Lunar Reconnaissance Orbiter

LROC
RDR Data Products
Software Interface Specification

Version 1.2
December 1, 2008

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Document Change Control

Date	Who	Sections	Descriptions
03/13/2008	Eric E.	All	Draft Outline.
04/21/2008	Eric E.	All	Draft complete for review by LROC team.
05/15/2008	Eric E.	All	LROC team comments incorporated into SIS. DRAFT Version 1.0 completed for PDS review
07/05/2008	Eric E.	All	Incorporated PDS review-team comments into SIS.
07/15/2008	Ernest B-C.	Table 2.2	
11/03/2008	Ernest B-C.		
12/01/2008	Ernest B-C.		Added Scott Brylow to Signature Page

TBD Items and Open Issues

#	Description
5	Table 2.2: Get final numbers for image frame width (km) row, and finalize filter band-pass and FWHM values.
6	Completed Section 3.2 when radiometric calibration algorithm is defined. Provide reference to calibration paper when it becomes available. Provide details for calculating I/F, including heliocentric distance correction.
7	Complete Section 3.3 when photometric normalization algorithm is defined.
9	Verify ~200 pixel overlap for NAC camera
10	Update the section 3.5 to describe the Digital Elevation Model used in the geometry process. Use of the LOLA DEM is dependent on availability of the product at the time of production of the RDR products.

Table of Contents

ACRONYMS AND ABBREVIATIONS

ASCII	American Standard Code for Information Interchange
BDR	Basic Data Record
CCD	Charged Couple Device
CLAT	Center latitude of the map projection
CLON	Center longitude of the map projection
DEM	Digital Elevation Model
DN	Digital Number
EME2000	Earth Mean Equator year 2000
FOV	Field of View
FPGA	Field Programmable Gate Array
FWHM	Full Width at Half Maximum
GeoTIFF	Interchange format for georeferenced raster imagery
GIS	Geographic Information Systems
I/F	Intensity/Flux (Radiance Factor)
ISO	International Standards Organization
J2000	Julian year 2000
JPEG	Joint Photographic Experts Group
LDWG	LRO Data Working Group
LRO	Lunar Reconnaissance Orbiter
LROC	Lunar Reconnaissance Orbiter Camera
MDR	Multispectral Data Record
MTF	Modulation Transfer Function
NAC	Narrow Angle Camera
NAC_DEM	NAC – Demonstration Digital Elevation Models
NAC_LS	NAC – Landing Site campaign
NAC_POLE	NAC – High-resolution polar mosaic campaign
NAIF	Navigation and Ancillary Information Facility
PDS	Planetary Data System
LPRP	Lunar Precursor Robotic Program
SCS	Sequence and Compressor System
SDVT	Science Data Validation Team
SIS	Software Interface Specification
SOC	Science Operations Center
SPICE	Spacecraft, Planet, Instrument, C-matrix Pointing, and Event Kernels
SDP	Special Data Product
TBD	To Be Determined
URL	Uniform Resource Locator
UUID	Universally Unique Identifier
UV	Ultraviolet imaging subsystem
VIS	Visible imaging subsystem
WAC	Wide Angle Camera
WAC-UV	WAC Ultraviolet imaging subsystem
WAC-VIS	WAC Visible imaging subsystem
WAC_GLOBAL	WAC – Global single-band basemap mosaic

WAC_MOVIE	WAC – single-band multi-temporal mosaic of the polar regions
WAC_UV	WAC – Ultraviolet imaging multispectral mosaic products
WAC_VIS	WAC – Visual imaging mosaic products
XML	Extensible Markup Language

1 Introduction

The Lunar Reconnaissance Orbiter Camera (LROC) is designed to address two of the prime LRO measurement requirements. 1) Assess meter- and smaller-scale features to *facilitate safety analysis for potential lunar landing sites* near polar resources, and elsewhere on the Moon. 2) Acquire multi-temporal synoptic imaging of the poles every orbit to *characterize the polar illumination environment* (100 m/pixel scale), identifying regions of permanent shadow and permanent or near-permanent illumination over a full year. The LROC consists of two coaligned narrow-angle camera components (NAC) to provide 0.5 m/pixel scale panchromatic images over a 5 km swath and a wide-angle camera component (WAC) to provide images at a scale of 75 m/pixel in five visible bandpasses and 400 m/pixel in two ultraviolet bandpasses over a 100 km swath at an orbital altitude of 50 km.

In addition to acquiring the two LRO prime measurement sets, LROC will return six other high-value data sets in support of LRO goals, the Lunar Precursor Robotic Program (LPRP), and basic lunar science. These additional data sets include: 3) meter-scale mapping of regions of permanent or near-permanent illumination of polar massifs; 4) multiple co-registered observations of portions of potential landing sites and elsewhere for derivation of high-resolution topography through stereogrammetric and photometric stereo analyses; 5) global multispectral coverage in seven wavelengths (300-680 nm) to characterize lunar resources, in particular ilmenite; 6) a global 100.0 m/pixel basemap with incidence angles (60-80°) favorable for morphologic interpretations; 7) sub-meter imaging of a variety of geologic units to characterize physical properties, variability of the regolith, and key science questions; and 8) meter-scale coverage overlapping with Apollo era panoramic images (1-2 m/pixel) to document the number of small impacts since 1971-1972, to ascertain hazards for future surface operations and interplanetary travel.

To meet these ends the LROC team will generate digital map products and image mosaics from a subset of the collected archive of images. Additionally, radiometrically-calibrated individual images, described in the "LROC EDR/CDR Data Product Software Interface Specification" companion document, are provided as part of the archive of LROC data products. The team maintains an internal archive of the RDR products until meaningful changes in data calibration and data processing methods no longer occur then releases it in an appropriate manner for public access including their final deposition to NASA's Planetary Data System (PDS). The nominal delivery of the RDR derived data products is scheduled for six months after the end of the primary science phase of the mission.

This Software Interface Specification (SIS), written for software developers, engineers, and scientists, provides a description of the derived products provided by the LROC Science Team. It is intended to offer enough information to enable users to read and understand the products. The SIS describes how products are processed, formatted, labeled, and uniquely identified. The document details standards used in generating the products. The SIS also provides a specification of the products delivered to the PDS. Finally, examples of the product labels are provided.

1.1 *Product Overview*

LROC derived products, summarized in Table 1.1, are organized into four data set types: 1) Map-projected single-band basemaps (BDRs) derived from NAC and WAC single-band imaging; 2) Map-projected multispectral basemaps (MDR) from WAC seven-band imaging; 3) Special Data Products (SDP) in support of photometric stereo research and development activities; and 4) Extra data products (EXTRA) such as video time-lapse movies of the north and south pole organized in the [TDB] video format.

Table 1.1 – Product Summary

Type	Product Name	Description	Purpose
BDR	NAC_LS	Approximately 50 NAC high-resolution uncontrolled image mosaics are created in support of high-priority landing site areas at 0.5 m/pixel sampling.	Assess meter and smaller-scale features to facilitate safety analysis of potential landing sites. Support science investigations.
BDR	NAC_POLE	NAC 1.0 m/pixel uncontrolled best-effort mosaics of polar regions 90 to 85.5˚ latitude	Provide detailed synoptic maps of polar regions
BDR	WAC_GLOBAL	WAC monochrome global uncontrolled best-effort basemap mosaic of high-incidence angle imaging (60˚-80˚) at 100.0 m/pixel scale	High-incidence angle imaging supports morphological analysis of the lunar surface
MDR	WAC_VIS WAC_UV	WAC seven-band multispectral regional uncontrolled best-effort demonstration mosaics at 100.0 m/pixel scale for spectral filters 415, 560, 600, 640, and 680; and 400-m/pixel scales for UV filters 315 and 360. WAC_VIS designates 5-band visible products and WAC_UV designates 2-band ultraviolet products.	Characterize lunar resources such as abundance of ilmenite.
BDR	WAC_MOVIE	WAC single-band multi-temporal uncontrolled synoptic mosaics of polar regions at 100.0 m/pixel scale	Identify regions of permanent shadow and permanent or near-permanent illumination over a full lunar year
SDP	NAC_DEM	Special Products consist of sets of images with appropriate illumination and viewing geometries suitable for geometric or photometric stereo research and development activities. Products created on a best effort basis. The products support research and development activities and may prove to be of insufficient quality to become a suitable product for delivery to the PDS.	Demonstrate DEM development through photometric stereo research methods using multiple high-resolution NAC images acquired under different illumination conditions.
EXTRA	WAC_MOVIE	WAC_MOVIE mosaics organized as a movie formatted in an appropriate [TDB] video format.	Identify regions of permanent shadow and permanent or near-permanent illumination over a full lunar year

The BDR and MDR products are mosaics of individual LROC observations that have been radiometrically calibrated, photometrically normalized to standard illumination conditions (except for polar products), and resampled to a standard map projection. Radiometric calibration corrects for varying instrument detector sensitivities, dark current, and nonlinearity; and converts pixel values to reflectance. The radiometric calibration is discussed in more detail in section 3.2. Observations that compose a mosaic are typically acquired under varying illumination conditions so a photometric normalization is applied in order to balance the overall brightness of the images (except in polar regions). The photometric normalization is discussed in more detail in section 3.3. The basemaps produced by the LROC team are geodetically uncontrolled. This means observations are map-projected using the spacecraft ephemerides and instrument-pointing data provided by the LRO project and a lunar ephemeris, and are not tied to a geodetic control system. A basemap's positional accuracy is limited by the overall accuracy of these data. Geometric processing is described in more detail in section 3.5.

Special Data Products (SDP) are intended to demonstrate the utility of the data collection and the methodology employed in the derivation of high-resolution Digital Elevation Models (DEMs) through photometric stereo techniques. SPDs are created on a best-effort basis. The techniques are experimental and may create products that are of insufficient quality to become a suitable product for distribution to the science community. The SPDs, and the experimental methods employed to derive these products, are summarized in Appendix C. These products cannot yet be described with PDS standards at this time, as the exact nature of these products are not yet known.

The MDR and BDR products are formatted and organized according to the PDS standards [2, 3, 4]. They are stored in the JPEG2000 (Joint Photographic Experts Group) format accompanied by a PDS detached label (Section 4.1) and a GeoTiff box (Section 4.3) providing supporting information about the digital image map. The PDS standard specifies the JPEG2000 code stream will be stored in a "JP2" file as described by the JPEG2000 part 1 standard [5].

1.2 Applicable Documents and References

The LROC Derived Data SIS is consistent with the following documents:

1. Lunar Reconnaissance Orbiter Project Data Management and Archive Plan, 431-PLAN-000182.

2. Planetary Data System Data Standards Reference, Version 3.7, JPL D-7669, Part 2, March 20, 2006.

3. Planetary Science Data Dictionary Document, JPL D-7116, Rev. E, August 28, 2002.

4. Planetary Data System Archive Preparation Guide, Version 1.1, JPL D-31224, August 29, 2006.

5. JPEG2000 image coding system: Core coding system, ISO/IEC 15444-1, September 15, 2004.

6. Acton, Jr., C.H., (1996), Ancillary data services of NASA's Navigation and Ancillary Information Facility, *Planet. Space Sci., Vol. 44, No. 1, .pp 65-70.*

7. Snyder, J.P. (1987), Map Projections, U.S. Geological Survey Professional Paper 1395.

8. LRO Project (2008), A Standardized Lunar Coordinate System for the Lunar Reconnaissance Orbiter, LRO Project White Paper, version 4 of May 14 [to become available at http://lunar.gsfc.nasa.gov/library/451-SCI-000958.pdf.]

9. LGCWG (2008), Recommendations for Formatting Large Lunar Datasets, May 18, draft.

1.3 Configuration Management

The LROC Software Development Team controls this document. Requests for changes to its scope and contents are made to the LROC Science Operations Center Manager, Ernest Bowman-Cisneros. An engineering change request will be evaluated against its impact on the LROC ground data processing system before acceptance.

The SIS has completed a formal PDS peer review where it was determined that the products herein described meet PDS data product standards. Members from the PDS Imaging and Engineering Nodes along with additional members from the planetary science community comprised the review panel.

2 Instrument Overview

The LROC consists of two narrow-angle camera components (NAC), a wide-angle camera component (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 5000 pixel CCD line-array providing a cross-track field-of-view (FOV) of 2.86°. The NAC readout noise is better than 100 e^- and the data are sampled at 12 bits. By ground command, these 12-bit pixel values are companded to 8-bit pixels using one of several selectable lookup tables during readout from the CCD. The NAC internal buffer holds 256 MB of uncompressed data, enough for a full-swath image 25 km long or a 2x2 binned image 100 km long. NAC specifications are summarized in Table 2.1.

The WAC electronics are a copy of those flown 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 1,000 x 1,000 pixel, electronically shuttered CCD area-array, one imaging in the visible/near infrared (VIS/near-IR), and the other in the Ultraviolet (UV). The VIS optics have a cross-track FOV of 90° and the UV optics a 60° FOV. From the nominal 50 km orbit, the WAC will provide a nadir, ground sample distance of 75 m/pixel sampling in the visible, and a swath width of ~75 km. 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 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 contain sufficient overlap. The WAC has a readout noise of less than 40 e^- and, as with the NAC, pixel values are digitized to 12-bits then companded to 8-bit values through selectable lookup tables. WAC specifications are summarized in Table 2.2. The two UV bands (315 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 400 m/pixel sampling but have improved signal properties.

The two NACs and the WAC interface with the Sequencing and Compressor System (SCS), the third element of the LROC (see Figure 2.4). 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.

Each NAC has an mass of 8.2 kg, the WAC is 1.3 kg, and the SCS is 1.6 kg, for a total LROC mass of 19.3 kg. Each NAC will use 10 W during image acquisition or readout, 6 W at all other times; the WAC will use 4 W (continuous), and the SCS will use 6 W (continuous), for a total LROC power dissipation of 30 W at peak usage, and 22 W during average usage.

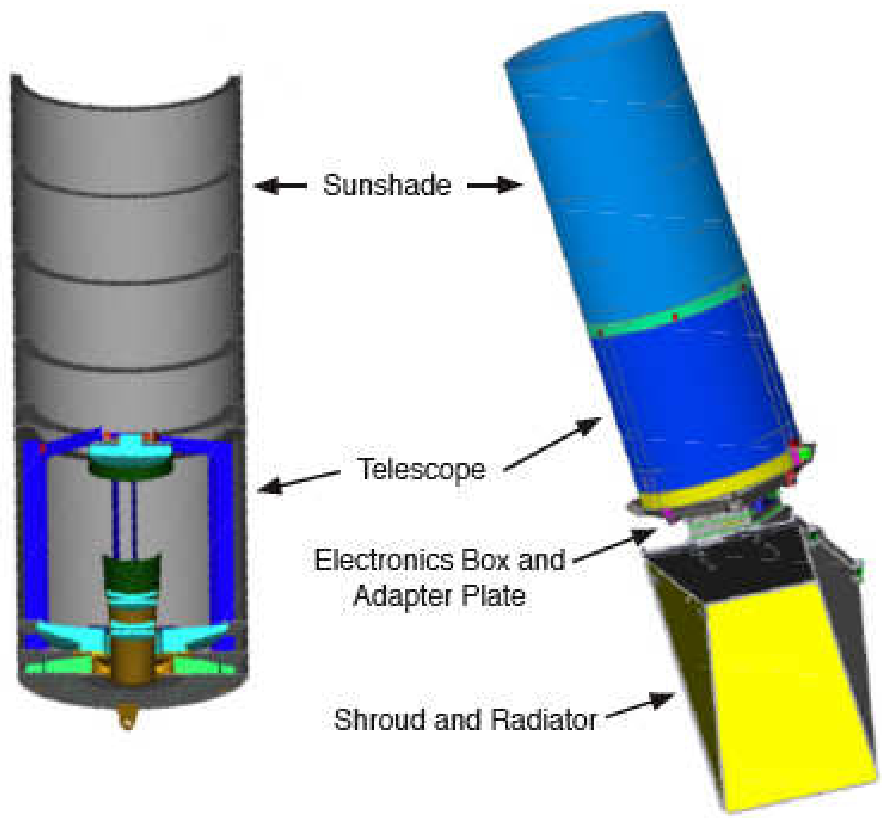

Figure 2.1 - LROC Narrow Angle Camera, 70 cm by 24 cm diameter.

