CLK1A, and USO1A produces **CLK1B** and **USO1B**, best estimates of LGRS to TDB and LGRS frequency at TDB.

The TTS Direct-to-Earth (DTE) experiment was devised to independently measure the absolute clock offset between the GRAIL Moon orbiters and Earth. This experiment prompted the development of software for acquiring weak signals and extracting observables (i.e., phase, range, range rate). Data collected during TTS DTE tracks enabled SDS team to compute more accurately the delay in the spacecraft which led to a more accurate gravity field solutions. The TTS DTE activities were done about once per week due to limitations in geometry and equipment availability at the DSN. Specifically, only DSS-24 had the necessary equipment allocated to collect the data.

The TDE00 product is the result of the TTS DTE experiment. TDE00 data provide the only direct measurement of the absolute LGRS time tag. This measurement is used to calibrate the CLK1A product as part of the generation of the CLK1B product.

4.2.2.2 Position

As an improved estimate for the Moon's gravity field is built, GRAIL-A and GRAIL-B orbital solutions are improved. Best estimates of the ephemerides are saved in two frames (further detailed in section 4.3.3):

GNI1B: EME 2000 Lunar-Centered Solar System Barycentric Frame

GNV1B: DE 421 Lunar Body-Fixed Frame

From the best ephemeris solution, spacecraft to DSN relative position and light time are computed in EME 2000 (**LTM1A**), and spacecraft to spacecraft relative position and light time are computed in DE 421 (**PLT1A**).

4.2.2.3 Ka-band

GRAIL science depends on estimating the relative movements of GRAIL-A and GRAIL-B. The estimate depends primarily on an inter-satellite Ka-band system: GRAIL-A carrier-phase-tracks a Ka-band signal from GRAIL-B, and GRAIL-B carrier-phase-tracks a Ka-band signal from GRAIL-A. In each continuous phase arc, carrier-phase gives a one-way range, biased by an unknown constant.

KBR1A records raw carrier-phase measurements, flagged for phase breaks. Gaps of up to 2 seconds are filled in by quadratic interpolation; longer gaps are classified as “missing data.”

KBR1C contains biased dual one-way range between GRAIL-A and GRAIL-B [17], digitally filtered, but not corrected for time of flight or antenna offset. After the dual one-way range combination has been formed, gaps of up to 20 seconds are filled in by quadratic interpolation. KBR1C also contains corrections for time of flight and antenna offset from center of mass.

In addition, KBR1C also contains the first and second derivatives of the biased dual one-way range between GRAIL-A and –B and associated time of flight and antenna offset corrections.

In general, the instantaneous range, range rate, and range acceleration is used for scientific analysis. The instantaneous range, range rate, and range acceleration are computed by adding the time of flight correction and antenna offset correction to the dual one-way range, range rate, or range acceleration measurement.

This (level 1B) product is designated as ‘1C’ to distinguish it from earlier versions of KBR1B which did not contain an additional four columns of information on the temperature range corrections. The raw temperature range correction, filtered temperature range correction, filtered temperature range rate correction, and filtered temperature range acceleration correction are the final four columns of the KBR1C product.

4.2.2.4 S-band

The S-band inter-satellite Time Transfer System (TTS) produces files in parallel to the Ka-band system mentioned above. Carrier phase and a modulating range code are tracked in products **SBR1A** and **SBR1B, which are analogous to KBR1A and KBR1C**. In SBR1B, a more accurate range is produced by carrier smoothing over each arc.

The **SNV1A** S-band navigation product contains ancillary information for TTS, which primarily serves to tell the ground whether GRAIL-A and GRAIL-B are communicating correctly with each other.

4.2.2.5 Satellite Attitude

Because GRAIL-A and GRAIL-B antennas are offset from the spacecraft center of mass, distance between GRAIL-A and GRAIL-B Ka-band antennas depends on spacecraft attitude. An on-board Kalman filter processes Star Tracker attitude data and Inertial Measurement Unit (IMU) angular rotation data. Filtered attitudes are saved in **SCA1A**, tagged by BTC time.

SCA1B contains the same results, tagged by TDB.

PCI1A lists Ka-band antenna range corrections, range rate corrections, and range acceleration corrections.

WRS1A lists rotational wheel speed data for each of the spacecraft's four reaction wheels, as determined by digital tachometer. **WRS1B** lists the same information in TDB.

4.2.2.6 Events

GRAIL-A and GRAIL-B events are noted in a variety of files. **ILG1A** contains log messages from the LGRS. **SAE1A** lists solar array short circuit currents and voltages, to identify eclipse events for spacecraft ephemeris models. **THR1A** contains thruster activation data, including time tags, cumulative work cycles by thruster, current thruster on time, and cumulative thruster on time.

SAE1B and **THR1B** contain the same information as in SAE1A and THR1A, but time-tagged by TDB rather than UTC SCET.

4.2.2.7 Satellite Condition

On-board sensors and a priori information describe spacecraft condition. **EHK1A** contains temperature sensor data for locations near LGRS instruments. Housekeeping data for the LGRS in **IHK1A** includes voltage, temperature, and current measurements; **IHS1A** includes other LGRS status data. **MAS1A** lists spacecraft mass as a function of UTC time, while **VCM1A** describes center of mass displacement from the spacecraft mechanical frame origin.

EHK1B, **MAS1B**, and **VCM1B** list results relative to TDB rather than UTC SCET.

The VKB1B file is the Ka boresight vector, as a result of Ka-Band boresight calibration analysis and is stored in VKB1B format in TDB format. Therefore, no VKB1A file exists.

4.2.2.8 DSN Tracking

GRAIL transmits information to the Deep Space Network using S-band. S-band communication from each GRAIL spacecraft to the DSN depends on a pair of low-gain antennas (LGAs), located on opposite sides of the spacecraft. At a given TDB, only one antenna can communicate with the DSN. The **VGS1B** product contains a time history of the active S-Band antenna phase center location, in TDB time. The vector is described in the Mechanical Frame (MF).

Each GRAIL spacecraft also transmits an unmodulated X-band carrier to the DSN through one of a pair of Radio Science Beacons (RSB). The **VGX1B** product contains a time history of the active X-Band antenna phase center location, in TDB time, The vector is described in the Mechanical Frame (MF).

4.2.3 RSS EDR

The RSS EDR data set contains raw radio science data, which include DSN Doppler tracking data, open-loop data, media calibrations, and others.

4.2.3.1 DSN Radio Data

X-Band Open-Loop data, used in the creation of USO1A (LGRS CDR data set), are recorded at the DSN on the Radio Science Receiver (**RSR**). The RSR is a computer-controlled open loop receiver that digitally records a spacecraft signal using an analog-to-digital converter (ADC) and up to four digital filter sub-channels. The digital samples from each sub-channel are stored to disk in one-second records in real time. In near real time the one-second records are partitioned and formatted into a sequence of RSR Standard Format Data Units (SFDUs) which are transmitted to the Advanced Multi-Mission Operations System (AMMOS) at the Jet Propulsion Laboratory (JPL). Included in each RSR SFDU are the ancillary data necessary to reconstruct the signal represented by the recorded data samples. See 0159_SCIENCE_L5.TXT [9] in the DOCUMENT directory for more information on this data type.

S-Band closed-loop data are recorded at the DSN and stored as Orbit Data Files (**ODF**s). ODFs are produced by the NASA/JPL Multi-Mission Navigation Radio Metric Data Conditioning Team for use in determining spacecraft trajectories, gravity fields affecting them, and radio propagation conditions. Each ODF consists of many 36-byte logical records, which fall into 7 primary groups plus an End-of-File Group. An ODF usually contains most groups, but may not have all. The first record in each of the 7 primary groups is a header record; depending on the group, there may be from zero to many data records following each header. See NAV023_ODF_2_18_REV3.HTM [18] in the DOCUMENT directory for more information.

The SDS also archives the Tracking and Navigation File (**TNF**). The TNF data type captures radiometric tracking data for delivery to navigation and radio science users from the Telecommunications Services at JPL. The product replaces data types formerly known as Archival Tracking Data Files and others. See TNFSIS.TXT [6] in the DOCUMENT directory for information. Although the TNF is not used for processing by the SDS, it is saved in parallel with the ODF for this archive.

RSR data are processed by the SDS to determine the X-Band sky frequency (**XFR,** an ASCII file) at the DSN versus UTC-Earth Received Time. XFR data are converted into Tracking Data Messages (**TDM**, also ASCII [34]). From the TDM, the (binary) Open Loop File (**OLF**) is created. The OLF contains the sky frequency information derived from RSR data, but in the format of the ODF. Along with the closed-loop S-Band ODF, the X-Band OLF is used for orbit determination, which is recorded in the GNI, GNV, LTM, and PLT products in the LGRS CDR data set.

The "biased TDM" product (BTM, ASCII [34]) is in exactly the same format as the TDM. It is generated by subtracting off a one-way Doppler frequency bias at X-band from the TDM file containing the raw one-way Doppler measurement provided by the radio science team. The one-way Doppler frequency bias was estimated every orbit (approximately 2 hours) as part of the gravity field determination process and the estimates are reported in the USO1A data product. The one-way Doppler bias is computed by linearly interpolating the one-way Doppler bias time series in the USO1A product to the time tag of the one-way Doppler measurement. The computed one-way Doppler bias is then subtracted from the original raw TDM value and the result in stored in the "biased TDM" product. The "biased TDM" product is intended to remove non-linear drifts in the one-way Doppler bias induced by solar activity during the GRAIL mission.

The (binary) Biased Open Loop File (BOF) is the same format as the OLF and is converted from the BTM.

4.2.3.2 Ancillary DSN Data

To calibrate the radio data recorded at the DSN, several data types are also collected as listed below:

The DSN and flight projects use Earth Orientation Parameters (**EOP**), which include Universal Time and Polar Motion data, in the process of performing orbit determination and generating prediction data. See TRK_2_21_950831.TXT [21] in the DOCUMENT directory.

Ionospheric Media Calibrations (**ION**) are created by the Radio Metric Modeling and Calibration (RMC) Subsystem and delivered to a central repository on the flight operations network by the DSN Operations and Maintenance Contract (OMC) Media Analyst. Ionosphere calibration files are specific to one spacecraft or other user and provide one calibration per tracking pass or other time period of interest at each Deep Space Communications Complex (DSCC) or Deep Space Station (DSS). See DSN006_MEDIALCAL_REV2.HTM [27] in the DOCUMENT directory.

Tropospheric Media Calibrations (**TRO**) are created by the Radio Metric Modeling and Calibration (RMC) Subsystem and delivered to a central repository on the flight operations network by the DSN Operations and Maintenance Contract (OMC) Media Analyst. Troposphere calibration files are spacecraft-independent; their calibrations collectively cover all 24 hours of each day at each Deep Space Communications Complex (DSCC) in contiguous “passes” of approximately six hours each. Two troposphere calibrations are provided for each such pass: a “dry” tropospheric delay calibration and a “wet” tropospheric delay calibration. See DSN006_MEDIALCAL_REV2.HTM [27] in the DOCUMENT directory.

Weather data (**WEA**) provided by the Deep Space Network (DSN) are used by radio science teams and other investigators to estimate meteorological corrections to radio tracking and propagation data. Measurements are recorded at one-minute intervals, thinned to a sampling rate that is determined by the user accuracy requirements, and delivered post-real time at intervals that are determined by the timeliness requirement of the primary users and by negotiations with the various DSN users. There will be one file per weather station at each complex for each delivery interval. See T2_24_L5.HTM [10] in the DOCUMENT directory.

4.2.4 LGRS RDR (NASA Level 2 Products)

The LGRS RDR data set contains Level 2 products resulting from analysis of the GRAIL science data. The products include:

The Spherical Harmonics ASCII Data Record (**SHADR**), which contains ASCII coefficients and/or an ASCII covariance matrix for a spherical harmonic expansion of the lunar gravity field. See SHADR.HTM [29] in the DOCUMENT directory.

The Spherical Harmonics Binary Data Record (**SHBDR**), which contains binary coefficients and/or a binary covariance matrix for a spherical harmonic expansion of the lunar gravity fields. See SHBDR.HTM [30] in the DOCUMENT directory.

Radio Science Digital Map Products (**RSDMAP**), which are geoid, isostatic anomaly, Bouguer anomaly, or other digital maps derived primarily from GRAIL science results including the spherical harmonics models above. See RSDMAP.HTM [19] in the DOCUMENT directory.

SPICE Spacecraft and Planet Ephemeris Kernels (**SPK**), which are the physical realization of two logical elements of the SPICE system—the S-kernel (spacecraft ephemeris) and the ephemeris portion of the P-kernel (planet, satellite, asteroid and comet ephemerides). When read using an appropriate subroutine from the SPICE Toolkit, an SPK file will yield state vectors—Cartesian position and velocity—of one user-specified ephemeris object relative to another, at a specified epoch and in a specified reference frame. See SPK_MM_SIS.HTM [5] in the DOCUMENT directory.

The SPK products in this data set differ from those archived by GRAIL navigation; they are created by the GRAIL SDS and make use of the LGRS to provide a more refined solution than those produced by GRAIL Navigation.

4.2.5 Data Flow and Product Generation

As shown in the downlink data flow diagram (Figure 3), telemetry packets from the Deep Space Network (DSN) are placed on the Telemetry Delivery System (TDS). Science data and engineering data packets are transferred from the TDS to the GRAIL SDS computers on a regular basis. The SDS also receives Level 1 Doppler (tracking) data from the Radio Science Group (X-band) and the Tracking Data System (S-band). Finally, the SDS receives high-rate telemetry data from the Multi-Mission Distributed Object Manager (MMDOM) servers, placed there by the Lockheed Mission Operations Center (MOC).

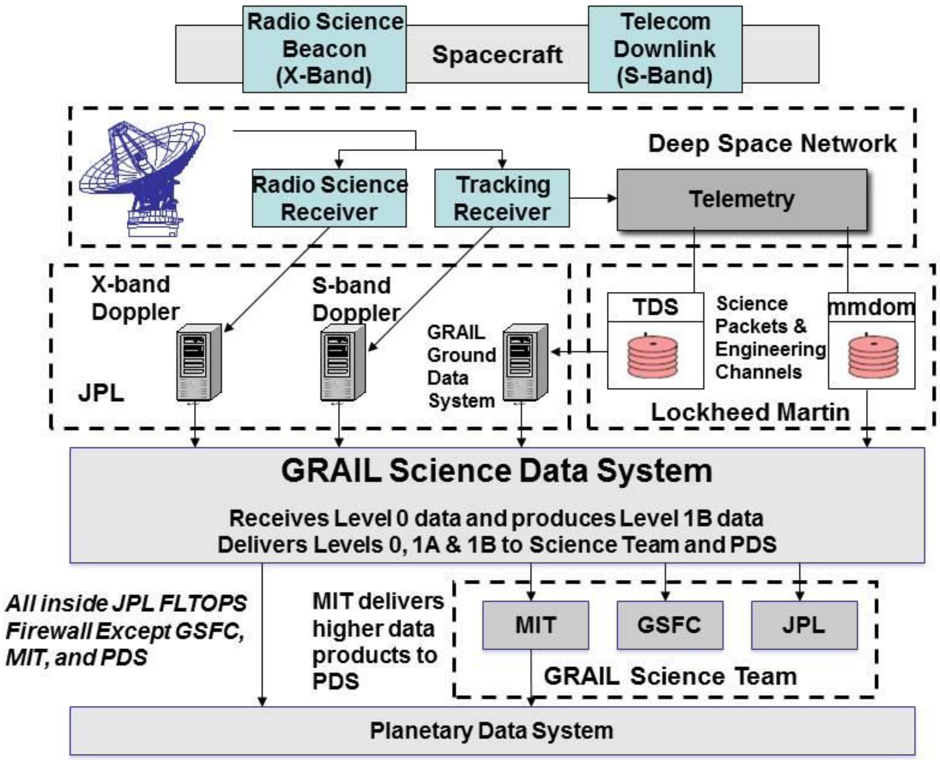

Figure 3. GRAIL Science Downlink Data Flow Diagram

4.2.6 Labeling and Identification

4.2.6.1 LGRS EDR and LGRS CDR File Naming Convention

For all LGRS data, the product identifier, in conjunction with either a date or a range of dates in a specified format, determines the filename containing the data product.

The file naming convention for most Level 0/1A/1B LGRS products is:

PRDID_YYYY_MM_DD_S_VV.EXT

where

PRDID	product identification label, *e.g.* CLK1B
YYYY	year
MM	month
DD	day of month
S	GRAIL satellite identifier: A GRAIL-A B GRAIL-B X combined product of GRAIL-A and GRAIL-B
VV	data product version number (starting from 00)

EXT	file extension indicating binary (DAT) or ASCII (ASC) files

The Product ID (PRDID) is of the form XXXLL, where:

XXX	is a three-character mnemonic, and
LL	specifies the data product Level (00, 1A, 1B).

The only exception to this naming convention is TDE00. To accommodate multiple direct-to-earth measurements within the same day, the convention is the same as above with the addition of the start time in seconds past midnight (NNNNN):

PRDID_YYYY_MM_DD_S_NNNNN_VV.EXT

4.2.6.2 RSS EDR File Naming Convention

Orbit Data Files (ODFs) and Tracking and Navigation Files (TNFs) are named, respectively, as follows:

sssttaayyyy_ddd_hhmmwuudV#.odf,
sssttaayyyy_ddd_hhmmwuudV#.tnf,

where

sss	3-character spacecraft identifier	
	GRA	GRAIL-A
	GRB	GRAIL-B
	GRX	both
tt	Target ID, e.g., LU = Moon	
aa	Activity/Experiment ID, e.g. GF = gravity field	
yyyy	year	
ddd	day of year	
hhmm	hours/minutes	
w	Ground Transmitter Band(s):	
	N	none
	M	multiple
	S	S-band
	X	X-band
uu	Uplinking Station(s) = the DSN station number, or	
	NN	none
	MM	multiple
d	way	
	1	one-way
	2	two-way
	M	multiple
V#	version number	

Radio Science Receiver (RSR) data, Tracking Data Messages (TDM), Biased Tracking Data Messages (BTM), Sky Frequency Files (XFR), Open Loop Files (OLF), and Biased Open Loop Files (BOF) are named, respectively, as follows:

sssttaayyyyddd_hhmmxuudrrpD.rcs,
sssttaayyyyddd_hhmmxuudrrpD.tdm,
sssttaayyyyddd_hhmmxuudrrpD.btm,
sssttaayyyyddd_hhmmxuudrrpD.xfr,
sssttaayyyyddd_hhmmxuudrrpD.olf
sssttaayyyyddd_hhmmxuudrrpD.bof

where:

sss	3-character spacecraft identifier

	GRA	GRAIL-A
	GRB	GRAIL-B
tt	Target ID, e.g., LU = Moon	
aa	Activity/Experiment ID, e.g. GF = gravity field	
yyyy	year	
ddd	day of year	
hhmm	hours/minutes	
xuu	Uplink Transmitter Band (e.g., S, X) and 2-digit Uplinking Station number, or "NNN" = 1-way	
drr	Downlink Band (e.g., X) and 2-digit Receiving Station number	
p	Polarization L = left hand; R = right hand; M = mixed	
D	Open-loop data type	
	D	RSR data
	V	VSR data
	W	WVSR data
rcs	RSR number + channel + subchannel	
tdm	Tracking Data Message	
btm	Biased Tracking Data Message	
xfr	Sky Frequency File	
olf	Open Loop File	
bof	Biased Open Loop File	

Ionospheric Media Calibration (ION) files, Tropospheric Media Calibration (TRO) files, Earth Orientation Parameter (EOP) files, and weather (WEA) files are named, respectively, as follows:

sssttaaYYYY_DDD_yyyy_ddd.ion,
sssttaaYYYY_DDD_yyyy_ddd.tro,
sssttaaYYYY_DDD_yyyy_ddd.eop,
sssttaaYYYYDDDyyyyddd_##.wea,

where:

sss	3-character spacecraft identifier	
	GRA	GRAIL-A
	GRB	GRAIL-B
	GRX	both
tt	Target ID, e.g., LU = Moon	
aa	Activity/Experiment ID, e.g. GF = gravity field	
YYYY	start year	
DDD	start day of year	
yyyy	end year	
ddd	end day of year	
##	DSN station number	

4.2.6.3 LGRS RDR File Naming Convention

Spherical Harmonics ASCII Data Records (SHADR) and Spherical Harmonics Binary Data Records (SHBDR) are named, respectively, as follows:

GTsss_nnnnvv_SHA.TAB,
GTsss_nnnnvv_SHB_Lccc.DAT,

where

G denotes the generating institution

- J Jet Propulsion Laboratory
- G Goddard Space Flight Center
- M Massachusetts Institute of Technology

T indicates the type of data represented

- G gravity field

sss a 3-character modifier specified by the data producer. This modifier is used to indicate the source spacecraft or project, such as GRX (the pair of GRAIL spacecraft).

nnnnvv a 4- to 6-character modifier specified by the data producer. Among other things, this modifier may be used to indicate the target body, whether the SHADR contains primary data values as specified by "T" or uncertainties/errors, and/or the version number. For GRAIL, this modifier indicates the degree and order of the solution for the gravity field.

"SHA" or “SHB” denotes that this is an ASCII or binary file, respectively.

“Lccc” is a 2- to 4-character modifier specified by the data producer to indicate the degree and order to which degree (L) the gravity covariance has been truncated, if applicable.

"TAB" or “DAT” denotes that this is an ASCII or binary file, respectively.

Bouguer gravity data products will have the name "Bouguer" following the degree and order identifier, i.e. GTsss_nnnnvv_BOUGUER_SHA.TAB

Radio Science Digital Map Products (RSDMAP) are named as follows:

GTsss_ffff_nnnn_cccc.IMG,

where

G denotes the generating institution:

- J Jet Propulsion Laboratory
- G Goddard Space Flight Center
- M Massachusetts Institute of Technology

T indicates the type of mission data represented:

- G gravity field

sss a 3-character modifier specified by the data producer. This modifier is used to indicate the source spacecraft or project, such as GRX (the pair of GRAIL spacecraft).

ffff a 4- to 6-character modifier specified by the data producer to indicate the degree and order of the solution for the gravity field.

nnnn a 4- to 8-character modifier indicating the type of data represented:

ANOM	free air gravity anomalies
ANOMERR	free air gravity anomaly errors (1)
GEOID	geoid heights
GEOIDERR	geoid height errors (1)
BOUG	Bouguer anomaly
ISOS	isostatic anomaly
TOPO	topography
MAGF	magnetic field
DIST	gravity disturbances
DEGSTR	degree strength

(1) Geoid and gravity anomaly errors are computed from a mapping of the error covariance matrix of the gravity field solution.

cccc a 2- to 4-character modifier specified by the data producer to indicate the degree and order to which the potential solution (gravity, topography or magnetic field) has been evaluated. In the case of the error maps for the gravity anomalies or geoid, this field indicates to which maximum degree and order the error covariance was used to propagate the spatial errors.

.IMG the data is stored as an image.

Spacecraft and Planet Ephemeris Kernels (SPK) are named as follows:

sssttaaYYYY_DDD_yyyy_ddd.spk,

where:

sss	3-character spacecraft identifier GRA GRAIL-A GRB GRAIL-B GRX both
tt	Target ID, e.g., LU = Moon
aa	Activity/Experiment ID, e.g. GF = gravity field
YYYY	start year
DDD	start day of year
yyyy	end year
ddd	end day of year

4.3 Standards Used in Generating Data Products

4.3.1 PDS Standards

All data products comply with Planetary Data System standards [25] for file formats and labels.

4.3.2 Time Standards

The objective of the GRAIL mission is to determine with high accuracy the lunar gravity field for scientific research. The input data for the gravity field determination process are Ka-Band phase measurements between the two GRAIL spacecraft; the phase measurements are used to compute the dual one-way range (DOWR). The DOWR measurement is then converted to instantaneous range, range rate and range acceleration measurements, which serve as inputs to the gravity field estimation process. Very accurate timing of the GRAIL measurements is crucial to achieving the high accuracy measurements needed for a high quality gravity field.

Science data from the GRAIL spacecraft are time tagged by onboard clocks. However, most of the SDS scientific computer programs process data with Barycentric Dynamic Time (TDB). Timing data from the Deep Space Network (DSN) and the onboard Time Transfer System (TTS) and frequency observations from the Radio Science Receiver (RSR) are combined to estimate the time tag conversion for the GRAIL science data. Figure 4 provides an overview of the relationships among the three timing systems; the three subsections which follow have additional detail.

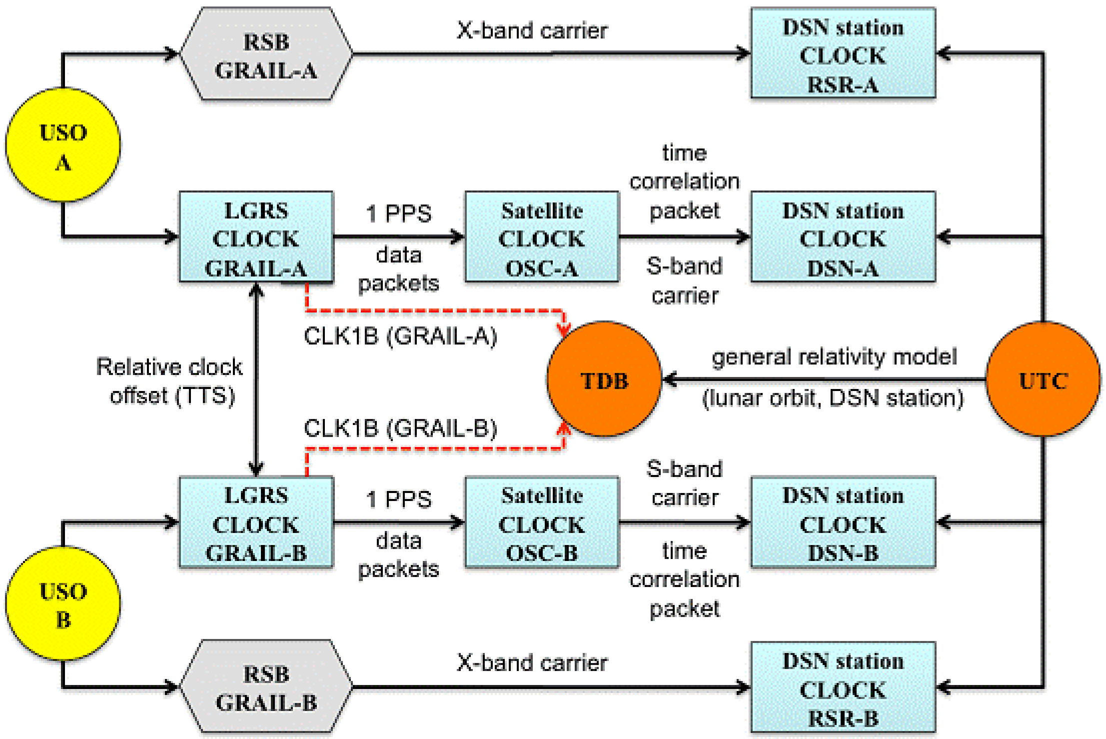

Figure 4. GRAIL clocks, models, and measurements used for timing [17]

4.3.2.1 LGRS clock

Each spacecraft has an LGRS clock; its USO frequency reference makes it very stable. The LGRS clock is used for timing of the LGRS Ka-Band phase measurement and the ranging data from the TTS. The LGRS clock has no notion of absolute time; instead, the LGRS clock reading is with respect to its startup epoch.

4.3.2.2 Onboard spacecraft clocks

The Onboard Spacecraft Clocks (OSC) are run by crystal oscillators, which have inferior stability characteristics compared to the USO (and LGRS clock). The two OSC clocks are the Real Time Clock (RTC) and the Base Time Clock (BTC). The real time clock starts at 0 at boot-up of the onboard computer, whereas the Base Time Clock is set at launch and is never reset. The OSCs are used for time tagging all spacecraft data and the arrival of the LGRS data packets (which include the LGRS 1 Pulse per Second (PPS) packets) by the onboard computer. By time tagging the arrival of LGRS data packets and the arrival of the LGRS 1 PPS, a time correlation can be established between the LGRS clock and the OSCs.

The RTC is used to time stamp spacecraft time correlation packets, which are then transmitted to a DSN station where the arrival time is recorded in UTC, thus providing a time correlation between the RTC and UTC. By combining LGRS/BTC, BTC/RTC, and RTC/UTC time correlation products, a time correlation between the LGRS and UTC can be determined, and the OSC clocks drop out. Hence, the stability characteristics of the OSCs do not affect the LGRS and UTC time correlation because the OSC errors over short intervals (< 1 second) are less than 1 microsecond.

4.3.2.3 UTC clock used by DSN

The DSN uses very stable clocks which are based on the DSN Frequency and Timing Subsystem (FTS) [33]. The DSN time stamps the arrival of telemetry and radio metric tracking data in UTC. Based on FTS reports, the real-time timing performance is at the microsecond level and post processing analysis improves the performance to the nanosecond level.

4.3.3 Coordinate Systems

Four coordinate systems are used to define the various GRAIL data products; see [23] for detail. The definitions are summarized below.

1) Mechanical Frame (MF) (Figure 5): This is defined by the spacecraft manufacturer. It is the reference frame for such things as KBR horn location, center of mass, and thruster locations (Figures 6 and 7).

   $+X_M$ = Parallel to, and in opposite direction from, the solar array normal vector
   $+Z_M$ = Normal to star tracker bus plate
   $+Y_M = +Z_M \times +X_M$

   An onboard attitude control system approximately orients the mechanical frame with $-Z_M$ along the line of flight and -/+ Y_M pointed towards the moon. For the orientation of the mechanical frame, during the primary and extended missions, see figures 8 and 9.

2) Science Reference Frame (SRF): This is the Mechanical Frame as realized by the Star Tracker. If the Star Tracker were perfectly aligned, MF would equal SRF. SRF is the reference frame for GRAIL science measurements.

3) EME 2000 Lunar-Centered Solar System Barycentric Frame: This is the Earth Mean Equator 2000 inertial reference frame [31], re-centered at the moon using the DE 421 planetary ephemeris. It is the reference frame for ephemeris products.

4) DE 421 Lunar Body-Fixed Frame: This is the lunar body-fixed frame as defined in the DE 421 planetary ephemeris [13]. It is the reference frame for gravity products. GRGM1200A products use the DE 430 ephemeris [37].

