# GRAIL DATA PRODUCT SOFTWARE INTERFACE SPECIFICATION

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<td>All</td>
</tr>
<tr>
<td>Version 1.1 submitted for PDS release.</td>
<td>12/13/12</td>
<td>All</td>
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<td>Version 1.2 initial team RDR review.</td>
<td>03/11/13</td>
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<tr>
<td>Version 1.3 release 2 updates.</td>
<td>06/11/13</td>
<td>All</td>
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<tr>
<td>Version 1.4 adjusted SHBDR file name. Submitted for RDR review.</td>
<td>06/18/13</td>
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<td>08/23/13</td>
<td>4.2.4, 7.3.4.1-7.3.4.4</td>
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<td>04/01/14</td>
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<td>06/18/14</td>
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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-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

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<td>Raw - Level 1</td>
<td>Telemetry with data embedded.</td>
</tr>
<tr>
<td>Level 0</td>
<td>Edited - Level 2</td>
<td>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.</td>
</tr>
<tr>
<td>Level 1A</td>
<td>Calibrated - Level 3</td>
<td>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 radian. No resampling, so original values can be recovered.</td>
</tr>
<tr>
<td>Level 1B</td>
<td>Resampled - Level 4</td>
<td>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.</td>
</tr>
<tr>
<td>Level 2</td>
<td>Derived - Level 5</td>
<td>Derived results, as maps, reports, graphics, etc.</td>
</tr>
<tr>
<td>Ancillary</td>
<td>Ancillary - Level 6</td>
<td>Non-science data needed to generate calibrated or resampled data sets. Consists of instrument gains and/or offsets, pointing information for scan platforms, etc.</td>
</tr>
</tbody>
</table>

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.
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_NVPL_L5.TXT [20]
090_REVX_1.TXT [1], and
0172_TELECOMM_Chdo_REV_E_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 to LGRS.

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 $\tau$ = 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.
GRAIL DATA PRODUCT SOFTWARE INTERFACE SPECIFICATION

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 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 (ODFs). 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 is 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).
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

<table>
<thead>
<tr>
<th>PRDID</th>
<th>product identification label, e.g. CLK1B</th>
</tr>
</thead>
<tbody>
<tr>
<td>YYYY</td>
<td>year</td>
</tr>
<tr>
<td>MM</td>
<td>month</td>
</tr>
<tr>
<td>DD</td>
<td>day of month</td>
</tr>
<tr>
<td>S</td>
<td>GRAIL satellite identifier:</td>
</tr>
<tr>
<td>A</td>
<td>GRAIL-A</td>
</tr>
<tr>
<td>B</td>
<td>GRAIL-B</td>
</tr>
<tr>
<td>X</td>
<td>combined product of GRAIL-A and GRAIL-B</td>
</tr>
<tr>
<td>VV</td>
<td>data product version number (starting from 00)</td>
</tr>
</tbody>
</table>
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:

sssttaayyyyy_ddd_hhmmwuudV#.odf,
sssttaayyyyy_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:

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

where:

sss 3-character spacecraft identifier
GRAIL DATA PRODUCT SOFTWARE INTERFACE SPECIFICATION

GRAIL-A
GRAIL-B

**tt** Target ID, e.g., LU = Moon

**aa** Activity/Experiment ID, e.g. GF = gravity field

**yyy** 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
- sssttaaYYYYDDD_yyyy_ddd.##.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).

$nnnvv$ 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_nnnncccc.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.

$ccc$ 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:

```
ssstaaYYYY_DDD_yyyy_ddd.spk,
```

where:

- **sss**: 3-character spacecraft identifier
  - GRAIL-A
  - GRAIL-B
  - 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.
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).

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

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 $X_MY_MZ_M$ in text)