Table 2.1 – NAC Specifications	
Image scale	0.5 meter per pixel (10 micro-radian IFOV)
Maximum Image size	2.5 x 25 km
Optics	f/3.59 Cassegrain (Ritchey-Chretien)
Effective Focal Length	700 mm
Primary Mirror Diameter	195 mm
FOV	2.86°(0.05 radian) per NAC
MTF (Nyquist)	> 0.20
Structure + baffle	Graphite-cyanate composite
Detector	Kodak KLI-5001G
Pixel format	1 x 5,000
Noise	100 e-
Analog/Digital Converter	Honeywell ADC9225
FPGA	Actel RT54SX32-S
Instrument Dimensions	70 cm x 26 cm diameter
Peak Power	10 W
Average Power	6 W
Spectral Response	400-750 nm

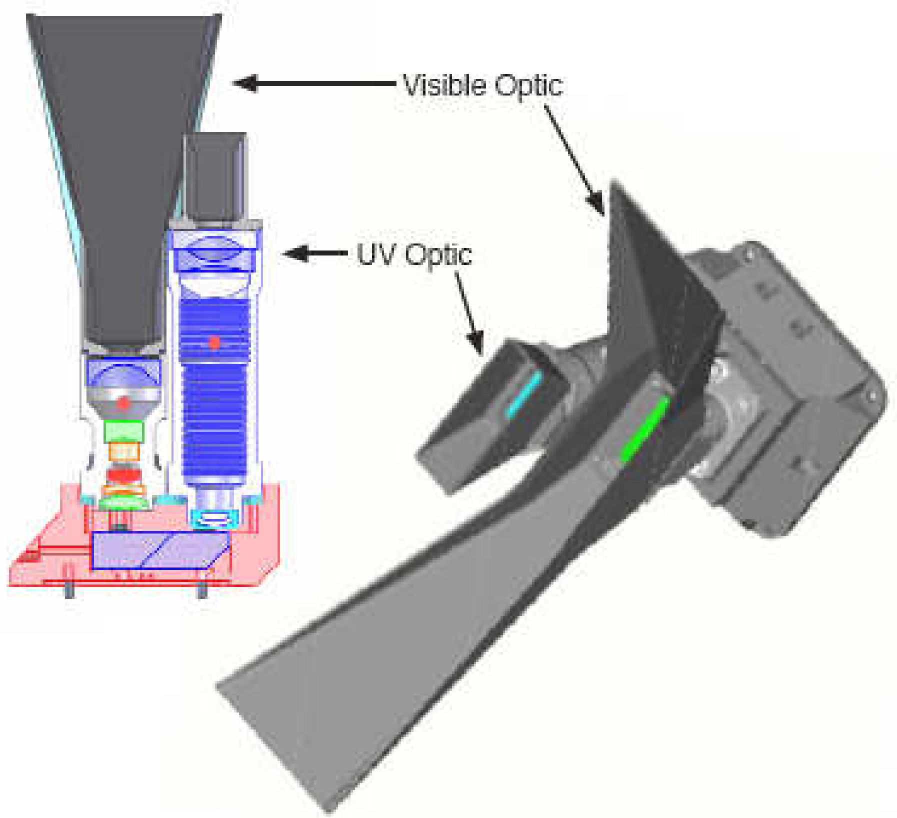

Figure 2.2. - LROC Wide Angle Camera

Table 2.2 – WAC Specifications	
Image format	1,024 x 16 pixels monochrome (push frame) 704 x 16 pixels 7-filter color (push frame)
Image scale	1.5 milliradian, 75 meters/pixel nadir (VIS) 2.0 milliradian, 400 meters/pixel nadir (UV, 4x binned)
Image frame width (km)	110 km (VIS monochrome) 88 km (VIS color) 88 km (UV)
Optics	f/5.1 (VIS) f/5.3 (UV)
Effective Focal Length	6.0 mm (VIS), 4.6 mm (UV)
Entrance Pupil Diameter	1.19 mm (VIS), 0.85 mm (UV)
Field of View	90° (VIS) 60° (UV)
System MTF (Nyquist)	> 0.2
Electronics	4 circuit boards
Detector	Kodak KLI-1001
Pixel format	1,024 x 1,024
Noise	50 e-
Instrument Dimensions	14.5 cm x 9.2 cm x 7.6 cm
Peak Power	4 W
Average Power	4 W
Filters	

Wavelength (nm)	FWHM (nm)
315	40
360	11
415	40
560	13
600	18
640	23
680	30

Table 2. WAC specifications.

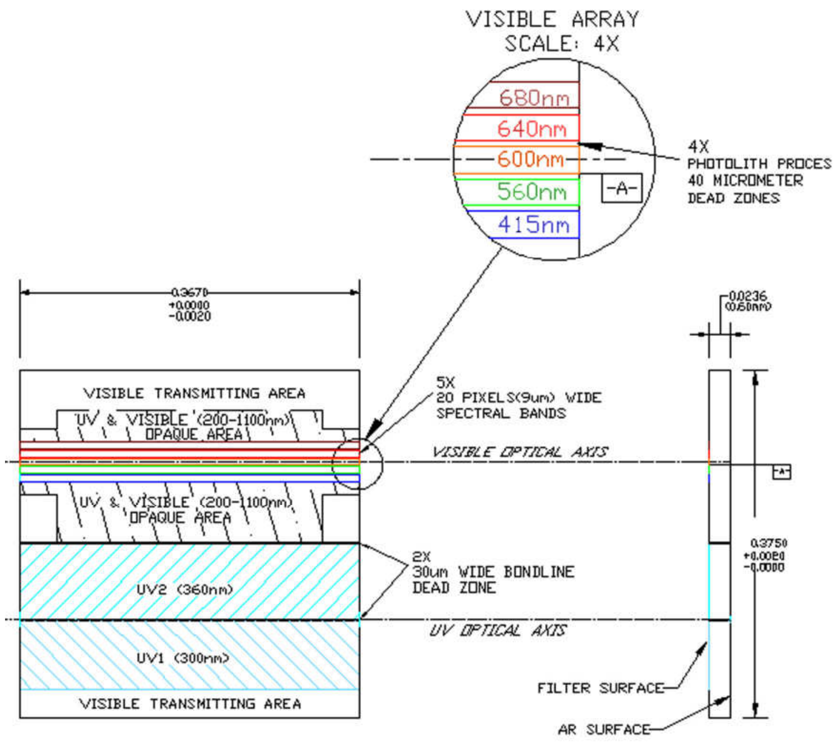

Figure 2.3 - Diagram of LROC Wide Angle Camera filter assembly.

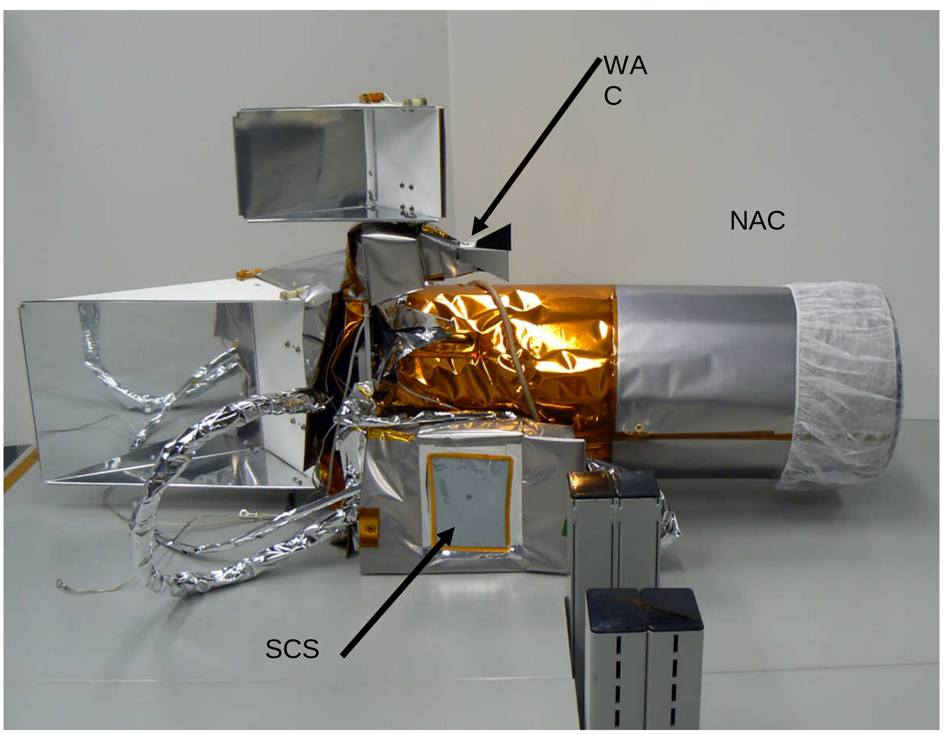

Figure 2.4 - LROC components include the WAC, NAC, and Sequence and Compressor System (SCS).

3 Product Generation

3.1 Map Projection and Layout

LROC digital map products use the Equirectangular and Polar Stereographic map projections [7]. The Polar Stereographic projection, ideal for maps covering the polar regions, minimizes scale and shape distortion at high-latitudes. The Equirectangular projection is typically used at middle and lower latitudes. With this projection, all lines of latitude are parallel to one another as is also the case with longitude lines. The transformation equations for these projections are discussed in Appendix B.

LROC digital basemaps are organized into map quadrangles (or tiles) with each quadrangle covering a subarea of the lunar globe. Map quadrangles are then stored as image files where the column and row coordinate of the image array can be translated to a geographic latitude and longitude coordinate through a map transformation equation (see Appendix B). The size and areal extent of a map quadrangle are balanced to accommodate a reasonable areal extent while having manageable image file sizes. The quadrangle layouts for the basemap mosaics are summarized here.

3.1.1 NAC_POLE

The NAC_POLE high-resolution basemap is organized into 103 quadrangles for each pole covering 90 to 85.5˚ latitude and 0 to 360˚ longitude as shown in Figure 3.1.1. Each quadrangle covers 1.0˚ of latitude and a longitude range depending on the latitude coverage. The basemap is available in both Polar Stereographic and Equirectangular projections. For the Polar Stereographic projection, the quadrangles share the same reference center latitude (CLAT = 90.0) and longitude (CLON = 0.0). With a common reference, it is possible to generate composite quadrangles by scaling and mosaicking individual quadrangles without the need for reprojection For the Equirectangular projection, the quadrangles share the same reference center longitude (CLON = 180.0). The mid-latitude of the quadrangle, an integer value in this case, is used as the reference center latitude (CLAT = [MinLat + MaxLat]/2). The basemap is scaled at 1.0 m/pixel. With this scale and the latitude and longitude coverage of a quadrangle, the images will typically be about 30,000 x 30,000 pixels or about 900 megapixels.

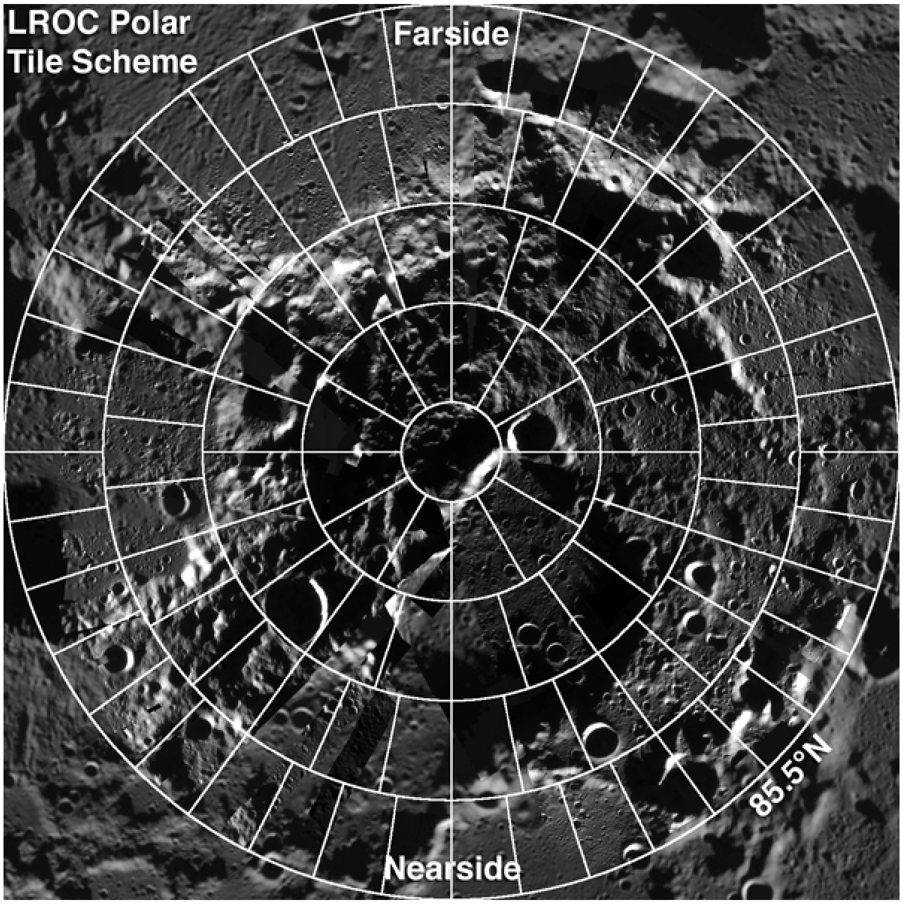

Figure 3.1.1 – Quadrangle layout of NAC_POLE basemap with 103 quadrangles covering latitude range 90 – 85.5˚ at each pole. Quadrangle longitude ranges depend on latitude coverage as shown in the table below.

Latitude Range	# Quads	Quadrangle Longitude Coverage
90.0 – 89.5	1	360˚ / 0-360
89.5 – 88.5	12	30˚ / 0-30, 30-60, 60-90, etc.
88.5 – 87.5	20	18˚ / 0-18, 18-36, 36-54, etc.
87.5 – 86.5	30	12˚ / 0-12, 12-24, 24-36, etc.
86.5 – 85.5	40	9˚ / 0-9, 9-18, 18-27, etc.
Total:	103	

3.1.2 WAC_GLOBAL

The WAC_GLOBAL monochrome basemap mosaic is created using high-incidence-angle imaging (typically 60˚ - 80˚) from the WAC's 600-nm filter. Taking advantage of the high scene contrast at these incidence angles, the product is ideally suited for morphological analysis of the lunar surface. The WAC_GLOBAL basemap mosaic is organized into 18 quadrangles covering the entire lunar globe as shown in Figure 3.1.2. Each quadrangle has 60˚ of latitude and longitude coverage mapped into the Equirectangular projection with center reference latitude 0˚ (CLAT = 0.0) and center reference longitude 180˚ (CLON = 180.0). Polar Stereographic maps are also created for the high-latitude regions from 60˚ to the poles with center reference latitude 90˚ (CLAT = 90.0) and center reference longitude 0˚ (CLON = 0.0). The basemap mosaic is scaled at 100.0 m/pixel. With this scale and latitude and longitude coverage, the quadrangles are about 18,000 x 18,000 pixels or about 324 megapixels.