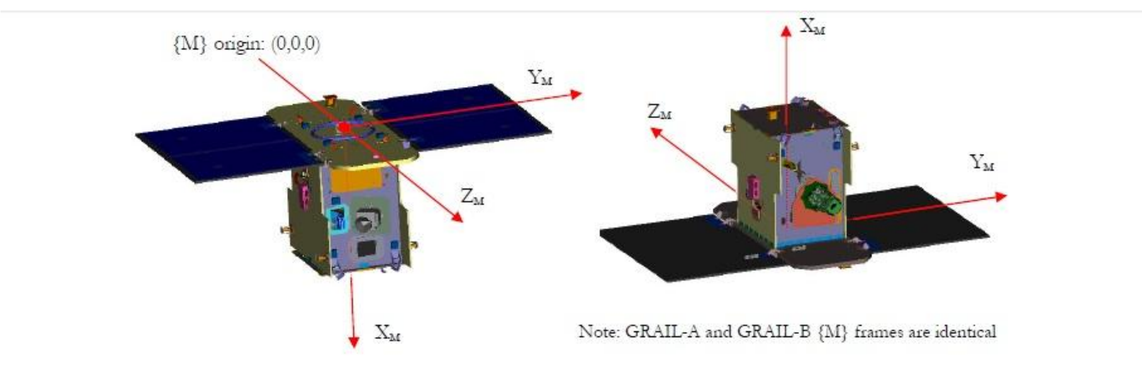

Figure 5: The GRAIL Mechanical Frame (MF) [23]

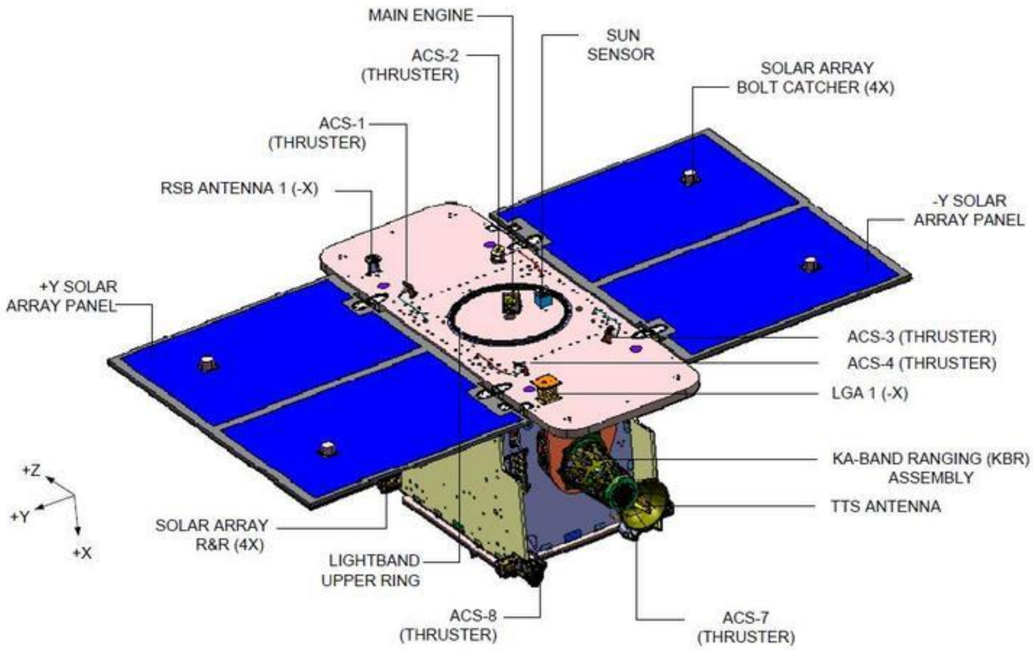

Figure 6: GRAIL thruster locations (XYZ is the same as $X_M Y_M Z_M$ in text)

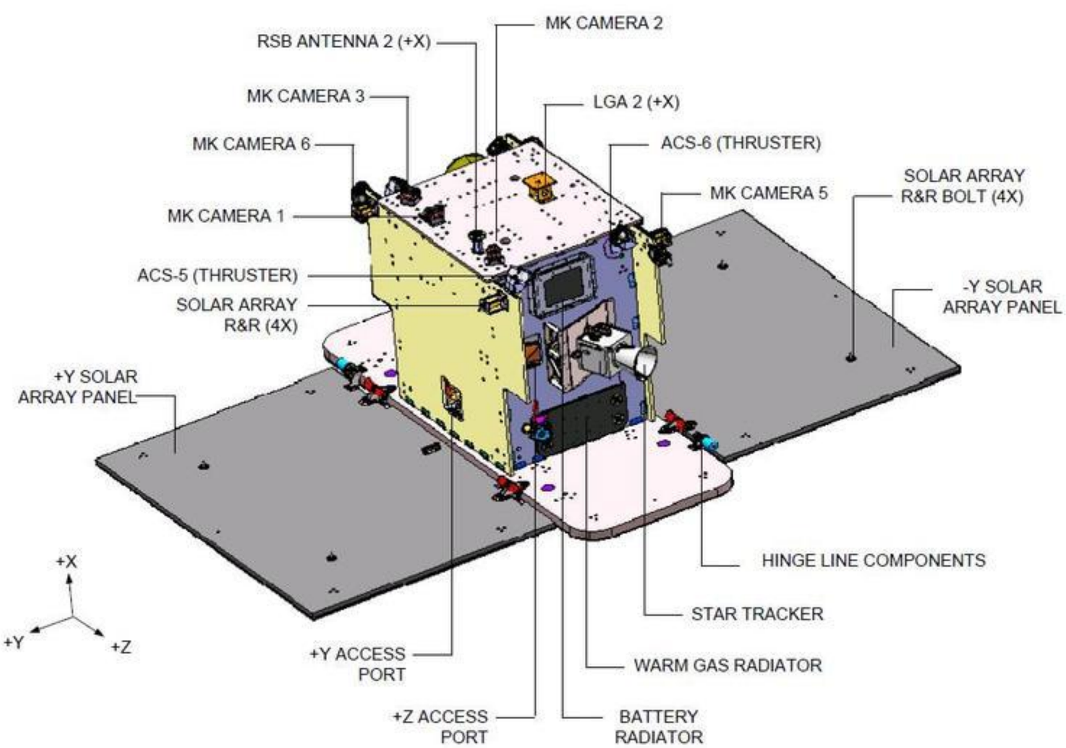

Figure 7: GRAIL thruster locations (XYZ is the same as $X_M Y_M Z_M$ in text)

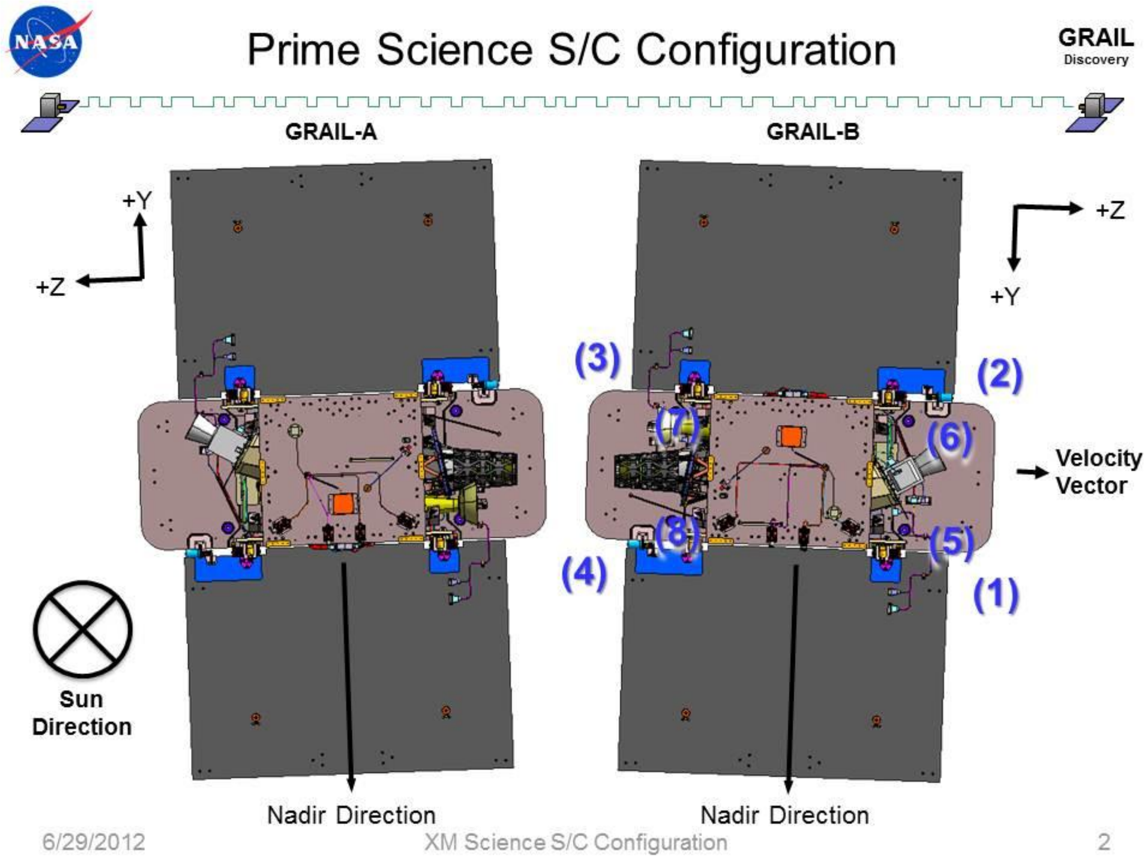

Figure 8: GRAIL primary science spacecraft configuration (XYZ is the same as $X_M Y_M Z_M$ in text)

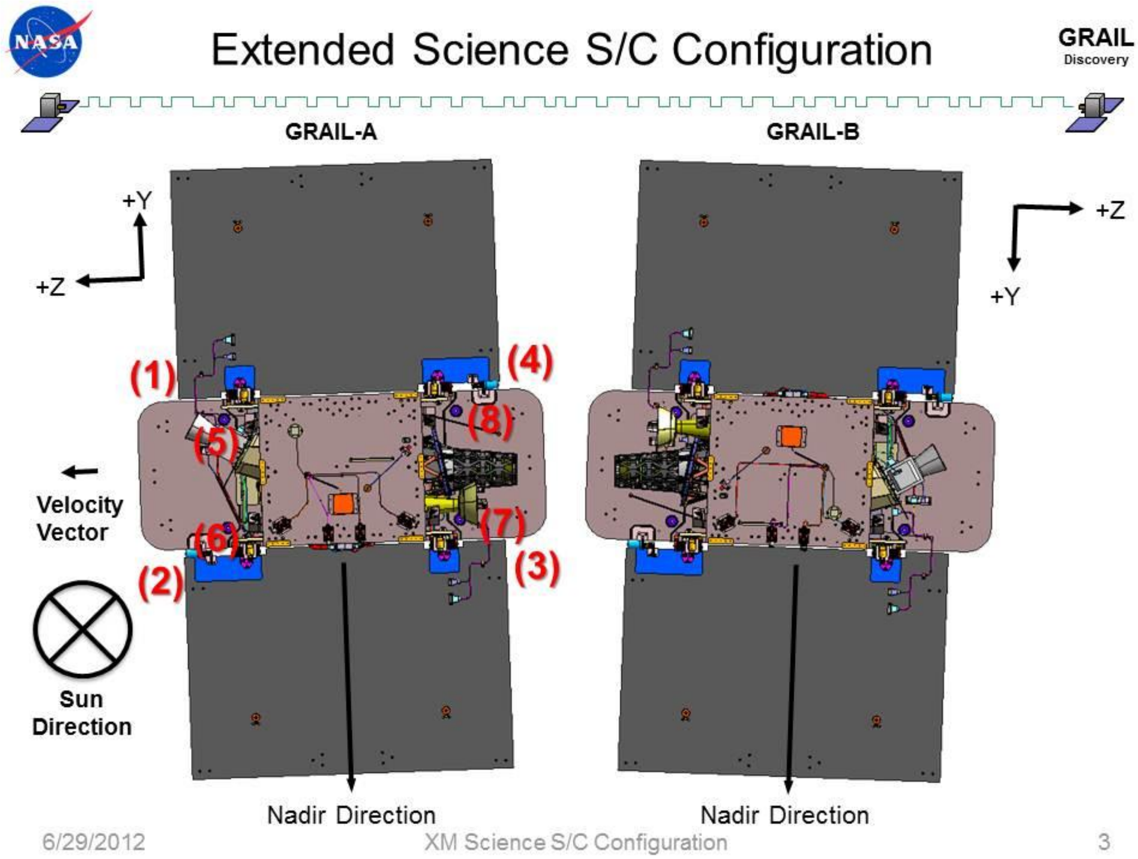

Figure 9: GRAIL extended science spacecraft configuration (XYZ is the same as $X_M Y_M Z_M$ in text)

4.4 Data Validation

Data validation occurs in three steps: validation of the data themselves, validation of the correctness and completeness of the data set documentation, and validation of the compliance of the archive with PDS standards. The primary method by which Science Team members will validate the various archive products is by using them for their own science. Calibrated data files (CDRs) will be derived from the raw data files (EDRs) in the archive; then reduced data records (RDRs) will be created from the archival CDRs. Errors in the raw and calibrated data products are likely to be caught by the science team in this process. The formal validation of data content, adequacy of documentation, and adherence to PDS archiving standards is finalized with an external peer review.

5 Detailed Data Product Specifications

5.1 Data Product Structure and Organization

The following table lists product identifiers and pointers to the corresponding format descriptions. Format descriptions can be found in the listed documents or in this document in section 5.2, Tables 3 through 53. Some products have headers, which are discussed in Section 5.3; all products have PDS labels, which are also discussed in Section 5.3.

A summary of all data products, including their product identifiers, follows.

Table 2. Summary of Data Products

Data Set	Product Identifier (XXXLL)	S/C*	Clock	Product	Format Description in DOCUMENT Directory…	… or Section 5.2 Table
LGRS EDR	DTC00	A/B	UTC SCET	Time Correlation Data Record File (DRF)		3
	EHK00	A/B	UTC SCET	Spacecraft Engineering Housekeeping Data		4
	LTB00	X	BTC	LGRS Time Bias		5
	MAS00	A/B	UTC SCET	Satellite Mass Data		6
	S7200	A/B	UTC SCET	Engineering SFDU (ID #72)	0161_TELECOMM_L5_8.LBL 0171_TELECOMM_NJPL_L5.LBL 090_REVC_1.LBL 0172_TELECOMM_CHDO_REVE_L5.LBL GPA_TD_D_71987_REVE.LBL BLACKJACKDLP.LBL	
	S7300	A/B	UTC SCET	Science SFDU (ID #73)	0161_TELECOMM_L5_8.LBL 0171_TELECOMM_NJPL_L5.LBL 090_REVC_1.LBL 0172_TELECOMM_CHDO_REVE_L5.LBL GPA_TD_D_71987_REVE.LBL BLACKJACKDLP.LBL	
	SAE00	A/B	UTC SCET	Solar Array Eclipse Data		7
	SCA00	A/B	UTC SCET	Star Tracker Data		8
	STC00	A/B	UTC SCET	Time Correlation SFDU	0161_TELECOMM_L5_8.LBL 0171_TELECOMM_NJPL_L5.LBL 090_REVC_1.LBL 0172_TELECOMM_CHDO_REVE_L5.LBL	
	TDE00	A/B	UTC ERT	Time Transfer System Direct to Earth		9
	THR00	A/B	UTC SCET	Thruster Activation Data		10
	WRS00	A/B	UTC SCET	Wheel Rotational Speed Data		11
LGRS CDR	CLK1A	A/B	TDB	TDB to LGRS time correlation		12
	DEL1A	X	LGRS + Bias	Inter-satellite LGRS clock offset		13
	EHK1A	A/B	UTC SCET	Spacecraft temperature sensor data from Engineering Housekeeping data		14
	IHK1A	A/B	LGRS +Bias	LGRS Housekeeping Data		15
	IHS1A	A/B	LGRS + Bias	Level 1A LGRS Health Status data		16
	ILG1A	A/B	LGRS + Bias	LGRS log messages		17
	KBR1A	A/B	LGRS	Ka-Band Ranging		18

			+ Bias	Data		
	LTM1A	A/B	TDB	Position vector and light time between one S/C and DSN station		19
	MAS1A	A/B	UTC SCET	Satellite Mass Data		20
	PCI1A	A/B	TDB	Phase Center to Center of Mass Correction		21
	PLT1A	X	TDB	Position vector and light time between two spacecraft		22
	PPS1A	A/B	LGRS + Bias	LGRS Pulse Per Second (PPS) Time Record		23
	REL1A	A/B	TDB	Relativistic time correction (TDB to onboard satellite proper time)		24
	SAE1A	A/B	UTC SCET	Solar Array Eclipse Data		25
	SBR1A	A/B	LGRS + Bias	S-Band Ranging Data		26
	SCA1A	A/B	BTC	Star Tracker Data		27
	SNV1A	A/B	LGRS + Bias	S-Band navigation product		28
	TC11A	A/B	LGRS + Bias	LGRS to BTC time correlation		29
	TC21A	A/B	LGRS + Bias	LGRS to BTC time correlation from BTC clock cycle counts		30
	TC31A	A/B	BTC	BTC to RTC time correlation		31
	TC41A	A/B	LGRS + Bias	LGRS to RTC time correlation		32
	TC51A	A/B	RTC	RTC to UTC time correlation		33
	TC61A	X	UTC	UTC to TDB time correlation		34
	THR1A	A/B	UTC SCET	Thruster Activation Data		35
	USO1A	A/B	TDB	Oscillator frequency data		36
	VCM1A	A/B	UTC SCET	center of mass displacement from spacecraft mechanical frame origin		37
	WRS1A	A/B	UTC SCET	Wheel Rotational Speed Data		38
	CLK1B	A/B	LGRS + Bias	Time correlation between LGRS time +Bias and TDB		39
	EHK1B	A/B	TDB	Spacecraft		40

				temperature sensor data from Engineering Housekeeping Data		
	GNI1B	A/B	TDB	satellite orbit solution in Moon centered Inertial frame		41
	GNV1B	A/B	TDB	satellite orbit Solution in lunar body fixed frame		42
	KBR1C	X	TDB	Dual-One-Way Ka-Band Ranging Data		43
	MAS1B	A/B	TDB	Satellite Mass Data		44
	SAE1B	A/B	TDB	Solar Array Eclipse Data		45
	SBR1B	X	TDB	Dual one-way S-Band Ranging data		46
	SCA1B	A/B	TDB	Star Tracker Data		47
	THR1B	A/B	TDB	Thruster Activation Data		48
	USO1B	A/B	TDB	USO Frequency Estimate		49
	VCM1B	A/B	TDB	center of mass displacement from spacecraft mechanical frame origin		50
	VGS1B	A/B	TDB	S-Band antenna offset vector and switch time (TDB time)		51
	VGX1B	A/B	TDB	X-Band antenna offset vector and switch time (TDB time)		52
	VKB1B	A/B	TDB	Ka-Band Boresight Vector		53
	WRS1B	A/B	TDB	Wheel Rotational Speed Data		54
RSS EDR	BOF	A/B	UTC	Biased Open Loop File	SEE LABEL FILE	
	BTM	A/B	UTC	Biased Tracking Data Message Standard		55
	EOP	X	TDB	Earth Orientation Parameters	TRK_2_21_950831.LBL	
	ION	A/B	UTC	Ionospheric Media Calibration	DSN006_MEDIACAL_REV2.LBL	
	ODF	A/B	UTC	Tracking Data, Orbit Data File	SEE LABEL FILE	
	OLF	A/B	UTC	Open Loop File	SEE LABEL FILE	
	RSR	A/B	UTC	Radio Science Receiver 0159	SEE LABEL FILE	
	TDM	A/B	UTC	Tracking Data Message Standard		56
	TNF	A/B	UTC	Tracking and Navigation File	TNFSIS.LBL	

	TRO	X	UTC	Tropospheric Media Calibration	DSN006_MEDIACAL_REV2.LBL	
	WEA	X	UTC	Weather Files	TRK_2_24.LBL	
	XFR	A/B	UTC	X-Band sky frequency		57
LGRS RDR	RSDMAP	X	N/A	Radio Science Digital Map Products	RSDMAP.LBL	
	SHADR	X	N/A	Spherical Harmonics ASCII Data Record	SHADR.LBL	
	SHBDR	X	N/A	Spherical Harmonics Binary Data Record	SHBDR.LBL	
	SPK	A/B	TDB	Spacecraft Ephemeris Kernel	SPK_MM_SIS.LBL	

* Spacecraft: Value “A/B” means that there is one file for GRAIL-A and a second file for GRAIL-B; value “X” means that GRAIL-A and GRAIL-B data are combined into a single file

5.2 Data Format Descriptions

For all LGRS RDR data, see documentation in Table 2 for format descriptions.

5.2.1 LGRS EDR (Level 0) Products

For S7200, S7300, and STC00 in LGRS EDR, see documentation in Table 2 for format descriptions. All other LGRS EDR (Level 0) products are in ASCII format and are delimited by a variable number of white spaces as described in Tables 3 through 10.

Table 3. DTC00 Record Format

Column #	DTC00 Time Correlation (DRF) Record Data may be missing in fields 2 through 7
1	UTC SCET (YY/DDD-HH:MM:SS.sss)
2.	Clock BTC fractional second counter (1/65536 seconds)
3.	Clock BTC second counter
4.	Clock USO fractional seconds count (1/65536 seconds) since last 1 PPS arrival at on board computer
5.	Clock USO seconds counter since last 1 PPS arrival at on board computer
6.	BTC Bias (seconds)
7.	RTC Seconds
8.	Application Packet ID

Table 4. EHK00 Record Format

Column #	EHK00 Level 0 Space temperature sensors for KBR data correction
1.	UTC SCET Time YY/DDD-HH:MM:SS.sss
2.	(Microwave Assembly T1 Temperature in C + 273.0718) / 0.1220652
3.	(Microwave Assembly T2 Temperature in C + 273.0718) / 0.1220652
4.	(Waveguide Transmit Module Ka-Band Assembly temperature in C + 273.0718) / 0.1220652
5.	(Waveguide Transmit Module Microwave Assembly temperature in C + 273.0718) / 0.1220652
6.	(Waveguide Receive Module Middle of Span temperature in C + 273.0718) / 0.1220652

7.	(Waveguide Transmit Module Middle of Span temperature in C + 273.0718) / 0.1220652
8.	(Aperture temperature in C + 273.0718) / 0.1220652
9.	(Radome temperature in C + 273.0718) / 0.1220652
10.	(Horn Base temperature in C + 273.0718) / 0.1220652
11.	(Midway on Horn temperature in C + 273.0718) / 0.1220652
12.	(Orthomode transducer (where transmit and receive modules are split off at base of horn) temperature + 273.0718) / 0.1220652 in C
13.	Ground Data System Application Packet Identification

Table 5. LTB00 Record Format

Column #	LTB00 LGRS Time Bias
1	BTC time (seconds)
2.	LGRS Bias (seconds)

Table 6. MAS00 Record Format

Column #	MAS00 Level 0 Spacecraft Mass Data
1.	Spacecraft Event name
2.	UTC SCET Date MM/DD/YYYY
3.	UTC SCET Day of Year YY-DDD
4.	UTC SCET Maneuver End Time HH:MM:SS.sss
5.	Fuel Mass Remaining Book Keeping (kg)
6.	Fuel Mass Remaining Book Keeping Uncertainty (kg)
7.	Post Maneuver Spacecraft Mass
8.	Post Maneuver Center of Mass X coordinate (meters) in mechanical reference frame
9.	Post Maneuver Center of Mass Y coordinate (meters) in mechanical reference frame
10.	Post Maneuver Center of Mass Z coordinate (meters) in mechanical reference frame
11.	Post Maneuver Boresight Vector X coordinate
12.	Post Maneuver Boresight Vector Y coordinate
13.	Post Maneuver Boresight Vector Z coordinate

Table 7. SAE00 Record Format

Column #	SAE00 Level 0 Solar array eclipse data
1.	UTC SCET Time YY/DDD-HH:MM:SS.sss
2.	Solar array short circuit current (Amperes / 2.442000E-04), as reported by the Solar Array Battery Control
3.	Solar array open circuit voltage (Volts / 9.760000E-04), as reported by the Solar Array Battery Control
4.	GDS Application Packet Identification

Table 8. SCA00 Record Format

Column #	SCA00 Level 0 Star Tracker Data
1.	UTC SCET Time YY/DDD-HH:MM:SS.sss
2.	1st element of current spacecraft attitude quaternion based on the onboard filter, phased as inertial to body.
3.	2nd element of current spacecraft attitude quaternion based on the onboard filter, phased as inertial to body.

4.	ADS (quat_body(3)). 3rd element of current spacecraft attitude quaternion based on the onboard filter, phased as inertial to body.
5.	ADS (quat_body(4)). Scalar component of current spacecraft attitude quaternion based on the onboard filter, phased as inertial to body.
6.	Star tracker time stamp (SCLK) of current spacecraft attitude quaternion based on the onboard filter
7.	GDS Application Packet Identification number

Table 9. TDE00 Record Format

Column #	TDE00 Time Transfer System Direct to Earth Data
1.	ΔERT = UTC-ERT: Seconds past initial start time in header (Data Date), indicating the time at which measurements in columns 2-4 were made
2.	Range (seconds), integrated carrier phase measurement with N-cycle ambiguity unresolved
3.	Pseudo range (seconds). Equal to Column 1 minus Column 4 plus a constant to set the pseudo range equal to zero at the start of the first observation of the primary and extended mission
4.	Transmit Time of the TTS range code in LGRS time (seconds). Computed by decoding the GRAIL data message and adding fractional timing information from the Code Delay Lock Loop

Table 10. THR00 Record Format

Column #	THR00 Level 0 Thruster Activation Data
1.	UTC SCET Time YY/DDD-HH:MM:SS.sss
2.	The cumulative on time for thruster Attitude Control System 1 (milliseconds).
3.	The cumulative on time for thruster Attitude Control System 2 (milliseconds).
4.	The cumulative on time for thruster Attitude Control System 3 (milliseconds).
5.	The cumulative on time for thruster Attitude Control System 4 (milliseconds).
6.	The cumulative on time for thruster Attitude Control System 5 (milliseconds).
7.	The cumulative on time for thruster Attitude Control System 6 (milliseconds).
8.	The cumulative on time for thruster Attitude Control System 7 (milliseconds).
9.	The cumulative on time for thruster Attitude Control System 8 (milliseconds).
10.	GDS Application Packet Identification

Table 11. WRS00 Record Format

Column #	WRS00 Level 0 Wheel Rotational Speed Data
1.	UTC SCET Activation Time YY/DDD-HH:MM:SS.sss
2.	Reaction wheel 1 rotational speed as determined by digital tachometer (radians/sec)
3.	Reaction wheel 2 rotational speed as determined by digital tachometer (radians/sec)
4.	Reaction wheel 3 rotational speed as determined by digital tachometer (radians/sec)
5.	Reaction wheel 4 rotational speed as determined by digital tachometer (radians/sec)

5.2.2 LGRS CDR Products

All LGRS CDR (Level 1A & 1B) products are in ASCII format and are delimited by a variable number of white spaces as described in Tables 11 through 51.

Many of the following data types contain **data product flags**. Read *right to left*, the data product flags indicate, with a 1, the presence of a certain field (column) or, with a 0, the absence of that field in the remainder of the record. Fields indicated as being present will exist in the file in consecutive columns in the same order as shown in Tables 11 through 51, with no gaps or spaces for fields indicated as absent. As a result, the number of fields may vary from record to record and there will never be as many fields in the data record as columns specified in the governing table (unless all data product flag digits have been set to 1).

Some data types contain **data quality flags**, in which a 1 indicates that the corresponding description is true. The digits in the data quality flags are also read right to left.

For example, a KBR1A file might contain, in the **data product flags**, a 1 at digit 13 (fourteenth digit from the right), and the rest zeros. This would indicate that after the **data quality flags** in column seven, the eighth column would contain Ka-Band carrier phase data. There would be no additional columns for fields represented by zeros in the data product flag.

Some SBR1A files have records with **data product flags** 0000001000001000, meaning that received S-Band carrier phase and S-Band receiver channel follow the **data quality flags**. Other records in the same file have **data product flags** 0000001001001001, meaning that S-Band pseudo-range, received S-Band carrier phase, S-Band SNR, and S-Band receiver channel follow the **data quality flags** in that order. Thus, records with 9 fields are interleaved with records having 11 fields; no SBR1A record has all 23 columns defined.

5.2.2.1 Level 1A

Table 12. CLK1A Record Format

Column #	CLK1A Level 1A TDB to LGRS + Bias time correlation
1.	TDB time , in integer seconds
2.	TDB time , microseconds part
3.	Input Time scale where ‘T’ = TDB
4.	GRAIL satellite ID ‘A’ or ‘B’
5.	Not applicable
6.	eps_time (seconds), where LGRS + bias Time = TDB time + eps_time
7.	Formal error on eps_time (s) (not used by GRAIL, set to 0)
8.	clock drift (s/s); if not calculated, then set to 0
9.	Formal error on clock drift (s/s); if not calculated, then set to 0
10.	bitrate of SFDU packet; if not calculated, then set to 0
11.	delay by bitrate of SFDU packet; if not calculated, then set to 0
12.	data quality flags (digit 0 is on the right, digit 7 is on the left) Set digits (value = 1) have the following meanings: digit 0 = 1 -> linear extrapolation not valid AFTER input time digit 1 = 1 -> linear extrapolation not valid BEFORE input time digit 2 = 1 -> filled data using KBR1C digit 3 = Not Defined digit 4 = Not Defined digit 5 = Not Defined digit 6 = Not Defined digit 7 = Not Defined

Table 13. DEL1A Record Format

Column #	DEL1A Inter-satellite LGRS clock offset between spacecraft
1.	TDB time, in integer seconds
2.	TDB time, microseconds part
3.	Input Time scale where ‘T’ = TDB
4.	GRAIL satellite ID ‘X’ to indicate a single product for two spacecraft
5.	Not applicable
6.	eps_time (in LGRS seconds), where eps_time = LGRS-A clock – LGRS-B clock
7.	Formal error on eps_time (s); if not calculated, then set to 0
8.	Clock offset corrected for LGRS resets. Identical to column 6 if no reset.
9.	Formal error on clock drift (s/s); if not calculated, then set to 0
10.	bitrate of SFDU packet; if not calculated, then set to 0
11.	delay by bitrate of SFDU packet; if not calculated, then set to 0
12.	data quality flags (digit 0 is on the right, digit 7 is on the left) Set digits (value = 1) have the following meanings: digit 0 = 1 -> linear extrapolation not valid AFTER input time digit 1 = 1 -> linear extrapolation not valid BEFORE input time digit 2 = 1 -> filled data using KBR1C digit 3 = Not Defined digit 4 = Not Defined digit 5 = Not Defined digit 6 = Not Defined digit 7 = Not Defined

Table 14. EHK1A Record Format

Column #	EHK1A Level 1A Spacecraft temperature sensor data from Engineering Housekeeping data for KBR data correction
1.	UTC SCET, integer seconds past 12:00:00 noon 01-Jan-2000
2.	UTC SCET, microseconds part
3.	Time reference where 'U' = UTC SCET
4.	GRAIL satellite ID ‘A’ or ‘B’
5.	Microwave Assembly T1 temperature in C
6.	Microwave Assembly T2 temperature in C
7.	Waveguide transmit Ka-Band Assembly temperature in C
8.	Waveguide transmit Microwave Assembly temperature in C
9.	Waveguide Rx Mid temperature in C
10.	Waveguide Tx Mid temperature in C
11.	Aperture temperature in C
12.	Radome temperature in C
13.	HornBase temperature in C
14.	Midway on Horn temperature in C
15.	Orthomode Transducer (where transmit and receive modules are split off at base of horn) temperature in C
16.	data quality flags (digit 0 is on the right, digit 7 is on the left) LSB = digit 0 digit 0 = Not Defined digit 1 = Not Defined digit 2 = Not Defined digit 3 = Not Defined digit 4 = Not Defined

	digit 5 = Not Defined digit 6 = Not Defined digit 7 = Not Defined

Table 15. IHK1A Record Format

Column #	IHK1A Level 1A LGRS Housekeeping Data
1.	LGRS time +Bias, integer seconds past 12:00:00 noon 01-Jan-2000
2.	LGRS time +Bias, microseconds part
3.	Time reference where 'R' = LGRS time +Bias
4.	GRAIL satellite ID
5.	data quality flags (digit 0 is on the right and digit 7 is on the left) Set digits (value = 1) have the following meanings: digit 0 = Not Defined digit 1 = Not Defined digit 2 = Not Defined digit 3 = Not Defined digit 4 = Not Defined digit 5 = Not Defined digit 6 = No On-Board Data Handler->Receiver time mapping digit 7 = No Clock correction available
6.	Observation type V = Voltage in Volts T = Temperature in Degrees C I = Current in Amperes ? = Observation type not applicable
7.	Value of observation
8.	Sensor name

Table 16. IHS1A Record Format

Column #	IHS1A LGRS Health Status Data
1.	LGRS time +Bias, seconds past 12:00:00 noon 01-Jan-2000
2.	GRAIL satellite ID ‘A’ or ‘B’
3.	Clock offset reported in latest time transfer packet (seconds)
4.	Seconds expired since last reboot
5.	time reported in latest PPS Time packet (seconds) in LGRS time
6.	count of times since reboot that integrity monitor has restarted trackers
7.	SNR reported in latest Ka band quadratic fit packet (0.1 dB-Hz)
8.	SNR reported in latest S-band quadratic fit packet (V/V)
9.	Data quality flags (digit 0 is on the right and digit 7 is on the left) LSB = digit 0 digit 0 = Not Defined digit 1 = Not Defined digit 2 = Not Defined digit 3 = Not Defined digit 4 = Not Defined digit 5 = Not Defined digit 6 = Not Defined digit 7 = Not Defined

Table 17. ILG1A Record Format

Column #	ILG1A

	LGRS Log Messages
1.	LGRS+Bias time, seconds past 12:00:00 noon 01-Jan-2000
2.	counts packets with that rcv_time (1,2,3,...)
3.	GRAIL satellite ID ‘A’ or ‘B’
4.	carriage-return terminated log message string

Table 18. KBR1A Record Format

Column #	KBR1A Level 1A Ka-Band Ranging Data
1	LGRS time +Bias, integer seconds past 12:00:00 noon 01-Jan-2000 (s)
2.	LGRS time +Bias, microseconds part
3.	GRAIL satellite ID ‘A’ or ‘B’
4.	GRAIL transmission channel number 50 for Ka-Band for both spacecraft
5.	KBR antenna ID on GRAIL spacecraft ant_id = 11 for KBR antenna
6.	data product flags. Set digits indicate quantities stored after column 7 as follows (digit 0 is on the right and digit 15 is on the left): Set digits (value = 1) have the following meanings: digit 0 = Not Defined digit 1 = Not Defined digit 2 = Not Defined digit 3 = Not Defined digit 4 = Not Defined digit 5 = Not Defined digit 6 = Not Defined digit 7 = Not Defined digit 8 = Not Defined digit 9 = Not Defined digit 10 = Not Defined digit 11 = Not Defined digit 12 = Correction of Ka phase digit 13 = Received Ka-band carrier phase minus transmitted Ka-band carrier phase (cycles) digit 14 = Not Defined digit 15 = Ka-Band SNR 0.1 dB-Hz
7.	data quality flags (digit 0 is on the right and digit 7 is on the left) Set digits (value = 1) have the following meanings: digit 0 = Not Defined digit 1 = phase break occurred in Ka-Band at LGRS time + Bias digit 2 = Not Defined digit 3 = cycle slip detected in Ka-Band digit 4 = corrupted Ka-Band phase reconstruction polynomial detected digit 5 = Not Defined digit 6 = Not Defined digit 7 = Ka SNR < 450
8.	Not Defined
9.	Not Defined
10.	Not Defined
11.	Not Defined
12.	Not Defined
13.	Not Defined
14.	Not Defined
15.	Not Defined

16.	Not Defined
17.	Not Defined
18.	Not Defined
19.	Not Defined
20.	Not Defined
21.	Ka-band carrier phase (cycles)
22.	Not Defined
23.	Ka-Band SNR (0.1 dB-Hz)

Table 19. LTM1A Record Format

Column #	LTM1A Position vector and light time in EME 2000 (Earth-centered) of transmitting spacecraft at time of signal reception at DSN station
1.	Receive time (TDB), seconds past 12:00:00 noon 01-Jan-2000
2.	Receiver ID number = DSN ID
3.	Transmitter ID 'A' = GRAIL-A 'B' = GRAIL-B
4.	Light time between transmitter and receiver (sec) (transmit time = receive time + light time)
5.	Position of transmitting spacecraft at receive time, x value (Earth-centered) (km)
6.	Position of transmitting spacecraft at receive time, y value (Earth-centered) (km)
7.	Position, of transmitting spacecraft at receive time z value (Earth-centered) (km)

Table 20. MAS1A Record Format

Column #	MAS1A Level 1A Spacecraft Mass Data
1.	UTC SCET, integer seconds past 12:00:00 noon 01-Jan-2000
2.	UTC SCET, microseconds part
3.	Time reference where 'U' = UTC SCET
4.	GRAIL satellite ID ‘A’ or ‘B’
5.	data quality flags (digit 0 is on the right and digit 7 is on the left) Set digits (value = 1) have the following meanings: digit 0 = Not Defined digit 1 = Not Defined digit 2 = Not Defined digit 3 = Not Defined digit 4 = Not Defined digit 5 = Not Defined digit 6 = Not Defined digit 7 = Not Defined
6.	data product flags. Set digits indicate quantities stored in following columns as follows (digit 0 is on the right and digit 7 is on the left): Set digits (value = 1) have the following meanings: digit 0 = spacecraft mass based on propellant consumption digit 1 = undefined digit 2 = undefined digit 3 = undefined digit 4 = undefined digit 5 = undefined digit 6 = undefined digit 7 = undefined
7	Spacecraft Mass based on propellant consumption in kg..