Figure 7: GRAIL thruster locations (XYZ is the same as $X_MY_MZ_M$ in text)
Figure 8: GRAIL primary 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>
<thead>
<tr>
<th>Data Set</th>
<th>Product Identifier (xxxll)</th>
<th>S/C</th>
<th>Clock</th>
<th>Product</th>
<th>Format Description in DOCUMENT Directory…</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>3.2 Table</td>
</tr>
<tr>
<td>LGRS CDR</td>
<td>CLK1A</td>
<td>A/B</td>
<td>TDB</td>
<td>TDB to LGRS time correlation</td>
<td>12</td>
</tr>
<tr>
<td></td>
<td>DEL1A</td>
<td>X</td>
<td>LGRS + Bias</td>
<td>Inter-satellite LGRS clock offset</td>
<td>13</td>
</tr>
<tr>
<td></td>
<td>EHK1A</td>
<td>A/B</td>
<td>UTC SCET</td>
<td>Spacecraft temperature sensor data from Engineering Housekeeping data</td>
<td>14</td>
</tr>
<tr>
<td></td>
<td>IHH1A</td>
<td>A/B</td>
<td>LGRS + Bias</td>
<td>LGRS Housekeeping Data</td>
<td>15</td>
</tr>
<tr>
<td></td>
<td>IHS1A</td>
<td>A/B</td>
<td>LGRS + Bias</td>
<td>Level 1A LGRS Health Status data</td>
<td>16</td>
</tr>
<tr>
<td></td>
<td>ILG1A</td>
<td>A/B</td>
<td>LGRS + Bias</td>
<td>LGRS log messages</td>
<td>17</td>
</tr>
<tr>
<td></td>
<td>KBR1A</td>
<td>A/B</td>
<td>LGRS</td>
<td>Ka-Band Ranging</td>
<td>18</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LGRS EDR</td>
<td>DTC00</td>
<td>A/B</td>
<td>UTC SCET</td>
<td>Time Correlation Data Record File (DRF)</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>EHK00</td>
<td>A/B</td>
<td>UTC SCET</td>
<td>Spacecraft Engineering Housekeeping Data</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>LTB00</td>
<td>X</td>
<td>BTC</td>
<td>LGRS Time Bias</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>MAS00</td>
<td>A/B</td>
<td>UTC SCET</td>
<td>Satellite Mass Data</td>
<td>6</td>
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<td>S7200</td>
<td>A/B</td>
<td>UTC SCET</td>
<td>Engineering SFDU (ID #72)</td>
<td>3</td>
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<td></td>
<td>S7300</td>
<td>A/B</td>
<td>UTC SCET</td>
<td>Science SFDU (ID #73)</td>
<td>4</td>
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<tr>
<td></td>
<td>SAE00</td>
<td>A/B</td>
<td>UTC SCET</td>
<td>Solar Array Eclipse Data</td>
<td>7</td>
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<td>SCA00</td>
<td>A/B</td>
<td>UTC SCET</td>
<td>Star Tracker Data</td>
<td>8</td>
</tr>
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<td>A/B</td>
<td>UTC SCET</td>
<td>Time Correlation SFDU</td>
<td>9</td>
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<td></td>
<td>TDE00</td>
<td>A/B</td>
<td>UTC SCET</td>
<td>Time Transfer System Direct to Earth</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>THR00</td>
<td>A/B</td>
<td>UTC SCET</td>
<td>Thruster Activation Data</td>
<td>11</td>
</tr>
<tr>
<td></td>
<td>WRS00</td>
<td>A/B</td>
<td>UTC SCET</td>
<td>Wheel Rotational Speed Data</td>
<td>12</td>
</tr>
<tr>
<td>+ Bias</td>
<td>Data</td>
<td>Page</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>--------</td>
<td>----------------------------------------------------------------------</td>
<td>------</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TDB</td>
<td>Position vector and light time between one S/C and DSN station</td>
<td>19</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>UTC</td>
<td>Satellite Mass Data</td>
<td>20</td>
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<tr>
<td>TDB</td>
<td>Phase Center to Center of Mass Correction</td>
<td>21</td>
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<td></td>
</tr>
<tr>
<td>TDB</td>
<td>Position vector and light time between two spacecraft</td>
<td>22</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LGRS</td>
<td>LGRS Pulse Per Second (PPS) Time Record</td>
<td>23</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TDB</td>
<td>Relativistic time correction (TDB to onboard satellite proper time)</td>
<td>24</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>UTC</td>
<td>Solar Array Eclipse Data</td>
<td>25</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LGRS</td>
<td>S-Band Ranging Data</td>
<td>26</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BTC</td>
<td>Star Tracker Data</td>
<td>27</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LGRS</td>
<td>S-Band navigation product</td>
<td>28</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LGRS</td>
<td>LGRS to BTC time correlation</td>
<td>29</td>
<td></td>
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<td></td>
</tr>
<tr>
<td>LGRS</td>
<td>LGRS to BTC time correlation from BTC clock cycle counts</td>
<td>30</td>
<td></td>
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<td></td>
</tr>
<tr>
<td>BTC</td>
<td>BTC to RTC time correlation</td>
<td>31</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LGRS</td>
<td>LGRS to RTC time correlation</td>
<td>32</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>RTC</td>
<td>RTC to UTC time correlation</td>
<td>33</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>UTC</td>
<td>UTC to TDB time correlation</td>
<td>34</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>UTC</td>
<td>Thruster Activation Data</td>
<td>35</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TDB</td>
<td>Oscillator frequency data</td>
<td>36</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>UTC</td>
<td>center of mass displacement from spacecraft mechanical frame origin</td>
<td>37</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>UTC</td>
<td>Wheel Rotational Speed Data</td>
<td>38</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LGRS</td>
<td>Time correlation between LGRS time +Bias and TDB</td>
<td>39</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TDB</td>
<td>Spacecraft</td>
<td>40</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>RSS EDR</td>
<td>Description</td>
<td>Format</td>
<td>Notes</td>
<td></td>
<td></td>
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<td>---------</td>
<td>-------------</td>
<td>--------</td>
<td>-------</td>
<td></td>
<td></td>
</tr>
<tr>
<td>GNI1B A/B</td>
<td>temperature sensor data from Engineering Housekeeping Data</td>
<td>TDB</td>
<td>41</td>
<td></td>
<td></td>
</tr>
<tr>
<td>GNV1B A/B</td>
<td>satellite orbit solution in Moon centered Inertial frame</td>
<td>TDB</td>
<td>42</td>
<td></td>
<td></td>
</tr>
<tr>
<td>KBR1C X</td>
<td>Dual-One-Way Ka-Band Ranging Data</td>
<td>TDB</td>
<td>43</td>
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<td></td>
</tr>
<tr>
<td>MAS1B A/B</td>
<td>Satellite Mass Data</td>
<td>TDB</td>
<td>44</td>
<td></td>
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<tr>
<td>SAE1B A/B</td>
<td>Solar Array Eclipse Data</td>
<td>TDB</td>
<td>45</td>
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<tr>
<td>SBR1B X</td>
<td>Dual one-way S-Band Ranging data</td>
<td>TDB</td>
<td>46</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SCA1B A/B</td>
<td>Star Tracker Data</td>
<td>TDB</td>
<td>47</td>
<td></td>
<td></td>
</tr>
<tr>
<td>THR1B A/B</td>
<td>Thruster Activation Data</td>
<td>TDB</td>
<td>48</td>
<td></td>
<td></td>
</tr>
<tr>
<td>USO1B A/B</td>
<td>USO Frequency Estimate</td>
<td>TDB</td>
<td>49</td>
<td></td>
<td></td>
</tr>
<tr>
<td>VCM1B A/B</td>
<td>center of mass displacement from spacecraft mechanical frame origin</td>
<td>TDB</td>
<td>50</td>
<td></td>
<td></td>
</tr>
<tr>
<td>VGS1B A/B</td>
<td>S-Band antenna offset vector and switch time (TDB time)</td>
<td>TDB</td>
<td>51</td>
<td></td>
<td></td>
</tr>
<tr>
<td>VGX1B A/B</td>
<td>X-Band antenna offset vector and switch time (TDB time)</td>
<td>TDB</td>
<td>52</td>
<td></td>
<td></td>
</tr>
<tr>
<td>VKB1B A/B</td>
<td>Ka-Band Boresight Vector</td>
<td>TDB</td>
<td>53</td>
<td></td>
<td></td>
</tr>
<tr>
<td>WRS1B A/B</td>
<td>Wheel Rotational Speed Data</td>
<td>TDB</td>
<td>54</td>
<td></td>
<td></td>
</tr>
<tr>
<td>BOF A/B</td>
<td>Biased Open Loop File</td>
<td>UTC</td>
<td>SEE LABEL FILE</td>
<td></td>
<td></td>
</tr>
<tr>
<td>BTM A/B</td>
<td>Biased Tracking Data Message Standard</td>
<td>UTC</td>
<td>55</td>
<td></td>
<td></td>
</tr>
<tr>
<td>EOP X</td>
<td>Earth Orientation Parameters</td>
<td>TDB</td>
<td>TRK_2_21_950831.LBL</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ION A/B</td>
<td>Ionospheric Media Calibration</td>
<td>UTC</td>
<td>DSN006_MEDIACAL_REV2.LBL</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ODF A/B</td>
<td>Tracking Data, Orbit Data File</td>
<td>UTC</td>
<td>SEE LABEL FILE</td>
<td></td>
<td></td>
</tr>
<tr>
<td>OLF A/B</td>
<td>Open Loop File</td>
<td>UTC</td>
<td>SEE LABEL FILE</td>
<td></td>
<td></td>
</tr>
<tr>
<td>RSR A/B</td>
<td>Radio Science Receiver 0159</td>
<td>UTC</td>
<td>SEE LABEL FILE</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TDM A/B</td>
<td>Tracking Data Message Standard</td>
<td>UTC</td>
<td>56</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TNF A/B</td>
<td>Tracking and Navigation File</td>
<td>UTC</td>
<td>TNFSIS.LBL</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
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

<table>
<thead>
<tr>
<th>Column #</th>
<th>DTC00</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>UTC SCET (YY/DDD-HH:MM:SS.sss)</td>
</tr>
<tr>
<td>2</td>
<td>Clock BTC fractional second counter (1/65536 seconds)</td>
</tr>
<tr>
<td>3</td>
<td>Clock BTC second counter</td>
</tr>
<tr>
<td>4</td>
<td>Clock USO fractional seconds count (1/65536 seconds) since last 1 PPS arrival at on board computer</td>
</tr>
<tr>
<td>5</td>
<td>Clock USO seconds counter since last 1 PPS arrival at on board computer</td>
</tr>
<tr>
<td>6</td>
<td>BTC Bias (seconds)</td>
</tr>
<tr>
<td>7</td>
<td>RTC Seconds</td>
</tr>
<tr>
<td>8</td>
<td>Application Packet ID</td>
</tr>
</tbody>
</table>

Table 4. EHK00 Record Format

<table>
<thead>
<tr>
<th>Column #</th>
<th>EHK00</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>UTC SCET Time YY/DDD-HH:MM:SS.sss</td>
</tr>
<tr>
<td>2</td>
<td>(Microwave Assembly TI Temperature in C + 273.0718) / 0.1220652</td>
</tr>
<tr>
<td>3</td>
<td>(Microwave Assembly T2 Temperature in C + 273.0718) / 0.1220652</td>
</tr>
<tr>
<td>4</td>
<td>(Waveguide Transmit Module Ka-Band Assembly temperature in C + 273.0718) / 0.1220652</td>
</tr>
<tr>
<td>5</td>
<td>(Waveguide Transmit Module Microwave Assembly temperature in C + 273.0718) / 0.1220652</td>
</tr>
<tr>
<td>6</td>
<td>(Waveguide Receive Module Middle of Span temperature in C + 273.0718) / 0.1220652</td>
</tr>
</tbody>
</table>
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

<table>
<thead>
<tr>
<th>Column #</th>
<th>LTB00</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>BTC time (seconds)</td>
</tr>
<tr>
<td>2</td>
<td>LGRS Bias (seconds)</td>
</tr>
</tbody>
</table>

Table 6. MAS00 Record Format

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

Table 7. SAE00 Record Format

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

Table 8. SCA00 Record Format

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

<table>
<thead>
<tr>
<th>Column #</th>
<th>TDE00</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Time Transfer System Direct to Earth Data</td>
</tr>
<tr>
<td>2.</td>
<td>ΔERT = UTC-ERT: Seconds past initial start time in header (Data Date), indicating the time at which measurements in columns 2-4 were made</td>
</tr>
<tr>
<td>3.</td>
<td>Range (seconds), integrated carrier phase measurement with N-cycle ambiguity unresolved</td>
</tr>
<tr>
<td>4.</td>
<td>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</td>
</tr>
<tr>
<td>5.</td>
<td>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</td>
</tr>
</tbody>
</table>