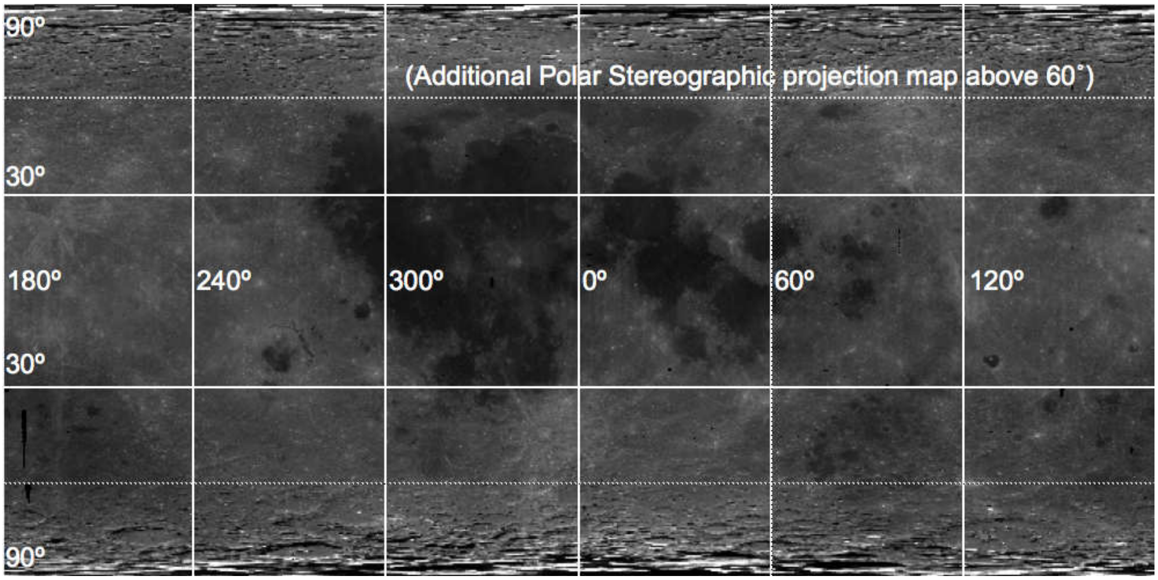

Figure 3.1.2 – Quadrangle layout of the WAC_GLOBAL basemap with 18 quadrangles covering the entire lunar globe mapped in the Equirectangular projection. Polar Stereographic maps are created for the 60˚- 90˚ latitude.

3.1.3 WAC_MOVIE

These basemap products, made from the WAC's 600-nm imaging, are used in the generation of uncontrolled illumination movies at both poles with an average time interval between each frame of approximately five hours. The movie sequence is intended to identify regions of permanent shadow and permanent or near-permanent illumination over a full lunar year. WAC_MOVIE is mapped into the Polar Stereographic projection and scaled at 100-m/pixel with latitude coverage of 80˚ to 90˚. The image dimension is about 6,060 x 6,060 pixels. Approximately 1,800 mosaics are created for each pole over a full lunar year. The WAC FOV will cover a swath ~100 km wide resulting in repeat coverage every orbit for the region between 88˚ and 90˚ at each pole. Figure 3.1.3 shows two WAC swaths taken 3.5 days apart at the Clementine North Pole basemap (summer). The area outlined in red in Figure 3.1.3 shows complete overlap of all observations. The individual 1,800 frames will be compiled into a movie sequence formatted in MPEG and QuickTime video formats. The PDS currently has no standards for video formats so these products will be made available in the "Extras" directory of the archive volume of the LROC Derived Data Products.

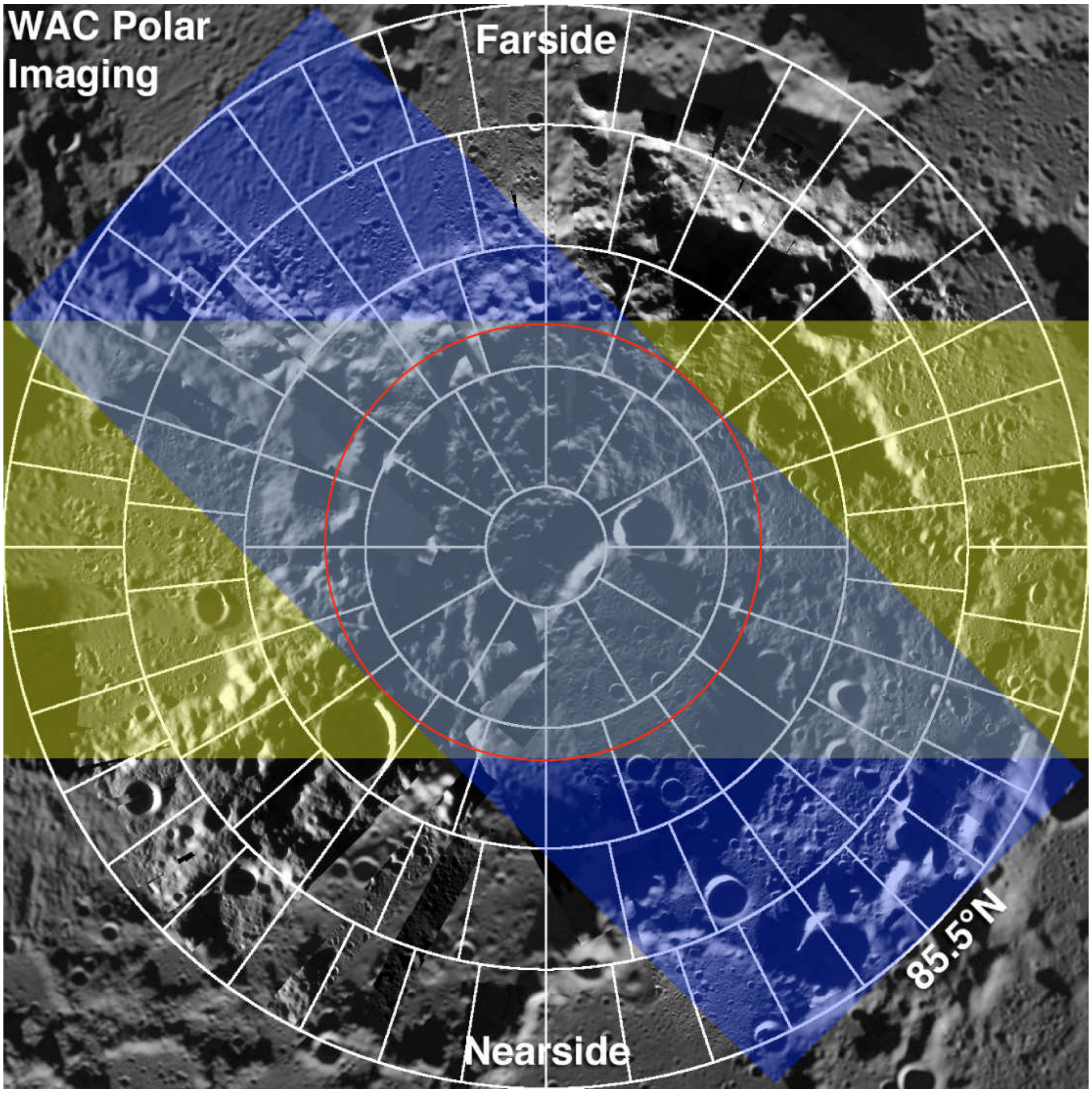

Figure 3.1.3 – Two WAC swaths (one shown in blue and one shown in yellow) taken 3.5 days apart at the North Pole. Every orbit has repeat coverage between 88˚ and 90˚ latitude.

3.1.4 NAC_LS

Fifty mosaics of high-priority proposed landing sites will be generated at 0.5-m/pixel and 1-m/pixel scales, depending on viewing and lighting conditions, and instrument commanding. Polar regions and areas above 60˚ latitude will be mapped to the Polar Stereographic projection (CLAT = 90.0, CLON = 0.0). For other latitude regions, the Equirectangular projection is used. To minimize scale and shape distortion for the Equirectangular projection, the reference center latitude is the nearest whole integer of the mid-latitude of the mosaic. The image size of each mosaic will depend on the chosen areal coverage of the mosaic.

3.1.5 WAC_VIS and WAC_UV

WAC_VIS and WAC_UV mosaics of 10 high-priority targets will be created at 100.0 m/pixel scaling for the visible spectral channels (WAC_VIS: 415, 560, 600, 640, and 680 nm) and at 400-m/pixel for the UV spectral channels (WAC_UV: 315 and 360 nm). Polar Stereographic projections are used for regions above 60˚ latitude and Equirectangular for lower latitudes. As with all other mosaics created by the LROC team, the mosaics are generated using the LRO-delivered spacecraft ephemerides and instrument pointing data and a lunar ephemeris produced by the PDS NAIF Node. They are uncontrolled mosaics not tied to a geodetic control network.

3.2 Radiometric Calibration Correction

[Radiometric Calibration Correction section will developed when the algorithm becomes better understood]

3.3 Photometric Normalization

[Photometric Normalization section will developed when the algorithm becomes better understood]

3.4 Converting DN to I/F

Pixels are stored as 16-bit unsigned integers with the dynamic range of 0-65535. The pixel values (radiometrically corrected and photometrically normalized) have been scaled to fit in the 16-bit unsigned range. To convert the 16-bit density number (DN) values back to radiance factor (I/F), a multiplicative and additive constant is applied. The *SCALING_FACTOR* and *OFFSET* values, found in the PDS label IMAGE object, are used for the conversion. The equation is as follows:

RADIANCE_FACTOR = (DN * SCALING_FACTOR) + OFFSET

3.5 Geometric Processing

Following photometric normalization, geometric processing corrects for the optical distortion of the instrument and projects the image from spacecraft viewing orientation to the map projections described in section 3.1. Geometric processing employs the NAIF Toolkit (http://naif.jpl.nasa.gov) using reconstructed SPICE kernels generated by the LRO project. Using the best digital elevation model (DEM) available at the time of the production, the geometry processing performs orthorectification wherein the geometric distortion introduced by the varying terrain is minimized. The map-projected products are uncontrolled and are not tied to a surface control net so there may be small spatial displacements among the images in the mosaic due to uncertainties in spacecraft pointing and position and lunar ephemeris as found in the SPICE kernels. Cubic convolution resampling is used in the geometric processing.

The Unified Lunar Control Network 2005 (ULCN 2005) will be used initially as the digital elevation model for orthorectification, until such time that the LOLA digital elevation model becomes available. Any RDR products that have been processed with the ULCN 2005 DEM will be reprocessed with the LOLA DEM.

For photometric and geometric stereo processing, it may be necessary to refine the instrument pointing (nominally captured in the SPICE CK kernels) by using the ~200 pixel overlap area between the two NAC cameras. Each NAC CCD sees the lunar surface at slightly different times. The spatial mismatch remaining in the overlap area after the nominal pointing is applied can be used to improve the instrument pointing information.

3.6 Brightness Equalization

The radiometric calibration and photometric normalization processing steps are not perfect, and as a result, residual brightness differences exist among neighboring images mosaicked together into a map quadrangle. To minimize the residual brightness differences, an empirical method is employed. Following geometric processing, image statistics (mean and standard deviation) are compiled for each of the overlapping areas of all neighborhood images. Typically, each image in a mosaic might have 4-5 neighbors where there is spatial overlap. Ideally, if the calibration and photometric normalization were perfect then the statistics of the overlap areas would be identical and no additional processing would be required. However, experience shows this is not the case. With the statistics computed for each overlap area, multiplicative adjustments are determined, through a least-squares method, to minimize the brightness differences of the overlap regions. These corrections are then applied to the image collection before the final mosaic and quadrangle assembly.

3.7 Mosaicking and Quadrangle Assembly

The final step in the processing is to mosaic together the individual map-projected brightness-equalized images that make up a quadrangle. In this process, an empty map quadrangle image file is initially created. The images that go into the mosaic are then individually placed into the quadrangle map at the appropriate spatial location. The geometric processing step ensures all of the images in the quadrangle have identical scale and map projection parameters. In overlap areas among neighboring images, the last image placed into the mosaic will overwrite the common area of the images previously inserted into the mosaic. The mosaic is assembled using the mosaic ordering with lowest image sampling resolution to highest so that the best data are preserved in the mosaic.

4 Standards

4.1 PDS Standards

The LROC Derived Data products comply with the PDS standards [2, 3, 4] for file formats and metadata labels, specifically using the PDS image object and the JPEG2000 compressed file object. The image files, formatted according to the JPEG2000 standard, use "JP2" as their filename extension. Detached PDS labels accompany products: files that have the same name as the image data file but use "LBL" for their filename extension. The label file provides image data characterization and science metadata information about the observation (see Section 5.4 on the contents of the PDS label).

4.2 JPEG2000 Standard

Derived products are stored in the JPEG2000 ISO/IEC Part 1 standard [5] format (http://www.jpeg.org/jpeg2000/), accepted as a PDS Standard in October 2005 [2]. The JPEG2000 standard offers benefits with distinct advantages for storage of and access to very large images. Advantages include excellent compression performance, multiple resolution levels from a single image data set, progressive decompression quality layers, lossless and lossy compression (LROC derived products use lossless compression), pixel datum precision up to 38 bits, multiple image components (or bands), and selective image area access. These features are achieved through use of an image coding system based on discrete wavelet transforms (DWT) resulting in a codestream that can render an image raster format using inverse transform algorithms.

The PDS Standard specifies that a JPEG2000 codestream will be stored in a "JP2" file as described by the JPEG2000 Part 1 standard [5, Appendix I]. This file format encapsulates one or more codestreams plus characterizes metadata in a contiguous sequence of binary data "boxes". The first two boxes of a JP2 file must be Signature and File Type specification boxes that uniquely identify the file as a JP2 file. This must be followed by a JP2 Header box that contains sub-boxes that characterize the Codestream box that follows with information such as the image dimensions, pixel datum precision, compression technique and color space mapping for image display purposes. The JP2 file may also contain additional boxes that contain UUID (universally unique identifier) signatures, URL (uniform resource locator) references, and XML (extensible markup language) sequences that can be used as desired by the data provider.

4.3 GeoTIFF Standard

The LROC JPEG2000 products contain metadata, defined by the GeoTIFF standard, relating the (x, y) Cartesian coordinate to a geographic (latitude and longitude) position on the lunar surface. GeoTIFF is an industry standard recognized by many Geographic Information Systems (GIS) software packages. The GeoTIFF UUID box is identified by its first sixteen UUID byte values (shown here in hexadecimal notation): B1, 4B, F8, BD, 08, 3D, 4B, 43, A5, AE, 8C, D7, D5, A6, CE, 03. The remainder of the box contains a standard TIFF (Tagged Image File Format) data set composed of TIFF tags with geospatial reference information derived from the IMAGE_MAP_PROJECTION parameters of the PDS label. The details of the GeoTIFF specification, and other related information, can be found at the Remote Sensing organization GeoTIFF web site (http://www.remotesensing.org/geotiff/).