Table 21. PCI1A Record Format

Column #	PCI1A Phase Center to Center of Mass Correction
1.	TDB, seconds past 12:00:00 noon 01-Jan-2000
2.	GRAIL satellite ID ‘A’ or ‘B’
3.	Antenna phase center range correction (m)
4.	Antenna phase center range rate correction (m/sec)
5.	Antenna phase center range acceleration correction (m/sec^2)
6.	data quality flags (digit 0 is on the right and digit 7 is on the left) Set digits (value = 1) have the following meanings: digit 0 = Not Defined digit 1 = bit 1 = From raw data for ka boresight calibration period or prediction change period digit 2 = Not Defined digit 3 = Not Defined digit 4 = Not Defined digit 5 = Not Defined digit 6 = Not Defined digit 7 = Not Defined

Table 22. PLT1A Record Format

Column #	PLT1A Position vector and light time in EME 2000 (moon centered) of transmitting spacecraft at time of signal reception at receiving spacecraft
1.	Receive time (TDB), seconds past 12:00:00 noon 01-Jan-2000
2.	Receiver ID 'A' = GRAIL-A 'B' = GRAIL-B
3.	Transmitter ID 'A' = GRAIL-A 'B' = GRAIL-B
4.	Light time between transmitter and receiver (sec) (transmit time = receive time + light time)
5.	Position of transmitting spacecraft at receive time, x value (moon centered) (km)
6.	Position of transmitting spacecraft at receive time, y value (moon centered) (km)
7.	Position of transmitting spacecraft at receive time z value (moon centered) (km)

Table 23. PPS1A Record Format

Column #	PPS1A LGRS Pulse Per Second (PPS) Time Record
1.	LGRS time +Bias, seconds past 12:00:00 noon 01-Jan-2000
2.	GRAIL satellite ID ‘A’ or ‘B’
3.	LGRS time

Table 24. REL1A Record Format

Column #	REL1A Relativistic time correction (TDB to onboard satellite proper time)
1.	TDB, in integer seconds
2.	TDB, microseconds part
3.	Time scale where ‘T’ = TDB
4.	GRAIL satellite ID ‘A’ or ‘B’
5.	Not applicable

6.	eps_time (seconds), where onboard satellite proper time = TDB + eps_time Correction to TDB to calculate proper spacecraft time
7.	Formal error on eps_time (s) (not used by GRAIL, set to 0)
8.	clock drift (s/s); if not calculated, then set to 0
9.	Formal error on clock drift (s/s); if not calculated, then set to 0
10.	bitrate of SFDU packet; if not calculated, then set to 0
11.	delay by bitrate of SFDU packet; if not calculated, then set to 0
12.	data quality flags (digit 0 is on the right, digit 7 is on the left) Set digits (value = 1) have the following meanings: digit 0 = 1 -> linear extrapolation not valid AFTER input time digit 1 = 1 -> linear extrapolation not valid BEFORE input time digit 2 = 1 -> filled data using KBR1C digit 3 = Not Defined digit 4 = Not Defined digit 5 = Not Defined digit 6 = Not Defined digit 7 = Not Defined

Table 25. SAE1A Record Format

Column #	SAE1A Level 1A Solar array eclipse data
1.	UTC SCET, integer seconds past 12:00:00 noon 01-Jan-2000
2.	UTC SCET, microseconds part
3.	Time reference frame where 'U' = UTC SCET
4.	GRAIL satellite ID ‘A’ or ‘B’
5.	Solar array short circuit current (Amperes / 2.442000E-04), as reported by the Solar Array Battery Control
6.	Solar array open circuit voltage (Volts / 9.760000E-04), as reported by the Solar Array Battery Control
7.	data quality flags (digit 0 is on the right and digit 7 is on the left) LSB = digit 0 digit 0 = Not Defined digit 1 = Not Defined digit 2 = Not Defined digit 3 = Not Defined digit 4 = Not Defined digit 5 = Not Defined digit 6 = Not Defined digit 7 = Not Defined

Table 26. SBR1A Record Format

Column #	SBR1A Level 1A S-Band Ranging Data
1	LGRS time +Bias, integer seconds past 12:00:00 noon 01-Jan-2000 (s)
2.	LGRS time +Bias, microseconds part
3.	GRAIL satellite ID ‘A’ or ‘B’
4.	GRAIL transmission channel number 2 for GRAIL-A 1 for GRAIL-B
5.	SBR antenna ID on GRAIL spacecraft Antenna ID = 3 for SBR antenna
6.	data product flags. Set digits indicate quantities stored after column 7 as follows (digit 0 is on the right and digit 15 is on the left):

	Set digits (value = 1) have the following meanings: digit 0 = S-band pseudo range (m) (includes transmitter and receiver clock errors) digit 1 = Not Defined digit 2 = Not Defined digit 3 = Received S-band carrier phase minus spacecraft-specific reference S-band carrier phase (cycles) digit 4 = Not Defined digit 5 = Not Defined digit 6 = S-Band SNR (V/V) digit 7 = Not Defined digit 8 = Not Defined digit 9 = S-band receiver channel digit 10 = Not Defined digit 11 = Not Defined digit 12 = Not Defined digit 13 = Not Defined digit 14 = Not Defined digit 15 = Not Defined
7.	data quality flags (digit 0 is on the right and digit 7 is on the left) Set digits (value = 1) have the following meanings: digit 0 = Not Defined digit 1 = Not Defined digit 2 = Not Defined digit 3 = Not Defined digit 4 = Not Defined digit 5 = Not Defined digit 6 = Not Defined digit 7 = Not Defined
8.	S-band pseudo Range (m) Pseudo range contains actual range + clock offset effect
9.	Not Defined
10.	Not Defined
11.	S-band carrier Phase (cycles)
12.	Not Defined
13.	Not Defined
14.	S-band SNR (V/V)
15.	Not Defined
16.	Not Defined
17.	S-band receiver channel number
18.	Not Defined
19.	Not Defined
20.	Not Defined
21.	Not Defined
22.	Not Defined
23.	Not Defined

Table 27. SCA1A Record Format

Column #	SCA1A Level 1A Star Tracker Data
1.	BTC time, in seconds
2.	GRAIL satellite ID ‘A’ or ‘B’
3.	Application Packet Identification
4.	cos mu/2 element of quaternion

5.	I element of quaternion rotation axis
6.	J element of quaternion rotation axis
7.	K element of quaternion rotation axis
8.	rss of formal error of quaternions; if not calculated, then set to 0
9.	data quality flags (digit 0 is at the right and digit 7 is at the left). LSB = digit 0 digit 0 = Not Defined digit 1 = Ka boresight calibration period or prediction change period digit 2 = Not Defined digit 3 = Not Defined digit 4 = Not Defined digit 5 = Not Defined digit 6 = Not Defined digit 7 = Not Defined

Table 28. SNV1A Record Format

Column #	SNV1A S-Band Navigation Product
1.	LGRS time + Bias, seconds past 12:00:00 noon 01-Jan-2000
2	LGRS time + Bias, microseconds part
3.	GRAIL satellite ID ‘A’ or ‘B’
4.	Measured range =(local measured pseudorange range + remote measured pseudorange)/2 (seconds). Pseudorange contains actual range + clock offset effect.
5.	Measured clock offset =(local measuredpseudorange– remote measured pseudorange)/2 (seconds). Pseudorange contains actual range + clock offset effect.
6.	Local spacecraft S-Band SNR (V/V)
7.	Remote spacecraft S-Band SNR (V/V); if not calculated, then set to 0
8.	Local spacecraft Ka-Band SNR (0.1 dB-Hz)
9.	Remote spacecraft Ka-Band SNR (0.1 dB-Hz); if not calculated, then set to 0
10.	data quality flags (digit 0 is on the right and digit 7 is on the left LSB = digit 0 digit 0 = Not Defined digit 1 = Not Defined digit 2 = Not Defined digit 3 = Not Defined digit 4 = Not Defined digit 5 = Not Defined digit 6 = Not Defined digit 7 = Not Defined

Table 29. TC11A Record Format

Column #	TC11A LGRS to BTC time correlation
1.	Input time, in integer seconds
2.	Input time, microseconds part
3.	Time scale where ‘L’ = LGRS time + Bias
4.	GRAIL satellite ID ‘A’ or ‘B’
5.	Not applicable
6.	eps_time (seconds), where Output time scale = Input time scale + eps_time
7.	Formal error on eps_time (s); if not calculated then set to 0
8.	Blackjack packet arrival time in RTC time

9.	Formal error on clock drift (s/s); if not calculated then set to 0
10.	bitrate of SFDU packet; if not calculated, then set to 0
11.	delay by bitrate of SFDU packet; if not calculated, then set to 0
12.	data quality flags (digit 0 is on the right, digit 7 is on the left) Set digits (value = 1) have the following meanings: digit 0 = 1 -> linear extrapolation not valid AFTER input time digit 1 = 1 -> linear extrapolation not valid BEFORE input time digit 2 = 1 -> filled data using KBR1C digit 3 = Not Defined digit 4 = Not Defined digit 5 = Not Defined digit 6 = Not Defined digit 7 = Not Defined

Table 30. TC21A Record Format

Column #	TC21A LGRS to BTC time correlation from BTC clock cycle counts
1.	LGRS time + Bias, in integer seconds
2.	LGRS time + Bias, microseconds part
3.	Time scale where ‘L’ = LGRS time + Bias
4.	GRAIL satellite ID ‘A’ or ‘B’
5.	Not applicable
6.	eps_time (seconds), where BTC time = LGRS time + Bias + eps_time
7.	Formal error on eps_time (s); if not calculated, then set to 0
8.	Not applicable and set to 0
9.	Formal error on clock drift (s/s); if not calculated, then set to 0
10.	bitrate of SFDU packet; if not calculated, then set to 0
11.	delay by bitrate of SFDU packet; if not calculated, then set to 0
12.	data quality flags (digit 0 is on the right, digit 7 is on the left) Set digits (value = 1) have the following meanings: digit 0 = 1 -> linear extrapolation not valid AFTER input time digit 1 = 1 -> linear extrapolation not valid BEFORE input time digit 2 = 1 -> filled data using KBR1C digit 3 = Not Defined digit 4 = Not Defined digit 5 = Not Defined digit 6 = Not Defined digit 7 = Not Defined

Table 31. TC31A Record Format

Column #	TC31A BTC to RTC time correlation
1.	BTC, in integer seconds
2.	BTC, microseconds part
3.	Time scale where ‘B’ = BTC time
4.	GRAIL satellite ID ‘A’ or ‘B’
5.	Not applicable
6.	eps_time (seconds), where RTC = BTC + eps_time
7.	Formal error on eps_time (s); if not calculated, then set to 0
8.	Not applicable and set to 0
9.	Formal error on clock drift (s/s); if not calculated, then set to 0
10.	bitrate of SFDU packet; if not calculated, then set to 0

11.	delay by bitrate of SFDU packet; if not calculated, then set to 0
12.	data quality flags (digit 0 is on the right, digit 7 is on the left) Set digits (value = 1) have the following meanings: digit 0 = 1 -> linear extrapolation not valid AFTER input time digit 1 = 1 -> linear extrapolation not valid BEFORE input time digit 2 = 1 -> filled data using KBR1C digit 3 = Not Defined digit 4 = Not Defined digit 5 = Not Defined digit 6 = Not Defined digit 7 = Not Defined

Table 32. TC41A Record Format

Column #	TC41A LGRS to RTC time correlation
1.	LGRS time + Bias, in integer seconds
2.	LGRS time + Bias, microseconds part
3.	Time scale where ‘L’ = LGRS time + Bias
4.	GRAIL satellite ID ‘A’ or ‘B’
5.	Not applicable
6.	eps_time (seconds), where RTC = LGRS time + Bias + eps_time
7.	Formal error on eps_time (s); if not calculated, then set to 0
8.	Not applicable and set to 0
9.	Formal error on clock drift (s/s); if not calculated, then set to 0
10.	bitrate of SFDU packet; if not calculated, then set to 0
11.	delay by bitrate of SFDU packet; if not calculated, then set to 0
12.	data quality flags (digit 0 is on the right, digit 7 is on the left) Set digits (value = 1) have the following meanings: digit 0 = 1 -> linear extrapolation not valid AFTER input time digit 1 = 1 -> linear extrapolation not valid BEFORE input time digit 2 = 1 -> filled data using KBR1C digit 3 = Not Defined digit 4 = Not Defined digit 5 = Not Defined digit 6 = Not Defined digit 7 = Not Defined

Table 33. TC51A Record Format

Column #	TC51A RTC to UTC time correlation
1.	RTC, in integer seconds
2.	RTC, microseconds part
3.	Time scale where ‘R’ = RTC time
4.	GRAIL satellite ID ‘A’ or ‘B’
5.	DSN station ID
6.	eps_time (seconds), where UTC at DSN station = RTC + eps_time and UTC is in seconds since 12:00:00 noon on 1 January 2000
7.	Formal error on eps_time (s); if not calculated, then set to 0
8.	Not applicable and set to 0
9.	Formal error on clock drift (s/s); if not calculated, then set to 0
10.	bitrate of SFDU packet
11.	delay by bitrate of SFDU packet; if not calculated, then set to 0

12.	data quality flags (digit 0 is on the right, digit 7 is on the left) Set digits (value = 1) have the following meanings: digit 0 = 1 -> linear extrapolation not valid AFTER input time digit 1 = 1 -> linear extrapolation not valid BEFORE input time digit 2 = 1 -> filled data using KBR1C digit 3 = Not Defined digit 4 = Not Defined digit 5 = Not Defined digit 6 = Not Defined digit 7 = Not Defined

Table 34. TC61A Record Format

Column #	TC61A UTC to TDB time correlation
1.	UTC, in integer seconds
2.	UTC, microseconds part
3.	Time scale where ‘U’ = UTC
4.	GRAIL satellite ID ‘X’ to indicate a single product for two spacecraft
5.	Not applicable
6.	eps_time (seconds), where TDB = UTC + eps_time
7.	Formal error on eps_time (s); if not calculated, then set to 0
8.	Clock drift (s/s) deps_time/dt
9.	Formal error on clock drift (s/s); if not calculated, then set to 0
10.	bitrate of SFDU packet ; if not calculated, then set to 0
11.	delay by bitrate of SFDU packet; if not calculated, then set to 0
12.	data quality flags (digit 0 is on the right, digit 7 is on the left) Set digits (value = 1) have the following meanings: digit 0 = 1 -> linear extrapolation not valid AFTER input time digit 1 = 1 -> linear extrapolation not valid BEFORE input time digit 2 = 1 -> filled data using KBR1C digit 3 = Not Defined digit 4 = Not Defined digit 5 = Not Defined digit 6 = Not Defined digit 7 = Not Defined

Table 35. THR1A Record Format

Column #	THR1A Level 1A Thruster Activation Data
1.	UTC SCET, integer seconds past 12:00:00 noon 01-Jan-2000
2.	UTC SCET, microseconds part
3.	Time reference frame where 'U' = UTC SCET
4.	GRAIL satellite ID ‘A’ or ‘B’
5-12.	Count of number of work cycles that each thruster has been activated Set to 0 for GRAIL.
13-20.	Thruster on-time for this activation time (milliseconds)
21-28.	Accumulated thruster firing duration time (milliseconds) integer will wrap after 4294967295
29.	data quality flags (digit 0 is on the right and digit 7 is on the left) Set digits (value = 1) have the following meanings: digit 0 = 1 On time not calculated digit 1 = 1 Multiple unaccounted thrusts prior to current record

	digit 2 = Not Defined digit 3 = Not Defined digit 4 = Not Defined digit 5 = Not Defined digit 6 = Not Defined digit 7 = Not Defined

Table 36. USO1A Record Format

Column #	USO1A Level 1A Ultra Stable Oscillator Stability Data
1.	TDB, seconds past 12:00:00 noon 01-Jan-2000
2.	GRAIL satellite ID 'A' or 'B'
3.	USO identification number set to 0
4.	Not applicable, set to 0
5.	X-Band RSB frequency (Hz)
6.	Not applicable, set to 0
7.	data quality flags (digit 0 is on the right and digit 7 is on the left) Set digits (value = 1) have the following meanings: digit 0 = Not Defined digit 1 = Not Defined digit 2 = Not Defined digit 3 = Not Defined digit 4 = Not Defined digit 5 = Not Defined digit 6 = Not Defined digit 7 = Not Defined

Table 37. VCM1A Record Format

Column #	VCM1A Level 1A Center of mass displacement from spacecraft mechanical frame origin
1.	UTC SCET, seconds past 12:00:00 noon 01-Jan-2000
2.	GRAIL satellite ID 'A' or 'B'
3.	Magnitude of center of mass vector in mechanical frame (m)
4.	Direction cosine of vector with Mechanical Reference Frame x-axis
5.	Direction cosine of vector with Mechanical Reference Frame y-axis
6.	Direction cosine of vector with Mechanical Reference Frame z-axis
7.	data quality flags (digit 0 is on the right and digit 7 is on the left) Set digits (value = 1) have the following meanings: digit 0 = Not Defined digit 1 = Not Defined digit 2 = Not Defined digit 3 = Not Defined digit 4 = Not Defined digit 5 = Not Defined digit 6 = Not Defined digit 7 = Not Defined

Table 38. WRS1A Record Format

Column #	WRS1A Level 1A Wheel rotational speed data
1.	UTC SCET Activation time, integer seconds past 12:00:00 noon 01-01-2000
2.	Activation time, microseconds part

3.	Time reference frame where 'U' = UTC time
4.	GRAIL satellite id ‘A’ or ‘B’
5.	Reaction wheel 1 rotational speed as determined by digital tachometer (radians/sec)
6.	Reaction wheel 2 rotational speed as determined by digital tachometer (radians/sec)
7.	Reaction wheel 3 rotational speed as determined by digital tachometer (radians/sec)
8.	Reaction wheel 4 rotational speed as determined by digital tachometer (radians/sec)
7.	data quality flags (digit 0 is on the right and digit 7 is on the left) Set digits (value = 1) have the following meanings: digit 0 = Not Defined digit 1 = Not Defined digit 2 = Not Defined digit 3 = Not Defined digit 4 = Not Defined digit 5 = Not Defined digit 6 = Not Defined digit 7 = Not Defined

5.2.2.2 Level 1B

Table 39. CLK1B Record Format

Column #	CLK1B Level 1B LGRS + bias to TDB Time correlation
1	LGRS time +Bias , seconds past 12:00:00 noon 01-Jan-2000 (s)
2.	GRAIL satellite ID ‘A’ or ‘B’
3.	Clock ID (set to 1)
4.	eps_time (seconds), where TDB = LGRS time + Bias + eps_time
5.	Formal error on eps_time (s) (not used by GRAIL, set to 0)
6.	Clock drift (s/s) deps_time/dt
7.	Formal error on clock drift (s/s); if not calculated, then set to 0
8.	data quality flags (digit 0 is on the right, digit 7 is on the left) Set digits (value = 1) have the following meanings: digit 0 = 1 -> linear extrapolation not valid AFTER LGRS time + bias digit 1 = 1 -> linear extrapolation not valid BEFORE LGRS time + bias digit 2 = Not Defined digit 3 = Not Defined digit 4 = Not Defined digit 5 = Not Defined digit 6 = Not Defined digit 7 = Not Defined

Table 40. EHK1B Record Format

Column #	EHK1B Level 1B Spacecraft temperature sensor data from Engineering Housekeeping data for KBR data correction
1.	TDB, integer seconds past 12:00:00 noon 01-Jan-2000
2.	TDB, microseconds part
3.	Time reference frame where 'T' = TDB
4.	GRAIL satellite ID ‘A’ or ‘B’
5.	Microwave Assembly T1 temperature in C
6.	Microwave Assembly T2 temperature in C
7.	Waveguide transmit Ka-Band Assembly temperature in C
8.	Waveguide transmit Microwave Assembly temperature in C
9.	Waveguide Rx Mid temperature in C
10.	Waveguide Tx Mid temperature in C
11.	Aperture temperature in C
12.	Radome temperature in C
13.	HornBase temperature in C
14.	Midway on Horn temperature in C
15.	Orthomode Transducer (where transmit and receive modules are split off at base of horn) temperature in C
16.	data quality flags (digit 0 is on the right, digit 7 is on the left) Set digits (value = 1) have the following meanings: digit 0 = Not Defined digit 1 = Not Defined digit 2 = Not Defined digit 3 = Not Defined digit 4 = Not Defined digit 5 = Not Defined digit 6 = Not Defined

	digit 7 = Not Defined

Table 41. GNI1B Record Format

Column #	GNI1B Navigation Level 1B satellite orbit solution in Moon-centered Inertial frame
1.	TDB, seconds past 12:00:00 noon 01-Jan-2000
2.	GRAIL satellite ID, '1' for GRAIL-A, '2' for GRAIL-B
3.	Coordinate reference frame where 'I' = Inertial centered on Moon in EME 2000 Solar System Barycentric Frame
4.	Position, x value (m)
5.	Position, y value (m)
6.	Position, z value (m)
7.	Formal error on x position (m); if not calculated, then set to 0
8.	Formal error on y position (m); if not calculated, then set to 0
9.	Formal error on z position (m); if not calculated, then set to 0
10.	Velocity along x-axis (m/s)
11.	Velocity along y-axis (m/s)
12.	Velocity along z-axis (m/s)
13.	Formal error in velocity along x-axis (m/s); if not calculated, then set to 0
14.	Formal error in velocity along y-axis (m/s); if not calculated, then set to 0
15.	Formal error in velocity along z-axis (m/s); if not calculated, then set to 0
16.	Data quality flags (digit 0 is on the right and digit 7 is on the left) Set digits (value = 1) have the following meanings: digit 0 = Not Defined digit 1 = Not Defined digit 2 = Not Defined digit 3 = Not Defined digit 4 = Not Defined digit 5 = Not Defined digit 6 = Not Defined digit 7 = Not Defined

Table 42. GNV1B Record Format

Column #	GNV1B Navigation Level 1B Satellite orbit solution in lunar body fixed frame
1.	TDB, seconds past 12:00:00 noon 01-Jan-2000
2.	GRAIL satellite ID, '1' for GRAIL-A, '2' for GRAIL-B
3.	Coordinate reference frame where 'M' = Moon-centered-body-fixed
4.	Position, x value (m)
5.	Position, y value (m)
6.	Position, z value (m)
7.	Formal error on x position (m); if not calculated, then set to 0
8.	Formal error on y position (m); if not calculated, then set to 0
9.	Formal error on z position (m); if not calculated, then set to 0
10.	Velocity along x-axis (m/s)
11.	Velocity along y-axis (m/s)
12.	Velocity along z-axis (m/s)
13.	Formal error in velocity along x-axis (m/s); if not calculated, then set to 0
14.	Formal error in velocity along y-axis (m/s); if not calculated, then set to 0
15.	Formal error in velocity along z-axis (m/s); if not calculated, then set to 0
16.	Data quality flags (digit 0 is on the right and digit 7 is on the left)

	Set digits (value = 1) have the following meanings: digit 0 = Not Defined digit 1 = Not Defined digit 2 = Not Defined digit 3 = Not Defined digit 4 = Not Defined digit 5 = Not Defined digit 6 = Not Defined digit 7 = Not Defined

Table 43. KBR1C Record Format

Column #	KBR1C Level 1B Dual-One-Way Ka-Band Ranging Data
1.	TDB, seconds past 12:00:00 noon 01-Jan-2000
2.	Biased dual one-way range between GRAIL-A and GRAIL-B (m)
3.	Range rate between GRAIL-A and GRAIL-B (m/s)
4.	Range acceleration between GRAIL-A and GRAIL-B (m/s**2)
5.	Biased ionospheric range correction between GRAIL-A and GRAIL-B for Ka-Band frequency (m). If not calculated, then set to 0
6.	Time of flight range correction between GRAIL-A and GRAIL-B (m). Includes relativistic effects.
7.	Time of flight range rate correction between GRAIL-A and GRAIL-B (m/sec). Includes relativistic effects.
8.	Time of flight range acceleration correction between GRAIL-A and GRAIL-B (m/sec^2). Includes relativistic effects.
9.	Ka-band antenna offset range correction (m)
10.	Ka-band antenna range rate correction (m/s)
11.	Ka-band antenna range acceleration correction (m/sec^2)
12.	Undefined (set to 0)
13.	SNR Ka band for GRAIL-A 0.1 db-Hz
14.	Undefined (set to 0)
15.	SNR Ka band for GRAIL-B 0.1 db-Hz
16. 17. 18. 19. 20.	data quality flags (digit 0 is on the right and digit 7 is on the left) Set digits (value = 1) have the following meanings: digit 0 = Not Defined digit 1 = From raw data for Ka boresight calibration slew for antenna correction data digit 2 = Not Defined digit 3 = Not Defined digit 4 = Not Defined digit 5 = Not Defined digit 6 = Not Defined digit 7 = Not Defined Raw temperature range correction (m) Filtered temperature range correction (m) Filtered temperature range rate correction (m/s) Filtered temperature range acceleration correction (m/s/s)

Table 44. MAS1B Record Format

Column #	MAS1B Level 1B Spacecraft Mass Data
1.	TDB, integer seconds past 12:00:00 noon 01-Jan-2000
2.	TDB, microseconds part
3.	Time reference frame where 'T' = TDB

4.	GRAIL satellite ID 'A' or 'B'
5.	data quality flags (digit 0 is on the right and digit 7 is on the left) Set digits (value = 1) have the following meanings: digit 0 = Not Defined digit 1 = Not Defined digit 2 = Not Defined digit 3 = Not Defined digit 4 = Not Defined digit 5 = Not Defined digit 6 = Not Defined digit 7 = Not Defined
6.	data product flags. Set digits indicate quantities stored in following columns as follows (digit 0 is on the right and digit 7 is on the left): Set digits (value = 1) have the following meanings: digit 0 = spacecraft mass based on propellant consumption digit 1 = undefined digit 2 = undefined digit 3 = undefined digit 4 = undefined digit 5 = undefined digit 6 = undefined digit 7 = undefined
7	Spacecraft Mass based on propellant consumption in kg..