Table 10. THR00 Record Format

<table>
<thead>
<tr>
<th>Column #</th>
<th>THR00</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>UTC SCET Time YY/DDD-HH:MM:SS,ss</td>
</tr>
<tr>
<td>2.</td>
<td>The cumulative on time for thruster Attitude Control System 1 (milliseconds).</td>
</tr>
<tr>
<td>3.</td>
<td>The cumulative on time for thruster Attitude Control System 2 (milliseconds).</td>
</tr>
<tr>
<td>4.</td>
<td>The cumulative on time for thruster Attitude Control System 3 (milliseconds).</td>
</tr>
<tr>
<td>5.</td>
<td>The cumulative on time for thruster Attitude Control System 4 (milliseconds).</td>
</tr>
<tr>
<td>6.</td>
<td>The cumulative on time for thruster Attitude Control System 5 (milliseconds).</td>
</tr>
<tr>
<td>7.</td>
<td>The cumulative on time for thruster Attitude Control System 6 (milliseconds).</td>
</tr>
<tr>
<td>8.</td>
<td>The cumulative on time for thruster Attitude Control System 7 (milliseconds).</td>
</tr>
<tr>
<td>9.</td>
<td>The cumulative on time for thruster Attitude Control System 8 (milliseconds).</td>
</tr>
<tr>
<td>10.</td>
<td>GDS Application Packet Identification</td>
</tr>
</tbody>
</table>

Table 11. WRS00 Record Format

<table>
<thead>
<tr>
<th>Column #</th>
<th>WRS00</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>UTC SCET Activation Time YY/DDD-HH:MM:SS,ss</td>
</tr>
<tr>
<td>2.</td>
<td>Reaction wheel 1 rotational speed as determined by digital tachometer (radians/sec)</td>
</tr>
<tr>
<td>3.</td>
<td>Reaction wheel 2 rotational speed as determined by digital tachometer (radians/sec)</td>
</tr>
<tr>
<td>4.</td>
<td>Reaction wheel 3 rotational speed as determined by digital tachometer (radians/sec)</td>
</tr>
<tr>
<td>5.</td>
<td>Reaction wheel 4 rotational speed as determined by digital tachometer (radians/sec)</td>
</tr>
</tbody>
</table>
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 000001000001000, 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 000001001001000, 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

<table>
<thead>
<tr>
<th>Column #</th>
<th>CLK1A Level 1A TDB to LGRS + Bias time correlation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>TDB time, in integer seconds</td>
</tr>
<tr>
<td>2.</td>
<td>TDB time, microseconds part</td>
</tr>
<tr>
<td>3.</td>
<td>Input Time scale where ‘T’ = TDB</td>
</tr>
<tr>
<td>4.</td>
<td>GRAIL satellite ID ‘A’ or ‘B’</td>
</tr>
<tr>
<td>5.</td>
<td>Not applicable</td>
</tr>
<tr>
<td>6.</td>
<td>eps_time (seconds), where LGRS + bias Time = TDB time + eps_time</td>
</tr>
<tr>
<td>7.</td>
<td>Formal error on eps_time (s) (not used by GRAIL, set to 0)</td>
</tr>
<tr>
<td>8.</td>
<td>clock drift (s/s); if not calculated, then set to 0</td>
</tr>
<tr>
<td>9.</td>
<td>Formal error on clock drift (s/s); if not calculated, then set to 0</td>
</tr>
<tr>
<td>10.</td>
<td>bitrate of SFDU packet; if not calculated, then set to 0</td>
</tr>
<tr>
<td>11.</td>
<td>delay by bitrate of SFDU packet; if not calculated, then set to 0</td>
</tr>
<tr>
<td>12.</td>
<td>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 -&gt; linear extrapolation not valid AFTER input time digit 1 = 1 -&gt; linear extrapolation not valid BEFORE input time digit 2 = 1 -&gt; filled data using KBR1C digit 3 = Not Defined digit 4 = Not Defined digit 5 = Not Defined digit 6 = Not Defined digit 7 = Not Defined</td>
</tr>
</tbody>
</table>
### Table 13. DEL1A Record Format

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

### Table 14. EHK1A Record Format

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

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Table 15. IHK1A Record Format

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

Table 16. IHS1A Record Format

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

Table 17. ILG1A Record Format

<table>
<thead>
<tr>
<th>Column #</th>
<th>ILG1A</th>
</tr>
</thead>
</table>
### 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

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

<table>
<thead>
<tr>
<th>Column #</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Receive time (TDB), seconds past 12:00:00 noon 01-Jan-2000</td>
</tr>
<tr>
<td>2.</td>
<td>Receiver ID number = DSN ID</td>
</tr>
<tr>
<td>3.</td>
<td>Transmitter ID 'A' = GRAIL-A 'B' = GRAIL-B</td>
</tr>
<tr>
<td>4.</td>
<td>Light time between transmitter and receiver (sec) (transmit time = receive time + light time)</td>
</tr>
<tr>
<td>5.</td>
<td>Position of transmitting spacecraft at receive time, x value (Earth-centered) (km)</td>
</tr>
<tr>
<td>6.</td>
<td>Position of transmitting spacecraft at receive time, y value (Earth-centered) (km)</td>
</tr>
<tr>
<td>7.</td>
<td>Position of transmitting spacecraft at receive time, z value (Earth-centered) (km)</td>
</tr>
</tbody>
</table>

Table 20. MAS1A Record Format

<table>
<thead>
<tr>
<th>Column #</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>UTC SCET, integer seconds past 12:00:00 noon 01-Jan-2000</td>
</tr>
<tr>
<td>2.</td>
<td>UTC SCET, microseconds part</td>
</tr>
<tr>
<td>3.</td>
<td>Time reference where 'U' = UTC SCET</td>
</tr>
<tr>
<td>4.</td>
<td>GRAIL satellite ID ‘A’ or ‘B’</td>
</tr>
<tr>
<td>5.</td>
<td>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</td>
</tr>
<tr>
<td>6.</td>
<td>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</td>
</tr>
<tr>
<td>7.</td>
<td>Spacecraft Mass based on propellant consumption in kg.</td>
</tr>
</tbody>
</table>
### Table 21. PCI1A Record Format

<table>
<thead>
<tr>
<th>Column #</th>
<th>PCI1A</th>
<th>Phase Center to Center of Mass Correction</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>TDB</td>
<td>TDB, seconds past 12:00:00 noon 01-Jan-2000</td>
</tr>
<tr>
<td>2.</td>
<td>ID</td>
<td>GRAIL satellite ID ‘A’ or ‘B’</td>
</tr>
<tr>
<td>3.</td>
<td>Antenna correction</td>
<td>Antenna phase center range correction (m)</td>
</tr>
<tr>
<td>4.</td>
<td>Rate</td>
<td>Antenna phase center range rate correction (m/sec)</td>
</tr>
<tr>
<td>5.</td>
<td>Acceleration</td>
<td>Antenna phase center range acceleration correction (m/sec^2)</td>
</tr>
<tr>
<td>6.</td>
<td>Flags</td>
<td>data quality flags (digit 0 is on the right and digit 7 is on the left)</td>
</tr>
</tbody>
</table>

Set digits (value = 1) have the following meanings:

- digit 0 = Not Defined
- digit 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

<table>
<thead>
<tr>
<th>Column #</th>
<th>PLT1A</th>
<th>Position vector and light time in EME 2000 (moon centered) of transmitting spacecraft at time of signal reception at receiving spacecraft</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Receive time (TDB)</td>
<td>Receive time (TDB), seconds past 12:00:00 noon 01-Jan-2000</td>
</tr>
<tr>
<td>4.</td>
<td>Light time</td>
<td>Light time between transmitter and receiver (sec) (transmit time = receive time + light time)</td>
</tr>
<tr>
<td>5.</td>
<td>Position</td>
<td>Position of transmitting spacecraft at receive time, x value (moon centered) (km)</td>
</tr>
<tr>
<td>6.</td>
<td></td>
<td>Position of transmitting spacecraft at receive time, y value (moon centered) (km)</td>
</tr>
<tr>
<td>7.</td>
<td></td>
<td>Position of transmitting spacecraft at receive time, z value (moon centered) (km)</td>
</tr>
</tbody>
</table>

