LROC EDR/CDR
DATA PRODUCT
SOFTWARE INTERFACE SPECIFICATION

Version 1.18
June 9, 2010

Signature Page

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DOCUMENT CHANGE LOG

Date	Change	Affected Portions
2008/03/17	First draft for PDS review	all
2008/03/28	Incorporated comments/suggestions from Eric Eliason and Stan Scott.	Sections 1.1, 2.2, 2.3.2, 2.3.4, 2.4.2, 3.1
2008/05/20	Incorporated comments/suggestions from SIS review panel	Sections 2.1, 2.3, 2.3.3, 2.3.4, 2.5, 3.2, 3.3, Appendix B
2008/05/26	Incorporated comments/suggestions from Stuart Sides (SIS Review panel)	Minor edits in multiple sections.
2008/12/01	Added keyword for recording temperatures at beginning, middle, and end of a WAC image series.	Sections 3.2.3, 3.2.4 and 3.3
2009/02/24	Updated numbers; major review	all
2009/02/26	Updated numbers; major review	all
2009/05/04	Added missing label keywords and correcting information on keyword description.	Sections 3.2.1, 3.2.2, 3.2.3 and 3.2.4
2009/06/01	Minor edits throughout document, NAC orientation, CDR data storage type, and header updates.	Sections 2.1, 2.2, 3.2., 3.3
2009/06/04	Minor edits throughout document, added keywords to labels	Sections 2.1, 3.2, 3.3, Appendix B
2009/06/08	Minor edit of NAC companding table	Appendix B
2009/06/11	Minor edit correcting maximum WAC file size Minor edit adding partition to sclk value description Minor correcting location of PDS UNITS keyword in labels	Section 2.2 Section 2.4.2 Sections 3.2.1, 3.2.2, 3.2.3, 3.2.4
2009/06/25	Acronym addition, minor edits, quotation fixes	Acronyms & Abbreviations, labels and keyword descriptions
2009/11/11	Updates to reflect new EDR/CDR header keywords and values	Sections 3.2-3.3
2010/01/31	Data quality description updated.	Section 3.3
2010/02/05	Updated CDR example labels and section describing label with Special Pixel information.	Sections 3.2.2, 3.2.4, 3.3
2010/03/12	Edits to correct typos, incorrect information, and formatting.	Sections 2.2, 3.2.3, 3.3
2010/06/09	Added new appendix describing image orientation, updated acronyms and abbreviations table	Appendix C, Acronyms and Abbreviations

TBD/TBR ITEMS

Section	Description	Person

Acronyms and Abbreviations

ASCII	American Standard Code for Information Interchange
ASU	Arizona State University
CCD	Charge Coupled Device
CDR	Calibrated Data Record
CD-ROM	Compact Disk – Read-Only Memory
CD-WO	Compact Disk – Write Once
CODMAC	Committee on Data Management, Archiving, and Computing
DN	Digital Number
EDR	Experiment Data Record
FK	Frames Kernel (NAIF SPICE kernel)
GSFC	Goddard Space Flight Center
I/F	See Appendix A – Glossary
IK	Instrument Kernel (NAIF SPICE kernel)
ISIS	Integrated Software for Imagers and Spectrometers
ISO	International Standards Organization
JPL	Jet Propulsion Laboratory
LDWG	LRO Data Working Group
LRO	Lunar Reconnaissance Orbiter
LROC	Lunar Reconnaissance Orbiter Camera
MD5	Message Digest algorithm 5
ME	Mean Earth
MET	Mission Elapsed Time
Mini-RF	Mini-Radio Frequency Technology Demonstration
MOC	Mission Operations Center
MTF	Modulation Transfer Function
NAC	Narrow Angle Camera
NAC-L	Narrow Angle Camera – Left (+X, A, 1)
NAC-R	Narrow Angle Camera – Right (-X, B, 2)
NAIF	Navigation Ancillary Information Facility
NASA	National Aeronautics and Space Administration
NSSDC	National Space Science Data Center
PDS	Planetary Data System
PSG	Project Science Group
PTIFF	Pyramid TIFF
SDVT	Science Data Validation Team
SIS	Software Interface Specification
SNR	Signal-to-Noise Ratio
SOC	Science Operations Center
SPICE	S – Spacecraft ephemeris, P – Planet, satellite, comet, or asteroid ephemeredes, I – Instrument description kernel, C – C-matrix pointing kernel, E – Events kernel
SSH	Secure Shell
TBD	To Be Determined
TBR	To Be Reviewed

UV	UltraViolet
VIS	Visible
WAC	Wide Angle Camera

1. Introduction

1.1. Purpose and Scope

This Software Interface Specification (SIS) outlines the generation of Lunar Reconnaissance Orbiter Camera (LROC) NAC and WAC EDR (CODMAC Level 2) and CDR (CODMAC Level 3) data products with a detailed description of the products and a description of how the products are generated, including data sources and destinations. The EDR products contain panchromatic NAC image data, monochromatic WAC image data, and seven band WAC image data, while the CDR products contain calibrated panchromatic NAC image data, calibrated monochromatic WAC image data, and seven band calibrated WAC image data.

This SIS is intended to provide enough information to enable users to read and understand the data products.

1.2. Applicable Documents

The following documents are applicable to the development and execution of this document:

1. Lunar Reconnaissance Orbiter Project Data Management and Archive Plan, 431-PLAN-00182. Check with the LRO Project Configuration Management Office to ensure the document is the most current version prior to use.
2. LROC Data Management and Archive Plan, LROC_SOC_PLAN_0001.
3. LROC EDR Archive Volume SIS, LROC_SOC_SPEC_0002.

This SIS is also consistent with the following Planetary Data System documents:

4. *Planetary Data System Archive Preparation Guide*, August 29, 2006, Version 1.1, JPL D-31224.
5. *Planetary Data System Standards Reference*, March 20, 2006, Version 3.7. JPL D-7669, Part 2.
6. *Planetary Data System Data Dictionary Document*, August 28, 2002, JPL D-7116, Rev. E

1.3. Relationships with Other Interfaces

The LROC EDR and CDR Archive Volume SIS describes how the data products specified by this document will be cataloged and made available through the LROC PDS Data Node.

2. Data Product Characteristics and Environment

2.1. Instrument Overview

The LROC consists of two Narrow-Angle Cameras (NACs), a Wide-Angle Camera (WAC), and a common Sequence and Compressor System (SCS).

Each NAC (see Figure 2.1) has a 700 mm focal length Cassegrain (Ritchey-Chretien) telescope that images onto a 5064-pixel CCD line-array providing a cross-track field-of-view (FOV) of 2.85°. The NAC readout noise is better than 101 e^- and the data are sampled at 12-bits. These 12-bit pixel values are companded to 8-bit pixels using one of several selectable piecewise linear mappings during readout from the CCD. The NAC internal buffer holds 256 MB of uncompressed data, enough for a full-resolution image 52,224 lines long. NAC specifications are summarized in Table 2.1.

The WAC electronics is a copy of those flown on cameras on Mars Climate Orbiter, Mars Polar Lander, Mars Odyssey, and Mars Reconnaissance Orbiter. The WAC (see Figure 2.2) has two lenses imaging onto the same 1024 x 1024 pixel, electronically shuttered CCD area-array, one imaging in the visible/near infrared (VIS), and the other in the Ultraviolet (UV). *In monochrome mode, 1024 x 14 pixels are read out in one visible band (645 nm). In color mode, only the center 704 x 14 visible pixels and 512 x 16 UV pixels binned to 128 x 4 pixels, are read out for each band.* The VIS optics have a cross-track FOV of 91.7° (monochrome) and 61.4° (color), and the UV optics a 58.96° FOV. From the nominal 50-km orbit, the WAC will provide a nadir ground sample distance of 74.9 m/pixel in the visible, and a swath width of 104.6 km (visible monochrome), 59.6 km (visible color) and 56.8 km (UV color). The seven-band color capability of the WAC is provided by a color filter array (see Figure 2.3) mounted directly over the detector, providing different sections of the CCD with different filters. Consequently the instrument has no moving parts; it acquires data in the seven channels in a "pushframe" mode, with scanning of the WAC FOV provided by motion of the spacecraft and target. Continuous color coverage of the lunar surface is possible by repeated imaging such that each of the narrow framelets of each color band overlap. The WAC has a readout noise less than 66 e^- and, pixel values are digitized to 11-bits and are then companded to 8-bit values through a square-root-like lookup table. WAC specifications are summarized in Table 2.2 and the spectral transmissivity of all seven WAC filters are displayed in figure 2.4. The two UV bands (320 and 360 nm) undergo 4x4 pixel on-chip analog summing before digitization to achieve better signal-to-noise ratio. Thus, UV pixels are recorded at reduced 383.5 m/pixel sampling but have improved signal properties. Only the center 704 pixels for the VIS are digitized when all seven bands are being acquired. WAC band passes are arranged first UV then VIS (320, 360, 415, 565, 605, 645, 690), but the order is reversed after LRO performs a 180° yaw maneuver to align the solar panels with the sun.

The two NACs and the WAC interface with the Sequencing and Compressor System (SCS), the third element of the LROC (see Figure 2.5). As the name implies, the SCS commands individual image acquisition by the NACs and WAC from a stored sequence, and losslessly compresses the NAC and WAC data as they are read out and passed to the spacecraft data system. The SCS provides a single command and data interface between the LROC and the LRO spacecraft data system through a spacewire interface.

The NACs are mounted on the spacecraft such that the CCDs are perpendicular to the spacecraft's X-axis. The NAC-L is off-pointed ~2.85° from the NAC-R so that the footprints of the two images overlap ~130 pixels. The NAC-R is also mounted 0.106° forward of the NAC-L. The NACs are mounted such that pixel 0 for the NAC-L is at the –Y (in spacecraft coordinates) end of its CCD and pixel 0 for the NAC-R is at the +Y end of its CCD. This orientation requires that one of the NAC frames from a NAC-L and NAC-R paired observation must be transformed such that both images have the same ground orientation

The mass of both the NACs combined is 16.4 kg, the WAC is 0.9 kg, and the SCS is 1.2 kg, for a total LROC mass of 18.5 kg. The peak and average power consumption for each NAC is 9.3 W and 6.4 W the WAC is 2.7 W and 2.6 W, and the SCS is 4.5 W and 4.0 W, for a total LROC power dissipation of 16.5 W and 13 W, respectively.

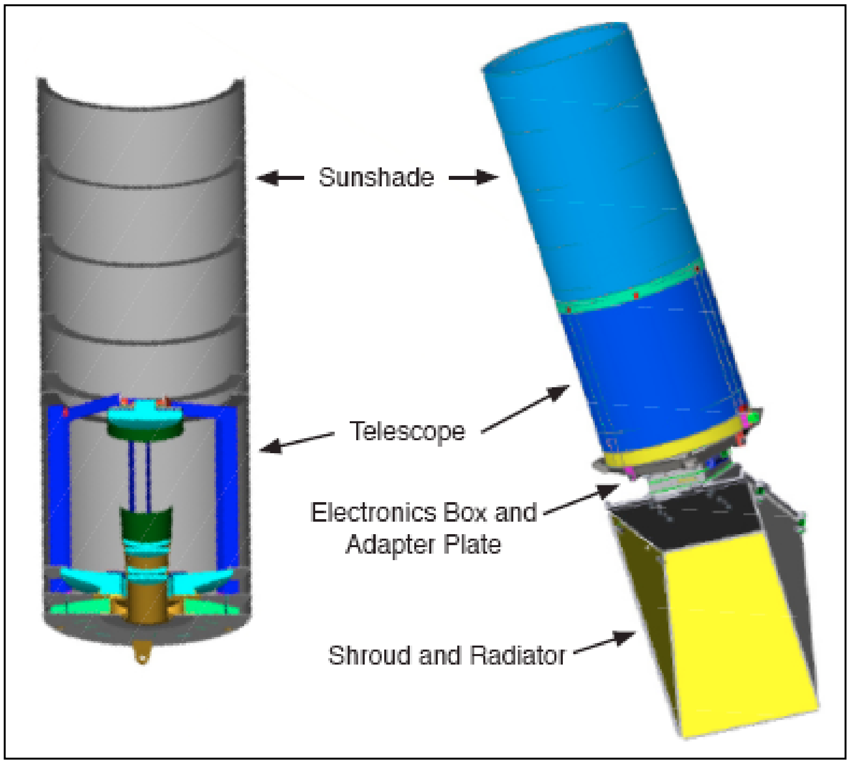

Figure 2.1 - LROC Narrow Angle Camera

	NAC-L	NAC-R
FOV	2.8502°	2.8412°
IFOV	10.0042 µrad	9.9764 µrad
Image scale at 50 km altitude	0.5 m/pixel	
Maximum image size at 50 km altitude	2.49 x 26 km	2.48 x 26.1 km
f/# (Ritchey-Chretien)	3.577	3.590
Effective focal length	699.62 ± 0.08 mm	701.57 ± 0.09 mm
Distortion coefficient	0.0000181 ± 0.0000005	0.0000183 ± 0.0000005
Optical center location	sample 2548 ± 8	sample 2568 ± 8
Primary mirror diameter	198 mm	
MTF (Nyquist)	0.23	
Gain	90.5 ± 2.6 e^-/DN	92.5 ± 1.5 e^-/DN
Noise	101 ± 7 e^-	97 ± 2 e^-
Detector Fullwell	334,000 ± 31,000 e^-	352,000 ± 4100 e^-
SNR (400-750 nm)	> 52	> 49
Detector digitization	12-bit, encoded to 8-bits	
Lossless compression ratio	1.7:1	
Structure + baffle	Graphite-cyanate composite	
Detector	Kodak KLI-5001G	
Pixel format	1 x 5,064*	
Analog/digital converter	Honeywell ADC9225	
FPGA	Actel RT54SX32-S	
Voltage	28 ± 7V DC	
Peak power	9.3 W	
Orbit average power	6.4 W	
Mass (both NACs)	16.4 kg	
Volume (length x diameter)	118 cm x 27 cm (incl. radiator)	

Table 2.1 – NAC Specificationss. * Of the 5064 pixels, 39 masked pixels on the right and 21 masked pixels on the left are used for dark reference.