Table 45. SAE1B Record Format

Column #	SAE1B Level 1B Solar array eclipse data
1.	TDB, integer seconds past 12:00:00 noon 01-Jan-2000
2.	TDB, microseconds part
3.	Time reference frame where 'T' = TDB
4.	GRAIL satellite ID 'A' or 'B'
5.	Solar array short circuit current (Amperes / 2.442000E-04), as reported by the Solar Array Battery Control
6.	Solar array open circuit voltage (Volts / 9.760000E-04), as reported by the Solar Array Battery Control
7.	data quality flags (digit 0 is on the right and digit 7 is on the left) Set digits (value = 1) have the following meanings: digit 0 = Not Defined digit 1 = Not Defined digit 2 = Not Defined digit 3 = Not Defined digit 4 = Not Defined digit 5 = Not Defined digit 6 = Not Defined digit 7 = Not Defined

Table 46. SBR1B Record Format

Column #	SBR1B Level 1B Biased dual one-way S-Band Ranging data
1.	TDB, seconds past 12:00:00 noon 01-Jan-2000
2.	Biased dual one-way range between GRAIL-A and B (m)
3.	Range rate between GRAIL-A and -B (m/s)
4.	Range acceleration between GRAIL-A & -B (m/s**2)

5.	Not Defined. Set to 0 for GRAIL
6.	Not defined. Set to 0 for GRAIL
7.	Not defined. Set to 0 for GRAIL
8.	Not defined. Set to 0 for GRAIL
9.	Not defined. Set to 0 for GRAIL
10.	Not defined. Set to 0 for GRAIL
11.	Not defined. Set to 0 for GRAIL
12.	Not defined. Set to 0 for GRAIL
13.	Not defined. Set to 0 for GRAIL
14.	Not defined. Set to 0 for GRAIL
15.	Not defined. Set to 0 for GRAIL
16.	data quality flags (digit 0 is on the right and digit 7 is on the left) Set digits (value = 1) have the following meanings: digit 0 = Not Defined digit 1 = From raw data for Ka boresight calibration slew for antenna correction data digit 2 = Not Defined digit 3 = Not Defined digit 4 = Not Defined digit 5 = Not Defined digit 6 = Not Defined digit 7 = Not Defined

Table 47. SCA1B Record Format

Column #	SCA1B Level 1B Star Tracker Data
1.	TDB, seconds past 12:00:00 noon 01-Jan-2000
2.	GRAIL satellite ID ‘A’ or ‘B’
3.	SCA identification number set to 1
4.	Cos mu/2 element of quaternion
5.	I element of quaternion rotation axis
6.	J element of quaternion rotation axis
7.	K element of quaternion rotation axis
8.	rss of formal error of quaternions; if not calculated, then set to 0
9.	data quality flags (digit 0 is at the right and digit 7 is at the left) Set digits (value = 1) have the following meanings: digit 0 = Data filled by interpolation digit 1 = Ka boresight calibration periodor prediction change period digit 2 = Not Defined digit 3 = Not Defined digit 4 = Not Defined digit 5 = Not Defined digit 6 = Not Defined digit 7 = Not Defined

Table 48. THR1B Record Format

Column #	THR1B Level 1B Thruster Activation Data
1.	TDB, integer seconds past 12:00:00 noon 01-Jan-2000
2.	TDB, microseconds part
3.	Time reference frame where 'T' = TDB
4.	GRAIL satellite ID ‘A’ or ‘B’
5-12.	Count of number of work cycles that each thruster has been activated

	Set to 0 for GRAIL.
13-20.	Thruster on-time for this activation time (milliseconds)
21-28.	Accumulated thruster firing duration time (milliseconds) integer will wrap after 4294967295
29.	data quality flags (digit 0 is on the right and digit 7 is on the left) Set digits (value = 1) have the following meanings: digit 0 = 1 On time not calculated digit 1 = 1 Multiple unaccounted thrusts prior to current record digit 2 = Not Defined digit 3 = Not Defined digit 4 = Not Defined digit 5 = Not Defined digit 6 = Not Defined digit 7 = Not Defined

Table 49. USO1B Record Format

Column #	USO1B Level 1B Ultra Stable Oscillator Stability Data
1.	TDB, seconds past 12:00:00 noon 01-Jan-2000
2.	GRAIL satellite ID ‘A’ or ‘B’
3.	USO identification number set to 0
4.	Frequency of USO (Hz)
5.	X-Band RSB frequency (Hz)
6.	Ka band frequency of KBR (Hz) for USO1B
7.	data quality flags (digit 0 is on the right and digit 7 is on the left) Set digits (value = 1) have the following meanings: digit 0 = Not Defined digit 1 = Not Defined digit 2 = Not Defined digit 3 = Not Defined digit 4 = Not Defined digit 5 = Not Defined digit 6 = Not Defined digit 7 = Not Defined

Table 50. VCM1B Record Format

Column #	VCM1B Level 1B Center of mass displacement from spacecraft mechanical frame origin
1.	TDB, seconds past 12:00:00 noon 01-Jan-2000
2.	GRAIL satellite ID ‘A’ or ‘B’
3.	Magnitude of center of mass vector in mechanical frame (m)
4.	Direction cosine of vector with Mechanical Reference Frame x-axis
5.	Direction cosine of vector with Mechanical Reference Frame y-axis
6.	Direction cosine of vector with Mechanical Reference Frame z-axis
7.	data quality flags (digit 0 is on the right and digit 7 is on the left) Set digits (value = 1) have the following meanings: digit 0 = Not Defined digit 1 = Not Defined digit 2 = Not Defined digit 3 = Not Defined digit 4 = Not Defined digit 5 = Not Defined digit 6 = Not Defined

	digit 7 = Not Defined

Table 51. VGS1B Record Format

Column #	VGS1B S-Band antenna offset vector and switch time (TDB)
1.	TDB, seconds past 12:00:00 noon 01-Jan-2000
2.	GRAIL satellite ID ‘A’ or ‘B’
3.	Magnitude of vector (m) for active antenna in mechanical reference frame
4.	Direction cosine of vector with Mechanical Reference Frame x-axis
5.	Direction cosine of vector with Mechanical Reference Frame y-axis
6.	Direction cosine of vector with Mechanical Reference Frame z-axis
7.	data quality flags (digit 0 is on the right and digit 7 is on the left) Set digits (value = 1) have the following meanings: digit 0 = Not Defined digit 1 = Not Defined digit 2 = Not Defined digit 3 = Not Defined digit 4 = Not Defined digit 5 = Not Defined digit 6 = Not Defined digit 7 = Not Defined

Table 52. VGX1B Record Format

Column #	VGX1B X-Band antenna offset vector and switch time (TDB)
1.	TDB, seconds past 12:00:00 noon 01-Jan-2000 in TDB
2.	GRAIL satellite ID ‘A’ or ‘B’
3.	Magnitude of vector (m) for active antenna in mechanical reference frame
4.	Direction cosine of vector with Mechanical Reference Frame x-axis
5.	Direction cosine of vector with Mechanical Reference Frame y-axis
6.	Direction cosine of vector with Mechanical Reference Frame z-axis
7.	data quality flags (digit 0 is on the right and digit 7 is on the left) Set digits (value = 1) have the following meanings: digit 0 = Not Defined digit 1 = Not Defined digit 2 = Not Defined digit 3 = Not Defined digit 4 = Not Defined digit 5 = Not Defined digit 6 = Not Defined digit 7 = Not Defined

Table 53. VKB1B Record Format

Column #	VKB1B Ka-Band Boresight Vector
1.	TDB, seconds past 12:00:00 noon 01-Jan-2000
2.	GRAIL satellite ID ‘A’ or ‘B’
3.	Magnitude of vector (m) for active antenna in science reference frame for VKB1B
4.	Direction cosine of vector with Science Reference Frame x-axis
5.	Direction cosine of vector with Science Reference Frame y-axis
6.	Direction cosine of vector with Science Reference Frame z-axis
7.	data quality flags (digit 0 is on the right and digit 7 is on the left) Set digits (value = 1) have the following meanings: digit 0 = Not Defined

	digit 1 = Not Defined digit 2 = Not Defined digit 3 = Not Defined digit 4 = Not Defined digit 5 = Not Defined digit 6 = Not Defined digit 7 = Not Defined

Table 54. WRS1B Record Format

Column #	WRS1B Level 1B Wheel rotational speed data
1.	TDB Activation time, integer seconds past 12:00:00 noon 01-01-2000
2.	Activation time, microseconds part
3.	Time reference frame where 'T' = TDB time
4.	GRAIL satellite id ‘A’ or ‘B’
5.	Reaction wheel 1 rotational speed as determined by digital tachometer (radians/sec)
6.	Reaction wheel 2 rotational speed as determined by digital tachometer (radians/sec)
7.	Reaction wheel 3 rotational speed as determined by digital tachometer (radians/sec)
8.	Reaction wheel 4 rotational speed as determined by digital tachometer (radians/sec)
7.	data quality flags (digit 0 is on the right and digit 7 is on the left) Set digits (value = 1) have the following meanings: digit 0 = Not Defined digit 1 = Not Defined digit 2 = Not Defined digit 3 = Not Defined digit 4 = Not Defined digit 5 = Not Defined digit 6 = Not Defined digit 7 = Not Defined

5.2.3 RSS EDR Products

For all products all except XFR, TDM and BTM, see documentation in Table 2 for format descriptions.

TDMs and BTMs are in ASCII format and are delimited by a single white space as described in Tables 55 and 56.

Table 55. BTM Record Format

Column #	BTM Biased Tracking Data Message – Biased X-Band Sky Frequency relative to frequency offset, from RSR data recorded at the DSN
1.	Data Field: set to RECEIVE_FREQ_2 for GRAIL 1-way downlink
2.	= sign
3.	UTC Earth Received Time in YYYY-MM-DDThh:mm:ss.###
4.	Frequency (Hz), defined as sky frequency minus FREQ_OFFSET as provided in metadata section

Table 56. TDM Record Format

Column #	TDM Tracking Data Message - X-Band Sky Frequency relative to frequency offset, from RSR data recorded at the DSN
1.	Data Field: set to RECEIVE_FREQ_2 for GRAIL 1-way downlink
2.	= sign

3.	UTC Earth Received Time in YYYY-MM-DDThh:mm:ss.###
4.	Frequency (Hz), defined as sky frequency minus FREQ_OFFSET as provided in metadata section

XFR data are in ASCII format and are delimited by a variable number of white spaces as described in Table 53.

Table 57. XFR Record Format

Column #	XFR X-Band Sky Frequency from RSR data recorded at the DSN
1.	Year (UTC Earth Received Time)
2.	Day of Year (UTC Earth Received Time)
3.	Seconds Past Midnight (UTC Earth Received Time)
4.	Sky Frequency (Hz)
5.	Internal processing parameter generated in the course of creating the XFR but not relevant to GRAIL
6.	Internal processing parameter generated in the course of creating the XFR but not relevant to GRAIL

5.3 Header Descriptions

5.3.1 Headers for LGRS EDR

Header information for S7200, S7300, and STC00 in LGRS EDR is found in the respective documentation in the DOCUMENT directory.

DTC00, EHK00, SAE00, SCA00, THR00, and WRS00 data files have four-row headers which contain standard description abbreviations from the GDS system. One of the rows contains, as a guideline only, format descriptions of the minimum number of digits in the data field.

LTB00 data files contain no header.

MAS00 data files have a four-row header. The column headers describe the data which follow.

TDE00 data files have a two-row header which includes a reference start time.

5.3.2 Headers for LGRS CDR

Each Level 1A or 1B ASCII data file contains a header with records of (at most) 80 bytes. The last ASCII header record is labeled "END OF HEADER" and is not counted in the number of header records. After the last header record, one or more data records follow.

The ASCII header for each format contains information similar to the following, with a variable number of lines being possible (a CLK1B header for GRAIL-B is used as an example):

```
PRODUCER AGENCY               : NASA
PRODUCER INSTITUTION          : JPL
FILE TYPE ipCLK1BF            : 17
FILE FORMAT 0=BINARY 1=ASCII  : 1
NUMBER OF HEADER RECORDS      : 23
SOFTWARE VERSION              : $Id: CombineLevel1.c 422 08-14/12 20:25:58 mp $
```

```
SOFTWARE LINK TIME             : @(#) 2012-08-20 18:03:05 mpaik  nearside.fltops
REFERENCE DOCUMENTATION        : GRAIL Level 1 Software Handbook
SATELLITE NAME                 : GRAIL A
SENSOR NAME                    : N/A
TIME EPOCH                     : 2000-01-01 12:00:00
TIME FIRST OBS(SEC PAST EPOCH): 384177600.000000 (2012-03-05 00:00:00.00)
TIME LAST OBS(SEC PAST EPOCH) : 384263990.000000 (2012-03-05 23:59:50.00)
NUMBER OF DATA RECORDS         : 8640
PRODUCT CREATE START TIME(UTC): 2012-08-21 01:32:22 by mpaik
PRODUCT CREATE END TIME(UTC)  : 2012-08-21 01:32:23 by mpaik
FILESIZE (BYTES)               : 572688
FILENAME                       : CLK1B_2012-03-05_A_02.asc
PROCESS LEVEL (1A OR 1B)       : 1B
INPUT FILE NAME                : CLK1B<-CLK1B_2012-03-01_A_00.dat_2012-07_04
INPUT FILE TIME TAG (UTC)      : CLK1B<-2011-01-31 20:56:03 by mpaik
INPUT FILE SOFTWARE VERSION    : CLK1B<-CombineLevel1.c 1.39 04/21/10 13:08:57 g
INPUT FILE LINKTIME TAG        : CLK1B<-2009-12-22 10:14:18 mpaik  itzhak
END OF HEADER
```

5.3.3 Headers for LGRS RDR

Header information for all LGRS RDR data types is found in the respective documentation in the DOCUMENT directory.

5.3.4 Headers for RSS EDR

Header information for all RSS EDR data types except TDM, BTM, and XFR is found in the respective documentation in the DOCUMENT directory.

XFR data files contain no header.

Each TDM or BTM contains a header similar to the following:

```
CCSDS_TDM_VERS = 1.0
COMMENT CREATED BY RADIO SCIENCE SYSTEMS GROUP 332K JPL
CREATION_DATE  = 2012-03-02T04:37:03
ORIGINATOR     = NASA/JPL/DSN
```

The header is followed by a metadata description similar to the following:

```
META_START
COMMENT SKY FREQUENCY COMPUTED FROM OPEN-LOOP DATA
TIME_SYSTEM            = UTC
START_TIME             = 2012-03-01T12:32:18.500
STOP_TIME              = 2012-03-02T00:53:30.500
PARTICIPANT_1          = GRAIL-A
PARTICIPANT_2          = DSS-65
MODE                   = SEQUENTIAL
PATH                   = 1,2
RECEIVE_BAND           = X
TURNAROUND_NUMERATOR   = 880
TURNAROUND_DENOMINATOR = 240
```

```
TIMETAG_REF             = RECEIVE
INTEGRATION_INTERVAL    = 1.000
INTEGRATION_REF         = MIDDLE
FREQ_OFFSET             = 8451600000
META_STOP
```

```
The data records are preceded by the string DATA_START and followed by the string
DATA_STOP.
```

6 Applicable Software

All products have already been processed with the appropriate software by the GRAIL SDS. Software in this archive is provided as an example only. The SOFTWARE directory contents are listed in table 2.9 of the Archive Volume SIS [16].

6.1 Utility Programs

The SOFTWARE directory on the GRAIL_0001 volume (GRAIL-L-LGRS-2-EDR-V1.0) contains utilities or application programs to aid the user in viewing or extracting data from the Level 0 data product files. The codes are provided as illustrations of how to extract the Blackjack packets from Blackjack binary data. See section 4.2.1 for a description of Blackjack.

7 Appendices

7.1 Glossary

Barycenter - center of mass; the unique point where the weighted relative position of a distributed mass sums to zero.

Barycentric Dynamical Time - the independent argument of ephemerides and dynamical theories that are referred to the solar system barycenter. See http://tycho.usno.navy.mil/systime.html for more information.

Base Time Clock (BTC) - On-board satellite clock, comparable in stability to a wristwatch. Roughly synced to UTC at launch time.

Coordinated Universal Time (UTC) - differs from International Atomic Time by an integral number of seconds. See http://tycho.usno.navy.mil/systime.html for more information.

Blackjack - a data format utilized by the science instruments on board the GRACE and GRAIL projects to encode telemetry.

Dual One Way Range (DOWR) - instantaneous measurement of distance, including a bias, between two spacecraft, which is formed by the combination of a range signal from spacecraft A to spacecraft B and from spacecraft B to spacecraft A.

Ephemeris - a table of values that gives the positions of astronomical objects at given times.

Gravity Recovery Processor Assembly (GPA) - the equipment that combines all the inputs received from the microwave assembly and the time transfer assembly to produce the radiometric data that are downlinked to the ground.

International Atomic Time (TAI) - the International Atomic Time scale, a statistical timescale based on a large number of atomic clocks. See http://tycho.usno.navy.mil/systime.html for more information.

Inertial Measurement Unit - an electronic device that measures and reports on a spacecraft's rotational velocities and accelerations experienced by the instrument.

Ka-Band - part of the microwave electromagnetic spectrum between 26.5 and 40 GHz.

Kalman filter - an algorithm which uses a series of measurements observed over time, containing noise (random variations) and other inaccuracies, and produces estimates of unknown variables that tend to be more precise than those that would be based on a single measurement alone.

Lunar Gravity Ranging System - The equipment responsible for sending and receiving the signals needed to accurately and precisely measure the changes in range between the two orbiters. Consists of an Ultra-Stable Oscillator (USO), Microwave Assembly (MWA), a Time-Transfer Assembly (TTA), and the Gravity Recovery Processor Assembly (GPA).

Microwave Assembly (MWA) - the equipment that converts the USO reference signal to Ka-band frequency, which is transmitted to the other orbiter.

Open Loop - does not use feedback to determine if the output has achieved the desired goal of the input.

Quaternion - A vector with four components that describes the attitude of a spacecraft. [36].

Radio Science - Utilization of the telecommunication links between spacecraft and Earth for scientific application involving examination of (sometimes very small) changes in the phase/frequency, amplitude, and/or polarization of radio signals.

Radio Science Receiver - a computer-controlled open loop receiver that digitally down-converts and records a spacecraft signal spectrum using an analog-to-digital converter (ADC) and up to four digital filter sub-channels.

Real Time Clock (RTC) - Flight software clock. Set to 0 when booted. Relatively unstable clock.

S-Band - part of the microwave electromagnetic spectrum between 2 and 4 GHz.

Science Data System (SDS) - the infrastructure at NASA's Jet Propulsion Laboratory (JPL) for the collection of all science and ancillary data relevant to the GRAIL mission. Includes hardware, software tools, procedures, and trained personnel. The SDS receives science packets and engineering data and carries out calibration, editing, and processing to produce NASA Level 1A and 1B GRAIL science data.

Time Transfer Assembly (TTA) - the equipment that generates an S-band signal from the USO reference frequency and sends a GPS-like ranging code to the other spacecraft. The function of the TTA is to provide a two-way time-transfer link between the spacecraft to both synchronize and measure the clock offset between the two LGRS clocks.

Ultra Stable Oscillator - electronic assembly that provides a highly stable timing and frequency reference signal onboard a spacecraft that is used by all of the instrument subsystems, typically based on ovenized quartz crystal or Rubidium atomic standard.

X-Band - part of the microwave radio region of the electromagnetic spectrum between 7 and 12 GHz.

7.2 Acronyms

ACS	Attitude control system
ADC	Analog-Digital Converter
AMMOS	Advanced Multi-Mission Operations System
ASCII	American Standard Code for Information Interchange
BTC	Base Time Clock
CCK	Spacecraft Orientation Kernel
CDR	Calibrated Data Record
CODMAC	Committee on Data Management, Archiving, and Computation
DOWR	Dual One Way Range
DSCC	Deep Space Communications Complex
DRF	Data Record File

DSN	Deep Space Network
DTE	Direct to Earth
EDR	Experimental Data Record
EPS	Epsilon
FTS	Frequency and Timing Subsystem
GDS	Ground Data System
GHz	gigahertz
GRACE	Gravity Recovery and Climate Experiment
GRAIL	Gravity Recovery and Interior Laboratory
GRLSCI	GRAIL Science
ICRF	International Celestial Reference Frame
IMU	Inertial Measurement Unit
JPL	Jet Propulsion Laboratory
KBR	Ka-Band Ranging System
LGA	Low Gain Antenna
LGRS	Lunar Gravity Ranging System
LSK	Leap Second Kernel
MF	Mechanical Frame
MMDOM	Multi-Mission Distributed Object Manager
MOC	Mission Operations Center
MOS	Mission Operations System
NAIF	Navigation and Ancillary Information Facility
NASA	National Aeronautics and Space Administration
ODF	Orbit Data File
OMC	Operations and Maintenance Contract
OSC	Onboard Spacecraft Clock
PDS	Planetary Data System
PPS	Pulse per Second
RDR	Reduced Data Record
RODAN	Radio Occultation Data Analysis Network
RSB	Radio Science Beacon
RSDMAP	Radio Science Digital Map
RSR	Radio Science Receiver
RSS	Radio Science Systems
RTC	Real-Time Clock
SABC	Solar Array Battery Control
SBR	S-Band Ranging System
SCA	Star Tracker Assembly
SCLK	Spacecraft Clock Kernel
SDS	Science Data System
SF	Satellite Frame
SFDU	Standard Formatted Data Unit
SIS	Software Interface Specification
SHADR	Spherical Harmonic ASCII Data Record
SHBDR	Spherical Harmonic Binary Data Record
SOE	Sequence of Events file
SPICE	**S-** Spacecraft ephemeris, given as a function of time. **P-** Planet, satellite, comet, or asteroid ephemerides, or more generally, location of any target body, given as a function of time. The P kernel also logically includes certain physical, dynamical and cartographic constants for target bodies, such as size and shape specifications, and orientation of the spin axis and prime meridian. **I-** Instrument description kernel, containing descriptive data peculiar to a particular scientific instrument, such as field-of-view size, shape and orientation parameters. **C-** Pointing kernel, containing a transformation, traditionally called the C-matrix, which

provides time-tagged pointing (orientation) angles for a spacecraft structure upon which science instruments are mounted. May also include angular rate data.
E- Events kernel, summarizing mission activities - both planned and unanticipated. Events data are contained in the SPICE EK file set, which consists of three components: Science Plans, Sequences, and Notes.

SPK	Spacecraft and Planetary Ephemeris Kernel
SRF	Science Reference Frame
TAI	International Atomic Time
TBD	To Be Done
TDB	Barycentric Dynamical Time
TDS	Telemetry Delivery System
TTS	Time Transfer System
USO	Ultra-Stable Oscillator
UTC	Coordinated Universal Time
V/V	Volts per Volt

7.3 Example PDS Labels

7.3.1 LGRS EDR

Products in the LGRS EDR data set (GRAIL-L-LGRS-2-EDR-V1.0) all have labels similar to the following:

```
PDS_VERSION_ID         = PDS3
RECORD_TYPE            = UNDEFINED
INSTRUMENT_NAME        = "LUNAR GRAVITY RANGING SYSTEM A"
TARGET_NAME            = "MOON"
DATA_SET_ID            = "GRAIL-L-LGRS-2-EDR-V1.0"
MISSION_NAME           = "GRAVITY RECOVERY AND INTERIOR LABORATORY"
INSTRUMENT_HOST_NAME   = "GRAVITY RECOVERY AND INTERIOR LABORATORY A"
PRODUCT_ID             = "STC00_2012_03_01_A_02.DAT"
FILE_NAME              = "STC00_2012_03_01_A_02.DAT"
ORIGINAL_PRODUCT_ID    = "TIME_CORR_A.SFDU"
START_TIME             = 2012-061T00:00:00
STOP_TIME              = 2012-061T23:59:59
PRODUCT_CREATION_TIME  = 2012-061T23:59:59
OBSERVATION_TYPE       = SCIENCE
PRODUCER_ID            = "SDS"
NOTE                   = "Time Correlation SFDU"
^DESCRIPTION           = {"0161_TELECOMM_L5_8.TXT",
                          "0171_TELECOMM_NJPL_L5.TXT",
                          "090_REVC_1.TXT",
                          "0172_TELECOMM_CHDO_REVE_L5.TXT"}
END
```

7.3.2 LGRS CDR

Products in the LGRS CDR data set (GRAIL-L-LGRS-3-CDR-V1.0) all have labels similar to the following:

```
PDS_VERSION_ID         = PDS3
RECORD_TYPE            = STREAM
INSTRUMENT_NAME        = "LUNAR GRAVITY RANGING SYSTEM A"
TARGET_NAME            = "MOON"
```

```
DATA_SET_ID           = "GRAIL-L-LGRS-3-CDR-V1.0"
MISSION_NAME          = "GRAVITY RECOVERY AND INTERIOR LABORATORY"
INSTRUMENT_HOST_NAME  = "GRAVITY RECOVERY AND INTERIOR LABORATORY A"
PRODUCT_ID            = "CLK1A_2012_03_01_A_02.ASC"
FILE_NAME             = "CLK1A_2012_03_01_A_02.ASC"
ORIGINAL_PRODUCT_ID   = "CLK1A_2012-03-01_A_02.ASC"
START_TIME            = 2012-061T12:43:45
STOP_TIME             = 2012-061T22:53:47
PRODUCT_CREATION_TIME = 2012-234T01:05:25
OBSERVATION_TYPE      = SCIENCE
PRODUCER_ID           = "SDS"
NOTE                  = "Level 1A TDB to LGRS time correlation.
                         See Table 11 in DPSIS.PDF for format."
^DESCRIPTION          = "DPSIS.PDF"
END
```

7.3.3 RSS EDR

Labels in the RSS EDR data set (GRAIL-L-RSS-2-EDR-V1.0) may be minimal or full.

7.3.3.1 BTM, EOP, ION, TDM, TNF, TRO, WEA, & XFR

Data products BTM, EOP, ION, TDM, TNF [22], TRO, WEA, and XFR have labels similar to the following:

```
PDS_VERSION_ID        = PDS3
RECORD_TYPE           = UNDEFINED
INSTRUMENT_NAME       = "LUNAR GRAVITY RANGING SYSTEM A"
TARGET_NAME           = "MOON"
DATA_SET_ID           = "GRAIL-L-RSS-2-EDR-V1.0"
MISSION_NAME          = "GRAVITY RECOVERY AND INTERIOR LABORATORY"
INSTRUMENT_HOST_NAME  = "GRAVITY RECOVERY AND INTERIOR LABORATORY A"
PRODUCT_ID            = "GRALUGF2012_148_0520SMMMV1.TNF"
FILE_NAME             = "GRALUGF2012_148_0520SMMMV1.TNF"
START_TIME            = 2012-148T05:20:00
STOP_TIME             = 2012-149T06:52:53
PRODUCT_CREATION_TIME = 2012-209T22:28:18
OBSERVATION_TYPE      = SCIENCE
PRODUCER_ID           = "DSN"
DESCRIPTION           = "
    The TNF data type captures radiometric tracking data for delivery
    to navigation and radio science users from the Telecommunications
    Services at JPL.  The product replaces data types formerly known
    as Orbit Data Files, Archival Tracking Data Files, and others.
    Format and content of the TNF data product is documented in:

                             820-013
                   Deep Space Mission System (DSMS)
                   External Interface Specification
                            JPL D-16765
                             TRK-2-34
               DSMS Tracking System Data Archival Format
                      Jet Propulsion Laboratory
                        4800 Oak Grove Drive
                      Pasadena, CA  91109-8099
```

```
    Background information on the radiometric system may be found in:

             Formulation for Observed and Computed Values
           of Deep Space Network Data Types  for Navigation
                         by Theodore D. Moyer
                  JPL Publication 00-7, October 2000
     Monograph 2, Deep Space Communications and Navigation Series
                      Jet Propulsion Laboratory
                        4800 Oak Grove Drive
                      Pasadena, CA  91109-8099        "
END
```