4.4 Data Storage Conventions

The LROC Derived Data products contain binary data. Image pixel values are stored within the JPEG2000 framework as 16-bit values with a dynamic range of 65536 DN levels. The PDS label sections are stored as ASCII character strings conforming to the requirements defined in the PDS Standards Reference.

4.5 Time Standards

LROC labels include time specifications in Coordinated Universal Time (UTC). The UTC has uniform seconds defined by the International Atomic Time, with leap second changes announced at irregular intervals to compensate for the Earth's varying rotation. Processing at the LROC SOC converts onboard spacecraft clock counts to UTC time using the SPICE NAIF toolkit [6]. Start and stop times refer to the observation acquisition times of the collection of source products used to compile the derived products.

4.6 Geodetic and Cartographic Standards

The LROC derived products are compatible with the recommendations of the LRO Data Working Group [8] and draft recommendations and mapping conventions identified by the LGCWG (the Lunar Geodesy and Cartography Working Group) [9]. The coordinate system used is the mean Earth/polar axis system, and using planetocentric latitude and east positive longitude direction. The planetocentric latitude is the angle from the equator to a point on the surface of an oblate planet. The longitude increases from west to east (left to right on an Equirectangular projection).

The planetary constants used in the camera model to produce the LROC derived products are obtained from the NAIF SPICE kernels. The SPICE kernel de421.bsp and associated Euler angles are used for the Moons ephemeris definition. For more information regarding the planetary constants please refer to the NAIF Node at http://naif.jpl.nasa.gov/naif/

5 Derived Product Specification

5.1 Data Volume

Table 5.1 summarizes the number of products and data volume for each of the product types described in the SIS. The number of products and data volumes may vary as image campaigns are further refined.

Table 5.1 – Product Volumes

Product Type	# Products	Volume (Gbytes)	Comments
NAC_LS	50 mosaics for landing sites, regolith, and impact rate studies	40	Map boundaries and areal coverage tailored to study areas.
NAC_POLE	103 quads per pole (Equirectangular) 103 quads per pole (Polar Stereographic)	345	North and South Pole coverage from 90˚ to 85.5˚ Latitude. Organized in both Polar Stereographic and Equirectangular projections
WAC_GLOBAL	18 quads (Equirectangular) 2 quads (Polar Stereographic)	14	Global coverage in Equirectangular projection. Polar coverage from 90˚ to 60˚ latitude in Polar Stereographic projection

WAC_VIS WAC_UV	10 mosaics each for VIS and UV products	5	Uncontrolled demonstration multispectral mosaics for high priority targets.
WAC_MOVIE	~1,800 movie frames	132	Movie frames spaced five hours over a Lunar year. Polar coverage from 90˚ to 85.5˚
NAC_DEM	~100	~150	Special Data products resulting from research and development activities (see Appendix C).

5.2 Data Validation

The LRO Data Working Group (LDWG) oversees and coordinates the validation of instrument team data products for release to the PDS in a process by which the science teams and the PDS participate. The LROC team is responsible for verifying that the products meet their science and engineering objectives and technical specifications identified in the SIS. The PDS Imaging Node verifies that the products conform to the Product SIS. The LROC team will make data products available to the LROC Data Node no later than six months from availability of processing inputs. The LROC SOC data processing pipeline includes data validation steps in the processing flow to help ensure engineering and technical specifications for these data are met.

5.3 Product Identification and File Naming Conventions

Each LROC derived product is uniquely identified with a product identification (PRODUCT_ID keyword in PDS labels). The file names are built directly from this unique identification. The product identification is constructed using the product name (see table 1.1), map projection, and coordinate of the center of the map mosaic. For the NAC_LS products an additional eleven characters are included in the product ID to designate the Landing Site name. Figure 5.3 shows how the product IDs are constructed. The latitude and longitude coordinates of the map center are multiplied buy 10 to retain the geographic position to the nearest 10^{th} of a degree, then rounded to the nearest integer. The product identification contains an additional designation for North (N) or South (S) latitude. For example, the NAC_POLE quadrangle centered at 88.0˚ North latitude and 27.0˚ East longitude in the Equirectangular projection would have the product identification "NAC_POLE_E880N0270". The file name for the JPEG2000 image product would have the extension ".JP2" and the detached PDS label would have the extension ".LBL". Additional file name examples are shown in Table 5.3.

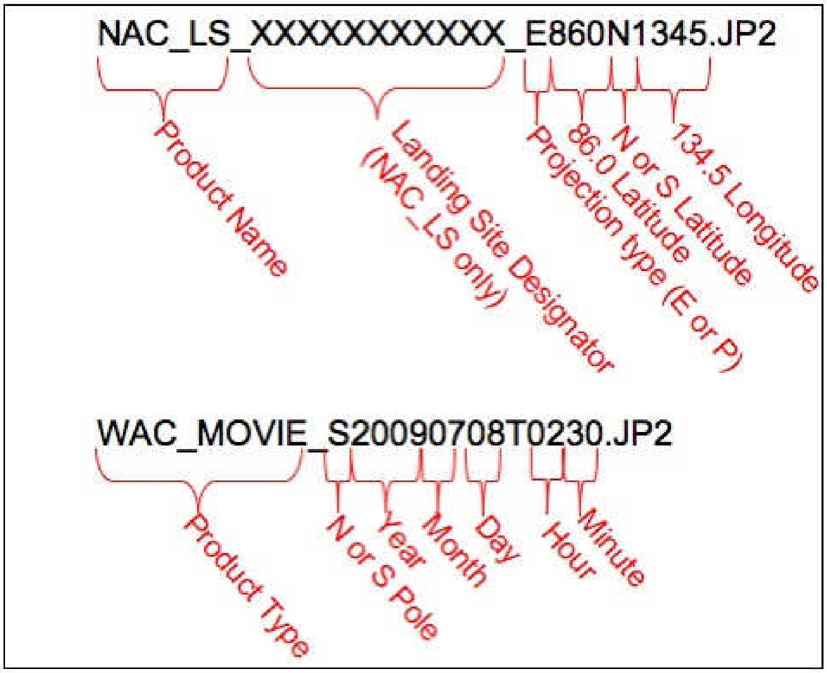

Figure 5.3 - Illustration how RDR file names are constructed.

For WAC_MOVIE products, the product identification includes a date and time stamp prefaced by the product name (see Figure 5.3). The UTC time of the earliest observation in the mosaic is used in the construction of the file name. An "S" or "N" is inserted in front of the time field to indicate a North or South Pole frame. For example, if a polar movie product at the North pole were created whose earliest observation was at UTC time 2009-11-08T02:30:23.406, then the product identification would be: "WAC_MOVIE_N20091108T0230".

Table 5.3 – Example Product Identifications for LROC derived products

PRODUCT_ID	Lat. Center	Lon. Center	Description
NAC_POLE_E860N0045	86.0	4.5	One of 103 quadrangles of the NAC high-resolution polar basemap in the Equirectangular projection
NAC_POLE_P860N0045	86.0	4.5	Same quadrangle as above but in the Polar Stereographic projection
WAC_GLOBAL_E150S0300	-15.0	30.0	One of the 18 WAC Global mosaics in the Equirectangular Projection
NAC_LS_XXXXXXXXXXX_P202S1005	-20.24	100.5	A NAC Landing Site mosaic mapped in the Polar Stereographic projection. An 11-character Landing site name ("X"s in the example) is included in the file name.
WAC_VIS_P202S1005 WAC_UV_P202S1005	-20.2	100.5	WAC Visual and UV mosaics.
WAC_MOVIE_S20090708T0230	-90.0	0.0	WAC polar movie for the south pole whose first image was acquired on UTC 2009-07-08T02:30:23.406.

5.4 PDS labels

An example derived product label in PDS form is shown below. The PDS label for a product is detached from the JPEG2000 file. Appendix-A provides a definition of each keyword listed.

************************ Example PDS Label ****************************

```
PDS_VERSION_ID             = PDS3

/* Identification Information  */
DATA_SET_ID                = "LRO-L-LROC-5-RDR-V1.0"
DATA_SET_NAME              = "LUNAR RECONNAISSANCE ORBITER CAMERA RDR V1.0"
PRODUCER_INSTITUTION_NAME  = "ARIZONA STATE UNIVERSITY"
PRODUCER_ID                = "ASU"
PRODUCER_FULL_NAME         = "MARK S. ROBINSON"
PRODUCT_ID                 = "XXXXXXXXXXXXXXX"
PRODUCT_VERSION_ID         = "V001"
PRODUCT_TYPE               = "RDR"
INSTRUMENT_HOST_NAME       = "LUNAR RECONNAISSANCE ORBITER"
INSTRUMENT_HOST_ID         = "LRO"
INSTRUMENT_NAME            = "LUNAR RECONNAISSANCE ORBITER CAMERA"
INSTRUMENT_ID              = "LROC"
TARGET_NAME                = "MOON"
MISSION_PHASE_NAME         = "XXXXXXXXXX"

/* List of LROC observation products used in the compilation of this product */
SOURCE_PRODUCT_ID          = ("XXXXXXXXXXX", "XXXXXXXXXX", "XXXXXXXXXX", "XXXXXXXXXXX",
"XXXXXXXXXXX", "XXXXXXXXXX", "XXXXXXXXXX", "XXXXXXXXXXX",
"XXXXXXXXXXX", "XXXXXXXXXX", "XXXXXXXXXX", "XXXXXXXXXXX",
"XXXXXXXXXXX", "XXXXXXXXXX", "XXXXXXXXXX", "XXXXXXXXXXX")
RATIONALE_DESC             = "NAC Uncontrolled Polar Mosaic"
SOFTWARE_NAME              = "Isis 3.X.XX | LROC-SOC-NPP VX.X"

/* Time Parameters */
START_TIME            = "N/A"
STOP_TIME             = "N/A"
SPACECRAFT_CLOCK_START_COUNT =  "N/A"
SPACECRAFT_CLOCK_STOP_COUNT  =  "N/A"
PRODUCT_CREATION_TIME = 2008-01-09T15:05:05

OBJECT = IMAGE_MAP_PROJECTION
    ^DATA_SET_MAP_PROJECTION     = "DSMAP.CAT"
    MAP_PROJECTION_TYPE          = "EQUIRECTANGULAR"
    PROJECTION_LATITUDE_TYPE     = "PLANETOCENTRIC"
    A_AXIS_RADIUS                = xxxxxx.xxxx <KM>
    B_AXIS_RADIUS                = xxxxxx.xxxx <KM>
    C_AXIS_RADIUS                = xxxxxx.xxxx <KM>
    COORDINATE_SYSTEM_TYPE       = "PLANETOCENTRIC"
    POSITIVE_LONGITUDE_DIRECTION = EAST
    KEYWORD_LATITUDE_TYPE        = "PLANETOCENTRIC"
    /* NOTE:  CENTER_LATITUDE and CENTER_LONGITUDE describe the location   */
    /* of the center of projection, which is not necessarily equal to the  */
    /* location of the center point of the image.                          */
    CENTER_LATITUDE              = xxx.xxxxxx <DEG>
    CENTER_LONGITUDE             = xxx.xxxxxx <DEG>
    LINE_FIRST_PIXEL             = 1
    LINE_LAST_PIXEL              = xxxxx
    SAMPLE_FIRST_PIXEL           = 1
    SAMPLE_LAST_PIXEL            = xxxxx
    MAP_PROJECTION_ROTATION      = xxx.xxxxx <DEG>
    MAP_RESOLUTION               = xxx.xxxxx <PIXELS/DEG>
    MAP_SCALE                    = x.xxxxxxx <METERS/PIXEL>
    MAXIMUM_LATITUDE             = x.xxxxxxx <DEG>
    MINIMUM_LATITUDE             = x.xxxxxxx <DEG>
    LINE_PROJECTION_OFFSET       = xxxxxxxxx.xxxxxx <PIXEL>
    SAMPLE_PROJECTION_OFFSET     = xxxxxxxxx.xxxxxx <PIXEL>
    EASTERNMOST_LONGITUDE        = xxxx.xxxx <DEG>
    WESTERNMOST_LONGITUDE        = xxxx.xxxx <DEG>
END_OBJECT = IMAGE_MAP_PROJECTION

/* The JPEG2000 image data file associated with this label. */
OBJECT = COMPRESSED_FILE
    FILE_NAME                  = "XXXXXXXXXXXXXXX.JP2"
    RECORD_TYPE                = UNDEFINED
    ENCODING_TYPE              = "JP2"
```

```
    ENCODING_TYPE_VERSION_NAME = "ISO/IEC15444-1:2004"
    INTERCHANGE_FORMAT         = BINARY
    /* The name of the original source file. */
    UNCOMPRESSED_FILE_NAME     = "XXXXXXXXXXXXXXX.IMG"
    /* The amount of original image data. */
    REQUIRED_STORAGE_BYTES     = XXXXXXXXXXXXX <BYTES>
    ^DESCRIPTION               = "JP2INFO.TXT"
END_OBJECT = COMPRESSED_FILE

/* The source image data definition. */
OBJECT = UNCOMPRESSED_FILE
   FILE_NAME    = "XXXXXXXXXXXXXXX.IMG"
   RECORD_TYPE  = FIXED_LENGTH
   RECORD_BYTES = XXXXX <BYTES>
   FILE_RECORDS = XXXXXXX
   ^IMAGE       = "XXXXXXXXXXXXXXX.IMG"

   OBJECT = IMAGE
        DESCRIPTION                = "LROC projected and mosaicked image product"
        LINES                      = xxxxx
        LINE_SAMPLES               = xxxxx
        BANDS                      = x
        SAMPLE_TYPE                = LSB_UNSIGNED_INTEGER
        SAMPLE_BITS                = 16
        SAMPLE_BIT_MASK            = 2#1111111111111111#

        /* NOTE: The conversion from DN to I/F (intensity/flux) is:  */
        /* I/F = (DN * SCALING_FACTOR) + OFFSET                      */
        /* I/F is defined as the ratio of the observed radiance and  */
        /* the radiance of a 100% lambertian reflector with the sun  */
        /* and camera orthogonal to the observing surface.           */
        SCALING_FACTOR             = xxxxxxxx.xxxx
        OFFSET                     = xxxxxxxx.xxxx
        BAND_STORAGE_TYPE          = BAND_SEQUENTIAL
        CORE_NULL                  = 0
        CORE_LOW_REPR_SATURATION   = 1
        CORE_LOW_INSTR_SATURATION  = 2
        CORE_HIGH_REPR_SATURATION  = 65535
        CORE_HIGH_INSTR_SATURATION = 65534
        CENTER_FILTER_WAVELENGTH   = 560 <NM>
        LRO:MINIMUM_STRETCH        = xxxx
        LRO:MAXIMUM_STRETCH        = xxxx
        FILTER_NAME                = "600"
   END_OBJECT = IMAGE
END_OBJECT = UNCOMPRESSED_FILE
END
```

Appendix A – PDS Label Definitions

Table A – Definition of keywords used in the LROC Product Labels	
Keyword	Definition
PDS_VERSION_ID	Always "PDS3", the version number of the PDS standards used in the construction of the labels.
DATA_SET_ID	"LRO-L-LROC-3-RDR-V1.0" The DATA_SET_ID element is a unique alphanumeric identifier for a data set or a data product. The value for a given data set or product is constructed according to flight project naming conventions.
DATA_SET_NAME	"LUNAR RECONNAISSANCE ORBITER CAMERA RDR V1.0" The DATA_SET_NAME element provides the full name given to a data set or a data product.
PRODUCER_INSTITUTION_NAME	"ARIZONA STATE UNIVERSITY" The PRODUCER_INSTITUTION_NAME element identifies university, research center, NASA center or other institution associated with the production of a data set.
PRODUCER_ID	"ASU" The PRODUCER_ID element provides a short name or acronym for the producer or producing team/group of a data set.
PRODUCER_FULL_NAME	The PRODUCER_FULL_NAME element provides the full name of the individual mainly responsible for the production of a data set.
PRODUCT_ID	The PRODUCT_ID data element represents a permanent, unique identifier assigned to a data product by its producer.
PRODUCT_VERSION_ID	The PRODUCT_VERSION_ID element identifies the version of an individual product within a data set.
INSTRUMENT_HOST_NAME	"LUNAR RECONNAISSANCE ORBITER" The INSTRUMENT_HOST_NAME element provides the full name of the host on which an instrument is based. This host can be either a spacecraft or an Earth base.
INSTRUMENT_HOST_ID	Always "LRO" The INSTRUMENT_HOST_ID element provides a unique identifier for the host where an instrument is mounted.
INSTRUMENT_NAME	Always "LUNAR RECONNAISSANCE ORBITER CAMERA" The INSTRUMENT_NAME element provides the full name of an instrument.
INSTRUMENT_ID	"LROC" The INSTRUMENT_ID element provides an abbreviated name or acronym that identifies an instrument.
TARGET_NAME	"MOON", "EARTH", etc. The TARGET_NAME element identifies a target of the observation.