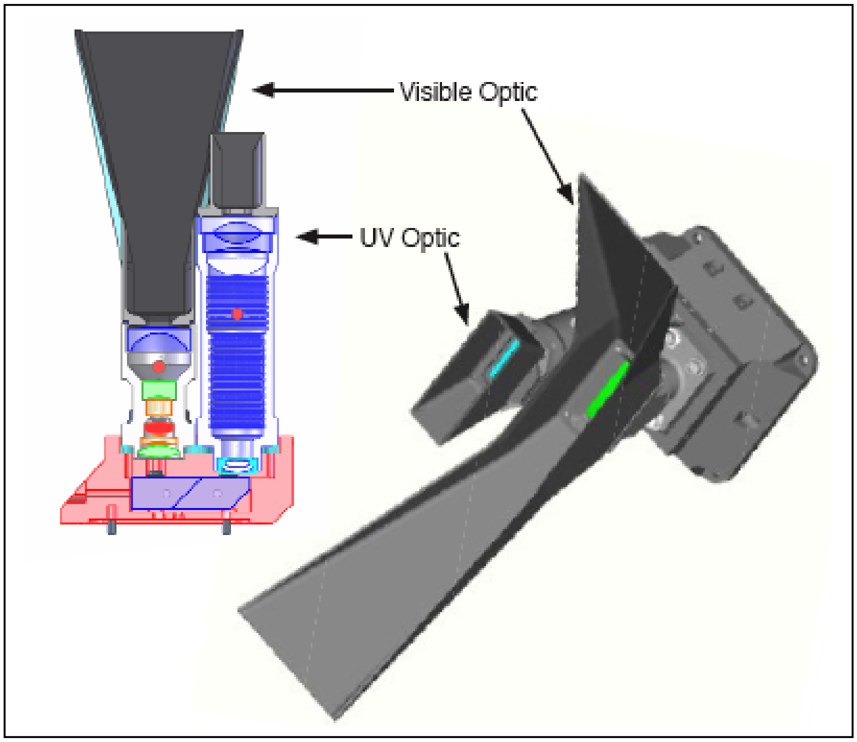

Figure 2.2. - LROC Wide Angle Camera

	Visible	UV	
FOV (monochrome / color)	91.7° / 61.4°	58.96°	
IFOV	1.498 mrad	7.67 mrad (4x4 binned)	
Image scale (nadir, 50 km altitude)	74.9 m/pixel	383.5 m/pixel (binned)	
Image frame width monochrome	104.6 km	-	
Image frame width 7-band color	59.6 km	56.8 km	
Image format monochrome	1024 samples x 14 lines	-	
Image format color (each band)	704 samples x 14 lines	128 samples x 4 lines (binned)	
f/#	5.052	5.65	
Effective focal length	6.013 mm	4.693 mm	
Entrance pupil diameter	1.19 mm	0.85 mm	
System MTF (Nyquist)	0.37		
Gain	25.9 ± 0.7 e^-/DN		
Noise	66 ± 4 e^-		
Detector fullwell	46,100 ± 3600 e^-		
Band | λ_{eff} | FWHM	320 nm 360 nm 415 nm 565 nm 605 nm 645 nm 690 nm	321 nm 360 nm 415 nm 566 nm 604 nm 643 nm 689 nm	32.3 nm 14.9 nm 36.1 nm 20.1 nm 20.4 nm 22.5 nm 38.6 nm
SNR (at 1000 DN)	> 150		
Detector digitization	11-bit, encoded to 8-bits		
Lossless compression ratio	1.7:1		
Electronics	4 circuit boards		
Detector	Kodak KLI-1001		
Pixel format	1,024 x 1,024		
Voltage	28±7 V DC		
Peak Power	2.7 W		
Orbit average power	2.6 W		
Mass	0.9 kg		
Volume (width x length x height)	15.8 cm x 23.2 cm x 32.3 cm (incl. radiator)		

Table 2.2 – WAC Specifications

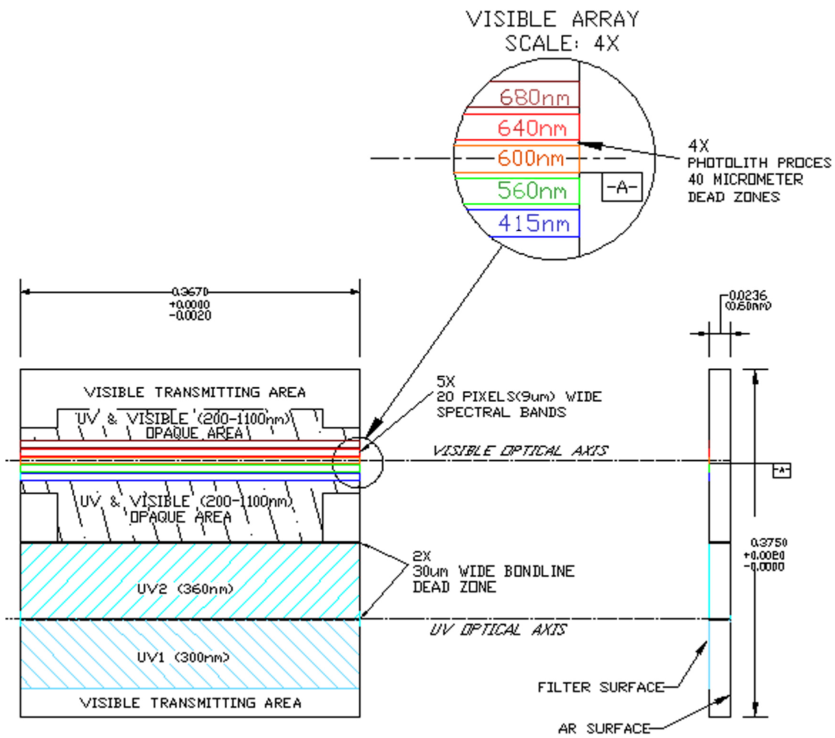

Figure 2.3 - Diagram of LROC Wide Angle Camera filter assembly.

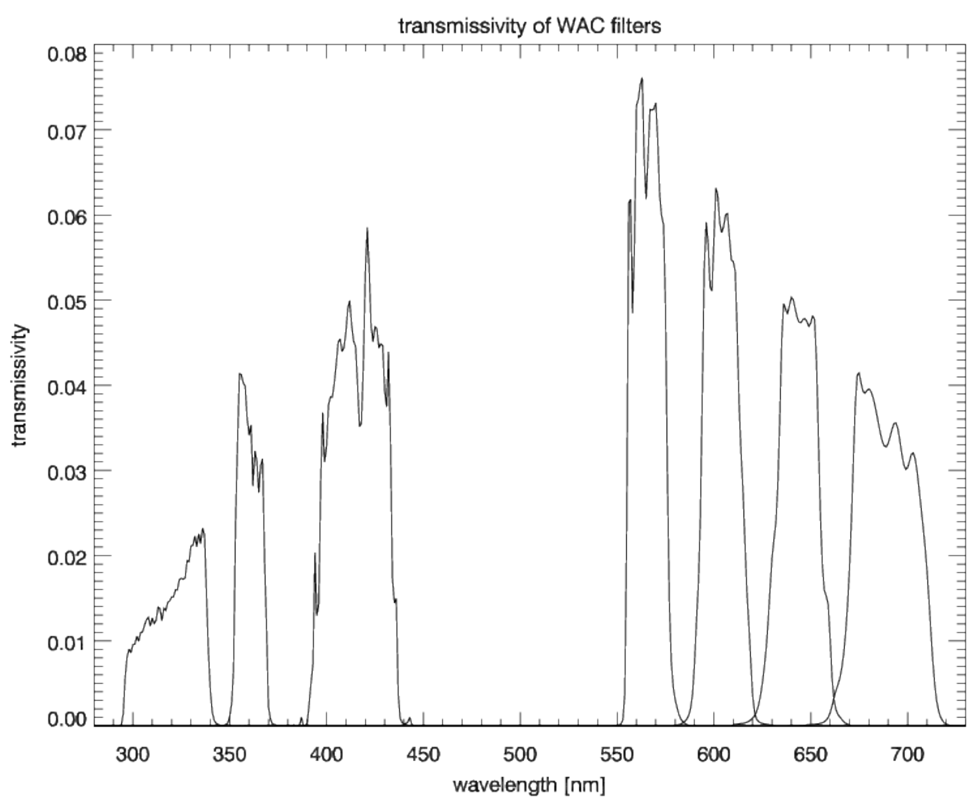

Figure 2.4 - The spectral transmissivity of the 7 WAC filters. The values of the y-axis represent the relative system throughput.

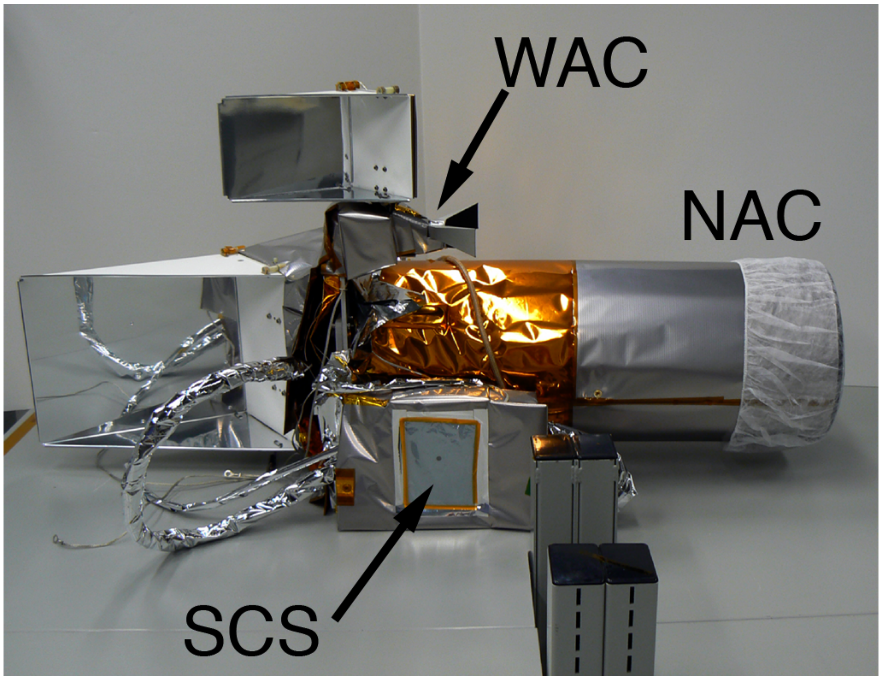

Figure 2.5 - LROC components include the WAC, NAC, and Sequence and Compressor System (SCS).

2.2. Data Product Overview

LROC EDR data products are comprised of the following files:

a. NAC panchromatic image corresponding to a single observation (either full resolution or summed), with Digital Number (DN) counts in 8-bit format, companded from 12-bit in the instrument. The NAC EDR file size will be a maximum of 256 MB for the full resolution 52,224 lines or summed 52,224 lines, with 5064 samples per line. NAC EDR file sizes will be smaller when fewer lines are acquired.
b. WAC image corresponding to a series of framelets, with DN counts in 8-bit format, companded from 11-bit in the instrument. Each framelet is in row-major order. The WAC EDR file size will not exceed 26.6 MB, which corresponds to observing 18.5º of latitude in multispectral mode. The WAC exposure and/or interframe gap parameters will be modified approximately every 10º of latitude, resulting in an average file size of 14.4 MB. It is important to note that the WAC EDR stores multispectral framelets in single band, not as separate bands within the EDR file.

LROC CDR data products are comprised of the following files:

a. NAC DNs will be decompanded and images will be radiometrically calibrated to radiance (i.e. star observations) or I/F (i.e. lunar observations). Radiance images will be archived as floating point values (4 bytes per pixel) and I/F images as scaled signed-integer values (2 bytes per pixel). The I/F values will be multiplied by 32767 before being converted to signed-integer. The NAC CDR file size will be approximately 512 MB for full resolution 52,224 line or summed 52,224 line radiance images (I/F images will be half as large), with 5064 samples per line. NAC CDR file sizes will be smaller when fewer lines are acquired.

b. WAC image corresponding to a series of framelet images, with decompanded DNs, radiometrically calibrated to radiance or I/F. The WAC CDR file size will not exceed a maximum of 256 MB, which corresponds to observing 80º of latitude in multispectral mode. The WAC exposure and/or interframe gap parameters will be modified approximately every 10º of latitude, resulting in an average file size of 28.8 MB. It is important to note that the WAC EDR stores multispectral framelets in single band, not as separate bands in the CDR file. The WAC CDR file will require further processing to separate framelets into their respective bands and to align the bands, in order to be viewed as a standard mutli-band image.

2.3. Data Processing

Post acquisition data processing for WAC and NAC images begins upon delivery of the images to SOC from the MOC. The SOC is designed to handle 440 Gbits per day of data downlink, not including ancillary products generated by the MOC. Owing to the large volume of data, the SOC has been designed with a high degree of automation in all aspects of the data processing.