7.3.3.2 ODF, OLF, and BOF

The ODF products have labels as follows. The OLF or BOF label is similar, with minor differences.

```
PDS_VERSION_ID             = PDS3
RECORD_TYPE                = FIXED_LENGTH
RECORD_BYTES               = 36
FILE_RECORDS               = 64288
DATA_SET_ID                = "GRAIL-L-RSS-2-EDR-V1.0"
TARGET_NAME                = "MOON"
INSTRUMENT_HOST_NAME       = "GRAVITY RECOVERY AND INTERIOR
                              LABORATORY A"
INSTRUMENT_NAME            = "LUNAR GRAVITY RANGING SYSTEM A"
INSTRUMENT_ID              = "LGRS-A"
PRODUCER_ID                = "DSN"
MISSION_NAME               = "GRAVITY RECOVERY AND INTERIOR
                              LABORATORY"
OBSERVATION_TYPE           = "SCIENCE"
DSN_STATION_NUMBER         = {45,24}
PRODUCT_CREATION_TIME      = 2012-151T17:12:37
PRODUCT_ID                 = "GRALUGF2012_148_0605SMMMV1.ODF"
ORIGINAL_PRODUCT_ID        = "GRALUGF2012_148_0605SMMMV1.ODF"
START_TIME                 = 2012-148T06:05:08
STOP_TIME                  = 2012-149T06:45:16
HARDWARE_MODEL_ID          = "TDDS"
SOFTWARE_NAME              = "AMMOS"
DESCRIPTION                = "Orbit Data Files (ODFs) are
    produced by the NASA/JPL Multi-Mission Navigation Radio
    Metric Data Conditioning Team for use in determining
    spacecraft trajectories, gravity fields affecting them,
    and radio propagation conditions.  Each ODF consists of
    many 36-byte logical records, which fall into 7 primary
    groups plus an End-of-File Group.  An ODF usually
    contains most groups, but may not have all.  The first
    record in each of the 7 primary groups is a header
    record; depending on the group, there may be from zero
    to many data records following each header.  The ODF is
    described in  JPL/DSN Document 820-13, TRK-2-18
    (various versions, with significant changes in April
    1997).  The latest version is included in this archive
    as NAV023_ODF_2_18_Rev3.htm in the DOCUMENT directory."
^ODF1A_TABLE               = ("MROMAGR2010_363_1716XMMMV1.ODF",1)
```

```
^ODF1B_TABLE                  = ("MROMAGR2010_363_1716XMMMV1.ODF",2)
^ODF2A_TABLE                  = ("MROMAGR2010_363_1716XMMMV1.ODF",3)
^ODF2B_TABLE                  = ("MROMAGR2010_363_1716XMMMV1.ODF",4)
^ODF3A_TABLE                  = ("MROMAGR2010_363_1716XMMMV1.ODF",5)
^ODF3C_TABLE                  = ("MROMAGR2010_363_1716XMMMV1.ODF",6)
^ODF4A26_TABLE                = ("MROMAGR2010_363_1716XMMMV1.ODF",58113)
^ODF4B26_TABLE                = ("MROMAGR2010_363_1716XMMMV1.ODF",58114)
^ODF4A43_TABLE                = ("MROMAGR2010_363_1716XMMMV1.ODF",58350)
^ODF4B43_TABLE                = ("MROMAGR2010_363_1716XMMMV1.ODF",58351)
^ODF4A55_TABLE                = ("MROMAGR2010_363_1716XMMMV1.ODF",58512)
^ODF4B55_TABLE                = ("MROMAGR2010_363_1716XMMMV1.ODF",58513)
^ODF8A_TABLE                  = ("MROMAGR2010_363_1716XMMMV1.ODF",58652)
^ODF8B_TABLE                  = ("MROMAGR2010_363_1716XMMMV1.ODF",58653)

OBJECT                        = ODF1A_TABLE
  NAME                          = "FILE LABEL GROUP HEADER"
  INTERCHANGE_FORMAT            = BINARY
  ROWS                          = 1
  COLUMNS                       = 4
  ROW_BYTES                     = 16
  ROW_SUFFIX_BYTES              = 20
  DESCRIPTION                   = "The File Label Group
     is usually the first of several groups of records in
     an Orbit Data File (ODF). It identifies the spacecraft,
     the file creation time, the hardware, and the software
     associated with the ODF.  The File Label Group Header
     is the first record in the File Label Group.  It is one
     36-byte record and is followed by one 36-byte data
     record.  Occasionally, the File Label Group is omitted
     from an ODF.  The row suffix bytes in the File Label
     Group Header are set to 0."

  OBJECT            = COLUMN
    COLUMN_NUMBER     = 1
    NAME              = "PRIMARY KEY"
    DATA_TYPE         = MSB_INTEGER
    START_BYTE        = 1
    BYTES             = 4
    DESCRIPTION = "Item 1:  The Primary Key indicates the type
       of data records to follow.  In the File Label Group Header
       this field is set to 101."
  END_OBJECT        = COLUMN

  OBJECT            = COLUMN
    COLUMN_NUMBER     = 2
    NAME              = "SECONDARY KEY"
    DATA_TYPE         = MSB_UNSIGNED_INTEGER
    START_BYTE        = 5
    BYTES             = 4
    DESCRIPTION = "Item 2:  The Secondary Key is not used in
       the ODF.  It is set to 0."
  END_OBJECT        = COLUMN

  OBJECT            = COLUMN
    COLUMN_NUMBER     = 3
```

```
    NAME             = "LOGICAL RECORD LENGTH"
    DATA_TYPE        = MSB_UNSIGNED_INTEGER
    START_BYTE       = 9
    BYTES            = 4
    UNIT             = PACKET
    DESCRIPTION = "Item 3:  The Logical Record Length gives the
       number of 36-byte physical records making up each logical
       record in a File Label Group data record.  For the File Label
       Group it is set to 1."
  END_OBJECT       = COLUMN

  OBJECT           = COLUMN
    COLUMN_NUMBER    = 4
    NAME             = "GROUP START PACKET NUMBER"
    DATA_TYPE        = MSB_UNSIGNED_INTEGER
    START_BYTE       = 13
    BYTES            = 4
    DESCRIPTION = "Item 4:  The Group Start Packet Number
       gives the number of the ODF packet containing the File
       Label Group Header.  Set to 0, since the File Label Group
       Header, when it appears, is always first."
  END_OBJECT       = COLUMN
END_OBJECT                   = ODF1A_TABLE

OBJECT                       = ODF1B_TABLE
  NAME                         = "FILE LABEL GROUP DATA"
  INTERCHANGE_FORMAT           = BINARY
  ROWS                         = 1
  COLUMNS                      = 7
  ROW_BYTES                    = 36
  DESCRIPTION                  = "The File Label Group
     is usually the first of several groups of records in
     an Orbit Data File (ODF). It identifies the spacecraft,
     the file creation time, the hardware, and the software
     associated with the ODF.  The File Label Group data
     record is the second record in the File Label Group. It
     is one 36-byte record and is preceded by one 36-byte
     File Label Group header record.  Occasionally, the File
     Label Group is omitted from an ODF."

  OBJECT           = COLUMN
    COLUMN_NUMBER    = 1
    NAME             = "SYSTEM ID"
    DATA_TYPE        = CHARACTER
    START_BYTE       = 1
    BYTES            = 8
    DESCRIPTION = "Items 1-8:  A character string identifying
       the hardware on which the ODF was created."
  END_OBJECT       = COLUMN

  OBJECT           = COLUMN
    COLUMN_NUMBER    = 2
    NAME             = "PROGRAM ID"
    DATA_TYPE        = CHARACTER
    START_BYTE       = 9
```

```
  BYTES             = 8
  DESCRIPTION = "Items 9-16:  A character string identifying
     the program under which the ODF was created."
END_OBJECT        = COLUMN

OBJECT            = COLUMN
  COLUMN_NUMBER     = 3
  NAME              = "SPACECRAFT ID"
  DATA_TYPE         = MSB_UNSIGNED_INTEGER
  START_BYTE        = 17
  BYTES             = 4
  DESCRIPTION = "Item 17:  ID number for the spacecraft.  These
       are specified in DSN document OPS-6-8.  Representative
       values include
                       Magellan              18
                       Voyager 1             31
                       Voyager 2             32
                       Clementine            64
                       Galileo Orbiter       77
                       Mars Global Surveyor  94"
END_OBJECT        = COLUMN

OBJECT            = COLUMN
  COLUMN_NUMBER     = 4
  NAME              = "FILE CREATION DATE"
  DATA_TYPE         = MSB_UNSIGNED_INTEGER
  START_BYTE        = 21
  BYTES             = 4
  DESCRIPTION = "Item 18:  The date on which the ODF was
     created, given as a single number of the form YYMMDD.
     where
              YY   is the two least significant digits of the year
              MM   is the month (01 through 12)
              DD   is the day of month (01 through 31)"
END_OBJECT          = COLUMN

OBJECT            = COLUMN
  COLUMN_NUMBER     = 5
  NAME              = "FILE CREATION TIME"
  DATA_TYPE         = MSB_UNSIGNED_INTEGER
  START_BYTE        = 25
  BYTES             = 4
  DESCRIPTION = "Item 19:  The time at which the ODF was
     created, given as a single number of the form HHMMSS.
     where
              HH   is the two-digit hour (00 through 23)
              MM   is the two-digit minute (00 through 59)
              SS   is the two-digit second (00 through 59)"
END_OBJECT          = COLUMN

OBJECT            = COLUMN
  COLUMN_NUMBER     = 6
  NAME              = "FILE REFERENCE DATE"
  DATA_TYPE         = MSB_UNSIGNED_INTEGER
  START_BYTE        = 29
```

```
    BYTES             = 4
    DESCRIPTION = "Item 20:  The reference date for ODF
                  time tags -- for example, 19500101
                  for EME50.  Older files which have
                  reference dates of zero will be
                  assumed to be EME50."
  END_OBJECT        = COLUMN

  OBJECT            = COLUMN
    COLUMN_NUMBER     = 7
    NAME              = "FILE REFERENCE TIME"
    DATA_TYPE         = MSB_UNSIGNED_INTEGER
    START_BYTE        = 33
    BYTES             = 4
    DESCRIPTION = "Item 21:  The reference time for ODF
                  time tags.  Set to 000000."
  END_OBJECT        = COLUMN
END_OBJECT                    = ODF1B_TABLE

OBJECT                        = ODF2A_TABLE
  NAME                          = "IDENTIFIER GROUP HEADER"
  INTERCHANGE_FORMAT            = BINARY
  ROWS                          = 1
  COLUMNS                       = 4
  ROW_BYTES                     = 16
  ROW_SUFFIX_BYTES              = 20
  DESCRIPTION                   = "The Identifier Group
     is usually the second of several groups of records in
     an Orbit Data File (ODF).  It is sometimes used to
     identify contents of data records that follow.  The
     Identifier Group Header is the first record in the
     Identifier Group.  It is one 36-byte record and is
     followed by one 36-byte Identifier Group data record.
     Occasionally the Identifier Group is omitted from an
     ODF.  The row suffix bytes in the Identifier Group
     Header are set to 0."

  OBJECT            = COLUMN
    COLUMN_NUMBER     = 1
    NAME              = "PRIMARY KEY"
    DATA_TYPE         = MSB_INTEGER
    START_BYTE        = 1
    BYTES             = 4
    DESCRIPTION = "Item 1:  The Primary Key indicates the type
       of data records to follow.  In the Identifier Group Header
       this field is set to 107."
  END_OBJECT        = COLUMN

  OBJECT            = COLUMN
    COLUMN_NUMBER     = 2
    NAME              = "SECONDARY KEY"
    DATA_TYPE         = MSB_UNSIGNED_INTEGER
    START_BYTE        = 5
    BYTES             = 4
    DESCRIPTION = "Item 2:  The Secondary Key is not used in
```

```
       the ODF.  It is set to 0."
  END_OBJECT       = COLUMN

  OBJECT           = COLUMN
    COLUMN_NUMBER    = 3
    NAME             = "LOGICAL RECORD LENGTH"
    DATA_TYPE        = MSB_UNSIGNED_INTEGER
    START_BYTE       = 9
    BYTES            = 4
    UNIT             = PACKET
    DESCRIPTION = "Item 3:  The Logical Record Length gives the
       number of 36-byte physical records making up each logical
       record in an Identifier Group data record.  For the
       Identifier Group it is set to 1."
  END_OBJECT       = COLUMN

  OBJECT           = COLUMN
    COLUMN_NUMBER    = 4
    NAME             = "GROUP START PACKET NUMBER"
    DATA_TYPE        = MSB_UNSIGNED_INTEGER
    START_BYTE       = 13
    BYTES            = 4
    DESCRIPTION = "Item 4:  The Group Start Packet Number
       gives the number of the ODF packet containing the
       Identifier Group Header.  Usually set to 2, since the
       Identifier Group usually follows the Label Group
       immediately in the ODF."
  END_OBJECT       = COLUMN
END_OBJECT                   = ODF2A_TABLE

OBJECT                       = ODF2B_TABLE
  NAME                         = "IDENTIFIER GROUP DATA"
  INTERCHANGE_FORMAT           = BINARY
  ROWS                         = 1
  COLUMNS                      = 3
  ROW_BYTES                    = 36
  DESCRIPTION                  = "The Identifier Group
     is usually the second of several groups of records in
     an Orbit Data File (ODF).  It is sometimes used to
     identify contents of data records that follow.  The
     Identifier Group data record is the second record in
     the Identifier Group.  It is one 36-byte record and is
     preceded by one 36-byte Identifier Group header record.
     Occasionally the Identifier Group is omitted from an
     ODF."

  OBJECT        = COLUMN
    COLUMN_NUMBER = 1
    NAME          = "ITEM 1"
    DATA_TYPE     = CHARACTER
    START_BYTE    = 1
    BYTES         = 8
    DESCRIPTION = "Item 1:  A character string sometimes used to
       identify contents of data records to follow.  Often the
       ASCII characters 'TIMETAG' followed by one ASCII 'blank'."
```

```
  END_OBJECT    = COLUMN

  OBJECT        = COLUMN
    COLUMN_NUMBER = 2
    NAME          = "ITEM 2"
    DATA_TYPE     = CHARACTER
    START_BYTE    = 9
    BYTES         = 8
    DESCRIPTION = "Item 2:  A character string sometimes used to
       identify contents of data records to follow.  Often the
       ASCII characters 'OBSRVBL' followed by one ASCII 'blank'."
  END_OBJECT    = COLUMN

  OBJECT        = COLUMN
    COLUMN_NUMBER = 3
    NAME          = "ITEM 3"
    DATA_TYPE     = CHARACTER
    START_BYTE    = 17
    BYTES         = 20
    DESCRIPTION = "Item 3:  A character string sometimes used to
       identify contents of data records to follow.  For example,
       ASCII characters 'OD-SAMPL-ID FRQ RSD '."
  END_OBJECT    = COLUMN
END_OBJECT                   = ODF2B_TABLE

OBJECT                       = ODF3A_TABLE
  NAME                         = "ORBIT DATA GROUP HEADER"
  INTERCHANGE_FORMAT           = BINARY
  ROWS                         = 1
  COLUMNS                      = 4
  ROW_BYTES                    = 16
  ROW_SUFFIX_BYTES             = 20
  DESCRIPTION                  = "The Orbit Data Group
     is usually the third of several groups of records in an
     Orbit Data File (ODF).  It contains the majority of the
     data included in the file.  The Orbit Data Group Header
     is the first record in the Orbit Data Group; it is
     usually followed by many Orbit Data Group data records,
     ordered by time.  All records in the Orbit Data Group
     have 36 bytes.  The row suffix bytes in the Orbit Data
     Group Header are set to 0.  This Orbit Data Group
     follows TRK-2-18, version of 1 August 1996."

  OBJECT           = COLUMN
    COLUMN_NUMBER    = 1
    NAME             = "PRIMARY KEY"
    DATA_TYPE        = MSB_INTEGER
    START_BYTE       = 1
    BYTES            = 4
    DESCRIPTION = "Item 1:  The Primary Key indicates the
       type of data records to follow.  In the Orbit Data
       Group Header this field is set to 109."
  END_OBJECT       = COLUMN

  OBJECT           = COLUMN
```

```
    COLUMN_NUMBER    = 2
    NAME             = "SECONDARY KEY"
    DATA_TYPE        = MSB_UNSIGNED_INTEGER
    START_BYTE       = 5
    BYTES            = 4
    DESCRIPTION = "Item 2:  The Secondary Key is not used in
       the ODF.  It is set to 0."
  END_OBJECT       = COLUMN

  OBJECT           = COLUMN
    COLUMN_NUMBER    = 3
    NAME             = "LOGICAL RECORD LENGTH"
    DATA_TYPE        = MSB_UNSIGNED_INTEGER
    START_BYTE       = 9
    BYTES            = 4
    UNIT             = PACKET
    DESCRIPTION = "Item 3:  The Logical Record Length gives the
       number of 36-byte physical records making up each logical
       record in an Orbit Data Group data record.  For the Orbit
       Data Group it is set to 1."
  END_OBJECT       = COLUMN

  OBJECT           = COLUMN
    COLUMN_NUMBER    = 4
    NAME             = "GROUP START PACKET NUMBER"
    DATA_TYPE        = MSB_UNSIGNED_INTEGER
    START_BYTE       = 13
    BYTES            = 4
    DESCRIPTION = "Item 4:  The Group Start Packet Number
       gives the number of the ODF packet containing the
       Orbit Data Group Header.  Since the Orbit Data Group
       usually follows immediately after the File Label Group
       and the Identifier Group, it is usually set to 4."
  END_OBJECT       = COLUMN
END_OBJECT                   = ODF3A_TABLE

OBJECT                       = ODF3C_TABLE
  NAME                         = "ORBIT DATA GROUP DATA"
  INTERCHANGE_FORMAT           = BINARY
  ROWS                         = 58107
  COLUMNS                      = 6
  ROW_BYTES                    = 36
  DESCRIPTION                  = "The Orbit Data Group
     is usually the third of several groups of records in an
     Orbit Data File (ODF).  It contains the majority of the
     data included in the file.  The Orbit Data Group Header
     is the first record in the Orbit Data Group; it is
     usually followed by many Orbit Data Group data records,
     ordered by time.  All records in the Orbit Data Group
     have 36 bytes.  Their format and content follows the
     specification in TRK-2-18, version of 1 August 1996."

  OBJECT        = COLUMN
    COLUMN_NUMBER = 1
    NAME          = "TIME TAG - INTEGER PART"
```

```
  DATA_TYPE     = MSB_UNSIGNED_INTEGER
  START_BYTE    = 1
  BYTES         = 4
  UNIT          = SECOND
  DESCRIPTION = "Item 1:  The integer part of the record
     time tag, measured from 0 hours UTC on 1 January 1950.
     The fractional part of the time tag is in Item 2."
END_OBJECT    = COLUMN

OBJECT        = COLUMN
  COLUMN_NUMBER = 2
  NAME          = "ITEMS 2-3"
  DATA_TYPE     = MSB_BIT_STRING
  START_BYTE    = 5
  BYTES         = 4
  DESCRIPTION = "Items 2-3 of the ODF."

  OBJECT        = BIT_COLUMN
    NAME          = "TIME TAG - FRACTIONAL PART"
    BIT_DATA_TYPE = MSB_UNSIGNED_INTEGER
    START_BIT     = 1
    BITS          = 10
    UNIT          = MILLISECOND
    DESCRIPTION = "Item 2:  The fractional part of the record
       time tag (see Column 1)."
  END_OBJECT    = BIT_COLUMN

  OBJECT        = BIT_COLUMN
    NAME          = "PRIMARY RECEIVING STATION DOWNLINK DELAY"
    BIT_DATA_TYPE = MSB_UNSIGNED_INTEGER
    START_BIT     = 11
    BITS          = 22
    UNIT          = NANOSECOND
    DESCRIPTION = "Item 3:  Downlink delay for the primary
       receiving station."
  END_OBJECT    = BIT_COLUMN

END_OBJECT    = COLUMN

OBJECT        = COLUMN
  COLUMN_NUMBER = 3
  NAME          = "OBSERVABLE - INTEGER PART"
  DATA_TYPE     = MSB_INTEGER
  START_BYTE    = 9
  BYTES         = 4
  DESCRIPTION = "Item 4:  The integer part of the observable.
     The fractional part is in Column 4 (Item 5).  See Item
     10 for the data type stored in these fields.

     The Doppler observable (in Hertz) is computed according
     to the following equation.  The time tag  tr  is the
     mid-point of the compression interval  ti  to  tj.

        Observable = [B/|B|]*[(Nj-Ni)/(tj-ti) - |Fb*K + B|]
```

```
where:
   B  = bias placed on receiver
   Ni = Doppler count at time  ti
   Nj = Doppler count at time  tj
   ti = start time of interval
   tj = end time of interval

   K = spacecraft transponder turnaround ratio, which varies
        with band used (see Item 11); set to
             1       for S-band receivers
             11/3    for X-band receivers
             176/27  for Ku-band receivers
             209/15  for Ka-band receivers
                (Note: future spacecraft transponders may
                 require different values of K)

   Fb = (X1/X2)*(X3*Fr + X4)
           -Fsc + R3                     for one-way Doppler
      = (X1/X2)*(X3*Fr + X4)
           -(T1/T2)*(T3*Ft + T4)         for all other Doppler
      where:
         Fr  = receiver (VCO) frequency at time  tr
         Fsc = spacecraft (beacon) frequency
         Ft  = transmitter frequency at time  tr-RTLT
         R3  = 0             for S-band receivers
             = 0             for X-band receivers
             = 0             for Ku-band receivers
             = 0             for Ka-band receivers
         T1  = 240  for S-band transmitters (see Item 12)
             = 240  for X-band transmitters
             = 142  for Ku-band transmitters
             = 14   for Ka-band transmitters
         T2  = 221  for S-band transmitters
             = 749  for X-band transmitters
             = 153  for Ku-band transmitters
             = 15   for Ka-band transmitters
         T3  =  96  for S-band transmitters
             =  32  for X-band transmitters
             = 1000 for Ku-band transmitters
             = 1000 for Ka-band transmitters
         T4  =    0        for S-band transmitters
             =  6.5 10^9   for X-band transmitters
             = -7.0 10^9   for Ku-band transmitters
             =  1.0 10^10  for Ka-band transmitters
         X1 to X4 have the same values as T1 to T4 but
              are dependent on the exciter band (Item 13)
         RTLT is the round-trip light time

For Doppler data the residual (sometimes called the
pseudo-residual) is the observed Doppler minus the predicted
Doppler

The range observable is computed as follows:

   Observable = R - C + Z - S
```

```
     where:
        R = range measurement
        C = station delay calibration
        Z = Z correction, which is the delay resulting from DSN
            station optics that is not included in routine closed
            loop calibrations (C)
        S = spacecraft delay"

END_OBJECT    = COLUMN

OBJECT        = COLUMN
  COLUMN_NUMBER = 4
  NAME          = "OBSERVABLE - FRACTIONAL PART"
  DATA_TYPE     = MSB_INTEGER
  START_BYTE    = 13
  BYTES         = 4
  DESCRIPTION = "Item 5:  The fractional part of the
     observable, scaled by 10^9.  See DESCRIPTION under
     Column 3 for details on definition."
END_OBJECT    = COLUMN

OBJECT        = COLUMN
  COLUMN_NUMBER = 5
  NAME          = "ITEMS 6-19"
  DATA_TYPE     = MSB_BIT_STRING
  START_BYTE    = 17
  BYTES         = 12
  DESCRIPTION = "Items 6-19 of the ODF."

  OBJECT        = BIT_COLUMN
    NAME          = "FORMAT ID"
    BIT_DATA_TYPE = MSB_UNSIGNED_INTEGER
    START_BIT     = 1
    BITS          = 3
    DESCRIPTION = "Item 6:  The Format ID.  Set to 2.  If this
       value is 1, the ODF was created on or before 1997-04-14
       and will not be accurately described by this set of
       object definitions.  If FORMAT ID = 1, see:
                 JPL/DSN Document 820-13; Rev A
                    DSN System Requirements
                    Detail Interface Design
                           TRK-2-18
                 DSN Tracking System Interfaces
                   Orbit Data File Interface
                           Mark IVA
                  Effective Date: May 15, 1984"
  END_OBJECT    = BIT_COLUMN

  OBJECT        = BIT_COLUMN
    NAME          = "PRIMARY RECEIVING STATION ID"
    BIT_DATA_TYPE = MSB_UNSIGNED_INTEGER
    START_BIT     = 4
    BITS          = 7
    DESCRIPTION = "Item 7:  The ID Number of the primary
```

```
     Receiving Station."
END_OBJECT    = BIT_COLUMN

OBJECT        = BIT_COLUMN
  NAME          = "TRANSMITTING STATION ID"
  BIT_DATA_TYPE = MSB_UNSIGNED_INTEGER
  START_BIT     = 11
  BITS          = 7
  DESCRIPTION = "Item 8:  Transmitting Station ID Number.
     Set to zero if quasar VLBI, one-way (Doppler, phase,
      or range), or angles data."
END_OBJECT    = BIT_COLUMN

OBJECT        = BIT_COLUMN
  NAME          = "NETWORK ID"
  BIT_DATA_TYPE = MSB_UNSIGNED_INTEGER
  START_BIT     = 18
  BITS          = 2
  DESCRIPTION = "Item 9:  Network ID Number for primary
     Receiving  Station:  Set to:
                  0   for DSN, Block V exciter
                  1   for other
                  2   for OTS (OVLBI Tracking Subnet, where
                        OVLBI is Orbiting VLBI)"
END_OBJECT    = BIT_COLUMN

OBJECT        = BIT_COLUMN
  NAME          = "DATA TYPE ID"
  BIT_DATA_TYPE = MSB_UNSIGNED_INTEGER
  START_BIT     = 20
  BITS          = 6
  DESCRIPTION = "Item 10:  Data Type ID Number.
     Allowed data type values include:
        01 = Narrowband spacecraft VLBI, Doppler mode; cycles
        02 = Narrowband spacecraft VLBI, phase mode; cycles
        03 = Narrowband quasar VLBI, Doppler mode; cycles
        04 = Narrowband quasar VLBI, phase mode; cycles
        05 = Wideband spacecraft VLBI; nanoseconds
        06 = Wideband quasar VLBI; nanoseconds
        11 = One-way Doppler; Hertz
        12 = Two-way Doppler; Hertz
        13 = Three-way Doppler; Hertz
        21 = One-way total-count phase; cycles
        22 = Two-way total-count phase; cycles
        23 = Three-way total-count phase; cycles
        36 = PRA Planetary operational discrete spectrum range;
               range units
        37 = SRA Planetary operational discrete spectrum range;
               range units
        41 = RE [GSTDN] Range; nanoseconds
        51 = Azimuth angle; degrees
        52 = Elevation angle; degrees
        53 = Hour angle; degrees
        54 = Declination angle; degrees
        55 = X angle (where +X is east); degrees
```

```
        56 = Y angle (where +X is east); degrees
        57 = X angle (where +X is south); degrees
        58 = Y angle (where +X is south); degrees

     Notes:  Some of the descriptions below refer to 'generic'
             data types.  These are defined as follows:

             Data Types     Generic Term
             ----------     ------------
                01-06       VLBI
                01-04       Narrowband VLBI
                05-06       Wideband VLBI
             03, 04, 06     Quasar
                11-58       Tracking or TRK
                01-58       Radiometric"

END_OBJECT    = BIT_COLUMN

OBJECT        = BIT_COLUMN
  NAME          = "DOWNLINK BAND ID"
  BIT_DATA_TYPE = MSB_UNSIGNED_INTEGER
  START_BIT     = 26
  BITS          = 2
  DESCRIPTION = "Item 11:  Downlink Band ID.  Allowed
     values include:
        0 = Not applicable if angle data,
            Ku-band otherwise
        1 = S-band
        2 = X-band
        3 = Ka-band"
END_OBJECT    = BIT_COLUMN

OBJECT        = BIT_COLUMN
  NAME          = "UPLINK BAND ID"
  BIT_DATA_TYPE = MSB_UNSIGNED_INTEGER
  START_BIT     = 28
  BITS          = 2
  DESCRIPTION = "Item 12:  Uplink Band ID.  Allowed
     values include:
        0 = Not applicable if angle data or 1-way data,
            Ku-band otherwise
        1 = S-band
        2 = X-band
        3 = Ka-band"
END_OBJECT    = BIT_COLUMN

OBJECT        = BIT_COLUMN
  NAME          = "EXCITER BAND ID"
  BIT_DATA_TYPE = MSB_UNSIGNED_INTEGER
  START_BIT     = 30
  BITS          = 2
  DESCRIPTION = "Item 13: Exciter Band ID.  Allowed
     values include:
        0 = Not applicable if angle data,
            Ku-band otherwise
```

```
        1 = S-band
        2 = X-band
        3 = Ka-band"
END_OBJECT    = BIT_COLUMN

OBJECT        = BIT_COLUMN
  NAME          = "DATA VALIDITY INDICATOR"
  BIT_DATA_TYPE = MSB_UNSIGNED_INTEGER
  START_BIT     = 32
  BITS          = 1
  DESCRIPTION = "Item 14:  The data validity flag.  Values are:
     0 = good
     1 = bad"
END_OBJECT    = BIT_COLUMN

OBJECT        = BIT_COLUMN
  NAME          = "ITEM 15"
  BIT_DATA_TYPE = MSB_UNSIGNED_INTEGER
  START_BIT     = 33
  BITS          = 7
  DESCRIPTION = "Item 15:
                  Second receiving station ID number, if VLBI data;
                  Lowest (last) component, if PRA/SRA range data;
                  Integer seconds of observable, if RE range data;
                  Set to  0,  otherwise."
END_OBJECT    = BIT_COLUMN

OBJECT        = BIT_COLUMN
  NAME          = "ITEM 16"
  BIT_DATA_TYPE = MSB_UNSIGNED_INTEGER
  START_BIT     = 40
  BITS          = 10
  DESCRIPTION = "Item 16:
                  Quasar ID, if VLBI quasar data;
                  Spacecraft ID,  otherwise."
END_OBJECT    = BIT_COLUMN

OBJECT        = BIT_COLUMN
  NAME          = "ITEM 17"
  BIT_DATA_TYPE = MSB_UNSIGNED_INTEGER
  START_BIT     = 50
  BITS          = 1
  DESCRIPTION = "Item 17:
                  Modulus indicator, if wideband VLBI data;
                  Phase Point indicator, if narrowband
                    VLBI data;
                  Receiver/exciter independent flag, if Doppler,
                    phase, or range data (0=no, 1=yes);
                  Set to  0,  otherwise."
END_OBJECT    = BIT_COLUMN

OBJECT        = BIT_COLUMN
  NAME          = "ITEM 18"
  BIT_DATA_TYPE = MSB_UNSIGNED_INTEGER
  START_BIT     = 51
```

```
    BITS          = 22
    DESCRIPTION = "Item 18:
                    Reference frequency, high part, milliHertz:
                      Transponder frequency, if one-way Doppler
                        or phase;
                      Receiver frequency, if ramped and not
                        one-way;
                      Transmitter frequency otherwise;
                    Set to  0,  if angles data."
  END_OBJECT    = BIT_COLUMN

  OBJECT        = BIT_COLUMN
    NAME          = "ITEM 19"
    BIT_DATA_TYPE = MSB_UNSIGNED_INTEGER
    START_BIT     = 73
    BITS          = 24
    DESCRIPTION = "Item 19:  Reference frequency, low part,
       milliHertz.  See DESCRIPTION under Item 18 for details."
  END_OBJECT    = BIT_COLUMN

END_OBJECT    = COLUMN

OBJECT        = COLUMN
  COLUMN_NUMBER = 6
  NAME          = "ITEMS 20-22"
  DATA_TYPE     = MSB_BIT_STRING
  START_BYTE    = 29
  BYTES         = 8
  DESCRIPTION = "Items 20-22 of the ODF."

  OBJECT        = BIT_COLUMN
    NAME          = "ITEM 20"
    BIT_DATA_TYPE = MSB_UNSIGNED_INTEGER
    START_BIT     = 1
    BITS          = 20
    DESCRIPTION = "Item 20:
       If narrowband VLBI data:
         (Phase Calibration Flag minus 1) times 100000, plus
           Channel ID Number times 10000.
       If wideband VLBI data:
         (Channel Sampling Flag minus 1) times 100000, plus
           Mode ID number times 10000, plus Modulus high-part
           in 10^-1 nanoseconds.
       If OTS Doppler data:
         Train Axis Angle in millidegrees.
       If PRA/SRA range data:
         Uplink Ranging Transmitter In-Phase Time Offset from
           Sample Timetag in seconds
       Otherwise, set to 0."
  END_OBJECT    = BIT_COLUMN

  OBJECT        = BIT_COLUMN
    NAME          = "ITEM 21"
    BIT_DATA_TYPE = MSB_UNSIGNED_INTEGER
    START_BIT     = 21
```

```
      BITS          = 22
      DESCRIPTION = "Item 21:
         If wideband VLBI data:
           Modulus low-part (units are nanoseconds after the value
             is multiplied by 10^-7).
         If Doppler, phase, or narrowband VLBI data:
           Compression time in hundredths of a second.
         If PRA/SRA range data:
           Highest (first) Component times 100000, plus
             Downlink Ranging Transmitter Coder In-Phase
             Time Offset from Sample Timetag in seconds.
         Otherwise, set to 0."
    END_OBJECT    = BIT_COLUMN

    OBJECT        = BIT_COLUMN
      NAME          = "ITEM 22"
      BIT_DATA_TYPE = MSB_UNSIGNED_INTEGER
      START_BIT     = 43
      BITS          = 22
      DESCRIPTION = "Item 22:
         If VLBI data:
           Second Receiving Station Downlink Delay in nanoseconds.
         If Doppler, phase, or range data:
           Transmitting Station Uplink Delay in nanoseconds.
         Otherwise, set to 0."
    END_OBJECT    = BIT_COLUMN

  END_OBJECT    = COLUMN
END_OBJECT                   = ODF3C_TABLE

OBJECT                       = ODF4A26_TABLE
  NAME                         = "RAMP GROUP 26 HEADER"
  INTERCHANGE_FORMAT           = BINARY
  ROWS                         = 1
  COLUMNS                      = 4
  ROW_BYTES                    = 16
  ROW_SUFFIX_BYTES             = 20
  DESCRIPTION                  = "Ramp Groups are
     usually the fourth of several groups of records in an
     Orbit Data File (ODF).  They contain information on
     tuning of receivers or transmitters.  There is usually
     one Ramp Group for each DSN station.  The Ramp Group
     Header is the first record in each Ramp Group.  It is
     one 36-byte record and is followed by one or more 36-
     byte Ramp Group data records.  Data records are time
     ordered within each Ramp Group.  The Ramp Group may be
     omitted from an ODF.  The row suffix bytes in the Ramp
     Group Header are set to 0."

  OBJECT           = COLUMN
    COLUMN_NUMBER    = 1
    NAME             = "PRIMARY KEY"
    DATA_TYPE        = MSB_INTEGER
    START_BYTE       = 1
    BYTES            = 4
```

```
    DESCRIPTION = "Item 1:  The Primary Key indicates the type
       of data records to follow.  In the Ramp Group Header
       this field is set to 2030."
  END_OBJECT       = COLUMN

  OBJECT           = COLUMN
    COLUMN_NUMBER    = 2
    NAME             = "SECONDARY KEY"
    DATA_TYPE        = MSB_UNSIGNED_INTEGER
    START_BYTE       = 5
    BYTES            = 4
    DESCRIPTION = "Item 2: Set to the Station ID Number."
  END_OBJECT       = COLUMN

  OBJECT           = COLUMN
    COLUMN_NUMBER    = 3
    NAME             = "LOGICAL RECORD LENGTH"
    DATA_TYPE        = MSB_UNSIGNED_INTEGER
    START_BYTE       = 9
    BYTES            = 4
    UNIT             = PACKET
    DESCRIPTION = "Item 3:  The Logical Record Length gives the
       number of 36-byte physical records making up each logical
       record in a Ramp Group data record.  For the Ramp Group
       it is set to 1."
  END_OBJECT       = COLUMN

  OBJECT           = COLUMN
    COLUMN_NUMBER    = 4
    NAME             = "GROUP START PACKET NUMBER"
    DATA_TYPE        = MSB_UNSIGNED_INTEGER
    START_BYTE       = 13
    BYTES            = 4
    DESCRIPTION = "Item 4:  The Group Start Packet Number
       gives the number of the ODF packet containing the
       Ramp Group Header; packet numbering starts with 0
       for the File Label Group Header."
  END_OBJECT       = COLUMN
END_OBJECT                   = ODF4A26_TABLE

OBJECT                       = ODF4B26_TABLE
  NAME                         = "RAMP GROUP 26 DATA"
  INTERCHANGE_FORMAT           = BINARY
  ROWS                         = 236
  COLUMNS                      = 9
  ROW_BYTES                    = 36
  DESCRIPTION                  = "Ramp Groups are
     usually the fourth of several groups of records in an
     Orbit Data File (ODF).  They contain information on
     tuning of receivers or transmitters.  There is usually
     one Ramp Group for each DSN station.  The Ramp Group
     Header is the first record in each Ramp Group.  It is
     one 36-byte record and is followed by one or more 36-
     byte Ramp Group data records.  Data records are time
     ordered within each Ramp Group.  The Ramp Group may be
```

```
   omitted from an ODF."

OBJECT         = COLUMN
  COLUMN_NUMBER = 1
  NAME          = "RAMP START TIME - INTEGER PART"
  DATA_TYPE     = MSB_UNSIGNED_INTEGER
  START_BYTE    = 1
  BYTES         = 4
  UNIT          = SECOND
  DESCRIPTION = "Item 1:  The integer part of the ramp
     start time, measured from 0 hours UTC on 1 January 1950."
END_OBJECT    = COLUMN

OBJECT         = COLUMN
  COLUMN_NUMBER = 2
  NAME          = "RAMP START TIME - FRACTIONAL PART"
  DATA_TYPE     = MSB_UNSIGNED_INTEGER
  START_BYTE    = 5
  BYTES         = 4
  UNIT          = NANOSECOND
  DESCRIPTION = "Item 2:  The fractional part of the ramp
     start time - see Column 1 (Item 1)."
END_OBJECT    = COLUMN

OBJECT         = COLUMN
  COLUMN_NUMBER = 3
  NAME          = "RAMP RATE - INTEGER PART"
  DATA_TYPE     = MSB_INTEGER
  START_BYTE    = 9
  BYTES         = 4
  DESCRIPTION = "Item 3:  The integer part of the ramp
     rate."
END_OBJECT    = COLUMN

OBJECT         = COLUMN
  COLUMN_NUMBER = 4
  NAME          = "RAMP RATE - FRACTIONAL PART"
  DATA_TYPE     = MSB_INTEGER
  START_BYTE    = 13
  BYTES         = 4
  DESCRIPTION = "Item 4:  The fractional part of the ramp
     rate, in units of 10^-9 of Column 3."
END_OBJECT    = COLUMN

OBJECT         = COLUMN
  COLUMN_NUMBER = 5
  NAME          = "ITEMS 5-6"
  DATA_TYPE     = MSB_BIT_STRING
  START_BYTE    = 17
  BYTES         = 4
  DESCRIPTION = "Items 5-6 of the ODF."

  OBJECT        = BIT_COLUMN
    NAME          = "RAMP START FREQUENCY - GHZ"
    BIT_DATA_TYPE = MSB_UNSIGNED_INTEGER
```

```
    START_BIT     = 1
    BITS          = 22
    UNIT          = GIGAHERTZ
    DESCRIPTION   = "Item 5: Ramp Start Frequency, integer GHz.
       If this value is non-zero, Ramp Start Frequency and Ramp
       Rate are at sky level."
  END_OBJECT    = BIT_COLUMN

  OBJECT        = BIT_COLUMN
    NAME          = "STATION ID"
    BIT_DATA_TYPE = MSB_UNSIGNED_INTEGER
    START_BIT     = 23
    BITS          = 10
    DESCRIPTION   = "Item 6: Receiving/Transmitting Station
       ID Number."
  END_OBJECT    = BIT_COLUMN

END_OBJECT    = COLUMN

OBJECT        = COLUMN
  COLUMN_NUMBER = 6
  NAME          = "RAMP START FREQUENCY - INTEGER PART"
  DATA_TYPE     = MSB_UNSIGNED_INTEGER
  START_BYTE    = 21
  BYTES         = 4
  UNIT          = HERTZ
  DESCRIPTION = "Item 7:  The integer part of the
     Ramp Start Frequency, modulo 10^9."
END_OBJECT    = COLUMN

OBJECT        = COLUMN
  COLUMN_NUMBER = 7
  NAME          = "RAMP START FREQUENCY - FRACTIONAL PART"
  DATA_TYPE     = MSB_UNSIGNED_INTEGER
  START_BYTE    = 25
  BYTES         = 4
  DESCRIPTION = "Item 8:  The fractional part of the
     Ramp Start Frequency, in units of 10^-9 of
     Column 6."
END_OBJECT    = COLUMN

OBJECT        = COLUMN
  COLUMN_NUMBER = 8
  NAME          = "RAMP END TIME - INTEGER PART"
  DATA_TYPE     = MSB_UNSIGNED_INTEGER
  START_BYTE    = 29
  BYTES         = 4
  UNIT          = SECOND
  DESCRIPTION = "Item 9:  The integer part of the ramp
     end time, measured from 0 hours UTC on 1 January 1950."
END_OBJECT    = COLUMN

OBJECT        = COLUMN
  COLUMN_NUMBER = 9
  NAME          = "RAMP END TIME - FRACTIONAL PART"
```

```
    DATA_TYPE     = MSB_UNSIGNED_INTEGER
    START_BYTE    = 33
    BYTES         = 4
    UNIT          = NANOSECOND
    DESCRIPTION = "Item 10:  The fractional part of the ramp
       end time (see Column 8)."
  END_OBJECT    = COLUMN
END_OBJECT                  = ODF4B26_TABLE

OBJECT                      = ODF4A43_TABLE
  NAME                        = "RAMP GROUP 43 HEADER"
  INTERCHANGE_FORMAT          = BINARY
  ROWS                        = 1
  COLUMNS                     = 4
  ROW_BYTES                   = 16
  ROW_SUFFIX_BYTES            = 20
  DESCRIPTION                 = "Ramp Groups are
     usually the fourth of several groups of records in an
     Orbit Data File (ODF).  They contain information on
     tuning of receivers or transmitters.  There is usually
     one Ramp Group for each DSN station.  The Ramp Group
     Header is the first record in each Ramp Group.  It is
     one 36-byte record and is followed by one or more 36-
     byte Ramp Group data records.  Data records are time
     ordered within each Ramp Group.  The Ramp Group may be
     omitted from an ODF.  The row suffix bytes in the Ramp
     Group Header are set to 0."

  OBJECT           = COLUMN
    COLUMN_NUMBER    = 1
    NAME             = "PRIMARY KEY"
    DATA_TYPE        = MSB_INTEGER
    START_BYTE       = 1
    BYTES            = 4
    DESCRIPTION = "Item 1:  The Primary Key indicates the type
       of data records to follow.  In the Ramp Group Header
       this field is set to 2030."
  END_OBJECT       = COLUMN

  OBJECT           = COLUMN
    COLUMN_NUMBER    = 2
    NAME             = "SECONDARY KEY"
    DATA_TYPE        = MSB_UNSIGNED_INTEGER
    START_BYTE       = 5
    BYTES            = 4
    DESCRIPTION = "Item 2: Set to the Station ID Number."
  END_OBJECT       = COLUMN

  OBJECT           = COLUMN
    COLUMN_NUMBER    = 3
    NAME             = "LOGICAL RECORD LENGTH"
    DATA_TYPE        = MSB_UNSIGNED_INTEGER
    START_BYTE       = 9
    BYTES            = 4
    UNIT             = PACKET
```

```
    DESCRIPTION = "Item 3:  The Logical Record Length gives the
       number of 36-byte physical records making up each logical
       record in a Ramp Group data record.  For the Ramp Group
       it is set to 1."
  END_OBJECT       = COLUMN

  OBJECT           = COLUMN
    COLUMN_NUMBER    = 4
    NAME             = "GROUP START PACKET NUMBER"
    DATA_TYPE        = MSB_UNSIGNED_INTEGER
    START_BYTE       = 13
    BYTES            = 4
    DESCRIPTION = "Item 4:  The Group Start Packet Number
       gives the number of the ODF packet containing the
       Ramp Group Header; packet numbering starts with 0
       for the File Label Group Header."
  END_OBJECT       = COLUMN
END_OBJECT                   = ODF4A43_TABLE

OBJECT                       = ODF4B43_TABLE
  NAME                         = "RAMP GROUP 43 DATA"
  INTERCHANGE_FORMAT           = BINARY
  ROWS                         = 161
  COLUMNS                      = 9
  ROW_BYTES                    = 36
  DESCRIPTION                  = "Ramp Groups are
     usually the fourth of several groups of records in an
     Orbit Data File (ODF).  They contain information on
     tuning of receivers or transmitters.  There is usually
     one Ramp Group for each DSN station.  The Ramp Group
     Header is the first record in each Ramp Group.  It is
     one 36-byte record and is followed by one or more 36-
     byte Ramp Group data records.  Data records are time
     ordered within each Ramp Group.  The Ramp Group may be
     omitted from an ODF."

  OBJECT        = COLUMN
    COLUMN_NUMBER = 1
    NAME          = "RAMP START TIME - INTEGER PART"
    DATA_TYPE     = MSB_UNSIGNED_INTEGER
    START_BYTE    = 1
    BYTES         = 4
    UNIT          = SECOND
    DESCRIPTION = "Item 1:  The integer part of the ramp
       start time, measured from 0 hours UTC on 1 January 1950."
  END_OBJECT    = COLUMN

  OBJECT        = COLUMN
    COLUMN_NUMBER = 2
    NAME          = "RAMP START TIME - FRACTIONAL PART"
    DATA_TYPE     = MSB_UNSIGNED_INTEGER
    START_BYTE    = 5
    BYTES         = 4
    UNIT          = NANOSECOND
    DESCRIPTION = "Item 2:  The fractional part of the ramp
```

```
     start time - see Column 1 (Item 1)."
END_OBJECT    = COLUMN

OBJECT        = COLUMN
  COLUMN_NUMBER = 3
  NAME          = "RAMP RATE - INTEGER PART"
  DATA_TYPE     = MSB_INTEGER
  START_BYTE    = 9
  BYTES         = 4
  DESCRIPTION = "Item 3:  The integer part of the ramp
     rate."
END_OBJECT    = COLUMN

OBJECT        = COLUMN
  COLUMN_NUMBER = 4
  NAME          = "RAMP RATE - FRACTIONAL PART"
  DATA_TYPE     = MSB_INTEGER
  START_BYTE    = 13
  BYTES         = 4
  DESCRIPTION = "Item 4:  The fractional part of the ramp
     rate, in units of 10^-9 of Column 3."
END_OBJECT    = COLUMN

OBJECT        = COLUMN
  COLUMN_NUMBER = 5
  NAME          = "ITEMS 5-6"
  DATA_TYPE     = MSB_BIT_STRING
  START_BYTE    = 17
  BYTES         = 4
  DESCRIPTION = "Items 5-6 of the ODF."

  OBJECT        = BIT_COLUMN
    NAME          = "RAMP START FREQUENCY - GHZ"
    BIT_DATA_TYPE = MSB_UNSIGNED_INTEGER
    START_BIT     = 1
    BITS          = 22
    UNIT          = GIGAHERTZ
    DESCRIPTION   = "Item 5: Ramp Start Frequency, integer GHz.
       If this value is non-zero, Ramp Start Frequency and Ramp
       Rate are at sky level."
  END_OBJECT    = BIT_COLUMN

  OBJECT        = BIT_COLUMN
    NAME          = "STATION ID"
    BIT_DATA_TYPE = MSB_UNSIGNED_INTEGER
    START_BIT     = 23
    BITS          = 10
    DESCRIPTION   = "Item 6: Receiving/Transmitting Station
       ID Number."
  END_OBJECT    = BIT_COLUMN

END_OBJECT    = COLUMN

OBJECT        = COLUMN
  COLUMN_NUMBER = 6
```

```
    NAME           = "RAMP START FREQUENCY - INTEGER PART"
    DATA_TYPE      = MSB_UNSIGNED_INTEGER
    START_BYTE     = 21
    BYTES          = 4
    UNIT           = HERTZ
    DESCRIPTION = "Item 7:  The integer part of the
       Ramp Start Frequency, modulo 10^9."
  END_OBJECT    = COLUMN

  OBJECT        = COLUMN
    COLUMN_NUMBER = 7
    NAME           = "RAMP START FREQUENCY - FRACTIONAL PART"
    DATA_TYPE      = MSB_UNSIGNED_INTEGER
    START_BYTE     = 25
    BYTES          = 4
    DESCRIPTION = "Item 8:  The fractional part of the
       Ramp Start Frequency, in units of 10^-9 of
       Column 6."
  END_OBJECT    = COLUMN

  OBJECT        = COLUMN
    COLUMN_NUMBER = 8
    NAME           = "RAMP END TIME - INTEGER PART"
    DATA_TYPE      = MSB_UNSIGNED_INTEGER
    START_BYTE     = 29
    BYTES          = 4
    UNIT           = SECOND
    DESCRIPTION = "Item 9:  The integer part of the ramp
       end time, measured from 0 hours UTC on 1 January 1950."
  END_OBJECT    = COLUMN

  OBJECT        = COLUMN
    COLUMN_NUMBER = 9
    NAME           = "RAMP END TIME - FRACTIONAL PART"
    DATA_TYPE      = MSB_UNSIGNED_INTEGER
    START_BYTE     = 33
    BYTES          = 4
    UNIT           = NANOSECOND
    DESCRIPTION = "Item 10:  The fractional part of the ramp
       end time (see Column 8)."
  END_OBJECT    = COLUMN
END_OBJECT                   = ODF4B43_TABLE

OBJECT                       = ODF4A55_TABLE
  NAME                         = "RAMP GROUP 55 HEADER"
  INTERCHANGE_FORMAT           = BINARY
  ROWS                         = 1
  COLUMNS                      = 4
  ROW_BYTES                    = 16
  ROW_SUFFIX_BYTES             = 20
  DESCRIPTION                  = "Ramp Groups are
     usually the fourth of several groups of records in an
     Orbit Data File (ODF).  They contain information on
     tuning of receivers or transmitters.  There is usually
     one Ramp Group for each DSN station.  The Ramp Group
```

```
      Header is the first record in each Ramp Group.  It is
      one 36-byte record and is followed by one or more 36-
      byte Ramp Group data records.  Data records are time
      ordered within each Ramp Group.  The Ramp Group may be
      omitted from an ODF.  The row suffix bytes in the Ramp
      Group Header are set to 0."

   OBJECT           = COLUMN
     COLUMN_NUMBER    = 1
     NAME             = "PRIMARY KEY"
     DATA_TYPE        = MSB_INTEGER
     START_BYTE       = 1
     BYTES            = 4
     DESCRIPTION = "Item 1:  The Primary Key indicates the type
        of data records to follow.  In the Ramp Group Header
        this field is set to 2030."
   END_OBJECT       = COLUMN

   OBJECT           = COLUMN
     COLUMN_NUMBER    = 2
     NAME             = "SECONDARY KEY"
     DATA_TYPE        = MSB_UNSIGNED_INTEGER
     START_BYTE       = 5
     BYTES            = 4
     DESCRIPTION = "Item 2: Set to the Station ID Number."
   END_OBJECT       = COLUMN

   OBJECT           = COLUMN
     COLUMN_NUMBER    = 3
     NAME             = "LOGICAL RECORD LENGTH"
     DATA_TYPE        = MSB_UNSIGNED_INTEGER
     START_BYTE       = 9
     BYTES            = 4
     UNIT             = PACKET
     DESCRIPTION = "Item 3:  The Logical Record Length gives the
        number of 36-byte physical records making up each logical
        record in a Ramp Group data record.  For the Ramp Group
        it is set to 1."
   END_OBJECT       = COLUMN

   OBJECT           = COLUMN
     COLUMN_NUMBER    = 4
     NAME             = "GROUP START PACKET NUMBER"
     DATA_TYPE        = MSB_UNSIGNED_INTEGER
     START_BYTE       = 13
     BYTES            = 4
     DESCRIPTION = "Item 4:  The Group Start Packet Number
        gives the number of the ODF packet containing the
        Ramp Group Header; packet numbering starts with 0
        for the File Label Group Header."
   END_OBJECT       = COLUMN
 END_OBJECT                  = ODF4A55_TABLE

 OBJECT                      = ODF4B55_TABLE
   NAME                        = "RAMP GROUP 55 DATA"
```

```
INTERCHANGE_FORMAT           = BINARY
ROWS                         = 139
COLUMNS                      = 9
ROW_BYTES                    = 36
DESCRIPTION                  = "Ramp Groups are
   usually the fourth of several groups of records in an
   Orbit Data File (ODF).  They contain information on
   tuning of receivers or transmitters.  There is usually
   one Ramp Group for each DSN station.  The Ramp Group
   Header is the first record in each Ramp Group.  It is
   one 36-byte record and is followed by one or more 36-
   byte Ramp Group data records.  Data records are time
   ordered within each Ramp Group.  The Ramp Group may be
   omitted from an ODF."

OBJECT        = COLUMN
  COLUMN_NUMBER = 1
  NAME          = "RAMP START TIME - INTEGER PART"
  DATA_TYPE     = MSB_UNSIGNED_INTEGER
  START_BYTE    = 1
  BYTES         = 4
  UNIT          = SECOND
  DESCRIPTION = "Item 1:  The integer part of the ramp
     start time, measured from 0 hours UTC on 1 January 1950."
END_OBJECT    = COLUMN

OBJECT        = COLUMN
  COLUMN_NUMBER = 2
  NAME          = "RAMP START TIME - FRACTIONAL PART"
  DATA_TYPE     = MSB_UNSIGNED_INTEGER
  START_BYTE    = 5
  BYTES         = 4
  UNIT          = NANOSECOND
  DESCRIPTION = "Item 2:  The fractional part of the ramp
     start time - see Column 1 (Item 1)."
END_OBJECT    = COLUMN

OBJECT        = COLUMN
  COLUMN_NUMBER = 3
  NAME          = "RAMP RATE - INTEGER PART"
  DATA_TYPE     = MSB_INTEGER
  START_BYTE    = 9
  BYTES         = 4
  DESCRIPTION = "Item 3:  The integer part of the ramp
     rate."
END_OBJECT    = COLUMN

OBJECT        = COLUMN
  COLUMN_NUMBER = 4
  NAME          = "RAMP RATE - FRACTIONAL PART"
  DATA_TYPE     = MSB_INTEGER
  START_BYTE    = 13
  BYTES         = 4
  DESCRIPTION = "Item 4:  The fractional part of the ramp
     rate, in units of 10^-9 of Column 3."
```

```
END_OBJECT    = COLUMN

OBJECT        = COLUMN
  COLUMN_NUMBER = 5
  NAME          = "ITEMS 5-6"
  DATA_TYPE     = MSB_BIT_STRING
  START_BYTE    = 17
  BYTES         = 4
  DESCRIPTION = "Items 5-6 of the ODF."

  OBJECT        = BIT_COLUMN
    NAME          = "RAMP START FREQUENCY - GHZ"
    BIT_DATA_TYPE = MSB_UNSIGNED_INTEGER
    START_BIT     = 1
    BITS          = 22
    UNIT          = GIGAHERTZ
    DESCRIPTION   = "Item 5: Ramp Start Frequency, integer GHz.
       If this value is non-zero, Ramp Start Frequency and Ramp
       Rate are at sky level."
  END_OBJECT    = BIT_COLUMN

  OBJECT        = BIT_COLUMN
    NAME          = "STATION ID"
    BIT_DATA_TYPE = MSB_UNSIGNED_INTEGER
    START_BIT     = 23
    BITS          = 10
    DESCRIPTION   = "Item 6: Receiving/Transmitting Station
       ID Number."
  END_OBJECT    = BIT_COLUMN

END_OBJECT    = COLUMN

OBJECT        = COLUMN
  COLUMN_NUMBER = 6
  NAME          = "RAMP START FREQUENCY - INTEGER PART"
  DATA_TYPE     = MSB_UNSIGNED_INTEGER
  START_BYTE    = 21
  BYTES         = 4
  UNIT          = HERTZ
  DESCRIPTION = "Item 7:  The integer part of the
     Ramp Start Frequency, modulo 10^9."
END_OBJECT    = COLUMN

OBJECT        = COLUMN
  COLUMN_NUMBER = 7
  NAME          = "RAMP START FREQUENCY - FRACTIONAL PART"
  DATA_TYPE     = MSB_UNSIGNED_INTEGER
  START_BYTE    = 25
  BYTES         = 4
  DESCRIPTION = "Item 8:  The fractional part of the
     Ramp Start Frequency, in units of 10^-9 of
     Column 6."
END_OBJECT    = COLUMN

OBJECT        = COLUMN
```

```
    COLUMN_NUMBER = 8
    NAME          = "RAMP END TIME - INTEGER PART"
    DATA_TYPE     = MSB_UNSIGNED_INTEGER
    START_BYTE    = 29
    BYTES         = 4
    UNIT          = SECOND
    DESCRIPTION = "Item 9:  The integer part of the ramp
       end time, measured from 0 hours UTC on 1 January 1950."
  END_OBJECT    = COLUMN

  OBJECT        = COLUMN
    COLUMN_NUMBER = 9
    NAME          = "RAMP END TIME - FRACTIONAL PART"
    DATA_TYPE     = MSB_UNSIGNED_INTEGER
    START_BYTE    = 33
    BYTES         = 4
    UNIT          = NANOSECOND
    DESCRIPTION = "Item 10:  The fractional part of the ramp
       end time (see Column 8)."
  END_OBJECT    = COLUMN
END_OBJECT                   = ODF4B55_TABLE

OBJECT                       = ODF8A_TABLE
  NAME                         = "END OF FILE GROUP HEADER"
  INTERCHANGE_FORMAT           = BINARY
  ROWS                         = 1
  COLUMNS                      = 4
  ROW_BYTES                    = 16
  ROW_SUFFIX_BYTES             = 20
  DESCRIPTION                  = "The End of File Group
     is usually the eighth and last of several groups of
     records in an Orbit Data File (ODF).  It is a single
     record of 36-bytes and denotes the logical end of the
     ODF.  Row  suffix bytes are set to 0."

  OBJECT           = COLUMN
    COLUMN_NUMBER    = 1
    NAME             = "PRIMARY KEY"
    DATA_TYPE        = MSB_INTEGER
    START_BYTE       = 1
    BYTES            = 4
    DESCRIPTION = "Item 1:  The Primary Key indicates the type
       of data records to follow.  In the End of File Group
       this field is set to -1."
  END_OBJECT       = COLUMN

  OBJECT           = COLUMN
    COLUMN_NUMBER    = 2
    NAME             = "SECONDARY KEY"
    DATA_TYPE        = MSB_UNSIGNED_INTEGER
    START_BYTE       = 5
    BYTES            = 4
    DESCRIPTION = "Item 2:  The Secondary Key is not used in
       the ODF.  It is set to 0."
  END_OBJECT       = COLUMN
```

```
  OBJECT            = COLUMN
    COLUMN_NUMBER    = 3
    NAME             = "LOGICAL RECORD LENGTH"
    DATA_TYPE        = MSB_UNSIGNED_INTEGER
    START_BYTE       = 9
    BYTES            = 4
    UNIT             = PACKET
    DESCRIPTION = "Item 3:  The Logical Record Length is set
       to 0 in the End of File Group, indicating that no
       logical records follow."
  END_OBJECT        = COLUMN

  OBJECT            = COLUMN
    COLUMN_NUMBER    = 4
    NAME             = "GROUP START PACKET NUMBER"
    DATA_TYPE        = MSB_UNSIGNED_INTEGER
    START_BYTE       = 13
    BYTES            = 4
    DESCRIPTION = "Item 4:  The Group Start Packet Number
       gives the number of the ODF packet containing the
       End of File Group; packet numbering starts with 0
       for the File Label Group Header."
  END_OBJECT        = COLUMN
END_OBJECT                   = ODF8A_TABLE

OBJECT                       = ODF8B_TABLE
  NAME                         = "END OF FILE GROUP DATA"
  INTERCHANGE_FORMAT           = BINARY
  ROWS                         = 35
  COLUMNS                      = 1
  ROW_BYTES                    = 36
  DESCRIPTION                  = "The End of File Group Data
     are the last several records in an Orbit Data File
     (ODF).  They are not defined, and simply fill out
     the final 8064-byte logical blocks in the file."
  OBJECT                       = COLUMN
    NAME                         = "SPARE"
    DATA_TYPE                    = MSB_INTEGER
    BYTES                        = 36
    START_BYTE                   = 1
    ITEMS                        = 9
    ITEM_BYTES                   = 4
    ITEM_OFFSET                  = 4
  END_OBJECT                   = COLUMN
END_OBJECT                   = ODF8B_TABLE

END
```

