# LUNAR RECONNAISSANCE ORBITER: INSTRUMENT SUITE AND OBJECTIVES

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**Abstract.** The Lunar Reconnaissance Orbiter (LRO) is the first mission in NASA's Vision for Space Exploration, a plan to return to the moon and then to travel to Mars and beyond. LRO will launch in late 2008 with the objectives to finding safe landing sites, locate potential resources, characterize the radiation environment, and demonstrate new technology. The spacecraft will be placed in low polar orbit (50 km) for a 1-year mission under NASA's Exploration Systems Mission Directorate. LRO will return global data, such as day night temperature maps, a global geodetic grid, high resolution color imaging and the moon's UV albedo. However there is particular emphasis on the polar regions of the moon where continuous access to solar illumination may be possible and the prospect of water in the permanently shadowed regions at the poles may exist. Although the objectives of LRO are explorative in nature, the payload includes instruments with considerable heritage from previous planetary science missions, enabling transition to a science phase under NASA's Science Mission Directorate. Here, we will introduce each of the instruments and give an overview of their objectives. The spacecraft and mission design is discussed in a companion paper presented at this conference.

## I. Introduction

Since the Apollo and Luna programs ended in the 1972 and 1976 the moon has been largely ignored by the space science and exploration communities with respect to robotic exploration missions. Over a period of 30 years only four orbiter missions to the moon have been undertaken. These were the Hiten, Clementine, Lunar Prospector and the Smart 1 missions. Meanwhile, the world's space faring nations have launched 15 space-craft to Mars including seven (2 successful) missions to the surface of Mars. The success of the Apollo and Russian Luna programs explains to a large degree the low priority given to lunar exploration. These missions returned mineral samples and conducted extensive remote sensing of the surface particularly in the equatorial regions. Through these data and those gathered by observations from the Earth, a consensus for the origin of the moon and its development has largely been reached. At the same time there were and remain many outstanding and important unanswered questions about the rest of the solar system that have drawn the attention of researchers. Also one should not fully discount a certain sense that further lunar research would be anticlimactic. Having sent humans to the Moon it has been difficult to generate universal excitement for continued robotic missions there, whatever the science value. Nevertheless, for as much as we have learned about our nearest celestial neighbor, we are now in the curious situation where in certain aspects we know more about Mars than we do the moon. We have better gravity maps for Mars, we have better topography and in the moons polar regions and on the farside our maps of the moon are poor with up to several kilometers uncertainty in the location of lunar features.

Over the coming years these deficiencies will be addressed as the world has turned its attention back to the moon. The Lunar Reconnaissance Orbiter (LRO) represents the first mission from NASA's Vision for Space Exploration, a program to return to the moon and then to Mars. The LRO mission joins host of new orbiter missions to the moon that are likely to be followed by robotic landers and eventually with a return of humans to the surface. The LRO mission focuses on preparing for a future landing on the moon. Its primary goals are to search out safe landing sites near potential lunar resources. LRO is scheduled for an October 2008 launch date, and the mission will have a duration of 14 months, including a 2 month commissioning phase after which operations will be transferred from NASA's Exploration Systems Mission Directorate to the Science Mission Directorate. The spacecraft carries a suite of 6 instruments as well as an advanced radar experiment as a technology demonstration. The instrument payload include the Cosmic Ray Telescope for the Effects of Radiation (CRaTER), the Diviner Lunar Radiometer Experiment (DLRE), Lyman Alpha Mapping Project (LAMP), Lunar Exploration Neutron Detector (LEND), Lunar Orbiter Laser Altimeter (LOLA), the Lunar Reconnaissance Orbital Camera (LROC), and the Miniature Radio Frequency Technology Demonstration (Mini-RF).

## 2. LRO measurement Objectives

The instrument suite was selected through a competitive process that solicited the LRO investigations to provide the following high quality measurement sets:

- Characterization of the deep space radiation environment in lunar orbit, including neutron albedo (especially at energies in excess of 10 MeV, as well as: characterization of biological effects caused by exposure to the lunar orbital radiation environment and characterization of changes in the properties of multifunctional radiation shielding materials caused by extended exposure to the lunar orbital environment
- Geodetic lunar global topography (at landing-site relevant scales)
- High spatial resolution hydrogen mapping of the Moon's surface
- Temperature mapping in the Moon's polar shadowed regions
- Landform-scale imaging of lunar surfaces in permanently shadowed regions
- Identification of putative deposits of appreciable near-surface water ice in the Moon's polar cold traps
- Assessment of meter and smaller-scale features to facilitate safety analysis for potential lunar landing sites
- Characterization of the illumination environment in the Moon's polar regions at relevant temporal scales