Data are pushed to the SOC using the SSH protocol, with delivery status being checked using MD5 checksums for each file. Failed transfers will be automatically re-initiated by the MOC. Stored housekeeping (spacecraft and LROC instrument), predict and definitive SPICE kernels, and command load reports are also delivered to the SOC, some of which are used during data processing. Upon receipt by the SOC, all files are handled by automated processing routines being run within the Rector framework, to allow for scalable growth as processing needs grow or recede. At each stage of the automated processing, quality assurance tests are performed, either before processing or after processing occurs, to insure valid products are flowing down-stream through the pipelines. Meta-data for each EDR and CDR file that is processed will be recorded into a PostgreSQL database, which then directs the generation of each archive delivery. Archive deliveries are pushed from our production storage array onto a data node storage array, where the data are accessible (in read-only mode) by the LROC PDS data node (http://lroc.sese.asu.edu).

NAC and WAC data should not experience missing data under nominal downlink conditions, owing to the use of the CCSDS File Delivery Protocol (CFDP). Should downlink conditions be degraded such that PDU data packets are missed/lost, the MOC will identify missing PDU data packets, record the start and end bytes values in the Meta-file, and fill the missing bytes with zero values. This strategy will allow the SOC to reconstruct the majority of observations with missing data.

2.3.1. Data Processing Level

The EDR product contains individual NAC and WAC framelet images, and associated engineering data, corresponding to NASA processing Level 0 (CODMAC Level 2).

The CDR product contains individual NAC and WAC framelet images, and associated engineering data, corresponding to NASA processing Level 1a (CODMAC Level 3).

2.3.2. **Data Product Generation**

The processing pipeline can be run through multiple iterations to account for software updates that affect the output data, updates to SPICE information, or if the calibration of the instruments is updated or modified. In either case it is expected the data will be reprocessed as calibration files are updated.

All LRO data will be transmitted from the LRO Orbiter to the MOC. The MOC and Flight Dynamics Facility will generate LRO SPICE data files for distribution to the SOCs. LROC image files, as delivered from the MOC, are coupled with engineering data and other previously recorded information in the LROC operations database, to create an EDR product. Valid EDR files are then used as input to the process that performs additional processing to generate CDR files.

NAC raw image data (hereafter referred to as science files) consist of 8-bit companded pixels as read out from the camera. The image file is composed first of the even pixels from each line (with a 20 byte CTX heritage header every 1 MB; MB = 1024×1024 bytes) and padded to a 1 MB boundary, followed by the odd pixels in the same style. The EDR file generation process extracts the odd and even pixels, interleaving them to reconstruct original scan lines. If compression was enabled at image acquisition, the data stream is first de-compressed before the interleaving is performed. Information from the meta-file, housekeeping, and the SOC database are combined to generate the PDS label with the binary data to compose the EDR file.

NAC EDR files are calibrated using routines developed in the SOC and archived as Calibrated Data Records (CDR).

WAC science files consist of frames in row-major order with a 4 byte validity marker separating each frame. If compression was enabled at image acquisition, the data stream is first de-compressed before further processing is performed. Information from the meta-file, housekeeping, and the SOC database are combined to generate the PDS label that combined with the binary data to produce the EDR file.

WAC EDR files are calibrated using routines developed in the SOC and archived as CDRs.

2.3.3. Data Flow

Each NAC image file is uniquely named to distinguish between the two NACs (see Section 2.3.4). LROC WAC observations are stored as a series of framelets, with each framelet corresponding to one or more of the seven available bands on the detector. LROC observation and housekeeping files are downlinked through the Ka-band antenna at Whites Sands, N.M., then sent to LRO MOC at Goddard Space Flight Center (GSFC). Real-time telemetry is downlinked via S-band antenna at various locations and also transferred to the MOC. Once observation and housekeeping files are processed by the MOC, including identification of any missing data segments, the observation files and housekeeping files are transferred to the LROC

SOC at ASU via Secure Shell (SSH) file copy protocol. Real-time telemetry is streamed to the LROC SOC as it is received at the MOC (with no processing).

The MOC also sends to the LROC SOC numerous products generated by the GSFC Flight Dynamics group, including predictive and definitive NAIF SPICE kernels. Once all necessary files are received, observations can be ingested into product generation pipelines to produce EDR and CDR PDS products. The pipeline process includes validation of the EDR and CDR products compliance with PDS label and format standards.

At intervals specified in the LROC Data and Management Archive document [*Applicable Documents* 2], EDR and CDR products will be delivered to the PDS, which is the LROC Data Node (http://lroc.sese.asu.edu) hosted at ASU.

2.3.4. Labeling and Identification

LROC EDR and CDR products are identified by a unique name and each file has a header that records salient information regarding each product. Data product names follow the convention as defined in the LROC EDR Archive Volume SIS [*Applicable Documents* 3].

The product header (as described in section 3.2) contains information regarding the processing and generation of the product. Should products be reprocessed, the version number in the header section will be updated to reflect the new product.

2.4. Standards Used in Generating Data Products

2.4.1. PDS Standards

The LROC EDR data product complies with Planetary Data System standards for file formats and labels, as specified in the PDS Standards Reference [*Applicable Documents* 5].

2.4.2. Time Standards

LROC EDR and CDR products comply with Planetary Data Systems standards for time, as well as complying with the LRO project agreement on time stamping of data. This includes UTC and S-clock recorded observation times in EDR and CDR product labels.

The LRO spacecraft clock (SCLK) time stamp consists of three fields: P/SSSSSSSSSS:FFFFF. The P field represents the clock partition, the SSSSSSSSSS field represents the count of on-board seconds and the FFFFF field represents the count of fractions of a second with one fraction being 1/65536 of a second. Converting between SCLK and other time formats is performed using the MOC provided LRO SCLK kernel and NAIF SPICE toolkit.

2.4.3. Data Storage Conventions

All binary files are arranged with fixed-length records, stored in most-significant-byte-first (big-endian) format. In text files each record is terminated with a carriage return (ASCII code 13) followed by a line feed (ASCII code 10).

2.5. Data Validation

All LROC EDR and CDR products will be validated by the LROC SOC Team and the PDS Imaging Node for compliance with PDS archive standards [*Applicable Documents* 5].

3. Detailed Data Product Specifications

3.1. Data Product Structure and Organization

LROC data products are organized according to the directory structure defined in the LROC EDR Archive Volume SIS [*Applicable Documents* 3]. Data product names follow the convention defined in the LROC EDR Archive Volume SIS [*Applicable Documents* 3].

3.2. Data Format Descriptions

Final label content and format will be validated by PDS Engineering and Imaging Nodes. Resulting changes should of course be reflected within all label descriptions.

3.2.1. Example label for LROC NAC EDR product:

```
PDS_VERSION_ID                     = PDS3

/* FILE CHARACTERISTICS */
RECORD_TYPE                        = FIXED_LENGTH
RECORD_BYTES                       = 5064
FILE_RECORDS                       = 52225
LABEL_RECORDS                      = 1
^IMAGE                             = 2

/* DATA IDENTIFICATION */
DATA_SET_ID                        = "LRO-L-LROC-2-EDR-V1.0"
ORIGINAL_PRODUCT_ID                = nacl000017a9
PRODUCT_ID                         = M102658937LE
MISSION_NAME                       = "LUNAR RECONNAISSANCE ORBITER"
MISSION_PHASE_NAME                 = "COMMISSIONING"
INSTRUMENT_HOST_NAME               = "LUNAR RECONNAISSANCE ORBITER"
INSTRUMENT_HOST_ID                 = LRO
INSTRUMENT_NAME                    = "LUNAR RECONNAISSANCE ORBITER CAMERA"
INSTRUMENT_ID                      = LROC
LRO:PREROLL_TIME                   = 2009-07-19T16:07:49.362
START_TIME                         = 2009-07-19T16:07:50.004
STOP_TIME                          = 2009-07-19T16:08:22.787
LRO:SPACECRAFT_CLOCK_PREROLL_COUNT = “1/269712469:21626"
SPACECRAFT_CLOCK_START_COUNT       = "1/269712469:63752"
```

```
SPACECRAFT_CLOCK_STOP_COUNT         = "1/269712502:49514"
ORBIT_NUMBER                        = 302
PRODUCER_ID                         = LRO LROC TEAM
PRODUCT_CREATION_TIME               = 2009-12-05T11:55:45
PRODUCER_INSTITUTION_NAME           = "ARIZONA STATE UNIVERSITY"
PRODUCT_TYPE                        = EDR
PRODUCT_VERSION_ID                  = "v1.2"
UPLOAD_ID                           = "SC_2009200_0200_B_V03.txt"

/* DATA DESCRIPTION */
TARGET_NAME                         = "MOON"
CROSSTRACK_SUMMING                  = 1
RATIONALE_DESC                      = "TARGET OF OPPORTUNITY"
FRAME_ID                            = "LEFT"
DATA_QUALITY_ID                     = “0”
DATA_QUALITY_DESC                   = "The DATA_QUALITY_ID is set to an 8-bit
value th
at encodes the
   following data quality information for the observation. For each bit
   a value of 0 means FALSE and a value of 1 means TRUE. More
   information about the data quality ID can be found in the LROC
   EDR/CDR SIS, section 3.3 'Label and Header Descriptions'.
       Bit 1: Temperature of focal plane array is out of bounds.
       Bit 2: Threshold for saturated pixels is reached.
       Bit 3: Threshold for under-saturated pixels is reached.
       Bit 4: Observation is missing telemetry packets.
       Bit 5: SPICE information is bad or missing.
       Bit 6: Observation or housekeeping information is bad or missing.
       Bit 7: Spare.
       Bit 8: Spare."

/*ENVIRONMENT*/
LRO:TEMPERATURE_SCS                 = 1.99 <degC>
LRO:TEMPERATURE_FPA                 = 17.22 <degC>
LRO:TEMPERATURE_FPGA                = -13.87 <degC>
LRO:TEMPERATURE_TELESCOPE           = 6.12 <degC>
LRO:TEMPERATURE_SCS_RAW             = 2854
LRO:TEMPERATURE_FPA_RAW             = 2138
LRO:TEMPERATURE_FPGA_RAW            = 3468
LRO:TEMPERATURE_TELESCOPE_RAW       = 2665

/*IMAGING PARAMETERS*/
CROSSTRACK_SUMMING                  = 1
BANDWIDTH                           = 300 <nm>
CENTER_FILTER_WAVELENGTH            = 600 <nm>
LINE_EXPOSURE_DURATION              = 0.627733 <ms>
LRO:LINE_EXPOSURE_CODE              = 34
LRO:DAC_RESET_LEVEL                 = 198
LRO:CHANNEL_A_OFFSET                = 43
LRO:CHANNEL_B_OFFSET                = 108
LRO:COMPAND_CODE                    = 0
LRO:LINE_CODE                       = 51
LRO:BTERM                           = (0,8,25,59,128)
LRO:MTERM                           = (0.5,0.25,0.125,0.0625,0.03125)
```

```
LRO:XTERM                          = (0,32,136,543,2207)
LRO:COMPRESSION_FLAG               = 1
LRO:MODE                           = 7

/*DATA OBJECT*/
OBJECT                        = IMAGE
    LINES                          = 52224
    LINE_SAMPLES                   = 5064
    SAMPLE_BITS                    = 8
    SAMPLE_TYPE                    = LSB_INTEGER
    UNIT                           = "RAW_INSTRUMENT_COUNT"
    MD5_CHECKSUM                   = "780fb38e328c8df1bd6279645e98134a"
END_OBJECT
END
```