7.3.3.3 RSR

The RSR data product has a label as follows:

```
PDS_VERSION_ID                  = PDS3
RECORD_TYPE                     = FIXED_LENGTH
RECORD_BYTES                    = 4260
FILE_RECORDS                    = 19801
DATA_SET_ID                     = "GRAIL-L-RSS-2-EDR-V1.0"
TARGET_NAME                     = "MOON"
INSTRUMENT_HOST_NAME            = "GRAVITY RECOVERY AND INTERIOR
                                   LABORATORY A"
INSTRUMENT_NAME                 = "LUNAR GRAVITY RANGING SYSTEM A"
MISSION_NAME                    = "GRAVITY RECOVERY AND INTERIOR
                                   LABORATORY"
OBSERVATION_TYPE                = "SCIENCE"
PRODUCER_ID                     = DSN
DSN_STATION_NUMBER              = 45
NOTE                            = ""
PRODUCT_CREATION_TIME           = 2012-148T11:35:00
PRODUCT_ID                      = "GRALUGF2012148_0605NNNX45RD.1A1"
^TABLE                          = "GRALUGF2012148_0605NNNX45RD.1A1"
START_TIME                      = 2012-148T06:05:00
STOP_TIME                       = 2012-148T11:35:00
SOFTWARE_NAME                   = "UNK"
DOCUMENT_NAME                   = "JPL D-16765"
OBJECT                          = TABLE
  INTERCHANGE_FORMAT              = BINARY
  ROWS                            = 19801
  COLUMNS                         = 72
  ROW_BYTES                       = 4260
  DESCRIPTION                     = "The Radio Science Receiver (RSR) is
  a computer-controlled open loop receiver that digitally records a
  spacecraft signal through the use of an analog to digital converter
  (ADC) and up to four digital filter sub-channels.  The digital samples
  from each sub-channel are stored to disk in one second records in real
  time.  In near real time the one second records are partitioned and
  formatted into a sequence of RSR Standard Format Data Units (SFDUs)
  which are transmitted to the Advanced Multi-Mission Operations System
  (AMMOS) at the Jet Propulsion Laboratory (JPL).  Included in each RSR
  SFDU are the ancillary data necessary to reconstruct the signal
  represented by the recorded data samples.

  Each SFDU is defined here as a single row in a PDS TABLE object; later
  SFDUs are later rows.  The first fields in each row contain the ancillary
  data (time tags and frequency estimates, for example) that applied while
  the samples at the end of the record were being collected.  The object
  definitions below explain where the fields are and what the contents
  represent.

  Analysis of variations in the amplitude, frequency, and phase of the
  recorded signals provides information on the ring structure, atmospheric
  density, magnetic field, and charged particle environment of planets
  which occult the spacecraft.  Variations in the recorded signal can also
  be used for detection of gravitational waves."
```

```
OBJECT                  = COLUMN
  NAME                    = "SFDU CONTROL AUTHORITY"
  COLUMN_NUMBER           = 1
  START_BYTE              = 1
  BYTES                   = 4
  DATA_TYPE               = CHARACTER
  UNIT                    = "N/A"
  DESCRIPTION             = "An ASCII string giving the SFDU
                             Control Authority for this data
                             type.  Set to 'NJPL', meaning the
                             data description information for
                             this type of SFDU is maintained
                             by the NASA/JPL Control Authority."
END_OBJECT              = COLUMN

OBJECT                  = COLUMN
  NAME                    = "SFDU LABEL VERSION ID"
  COLUMN_NUMBER           = 2
  START_BYTE              = 5
  BYTES                   = 1
  DATA_TYPE               = CHARACTER
  UNIT                    = "N/A"
  DESCRIPTION             = "An ASCII character giving the SFDU
                             Label Version Identifier.  Set to
                             '2', meaning the length given in
                             bytes 13-20 is formatted as a
                             binary unsigned integer."
END_OBJECT              = COLUMN

OBJECT                  = COLUMN
  NAME                    = "SFDU CLASS ID"
  COLUMN_NUMBER           = 3
  START_BYTE              = 6
  BYTES                   = 1
  DATA_TYPE               = CHARACTER
  UNIT                    = "N/A"
  DESCRIPTION             = "An ASCII character giving the SFDU
                             Class Identifier.  Set to 'I',
                             meaning this is a Compressed Header
                             Data Object (CHDO) structured SFDU."
END_OBJECT              = COLUMN

OBJECT                  = COLUMN
  NAME                    = "SFDU RESERVED"
  COLUMN_NUMBER           = 4
  START_BYTE              = 7
  BYTES                   = 2
  DATA_TYPE               = MSB_INTEGER
  UNIT                    = "N/A"
  DESCRIPTION             = "These two bytes are not defined."
END_OBJECT              = COLUMN

OBJECT                  = COLUMN
  NAME                    = "SFDU DATA DESCRIPTION ID"
```

```
    COLUMN_NUMBER            = 5
    START_BYTE               = 9
    BYTES                    = 4
    DATA_TYPE                = CHARACTER
    UNIT                     = "N/A"
    DESCRIPTION              = "An ASCII string giving the SFDU Data
                                Description Identifier.  Set to
                                'C997', a unique identifier for the
                                RSR data type within the NASA/JPL
                                Control Authority."
  END_OBJECT               = COLUMN

  OBJECT                   = COLUMN
    NAME                     = "SFDU RSR LENGTH PAD"
    COLUMN_NUMBER            = 6
    START_BYTE               = 13
    BYTES                    = 4
    DATA_TYPE                = MSB_UNSIGNED_INTEGER
    UNIT                     = "N/A"
    DESCRIPTION              = "The high-order 32 bits of a 64-bit
                                unsigned binary integer giving the
                                number of remaining bytes in
                                the SFDU after the 20-byte label.
                                Always '0' in the RSR SFDU."
  END_OBJECT               = COLUMN

  OBJECT                   = COLUMN
    NAME                     = "SFDU RSR LENGTH"
    COLUMN_NUMBER            = 7
    START_BYTE               = 17
    BYTES                    = 4
    DATA_TYPE                = MSB_UNSIGNED_INTEGER
    UNIT                     = "BYTE"
    DESCRIPTION              = "The number of remaining bytes in
                                the SFDU after the 20-byte label.
                                Always less than 31000."
  END_OBJECT               = COLUMN

  OBJECT                   = COLUMN
    NAME                     = "HEADER AGGREGATION CHDO TYPE"
    COLUMN_NUMBER            = 8
    START_BYTE               = 21
    BYTES                    = 2
    DATA_TYPE                = MSB_UNSIGNED_INTEGER
    UNIT                     = "N/A"
    DESCRIPTION              = "Header Aggregation CHDO Type.  Set
                                to '1', meaning this CHDO is an
                                aggregation of header CHDOs.  The
                                NJPL Control Authority maintains a
                                registry of CHDO types."
  END_OBJECT               = COLUMN

  OBJECT                   = COLUMN
    NAME                     = "HEADER AGGREGATION CHDO LENGTH"
    COLUMN_NUMBER            = 9
```

```
  START_BYTE              = 23
  BYTES                   = 2
  DATA_TYPE               = MSB_UNSIGNED_INTEGER
  UNIT                    = "BYTE"
  DESCRIPTION             = "Header Aggregation CHDO Length. Set
                             to '232', meaning length of the
                             value field of the Header Aggregation
                             CHDO is 232 bytes (bytes 25-256)."
END_OBJECT              = COLUMN

OBJECT                  = COLUMN
  NAME                    = "PRIMARY HEADER CHDO TYPE"
  COLUMN_NUMBER           = 10
  START_BYTE              = 25
  BYTES                   = 2
  DATA_TYPE               = MSB_UNSIGNED_INTEGER
  UNIT                    = "N/A"
  DESCRIPTION             = "Primary Header CHDO Type.  Set to
                             to '2', meaning this CHDO is a
                             primary header CHDO.  The NJPL
                             Control Authority maintains a
                             registry of CHDO types."
END_OBJECT              = COLUMN

OBJECT                  = COLUMN
  NAME                    = "PRIMARY HEADER CHDO LENGTH"
  COLUMN_NUMBER           = 11
  START_BYTE              = 27
  BYTES                   = 2
  DATA_TYPE               = MSB_UNSIGNED_INTEGER
  UNIT                    = "BYTE"
  DESCRIPTION             = "Primary Header CHDO Length. Set to
                             '4', meaning length of the value
                             field of the Primary Header CHDO is
                             4 bytes (bytes 29-32)."
END_OBJECT              = COLUMN

OBJECT                  = COLUMN
  NAME                    = "MAJOR DATA CLASS"
  COLUMN_NUMBER           = 12
  START_BYTE              = 29
  BYTES                   = 1
  DATA_TYPE               = MSB_UNSIGNED_INTEGER
  UNIT                    = "N/A"
  DESCRIPTION             = "Major Data Class.  Set to '21',
                             meaning this SFDU contains Radio
                             Science data."
END_OBJECT              = COLUMN

OBJECT                  = COLUMN
  NAME                    = "MINOR DATA CLASS"
  COLUMN_NUMBER           = 13
  START_BYTE              = 30
  BYTES                   = 1
  DATA_TYPE               = MSB_UNSIGNED_INTEGER
```

```
  UNIT                      = "N/A"
  DESCRIPTION               = "Minor Data Class.  Set to '4'.
                               This Major/Minor Data Class
                               combination means the SFDU contains
                               Radio Science RSR data."
END_OBJECT                = COLUMN

OBJECT                    = COLUMN
  NAME                      = "MISSION IDENTIFIER"
  COLUMN_NUMBER             = 14
  START_BYTE                = 31
  BYTES                     = 1
  DATA_TYPE                 = MSB_UNSIGNED_INTEGER
  UNIT                      = "N/A"
  DESCRIPTION               = "Mission Identifier.  Set to '0',
                               meaning the RSR does not use this
                               field.  The value may be changed
                               if the Ground Data System handles
                               the data. If a Mission Identifier
                               is needed, values may be found in
                               DSN document 820-013, OPS-6-21A,
                               Table 3-4."
END_OBJECT                = COLUMN

OBJECT                    = COLUMN
  NAME                      = "FORMAT CODE"
  COLUMN_NUMBER             = 15
  START_BYTE                = 32
  BYTES                     = 1
  DATA_TYPE                 = MSB_UNSIGNED_INTEGER
  UNIT                      = "N/A"
  DESCRIPTION               = "Format Code.  Set to '0'.  The RSR
                               supports only one data format."
END_OBJECT                = COLUMN

OBJECT                    = COLUMN
  NAME                      = "SECONDARY HEADER CHDO TYPE"
  COLUMN_NUMBER             = 16
  START_BYTE                = 33
  BYTES                     = 2
  DATA_TYPE                 = MSB_UNSIGNED_INTEGER
  UNIT                      = "N/A"
  DESCRIPTION               = "Secondary Header CHDO Type.  Set to
                               to '104', meaning this CHDO is an
                               RSR secondary header CHDO.  The NJPL
                               Control Authority maintains a
                               registry of CHDO types."
END_OBJECT                = COLUMN

OBJECT                    = COLUMN
  NAME                      = "SECONDARY HEADER CHDO LENGTH"
  COLUMN_NUMBER             = 17
  START_BYTE                = 35
  BYTES                     = 2
  DATA_TYPE                 = MSB_UNSIGNED_INTEGER
```

```
  UNIT                      = "BYTE"
  DESCRIPTION               = "Secondary Header CHDO Length. Set to
                               '220', meaning length of the value
                               field of the Secondary Header CHDO is
                               220 bytes (bytes 37-256)."
END_OBJECT                = COLUMN

OBJECT                    = COLUMN
  NAME                      = "ORIGINATOR ID"
  COLUMN_NUMBER             = 18
  START_BYTE                = 37
  BYTES                     = 1
  DATA_TYPE                 = MSB_UNSIGNED_INTEGER
  UNIT                      = "N/A"
  DESCRIPTION               = "Originator Identifier.  A value '48'
                               means the data originated within the
                               DSN."
END_OBJECT                = COLUMN

OBJECT                    = COLUMN
  NAME                      = "LAST MODIFIER ID"
  COLUMN_NUMBER             = 19
  START_BYTE                = 38
  BYTES                     = 1
  DATA_TYPE                 = MSB_UNSIGNED_INTEGER
  UNIT                      = "N/A"
  DESCRIPTION               = "Last Modifier Identifier.  A value
                               '48' means the contents of the SFDU
                               were last modified by the DSN."
END_OBJECT                = COLUMN

OBJECT                    = COLUMN
  NAME                      = "RSR SOFTWARE ID"
  COLUMN_NUMBER             = 20
  START_BYTE                = 39
  BYTES                     = 2
  DATA_TYPE                 = MSB_UNSIGNED_INTEGER
  UNIT                      = "N/A"
  DESCRIPTION               = "RSR Software Identifier. The version
                               of the RSR software is indicated by
                               an unsigned binary integer between
                               0 and 65535."
END_OBJECT                = COLUMN

OBJECT                    = COLUMN
  NAME                      = "RECORD SEQUENCE NUMBER"
  COLUMN_NUMBER             = 21
  START_BYTE                = 41
  BYTES                     = 2
  DATA_TYPE                 = MSB_UNSIGNED_INTEGER
  UNIT                      = "N/A"
  DESCRIPTION               = "The Record Sequence Number (RSN)
                               starts at 0 for the first RSR SFDU
                               and increments by 1 for each
                               successive SFDU to a maximum of
```

```
                             65535, after which it resets to 0
                             and begins incrementing again.
                             The RSN may be reset at other times,
                             such as when the RSR is started or
                             restarted.  The RSN is provided by
                             the originator of the SFDU and should
                             not be changed during subsequent
                             handling or modification."
END_OBJECT                 = COLUMN

OBJECT                     = COLUMN
  NAME                       = "SIGNAL PROCESSING CENTER"
  COLUMN_NUMBER              = 22
  START_BYTE                 = 43
  BYTES                      = 1
  DATA_TYPE                  = MSB_UNSIGNED_INTEGER
  UNIT                       = "N/A"
  DESCRIPTION                = "Signal Processing Center (SPC)
                             Identifier. Valid numbers include
                               10   Goldstone
                               40   Canberra
                               60   Madrid
                               21   DTF21"
END_OBJECT                 = COLUMN

OBJECT                     = COLUMN
  NAME                       = "DEEP SPACE STATION"
  COLUMN_NUMBER              = 23
  START_BYTE                 = 44
  BYTES                      = 1
  DATA_TYPE                  = MSB_UNSIGNED_INTEGER
  UNIT                       = "N/A"
  DESCRIPTION                = "Deep Space Station (DSS) Identifier.
                             This is the DSS identifier listed in
                             the frequency predicts file used to
                             collect the data in this SFDU.  DSS
                             identifiers are listed in DSN
                             document 820-013, OPS-6-3 and include
                             valid numbers such as 14, 15, 25, 43,
                             45, 54, and 63."
END_OBJECT                 = COLUMN

OBJECT                     = COLUMN
  NAME                       = "RADIO SCIENCE RECEIVER"
  COLUMN_NUMBER              = 24
  START_BYTE                 = 45
  BYTES                      = 1
  DATA_TYPE                  = MSB_UNSIGNED_INTEGER
  UNIT                       = "N/A"
  DESCRIPTION                = "Radio Science Receiver (RSR)
                             Identifier.  Values can be in the
                             range 1-16 and specify the RSR used
                             to collect the data in this SFDU.
                             For example,
                                  RSR ID = 1  denotes  RSR1A
```

```
                                RSR ID = 2  denotes  RSR1B
                                RSR ID = 3  denotes  RSR2A
                           The SPC ID and RSR ID uniquely
                           specify the hardware used in the
                           data acquisition.  SPC 10 has three
                           RSR racks; SPC 40 and SPC 60 each
                           have two.  Each rack has two
                           receivers (A and B).  Except for the
                           analog components in the ADCs, the
                           end-to-end performance of every RSR
                           should be identical."
END_OBJECT                = COLUMN

OBJECT                    = COLUMN
  NAME                      = "SUB-CHANNEL IDENTIFIER"
  COLUMN_NUMBER             = 25
  START_BYTE                = 46
  BYTES                     = 1
  DATA_TYPE                 = MSB_UNSIGNED_INTEGER
  UNIT                      = "N/A"
  DESCRIPTION               = "Sub-Channel Identifier.  This can be
                           in the range 1-4 and specifies the
                           RSR sub-channel used to acquire the
                           the data in this SFDU."
END_OBJECT                = COLUMN

OBJECT                    = COLUMN
  NAME                      = "SECONDARY HEADER CHDO RESERVED"
  COLUMN_NUMBER             = 26
  START_BYTE                = 47
  BYTES                     = 1
  DATA_TYPE                 = MSB_UNSIGNED_INTEGER
  UNIT                      = "N/A"
  DESCRIPTION               = "This field is not used."
END_OBJECT                = COLUMN

OBJECT                    = COLUMN
  NAME                      = "SPACECRAFT"
  COLUMN_NUMBER             = 27
  START_BYTE                = 48
  BYTES                     = 1
  DATA_TYPE                 = MSB_UNSIGNED_INTEGER
  UNIT                      = "N/A"
  DESCRIPTION               = "Spacecraft Identifier, as listed in
                           the frequency predicts file used to
                           collect the data in this SFDU. Values
                           are assigned by the Deep Space
                           Mission System (DSMS) and are in the
                           range 0-255.  Assignments are given
                           in DSN document 820-013, OPS-6-21A,
                           Table 3-4."
END_OBJECT                = COLUMN

OBJECT                    = COLUMN
  NAME                      = "PREDICTS PASS NUMBER"
```

```
  COLUMN_NUMBER             = 28
  START_BYTE                = 49
  BYTES                     = 2
  DATA_TYPE                 = MSB_UNSIGNED_INTEGER
  UNIT                      = "N/A"
  DESCRIPTION               = "Predicts Pass Number (range 0-65535)
                               gives the DSN pass number in the
                               predicts file used to collect the
                               data in this SFDU."
END_OBJECT                = COLUMN

OBJECT                    = COLUMN
  NAME                      = "UPLINK FREQUENCY BAND"
  COLUMN_NUMBER             = 29
  START_BYTE                = 51
  BYTES                     = 1
  DATA_TYPE                 = CHARACTER
  UNIT                      = "N/A"
  DESCRIPTION               = "The Uplink Frequency Band specified
                               in the predicts file used to collect
                               the data in this SFDU.  Possible
                               values include 'S' (S-Band), 'X' (X-
                               Band), and 'K' (Ka-Band)."
END_OBJECT                = COLUMN

OBJECT                    = COLUMN
  NAME                      = "DOWNLINK FREQUENCY BAND"
  COLUMN_NUMBER             = 30
  START_BYTE                = 52
  BYTES                     = 1
  DATA_TYPE                 = CHARACTER
  UNIT                      = "N/A"
  DESCRIPTION               = "The Downlink Frequency Band specified
                               in the predicts file used to collect
                               the data in this SFDU.  Possible
                               values include 'S' (S-Band), 'X' (X-
                               Band), and 'K' (Ka-Band)."
END_OBJECT                = COLUMN

OBJECT                    = COLUMN
  NAME                      = "TRACKING MODE"
  COLUMN_NUMBER             = 31
  START_BYTE                = 53
  BYTES                     = 1
  DATA_TYPE                 = MSB_UNSIGNED_INTEGER
  UNIT                      = "N/A"
  DESCRIPTION               = "The Tracking Mode in use when the
                               data in this SFDU were acquired.
                               Possible values are '1' (one-way),
                               '2' (two-way), and '3' (three-way)."
END_OBJECT                = COLUMN

OBJECT                    = COLUMN
  NAME                      = "UPLINK DSS ID FOR 3-WAY TRACKING"
  COLUMN_NUMBER             = 32
```

```
  START_BYTE             = 54
  BYTES                  = 1
  DATA_TYPE              = MSB_UNSIGNED_INTEGER
  UNIT                   = "N/A"
  DESCRIPTION            = "Deep Space Station (DSS) Identifier
                            for the uplink antenna when
                            TRACKING_MODE=3; otherwise,
                            undefined.  DSS identifiers are
                            listed in DSN document 820-013,
                            OPS-6-3 and include valid numbers
                            such as 14, 15, 25, 43, 45, 54, and
                            63."
END_OBJECT             = COLUMN

OBJECT                 = COLUMN
  NAME                   = "FGAIN"
  COLUMN_NUMBER          = 33
  START_BYTE             = 55
  BYTES                  = 1
  DATA_TYPE              = MSB_INTEGER
  UNIT                   = "DECIBEL HERTZ"
  DESCRIPTION            = "Expected ratio of signal power to
                            noise power in a one Hz bandwidth
                            when the data in this SFDU were
                            collected.  This parameter is used
                            to estimate the sample voltage
                            amplitudes at the RSR output and
                            to compute settings of the
                            sub-channel filter gain so that
                            there is no clipping of the sample
                            values. Possible values are in the
                            range -127 to +128."
END_OBJECT             = COLUMN

OBJECT                 = COLUMN
  NAME                   = "FGAIN IF BANDWIDTH"
  COLUMN_NUMBER          = 34
  START_BYTE             = 56
  BYTES                  = 1
  DATA_TYPE              = MSB_UNSIGNED_INTEGER
  UNIT                   = "MEGAHERTZ"
  DESCRIPTION            = "IF Bandwidth expected to be in use
                            by the RSR at the time the data in
                            this SFDU were acquired. This value
                            is used to compute the settings of
                            the sub-channel filter gain. Values
                            can be in the range 1-127."
END_OBJECT             = COLUMN

OBJECT                 = COLUMN
  NAME                   = "FROV FLAG"
  COLUMN_NUMBER          = 35
  START_BYTE             = 57
  BYTES                  = 1
  DATA_TYPE              = MSB_UNSIGNED_INTEGER
```

```
  UNIT                      = "N/A"
  DESCRIPTION               = "Frequency Predicts Override Flag.
                               Set to '0', this indicates that the
                               frequency predicts file was in use;
                               any other value indicates that the
                               frequency specified by the FROV
                               command was in use.  The value of
                               the override frequency is given by
                               PREDICTS_FREQUENCY_OVERRIDE in
                               Column 51."
END_OBJECT                = COLUMN

OBJECT                    = COLUMN
  NAME                      = "DIG ATTENUATION"
  COLUMN_NUMBER             = 36
  START_BYTE                = 58
  BYTES                     = 1
  DATA_TYPE                 = MSB_UNSIGNED_INTEGER
  UNIT                      = "N/A"
  DESCRIPTION               = "RSR Digitizer Subassembly (DIG)
                               setting.  Values are in the range
                               0-63, which correspond to 0.5 dB
                               increments in attenuation."
END_OBJECT                = COLUMN

OBJECT                    = COLUMN
  NAME                      = "DIG ADC RMS"
  COLUMN_NUMBER             = 37
  START_BYTE                = 59
  BYTES                     = 1
  DATA_TYPE                 = MSB_UNSIGNED_INTEGER
  UNIT                      = "N/A"
  DESCRIPTION               = "Root-mean-square amplitude of about
                               10000 8-bit samples taken from the DIG
                               ADC stream.  Time of the measurement
                               is stored in bytes Columns 39-41."
END_OBJECT                = COLUMN

OBJECT                    = COLUMN
  NAME                      = "DIG ADC PEAK"
  COLUMN_NUMBER             = 38
  START_BYTE                = 60
  BYTES                     = 1
  DATA_TYPE                 = MSB_UNSIGNED_INTEGER
  UNIT                      = "N/A"
  DESCRIPTION               = "Peak amplitude from about 10000 8-bit
                               samples taken from the DIG ADC stream.
                               Time for the measurement is stored in
                               Columns 39-41."
END_OBJECT                = COLUMN

OBJECT                    = COLUMN
  NAME                      = "DIG ADC YEAR"
  COLUMN_NUMBER             = 39
  START_BYTE                = 61
```

```
    BYTES                   = 2
    DATA_TYPE               = MSB_UNSIGNED_INTEGER
    UNIT                    = "N/A"
    DESCRIPTION             = "UTC year on which the ADC data were
                               computed.  Values can range over
                               1900-3000."
  END_OBJECT              = COLUMN

  OBJECT                  = COLUMN
    NAME                    = "DIG ADC DAY OF YEAR"
    COLUMN_NUMBER           = 40
    START_BYTE              = 63
    BYTES                   = 2
    DATA_TYPE               = MSB_UNSIGNED_INTEGER
    UNIT                    = "N/A"
    DESCRIPTION             = "UTC day-of-year on which the ADC
                               data were computed.  Values can
                               range over 1-366."
  END_OBJECT              = COLUMN

  OBJECT                  = COLUMN
    NAME                    = "DIG ADC SECOND"
    COLUMN_NUMBER           = 41
    START_BYTE              = 65
    BYTES                   = 4
    DATA_TYPE               = MSB_UNSIGNED_INTEGER
    UNIT                    = "SECOND"
    DESCRIPTION             = "UTC second of day on which the ADC
                               data were computed.  Values can
                               range over 0-86400."
  END_OBJECT              = COLUMN

  OBJECT                  = COLUMN
    NAME                    = "SAMPLE RESOLUTION"
    COLUMN_NUMBER           = 42
    START_BYTE              = 69
    BYTES                   = 1
    DATA_TYPE               = MSB_UNSIGNED_INTEGER
    UNIT                    = "BIT"
    DESCRIPTION             = "Bits per sample in the data in this
                               SFDU.  Valid values are 1, 2, 4, 8,
                               and 16 and are selected by the RSR
                               operator while it is in configure
                               state."
  END_OBJECT              = COLUMN

  OBJECT                  = COLUMN
    NAME                    = "DATA ERROR COUNT"
    COLUMN_NUMBER           = 43
    START_BYTE              = 70
    BYTES                   = 1
    DATA_TYPE               = MSB_UNSIGNED_INTEGER
    UNIT                    = "N/A"
    DESCRIPTION             = "Number of hardware errors encountered
                               while the data in this SFDU were
```

```
                             being recorded. Values can range over
                             0-255, but any value greater than 0
                             indicates data may have been
                             corrupted by hardware errors."
END_OBJECT                = COLUMN

OBJECT                    = COLUMN
  NAME                      = "SAMPLE RATE"
  COLUMN_NUMBER             = 44
  START_BYTE                = 71
  BYTES                     = 2
  DATA_TYPE                 = MSB_UNSIGNED_INTEGER
  UNIT                      = "KILOSAMPLE PER SECOND"
  DESCRIPTION               = "The rate at which samples were
                             collected in this SFDU. Sample rate
                             or bandwidth is specified by the
                             operator while the RSR is in the
                             configure state."
END_OBJECT                = COLUMN

OBJECT                    = COLUMN
  NAME                      = "DDC LO FREQUENCY"
  COLUMN_NUMBER             = 45
  START_BYTE                = 73
  BYTES                     = 2
  DATA_TYPE                 = MSB_UNSIGNED_INTEGER
  UNIT                      = "MEGAHERTZ"
  DESCRIPTION               = "Digital Down Converter (DDC) Local
                             Oscillator (LO) Frequency. This
                             specifies the downconversion applied
                             to the signal in the DIG and DDC.
                             This frequency is needed to compute
                             the sky frequency of the data in
                             this SFDU:

                                   Fsky = RFtoIF_LO +
                                          DDC_LO -
                                          NCO_Freq +
                                          Fresid
                             where

                                  RFtoIF_LO is in Column 46,
                                  DDC_LO is in Column 45,
                                  NCO_Freq from Columns 61-63, and
                                  Fresid is the signal offset
                                     from DC in the RSR data."
END_OBJECT                = COLUMN

OBJECT                    = COLUMN
  NAME                      = "RF-IF LO FREQUENCY"
  COLUMN_NUMBER             = 46
  START_BYTE                = 75
  BYTES                     = 2
  DATA_TYPE                 = MSB_UNSIGNED_INTEGER
  UNIT                      = "MEGAHERTZ"
```

```
  DESCRIPTION             = "RF to IF Down Converter Local
                               Oscillator (LO) Frequency. This
                               specifies the total downconversion
                               applied to the signal before it
                               entered the RSR DIG.  The value is
                               subtracted from the RF predict
                               points in order to obtain the
                               frequency of the desired signal at
                               IF.  The RSR selects a default value
                               based on the downlink band: 2000
                               (S-Band), 8100 (X-Band), or 31700
                               (Ka-Band).  This frequency is needed
                               in order to reconstruct the sky
                               frequency of the data contained in
                               this SFDU:

                                     Fsky = RFtoIF_LO +
                                            DDC_LO -
                                            NCO_Freq +
                                            Fresid
                               where

                                    RFtoIF_LO is in Column 46,
                                    DDC_LO is in Column 45,
                                    NCO_Freq from Columns 61-63, and
                                    Fresid is the signal offset
                                       from DC in the RSR data."
END_OBJECT                = COLUMN

OBJECT                    = COLUMN
  NAME                      = "SFDU YEAR"
  COLUMN_NUMBER             = 47
  START_BYTE                = 77
  BYTES                     = 2
  DATA_TYPE                 = MSB_UNSIGNED_INTEGER
  UNIT                      = "N/A"
  DESCRIPTION               = "UTC year for the SFDU data and
                               models.  Values can range over
                               1900-3000."
END_OBJECT                = COLUMN

OBJECT                    = COLUMN
  NAME                      = "SFDU DAY OF YEAR"
  COLUMN_NUMBER             = 48
  START_BYTE                = 79
  BYTES                     = 2
  DATA_TYPE                 = MSB_UNSIGNED_INTEGER
  UNIT                      = "N/A"
  DESCRIPTION               = "UTC day-of-year for the SFDU
                               data and models.  Values can
                               range over 1-366."
END_OBJECT                = COLUMN

OBJECT                    = COLUMN
  NAME                      = "SFDU SECOND"
```

```
    COLUMN_NUMBER            = 49
    START_BYTE               = 81
    BYTES                    = 8
    DATA_TYPE                = IEEE_REAL
    UNIT                     = "SECOND"
    DESCRIPTION              = "UTC seconds of day for the SFDU
                                data and models.  Values can range
                                over 0-86400."
  END_OBJECT               = COLUMN

  OBJECT                   = COLUMN
    NAME                     = "PREDICTS TIME SHIFT"
    COLUMN_NUMBER            = 50
    START_BYTE               = 89
    BYTES                    = 8
    DATA_TYPE                = IEEE_REAL
    UNIT                     = "SECOND"
    DESCRIPTION              = "The number of seconds added to the
                                time tags of the frequency predicts
                                to shift them in time. This feature
                                allows testing the RSR with old
                                predict files.  The value should be
                                0.0 during normal operations."
  END_OBJECT               = COLUMN

  OBJECT                   = COLUMN
    NAME                     = "PREDICTS FREQUENCY OVERRIDE"
    COLUMN_NUMBER            = 51
    START_BYTE               = 97
    BYTES                    = 8
    DATA_TYPE                = IEEE_REAL
    UNIT                     = "HERTZ"
    DESCRIPTION              = "The value of the predicts frequency
                                override specified by the FROV
                                command; this constant value is
                                substituted for the value derived
                                from the predicts.  The flag in
                                Column 35 indicates whether the
                                frequency override is active."
  END_OBJECT               = COLUMN

  OBJECT                   = COLUMN
    NAME                     = "PREDICTS FREQUENCY RATE"
    COLUMN_NUMBER            = 52
    START_BYTE               = 105
    BYTES                    = 8
    DATA_TYPE                = IEEE_REAL
    UNIT                     = "HERTZ PER SECOND"
    DESCRIPTION              = "The frequency rate added to the RF
                                frequency predicts as specified by
                                the FRR command. The allowable range
                                is -8000 to +8000 Hz/s."
  END_OBJECT               = COLUMN

  OBJECT                   = COLUMN
```

```
  NAME                      = "PREDICTS FREQUENCY OFFSET"
  COLUMN_NUMBER             = 53
  START_BYTE                = 113
  BYTES                     = 8
  DATA_TYPE                 = IEEE_REAL
  UNIT                      = "HERTZ"
  DESCRIPTION               = "The total frequency added to the
                               RF frequency predicts as specified
                               the FRO command and the accumulated
                               frequency rate as specified by the
                               FRR command. The allowable
                               range is -8 to +8 MHz."
END_OBJECT                = COLUMN

OBJECT                    = COLUMN
  NAME                      = "SUB-CHANNEL FREQUENCY OFFSET"
  COLUMN_NUMBER             = 54
  START_BYTE                = 121
  BYTES                     = 8
  DATA_TYPE                 = IEEE_REAL
  UNIT                      = "HERTZ"
  DESCRIPTION               = "The frequency added to the frequency
                               predicts for this sub-channel as
                               specified by the SFRO command."
END_OBJECT                = COLUMN

OBJECT                    = COLUMN
  NAME                      = "RF POINT 1"
  COLUMN_NUMBER             = 55
  START_BYTE                = 129
  BYTES                     = 8
  DATA_TYPE                 = IEEE_REAL
  UNIT                      = "HERTZ"
  DESCRIPTION               = "The radio frequency at the beginning
                               of the second as calculated from the
                               predicts."
END_OBJECT                = COLUMN

OBJECT                    = COLUMN
  NAME                      = "RF POINT 2"
  COLUMN_NUMBER             = 56
  START_BYTE                = 137
  BYTES                     = 8
  DATA_TYPE                 = IEEE_REAL
  UNIT                      = "HERTZ"
  DESCRIPTION               = "The radio frequency at the middle
                               of the second as calculated from the
                               predicts."
END_OBJECT                = COLUMN

OBJECT                    = COLUMN
  NAME                      = "RF POINT 3"
  COLUMN_NUMBER             = 57
  START_BYTE                = 145
  BYTES                     = 8
```

```
  DATA_TYPE                = IEEE_REAL
  UNIT                     = "HERTZ"
  DESCRIPTION              = "The radio frequency at the end
                              of the second as calculated from the
                              predicts."
END_OBJECT               = COLUMN

OBJECT                   = COLUMN
  NAME                     = "SUB-CHANNEL FREQUENCY POINT 1"
  COLUMN_NUMBER            = 58
  START_BYTE               = 153
  BYTES                    = 8
  DATA_TYPE                = IEEE_REAL
  UNIT                     = "HERTZ"
  DESCRIPTION              = "The sub-channel frequency at the
                              beginning of the second.  This
                              point is used to create the
                              sub-channel frequency and phase
                              polynomials."
END_OBJECT               = COLUMN

OBJECT                   = COLUMN
  NAME                     = "SUB-CHANNEL FREQUENCY POINT 2"
  COLUMN_NUMBER            = 59
  START_BYTE               = 161
  BYTES                    = 8
  DATA_TYPE                = IEEE_REAL
  UNIT                     = "HERTZ"
  DESCRIPTION              = "The sub-channel frequency at the
                              middle of the second.  This
                              point is used to create the
                              sub-channel frequency and phase
                              polynomials."
END_OBJECT               = COLUMN

OBJECT                   = COLUMN
  NAME                     = "SUB-CHANNEL FREQUENCY POINT 3"
  COLUMN_NUMBER            = 60
  START_BYTE               = 169
  BYTES                    = 8
  DATA_TYPE                = IEEE_REAL
  UNIT                     = "HERTZ"
  DESCRIPTION              = "The sub-channel frequency at the
                              end of the second.  This
                              point is used to create the
                              sub-channel frequency and phase
                              polynomials."
END_OBJECT               = COLUMN

OBJECT                   = COLUMN
  NAME                     = "SUB-CHANNEL FREQUENCY COEF F1"
  COLUMN_NUMBER            = 61
  START_BYTE               = 177
  BYTES                    = 8
  DATA_TYPE                = IEEE_REAL
```

```
  UNIT                      = "HERTZ"
  DESCRIPTION               = "The sub-channel frequency polynomial
                               coefficient F1 where the frequency
                               over a one millisecond interval
                               beginning at t in msec is evaluated
                                 F(t) = F1 +
                                        F2*((t+0.5)/1000) +
                                        F3*((t+0.5)/1000)**2
                               The coefficients are derived from
                               the frequency points in columns
                               58-60."
END_OBJECT                = COLUMN

OBJECT                    = COLUMN
  NAME                      = "SUB-CHANNEL FREQUENCY COEF F2"
  COLUMN_NUMBER             = 62
  START_BYTE                = 185
  BYTES                     = 8
  DATA_TYPE                 = IEEE_REAL
  UNIT                      = "HERTZ"
  DESCRIPTION               = "The sub-channel frequency polynomial
                               coefficient F2 where the frequency
                               over a one millisecond interval
                               beginning at t in msec is evaluated
                                 F(t) = F1 +
                                        F2*((t+0.5)/1000) +
                                        F3*((t+0.5)/1000)**2
                               The coefficients are derived from
                               the frequency points in columns
                               58-60."
END_OBJECT                = COLUMN

OBJECT                    = COLUMN
  NAME                      = "SUB-CHANNEL FREQUENCY COEF F3"
  COLUMN_NUMBER             = 63
  START_BYTE                = 193
  BYTES                     = 8
  DATA_TYPE                 = IEEE_REAL
  UNIT                      = "HERTZ"
  DESCRIPTION               = "The sub-channel frequency polynomial
                               coefficient F3 where the frequency
                               over a one millisecond interval
                               beginning at t in msec is evaluated
                                 F(t) = F1 +
                                        F2*((t+0.5)/1000) +
                                        F3*((t+0.5)/1000)**2
                               The coefficients are derived from
                               the frequency points in columns
                               58-60."
END_OBJECT                = COLUMN

OBJECT                    = COLUMN
  NAME                      = "SUB-CHANNEL ACCUMULATED PHASE"
  COLUMN_NUMBER             = 64
  START_BYTE                = 201
```

```
    BYTES                     = 8
    DATA_TYPE                 = IEEE_REAL
    UNIT                      = "CYCLE"
    DESCRIPTION               = "The accumulated whole turns of the
                                 sub-channel phase at the beginning
                                 of the present second.  The phase
                                 during this second is the accumulated
                                 phase incremented by the phase
                                 computed using the coefficients in
                                 Columns 65-68."
  END_OBJECT                = COLUMN

  OBJECT                    = COLUMN
    NAME                      = "SUB-CHANNEL PHASE COEF P1"
    COLUMN_NUMBER             = 65
    START_BYTE                = 209
    BYTES                     = 8
    DATA_TYPE                 = IEEE_REAL
    UNIT                      = "CYCLE"
    DESCRIPTION               = "The sub-channel phase polynomial
                                 coefficient P1 where the phase
                                 over a one millisecond interval
                                 beginning at t in msec is evaluated
                                   P(t) = P1 +
                                          P2*((t+0.5)/1000) +
                                          P3*((t+0.5)/1000)**2 +
                                          P4*((t+0.5)/1000)**3
                                 The coefficients are derived from
                                 the frequency points in columns
                                 58-60."
  END_OBJECT                = COLUMN

  OBJECT                    = COLUMN
    NAME                      = "SUB-CHANNEL PHASE COEF P2"
    COLUMN_NUMBER             = 66
    START_BYTE                = 217
    BYTES                     = 8
    DATA_TYPE                 = IEEE_REAL
    UNIT                      = "CYCLE"
    DESCRIPTION               = "The sub-channel phase polynomial
                                 coefficient P2 where the phase
                                 over a one millisecond interval
                                 beginning at t in msec is evaluated
                                   P(t) = P1 +
                                          P2*((t+0.5)/1000) +
                                          P3*((t+0.5)/1000)**2 +
                                          P4*((t+0.5)/1000)**3
                                 The coefficients are derived from
                                 the frequency points in columns
                                 58-60."
  END_OBJECT                = COLUMN

  OBJECT                    = COLUMN
    NAME                      = "SUB-CHANNEL PHASE COEF P3"
    COLUMN_NUMBER             = 67
```

```
    START_BYTE              = 225
    BYTES                   = 8
    DATA_TYPE               = IEEE_REAL
    UNIT                    = "CYCLE"
    DESCRIPTION             = "The sub-channel phase polynomial
                               coefficient P3 where the phase
                               over a one millisecond interval
                               beginning at t in msec is evaluated
                                 P(t) = P1 +
                                        P2*((t+0.5)/1000) +
                                        P3*((t+0.5)/1000)**2 +
                                        P4*((t+0.5)/1000)**3
                               The coefficients are derived from
                               the frequency points in columns
                               58-60."
  END_OBJECT              = COLUMN

  OBJECT                  = COLUMN
    NAME                    = "SUB-CHANNEL PHASE COEF P4"
    COLUMN_NUMBER           = 68
    START_BYTE              = 233
    BYTES                   = 8
    DATA_TYPE               = IEEE_REAL
    UNIT                    = "CYCLE"
    DESCRIPTION             = "The sub-channel phase polynomial
                               coefficient P4 where the phase
                               over a one millisecond interval
                               beginning at t in msec is evaluated
                                 P(t) = P1 +
                                        P2*((t+0.5)/1000) +
                                        P3*((t+0.5)/1000)**2 +
                                        P4*((t+0.5)/1000)**3
                               The coefficients are derived from
                               the frequency points in columns
                               58-60."
  END_OBJECT              = COLUMN

  OBJECT                  = COLUMN
    NAME                    = "SPARES"
    COLUMN_NUMBER           = 69
    BYTES                   = 16
    ITEMS                   = 16
    START_BYTE              = 241
    ITEM_BYTES              = 1
    ITEM_OFFSET             = 1
    DATA_TYPE               = MSB_UNSIGNED_INTEGER
    UNIT                    = "N/A"
    DESCRIPTION             = "These 16 bytes are undefined."
  END_OBJECT              = COLUMN

  OBJECT                  = COLUMN
    NAME                    = "DATA CHDO TYPE"
    COLUMN_NUMBER           = 70
    START_BYTE              = 257
    BYTES                   = 2
```

```
    DATA_TYPE                  = MSB_UNSIGNED_INTEGER
    UNIT                       = "N/A"
    DESCRIPTION                = "Data CHDO Type.  Set to '10', meaning
                                  this CHDO contains binary data.  The
                                  NJPL Control Authority maintains a
                                  registry of CHDO types."
  END_OBJECT                 = COLUMN

  OBJECT                     = COLUMN
    NAME                       = "DATA CHDO LENGTH"
    COLUMN_NUMBER              = 71
    START_BYTE                 = 259
    BYTES                      = 2
    DATA_TYPE                  = MSB_UNSIGNED_INTEGER
    UNIT                       = "BYTE"
    DESCRIPTION                = "Data CHDO Length. Gives the number of
                                  bytes in the value field of the Data
                                  CHDO -- the number of bytes containing
                                  I and Q samples."
  END_OBJECT                 = COLUMN

  OBJECT                     = COLUMN
    NAME                       = "SAMPLE WORDS"
    COLUMN_NUMBER              = 72
    START_BYTE                 = 261
    BYTES                      = 4000
    ITEMS                      = 1000
    ITEM_BYTES                 = 4
    ITEM_OFFSET                = 4
    DATA_TYPE                  = MSB_UNSIGNED_INTEGER
    UNIT                       = "N/A"
    DESCRIPTION                = "Each ITEM contains one 32-bit sample
                                  word: quadrature (Q) sample data in
                                  the 16 most significant bits (MSBs)
                                  followed by in-phase (I) sample data
                                  in the 16 least significant bits
                                  (LSBs).  Within each Q and I word,
                                  individual outputs from the analog
                                  to digital converters (ADCs) are
                                  stored as 1, 2, 4, 8, or 16 bit values
                                  in LSB to MSB time order (the sample
                                  size is set in Column 42).  For
                                  example, if the data were collected
                                  using 8-bit samples, the arrangement
                                  would be

                                       BYTES 1-2
                                       +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
                                  BITS |1|2|3|4|5|6|7|8|1|2|3|4|5|6|7|8|
                                       +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
                                       |<------Q2----->|<------Q1----->|
                                       +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+

                                       BYTES 3-4
                                       +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