MISSION_PHASE_NAME	"COMMISSIONING", "NOMINAL MISSION" or "EXTENDED MISSION" The MISSION_PHASE_NAME element provides the commonly used identifier of a mission phase.
SOURCE_PRODUCT_ID	The SOURCE_PRODUCT_ID data element identifies a product used as input to create a new product.
RATIONALE_DESC	The RATIONALE_DESC element describes the rationale for the provided product.
SOFTWARE_NAME	The SOFTWARE_NAME element identifies data processing software such as a program or a program library.
START_TIME	For LROC mosaic products this is the START_TIME of the earliest acquired observation in the mosaic. The time is in the UTC system, formatted as: YYYY-MM-DDThh:mm:ss.fff.
SPACECRAFT_CLOCK_START_COUNT	Always "N/A" This required keyword is not applicable for LROC mosaic products.
STOP_TIME	For LROC mosaic products, this is the STOP_TIME of the latest acquired observation in the mosaic. The time is in the UTC system, formatted as: YYYY-MM-DDThh:mm:ss.fff.
SPACECRAFT_CLOCK_STOP_COUNT	Always "N/A" This required keyword is not applicable for LROC mosaic products.
PRODUCT_CREATION_TIME	The PRODUCT_CREATION_TIME element defines the UTC system format time when a product was created, formatted as: YYYY-MM-DDThh:mm:ss.fff.
IMAGE_MAP_PROJECTION	**Object within label**
^DATA_SET_MAP_PROJECTION	The DATA_SET_MAP_PROJECTION object is one of two distinct objects that define the map projection used in creating the digital images in a PDS data set. The name of other associated object that completes the definition is called IMAGE_MAP_PROJECTION. The map projection information resides in these two objects, essentially to reduce data redundancy and at the same time allow the inclusion of elements needed to process the data at the image level. Static information applicable to the complete data set resides in the DATA_SET_MAP_PROJECTION object, while dynamic information that is applicable to the individual images resides in the IMAGE_MAP_PROJECTION object. The DATA_SET_MAP_PROJECTION object is to be included in an Archive Quality Data Product Label, and used to load the map projection catalog data into a PDS Catalog.
MAP_PROJECTION_TYPE	"EQUIRECTANGULAR" or "POLAR STEROGRAPHIC" The MAP_PROJECTION_TYPE element identifies the type of projection characteristic of a given map.
PROJECTION_LATITUDE_TYPE	"PLANETOCENTRIC" Identifies the type of latitude that is sampled in equal increments by successive image lines. These projections are sometimes known informally as 'database projections' because their simplicity and global applicability for storing data for an entire planet are of greater interest than their formal cartographic properties.
A_AXIS_RADIUS	1737.4 <KM>

	The A_AXIS_RADIUS element provides the value of the semimajor axis of the ellipsoid that defines the approximate shape of a target body. 'A' is usually in the equatorial plane.
B_AXIS_RADIUS	1737.4 <KM> The B_AXIS_RADIUS element provides the value of the intermediate axis of the ellipsoid that defines the approximate shape of a target body. 'B' is usually in the equatorial plane.
C_AXIS_RADIUS	1737.4 <KM> The C_AXIS_RADIUS element provides the value of the semiminor axis of the ellipsoid that defines the approximate shape of a target body. 'C' is normal to the plane defined by 'A' and 'B'.
COORDINATE_SYSTEM_NAME	PLANETOCENTRIC The COORDINATE_SYSTEM_NAME element provides the full name of the coordinate system to which the state vectors are referenced. PDS has currently defined body-fixed rotating coordinate systems. The Planetocentric system has an origin at the center of mass of the body. The planetocentric latitude is the angle between the equatorial plane and a vector connecting the point of interest and the origin of the coordinate system. Latitudes are defined to be positive in the northern hemisphere of the body, where north is in the direction of Earth's angular momentum vector (i.e., pointing toward the hemisphere north of the solar system invariant plane). Longitudes increase toward the east making the Planetocentric system right-handed.
POSITIVE_LONGITUDE_DIRECTION	"EAST" The POSITIVE_LONGITUDE_DIRECTION element identifies the direction of longitude (e.g. EAST, WEST) for a body.
KEYWORD_LATITUDE_TYPE	"PLANETOCENTRIC" Identifies the type of latitude (planetographic or planetocentric) used in the labels (e.g., for the maximum, minimum, center, reference, and standard-parallel latitudes). This can differ from the type of latitude that is equally sampled in certain database projections.
CENTER_LATITUDE	The CENTER_LATITUDE element provides the reference latitude of the map projection. The MAP_SCALE (or MAP_RESOLUTION) is typically defined at the CENTER_LATITUDE and CENTER_LONGITUDE of the map projection.
CENTER_LONGITUDE	The CENTER_LONGITUDE element provides a reference longitude for certain map projections. For example, in an Orthographic projection, the CENTER_LONGITUDE, along with the CENTER_LATITUDE, defines the point or tangency between the sphere of the planet and the plane of the projection. The MAP_SCALE (or MAP_RESOLUTION) is typically defined at the CENTER_LATITUDE and CENTER_LONGITUDE. In unprojected images, CENTER_LONGITUDE represents the longitude at the center of the image frame.
LINE_FIRST_PIXEL	The LINE_FIRST_PIXEL element provides the line (row) index for the first pixel that was physically recorded at the beginning of the image array. Note: For a fuller explanation on the use of this data element in the Image Map Projection Object, please refer to the PDS Standards Reference.
LINE_LAST_PIXEL	The LINE_LAST_PIXEL element provides the line

	(rows) index for the last pixel that was physically recorded at the end of the image array. Note: For a fuller explanation on the use of this data element in the Image Map Projection Object, please refer to the PDS Standards Reference.
SAMPLE_FIRST_PIXEL	The SAMPLE_FIRST_PIXEL element provides the sample (column) index for the first pixel that was physically recorded at the beginning of the image array. Note: For a fuller explanation on the use of this data element in the Image Map Projection Object, please refer to the PDS Standards Reference.
SAMPLE_LAST_PIXEL	The SAMPLE_LAST_PIXEL element provides the sample (column) index for the last pixel that was physically recorded at the end of the image array. Note: For a fuller explanation on the use of this data element in the Image Map Projection Object, please refer to the PDS Standards Reference.
MAP_PROJECTION_ROTATION	Always 0.0 The MAP_PROJECTION_ROTATION element provides the clockwise rotation, in degrees, of the line and sample coordinates with respect to the map projection origin (LINE_PROJECTION_OFFSET, LINE_PROJECTION_OFFSET).
MAP_RESOLUTION	The MAP_RESOLUTION element identifies the resolution of a map in pixels/degree and the center latitude and longitude of the projection.
MAP_SCALE	The MAP_SCALE element identifies the scale of a given map in meters/pixel at the center latitude and longitude of the projection.
MAXIMUM_LATITUDE	The MAXIMUM_LATITUDE element specifies the northernmost latitude of the map.
MINIMUM_LATITUDE	The MINIMUM_LATITUDE element specifies the southernmost latitude of a spatial area, such as a map, mosaic, bin, feature, or region.
LINE_PROJECTION_OFFSET	The LINE_PROJECTION_OFFSET element provides the line offset value of the map projection origin position from the line and sample 1,1 (line and sample 1,1 is considered the upper left corner of the digital array) Note: that the positive direction is to the right and down.
SAMPLE_PROJECTION_OFFSE0T	The SAMPLE_PROJECTION_OFFSET element provides the sample offset value of the map projection origin position from line and sample 1,1 (line and sample 1,1 is considered the upper left corner of the digital array). Note: that the positive direction is to the right and down.
EASTERNMOST_LONGITUDE	The following definitions describe easternmost longitude for the body-fixed, rotating coordinate systems: For Planetocentric coordinates and for Planetographic coordinates in which longitude increases toward the east, the easternmost (rightmost) longitude of a spatial area (e.g., a map, mosaic, bin, feature or region) is the maximum numerical value of longitude unless it crosses the Prime Meridian.
WESTERNMOST_LONGITUDE	The following definitions describe westernmost longitude for the body-fixed, rotating coordinate systems: For Planetocentric coordinates and for Planetographic coordinates in which longitude

	increases toward the east, the westernmost (leftmost) longitude of a spatial area (e.g., a map, mosaic, bin, feature or region) is the minimum numerical value of longitude unless it crosses the Prime Meridian.
COMPRESSED_FILE	**Object within label**
FILE_NAME	File name of the compressed file. The FILE_NAME element provides the location independent name of a file. To promote portability across multiple platforms, PDS requires the FILE_NAME to be limited to a 27-character basename, a full stop (. period), and a 3-character extension. Valid characters include capital letters A - Z, numerals 0 - 9, and the underscore character (_).
RECORD_TYPE	UNDEFINED Designated record type of the compressed file.
ENCODING_TYPE	"JP2" Encoding type of the compressed file. The JP2 designation indicates JPEG2000 standard JP2 file format.
ENCODING_TYPE_VERSION_NAME	ISO/IEC15444-1:2004 The ISO/IEC Standard version designation.
INTERCHANGE_FORMAT	"BINARY" The compressed file is a binary file.
UNCOMPRESSED_FILE_NAME	The name of the uncompressed file used to construct the compressed file.
REQUIRED_STORAGE_BYTES	Total number of bytes that make up the compressed file.
^DESCRIPTION	"JP2INFO.TXT" File containing supplemental information about the JPEG2000 file. This file can be found in the DOCUMENT directory of the PDS volume housing the product.
UNCOMPRESSED_FILE	**Object within label**
FILE_NAME	File name of the source uncompressed file.
RECORD_TYPE	"FIXED_LENGTH" Record type of uncompressed image file.
RECORD_BYTES	Number of bytes per record
^IMAGE	The ^IMAGE element provides the location of the image object of the uncompressed file.
IMAGE	**Object within label**
DESCRIPTION	Description of the product.
LINES	Number of image lines (rows) in the image object.
LINE_SAMPLES	Number of samples (columns) per image line. This dimension is most rapidly varying dimension of the image array.
BANDS	Number of bands.
SAMPLE_TYPE	"LSB_UNSIGNED_INTEGER" Sample or pixel type.

SAMPLE_BITS	Always 16, number of bits per sample or pixel.
SAMPLE_BIT_MASK	Always 2#1111111111111111# The SAMPLE_BIT_MASK element identifies the active bits in each sample. Note: The domain of SAMPLE_BIT_MASK is dependent upon the currently described value in the SAMPLE_BITS element and only applies to integer values.
SCALING_FACTOR	The SCALING_FACTOR and OFFSET elements provide the constant values by which the stored pixel values are converted to I/F. Note: Expressed as an equation: true value (I/F) = offset value + (scaling factor x stored value).
OFFSET	See SCALING_FACTOR keyword above.
BAND_STORAGE_TYPE	Always "BAND_SEQUENTIAL" The BAND_STORAGE_TYPE element indicates the storage sequence of lines, samples and bands in an image. The values describe, for example, how different samples are interleaved in image lines, or how samples from different bands are arranged sequentially. Example values: "BAND SEQUENTIAL", "SAMPLE INTERLEAVED", "LINE INTERLEAVED".
CENTER_FILTER_WAVELENGTH	The CENTER_FILTER_WAVELENGTH element provides the middle point wavelength value between the minimum and maximum instrument filter wavelength values.
CORE_NULL	The CORE_NULL element identifies a special value whose presence indicates missing data.
CORE_LOW_REPR_SATURATION	The CORE_LOW_REPR_SATURATION element identifies a special value whose presence indicates the true value cannot be represented in the chosen data type and length.
CORE_LOW_INSTR_SATURATION	The CORE_LOW_INSTR_SATURATION element identifies a special value whose presence indicates the measuring instrument was saturated at the low end.
CORE_HIGH_REPR_SATURATION	The CORE_HIGH_REPR_SATURATION element identifies a special value whose presence indicates the true value cannot be represented in the chosen data type and length.
CORE_HIGH_INSTR_SATURATION	The CORE_HIGH_INSTR_SATURATION element identifies a special value whose presence indicates the measuring instrument was saturated at the high end.
LRO:MINIMUM_STRETCH	This element provides contrast stretch values to be used in the display of a LROC Image. The parameter is the minimum DN value to map to the 0 DN (Black) value of the display. For color images, there will be three values, one for each color.
LRO:MAXIMUM_STRETCH	This element provides a contrast stretch value to be used in the display of a LROC Image. The parameter specifies the DN value to map to the 255 DN value of the display. For color images, there will be three values, one for each color.
FILTER_NAME	315, 360, 415, 560, 600, 640, or 680 The FILTER_NAME element provides the commonly used name of the instrument filter through which an image or measurement was acquired or which is associated with a given instrument mode.

Appendix B – Map Projection Equations

Equirectangular Projection

The Equirectangular projection is based on the formula for a sphere. To eliminate confusion in the IMAGE_MAP_PROJECTION object we have set all three values, A_AXIS_RADIUS, B_AXIS_RADIUS, and C_AXIS_RADIUS to the same number.

The Equirectangular projection [7] is a simple projection providing a linear relationship between the geographic coordinates of latitude and longitude and the Cartesian space of the map. In continuous form, the equations relating map coordinates (x, y) to geographic coordinates (Lat, Lon) are:

$$\mathbf{x = R \cdot (Lon - LonP) \cdot COS(LatP)}$$

$$\mathbf{y = R \cdot Lat}$$

where LonP is the center longitude of the map projection, LatP is the center latitude of the projection at which scale is given, and R the radius of the body.