3.2.2. Example label for LROC NAC CDR product:

```
/* FILE CHARACTERISTICS */
RECORD_TYPE                        = FIXED_LENGTH
RECORD_BYTES                       = 5064
FILE_RECORDS                       = 52225
LABEL_RECORDS                      = 1
^IMAGE                             = 2

/* DATA IDENTIFICATION */
DATA_SET_ID                        = "LRO-L-LROC-3-CDR-V1.0"
ORIGINAL_PRODUCT_ID                = nacl000017a9
PRODUCT_ID                         = M102658937LC
MISSION_NAME                       = "LUNAR RECONNAISSANCE ORBITER"
MISSION_PHASE_NAME                 = "COMMISSIONING"
INSTRUMENT_HOST_NAME               = "LUNAR RECONNAISSANCE ORBITER"
INSTRUMENT_HOST_ID                 = LRO
INSTRUMENT_NAME                    = "LUNAR RECONNAISSANCE ORBITER CAMERA"
INSTRUMENT_ID                      = LROC
LRO:PREROLL_TIME                   = 2009-07-19T16:07:49.362
START_TIME                         = 2009-07-19T16:07:50.004
STOP_TIME                          = 2009-07-19T16:08:22.787
LRO:SPACECRAFT_CLOCK_PREROLL_COUNT = "1/269712469:21626"
SPACECRAFT_CLOCK_START_COUNT       = "1/269712469:63752"
SPACECRAFT_CLOCK_STOP_COUNT        = "1/269712502:49514"
ORBIT_NUMBER                       = 302
PRODUCER_ID                        = LRO LROC TEAM
PRODUCT_CREATION_TIME              = 2009-12-05T11:55:45
PRODUCER_INSTITUTION_NAME          = "ARIZONA STATE UNIVERSITY"
PRODUCT_TYPE                       = CDR
PRODUCT_VERSION_ID                 = "v1.1"
UPLOAD_ID                          = "SC_2009200_0200_B_V03.txt"

/* DATA DESCRIPTION */
TARGET_NAME                        = "MOON"
CROSSTRACK_SUMMING                 = 1
RATIONALE_DESC                     = "TARGET OF OPPORTUNITY"
```

```
FRAME_ID                            = "LEFT"
DATA_QUALITY_ID                     = “0”
DATA_QUALITY_DESC                   = "The DATA_QUALITY_ID is set to an 8-bit
value th
at encodes the
   following data quality information for the observation. For each bit
   a value of 0 means FALSE and a value of 1 means TRUE. More
   information about the data quality ID can be found in the LROC
   EDR/CDR SIS, section 3.3 'Label and Header Descriptions'.
       Bit 1: Temperature of focal plane array is out of bounds.
       Bit 2: Threshold for saturated pixels is reached.
       Bit 3: Threshold for under-saturated pixels is reached.
       Bit 4: Observation is missing telemetry packets.
       Bit 5: SPICE information is bad or missing.
       Bit 6: Observation or housekeeping information is bad or missing.
       Bit 7: Spare.
       Bit 8: Spare."

/*ENVIRONMENT*/
LRO:TEMPERATURE_SCS                 = 1.99 <degC>
LRO:TEMPERATURE_FPA                 = 17.22 <degC>
LRO:TEMPERATURE_FPGA                = -13.87 <degC>
LRO:TEMPERATURE_TELESCOPE           = 6.12 <degC>
LRO:TEMPERATURE_SCS_RAW             = 2854
LRO:TEMPERATURE_FPA_RAW             = 2138
LRO:TEMPERATURE_FPGA_RAW            = 3468
LRO:TEMPERATURE_TELESCOPE_RAW       = 2665

/*IMAGING PARAMETERS*/
CROSSTRACK_SUMMING                  = 1
BANDWIDTH                           = 300 <nm>
CENTER_FILTER_WAVELENGTH            = 600 <nm>
LINE_EXPOSURE_DURATION              = 0.627733 <ms>
LRO:LINE_EXPOSURE_CODE              = 34
LRO:DAC_RESET_LEVEL                 = 198
LRO:CHANNEL_A_OFFSET                = 43
LRO:CHANNEL_B_OFFSET                = 108
LRO:COMPAND_CODE                    = 0
LRO:LINE_CODE                       = 51
LRO:BTERM                           = (0,8,25,59,128)
LRO:MTERM                           = (0.5,0.25,0.125,0.0625,0.03125)
LRO:XTERM                           = (0,32,136,543,2207)
LRO:COMPRESSION_FLAG                = 1
LRO:MODE                            = 7

/* DATA OBJECT */
OBJECT                              = IMAGE
  LINES                             = 52224
  LINE_SAMPLES                      = 5064
  SAMPLE_BITS                       = 16
  SAMPLE_TYPE                       = LSB_INTEGER
  SCALING_FACTOR                    = 32767
  VALID_MINIMUM                     = -32752
  NULL                              = -32768
```

```
  LOW_REPR_SATURATION              = -32767
  LOW_INSTR_SATURATION             = -32766
  HIGH_INSTR_SATURATION            = -32765
  HIGH_REPR_SATURATION             = -32764
  UNIT                             = "Scaled I/F"
  MD5_CHECKSUM                     = "5ae7138e328c8df1bd6279645e982f44"
END_OBJECT
END
```

3.2.3. Example label for LROC WAC EDR product:

```
PDS_VERSION_ID                 = PDS3

/*FILE CHARACTERISTICS*/
RECORD_TYPE                    = FIXED_LENGTH
RECORD_BYTES                   = 704
FILE_RECORDS                   = 19276
LABEL_RECORDS                  = 10
^IMAGE                         = 11

/*DATA IDENTIFICATION*/
DATA_SET_ID                    = "LRO-L-LROC-2-EDR-V1.0"
ORIGINAL_PRODUCT_ID            = wac000017b9
PRODUCT_ID                     = M102686980CE
MISSION_NAME                   = "LUNAR RECONNAISSANCE ORBITER"
MISSION_PHASE_NAME             = "COMMISSIONING"
INSTRUMENT_HOST_NAME           = "LUNAR RECONNAISSANCE ORBITER"
INSTRUMENT_HOST_ID             = LRO
INSTRUMENT_NAME                = "LUNAR RECONNAISSANCE ORBITER CAMERA"
INSTRUMENT_ID                  = LROC
START_TIME                     = 2009-07-19T23:55:12.604
STOP_TIME                      = 2009-07-20T00:02:05.557
SPACECRAFT_CLOCK_START_COUNT   = "1/269740512:37355"
SPACECRAFT_CLOCK_STOP_COUNT    = "1/269740925:34283"
ORBIT_NUMBER                   = 306
PRODUCT_CREATION_TIME          = 2009-12-05T12:22:21
PRODUCER_ID                    = LRO_LROC_TEAM
PRODUCER_INSTITUTION_NAME      = "ARIZONA STATE UNIVERSITY"
PRODUCT_TYPE                   = EDR
PRODUCT_VERSION_ID             = "v1.2"
UPLOAD_ID                      = "SC_2009200_0200_B_V03.txt"

/*DATA DESCRIPTION*/
TARGET_NAME                    = "MOON"
RATIONALE_DESC                 = "GLOBAL COVERAGE"
DATA_QUALITY_ID                = "0"
DATA_QUALITY_DESC                  = "The DATA_QUALITY_ID is set to an 8-bit
value that e
ncodes the
   following data quality information for the observation. For each bit
   a value of 0 means FALSE and a value of 1 means TRUE. More
   information about the data quality ID can be found in the LROC
```

```
   EDR/CDR SIS, section 3.3 'Label and Header Descriptions'.
       Bit 1: Temperature of focal plane array is out of bounds.
       Bit 2: Threshold for saturated pixels is reached.
       Bit 3: Threshold for under-saturated pixels is reached.
       Bit 4: Observation is missing telemetry packets.
       Bit 5: SPICE information is bad or missing.
       Bit 6: Observation or housekeeping information is bad or missing.
       Bit 7: Spare.
       Bit 8: Spare."

/*ENVIRONMENT*/
LRO:BEGIN_TEMPERATURE_SCS      = 2.11 <degC>
LRO:MIDDLE_TEMPERATURE_SCS     = 2.01 <degC>
LRO:END_TEMPERATURE_SCS        = 2.08 <degC>
LRO:BEGIN_TEMPERATURE_FPA      = -23.43 <degC>
LRO:MIDDLE_TEMPERATURE_FPA     = -23.15 <degC>
LRO:END_TEMPERATURE_FPA        = -22.80 <degC>
LRO:BEGIN_TEMPERATURE_SCS_RAW  = 2850
LRO:MIDDLE_TEMPERATURE_SCS_RAW = 2853
LRO:END_TEMPERATURE_SCS_RAW    = 2850
LRO:BEGIN_TEMPERATURE_FPA_RAW  = 3727
LRO:MIDDLE_TEMPERATURE_FPA_RAW = 3719
LRO:END_TEMPERATURE_FPA_RAW    = 3711

/*IMAGING PARAMETERS*/
EXPOSURE_DURATION              = 50.0 <ms>
LRO:EXPOSURE_CODE              = 500
INTERFRAME_DELAY               = 1671.875 <ms>
INSTRUMENT_MODE_ID             = "COLOR"
FILTER_NUMBER                  = ("1", "2", "3", "4", "5", "6", "7")
CENTER_FILTER_WAVELENGTH       = (321 <nm>, 360 <nm>, 415 <nm>, 566 <nm>, 604
<nm>, 643 <nm>, 689 <nm>)
BANDWIDTH                      = (32 <nm>, 15 <nm>, 36 <nm>, 20 <nm>, 20 <nm>,
23 <nm>, 39 <nm>)
LRO:LOOKUP_TABLE_TYPE          = STORED
LRO:LOOKUP_CONVERSION_TABLE                   =     ((0,1),(2,2),(3,3),(-9998,-
9998),(4,4),(5,5),(-9998,
9998),(6,6),(7,7),(8,8),(9,9),(10,10),(11,11),(12,13),(14,14),(15,15),(16,17)
,(18,18),(19,19),(20,21),(22,23),(24,24),(25,26),(27,28),(29,30),(31,32),(33,
33),(34,36),(37,38),(39,40),(41,42),(43,44),(45,47),(48,49),(50,51),(52,54),(
55,56),(57,59),(60,62),(63,64),(65,67),(68,70),(71,73),(74,76),(77,79),(80,82
),(83,85),(86,88),(89,92),(93,95),(96,98),(99,102),(103,105),(106,109),(110,1
13),(114,116),(117,120),(121,124),(125,128),(129,132),(133,136),(137,140),(14
1,144),(145,148),(149,152),(153,156),(157,161),(162,165),(166,170),(171,174),
(175,179),(180,183),(184,188),(189,193),(194,198),(199,203),(204,208),(209,21
3),(214,218),(219,223),(224,228),(229,233),(234,238),(239,244),(245,249),(250
,255),(256,260),(261,266),(267,271),(272,277),(278,283),(284,289),(290,295),(
296,301),(302,307),(308,313),(314,319),(320,325),(326,331),(332,337),(338,344
),(345,350),(351,357),(358,363),(364,370),(371,376),(377,383),(384,390),(391,
397),(398,404),(405,411),(412,418),(419,425),(426,432),(433,439),(440,446),(4
47,454),(455,461),(462,468),(469,476),(477,483),(484,491),(492,499),(500,506)
,(507,514),(515,522),(523,530),(531,538),(539,546),(547,554),(555,562),(563,5
70),(571,579),(580,587),(588,595),(596,604),(605,612),(613,621),(622,630),(63
1,638),(639,647),(648,656),(657,665),(666,674),(675,683),(684,692),(693,701),
```

```
(702,710),(711,719),(720,728),(729,738),(739,747),(748,756),(757,766),(767,77
6),(777,785),(786,795),(796,805),(806,814),(815,824),(825,834),(835,844),(845
,854),(855,864),(865,874),(875,885),(886,895),(896,905),(906,916),(917,926),(
927,937),(938,947),(948,958),(959,969),(970,979),(980,990),(991,1001),(1002,1
012),(1013,1023),(1024,1034),(1035,1045),(1046,1056),(1057,1068),(1069,1079),
(1080,1090),(1091,1102),(1103,1113),(1114,1125),(1126,1136),(1137,1148),(1149
,1160),(1161,1171),(1172,1183),(1184,1195),(1196,1207),(1208,1219),(1220,1231
),(1232,1243),(1244,1255),(1256,1268),(1269,1280),(1281,1292),(1293,1305),(13
06,1317),(1318,1330),(1331,1342),(1343,1355),(1356,1368),(1369,1380),(1381,13
93),(1394,1406),(1407,1419),(1420,1432),(1433,1445),(1446,1458),(1459,1472),(
1473,1485),(1486,1498),(1499,1512),(1513,1525),(1526,1538),(1539,1552),(1553,
1566),(1567,1579),(1580,1593),(1594,1607),(1608,1621),(1622,1635),(1636,1648)
,(1649,1663),(1664,1677),(1678,1691),(1692,1705),(1706,1719),(1720,1734),(173
5,1748),(1749,1762),(1763,1777),(1778,1791),(1792,1806),(1807,1821),(1822,183
5),(1836,1850),(1851,1865),(1866,1880),(1881,1895),(1896,1910),(1911,1925),(1
926,1940),(1941,1955),(1956,1971),(1972,1986),(1987,2001),(2002,2017),(2018,2
032),(2033,2047))
LRO:COMPRESSION_FLAG          = 0
LRO:MODE                      = 0
LRO:NFRAMES                   = 247
LRO:BAND_CODE                 = 127
LRO:INTERFRAME_GAP_CODE       = 82
LRO:COMPAND_CODE              = 0
LRO:BACKGROUND_OFFSET         = 56

/* DATA OBJECT */
OBJECT                       = IMAGE
LINES                     = 19266
    LINE_SAMPLES              = 704
    SAMPLE_BITS               = 8
    SAMPLE_TYPE               = LSB_INTEGER
    UNIT                      = "RAW_INSTRUMENT_COUNT"
    MD5_CHECKSUM              = "dee3088477b54635963ae2518a4bdf1e"
END_OBJECT
END
```