```
                                BITS |1|2|3|4|5|6|7|8|1|2|3|4|5|6|7|8|
                                     |<------I2----->|<------I1----->|
                                     +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+

                                where (Q1,I1) is the earlier sample
                                and (Q2,I2) was taken later."
  END_OBJECT              = COLUMN

END_OBJECT                 = TABLE

END
```

7.3.4 LGRS RDR

Products in the LGRS RDR data set (GRAIL-L-LGRS-5-RDR-V1.0) have labels as follows:

7.3.4.1 Radio Science Digital Map Products (RSDMAP)

```
PDS_VERSION_ID                = PDS3
RECORD_TYPE                   = FIXED_LENGTH
RECORD_BYTES                  = 5760
FILE_RECORDS                  = 721
^IMAGE                        = ("JGGRX_0660B_ANOM_L320.IMG",1)
INSTRUMENT_HOST_NAME          = {"GRAVITY RECOVERY AND INTERIOR LABORATORY A",
                                 "GRAVITY RECOVERY AND INTERIOR LABORATORY B"}
TARGET_NAME                   = "MOON"
INSTRUMENT_NAME               = {"LUNAR GRAVITY RANGING SYSTEM A",
                                 "LUNAR GRAVITY RANGING SYSTEM B"}
DATA_SET_ID                   = "GRAIL-L-LGRS-5-RDR-V1.0"
ORIGINAL_PRODUCT_ID           = "GL0660B_ANOMALY_TRUNCATE_N=320"
PRODUCT_ID                    = "JGGRX_0660B_ANOM_L320.IMG"
PRODUCT_RELEASE_DATE          = 2013-02-05
DESCRIPTION                   = "
 This file contains a digital map of the gravity anomaly derived from
 the JPL GL0660B model of the Moon's gravity field.  Each point gives the
 Lunar gravity anomaly in milligals, which is the difference of the model
 gravity on the geoid from the gravity on a reference sphere
 with semi-major-axis = 1738.0 km, GM = 4902.8003055554 km**3/s**2,
 and zero rotation rate.

 The JGGRX_0660B_ANOM_320 gravity anomaly is computed from a truncated
 GL0660B solution (from degree 2 up to degree 320).

 The reference for the GL0660B gravity field is KONOPLIVETAL2013,
 published in the Journal of Geophysical Research with the DOI number
 0.1002/jgre.20097."

START_TIME                    = 2012-03-01T16:28:00.000
STOP_TIME                     = 2012-05-29T16:36:00.000
PRODUCT_CREATION_TIME         = 2013-02-05T00:00:00.000
PRODUCER_ID                   = "JPL LEVEL-2 TEAM"

OBJECT                = IMAGE
  LINES                       = 721
```

```
  LINE_SAMPLES               = 1440
  SAMPLE_TYPE                = "PC_REAL"
  SAMPLE_BITS                = 32
  UNIT                       = "MILLIGALS"
  OFFSET                     = 0.0E+00
  SCALING_FACTOR             = 1.0E+00
  DESCRIPTION                = "The Digital Map contains
   values of the gravity anomaly.  The values can be obtained
   by multiplying the sample in the map by SCALING_FACTOR
   and then adding OFFSET.  One milligal equals 0.01 mm/s/s."
END_OBJECT            = IMAGE

OBJECT                = IMAGE_MAP_PROJECTION
  ^DATA_SET_MAP_PROJECTION     = "DSMAP.CAT"
  COORDINATE_SYSTEM_TYPE       = "BODY-FIXED ROTATING"
  COORDINATE_SYSTEM_NAME       = PLANETOCENTRIC
  MAP_PROJECTION_TYPE          = "SIMPLE CYLINDRICAL"
  A_AXIS_RADIUS                = 1738.0 <km>
  B_AXIS_RADIUS                = 1738.0 <km>
  C_AXIS_RADIUS                = 1738.0 <km>
  FIRST_STANDARD_PARALLEL      = "N/A"
  SECOND_STANDARD_PARALLEL     = "N/A"
  POSITIVE_LONGITUDE_DIRECTION = "EAST"
  CENTER_LATITUDE              = 0.0 <DEGREE>
  CENTER_LONGITUDE             = 0.0 <DEGREE>
  REFERENCE_LATITUDE           = 0.0 <DEGREE>
  REFERENCE_LONGITUDE          = 0.0 <DEGREE>
  LINE_FIRST_PIXEL             = 1
  LINE_LAST_PIXEL              = 721
  SAMPLE_FIRST_PIXEL           = 1
  SAMPLE_LAST_PIXEL            = 1440
  MAP_PROJECTION_ROTATION      = 0.0 <DEGREE>
  MAP_RESOLUTION               = 4.0 <PIXEL/DEG>
  MAP_SCALE                    = 7583.4556 <M/PIXEL>
  MAXIMUM_LATITUDE             = 90.0 <DEGREE>
  MINIMUM_LATITUDE             = -90.0 <DEGREE>
  EASTERNMOST_LONGITUDE        = 179.75 <DEGREE>
  WESTERNMOST_LONGITUDE        = -180.0 <DEGREE>
  LINE_PROJECTION_OFFSET       = 361.0
  SAMPLE_PROJECTION_OFFSET     = 720.5
END_OBJECT            = IMAGE_MAP_PROJECTION

END
```

7.3.4.2 Spherical Harmonics ASCII Data Record (SHADR)

```
PDS_VERSION_ID               = "PDS3"
RECORD_TYPE                  = FIXED_LENGTH
RECORD_BYTES                 = 122
FILE_RECORDS                 = 218792
^SHADR_HEADER_TABLE          = ("JGGRX_0660B_SHA.TAB",1)
^SHADR_COEFFICIENTS_TABLE    = ("JGGRX_0660B_SHA.TAB",3)
INSTRUMENT_HOST_NAME         = {"GRAVITY RECOVERY AND INTERIOR LABORATORY A",
                                "GRAVITY RECOVERY AND INTERIOR LABORATORY B"}
```

```
TARGET_NAME                  = "MOON"
INSTRUMENT_NAME              = {"LUNAR GRAVITY RANGING SYSTEM A",
                                "LUNAR GRAVITY RANGING SYSTEM B"}
DATA_SET_ID                  = "GRAIL-L-LGRS-5-RDR-V1.0"
OBSERVATION_TYPE             = "GRAVITY FIELD"
ORIGINAL_PRODUCT_ID          = "GL0660B"
PRODUCT_ID                   = "JGGRX_0660B_SHA.TAB"
PRODUCT_RELEASE_DATE         = 2013-02-05
DESCRIPTION                  = "
 This file contains coefficients and related data for the JPL Lunar gravity
 field GL0660B, a 660th degree and order spherical harmonic model. It is
 a JPL gravity field that includes the entire primary mission of
 GRAIL tracking data (March 1, 16:30 to May 29, 16:36:00, 2012).

 Some details describing this model are:
   The spherical harmonic coefficients are fully normalized.
   The reference radius = 1738.0 km
   The planetary ephemeris is de421 and defines the lunar body-fixed
       coordinate system.
   A Kaula type power law constraint is applied to the spherical harmonics
       coefficients for degrees >330 (3.6e-4/n^2).
   The weighting of the KBRR data is mostly 0.03 microns/sec.

   The second degree Love number solution is k2=0.02405. The second degree
   gravity coefficients of this model do not include the permanent tide.

 The reference for the GL0660B gravity field is KONOPLIVETAL2013,
 published in the Journal of Geophysical Research with the DOI number
 0.1002/jgre.20097.

 This file is a pair of ASCII tables: a header table and a table of
 436920 coefficients plus a value for GM.  Definitions of the tables
 follow."

START_TIME                   = 2012-03-01T16:28:00.000
STOP_TIME                    = 2012-05-29T16:36:00.000
PRODUCT_CREATION_TIME        = 2013-02-05T00:00:00.000
PRODUCER_FULL_NAME           = "JPL LEVEL-2 TEAM"
PRODUCER_INSTITUTION_NAME    = "JET PROPULSION LABORATORY"
PRODUCT_VERSION_TYPE         = "PRELIMINARY"
PRODUCER_ID                  = "GRAIL"


OBJECT               = SHADR_HEADER_TABLE
ROWS                       = 1
COLUMNS                    = 8
ROW_BYTES                  = 137
ROW_SUFFIX_BYTES           = 107
INTERCHANGE_FORMAT         = ASCII
DESCRIPTION                = "The SHADR header includes
descriptive information about the spherical harmonic
coefficients which follow in SHADR_COEFFICIENTS_TABLE.
The header consists of a single record of eight (delimited)
data columns requiring 137 bytes, a pad of 105 unspecified
ASCII characters, an ASCII carriage-return, and an ASCII
```

```
line-feed."

  OBJECT                    = COLUMN
    NAME                          = "REFERENCE RADIUS"
    DATA_TYPE                     = ASCII_REAL
    START_BYTE                    = 1
    BYTES                         = 23
    FORMAT                        = "E23.16"
    UNIT                          = "KILOMETER"
    DESCRIPTION                   = "The assumed reference
    radius of the spherical planet."
  END_OBJECT                = COLUMN

  OBJECT                    = COLUMN
    NAME                          = "CONSTANT"
    DATA_TYPE                     = ASCII_REAL
    START_BYTE                    = 25
    BYTES                         = 23
    FORMAT                        = "E23.16"
    UNIT                          = "N/A"
    DESCRIPTION                   = "For a gravity field model
    the assumed gravitational constant GM in kilometers cubed
    per seconds squared for the planet.  For a topography
    model, set to 1."
  END_OBJECT                = COLUMN

  OBJECT                    = COLUMN
    NAME                          = "UNCERTAINTY IN CONSTANT"
    DATA_TYPE                     = ASCII_REAL
    START_BYTE                    = 49
    BYTES                         = 23
    FORMAT                        = "E23.16"
    UNIT                          = "N/A"
    DESCRIPTION                   = "For a gravity field model
    the uncertainty in the gravitational constant GM in kilometers
    cubed per seconds squared for the planet.  For a topography
    model, set to 0."
  END_OBJECT                = COLUMN

  OBJECT                    = COLUMN
    NAME                          = "DEGREE OF FIELD"
    DATA_TYPE                     = ASCII_INTEGER
    START_BYTE                    = 73
    BYTES                         = 5
    FORMAT                        = "I5"
    UNIT                          = "N/A"
    DESCRIPTION                   = "The degree of model field."
  END_OBJECT                = COLUMN

  OBJECT                    = COLUMN
    NAME                          = "ORDER OF FIELD"
    DATA_TYPE                     = ASCII_INTEGER
    START_BYTE                    = 79
    BYTES                         = 5
    FORMAT                        = "I5"
```

```
    UNIT                          = "N/A"
    DESCRIPTION                   = "The order of the model field."
  END_OBJECT                 = COLUMN

  OBJECT                     = COLUMN
    NAME                          = "NORMALIZATION STATE"
    DATA_TYPE                     = ASCII_INTEGER
    START_BYTE                    = 85
    BYTES                         = 5
    FORMAT                        = "I5"
    UNIT                          = "N/A"
    DESCRIPTION                   = "The normalization indicator.
    For gravity field:
        0   coefficients are unnormalized
        1   coefficients are normalized
        2   other."
  END_OBJECT                 = COLUMN

  OBJECT                     = COLUMN
    NAME                          = "REFERENCE LONGITUDE"
    POSITIVE_LONGITUDE_DIRECTION = "EAST"
    DATA_TYPE                     = ASCII_REAL
    START_BYTE                    = 91
    BYTES                         = 23
    FORMAT                        = "E23.16"
    UNIT                          = "DEGREE"
    DESCRIPTION                   = "The reference longitude for
    the spherical harmonic expansion; normally 0."
  END_OBJECT                 = COLUMN

  OBJECT                     = COLUMN
    NAME                          = "REFERENCE LATITUDE"
    DATA_TYPE                     = ASCII_REAL
    START_BYTE                    = 115
    BYTES                         = 23
    FORMAT                        = "E23.16"
    UNIT                          = "DEGREE"
    DESCRIPTION                   = "The reference latitude for
    the spherical harmonic expansion; normally 0."
  END_OBJECT                 = COLUMN

END_OBJECT             = SHADR_HEADER_TABLE

OBJECT                 = SHADR_COEFFICIENTS_TABLE
  ROWS                       = 218790
  COLUMNS                    = 6
  ROW_BYTES                  = 107
  ROW_SUFFIX_BYTES           = 15
  INTERCHANGE_FORMAT         = ASCII
  DESCRIPTION                = "The SHADR coefficients table
  contains the coefficients for the spherical harmonic model.
  Each row in the table contains the degree index m, the
  order index n, the coefficients Cmn and Smn, and the
  uncertainties in Cmn and Smn.  The (delimited) data
  require 107 ASCII characters; these are followed by a pad
```

```
of 13 unspecified ASCII characters, an ASCII carriage-
return, and an ASCII line-feed."

OBJECT                    = COLUMN
  NAME                          = "COEFFICIENT DEGREE"
  DATA_TYPE                     = ASCII_INTEGER
  START_BYTE                    = 1
  BYTES                         = 5
  FORMAT                        = "I5"
  UNIT                          = "N/A"
  DESCRIPTION                   = "The degree index m of the
  C and S coefficients in this record."
END_OBJECT                = COLUMN

OBJECT                    = COLUMN
  NAME                          = "COEFFICIENT ORDER"
  DATA_TYPE                     = ASCII_INTEGER
  START_BYTE                    = 7
  BYTES                         = 5
  FORMAT                        = "I5"
  UNIT                          = "N/A"
  DESCRIPTION                   = "The order index n of the
  C and S coefficients in this record."
END_OBJECT                = COLUMN

OBJECT                    = COLUMN
  NAME                          = "C"
  DATA_TYPE                     = ASCII_REAL
  START_BYTE                    = 13
  BYTES                         = 23
  FORMAT                        = "E23.16"
  UNIT                          = "N/A"
  DESCRIPTION                   = "The coefficient Cmn
  for this spherical harmonic model."
END_OBJECT                = COLUMN

OBJECT                    = COLUMN
  NAME                          = "S"
  DATA_TYPE                     = ASCII_REAL
  START_BYTE                    = 37
  BYTES                         = 23
  FORMAT                        = "E23.16"
  UNIT                          = "N/A"
  DESCRIPTION                   = "The coefficient Smn
  for this spherical harmonic model."
END_OBJECT                = COLUMN

OBJECT                    = COLUMN
  NAME                          = "C UNCERTAINTY"
  DATA_TYPE                     = ASCII_REAL
  START_BYTE                    = 61
  BYTES                         = 23
  FORMAT                        = "E23.16"
  UNIT                          = "N/A"
  DESCRIPTION                   = "The uncertainty in the
```

```
    coefficient Cmn for this spherical harmonic model."
  END_OBJECT               = COLUMN

  OBJECT                   = COLUMN
    NAME                         = "S UNCERTAINTY"
    DATA_TYPE                    = ASCII_REAL
    START_BYTE                   = 85
    BYTES                        = 23
    FORMAT                       = "E23.16"
    UNIT                         = "N/A"
    DESCRIPTION                  = "The uncertainty in the
    coefficient Smn for this spherical harmonic model."
  END_OBJECT               = COLUMN

END_OBJECT           = SHADR_COEFFICIENTS_TABLE

END
```

7.3.4.3 Spherical Harmonics Binary Data Record (SHBDR)

```
PDS_VERSION_ID                = "PDS3"
FILE_NAME                     = "JGGRX_0660B_SHB_L50.DAT"

RECORD_TYPE                   = FIXED_LENGTH
RECORD_BYTES                  = 512
FILE_RECORDS                  = 52835
^SHBDR_HEADER_TABLE           = ("JGGRX_0660B_SHB_L50.DAT",1)
^SHBDR_NAMES_TABLE            = ("JGGRX_0660B_SHB_L50.DAT",2)
^SHBDR_COEFFICIENTS_TABLE     = ("JGGRX_0660B_SHB_L50.DAT",43)
^SHBDR_COVARIANCE_TABLE       = ("JGGRX_0660B_SHB_L50.DAT",84)

INSTRUMENT_HOST_NAME          = {"GRAVITY RECOVERY AND INTERIOR LABORATORY A",
                                 "GRAVITY RECOVERY AND INTERIOR LABORATORY B"}
TARGET_NAME                   = "MOON"
INSTRUMENT_NAME               = {"LUNAR GRAVITY RANGING SYSTEM A",
                                 "LUNAR GRAVITY RANGING SYSTEM B"}
DATA_SET_ID                   = "GRAIL-L-LGRS-5-RDR-V1.0"
OBSERVATION_TYPE              = "GRAVITY FIELD"
PRODUCT_ID                    = "JGGRX_0660B_SHB_L50.DAT"
PRODUCT_RELEASE_DATE          = 2012-07-31
DESCRIPTION                   = "
 This file contains coefficients and related data for the JPL Lunar gravity
 field GL0660B, a 660th degree and order spherical harmonic model. It is
 a JPL gravity field that includes the entire primary mission of
 GRAIL tracking data (March 1, 16:30 to May 29, 16:36:00, 2012).

 Some details describing this model are:
   The spherical harmonic coefficients are fully normalized.
   The reference radius = 1738.0 km
   The planetary ephemeris is de421 and defines the lunar body-fixed
       coordinate system.
   A Kaula type power law constraint is applied to the spherical harmonics
       coefficients for degrees >330 (3.6e-4/n^2).
   The weighting of the KBRR data is mostly 0.03 microns/sec.
```

```
   The second degree Love number solution is k2=0.02405. The second degree
   gravity coefficients of this model do not include the permanent tide.

 This product contains the truncated n=50 covariance of the GL0660B
 gravity model or JGGRX_0660B_SHA.

 The reference for the GL0660B gravity field is KONOPLIVETAL2013,
 published in the Journal of Geophysical Research with the DOI number
 0.1002/jgre.20097.

 This product is a set of binary tables:
 a header table, a names table, a coefficients table, and a covariance
 table. Definitions of the tables follow. This GRAIL moon gravity model
 is in the form of a Spherical Harmonics Binary Data Record (SHBDR)."

START_TIME                    = 2012-03-01T16:28:00.000
STOP_TIME                     = 2012-05-29T16:36:00.000
PRODUCT_CREATION_TIME         = 2013-06-06T00:00:00.000
PRODUCER_FULL_NAME            = "JPL LEVEL-2 TEAM"
PRODUCER_INSTITUTION_NAME     = "JET PROPULSION LABORATORY"
PRODUCT_VERSION_TYPE          = "PRELIMINARY"
PRODUCER_ID                   = "GRAIL"

/* Structure Objects */

OBJECT                      = SHBDR_HEADER_TABLE
  ROWS                        = 1
  COLUMNS                     = 9
  ROW_BYTES                   = 56
  INTERCHANGE_FORMAT          = BINARY
  DESCRIPTION                 = "The SHBDR Header includes
  descriptive information about the spherical harmonic
  coefficients which follow in SHBDR_COEFFICIENTS_TABLE.
  The header consists of a single record of nine data
  columns requiring 56 bytes.  The Header is followed by
  a pad of binary integer zeroes to ensure alignment
  with RECORD_BYTES."

  OBJECT                    = COLUMN
    NAME                          = "REFERENCE RADIUS"
    DATA_TYPE                     = PC_REAL
    START_BYTE                    = 1
    BYTES                         = 8
    UNIT                          = "KILOMETER"
    DESCRIPTION                   = "The assumed reference
    radius of the spherical planet."
  END_OBJECT                = COLUMN

  OBJECT                    = COLUMN
    NAME                          = "CONSTANT"
    DATA_TYPE                     = PC_REAL
    START_BYTE                    = 9
    BYTES                         = 8
    UNIT                          = "N/A"
```

```
  DESCRIPTION                  = "For a gravity field model
  the gravitational constant GM in kilometers cubed per seconds
  squared for the planet.  For a topography model, set to 1."
END_OBJECT                = COLUMN

OBJECT                    = COLUMN
  NAME                         = "UNCERTAINTY IN CONSTANT"
  DATA_TYPE                    = PC_REAL
  START_BYTE                   = 17
  BYTES                        = 8
  UNIT                         = "N/A"
  DESCRIPTION                  = "For a gravity field model
  the uncertainty in the gravitational constant GM in kilometers
  cubed per seconds squared for the planet.  For a topography
  model, set to 0."
END_OBJECT                = COLUMN

OBJECT                    = COLUMN
  NAME                         = "DEGREE OF FIELD"
  DATA_TYPE                    = LSB_INTEGER
  START_BYTE                   = 25
  BYTES                        = 4
  UNIT                         = "N/A"
  DESCRIPTION                  = "Degree of the model field."
END_OBJECT                = COLUMN

OBJECT                    = COLUMN
  NAME                         = "ORDER OF FIELD"
  DATA_TYPE                    = LSB_INTEGER
  START_BYTE                   = 29
  BYTES                        = 4
  UNIT                         = "N/A"
  DESCRIPTION                  = "Order of the model field."
END_OBJECT                = COLUMN

OBJECT                    = COLUMN
  NAME                         = "NORMALIZATION STATE"
  DATA_TYPE                    = LSB_INTEGER
  START_BYTE                   = 33
  BYTES                        = 4
  UNIT                         = "N/A"
  DESCRIPTION                  = "The normalization indicator.
  For gravity field:
      0   coefficients are unnormalized
      1   coefficients are normalized
      2   other."
END_OBJECT                = COLUMN

OBJECT                    = COLUMN
  NAME                         = "NUMBER OF NAMES"
  DATA_TYPE                    = LSB_INTEGER
  START_BYTE                   = 37
  BYTES                        = 4
  UNIT                         = "N/A"
  DESCRIPTION                  = "Number of valid names in
```

```
    the SHBDR Names Table.  Also, the number of valid
    coefficients in the SHBDR Coefficients Table."
  END_OBJECT               = COLUMN

  OBJECT                   = COLUMN
    NAME                         = "REFERENCE LONGITUDE"
    POSITIVE_LONGITUDE_DIRECTION = "EAST"
    DATA_TYPE                    = PC_REAL
    START_BYTE                   = 41
    BYTES                        = 8
    UNIT                         = "DEGREE"
    DESCRIPTION                  = "The reference longitude for
    the spherical harmonic expansion; normally 0."
  END_OBJECT               = COLUMN

  OBJECT                   = COLUMN
    NAME                         = "REFERENCE LATITUDE"
    DATA_TYPE                    = PC_REAL
    START_BYTE                   = 49
    BYTES                        = 8
    UNIT                         = "DEGREE"
    DESCRIPTION                  = "The reference latitude for
    the spherical harmonic expansion; normally 0."
  END_OBJECT               = COLUMN

END_OBJECT           = SHBDR_HEADER_TABLE

OBJECT               = SHBDR_NAMES_TABLE
  ROWS                     = 2598
  COLUMNS                  = 1
  ROW_BYTES                = 8
  INTERCHANGE_FORMAT       = BINARY
  DESCRIPTION              = "The SHBDR Names Table
  contains names for the solution parameters (including
  gravity field coefficients) which will follow in
  SHBDR_COEFFICIENTS_TABLE.  The order of the names
  in SHBDR_NAMES_TABLE corresponds identically to the
  order of the parameters in SHBDR_COEFFICIENTS_TABLE.
  Each coefficient  name is of the form  Cij  or  Sij
  where  i  is the degree of the coefficient and  j  is
  the order of the coefficient.  Both indices are three-
  digit zero-filled right-justified ASCII character strings
  (for example,  C010005  for the 10th degree 5th order C
  coefficient, or  S002001  for the 2nd degree 1st order
  S  coefficient).  The eighth byte in the table is an
  ASCII blank used to ensure that the row length
  is equal to RECORD_BYTES.  Names of other solution
  parameters are limited to 8 ASCII characters; if less
  than 8, they will be left-justified and padded with
  ASCII blanks.  The Names Table itself will be padded
  with ASCII blanks, if necessary, so that its length is
  an integral multiple of RECORD_BYTES."

  OBJECT                   = COLUMN
    NAME                         = "PARAMETER NAME"
```

```
    DATA_TYPE                    = CHARACTER
    START_BYTE                   = 1
    BYTES                        = 8
    UNIT                         = "N/A"
    DESCRIPTION                  = "The name of the
    coefficient or other solution parameter, left-
    justified and padded with ASCII blanks (if needed)
    to 8 characters."
  END_OBJECT                = COLUMN

END_OBJECT            = SHBDR_NAMES_TABLE

OBJECT                = SHBDR_COEFFICIENTS_TABLE
  ROWS                      = 2598
  COLUMNS                   = 1
  ROW_BYTES                 = 8
  INTERCHANGE_FORMAT        = BINARY
  DESCRIPTION               = "The SHBDR Coefficients Table
  contains the coefficients and other solution parameters
  for the spherical harmonic model.  The order of the
  coefficients in this table corresponds exactly to the
  order of the coefficient and parameter names in
  SHBDR_NAMES_TABLE.  The SHBDR Coefficients Table will be
  padded with double precision DATA_TYPE zeroes so that
  its total length is an integral multiple of RECORD_BYTES."

  OBJECT                    = COLUMN
    NAME                         = "COEFFICIENT VALUE"
    DATA_TYPE                    = PC_REAL
    START_BYTE                   = 1
    BYTES                        = 8
    UNIT                         = "N/A"
    DESCRIPTION                  = "A coefficient Cij or
    Sij or other solution parameter as specified in the
    SHBDR Names Table."
  END_OBJECT                = COLUMN

END_OBJECT            = SHBDR_COEFFICIENTS_TABLE

OBJECT                = SHBDR_COVARIANCE_TABLE
  ROWS                      = 3376101
  COLUMNS                   = 1
  ROW_BYTES                 = 8
  INTERCHANGE_FORMAT        = BINARY
  DESCRIPTION               = "The SHBDR Covariance Table
  contains the covariances for the spherical harmonic model
  coefficients and other solution parameters.  The order of
  the covariances in this table is defined as columnwise
  vector storage of the upper triangular matrix formed by
  the product of the SHBDR Names Table with its transpose.
  For example, if the Names Table has four entries  A, B,
  C, and D,  then the covariances are given by the column
  vectors in the upper triangular matrix of

           | A | [ A B C D ] = | AA AB AC AD |
```

```
          | B |               | BA BB BC BD |
          | C |               | CA CB CC CD |
          | D |               | DA DB DC DD |

  That is, the covariance table will list (in this order)
  AA, AB, BB, AC, BC, CC, AD, BD, CD, and DD.
  The SHBDR Covariance Table will be padded with double
  precision DATA_TYPE zeroes so that its total length is
  an integral multiple of RECORD_BYTES."

  OBJECT                   = COLUMN
    NAME                         = "COVARIANCE VALUE"
    DATA_TYPE                    = PC_REAL
    START_BYTE                   = 1
    BYTES                        = 8
    UNIT                         = "N/A"
    DESCRIPTION                  = "The covariance value
    for the coefficients and other solution parameters
    specified by the product of SHBDR_NAMES_TABLE with
    its transpose, after omitting redundant terms."
  END_OBJECT               = COLUMN

END_OBJECT           = SHBDR_COVARIANCE_TABLE

END
```

7.3.4.4 SPICE ephemeris files (SPK)

SPK files have labels similar to the following:

```
PDS_VERSION_ID         = PDS3
RECORD_TYPE            = UNDEFINED
RECORD_BYTES           = 1024
INSTRUMENT_NAME        = "LUNAR GRAVITY RANGING SYSTEM A"
INSTRUMENT_ID          = "LGRS-A"
TARGET_NAME            = "MOON"
DATA_SET_ID            = "GRAIL-L-LGRS-5-RDR-V1.0"
MISSION_NAME           = "GRAVITY RECOVERY AND INTERIOR LABORATORY"
INSTRUMENT_HOST_NAME   = "GRAVITY RECOVERY AND INTERIOR LABORATORY A"
PRODUCT_ID             = "GRALUGF2012_061_2012_062.SPK"
FILE_NAME              = "GRALUGF2012_061_2012_062.SPK"
ORIGINAL_PRODUCT_ID    = "GRA_LUGF2012_061_2012_061.BSP"
START_TIME             = 2012-061T10:01:06
STOP_TIME              = 2012-062T00:01:06
PRODUCT_CREATION_TIME = 2012-242T20:27:11
OBSERVATION_TYPE       = SCIENCE
PRODUCER_ID            = "SDS"
NOTE                   = "Based on V02 data, gravity field 660c7b"
^DESCRIPTION           = "SPK_MM_SIS.LBL"
END
```

8 Applicable Documents

Bolded documents can be found in the DOCUMENT directory of the archive volumes.

1. **0172 Telecomm-090 Rev C: Multi-Mission TIS Packet Secondary, Turbo-era Data, 2010.**
2. Acton, C., CK-MM-SIS, Multimission Software Interface Specification, SPICE C-Matrix Kernel, NAIF Document No. 370, 14 June 2000.
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