### Table 23. PPS1A Record Format

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

### Table 24. REL1A Record Format

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

39
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 and 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

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

Table 26. SBR1A Record Format

<table>
<thead>
<tr>
<th>Column #</th>
<th>SBR1A Level 1A S-Band Ranging Data</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>LGRS time +Bias, integer seconds past 12:00:00 noon 01-Jan-2000 (s)</td>
</tr>
<tr>
<td>2.</td>
<td>LGRS time +Bias, microseconds part</td>
</tr>
<tr>
<td>3.</td>
<td>GRAIL satellite ID ‘A’ or ‘B’</td>
</tr>
<tr>
<td>4.</td>
<td>GRAIL transmission channel number</td>
</tr>
<tr>
<td></td>
<td>2 for GRAIL-A</td>
</tr>
<tr>
<td></td>
<td>1 for GRAIL-B</td>
</tr>
<tr>
<td>5.</td>
<td>SBR antenna ID on GRAIL spacecraft</td>
</tr>
<tr>
<td></td>
<td>Antenna ID = 3 for SBR antenna</td>
</tr>
<tr>
<td>6.</td>
<td>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):</td>
</tr>
</tbody>
</table>
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

data quality flags (digit 0 is on the right and digit 7 is on the left)

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

<table>
<thead>
<tr>
<th>Column #</th>
<th>SNV1A S-Band Navigation Product</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>LGRS time + Bias, seconds past 12:00:00 noon 01-Jan-2000</td>
</tr>
<tr>
<td>2.</td>
<td>LGRS time + Bias, microseconds part</td>
</tr>
<tr>
<td>3.</td>
<td>GRAIL satellite ID ‘A’ or ‘B’</td>
</tr>
<tr>
<td>4.</td>
<td>Measured range = (local measured pseudorange range + remote measured pseudorange)/2 (seconds). Pseudorange contains actual range + clock offset effect.</td>
</tr>
<tr>
<td>5.</td>
<td>Measured clock offset = (local measured pseudorange− remote measured pseudorange)/2 (seconds). Pseudorange contains actual range + clock offset effect.</td>
</tr>
<tr>
<td>6.</td>
<td>Local spacecraft S-Band SNR (V/V)</td>
</tr>
<tr>
<td>7.</td>
<td>Remote spacecraft S-Band SNR (V/V); if not calculated, then set to 0</td>
</tr>
<tr>
<td>8.</td>
<td>Local spacecraft Ka-Band SNR (0.1 dB-Hz)</td>
</tr>
<tr>
<td>9.</td>
<td>Remote spacecraft Ka-Band SNR (0.1 dB-Hz); if not calculated, then set to 0</td>
</tr>
</tbody>
</table>
| 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

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

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

Table 31. TC31A Record Format

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

<table>
<thead>
<tr>
<th>Column #</th>
<th>TC41A</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>LGRS to RTC time correlation</td>
</tr>
<tr>
<td>1.</td>
<td>LGRS time + Bias, in integer seconds</td>
</tr>
<tr>
<td>2.</td>
<td>LGRS time + Bias, microseconds part</td>
</tr>
<tr>
<td>3.</td>
<td>Time scale where ‘L’ = LGRS time + Bias</td>
</tr>
<tr>
<td>4.</td>
<td>GRAIL satellite ID ‘A’ or ‘B’</td>
</tr>
<tr>
<td>5.</td>
<td>Not applicable</td>
</tr>
<tr>
<td>6.</td>
<td>eps_time (seconds), where RTC = LGRS time + Bias + eps_time</td>
</tr>
<tr>
<td>7.</td>
<td>Formal error on eps_time (s); if not calculated, then set to 0</td>
</tr>
<tr>
<td>8.</td>
<td>Not applicable and set to 0</td>
</tr>
<tr>
<td>9.</td>
<td>Formal error on clock drift (s/s); if not calculated, then set to 0</td>
</tr>
<tr>
<td>10.</td>
<td>bitrate of SFDU packet; if not calculated, then set to 0</td>
</tr>
<tr>
<td>11.</td>
<td>delay by bitrate of SFDU packet; if not calculated, then set to 0</td>
</tr>
<tr>
<td>12.</td>
<td>data quality flags (digit 0 is on the right, digit 7 is on the left)</td>
</tr>
</tbody>
</table>
   - 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

<table>
<thead>
<tr>
<th>Column #</th>
<th>TC51A</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>RTC to UTC time correlation</td>
</tr>
<tr>
<td>1.</td>
<td>RTC, in integer seconds</td>
</tr>
<tr>
<td>2.</td>
<td>RTC, microseconds part</td>
</tr>
<tr>
<td>3.</td>
<td>Time scale where ‘R’ = RTC time</td>
</tr>
<tr>
<td>4.</td>
<td>GRAIL satellite ID ‘A’ or ‘B’</td>
</tr>
<tr>
<td>5.</td>
<td>DSN station ID</td>
</tr>
<tr>
<td>6.</td>
<td>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</td>
</tr>
<tr>
<td>7.</td>
<td>Formal error on eps_time (s); if not calculated, then set to 0</td>
</tr>
<tr>
<td>8.</td>
<td>Not applicable and set to 0</td>
</tr>
<tr>
<td>9.</td>
<td>Formal error on clock drift (s/s); if not calculated, then set to 0</td>
</tr>
<tr>
<td>10.</td>
<td>bitrate of SFDU packet</td>
</tr>
<tr>
<td>11.</td>
<td>delay by bitrate of SFDU packet; if not calculated, then set to 0</td>
</tr>
</tbody>
</table>
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

<table>
<thead>
<tr>
<th>Column #</th>
<th>TC61A</th>
<th>UTC to TDB time correlation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>UTC</td>
<td>integer seconds</td>
</tr>
<tr>
<td>2.</td>
<td>UTC</td>
<td>microseconds part</td>
</tr>
<tr>
<td>3.</td>
<td>Time scale where ‘U’ = UTC</td>
<td></td>
</tr>
<tr>
<td>4.</td>
<td>GRAIL satellite ID ‘X’ to indicate a single product for two spacecraft</td>
<td></td>
</tr>
<tr>
<td>5.</td>
<td>Not applicable</td>
<td></td>
</tr>
<tr>
<td>6.</td>
<td>eps_time (seconds), where TDB = UTC + eps_time</td>
<td></td>
</tr>
<tr>
<td>7.</td>
<td>Formal error on eps_time (s); if not calculated, then set to 0</td>
<td></td>
</tr>
<tr>
<td>8.</td>
<td>Clock drift (s/s) deps_time/dt</td>
<td></td>
</tr>
<tr>
<td>9.</td>
<td>Formal error on clock drift (s/s); if not calculated, then set to 0</td>
<td></td>
</tr>
<tr>
<td>10.</td>
<td>bitrate of SFDU packet; if not calculated, then set to 0</td>
<td></td>
</tr>
<tr>
<td>11.</td>
<td>delay by bitrate of SFDU packet; if not calculated, then set to 0</td>
<td></td>
</tr>
<tr>
<td>12.</td>
<td>data quality flags (digit 0 is on the right, digit 7 is on the left)</td>
<td></td>
</tr>
</tbody>
</table>
   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

<table>
<thead>
<tr>
<th>Column #</th>
<th>THR1A</th>
<th>Level 1A Thruster Activation Data</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>UTC</td>
<td>SCET, integer seconds past 12:00:00 noon 01-Jan-2000</td>
</tr>
<tr>
<td>2.</td>
<td>UTC</td>
<td>SCET, microseconds part</td>
</tr>
<tr>
<td>3.</td>
<td>Time reference frame where ‘U’ = UTC SCET</td>
<td></td>
</tr>
<tr>
<td>4.</td>
<td>GRAIL satellite ID ‘A’ or ‘B’</td>
<td></td>
</tr>
<tr>
<td>5-12.</td>
<td>Count of number of work cycles that each thruster has been activated</td>
<td></td>
</tr>
</tbody>
</table>
   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