3.2.4. Example label for LROC WAC CDR product:

```
PDS_VERSION_ID               = PDS3

/* FILE CHARACTERISTICS */
RECORD_TYPE                   = FIXED_LENGTH
RECORD_BYTES                  = 704
FILE_RECORDS                  = 19276
LABEL_RECORDS                 = 10
^IMAGE                        = 11

/*DATA IDENTIFICATION*/
DATA_SET_ID                   = "LRO-L-LROC-3-CDR-V1.0"
ORIGINAL_PRODUCT_ID           = wac000017b9
PRODUCT_ID                    = M102686980CC
MISSION_NAME                  = "LUNAR RECONNAISSANCE ORBITER"
```

```
MISSION_PHASE_NAME               = "COMMISSIONING"
INSTRUMENT_HOST_NAME             = "LUNAR RECONNAISSANCE ORBITER"
INSTRUMENT_HOST_ID               = LRO
INSTRUMENT_NAME                  = "LUNAR RECONNAISSANCE ORBITER CAMERA"
INSTRUMENT_ID                    = LROC
START_TIME                       = 2009-07-19T23:55:12.604
STOP_TIME                        = 2009-07-20T00:02:05.557
SPACECRAFT_CLOCK_START_COUNT     = "1/269740512:37355"
SPACECRAFT_CLOCK_STOP_COUNT      = "1/269740925:34283"
ORBIT_NUMBER                     = 306
PRODUCT_CREATION_TIME            = 2009-12-05T12:22:21
PRODUCER_ID                      = LRO_LROC_TEAM
PRODUCER_INSTITUTION_NAME        = "ARIZONA STATE UNIVERSITY"
PRODUCT_TYPE                     = CDR
PRODUCT_VERSION_ID               = "v1.1"
UPLOAD_ID                        = "SC_2009200_0200_B_V03.txt"

/*DATA DESCRIPTION*/
TARGET_NAME                      = "MOON"
RATIONALE_DESC                   = "GLOBAL COVERAGE"
DATA_QUALITY_ID                  = "0"
DATA_QUALITY_DESC               = "The DATA_QUALITY_ID is set to an 8-bit value
that encodes the
   following data quality information for the observation. For each bit
   a value of 0 means FALSE and a value of 1 means TRUE. More
   information about the data quality ID can be found in the LROC
   EDR/CDR SIS, section 3.3 'Label and Header Descriptions'.
       Bit 1: Temperature of focal plane array is out of bounds.
       Bit 2: Threshold for saturated pixels is reached.
       Bit 3: Threshold for under-saturated pixels is reached.
       Bit 4: Observation is missing telemetry packets.
       Bit 5: SPICE information is bad or missing.
       Bit 6: Observation or housekeeping information is bad or missing.
       Bit 7: Spare.
       Bit 8: Spare."

/*ENVIRONMENT*/
LRO:BEGIN_TEMPERATURE_SCS        = 2.11 <degC>
LRO:MIDDLE_TEMPERATURE_SCS       = 2.01 <degC>
LRO:END_TEMPERATURE_SCS          = 2.08 <degC>
LRO:BEGIN_TEMPERATURE_FPA        = -23.43 <degC>
LRO:MIDDLE_TEMPERATURE_FPA       = -23.15 <degC>
LRO:END_TEMPERATURE_FPA          = -22.80 <degC>
LRO:BEGIN_TEMPERATURE_SCS_RAW    = 2850
LRO:MIDDLE_TEMPERATURE_SCS_RAW   = 2853
LRO:END_TEMPERATURE_SCS_RAW      = 2850
LRO:BEGIN_TEMPERATURE_FPA_RAW    = 3727
LRO:MIDDLE_TEMPERATURE_FPA_RAW   = 3719
LRO:END_TEMPERATURE_FPA_RAW      = 3711

/*IMAGING PARAMETERS*/
EXPOSURE_DURATION                = 50.0 <ms>
LRO:EXPOSURE_CODE                = 500
INTERFRAME_DELAY                 = 1671.875 <ms>
```

```
INSTRUMENT_MODE_ID               = "COLOR"
FILTER_NUMBER                    = ("1", "2", "3", "4", "5", "6", "7")
CENTER_FILTER_WAVELENGTH         = (321 <nm>, 360 <nm>, 415 <nm>, 566 <nm>, 604
<nm>, 643 <nm>, 689 <nm>)
BANDWIDTH                        = (32 <nm>, 15 <nm>, 36 <nm>, 20 <nm>, 20 <nm>,
23 <nm>, 39 <nm>)
LRO:LOOKUP_TABLE_TYPE            = STORED
LRO:LOOKUP_CONVERSION_TABLE                   =    ((0,1),(2,2),(3,3),(-9998,-
9998),(4,4),(5,5),(-9998,-
9998),(6,6),(7,7),(8,8),(9,9),(10,10),(11,11),(12,13),(14,14),(15,15),(16,17)
,(18,18),(19,19),(20,21),(22,23),(24,24),(25,26),(27,28),(29,30),(31,32),(33,
33),(34,36),(37,38),(39,40),(41,42),(43,44),(45,47),(48,49),(50,51),(52,54),(
55,56),(57,59),(60,62),(63,64),(65,67),(68,70),(71,73),(74,76),(77,79),(80,82
),(83,85),(86,88),(89,92),(93,95),(96,98),(99,102),(103,105),(106,109),(110,1
13),(114,116),(117,120),(121,124),(125,128),(129,132),(133,136),(137,140),(14
1,144),(145,148),(149,152),(153,156),(157,161),(162,165),(166,170),(171,174),
(175,179),(180,183),(184,188),(189,193),(194,198),(199,203),(204,208),(209,21
3),(214,218),(219,223),(224,228),(229,233),(234,238),(239,244),(245,249),(250
,255),(256,260),(261,266),(267,271),(272,277),(278,283),(284,289),(290,295),(
296,301),(302,307),(308,313),(314,319),(320,325),(326,331),(332,337),(338,344
),(345,350),(351,357),(358,363),(364,370),(371,376),(377,383),(384,390),(391,
397),(398,404),(405,411),(412,418),(419,425),(426,432),(433,439),(440,446),(4
47,454),(455,461),(462,468),(469,476),(477,483),(484,491),(492,499),(500,506)
,(507,514),(515,522),(523,530),(531,538),(539,546),(547,554),(555,562),(563,5
70),(571,579),(580,587),(588,595),(596,604),(605,612),(613,621),(622,630),(63
1,638),(639,647),(648,656),(657,665),(666,674),(675,683),(684,692),(693,701),
(702,710),(711,719),(720,728),(729,738),(739,747),(748,756),(757,766),(767,77
6),(777,785),(786,795),(796,805),(806,814),(815,824),(825,834),(835,844),(845
,854),(855,864),(865,874),(875,885),(886,895),(896,905),(906,916),(917,926),(
927,937),(938,947),(948,958),(959,969),(970,979),(980,990),(991,1001),(1002,1
012),(1013,1023),(1024,1034),(1035,1045),(1046,1056),(1057,1068),(1069,1079),
(1080,1090),(1091,1102),(1103,1113),(1114,1125),(1126,1136),(1137,1148),(1149
,1160),(1161,1171),(1172,1183),(1184,1195),(1196,1207),(1208,1219),(1220,1231
),(1232,1243),(1244,1255),(1256,1268),(1269,1280),(1281,1292),(1293,1305),(13
06,1317),(1318,1330),(1331,1342),(1343,1355),(1356,1368),(1369,1380),(1381,13
93),(1394,1406),(1407,1419),(1420,1432),(1433,1445),(1446,1458),(1459,1472),(
1473,1485),(1486,1498),(1499,1512),(1513,1525),(1526,1538),(1539,1552),(1553,
1566),(1567,1579),(1580,1593),(1594,1607),(1608,1621),(1622,1635),(1636,1648)
,(1649,1663),(1664,1677),(1678,1691),(1692,1705),(1706,1719),(1720,1734),(173
5,1748),(1749,1762),(1763,1777),(1778,1791),(1792,1806),(1807,1821),(1822,183
5),(1836,1850),(1851,1865),(1866,1880),(1881,1895),(1896,1910),(1911,1925),(1
926,1940),(1941,1955),(1956,1971),(1972,1986),(1987,2001),(2002,2017),(2018,2
032),(2033,2047))
LRO:COMPRESSION_FLAG             = 0
LRO:MODE                         = 0
LRO:NFRAMES                      = 247
LRO:BAND_CODE                    = 127
LRO:INTERFRAME_GAP_CODE          = 82
LRO:COMPAND_CODE                 = 0
LRO:BACKGROUND_OFFSET            = 56

/* DATA OBJECT */
OBJECT                          = IMAGE
  LINES                         = 10452
```

```
  LINE_SAMPLES                  = 704
  SAMPLE_BITS                   = 32
  SAMPLE_TYPE                   = PC_REAL
  VALID_MINIMUM                 = 16#FF7FFFFA#
  NULL                          = 16#FF7FFFFB#
  LOW_REPR_SATURATION           = 16#FF7FFFFC#
  LOW_INSTR_SATURATION          = 16#FF7FFFFD#
  HIGH_INSTR_SATURATION         = 16#FF7FFFFE#
  HIGH_REPR_SATURATION          = 16#FF7FFFFF#
  UNIT                          = "W / (m**2 micrometer sr)"
  MD5_CHECKSUM                  = "3c234ada4401c044edde0190c1211fe2"
END_OBJECT

END
```

3.3. Label and Header Descriptions

PDS_VERSION_ID
: The PDS version number for the header format; always PDS3.

RECORD_TYPE
: The record type for this file; always FIXED_LENGTH.

RECORD_BYTES
: The number of bytes per record.

FILE_RECORDS
: The total number of records in this file.

LABEL_RECORDS
: The total number of records used for the header data.

^IMAGE
: A pointer to the starting record of the image object.

DATA_SET_ID
: For EDR products, set to "LRO-L-LROC-2-EDR-V1.1". For CDR products, set to "LRO-L-LROC-3-CDR-V1.1".

ORIGINAL_PRODUCT_ID
: Filename of this image as received from the LRO MOC. For NAC observations, the filename is either *nacl00000000* or *nacr00000000* (NAC-LEFT or NAC-RIGHT respectively). For WAC observations, the filename is *wac00000000*.

PRODUCT_ID
: Unique identifier for this LROC NAC and WAC EDR/CDR product. Example [TARGET][MET][INSTRUMENT][PRODUCT] where [TARGET] is a single character denoting the observation target [(M)oon, (E)arth, (C)alibration or (S)tar, [MET] is a nine digit number reflecting the MET of acquisition (with a single digit for partition), [INSTRUMENT] is a single character denoting the instrument [(R)ight NAC, (L)eft NAC, (M)onochrome WAC, (C)olor WAC, (U)V only WAC, (V)isible only WAC, and [PRODUCT] is a single character denoting an (E)DR product or (C)DR product.

MISSION_NAME
: Always "LUNAR RECONNAISSANCE ORBITER".

MISSION_PHASE_NAME

Name of the mission phase; "COMMISSIONING", "NOMINAL MISSION" or "EXTENDED MISSION".

INSTRUMENT_HOST_NAME
: Always "LUNAR RECONNAISSANCE ORBITER".

INSTRUMENT_HOST_ID
: Always LRO.

INSTRUMENT_NAME
: Always "LUNAR RECONNAISSANCE ORBITER CAMERA".

INSTRUMENT_ID
: Always LROC.

LRO:PREROLL_TIME
: The UTC time and date at the start of the image acquisition command, corresponding to the acquisition of 1024 lines at the given exposure prior to the actual image acquisition.

START_TIME
: The UTC time and date at the start of the image acquisition.

STOP_TIME
: The UTC time and date at the end of the image acquisition.

LRO:SPACECRAFT_CLOCK_PREROLL_COUNT
: Set to the sclk string for the start of an observation preroll acquisition.

SPACECRAFT_CLOCK_START_COUNT
: Set to the sclk string for the start of an observation.

SPACECRAFT_CLOCK_STOP_COUNT
: Set to the sclk string for the stop of an observation.

ORBIT_NUMBER
: Set to the LRO orbit revolution on which this image was acquired.

PRODUCT_CREATION_TIME
: Set to time and date for the creation of this PDS product file, in the form of CCYY-MM-DDThh:mm:ss.sss.

PRODUCER_ID
: Always set to LRO LROC TEAM.

PRODUCER_INSTITUTION_NAME
: Always set to "ARIZONA STATE UNIVERSITY".

PRODUCT_TYPE
: What kind of PDS product this file represents. Can be either EDR or CDR.

PRODUCT_VERSION_ID
: The product version of this file, currently “v1.2” for EDR and “v1.0” for CDR.

UPLOAD_ID
: The string identifier for the ATS command report which corresponds to the ATS command load used to acquire this image.

TARGET_NAME
: Set to the target body: “MOON” for any nominal lunar imaging, “EARTH” for any observations of the Earth, “CAL” for any non-STAR calibration images, and “STAR“ for star calibration images.

RATIONALE_DESC
: For NAC observations, set to one of the following: the keywords recorded in the REACT ROI, the appropriate NAC campaign, or set to the string “TARGET OF

OPPORTUNITY". For WAC observations, set to either the appropriate campaign or "GLOBAL_COVERAGE".

FRAME_ID

For NAC, records if the image was acquired from the "LEFT" or "RIGHT" NAC.

DATA_QUALITY_ID

Set to an 8-bit value that encodes data quality information for the observation.

DATA_QUALITY_DESC

The DATA_QUALITY_ID is set to an 8-bit value that encodes the following data quality information for the observation. For each bit a value of 0 means FALSE and a value of 1 means TRUE.

Bit 1: Temperature of focal plane array is out of bounds. Bit 1 is set to a value of 1 if temperature data is present and in not in the range -50C to +45C.

Bit 2: Threshold for saturated pixels is reached. Bit 2 is set to a value of 1 if count of DNs 250 or over exceeds 0.1% of all DN values.

Bit 3: Threshold for under-saturated pixels is reached. Bit 3 is set to a value of 1 if count of DNs 5 or under exceeds 0.1% of all DN values.

Bit 4: Observation is missing telemetry packets. Bit 4 is set to a value of 1 if the actual observation file (science file) is missing bits as recorded in the science META file.

Bit 5: SPICE information is bad or missing. Bit 5 is set to a value of 1 if the defintive NAIF SPK or CK covering the observation acquisition time is missing or incorrect.

Bit 6: Observation or housekeeping information is bad or missing. Bit 6 is set to a value of 1 if the observation header or it's housekeeping (APID 138) information is incorrect or missing.

Bit 7: Spare.

Bit 8: Spare.

LRO:TEMPERATURE_SCS

Set to the temperature of the LROC SCS in degrees Celsius, as converted from the raw engineering counts.

LRO:TEMPERATURE_FPA

Set to the temperature of the LROC FPA in degrees Celsius, as converted from the raw engineering counts.

LRO:TEMPERATURE_FPGA

Set to the temperature of the LROC FPGA in degrees Celsius, as converted from the raw engineering counts.

LRO:TEMPERATURE_TELESCOPE

Set to the temperature of the LROC telescope corresponding to NAC-L or NAC-R, as converted from the raw engineering counts.

LRO:TEMPERATURE_SCS_RAW

Set to the raw engineering counts for the LROC SCS.

LRO:TEMPERATURE_FPA_RAW

Set to the raw engineering counts for the LROC (F)ocal (P)lane (A)rray.

LRO:TEMPERATURE_FPGA_RAW

Set to the raw engineering counts for the LROC (F)ield (P)rogrammable (G)ate (A)rray.

LRO:TEMPERATURE_TELESCOPE_RAW

Set to the raw engineering counts for the LROC Telescope corresponding to NAC-L or NAC-R.

LRO:BEGIN_TEMPERATURE_SCS
: Set to the temperature of the LROC SCS in degrees Celsius, as converted from the raw engineering counts, at the beginning of a series of WAC frames.