The explorative nature of the mission is revealed in the solicitation, and the mission objectives were further refined by the ultimate selection of the instruments. LRO focuses on four objectives: 1) finding safe landing sites 2) locate potential resources 3) characterize the radiation environment, and 4) demonstrate new technology. Each of the instruments contributes to one or more of these objectives. While focusing on exploration the instrument suite is well suited for scientific investigations as well. The instruments possess a high level of heritage from previous science-focused planetary missions which enables the

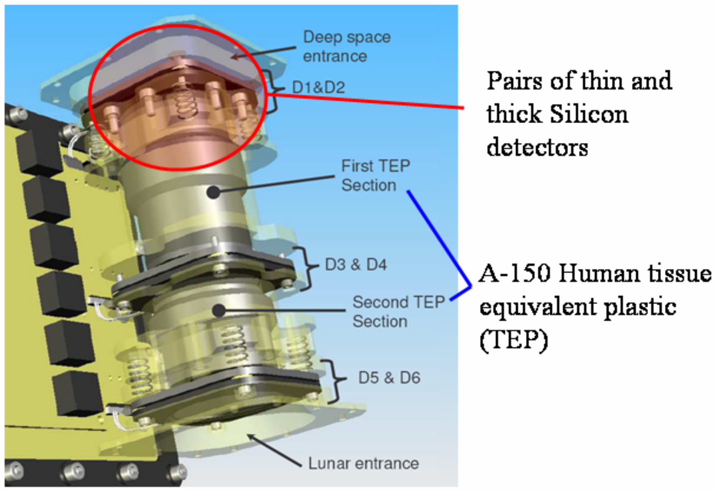


**Fig. 1. CRaTER Measurement Concept**

transition, after the first year of operation, to NASA's Science Mission Directorate. All data collected during the LRO mission will be delivered to the Planetary Data System within six months from the time of acquisition.

This presentation briefly updates and reviews the LRO Instrument and their objectives while a more complete description can be found in Chin et al.[1] The spacecraft and mission design are described in a companion paper at this conference[2].

## 3. Instrument Suite, Objectives and Capabilities

What follows are brief descriptions of each of the instruments with their characteristic performance parameters collected in table 1.

3.1 *Cosmic Ray Telescope for the effects of Radiation.* CRaTER is designed to answer key questions to enable future human exploration of the Solar System, and to address one of the prime objectives of LRO. Specifically, CRaTER addresses an objective required by NASA's Exploration Initiative to safely return humans to the Moon; CRaTER is designed to achieve characterization of the global lunar radiation environment and its biological impacts and potential mitigation, as well as investigation of shielding capabilities and validation of other deep space radiation mitigation strategies involving materials.

CRaTER's primary measurement goal is to measure directly the linear energy transfer (LET) spectra caused by space radiation penetrating shielding material. Such LET spectra are a missing link, currently derived by models which require experimental measurements to provide ground truth. LET is defined as the mean energy absorbed locally, per unit path length, when an energetic particle traverses material. An LET spectrometer measures the amount of energy deposited in a detector of known thickness and material property when an energetic particle passes through it, usually without stopping. LET measurements behind various thicknesses and types of material are of great importance to spacecraft engineers and radiation health specialists.

The CRaTER measurement concept is shown in the see-thru telescope drawing below (Figure 1). The investigation hardware consists of a single, integrated telescope and electronics box with straightforward electronic and mechanical interfaces to the spacecraft. The zenith-nadir viewing telescope employs a stack of three pairs of detectors embedded within aluminum structure and tissue-equivalent plastic (TEP) to establish the LET spectra of cosmic radiation relevant for human health and electronics part concerns. Galactic cosmic rays and solar energetic particles enter the telescope through the zenith or nadir entrance, depositing energy in the telescope stack through ionizing radiation and producing secondary particles through nuclear interactions. The primary and secondary particles interact with one or more of the six detectors through the stack: the thin (thick) detectors are optimized for high (low) LET interactions. Events with sufficient energy deposition in a detector cross a trigger threshold. Digital logic then compares multi-detection coincidences with predefined event masks to identify desirable events. Pulse height analysis is performed on every detector to measure LET at each point in the stack.