<table>
<thead>
<tr>
<th>Column #</th>
<th>USO1A Level 1A Ultra Stable Oscillator Stability Data</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>TDB, seconds past 12:00:00 noon 01-Jan-2000</td>
</tr>
<tr>
<td>2.</td>
<td>GRAIL satellite ID ‘A’ or ‘B’</td>
</tr>
<tr>
<td>3.</td>
<td>USO identification number set to 0</td>
</tr>
<tr>
<td>4.</td>
<td>Not applicable, set to 0</td>
</tr>
<tr>
<td>5.</td>
<td>X-Band RSB frequency (Hz)</td>
</tr>
<tr>
<td>6.</td>
<td>Not applicable, set to 0</td>
</tr>
</tbody>
</table>
| 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:
% | 0 = Not Defined
| 1 = Not Defined
| 2 = Not Defined
| 3 = Not Defined
| 4 = Not Defined
| 5 = Not Defined
| 6 = Not Defined
| 7 = Not Defined

Table 37. VCM1A Record Format

<table>
<thead>
<tr>
<th>Column #</th>
<th>VCM1A Level 1A Center of mass displacement from spacecraft mechanical frame origin</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>UTC SCET, seconds past 12:00:00 noon 01-Jan-2000</td>
</tr>
<tr>
<td>2.</td>
<td>GRAIL satellite ID ‘A’ or ‘B’</td>
</tr>
<tr>
<td>3.</td>
<td>Magnitude of center of mass vector in mechanical frame (m)</td>
</tr>
<tr>
<td>4.</td>
<td>Direction cosine of vector with Mechanical Reference Frame x-axis</td>
</tr>
<tr>
<td>5.</td>
<td>Direction cosine of vector with Mechanical Reference Frame y-axis</td>
</tr>
<tr>
<td>6.</td>
<td>Direction cosine of vector with Mechanical Reference Frame z-axis</td>
</tr>
</tbody>
</table>
| 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:
| 0 = Not Defined
| 1 = Not Defined
| 2 = Not Defined
| 3 = Not Defined
| 4 = Not Defined
| 5 = Not Defined
| 6 = Not Defined
| 7 = Not Defined

Table 38. WRS1A Record Format

<table>
<thead>
<tr>
<th>Column #</th>
<th>WRS1A Level 1A Wheel rotational speed data</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>UTC SCET Activation time, integer seconds past 12:00:00 noon 01-01-2000</td>
</tr>
<tr>
<td>2.</td>
<td>Activation time, microseconds part</td>
</tr>
</tbody>
</table>
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

<table>
<thead>
<tr>
<th>Column #</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>LGRS time + Bias, seconds past 12:00:00 noon 01-Jan-2000 (s)</td>
</tr>
<tr>
<td>2</td>
<td>GRAIL satellite ID ‘A’ or ‘B’</td>
</tr>
<tr>
<td>3</td>
<td>Clock ID (set to 1)</td>
</tr>
<tr>
<td>4</td>
<td>eps_time (seconds), where TDB = LGRS time + Bias + eps_time</td>
</tr>
<tr>
<td>5</td>
<td>Formal error on eps_time (s) (not used by GRAIL, set to 0)</td>
</tr>
<tr>
<td>6</td>
<td>Clock drift (s/s) deps_time/dt</td>
</tr>
<tr>
<td>7</td>
<td>Formal error on clock drift (s/s); if not calculated, then set to 0</td>
</tr>
<tr>
<td>8</td>
<td>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 = linear extrapolation not valid AFTER 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</td>
</tr>
</tbody>
</table>

Table 40. EHK1B Record Format

<table>
<thead>
<tr>
<th>Column #</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>TDB, integer seconds past 12:00:00 noon 01-Jan-2000</td>
</tr>
<tr>
<td>2</td>
<td>TDB, microseconds part</td>
</tr>
<tr>
<td>3</td>
<td>Time reference frame where ‘T’ = TDB</td>
</tr>
<tr>
<td>4</td>
<td>GRAIL satellite ID ‘A’ or ‘B’</td>
</tr>
<tr>
<td>5</td>
<td>Microwave Assembly T1 temperature in C</td>
</tr>
<tr>
<td>6</td>
<td>Microwave Assembly T2 temperature in C</td>
</tr>
<tr>
<td>7</td>
<td>Waveguide transmit Ka-Band Assembly temperature in C</td>
</tr>
<tr>
<td>8</td>
<td>Waveguide transmit Microwave Assembly temperature in C</td>
</tr>
<tr>
<td>9</td>
<td>Waveguide Rx Mid temperature in C</td>
</tr>
<tr>
<td>10</td>
<td>Waveguide Tx Mid temperature in C</td>
</tr>
<tr>
<td>11</td>
<td>Aperture temperature in C</td>
</tr>
<tr>
<td>12</td>
<td>Radome temperature in C</td>
</tr>
<tr>
<td>13</td>
<td>HornBase temperature in C</td>
</tr>
<tr>
<td>14</td>
<td>Midway on Horn temperature in C</td>
</tr>
<tr>
<td>15</td>
<td>Orthomode Transducer (where transmit and receive modules are split off at base of horn) temperature in C</td>
</tr>
<tr>
<td>16</td>
<td>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</td>
</tr>
</tbody>
</table>
Table 41. GNI1B Record Format

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

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

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

<table>
<thead>
<tr>
<th>Column #</th>
<th>KBR1C</th>
<th>Level 1B Dual-One-Way Ka-Band Ranging Data</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>TDB,</td>
<td>integer seconds past 12:00:00 noon 01-Jan-2000</td>
</tr>
<tr>
<td>2.</td>
<td>Biased</td>
<td>dual one-way range between GRAIL-A and GRAIL-B (m)</td>
</tr>
<tr>
<td>3.</td>
<td>Range</td>
<td>rate between GRAIL-A and GRAIL-B (m)</td>
</tr>
<tr>
<td>4.</td>
<td>Range</td>
<td>acceleration between GRAIL-A and GRAIL-B (m/s)**2</td>
</tr>
<tr>
<td>5.</td>
<td>Biased</td>
<td>ionospheric range correction between GRAIL-A and GRAIL-B for Ka-Band frequency (m). If not calculated, then set to 0</td>
</tr>
<tr>
<td>6.</td>
<td>Time of</td>
<td>flight range correction between GRAIL-A and GRAIL-B (m). Includes relativistic effects.</td>
</tr>
<tr>
<td>7.</td>
<td>Time of</td>
<td>flight range rate correction between GRAIL-A and GRAIL-B (m/sec). Includes relativistic effects.</td>
</tr>
<tr>
<td>8.</td>
<td>Time of</td>
<td>flight range acceleration correction between GRAIL-A and GRAIL-B (m/sec^2). Includes relativistic effects.</td>
</tr>
<tr>
<td>9.</td>
<td>Ka-band antenna offset range correction (m)</td>
<td></td>
</tr>
<tr>
<td>10.</td>
<td>Ka-band antenna range rate correction (m/s)</td>
<td></td>
</tr>
<tr>
<td>11.</td>
<td>Ka-band antenna range acceleration correction (m/sec^2)</td>
<td></td>
</tr>
<tr>
<td>12.</td>
<td>Undefined (set to 0)</td>
<td></td>
</tr>
<tr>
<td>13.</td>
<td>SNR Ka band for GRAIL-A 0.1 db-Hz</td>
<td></td>
</tr>
<tr>
<td>14.</td>
<td>Undefined (set to 0)</td>
<td></td>
</tr>
<tr>
<td>15.</td>
<td>SNR Ka band for GRAIL-B 0.1 db-Hz</td>
<td></td>
</tr>
<tr>
<td>16.</td>
<td>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</td>
<td></td>
</tr>
<tr>
<td>17.</td>
<td>Raw temperature range correction (m)</td>
<td></td>
</tr>
<tr>
<td>18.</td>
<td>Filtered temperature range correction (m)</td>
<td></td>
</tr>
<tr>
<td>19.</td>
<td>Filtered temperature range rate correction (m/s)</td>
<td></td>
</tr>
<tr>
<td>20.</td>
<td>Filtered temperature range acceleration correction (m/s^2)</td>
<td></td>
</tr>
</tbody>
</table>

Table 44. MAS1B Record Format

<table>
<thead>
<tr>
<th>Column #</th>
<th>MAS1B</th>
<th>Level 1B Spacecraft Mass Data</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>TDB,</td>
<td>integer seconds past 12:00:00 noon 01-Jan-2000</td>
</tr>
<tr>
<td>2.</td>
<td>TDB,</td>
<td>microseconds part</td>
</tr>
<tr>
<td>3.</td>
<td>Time</td>
<td>reference frame where 'T' = TDB</td>
</tr>
</tbody>
</table>
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