LRO:MIDDLE_TEMPERATURE_SCS
: Set to the temperature of the LROC SCS in degrees Celsius, as converted from the raw engineering counts, at the middle of a series of WAC frames.

LRO:END_TEMPERATURE_SCS
: Set to the temperature of the LROC SCS in degrees Celsius, as converted from the raw engineering counts, at the end of a series of WAC frames.

LRO:BEGIN_TEMPERATURE_FPA
: Set to the temperature of the LROC FPA in degrees Celsius, as converted from the raw engineering counts, at the beginning of a series of WAC frames.

LRO:MIDDLE_TEMPERATURE_FPA
: Set to the temperature of the LROC FPA in degrees Celsius, as converted from the raw engineering counts, at the middle of a series of WAC frames.

LRO:END_TEMPERATURE_FPA
: Set to the temperature of the LROC FPA in degrees Celsius, as converted from the raw engineering counts, at the end of a series of WAC frames.

LRO:BEGIN_TEMPERATURE_SCS_RAW
: Set to the raw engineering counts for the LROC SCS at the beginning of a series of WAC frames.

LRO:MIDDLE_TEMPERATURE_SCS_RAW
: Set to the raw engineering counts for the LROC SCS at the middle of a series of WAC frames.

LRO:END_TEMPERATURE_SCS_RAW
: Set to the raw engineering counts for the LROC SCS at the end of a series of WAC frames.

LRO:BEGIN_TEMPERATURE_FPA_RAW
: Set to the raw engineering counts for the LROC (F)ocal (P)lane (A)rray at the beginning of a series of WAC frames.

LRO:MIDDLE_TEMPERATURE_FPA_RAW
: Set to the raw engineering counts for the LROC (F)ocal (P)lane (A)rray at the middle of a series of WAC frames.

LRO:END_TEMPERATURE_FPA_RAW
: Set to the raw engineering counts for the LROC (F)ocal (P)lane (A)rray at the end of a series of WAC frames.

CROSSTRACK_SUMMING
: Indicates if NAC observation was taken with crosstrack summing (2) or no crosstrack summing (1). Keyword only applies to NAC products.

BANDWIDTH
: Set to the bandwidth value, in nanometers, for both NAC and WAC observations. For NACs the value is 300nm, for WAC it can be a combination of the following: 32, 15, 36, 20, 20, 23, 39, dependent on which UV and/or Vis bands were acquired.

CENTER_FILTER_WAVELENGTH

Set to the center filter wavelength, in nanometers, for both NAC and WAC observations. For NACs the value is 600nm. For WAC it can be a combination of the following: 321, 360, 415, 566, 604, 643, 689, dependent on which UV and/or Vis bands were acquired.

LINE_EXPOSURE_DURATION

For NAC products, LINE_EXPOSURE_DURATION can have values between 337.6 and 35,281.6 microseconds, in 128/15 microsecond increments (LINE_EXPOSURE_DURATION = [LINE_EXPOSURE_CODE * 128/15] + 337.6).

LRO:LINE_EXPOSURE_CODE

Index range from 0 to 4095 each corresponding to one LINE_EXPOSURE_DURATION increment.

LRO:DAC_RESET_LEVEL

Records the commanded DAC reset level for either the NAC LEFT or NAC RIGHT.

LRO:CHANNEL_A_OFFSET

Records the commanded NAC channel A offset for either the NAC LEFT or NAC RIGHT.

LRO:CHANNEL_B_OFFSET

Records the commanded NAC channel B offset for either the NAC LEFT or NAC RIGHT.

LRO:COMPAND CODE

Indicates which stored companding table was used (0-7) (see Appendix B).

LRO:LINE CODE

Records the commanded value for the number of NAC lines to acquire, in 1024 increments (LINES = LINES_CODE * 1024)

LRO:BTERM

NAC companding bterms (see Appendix B)

LRO:MTERM

NAC companding mterm (see Appendix B)

LRO:XTERM

NAC companding xterms (see Appendix B)

LRO:COMPRESSION_FLAG:

Indicates if lossless compression was commanded (0=no, 1=yes)

LRO:MODE

Set to the mode value as commanded for both NAC and WAC observations.

EXPOSURE_DURATION

For WAC products, LINE_EXPOSURE_DURATION can have values between 0 and 6.5535 seconds, in 100 microsecond incremenets.

LRO:EXPOSURE_CODE

Records the commanded exposure code for a WAC observation.

INTERFRAME_DELAY

Set to the value of the interframe delay between WAC framelets. Keyword can have values between 25/64 and 280/64 seconds, in 1/64 seconds increments.

INSTRUMENT_MODE_ID

Records the commanded WAC mode: BW, COLOR, VIS or UV.

FILTER_NUMBER

Records the WAC filter numbers taken during an observation, which corresponds to the INSTRUMENT_MODE_ID: (4) or (5) or (1,2,3,4,5,6,7) or (1,2,3,4,5) or (6,7). Filter (4) is optimal BW band, with filter (5) as an alternate.

LRO:LOOKUP_TABLE_TYPE

Always set to STORED.

LRO:LOOKUP_CONVERSION_TABLE

The table defines the onboard translation from 11-bit to 8-bit pixels. There are 2048 pairs of values in the table. The first pair in the table corresponds to the range of 11-bit pixels that map to 0 DN value of the output 8-bit pixel. Subsequent pairs correspond to incremental output DN values. Table is included in CDR products for completeness, de-companding has already occurred during the generation of the CDR. Example:

LRO:LOOKUP_CONVERSION_TABLE= ((0,1), (2,3), (4,5),...)

Input pixel values 0-1 were mapped to output DN value 0, 2-3 mapped to DN value 1, 4-5 mapped to DN 2, etc.)

LRO:NFRAMES

Records the commanded number of frames for a WAC observation.

LRO:BAND_CODE

Records the commanded band code for a WAC observation.

LRO:INTERFRAME_GAP_CODE

Records the commanded interframe gap code for a WAC observation.

LINES

Set to the number of lines captured by the observation.

LINE_SAMPLES

Set to the number of samples in a line.

SAMPLE_BITS

Set to 8-bit for NAC or WAC EDR products. Set to 16-bit for NAC CDR products with I/F units. Set to 32-bit for NAC CDR products with RADIANCE units and all WAC CDR products.

SAMPLE_TYPE

Set to LSB_INTEGER for EDR products and NAC CDR products with I/F units. Set to PC_REAL for NAC CDR products with RADIANCE units and any WAC CDR product.

VALID_MINIMUM

Set to the value denoting the valid minimum within the image.

NULL

Set to the value denoting "no data" or "absence of data" in the image.

LOW_REPR_SATURATION

Set to the value denoting the low representation saturation within the image.

LOW_INSTR_SATURATION

Set to the value denoting the low instrument saturation within the image.

HIGH_INSTR_SATURATION

Set to the value denoting the high instrument saturation within the image.

HIGH_REPR_SATURATION

Set to the value denoting the high representation saturation within the image.

UNIT

Unit of measurement represented by pixel values (digital number or DN). NAC and WAC EDR files have a value of "RAW INSTRUMENT COUNT" for this keyword. NAC CDR files can have a value of Scaled I/F (a 2 byte integer) or radiance (W / (m**2 micrometer sr) (a 4 byte real). WAC CDR files can have a value of I/F or radiance (a 4 byte real).

MD5_CHECKSUM

The calculated MD5 checksum for the data stream, as a 32 character string value.

Appendix A – Glossary

Archive – An archive consists of one or more data sets along with all the documentation and ancillary information needed to understand and use the data. An archive is a logical construct independent of the medium on which it is stored.

Archive Volume, Archive Volume Set – A volume is a unit of media on which data products are stored; for example, one CD-ROM or DVD-ROM. An *archive volume* is a volume containing all or part of an archive; that is, data products plus documentation and ancillary files. When an archive spans multiple volumes, they are called an *archive volume set*. Usually the documentation and some ancillary files are repeated on each volume of the set, so that a single volume can be used alone. The LROC EDR Archive will be stored, distributed, and archived solely on computer disk for the foreseeable future (there will be no formal hard-copy archive such as CD-ROM or DVD-ROM).

Catalog Information – Descriptive information about a data set (e.g. mission description, spacecraft description, instrument description), expressed in Object Description Language (ODL) that is suitable for loading into a PDS catalog.

Companding – A method for mitigating the detrimental effects of a channel with limited dynamic range. The use of companding allows signals with a large dynamic range to be transmitted over facilities that have a smaller dynamic range capability.

Data Product – A labeled grouping of data resulting from a scientific observation, usually stored in one file. A product label identifies, describes, and defines the structure of the data. An example of a data product is a planetary image, a spectrum table, or a time series table.

Data Set – An accumulation of data products. A data set together with supporting documentation and ancillary files is an archive.

I/F – Defined as the spectral radiance divided by the solar spectral irradiance of the Sun at target distance divided by pi. Thus, it is the ratio of the radiance observed from a surface to that of a perfect white Lambertian surface illuminated by the same light source but at normal incidence.

MD5 – The Message Digest algorithm 5 is widely used cryptographic hash function with a 128-bit hash value, commonly used to check the integrity of files. An MD5 hash is typically expressed as a 32-character string of hexadecimal numbers.

Standard Data Product – A data product generated in a predefined way using well-understood procedures, processed in "pipeline" fashion. Data products that are generated in a nonstandard way are sometimes called *special data products*.

Appendix B – NAC and WAC Companding Schemes

NAC images are companded using a piecewise linear transfer function with up to five segments. The LROC instrument can store up to eight NAC transfer functions, currently six functions are defined. The six transfer functions implemented in NAC hardware can be expressed in pseudo code.

Pseudo code

The companding logic operates as follows:

if pixin < xterm0 then pix <= pixin(7 downto 0)
elsif pixin < xterm1 then pix <= pixin/2+$bterm_0$
elsif pixin < xterm2 then pix <= pixin/4+$bterm_1$
elsif pixin < xterm3 then pix <= pixin/8+$bterm_2$
elsif pixin < xterm4 then pix <= pixin/16+$bterm_3$
else pix <= pixin/32+$bterm_4$
end if

The code parameters are:

- "bterm" (i.e. the y-intercept of the linear function):
  bterm = [[0, 8, 25, 59, 128], [0, 0, 0, 0, 0], [0, 0, 0, 0, 0], [0, 16, 69, 103, 128], [0, 0, 0, 65, 128], [0, 0, 14, 65, 128]]
- "xterm" (i.e. the inflection point on the x-axis (12-bit axis)):
  xterm = [[0, 32, 136, 543, 2207], [511, 0, 0, 0, 0], [0, 0, 0, 0, 4095], [0, 64, 424, 536, 800], [0, 0, 0, 1040, 2000], [0, 0, 112, 816, 2000]]
- "pixin" is input 12-bit DN
- The first line of the code makes sure that only the 8 least significant bits are processed ("7 downto 0" refers to the bit number of a 12-bit byte), i.e. a 12-bit value of 256 DN rolls over to a value of 0 DN.

The companding scheme can also be described as linear functions with corresponding segments defined by 12-bit DN ranges.

Code 0: NAC nominal table (square-root-like)

	linear function	12-bit DN range (y)	8-bit DN range (x)
segment 1	y = ½ · x + 0	0 – 31	0 – 15
segment 2	y = ¼ · x + 8	32 – 135	16 – 41
segment 3	y = 1/8 · x + 25	136 – 542	42 – 92
segment 4	y = 1/16 · x + 59	543 – 2206	92 – 196
segment 5	y = 1/32 · x + 128	2207 – 4095	196 – 255

Code 1: NAC lin1 (0 DN to 255 DN mapped one-to-one)

	linear function	12-bit DN range (y)	8-bit DN range (x)
segment 1	y = x	0 – 255	0 – 255
segment 2	y = x – 256	256 – 510	0 – 254
segment 3	y = 1/32 · x	511 – 4095	15 – 127

Code 2: NAC lin16 (12 bit to 8 bit linear)

	linear function	12-bit DN range (y)	8-bit DN range (x)
segment 1	y = 1/16 · x	0 – 4094	0 – 255
segment 2	y = 1/32 · x	4095 – 4095	127 – 127

Code 3: NAC low signal table (optimized for DN < 500)

	linear function	12-bit DN range (y)	8-bit DN range (x)
segment 1	y = ½ · x + 0	0 – 63	0 – 31
segment 2	y = ¼ · x + 16	64 – 423	32 – 121
segment 3	y = 1/8 · x + 69	424 – 535	122 – 135
segment 4	y = 1/16 · x + 103	536 – 799	136 – 152
segment 5	y = 1/32 · x + 128	800 – 4095	153 – 255

Code 4: NAC high signal table (optimized for 500 < DN < 2000)

	linear function	12-bit DN range (y)	8-bit DN range (x)
segment 1	y = 1/8 · x + 0	0 – 1039	0 – 129
segment 2	y = 1/16 · x + 65	1040 – 1999	130 – 189
segment 3	y = 1/32 · x + 128	2000 – 4095	190 – 255

Code 5: NAC cap Nq/Ne table (minimize quantization noise for low DN)

	linear function	12-bit DN range (y)	8-bit DN range (x)
segment 1	y = ¼ · x + 0	0 – 111	0 – 27
segment 2	y = 1/8 · x + 14	112 – 815	28 – 115
segment 3	y = 1/16 · x + 65	816 – 1999	116 – 189
segment 4	y = 1/32 · x + 128	2000 – 4095	190 – 255

Simply inverting the companding equations allows the 8-bit value to be decompanded back to the original 12-bit DN. However there is an ambiguity when inverting, the 8-bit value could have been any of a number of 12-bit values within the particular bin. The inverted equation returns the lowest 12-bit DN within the bin. An alternate method is to use a lookup table and for a particular implementation the analyst can choose the lowest, middle, or highest value within a bin (or any value that meets the particular requirements).