The inverse formulas for Lat and Lon from x and y position in the projection are:

$$\mathbf{Lat = y/R}$$

$$\mathbf{Lon = LonP + x/(R \cdot COS(LatP))}$$

The Conversion from (x, y) map coordinates to image array coordinates (sample, line) is standard for all map projections and is:

$$\mathbf{x = (Sample - S_0) \cdot Scale}$$

$$\mathbf{y = (-L_0 - Line) \cdot Scale}$$

where "Scale" is the map resolution in km/pixel (located at the center planetocentric latitude of the projection). "Line" and "Sample" are the coordinates of the image array, and line (L_0) and sample offsets (S_0) are the respective image coordinate displacements from pixel (1,1) to the origin of the projection (x,y) = (0,0). Please note, pixel (1,1) is spatially located in the upper-left corner of the image array.

The equations from (x, y) to (Sample, Line) are:

$$\mathbf{Sample = x/Scale + S_0 + 1}$$

$$\mathbf{Line = -y/Scale - L_0 + 1}$$

The equation from (Sample, Line) to (Lat, Lon) is:

$$\mathbf{Lat = y/R}$$
$$\mathbf{y\ \ = (1\text{-}L_0\text{-}Line)\cdot Scale}$$
$$\mathbf{Lat = (1\text{-}L_0\text{-}Line)\cdot Scale/R}$$

$$\mathbf{Lon = LonP + x/(R\cdot COS(LatP))}$$
$$\mathbf{x\ \ = (Sample\text{-}S_0\text{-}1)\cdot Scale}$$
$$\mathbf{Lon = LonP + (Sample\text{-}S_0\text{-}1)\cdot Scale/(R\cdot COS(LatP))}$$

The keywords corresponding to the Equirectangular projection parameters are located in the IMAGE_MAP_PROJECTION object found in the PDS labels. The keywords for each equation parameter are shown below

PDS Keywords for corresponding Equirectangular projection equation parameters	
Equation	Keyword
LonP	CENTER_LONGITUDE
LatP	CENTER_LATITUDE
L_0	LINE_PROJECTION_OFFSET
S_0	SAMPLE_PROJECTION_OFFSET
Scale	MAP_SCALE
R	A_AXIS_RADIUS (same as B_AXIS_RADIUS and C_AXIS_RADIUS)

Polar Stereographic Projection

The Polar Stereographic projection [7], used for observations acquired at higher latitudes, is ideally suited for observations near the poles as shape and scale distortion are minimized. The LROC derived products in Polar Stereographic projection use the ellipsoid form of the equations.

In continuous form, the spherical equations relating map coordinates (x, y) to planetocentric coordinates (Lat, Lon) are:

North Polar Stereographic:

$$\mathbf{x = \ 2\cdot R\cdot TAN(Pi/4\text{-}Lat/2)\cdot SIN(Lon\text{-}LonP)}$$

$$\mathbf{y = -2\cdot R\cdot TAN(Pi/4\text{-}Lat/2)\cdot COS(Lon\text{-}LonP)}$$

South Polar Stereographic:

$$\mathbf{x = \ 2\cdot R\cdot TAN(Pi/4+Lat/2)\cdot SIN(Lon\text{-}LonP)}$$

$$\mathbf{y = \ 2\cdot R\cdot TAN(Pi/4+Lat/2)\cdot COS(Lon\text{-}LonP)}$$

Where LonP is the central longitude, LatP is the latitude of true scale and is always 90 or -90, and R is the polar radius of the Moon, or 1,737.4 km.

The spherical inverse formulas for Lat and Lon from X and Y position in the image array are:

$$\mathbf{Lat = ARCSIN[COS(C) \cdot SIN(LatP)+y \cdot SIN(C) \cdot COS(LatP)/P]}$$

North Polar Stereographic:

$$\mathbf{Lon = LonP + ARCTAN[x/(-y)]}$$

South Polar Stereographic:

$$\mathbf{Lon = LonP + ARCTAN[x/y]}$$

where:

$$\mathbf{P = SQRT(x^2 + y^2)}$$
$$\mathbf{C = 2 \cdot ARCTAN(P/2*R)}$$

recall:

$$\mathbf{x = (Sample\text{-}S_0\text{-}1) \cdot Scale}$$
$$\mathbf{y = (1\text{-}L_0\text{-}Line) \cdot Scale}$$

The keywords corresponding to the equation parameters for the Polar Stereographic projection are located in the IMAGE_MAP_PROJECTION object found in the PDS labels. The keywords for each equation parameter are shown above.

Appendix C – Photometric Stereo Products and Methods

Photometric stereo is well known to the artificial intelligence and robotic vision community but not in the planetary science community. Photoclinometry from single images (or shape from shading) is well known, but the problem is unconstrained. The major unknowns are slope, slope azimuth, and the albedo of the surface. Photometric stereo resolves these ambiguities from the use of two or more images of the scene from nearly the same viewing geometry but different illumination angles. Planetary scientists have rarely exploited this technique because few missions have provided more than a rare set of appropriate images.

Even when albedo is uniform there are often two solutions for slope and slope azimuth. This ambiguity can be resolved via use of a 3rd image acquired with different (not co-planar) illumination; albedo can be extracted as well. The solution can be obtained rapidly by creating a three-dimensional lookup table for each triplet of images in which the calibrated intensity of each image is quantized to form the indices, slope, slope azimuth, and albedo are calculated for each triplet of intensities with the photometric function. The slope and slope azimuth solutions form vectors or a "needle diagram" in the three-dimensional table, and albedo is defined by position along the vector. The three images for photometric stereo must be co-registered to sub-pixel accuracy to obtain reliable results at the scale of single pixels. If registration is poor then pixels will be binned to minimize spurious results.

LRO's orbit is ideal for the acquisition of triplets of images appropriate for photometric stereo with the best lighting geometry coming from the latitude bands near ±30˚-70˚ because image triplets with non-coplanar illumination can be easily acquired and there are few large shadows except in the early morning and late afternoon.

Once the output files of slope and slope azimuth are created, it is possible to derive relative elevations by integrating slopes across the image. Low-frequency topography can be corrected to match the best available altimetry values over the scene thereby providing high-resolution absolute elevations relative to the center of mass.

The LROC photometric stereo special products, briefly listed in the table shown below, are experimental products intended to demonstrate the utility of the data collection and the methodology employed in the derivation of high-resolution Digital Elevation Models (DEM). These products are created on a best-effort basis. The techniques are experimental and may produce products that are of insufficient quality to become a suitable product for distribution to the science community within the nominal Exploration System Mission Directorate. Additionally, the products' organization and properties cannot be properly described until future investigations are carried out. Thus, it will not be possible to formally provide these products. The products will contain simple PDS labels that will assist users in understanding these products.

	Description
1	Approximately 100 stereo sets of appropriate illumination and viewing geometries for geometric or photometric stereo that are calibrated and co-registered.
2	A few digital elevation models produced to demonstrate the utility of the photometric stereo methods.

LROC EDR/CDR
DATA PRODUCT
SOFTWARE INTERFACE SPECIFICATION

Version 1.6
December 3, 2008

SCHOOL OF EARTH & SPACE EXPLORATION
ARIZONA STATE UNIVERSITY

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TABLE OF CONTENTS

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
2008/12/03	Moved md5_checksum keyword to image object for each label example (CIsbell)	Section 3.2
2008/12/03	Added 'object' to md5_checksum description	Section 3.3

TBD/TBR ITEMS

Section	Description	Person

Acronyms and Abbreviations

ASCII	American Standard Code for Information Interchange
ASU	Arizona State University
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	Engineering Data Record
I/F	See Appendix A -Glossary
ISIS	Integrated Software for Imagers and Spectrometers
ISO	International Standards Organization
JPL	Jet Propulsion Laboratory
LDWG	LRO Data Working Group
LROC	Lunar Reconnaissance Orbiter Camera
MD5	Message Digest algorithm 5
ME	Mean Earth
MET	Mission Elapsed Time
Mini-RF	Mini-Radio Frequency Technology Demonstration
NAC	Narrow Angle Camera
NSSDC	National Space Science Data Center
PDS	Planetary Data System
PSG	Project Science Group
SDVT	Science Data Validation Team
SIS	Software Interface Specification
SOC	Science Operations Center
TBD	To Be Determined
TBR	To Be Reviewed
UV	Ultra-Violet
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 camera components (NACs), a wide-angle camera component (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 5000-pixel CCD line-array providing a cross-track field-of-view (FOV) of 2.86°. The NAC readout noise is better than 100 e^- and the data are sampled at 12 bits. By ground command, these 12-bit pixel values are companded to 8-bit pixels using one of several selectable lookup tables during readout from the CCD. The NAC internal buffer holds 256 MB of uncompressed data, enough for a full-swath image 25-km long or a 2x2 binned image 100-km long. NAC specifications are summarized in Table 2.1.

The WAC electronics are 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 1000 x 1000 pixel, electronically shuttered CCD area-array, one imaging in the visible/near infrared (VIS), and the other in the Ultraviolet (UV). The VIS optics have a cross-track FOV of 90° and the UV optics a 60° FOV. From the nominal 50-km orbit, the WAC will provide a nadir, ground sample distance of 75-m/pixel in the visible, and a swath width of ~75 km. 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 40 e^- and, as with the NAC, pixel values are digitized to 12-bits and are then commanded to 8-bit values through selectable lookup tables. WAC specifications are summarized in Table 2.2. The two UV bands (315 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 400-m/pixel sampling but have improved signal properties. Only the center 704 pixels for the visible are digitized when all seven bands are being acquired. WAC band passes are collected UV then VIS (315, 360, 415, 560, 600, 640, 680), 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 2.4). 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.

Each NAC has an estimated mass of 5.4 kg, the WAC is 0.6 kg, and the SCS is 0.6 kg, for a total LROC mass of 12 kg. Each NAC will use 10 W during image acquisition or readout, 6 W at all other times; the WAC will use 4 W (continuous), and the SCS will use 6 W (continuous), for a total LROC power dissipation of 30 W peak, 22 W average.

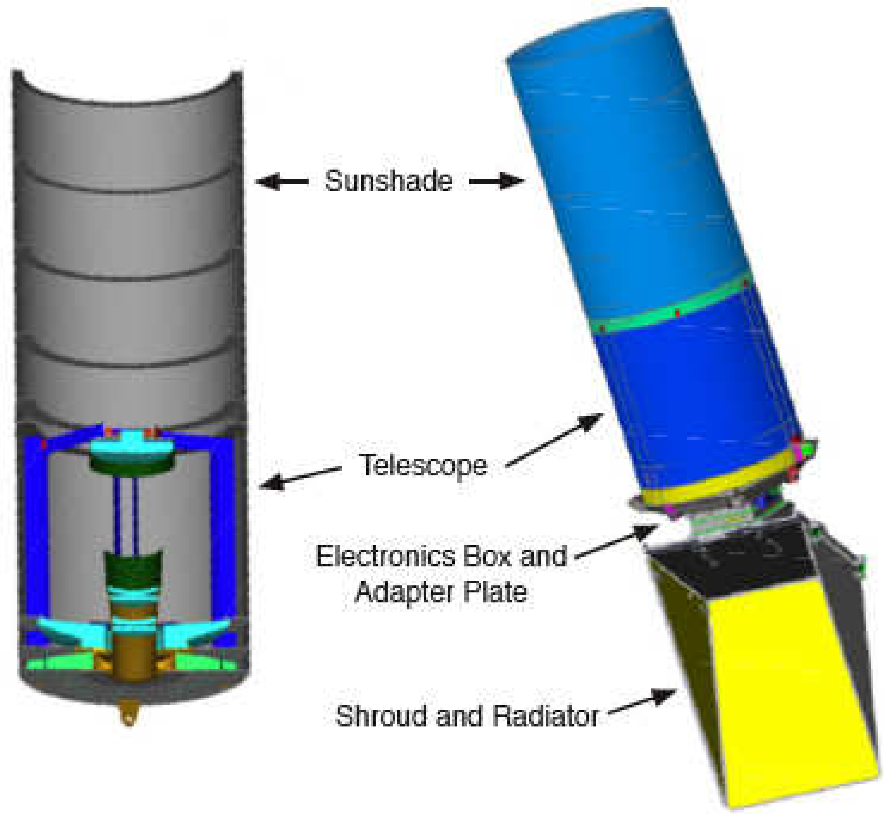

Figure 2.1 - LROC Narrow Angle Camera, 70 cm by 24 cm diameter.

Table 2.1 – NAC Specifications	
Image scale	0.5 meter per pixel (10 micro-radian IFOV)
Maximum Image size	2.5 x 25 km
Optics	f/3.59 Cassegrain (Ritchey-Chretien)
Effective Focal Length	700 mm
Primary Mirror Diameter	195 mm
FOV	2.86°(0.05 radian) per NAC
MTF (Nyquist)	> 0.20
Structure + baffle	Graphite-cyanate composite
Detector	Kodak KLI-5001G
Pixel format	1 x 5,000*
Noise	100 e-
Analog/Digital Converter	Honeywell ADC9225
FPGA	Actel RT54SX32-S
Volume	70 cm x 26 cm diameter
Peak Power	10 W
Average Power	6 W
Spectral Response	400-750 nm

* CCD specification is actually 5056 pixels, with 32 on the right and left representing dark reference pixels. TBD if these pixels will be recorded into image file.

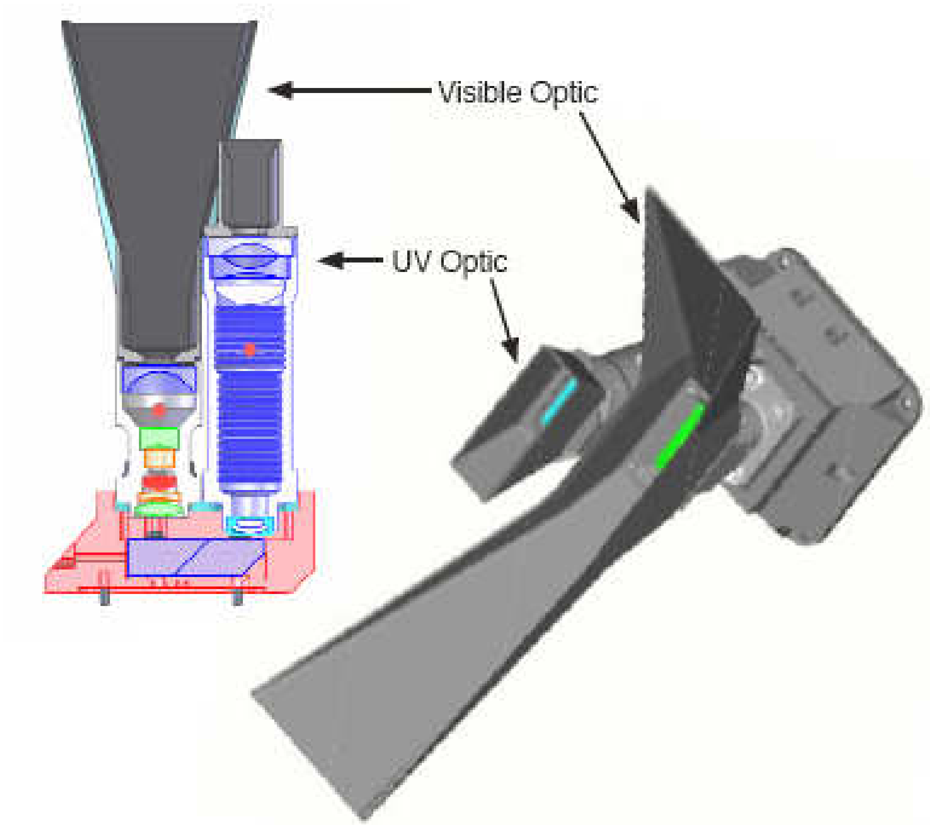

Figure 2.2. - LROC Wide Angle Camera

Table 2.2 – WAC Specifications	
Image format	1024 x 16 pixels monochrome (push frame) 704 x 16 pixels 7-filter color (push frame)
Image scale	1.5 milliradian, 75 meters/pixel nadir (vis) 2.0 milliradian, 400 meters/pixel nadir (UV, 4x binned)
Image frame width (km)	110 km (vis monochrome) 88 km (vis color) 88 km (UV)
Optics	f/5.1 (vis) f/5.3 (UV)
Effective Focal Length	6.0 mm (vis), 4.6 mm (UV)
Entrance Pupil Diameter	1.19 mm (vis), 0.85 mm (UV)
Field of View	90° (vis) 60° (UV)
System MTF (Nyquist)	> 0.2
Electronics	4 circuit boards
Detector	Kodak KLI-1001
Pixel format	1,024 x 1,024 *

Table 2.2 – WAC Specifications	
Noise	50 e-
Volume	14.5 cm x 9.2 cm x 7.6 cm
Peak Power	4 W
Average Power	4 W
Filters	315 nm 360 nm 415 nm 560 nm 600 nm 640 nm 680 nm

** In BW mode, 1024 pixels are read out. In color mode only the center 704 VIS pixels are read out.*

Table 2. WAC specifications.