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

---

Table 46. SBR1B Record Format

<table>
<thead>
<tr>
<th>Column #</th>
<th>SBR1B</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Level 1B Biased dual one-way S-Band Ranging data</td>
</tr>
<tr>
<td>1.</td>
<td>TDB, seconds past 12:00:00 noon 01-Jan-2000</td>
</tr>
<tr>
<td>2.</td>
<td>Biased dual one-way range between GRAIL-A and B (m)</td>
</tr>
<tr>
<td>3.</td>
<td>Range rate between GRAIL-A and -B (m/s)</td>
</tr>
<tr>
<td>4.</td>
<td>Range acceleration between GRAIL-A &amp; -B (m/s**2)</td>
</tr>
</tbody>
</table>
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 = Data filled by interpolation

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

<table>
<thead>
<tr>
<th>Column #</th>
<th>SCA1B Level 1B Star Tracker Data</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>TDB, seconds past 12:00:00 noon 01-Jan-2000</td>
</tr>
<tr>
<td>2.</td>
<td>GRAIL satellite ID ‘A’ or ‘B’</td>
</tr>
<tr>
<td>3.</td>
<td>SCA identification number set to 1</td>
</tr>
<tr>
<td>4.</td>
<td>Cos ( \mu/2 ) element of quaternion</td>
</tr>
<tr>
<td>5.</td>
<td>I element of quaternion rotation axis</td>
</tr>
<tr>
<td>6.</td>
<td>J element of quaternion rotation axis</td>
</tr>
<tr>
<td>7.</td>
<td>K element of quaternion rotation axis</td>
</tr>
<tr>
<td>8.</td>
<td>rss of formal error of quaternions; if not calculated, then set to 0</td>
</tr>
<tr>
<td>9.</td>
<td>data quality flags (digit 0 is at the right and digit 7 is at the left)</td>
</tr>
</tbody>
</table>

Set digits (value = 1) have the following meanings:

digit 0 = Data filled by interpolation

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 48. THR1B Record Format

<table>
<thead>
<tr>
<th>Column #</th>
<th>THR1B Level 1B Thruster Activation Data</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>TDB, integer seconds past 12:00:00 noon 01-Jan-2000</td>
</tr>
<tr>
<td>2.</td>
<td>TDB, microseconds part</td>
</tr>
<tr>
<td>3.</td>
<td>Time reference frame where 'T' = TDB</td>
</tr>
<tr>
<td>4.</td>
<td>GRAIL satellite ID ‘A’ or ‘B’</td>
</tr>
<tr>
<td>5-12.</td>
<td>Count of number of work cycles that each thruster has been activated</td>
</tr>
</tbody>
</table>
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 = 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 49. USO1B Record Format

<table>
<thead>
<tr>
<th>Column #</th>
<th>USO1B</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Level 1B Ultra Stable Oscillator Stability Data</td>
</tr>
<tr>
<td>1.</td>
<td>TDB, seconds past 12:00:00 noon 01-Jan-2000</td>
</tr>
<tr>
<td>2.</td>
<td>GRAIL satellite ID ‘A’ or ‘B’</td>
</tr>
<tr>
<td>3.</td>
<td>USO identification number set to 0</td>
</tr>
<tr>
<td>4.</td>
<td>Frequency of USO (Hz)</td>
</tr>
<tr>
<td>5.</td>
<td>X-Band RSB frequency (Hz)</td>
</tr>
<tr>
<td>6.</td>
<td>Ka band frequency of KBR (Hz) for USO1B</td>
</tr>
<tr>
<td>7.</td>
<td>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</td>
</tr>
</tbody>
</table>

Table 50. VCM1B Record Format

<table>
<thead>
<tr>
<th>Column #</th>
<th>VCM1B</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Level 1B Center of mass displacement from spacecraft mechanical frame origin</td>
</tr>
<tr>
<td>1.</td>
<td>TDB, seconds past 12:00:00 noon 01-Jan-2000</td>
</tr>
<tr>
<td>2.</td>
<td>GRAIL satellite ID ‘A’ or ‘B’</td>
</tr>
<tr>
<td>3.</td>
<td>Magnitude of center of mass vector in mechanical frame (m)</td>
</tr>
<tr>
<td>4.</td>
<td>Direction cosine of vector with Mechanical Reference Frame x-axis</td>
</tr>
<tr>
<td>5.</td>
<td>Direction cosine of vector with Mechanical Reference Frame y-axis</td>
</tr>
<tr>
<td>6.</td>
<td>Direction cosine of vector with Mechanical Reference Frame z-axis</td>
</tr>
<tr>
<td>7.</td>
<td>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</td>
</tr>
</tbody>
</table>
digit 7 = Not Defined
Table 51. VGS1B Record Format

<table>
<thead>
<tr>
<th>Column #</th>
<th>VGS1B</th>
<th>S-Band antenna offset vector and switch time (TDB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>TDB</td>
<td>seconds past 12:00:00 noon 01-Jan-2000</td>
</tr>
<tr>
<td>2.</td>
<td>GRAIL satellite ID ‘A’ or ‘B’</td>
<td></td>
</tr>
<tr>
<td>3.</td>
<td>Magnitude of vector (m) for active antenna in mechanical reference frame</td>
<td></td>
</tr>
<tr>
<td>4.</td>
<td>Direction cosine of vector with Mechanical Reference Frame x-axis</td>
<td></td>
</tr>
<tr>
<td>5.</td>
<td>Direction cosine of vector with Mechanical Reference Frame y-axis</td>
<td></td>
</tr>
<tr>
<td>6.</td>
<td>Direction cosine of vector with Mechanical Reference Frame z-axis</td>
<td></td>
</tr>
</tbody>
</table>
| 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

<table>
<thead>
<tr>
<th>Column #</th>
<th>VGX1B</th>
<th>X-Band antenna offset vector and switch time (TDB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>TDB</td>
<td>seconds past 12:00:00 noon 01-Jan-2000 in TDB</td>
</tr>
<tr>
<td>2.</td>
<td>GRAIL satellite ID ‘A’ or ‘B’</td>
<td></td>
</tr>
<tr>
<td>3.</td>
<td>Magnitude of vector (m) for active antenna in mechanical reference frame</td>
<td></td>
</tr>
<tr>
<td>4.</td>
<td>Direction cosine of vector with Mechanical Reference Frame x-axis</td>
<td></td>
</tr>
<tr>
<td>5.</td>
<td>Direction cosine of vector with Mechanical Reference Frame y-axis</td>
<td></td>
</tr>
<tr>
<td>6.</td>
<td>Direction cosine of vector with Mechanical Reference Frame z-axis</td>
<td></td>
</tr>
</tbody>
</table>
| 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

<table>
<thead>
<tr>
<th>Column #</th>
<th>VKB1B</th>
<th>Ka-Band Boresight Vector</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>TDB</td>
<td>seconds past 12:00:00 noon 01-Jan-2000</td>
</tr>
<tr>
<td>2.</td>
<td>GRAIL satellite ID ‘A’ or ‘B’</td>
<td></td>
</tr>
<tr>
<td>3.</td>
<td>Magnitude of vector (m) for active antenna in science reference frame for VKB1B</td>
<td></td>
</tr>
<tr>
<td>4.</td>
<td>Direction cosine of vector with Science Reference Frame x-axis</td>
<td></td>
</tr>
<tr>
<td>5.</td>
<td>Direction cosine of vector with Science Reference Frame y-axis</td>
<td></td>
</tr>
<tr>
<td>6.</td>
<td>Direction cosine of vector with Science Reference Frame z-axis</td>
<td></td>
</tr>
</tbody>
</table>
| 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  |
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