Example 12-bit bins for companding Scheme 0 (square root).

The first 12-bit bin (0, 1) maps to the 8-bit value 0, the second 12-bit bin (2, 3) maps to the 8-bit value 1, the third 12-bit (4, 5) bin maps to the 8-bit value 2 so on and so forth until the 256th 12-bit bin (4064, 4095) which maps to 255.

(0, 1), (2, 3), (4, 5), (6, 7), (8, 9), (10, 11), (12, 13), (14, 15), (16, 17), (18, 19), (20, 21), (22, 23), (24, 25), (26, 27), (28, 29), (30, 31), (32, 35), (36, 39), (40, 43), (44, 47), (48, 51), (52, 55), (56, 59), (60, 63), (64, 67), (68, 71), (72, 75), (76, 79), (80, 83), (84, 87), (88, 91), (92, 95), (96, 99), (100, 103), (104, 107), (108, 111), (112, 115), (116, 119), (120, 123), (124, 127), (128, 131), (132, 135), (136, 143), (144, 151), (152, 159), (160, 167), (168, 175), (176, 183), (184, 191), (192, 199), (200, 207), (208, 215), (216, 223), (224, 231), (232, 239), (240, 247), (248, 255), (256, 263), (264, 271), (272, 279), (280, 287), (288, 295), (296, 303), (304, 311), (312, 319), (320, 327), (328, 335), (336, 343), (344, 351), (352, 359), (360, 367), (368, 375), (376, 383), (384, 391), (392, 399), (400, 407), (408, 415), (416, 423), (424, 431), (432, 439), (440, 447), (448, 455), (456, 463), (464, 471), (472, 479), (480, 487), (488, 495), (496, 503), (504, 511), (512, 519), (520, 527), (528, 535), (536, 543), (544, 559), (560, 575), (576, 591), (592, 607), (608, 623), (624, 639), (640, 655), (656, 671), (672, 687), (688, 703), (704, 719), (720, 735), (736, 751), (752, 767), (768, 783), (784, 799), (800, 815), (816, 831), (832, 847), (848, 863), (864, 879), (880, 895), (896, 911), (912, 927), (928, 943), (944, 959), (960, 975), (976, 991), (992, 1007), (1008, 1023), (1024, 1039), (1040, 1055), (1056, 1071), (1072, 1087), (1088, 1103), (1104, 1119), (1120, 1135), (1136, 1151), (1152, 1167), (1168, 1183), (1184, 1199), (1200, 1215), (1216, 1231), (1232, 1247), (1248, 1263), (1264, 1279), (1280, 1295), (1296, 1311), (1312, 1327), (1328, 1343), (1344, 1359), (1360, 1375), (1376, 1391), (1392, 1407), (1408, 1423), (1424, 1439), (1440, 1455), (1456, 1471), (1472, 1487), (1488, 1503), (1504, 1519), (1520, 1535), (1536, 1551), (1552, 1567), (1568, 1583), (1584, 1599), (1600, 1615), (1616, 1631), (1632, 1647), (1648, 1663), (1664, 1679), (1680, 1695), (1696, 1711), (1712, 1727), (1728, 1743), (1744, 1759), (1760, 1775), (1776, 1791), (1792, 1807), (1808, 1823), (1824, 1839), (1840, 1855), (1856, 1871), (1872, 1887), (1888, 1903), (1904, 1919), (1920, 1935), (1936, 1951), (1952, 1967), (1968, 1983), (1984, 1999), (2000, 2015), (2016, 2031), (2032, 2047), (2048, 2063), (2064, 2079), (2080, 2095), (2096, 2111), (2112, 2127), (2128, 2143), (2144, 2159), (2160, 2175), (2176, 2191), (2192, 2207), (2208, 2239), (2240, 2271), (2272, 2303), (2304, 2335), (2336, 2367), (2368, 2399), (2400, 2431), (2432, 2463), (2464, 2495), (2496, 2527), (2528, 2559), (2560, 2591), (2592, 2623), (2624, 2655), (2656, 2687), (2688, 2719), (2720, 2751), (2752, 2783), (2784, 2815), (2816, 2847), (2848, 2879), (2880, 2911), (2912, 2943), (2944, 2975), (2976, 3007), (3008, 3039), (3040, 3071), (3072, 3103), (3104, 3135), (3136, 3167), (3168, 3199), (3200, 3231), (3232, 3263), (3264, 3295), (3296, 3327), (3328, 3359), (3360, 3391), (3392, 3423), (3424, 3455), (3456, 3487), (3488, 3519), (3520, 3551), (3552, 3583), (3584, 3615), (3616, 3647), (3648, 3679), (3680, 3711), (3712, 3743), (3744, 3775), (3776, 3807), (3808, 3839), (3840, 3871), (3872, 3903), (3904, 3935), (3936, 3967), (3968, 3999), (4000, 4031), (4032, 4063), (4064, 4095)

WAC data are companded with a square root scheme similar to NAC scheme 0. WAC companding is implemented through a lookup table reproduced here.

WAC square-root companding table: 11-bit to 8-bit

0	0	25	22	50	34	75	43	100	51	125	58
1	0	26	22	51	34	76	43	101	51	126	58
2	1	27	23	52	35	77	44	102	51	127	58
3	2	28	23	53	35	78	44	103	52	128	58
4	4	29	24	54	35	79	44	104	52	129	59
5	5	30	24	55	36	80	45	105	52	130	59
6	7	31	25	56	36	81	45	106	53	131	59
7	8	32	25	57	37	82	45	107	53	132	59
8	9	33	26	58	37	83	46	108	53	133	60
9	10	34	27	59	37	84	46	109	53	134	60
10	11	35	27	60	38	85	46	110	54	135	60
11	12	36	27	61	38	86	47	111	54	136	60
12	13	37	28	62	38	87	47	112	54	137	61
13	13	38	28	63	39	88	47	113	54	138	61
14	14	39	29	64	39	89	48	114	55	139	61
15	15	40	29	65	40	90	48	115	55	140	61
16	16	41	30	66	40	91	48	116	55	141	62
17	16	42	30	67	40	92	48	117	56	142	62
18	17	43	31	68	41	93	49	118	56	143	62
19	18	44	31	69	41	94	49	119	56	144	62
20	19	45	32	70	41	95	49	120	56	145	63
21	19	46	32	71	42	96	50	121	57	146	63
22	20	47	32	72	42	97	50	122	57	147	63
23	20	48	33	73	42	98	50	123	57	148	63
24	21	49	33	74	43	99	51	124	57	149	64

150	64	204	76	258	86	312	95	366	104	420	112
151	64	205	76	259	86	313	95	367	104	421	112
152	64	206	76	260	86	314	96	368	104	422	112
153	65	207	76	261	87	315	96	369	104	423	112
154	65	208	76	262	87	316	96	370	104	424	112
155	65	209	77	263	87	317	96	371	105	425	112
156	65	210	77	264	87	318	96	372	105	426	113
157	66	211	77	265	87	319	96	373	105	427	113
158	66	212	77	266	87	320	97	374	105	428	113
159	66	213	77	267	88	321	97	375	105	429	113
160	66	214	78	268	88	322	97	376	105	430	113
161	66	215	78	269	88	323	97	377	106	431	113
162	67	216	78	270	88	324	97	378	106	432	113
163	67	217	78	271	88	325	97	379	106	433	114
164	67	218	78	272	89	326	98	380	106	434	114
165	67	219	79	273	89	327	98	381	106	435	114
166	68	220	79	274	89	328	98	382	106	436	114
167	68	221	79	275	89	329	98	383	106	437	114
168	68	222	79	276	89	330	98	384	107	438	114
169	68	223	79	277	89	331	98	385	107	439	114
170	68	224	80	278	90	332	99	386	107	440	115
171	69	225	80	279	90	333	99	387	107	441	115
172	69	226	80	280	90	334	99	388	107	442	115
173	69	227	80	281	90	335	99	389	107	443	115
174	69	228	80	282	90	336	99	390	107	444	115
175	70	229	81	283	90	337	99	391	108	445	115
176	70	230	81	284	91	338	100	392	108	446	115
177	70	231	81	285	91	339	100	393	108	447	116
178	70	232	81	286	91	340	100	394	108	448	116
179	70	233	81	287	91	341	100	395	108	449	116
180	71	234	82	288	91	342	100	396	108	450	116
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2037	255
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2040	255
2041	255
2042	255
2043	255
2044	255
2045	255
2046	255
2047	255

Appendix C - Orientation of NAC frames: From NAC image acquisition to EDR output

1: Image Acquistion

NAC image pairs are acquired by LROC through two linear array CCDs. The NACs are mounted on the spacecraft rotated 180° with respect to each other, thus their relative pixel ordering is reversed (Figure 1).

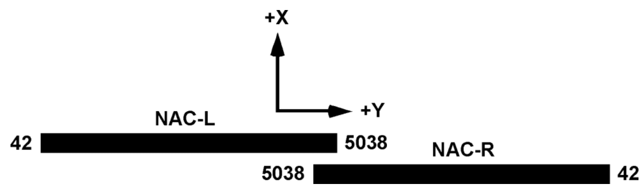

Figure 1. Orientations of NAC CCDs as mounted on LRO. Numbers show pixel addresses, where the starting coordinate is zero (pixel numbers 0-41 and 5039-5063 are masked for calibration purposes). The NACs overlap ~135 imaging pixels in the crosstrack direction (Y-axis) and are separated ~0.106° (185 pixels) downtrack (X-axis) (Robinson, et al., 2010).

The forward motion of the LRO spacecraft is used to "push" the CCDs (NAC-L and NAC-R) over the lunar surface. In addition, the even and odd pixels for each NAC are read out separately during observations. This function halves the time for readout and transfer to the buffer, thus enabling the ground track motion to correspond to a single pixel (Robinson, et al., 2010). Based on LRO velocity and exposure time per line, NAC images are constructed line-by-line as the CCDs scan the surface at regular intervals, resulting in two slightly overlapping images.

Once acquired, the image data are stored as science files within the solid-state recorder on LRO. In these files, the upper left corner of each image is the first line and first pixel imaged by LROC. Thus, pixels are stored from left to right (pixel 0 to 5063), top down (line 1 up to 52224), in the array. Although not typically viewed or used for analysis in this format, the right frame is mirrored about the vertical axis (because of storage order) with respect to the left (Figure 2b).

The science files are transmitted to the GSFC MOC for data packet validation and processing, and then transferred to the LROC SOC where the images are processed and archived. The resulting data products include engineering data records (EDRs), calibrated data records (CDRs), and browse images (PTIFs). Part of the archive process of converting the science files to EDR (Figure 2) includes flipping the NAC-R frame to match the orientation of the NAC-L. In this way, the images will always appear contiguous along the central overlap area. The LROC frames (FK) and instrument kernels (IK) assumes the NAC-R orientation has been reversed in the sample direction.

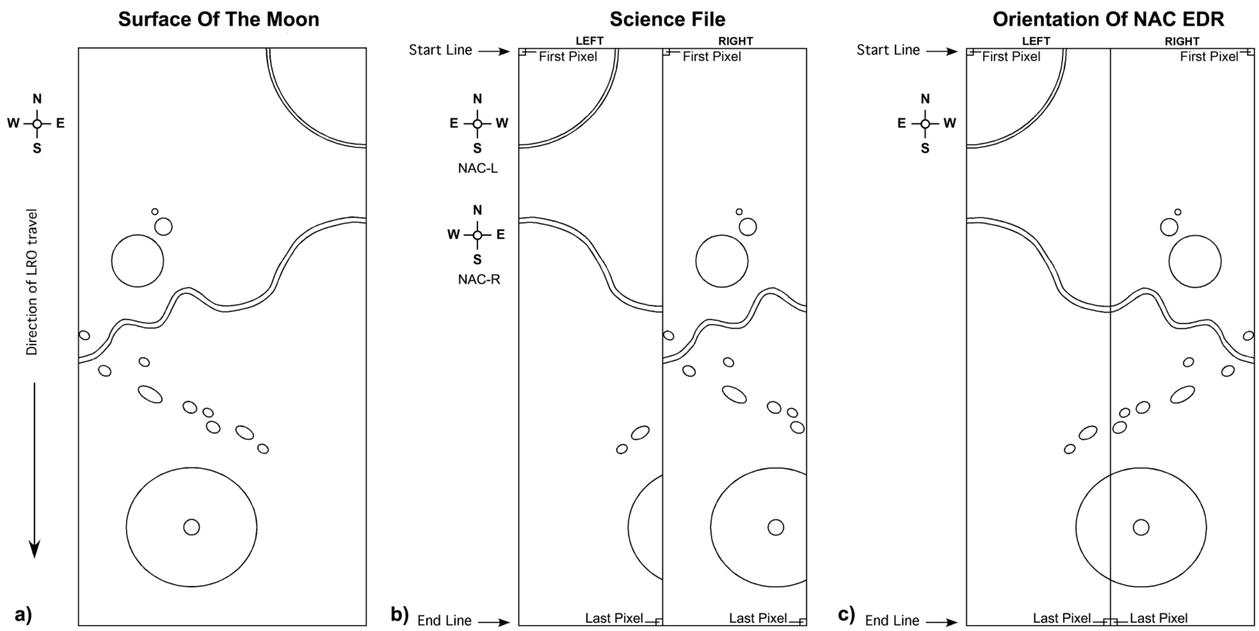

Figure 2. Schematic of NAC image acquisition. Figure a) represents a north-oriented region of the Moon to be imaged. In this example, the LRO spacecraft is in a dayside descending orbit (traveling north to south in the +X orientation). Figure b) depicts the orientation of NAC left and right image frames in the science file. Figure c) indicates the final orientation of the frames in EDR format (as well as CDR and PTIF products).