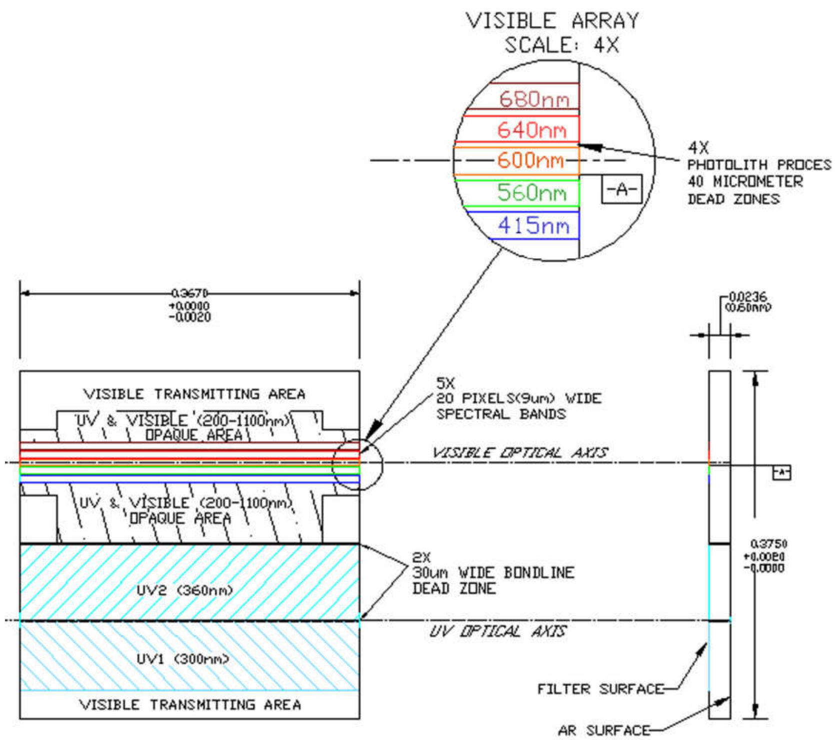

Figure 2.3 - Diagram of LROC Wide Angle Camera filter assembly.

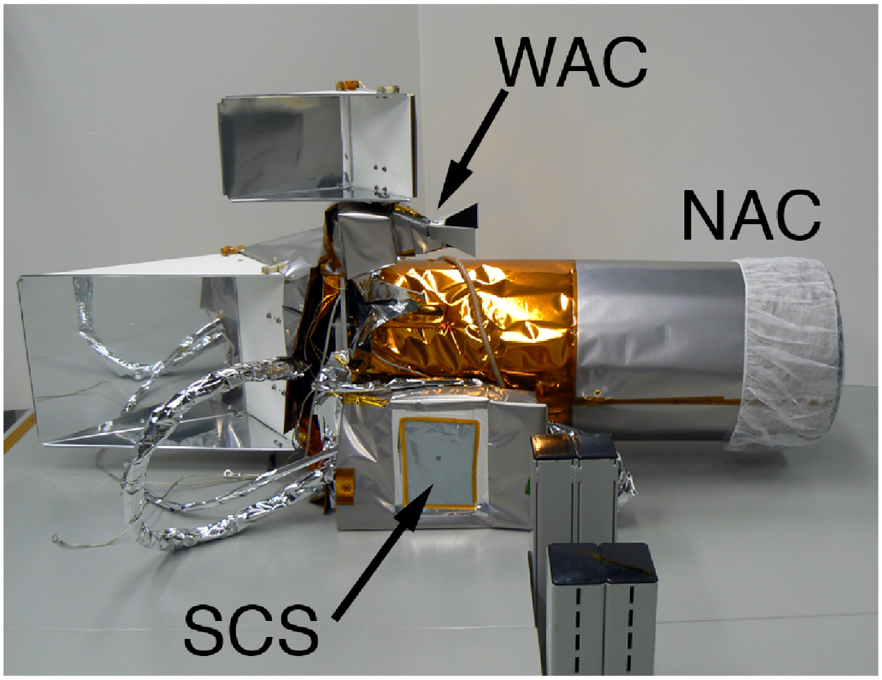

Figure 2.4 - LROC components include the WAC, NAC, and Sequence and Compressor System (SCS).

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 un-summed or summed), with Digital Numbers (DN) counts in a 12-bit to 8-bit companded format. The NAC EDR file size will be a maximum of 256MB for the un-summed 50000 lines or summed 100,000 lines. NAC EDR file sizes will be smaller when fewer lines are acquired.
b. WAC image corresponding to a series of framelet images, with DN counts in a 12-bit to 8-bit companded format. Each framelet is in row-major order. The WAC EDR file size will not exceed 256MB, which corresponds to observing 18.5º of latitude in multi-spectral mode. The WAC exposure and/or inter-frame gap parameters will be modified approximately every 10º of latitude, resulting in an average file size of 139MB. It is important to note that the WAC EDR stores multi-spectral framelets in single band, not as seperate bands with the EDR file.

LROC CDR data products are comprised of the following files:

a. NAC panchromatic image corresponding to a single observation (either un-summed or summed), with un-companded DNs, radiometrically calibrated to radiance or I/F. The NAC CDR file size will be a maximum of 512MB for the decompanded, un-summed 50000 lines or decompanded, summed 100,000 lines. NAC CDR file sizes will be smaller when fewer lines are acquired.
b. WAC image corresponding to a series of framelet images, with un-companded DNs, radiometrically calibrated to radiance or I/F. The WAC CDR file size will not exceed a maximum of 512MB, which corresponds to observing 18.5º of latitude in multi-spectral

mode. The WAC exposure and/or inter-frame gap parameters will be modified approximately every 10º of latitude, resulting in an average file size of 278MB. It is important to note that the WAC EDR stores multi-spectral framelets in single band, not as seperate bands the 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 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 300Gbits 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 is 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, 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 Conductor framework, to allow for scaleable growth as processing needs grow and 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 about each EDR and CDR file that is processed will be recorded into a PostgreSQL database, which is then be used for the generation of each archive delivery. Archive deliveries are pushed from our production storage array onto a data node storage array, where the data is accessible (in read-only mode) by the LROC PDS data node (http://lroc.sese.asu.edu).

NAC and WAC data should not experience issues with 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 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 4).

2.3.2. Data Product Generation

The data processing pipeline, executed within the LROC SOC, ingests image files and engineering data, and then combines them with meta-data contained in a relational database, to generate products described by this SIS. LROC image data are companded from 12bit to 8bit, and then losslessly compressed before being written to the spacecraft data recorder.

The processing pipeline can be run multiple iterations to account for discovered software bugs 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 by revised software and made available.

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 science files consist of 8-bit companded pixels as read out from the camera. The image is all of the even pixels from each line (with a 20-byte CTX-heritage header every 1M=1024*1024 bytes) and padded to a 1M 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 that combined with the binary data to product the EDR file.

The NAC EDR file is then read in so that the data steam can be uncompanded from 8bit to 16bit. A radiometric calibration is performed on uncompanded DN values, and the resulting data stream is then written out as a PDS compliant CDR file.

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 product the EDR file.

The WAC EDR file is then read in so that the data steam can be uncompanded from 8bit to 16bit. A radiometric calibration is performed on uncompanded DN values, and the resulting data stream is then written out as a PDS compliant CDR file.

2.3.3. Data Flow

LROC NAC observations are stored in individual files that correspond to one of the two NAC detectors. Each 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 down-linked through the Ka band antenna at Whites Sands, N.M., then sent to LRO MOC at Goddard Space Flight Center (GSFC), while real-time telemetry is down-linked via S-band antenna at various locations then transferred to the MOC which then sends the stream to the LROC SOC. 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, including a version number for 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 two fields: SSSSSSSSSS:FFFFF. 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                   = nn
FILE_RECORDS                   = nn
LABEL_RECORDS                  = nn
^IMAGE                         = nn

/* DATA IDENTIFICATION */
DATA_SET_ID                    = "LRO-L-LROC-2-EDR-V1.0"
ORIGINAL_PRODUCT_ID            = "0x76a"
PRODUCT_ID                     = "M010368000LE"
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                     = CCYY-MM-DDThh:mm:ss.sss
STOP_TIME                      = CCYY-MM-DDThh:mm:ss.sss
SPACECRAFT_CLOCK_START_COUNT   = sclk string
SPACECRAFT_CLOCK_STOP_COUNT    = “N/A”
```

```
ORBIT_NUMBER                  = nnnnn
PRODUCER_ID                   = "LRO_LROC_TEAM"
PRODUCT_CREATION_TIME         = CCYY-MM-DDThh:mm:ss.sss
PRODUCER_INSTITUTION_NAME     = "ARIZONA STATE UNIVERSITY"
PRODUCT_TYPE                  = EDR
PRODUCT_VERSION_ID            = "V001"
UPLOAD_ID                     = "command file id"

/* DATA DESCRIPTION */
CROSSTRACK_SUMMING            = 1
RATIONALE_DESC                = List of keywords captured in REACT or the
                                string "TARGET OF OPPORTUNITY"
DATA_QUALITY_ID               = 00000000
TARGET_NAME                   = "MOON"
FRAME_ID                      = “LEFT”
LRO:TEMPERATURE_SCS_RAW       =
LRO:TEMPERATURE_SCS           = <degC>
LRO:TEMPERATURE_FPA_RAW       =
LRO:TEMPERATURE_FPA           = <degC>
LRO:TEMPERATURE_FPGA_RAW      =
LRO:TEMPERATURE_FPGA          = <degC>
LRO:TEMPERATURE_TELESCOPE_RAW =
LRO:TEMPERATURE_TELESCOPE     = <degC>
LINE_EXPOSURE_DURATION        = fffff.f
LRO:LOOKUP_TABLE_TYPE         = "STORED"
LRO:LOOKUP_CONVERSION_TABLE   = <replace with companding table used>

/* DATA OBJECT */
OBJECT                        = IMAGE
  LINES                       = 0
  LINE_SAMPLES                = 0
  SAMPLE_BITS                 = 8
  SAMPLE_TYPE                 = LSB_INTEGER
  MD5_CHECKSUM                = "CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC"
END_OBJECT

END
```

3.2.2. Example label for LROC NAC CDR product:

```
PDS_VERSION_ID                = PDS3

/* FILE CHARACTERISTICS */
RECORD_TYPE                   = FIXED_LENGTH
RECORD_BYTES                  = nn
FILE_RECORDS                  = nn
LABEL_RECORDS                 = nn
^IMAGE                        = nn

/* DATA IDENTIFICATION */
DATA_SET_ID                   = "LRO-L-LROC-3-CDR-V1.0"
ORIGINAL_PRODUCT_ID           = "0x76a"
PRODUCT_ID                    = "M010368000RC"
MISSION_NAME                  = "LUNAR RECONNAISSANCE ORBITER"
MISSION_PHASE_NAME            = "COMMISSIONING"
INSTUMENT_HOST_NAME           = "LUNAR RECONNAISSANCE ORBITER"
INSTRUMENT_HOST_ID            = LRO
INSTRUMENT_NAME               = "LUNAR RECONNAISSANCE ORBITER CAMERA"
INSTRUMENT_ID                 = ”LROC”
START_TIME                    = CCYY-MM-DDThh:mm:ss.sss
STOP_TIME                     = CCYY-MM-DDThh:mm:ss.sss
SPACECRAFT_CLOCK_START_COUNT  = sclk string
```

```
SPACECRAFT_CLOCK_STOP_COUNT   = “N/A”
ORBIT_NUMBER                  = nnnnn
PRODUCER_ID                   = "LRO_LROC_TEAM"
PRODUCT_CREATION_TIME         = CCYY-MM-DDThh:mm:ss.sss
PRODUCER_INSTITUTION_NAME     = "ARIZONA STATE UNIVERSITY"
PRODUCT_TYPE                  = EDR
PRODUCT_VERSION_ID            = "V001"
UPLOAD_ID                     = "command file id"

/* DATA DESCRIPTION */
CROSSTRACK_SUMMING            = 1
RATIONALE_DESC                = List of keywords captured in REACT or the
                                string "TARGET OF OPPORTUNITY"
DATA_QUALITY_ID               = 00000000
TARGET_NAME                   = "MOON"
FRAME_ID                      = “RIGHT”
LRO:TEMPERATURE_SCS_RAW       = nnnn
LRO:TEMPERATURE_SCS           = <degC>
LRO:TEMPERATURE_FPA_RAW       = nnnn
LRO:TEMPERATURE_FPA           = <degC>
LRO:TEMPERATURE_FPGA_RAW      = nnnn
LRO:TEMPERATURE_FPGA          = <degC>
LRO:TEMPERATURE_TELESCOPE_RAW = nnnn
LRO:TEMPERATURE_TELESCOPE     = <degC>
LINE_EXPOSURE_DURATION        = fffff.f
LRO:LOOKUP_TABLE_TYPE         = "STORED"
LRO:LOOKUP_CONVERSION_TABLE   = <replace with companding table used>

/* DATA OBJECT */
OBJECT                        = IMAGE
  LINES                       = 0
  LINE_SAMPLES                = 0
  SAMPLE_BITS                 = 16
  SAMPLE_TYPE                 = LSB_INTEGER
  MD5_CHECKSUM                = "CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC"
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                  = nn
FILE_RECORDS                  = nn
LABEL_RECORDS                 = nn
^IMAGE                        = nn

/* DATA IDENTIFICATION */
DATA_SET_ID                   = "LRO-L-LROC-2-EDR-V1.0"
ORIGINAL_PRODUCT_ID           = "0x66a"
PRODUCT_ID                    = "M010368000CE"
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                    = CCYY-MM-DDThh:mm:ss.sss
```