<table>
<thead>
<tr>
<th>Column #</th>
<th>WRS1B</th>
<th>Level 1B Wheel rotational speed data</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>TDB</td>
<td>Activation time, integer seconds past 12:00:00 noon 01-01-2000</td>
</tr>
<tr>
<td>2</td>
<td></td>
<td>Activation time, microseconds part</td>
</tr>
<tr>
<td>3</td>
<td></td>
<td>Time reference frame where 'T' = TDB time</td>
</tr>
<tr>
<td>4</td>
<td></td>
<td>GRAIL satellite id ‘A’ or ‘B’</td>
</tr>
<tr>
<td>5</td>
<td></td>
<td>Reaction wheel 1 rotational speed as determined by digital tachometer (radians/sec)</td>
</tr>
<tr>
<td>6</td>
<td></td>
<td>Reaction wheel 2 rotational speed as determined by digital tachometer (radians/sec)</td>
</tr>
<tr>
<td>7</td>
<td></td>
<td>Reaction wheel 3 rotational speed as determined by digital tachometer (radians/sec)</td>
</tr>
<tr>
<td>8</td>
<td></td>
<td>Reaction wheel 4 rotational speed as determined by digital tachometer (radians/sec)</td>
</tr>
</tbody>
</table>

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

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

Table 56. TDM Record Format

<table>
<thead>
<tr>
<th>Column #</th>
<th>TDM</th>
<th>Tracking Data Message - X-Band Sky Frequency relative to frequency offset, from RSR data recorded at the DSN</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td>Data Field: set to RECEIVE_FREQ_2 for GRAIL 1-way downlink</td>
</tr>
<tr>
<td>2</td>
<td></td>
<td>= sign</td>
</tr>
</tbody>
</table>

56
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

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

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 $
```
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
```

END OF HEADER
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  SPICE for 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, as well as the 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:

```plaintext
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 = 2012-06T00:00:00
STOP_TIME = 2012-06T23:59:59
PRODUCT_CREATION_TIME = 2012-06T23:59:59
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"}
```

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:

```plaintext
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, 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"

<table>
<thead>
<tr>
<th>Spacecraft</th>
<th>ID</th>
</tr>
</thead>
<tbody>
<tr>
<td>Magellan</td>
<td>18</td>
</tr>
<tr>
<td>Voyager 1</td>
<td>31</td>
</tr>
<tr>
<td>Voyager 2</td>
<td>32</td>
</tr>
<tr>
<td>Clementine</td>
<td>64</td>
</tr>
<tr>
<td>Galileo Orbiter</td>
<td>77</td>
</tr>
<tr>
<td>Mars Global Surveyor</td>
<td>94</td>
</tr>
</tbody>
</table>

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

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

END_OBJECT

OBJECT = ODF1B_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

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 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 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 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.

\[
\text{Observable} = \frac{B}{|B|} \left( \frac{N_j-N_i}{t_j-t_i} \right) - |F_b*K + B|
\]
where:

- \( B \) = bias placed on receiver
- \( N_i \) = Doppler count at time \( t_i \)
- \( N_j \) = Doppler count at time \( t_j \)
- \( t_i \) = start time of interval
- \( t_j \) = 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 \( K \))

\[
F_b = \frac{X_1}{X_2} \left( X_3 F_r + X_4 \right) - F_{sc} + R_3 \quad \text{for one-way Doppler}
\]
\[
= \left( \frac{X_1}{X_2} \right) \left( X_3 F_r + X_4 \right) - \left( \frac{T_1}{T_2} \right) \left( X_3 F_t + T_4 \right) \quad \text{for all other Doppler}
\]

where:

- \( F_r \) = receiver (VCO) frequency at time \( t_r \)
- \( F_{sc} \) = spacecraft (beacon) frequency
- \( F_t \) = transmitter frequency at time \( t_r \) - RTLT
- \( R_3 \) = 0 for S-band receivers
- \( = 0 \) for X-band receivers
- \( = 0 \) for Ku-band receivers
- \( = 0 \) for Ka-band receivers
- \( T_1 \) = 240 for S-band transmitters (see Item 12)
- \( = 240 \) for X-band transmitters
- \( = 142 \) for Ku-band transmitters
- \( = 14 \) for Ka-band transmitters
- \( T_2 \) = 221 for S-band transmitters
- \( = 749 \) for X-band transmitters
- \( = 153 \) for Ku-band transmitters
- \( = 15 \) for Ka-band transmitters
- \( T_3 \) = 96 for S-band transmitters
- \( = 32 \) for X-band transmitters
- \( = 1000 \) for Ku-band transmitters
- \( = 1000 \) for Ka-band transmitters
- \( T_4 \) = 0 for S-band transmitters
- \( = 6.5 \times 10^9 \) for X-band transmitters
- \( = -7.0 \times 10^9 \) for Ku-band transmitters
- \( = 1.0 \times 10^{10} \) for Ka-band transmitters

\( X_1 \) to \( X_4 \) have the same values as \( T_1 \) to \( T_4 \) 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:

\[
\text{Observable} = R - C + Z - S
\]
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
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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:

<table>
<thead>
<tr>
<th>Data Types</th>
<th>Generic Term</th>
</tr>
</thead>
<tbody>
<tr>
<td>01-06</td>
<td>VLBI</td>
</tr>
<tr>
<td>01-04</td>
<td>Narrowband VLBI</td>
</tr>
<tr>
<td>05-06</td>
<td>Wideband VLBI</td>
</tr>
<tr>
<td>03, 04, 06</td>
<td>Quasar</td>
</tr>
<tr>
<td>11-58</td>
<td>Tracking or TRK</td>
</tr>
<tr>
<td>01-58</td>
<td>Radiometric</td>
</tr>
</tbody>
</table>

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
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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
BIT_DATA_TYPE = MSB_UNSIGNED_INTEGER
START_BIT = 43
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_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_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_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 = ODF4

OBJECT
   = ODF4B26_TABLE
   NAME = "RAMP GROUP 26 DATA"
   INTERCHANGE_FORMAT = BINARY
   ROWS = 236
   COLUMNS = 9
   ROW_BYTES = 3
   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
<table>
<thead>
<tr>
<th>NAME</th>
<th>&quot;RAMP START FREQUENCY - INTEGER PART&quot;</th>
</tr>
</thead>
<tbody>
<tr>
<td>DATA_TYPE</td>
<td>MSB_UNSIGNED_INTEGER</td>
</tr>
<tr>
<td>START_BYTE</td>
<td>21</td>
</tr>
<tr>
<td>BYTES</td>
<td>4</td>
</tr>
<tr>
<td>UNIT</td>
<td>Hertz</td>
</tr>
<tr>
<td>DESCRIPTION</td>
<td>&quot;Item 7: The integer part of the Ramp Start Frequency, modulo 10^9.&quot;</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>OBJECT</th>
<th>COLUMN</th>
</tr>
</thead>
<tbody>
<tr>
<td>COLUMN_NUMBER</td>
<td>7</td>
</tr>
<tr>
<td>NAME</td>
<td>&quot;RAMP START FREQUENCY - FRACTIONAL PART&quot;</td>
</tr>
<tr>
<td>DATA_TYPE</td>
<td>MSB_UNSIGNED_INTEGER</td>
</tr>
<tr>
<td>START_BYTE</td>
<td>25</td>
</tr>
<tr>
<td>BYTES</td>
<td>4</td>
</tr>
<tr>
<td>DESCRIPTION</td>
<td>&quot;Item 8: The fractional part of the Ramp Start Frequency, in units of 10^-9 of Column 6.&quot;</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>OBJECT</th>
<th>COLUMN</th>
</tr>
</thead>
<tbody>
<tr>
<td>COLUMN_NUMBER</td>
<td>8</td>
</tr>
<tr>
<td>NAME</td>
<td>&quot;RAMP END TIME - INTEGER PART&quot;</td>
</tr>
<tr>
<td>DATA_TYPE</td>
<td>MSB_UNSIGNED_INTEGER</td>
</tr>
<tr>
<td>START_BYTE</td>
<td>29</td>
</tr>
<tr>
<td>BYTES</td>
<td>4</td>
</tr>
<tr>
<td>UNIT</td>
<td>SECOND</td>
</tr>
<tr>
<td>DESCRIPTION</td>
<td>&quot;Item 9: The integer part of the ramp end time, measured from 0 hours UTC on 1 January 1950.&quot;</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>OBJECT</th>
<th>COLUMN</th>
</tr>
</thead>
<tbody>
<tr>
<td>COLUMN_NUMBER</td>
<td>9</td>
</tr>
<tr>
<td>NAME</td>
<td>&quot;RAMP END TIME - FRACTIONAL PART&quot;</td>
</tr>
<tr>
<td>DATA_TYPE</td>
<td>MSB_UNSIGNED_INTEGER</td>
</tr>
<tr>
<td>START_BYTE</td>
<td>33</td>
</tr>
<tr>
<td>BYTES</td>
<td>4</td>
</tr>
<tr>
<td>UNIT</td>
<td>NANOSECOND</td>
</tr>
<tr>
<td>DESCRIPTION</td>
<td>&quot;Item 10: The fractional part of the ramp end time (see Column 8).&quot;</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>OBJECT</th>
<th>ODF4B43_TABLE</th>
</tr>
</thead>
<tbody>
<tr>
<td>NAME</td>
<td>&quot;RAMP GROUP 55 HEADER&quot;</td>
</tr>
<tr>
<td>INTERCHANGE_FORMAT</td>
<td>BINARY</td>
</tr>
<tr>
<td>ROWS</td>
<td>1</td>
</tr>
<tr>
<td>COLUMNS</td>
<td>4</td>
</tr>
<tr>
<td>ROW_ITEMS</td>
<td>16</td>
</tr>
<tr>
<td>ROW_SUFFIX_BYTES</td>
<td>20</td>
</tr>
<tr>
<td>DESCRIPTION</td>
<td>&quot;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&quot;</td>
</tr>
</tbody>
</table>
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.