Over a given lunar surface area at a given time (Figure 2a), LRO orbits either in a north-to-south or south-to-north direction. In this example, the LRO is traveling from north to south and is oriented in the forward-facing direction (+X is in the same direction of velocity vector). LROC will "see" the north part of the surface first (Start Line) and south last (End Line) (Figure 2b). The raw data are stored in science files where the pixels for both frames are ordered from left to right. In these files the NAC-R frame is mirrored with respect to the NAC-L, although in practice the science files are rarely viewed. When the science files are processed into EDR products, the NAC-R image is mirrored right to left (sample direction) to match the orientation of the NAC-L frame (Figure 2c).

2: Geometric Orientation Of Images

Because LRO travels in a polar orbit, LROC targeting is generally oriented along lines of longitude; although north is not always at the top of the images. Image orientation is controlled by two factors: direction of travel in orbit (ascending or descending) and orientation of the spacecraft (LRO +X-axis forward or –X-axis forward).

The convention for incrementing orbits is when LRO crosses the ecliptic on the night side. Ecliptic crossing is referred to as a node crossing and the direction of crossing can be either ascending (from south to north) or descending (from north to south). Two node crossings occur during each orbit; these are referenced by the respective lighting conditions ,"day" or "night", at the time of crossing. Thus there are four possible combinations of node crossing: ascending day, descending day, ascending night, or descending night (Figure 3). This node designation is maintained for the duration of the orbit until the next equatorial crossing. Thus, during the first half of the ascending day node, the spacecraft is traveling north (towards the pole) in the daylight, but during the second half LRO is actually traveling south on the night side.

The change in LRO orientation (+/–X-axis relative to velocity vector) occurs every six months near Beta-angle 0° (the angle between the vector of the Sun and the orbital plane of the spacecraft; 0° means that the Sun and the orbit of LRO are in alignment). This maneuver is performed to allow the solar panel array full range of motion when the relative position of the Sun moves from one side of LRO to the other and to maintain power and thermal values. Additionally, the lighting conditions for ascending/descending node will change following terminator crossing through Beta-angle 90°. This event also occurs twice a year, between the reorientation maneuvers (Tooley, et al., 2010). Thus NAC images have four possible orientations with respect to the surface of the Moon. Each of these cases is described below. All references to direction of travel refer to the illuminated side of the Moon.

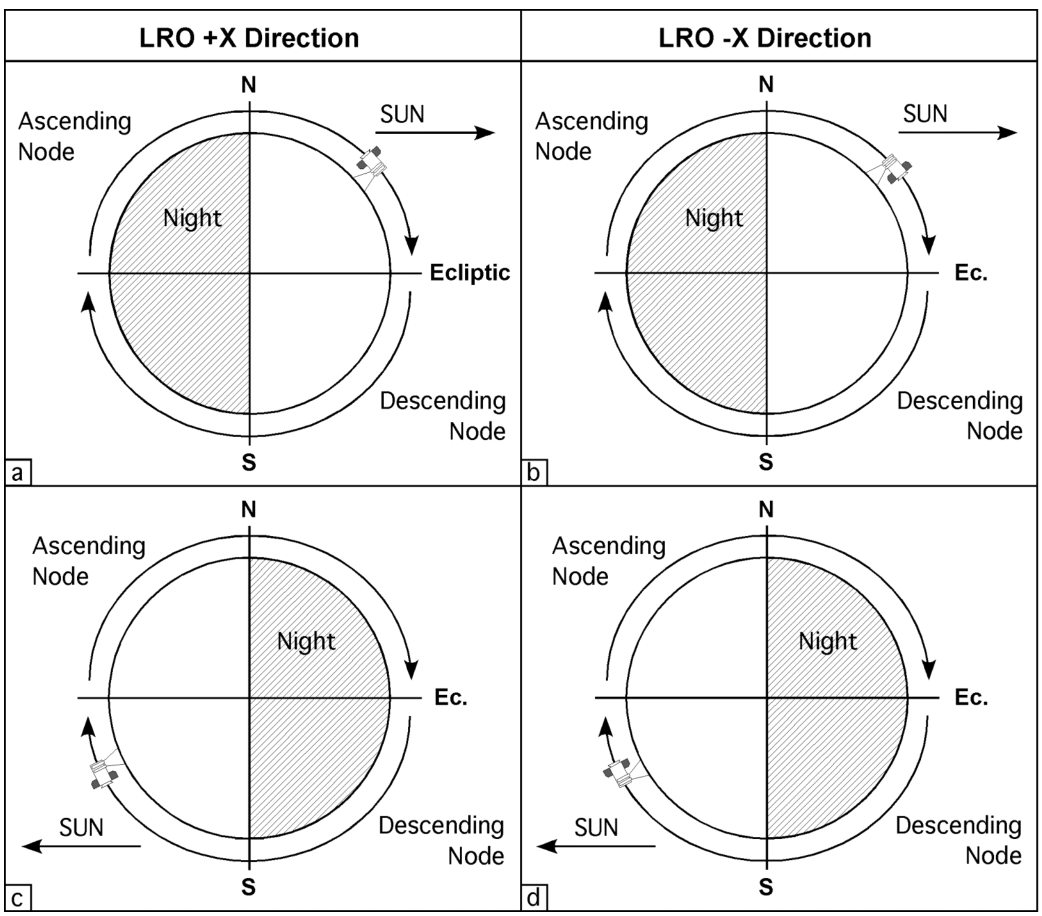

Figure 3. The four possible cases of LRO orientation based on LRO direction of travel (+X or –X axis forward) and lighting conditions at a given node crossing.

Case 1 (Figure 3a)
LRO is traveling from north to south in the spacecraft's +X direction on the illuminated side of the Moon. In this orientation, the first imaged, left-most pixel of NAC-L (pixel #42, line 1) will capture the northeast corner of the frame, the last pixel captured being the southwest corner of the frame. The first right-most pixel of NAC-R (also pixel #42, line 1) will image the northwest corner of the frame, the last left-most pixel imaging the southeast corner. The illustration of this example was used in Figure 2. The EDR files of the NAC pair will appear mirrored about the vertical axis, that is, both images are flipped from left to right.

Note that the final orientation already takes into account the flipping of the NAC-R to correspond to the NAC-L orientation and is true for all cases. Additionally, in each of the following cases, the NAC-R will image in the reverse direction (in the east-west direction) with respect to NAC-L.

Case 2 (Figure 3b)
LRO is traveling from north to south in the –X direction. In this orientation, the first left-most pixel of NAC-L will capture the northwest corner of the frame, the last pixel captured being the southeast corner of the frame (Figure 4). The resulting NAC pair is identical to the observed north-oriented surface area.

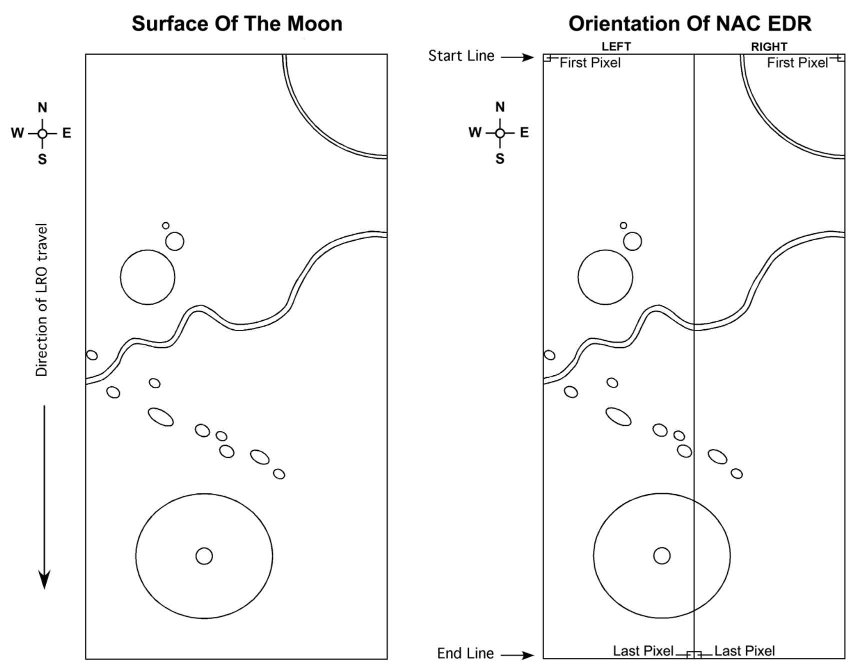

Figure 4. Case 2: LRO is traveling north to south in the –X direction.

Case 3 (Figure 3c)
When LRO is traveling from south to north in the +X direction, the first left-most pixel of NAC-L will capture the southwest corner of the frame and the last pixel will capture the northeast corner of the frame (Figure 5). The resulting image pair is mirrored about the horizontal axis (south end up as a result of mirroring from top to bottom).

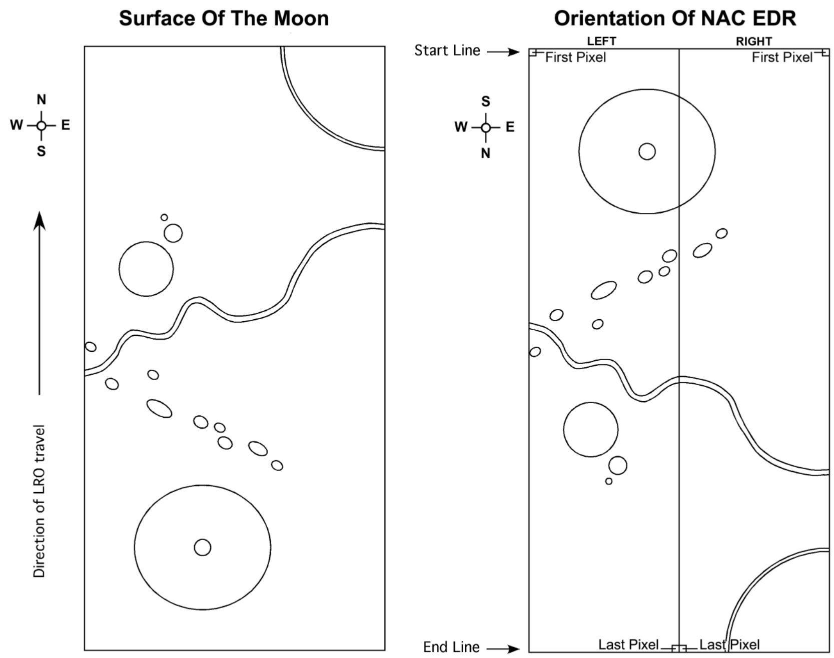

Figure 5. Case 3: LRO is traveling south to north in the +X direction.

Case 4 (Figure 3d)
In the final case, LRO is traveling from south to north in the –X direction. The first left-most pixel of NAC-L will capture the southeast corner of the frame, the last pixel captured being the northwest corner of the frame (Figure 6). The EDR NAC products of this observation will be rotated 180° (south end up, but without mirroring).

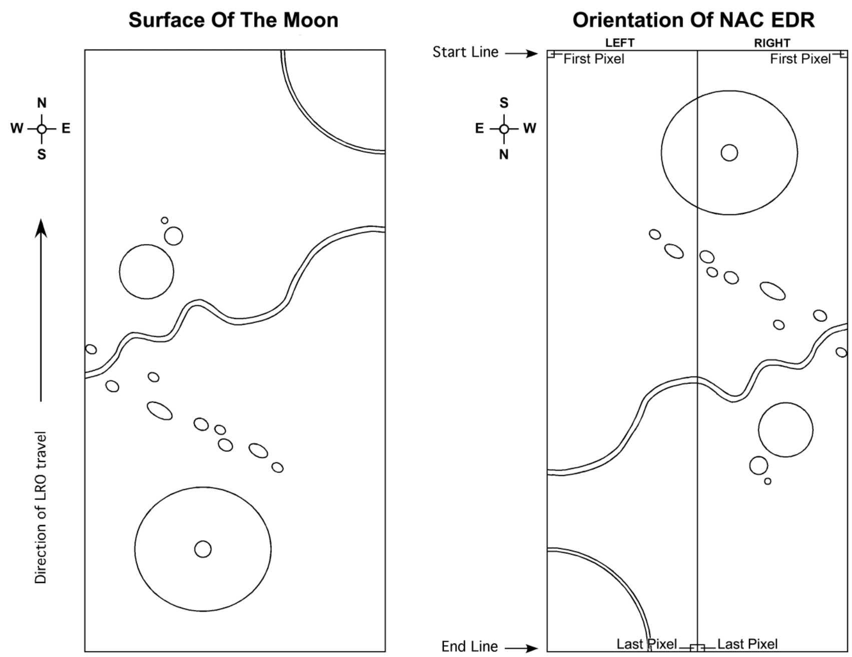

Figure 6. Case 4: LRO is traveling south to north in the –X direction.

<u>Coordinate Information</u>

In each of the cases, the coordinates of the corner points (upper right and left, lower right and left) of the NAC science files are calculated. These coordinates represent values for the corners *after* the right frame has been flipped to match the left frame and do not reflect a north-oriented preference. That is, the upper coordinates represent the starting line of imaging and the lower coordinates are from the ending line. This means that in cases 3 and 4, where south is at the "top" of the images, the upper coordinates are south of the lower coordinates.

References:

M.S. Robinson, et al., Lunar Reconnaissance Orbiter (LROC) Instrument Overview, Space Sci Rev, **150**, 81-124 (2010)

C. Tooel, et al., Lunar Reconnaissance Orbiter Mission and Spacecraft Design, Space Sci Rev, **150**, 23-62 (2010)