```
STOP_TIME                        = CCYY-MM-DDThh:mm:ss.sss
SPACECRAFT_CLOCK_START_COUNT     = sclk string
SPACECRAFT_CLOCK_STOP_COUNT      = “N/A”
ORBIT_NUMBER                     = nnnnn
PRODUCT_CREATION_TIME            = CCYY-MM-DDThh:mm:ss.sss
PRODUCER_ID                      = "LRO_LROC_TEAM"
PRODUCER_INSTITUTION_NAME        = "ARIZONA STATE UNIVERSITY"
PRODUCT_TYPE                     = EDR
PRODUCT_VERSION_ID               = "V001"
UPLOAD_ID                        = "command file id"

/* DATA DESCRIPTION */
RATIONALE_DESC                   = "TEST IMAGE, N/A RATIONALE"
DATA_QUALITY_ID                  = 00000000
TARGET_NAME                      = "MOON"
LRO:BEGIN_TEMPERATURE_SCS_RAW          = nnnn
LRO:BEGIN_TEMPERATURE_SCS              = <degC>
LRO:BEGIN_TEMPERATURE_FPA_RAW          = nnnn
LRO:BEGIN_TEMPERATURE_FPA              = <degC>
LRO:MIDDLE_TEMPERATURE_SCS_RAW         = nnnn
LRO:MIDDLE_TEMPERATURE_SCS             = <degC>
LRO:MIDDLE_TEMPERATURE_FPA_RAW         = nnnn
LRO:MIDDLE_TEMPERATURE_FPA             = <degC>
LRO:END_TEMPERATURE_SCS_RAW            = nnnn
LRO:END_TEMPERATURE_SCS                = <degC>
LRO:END_TEMPERATURE_FPA_RAW            = nnnn
LRO:END_TEMPERATURE_FPA                = <degC>
LINE_EXPOSURE_DURATION           = f.ffff
INTERFRAME_DELAY                 = f.ffffff
INSTRUMENT_MODE_ID               = "BW" or "COLOR" or "UV" or "VIS"
FILTER_NUMBER                    = (4) or (5) (1,2,3,4,5,6,7) or (1,2) or
                                   (3,4,5,6,7)
FILTER_NAME                      = (560) or (600) or (315, 360, 415, 560, 600,
                                   640, 680) or (315, 360) or (415, 560, 600,
                                   640, 680)
LRO:LOOKUP_TABLE_TYPE            = "STORED"
LRO:LOOKUP_CONVERSION_TABLE      = <replace with companding table used>

/* DATA OBJECT */
OBJECT                           = IMAGE
  LINES                          = 0
  LINE_SAMPLES                   = 0
  SAMPLE_BITS                    = 8
  SAMPLE_TYPE                    = LSB_INTEGER
  MD5_CHECKSUM                   = "CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC"
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                     = nn
FILE_RECORDS                     = nn
LABEL_RECORDS                    = nn
^IMAGE                           = nn

/* DATA IDENTIFICATION */
```

```
DATA_SET_ID                   = "LRO-L-LROC-3-CDR-V1.0"
ORIGINAL_PRODUCT_ID           = "0x66a"
PRODUCT_ID                    = "M010368000MC"
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                    = CCYY-MM-DDThh:mm:ss.sss
STOP_TIME                     = CCYY-MM-DDThh:mm:ss.sss
SPACECRAFT_CLOCK_START_COUNT  = sclk string
SPACECRAFT_CLOCK_STOP_COUNT   = “N/A”
ORBIT_NUMBER                  = nnnnn
PRODUCT_CREATION_TIME         = CCYY-MM-DDThh:mm:ss.sss
PRODUCER_ID                   = "LRO_LROC_TEAM"
PRODUCER_INSTITUTION_NAME     = "ARIZONA STATE UNIVERSITY"
PRODUCT_TYPE                  = CDR
PRODUCT_VERSION_ID            = "V001"
UPLOAD_ID                     = "command file id"

/* DATA DESCRIPTION */
RATIONALE_DESC                = "TEST IMAGE, N/A RATIONALE"
DATA_QUALITY_ID               = 00000000
TARGET_NAME                   = "MOON"
LRO:BEGIN_TEMPERATURE_SCS_RAW       = nnnn
LRO:BEGIN_TEMPERATURE_SCS           = <degC>
LRO:BEGIN_TEMPERATURE_FPA_RAW       = nnnn
LRO:BEGIN_TEMPERATURE_FPA           = <degC>
LRO:MIDDLE_TEMPERATURE_SCS_RAW      = nnnn
LRO:MIDDLE_TEMPERATURE_SCS          = <degC>
LRO:MIDDLE_TEMPERATURE_FPA_RAW      = nnnn
LRO:MIDDLE_TEMPERATURE_FPA          = <degC>
LRO:END_TEMPERATURE_SCS_RAW         = nnnn
LRO:END_TEMPERATURE_SCS             = <degC>
LRO:END_TEMPERATURE_FPA_RAW         = nnnn
LRO:END_TEMPERATURE_FPA             = <degC>
LINE_EXPOSURE_DURATION        = f.ffff
INTERFRAME_DELAY              = f.ffffff
INSTRUMENT_MODE_ID            = "BW" or "COLOR" or "UV" or "VIS"
FILTER_NUMBER                 = (4) or (5) (1,2,3,4,5,6,7) or (1,2) or
                                (3,4,5,6,7)
FILTER_NAME                   = (560) or (600) or (315, 360, 415, 560, 600,
                                640, 680) or (315, 360) or (415, 560, 600,
                                640, 680)
LRO:LOOKUP_TABLE_TYPE         = "STORED"
LRO:LOOKUP_CONVERSION_TABLE   = <replace with companding table used>

/* DATA OBJECT */
OBJECT                        = IMAGE
  LINES                       = 0
  LINE_SAMPLES                = 0
  SAMPLE_BITS                 = 16
  SAMPLE_TYPE                 = LSB_INTEGER
  MD5_CHECKSUM                = "CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC"
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-V1.0. For CDR products, set to LRO-L-LROC-3-CDR-V1.0.

ORIGINAL_PRODUCT_ID

Product ID of this image as received from the LRO MOC. Example LROC_YYYYDDD_TTTTHHHHHHHH.sci, where YYYY is the year, DDD is the day of year, TTTT is the LROC instrument (NAC_L, NAC_R, WAC) and HHHHHHHH is the hex encoded Image ID.

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, or (C)olor 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”.

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.

SPACECRAFT_CLOCK_START_COUNT

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

SPACECRAFT_CLOCK_STOP_COUNT
Not applicable to NAC or WAC observation timing.
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, starting at V001 and incremented for each version released.
UPLOAD_ID
The identifier for the command load used to acquire this image.
CROSSTRACK_SUMMING
Indicates if NAC observation was taken with crosstrack summing (2) or no crosstrack summing (1). Keyword only applies to NAC products.
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.
DATA_QUALITY_ID
Set to an 8-bit value which encodes data quality information for the observation. The 8-bit value is interpreted as:
Bit 1: Records if temperature is out of bounds for focal plane array.
0 = nominal temperature
1 = out-of-bounds
Bit 2: Records if threshold for saturated pixels is reached (> 0.1% of total pixels).
0 = saturated pixel count is below 0.1% threshold
1 = saturated pixel count is equal to or greater than 0.1% threshold
Bit 3: Records if threshold for under-saturated pixels is reached (> 0.1% of total pixels).
0 = under-saturated pixel count is below 0.1% threshold
1 = under-saturated pixel counts is equal to or greater than 0.1% threshold
Bit 4: Records if observation is missing telemetry packets.
0 = no missing telemetry packets
1 = missing telemetry packets
Bit 5: Records if SPICE information is bad or missing for observation acquisition time.
0 = no bad or missing SPICE information for observation
1 = bad or missing SPICE information for observation
Bit 6: Records if observation or spacecraft housekeeping information is bad or missing for observation acquisition time.
0 = no bad or missing observation or spacecraft housekeeping information

1= bad or missing observation or spacecraft housekeeping information

Bit 7: Spare

Bit 8: Spare

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.

LRO:TEMPERATURE_SCS_RAW

Set to the raw engineering counts for the LROC SCS.

LRO:TEMPERATURE_SCS

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

LRO:TEMPERATURE_FPA_RAW

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

LRO:TEMPERATURE_FPA

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

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:BEGIN_TEMPERATURE_SCS

Set to the temperature of the LROC SCS in degrees C, as converted from the raw engineering counts, at the beginning 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:BEGIN_TEMPERATURE_FPA

Set to the temperature of the LROC FPA in degrees C, as converted from the raw engineering counts, 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:MIDDLE_TEMPERATURE_SCS

Set to the temperature of the LROC SCS in degrees C, as converted from the raw engineering counts, at the middle 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:MIDDLE_TEMPERATURE_FPA

Set to the temperature of the LROC FPA in degrees C, as converted from the raw engineering counts, 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:END_TEMPERATURE_SCS

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

LRO:END_TEMPERATURE_FPA

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

LRO:TEMPERATURE_FPGA_RAW

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

LRO:TEMPERATURE_FPGA

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

LRO:TEMPERATURE_TELESCOPE_RAW

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

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.

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.

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

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.

FRAME_ID

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

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.

FILTER_NAME

Records the WAC filter names taken during an observation, which corresponds to the FILTER_NUMBER: (560) or (600) or (315,360,415,560,600,640,680) or (315,360,415,560,600) or (640,680).

LRO:LOOKUP_TABLE_TYPE

Always set to STORED.

LRO:LOOKUP_CONVERSION_TABLE

The table defines the translation from 8-bit back to 12-bit pixels. There are 256 pairs of values in the table. The first pair in the table corresponds to the range of 12-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= ((0,100), (101,200), (201,300),...)

Input pixel values 0-100 were mapped to output DN value 0, 101-200 mapped to DN value 1, 201-300 mapped to DN 2, etc.)

MD5_CHECKSUM

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

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 EDR products and set to 16-bit for CDR products.

SAMPLE_TYPE

Always set to LSB_INTEGER.

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) which 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 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 Lookup Table

NAC square-root companding table:

8-bit	12-bit
0	0
1	2
2	4
3	6
4	8
5	10
6	12
7	14
8	16
9	18
10	20
11	22
12	24
13	26
14	28
15	30
16	32
17	36
18	40
19	44
20	48
21	52
22	56
23	60
24	64
25	68
26	72
27	76
28	80
29	84
30	88
31	92
32	96
33	100
34	104
35	108
36	112
37	116
38	120
39	124
40	128

41	132
42	136
43	144
44	152
45	160
46	168
47	176
48	184
49	192
50	200
51	208
52	216
53	224
54	232
55	240
56	248
57	256
58	264
59	272
60	280
61	288
62	296
63	304
64	312
65	320
66	328
67	336
68	344
69	352
70	360
71	368
72	376
73	384
74	392
75	400
76	408
77	416
78	424
79	432
80	440
81	448
82	456
83	464
84	472
85	480
86	488

87	496
88	504
89	512
90	520
91	528
92	536
93	552
94	568
95	584
96	600
97	616
98	632
99	648
100	664
101	680
102	696
103	712
104	728
105	744
106	760
107	776
108	792
109	808
110	824
111	840
112	856
113	872
114	888
115	904
116	920
117	936
118	952
119	968
120	984
121	1000
122	1016
123	1032
124	1048
125	1064
126	1080
127	1096
128	1112
129	1128
130	1144
131	1160
132	1176

133	1192
134	1208
135	1224
136	1240
137	1256
138	1272
139	1288
140	1304
141	1320
142	1336
143	1352
144	1368
145	1384
146	1400
147	1416
148	1432
149	1448
150	1464
151	1480
152	1496
153	1512
154	1528
155	1544
156	1560
157	1576
158	1592
159	1608
160	1624
161	1640
162	1656
163	1672
164	1688
165	1704
166	1720
167	1736
168	1752
169	1768
170	1784
171	1800
172	1816
173	1832
174	1848
175	1864
176	1880
177	1896
178	1912

179	1928
180	1944
181	1960
182	1976
183	1992
184	2008
185	2024
186	2040
187	2056
188	2072
189	2088
190	2104
191	2120
192	2136
193	2152
194	2168
195	2184
196	2200
197	2232
198	2264
199	2296
200	2328
201	2360
202	2392
203	2424
204	2456
205	2488
206	2520
207	2553
208	2585
209	2617
210	2649
211	2681
212	2713
213	2746
214	2778
215	2810
216	2842
217	2874
218	2906
219	2938
220	2970
221	3002
222	3035
223	3067
224	3099

225	3131
226	3163
227	3195
228	3227
229	3259
230	3292
231	3324
232	3356
233	3388
234	3420
235	3452
236	3484
237	3516
238	3548
239	3581
240	3613
241	3645
242	3677
243	3709
244	3741
245	3773
246	3805
247	3838
248	3870
249	3902
250	3934
251	3966
252	3998
253	4030
254	4062
255	4095

WAC square-root companding table:

8-bit	11-bit
0	0
1	3
2	6
3	9
4	12
5	15
6	18
7	21
8	24
9	27

10	30
11	33
12	36
13	39
14	42
15	45
16	48
17	51
18	54
19	57
20	60
21	63
22	66
23	69
24	72
25	75
26	78
27	81
28	84
29	87
30	90
31	93
32	96
33	99
34	102
35	105
36	108
37	111
38	114
39	117
40	120
41	127
42	132
43	138
44	143
45	149
46	154
47	160
48	165
49	171
50	176
51	182
52	187
53	193
54	198
55	204

56	209
57	215
58	220
59	226
60	231
61	237
62	242
63	248
64	253
65	259
66	264
67	270
68	275
69	281
70	286
71	292
72	297
73	303
74	308
75	314
76	319
77	325
78	330
79	336
80	341
81	347
82	352
83	358
84	363
85	369
86	374
87	380
88	385
89	391
90	396
91	402
92	407
93	413
94	418
95	424
96	429
97	435
98	440
99	446
100	451
101	457

102	462
103	468
104	474
105	481
106	489
107	497
108	505
109	513
110	520
111	528
112	536
113	544
114	552
115	559
116	567
117	575
118	583
119	591
120	598
121	606
122	614
123	622
124	630
125	637
126	645
127	653
128	661
129	669
130	676
131	684
132	692
133	700
134	708
135	715
136	723
137	731
138	739
139	747
140	754
141	762
142	770
143	778
144	786
145	793
146	801
147	809

148	817
149	825
150	832
151	840
152	848
153	856
154	864
155	871
156	879
157	887
158	895
159	903
160	910
161	918
162	926
163	934
164	942
165	949
166	957
167	965
168	973
169	981
170	990
171	1000
172	1011
173	1021
174	1032
175	1042
176	1053
177	1063
178	1074
179	1084
180	1095
181	1105
182	1116
183	1126
184	1137
185	1147
186	1158
187	1168
188	1179
189	1189
190	1200
191	1210
192	1221
193	1231

194	1242
195	1252
196	1263
197	1273
198	1284
199	1294
200	1305
201	1315
202	1326
203	1336
204	1347
205	1357
206	1368
207	1378
208	1389
209	1399
210	1410
211	1420
212	1431
213	1441
214	1452
215	1462
216	1473
217	1483
218	1494
219	1504
220	1515
221	1525
222	1536
223	1546
224	1557
225	1567
226	1578
227	1588
228	1599
229	1609
230	1620
231	1630
232	1641
233	1651
234	1662
235	1672
236	1683
237	1693
238	1704
239	1714

240	1725
241	1735
242	1746
243	1756
244	1767
245	1782
246	1800
247	1817
248	1835
249	1853
250	1870
251	1888
252	1906
253	1924
254	1941
255	2047