```plaintext
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"
```
GRAIL DATA PRODUCT SOFTWARE INTERFACE SPECIFICATION

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."
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."

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."

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."

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."

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

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
END_OBJECT

OBJECT = ODF8A_TABLE
END_OBJECT

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
END_OBJECT

END_OBJECT

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_0605NNX45RD.1A1"
^TABLE = "GRALUGF2012148_0605NNX45RD.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
<table>
<thead>
<tr>
<th>Name</th>
<th>Column Number</th>
<th>Start Byte</th>
<th>Bytes</th>
<th>Data Type</th>
<th>Unit</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>PRIMARY HEADER CHDO TYPE</td>
<td>10</td>
<td>25</td>
<td>2</td>
<td>MSB_UNSIGNED_INTEGER</td>
<td>N/A</td>
<td>Primary Header CHDO Type. Set to '2', meaning this CHDO is a primary header CHDO. The NJPL Control Authority maintains a registry of CHDO types.</td>
</tr>
<tr>
<td>PRIMARY HEADER CHDO LENGTH</td>
<td>11</td>
<td>27</td>
<td>2</td>
<td>MSB_UNSIGNED_INTEGER</td>
<td>BYTE</td>
<td>Primary Header CHDO Length. Set to '4', meaning length of the value field of the Primary Header CHDO is 4 bytes (bytes 29-32).</td>
</tr>
<tr>
<td>MAJOR DATA CLASS</td>
<td>12</td>
<td>29</td>
<td>1</td>
<td>MSB_UNSIGNED_INTEGER</td>
<td>N/A</td>
<td>Major Data Class. Set to '21', meaning this SFDU contains Radio Science data.</td>
</tr>
<tr>
<td>MINOR DATA CLASS</td>
<td>13</td>
<td>30</td>
<td>1</td>
<td>MSB_UNSIGNED_INTEGER</td>
<td>N/A</td>
<td></td>
</tr>
</tbody>
</table>
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

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

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

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

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"
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 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"

99
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

101
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

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

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

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

OBJECT = COLUMN
NAME = "DIG ADC YEAR"
COLUMN_NUMBER = 39
START_BYTE = 61
<table>
<thead>
<tr>
<th>NAME</th>
<th>DIG ADC DAY OF YEAR</th>
<th>COLUMN_NUMBER</th>
<th>40</th>
<th>START_BYTE</th>
<th>63</th>
<th>BYTES</th>
<th>2</th>
<th>DATA_TYPE</th>
<th>MSB_UNSIGNED_INTEGER</th>
<th>UNIT</th>
<th>N/A</th>
<th>DESCRIPTION</th>
<th>UTC day-of-year on which the ADC data were computed. Values can range over 1-366.</th>
</tr>
</thead>
<tbody>
<tr>
<td>NAME</td>
<td>DIG ADC SECOND</td>
<td>COLUMN_NUMBER</td>
<td>41</td>
<td>START_BYTE</td>
<td>65</td>
<td>BYTES</td>
<td>4</td>
<td>DATA_TYPE</td>
<td>MSB_UNSIGNED_INTEGER</td>
<td>UNIT</td>
<td>N/A</td>
<td>DESCRIPTION</td>
<td>UTC second of day on which the ADC data were computed. Values can range over 0-86400.</td>
</tr>
<tr>
<td>NAME</td>
<td>SAMPLE RESOLUTION</td>
<td>COLUMN_NUMBER</td>
<td>42</td>
<td>START_BYTE</td>
<td>69</td>
<td>BYTES</td>
<td>1</td>
<td>DATA_TYPE</td>
<td>MSB_UNSIGNED_INTEGER</td>
<td>UNIT</td>
<td>N/A</td>
<td>DESCRIPTION</td>
<td>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.</td>
</tr>
<tr>
<td>NAME</td>
<td>DATA ERROR COUNT</td>
<td>COLUMN_NUMBER</td>
<td>43</td>
<td>START_BYTE</td>
<td>70</td>
<td>BYTES</td>
<td>1</td>
<td>DATA_TYPE</td>
<td>MSB_UNSIGNED_INTEGER</td>
<td>UNIT</td>
<td>N/A</td>
<td>DESCRIPTION</td>
<td>Number of hardware errors encountered while the data in this SFDU were</td>
</tr>
</tbody>
</table>
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:

\[ F_{\text{sky}} = F_{\text{RFtoIF_LO}} + \]
\[ DDC_{\text{LO}} - \]
\[ NCO_{\text{Freq}} + \]
\[ F_{\text{resid}} \]

where

- \( F_{\text{RFtoIF_LO}} \) is in Column 46,
- \( DDC_{\text{LO}} \) is in Column 45,
- \( NCO_{\text{Freq}} \) from Columns 61-63, and
- \( F_{\text{resid}} \) 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:

\[ F_{sky} = RF_{toIF}LO + DDC_{LO} - NCO_{Freq} + Fresid \]

where

- \( RF_{toIF}LO \) 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


106
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 by 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
+--------------------------+
|1|2|3|4|5|6|7|8|1|2|3|4|5|6|7|8|
+--------------------------+
|<------Q2------>|<------Q1------>|
+--------------------------+

BYTES 3-4
+--------------------------+
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)

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.
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")
GRAIL DATA PRODUCT SOFTWARE INTERFACE SPECIFICATION

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**

**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**

**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**

**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**

**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 $C_{mn}$ 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 $S_{mn}$ for this spherical harmonic model."

END_OBJECT = COLUMN

END_OBJECT = SHADR_COEFFICIENTS_TABLE

END

### 7.3.4.3 Spherical Harmonics Binary Data Record (SHBDR)

```plaintext
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.

This file includes:
- Shape coefficients ($S_{mn}$)
- Uncertainties in shape coefficients ($S_{uncertainty}$)
- Covariance matrix of shape coefficients
- Uncertainties in shape coefficients ($S_{uncertainty}$)
- Shape model summary

This file is intended for users who need high-precision gravity information for the Moon.

The data is organized as follows:
- 660th degree and order spherical harmonic model
- Shape model coefficients
- Uncertainties in shape model coefficients
- Covariance matrix of shape model coefficients

This file is a valuable resource for astronomers and geoscientists studying the gravitational field of the Moon.

The file contains 52835 records, each record containing 512 bytes of data.

The file includes the following tables:
- Header table
- Names table
- Shape coefficients table
- Covariance table

The file is a valuable resource for researchers studying the lunar gravity field.

The file also includes the following metadata:
- PDS Version ID: PDS3
- File Name: JGGRX_0660B_SHB_L50.DAT
- Record Type: FIXED_LENGTH
- Record Bytes: 512
- File Records: 52835

The file is a valuable resource for researchers studying the lunar gravity field.
The second degree Love number solution is $k_2 = 0.02405$. 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 10.1002/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).

```plaintext
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."

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

120
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

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

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

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 C_{ij} or S_{ij} 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 |
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 = COLUMNSHBDR_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
RECORDgetBytes = 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 = "GRAULUGF2012_061_2012_062.SPK"
FILE_NAME = "GRAULUGF2012_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.

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