**Fig. 2 The MRO MCS Flight Model during thermal vacuum testing at JPL**

3.2 *Diviner Lunar Radiometer Experiment.* DLRE will provide a complete set of precise radiometric lunar surface temperature measurements over the full 40-400K anticipated range. Over the course of the LRO mission, Diviner will acquire a dataset of fundamental importance to future human exploration. Data obtained by Diviner may be used to assess day and night surface and subsurface thermal conditions, or to determine rock abundances at future landing sites. Diviner will also identify and characterize permanently shadowed cold-traps that may contain near-surface water ice resources.

The nine-channel Diviner visible and infrared radiometer closely follows the design of the 2005 Mars Reconnaissance Orbiter (MRO) Mars Climate Sounder (MCS) [4]. (Figure 2). The MCS employs precise multichannel filter radiometry to measure vertical temperature profiles, dust and water vapor in the Martian atmosphere, as well as the Martian surface temperature. The LRO DLRE will use the same general-purpose filter radiometer capabilities to measure lunar surface temperatures, however, a different set of spectral filters will be used and the signal sampling rate will be increased.

3.3 *Lyman Alpha Mapping Project.* The objectives of LAMP are to search for exposed water ice near the lunar poles and in PSRs using reflected Lyman-Alpha sky-glow and far-ultraviolet starlight, obtain landform maps in the PSR regions and serve as a pathfinder for a lunar natural light night

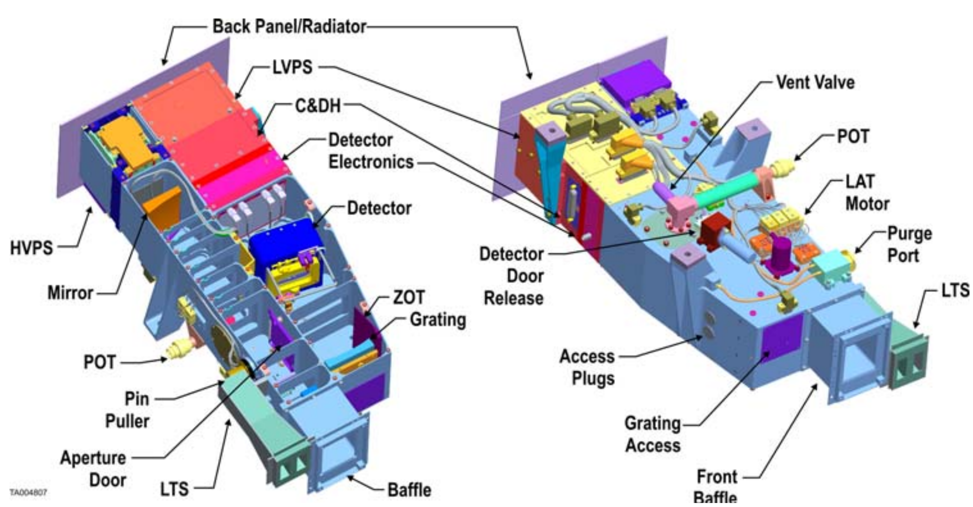


**Fig. 3 LAMP design as seen from above (left) and below (right).**

vision system and obtain data on the tenuous lunar atmosphere.

The LAMP instrument is essentially a copy of the Pluto ALICE (P-ALICE) instrument design [4,5] with only very minor changes (Figure 3). The primary difference between LAMP and Pluto-Alice is the addition of a terminator sensor to gate the instrument on and off.

The presence of an excess hydrogen signature, as detected by neutron spectroscopy, cannot guarantee the hydrogen is in the form of water without other supporting measurements. LAMP provides LRO with the unique capability of being able to spectrally fingerprint exposed $H_2O$ frost in the lunar polar regions. This will be accomplished using observations illuminated purely by Lyman-α sky-glow and broadband far ultra-violet (FUV) starlight.

LAMP data will also be used to compile the first FUV albedo maps of the entire Moon assembled over the course of the baseline mission.

LAMP is comprised of a telescope and Rowland-circle spectrograph. LAMP has a single 40×40 mm2 entrance aperture that feeds light to the telescope section of the instrument. Entering light is collected and focused by an f/3 off-axis paraboloidal (OAP) primary mirror at the back end of the telescope section onto the instrument's entrance slit. After passing through the entrance slit, the light falls onto a toroidal holographic diffraction grating, which disperses the light onto a double-delay line (DDL) microchannel plate (MCP) detector.

3.4 *Lunar Exploration Neutron Detector.* The LEND instrument Lunar Exploration Neutron Detector's (LEND's) most important attribute is that it is capable of providing high spatial resolution mapping of epithermal

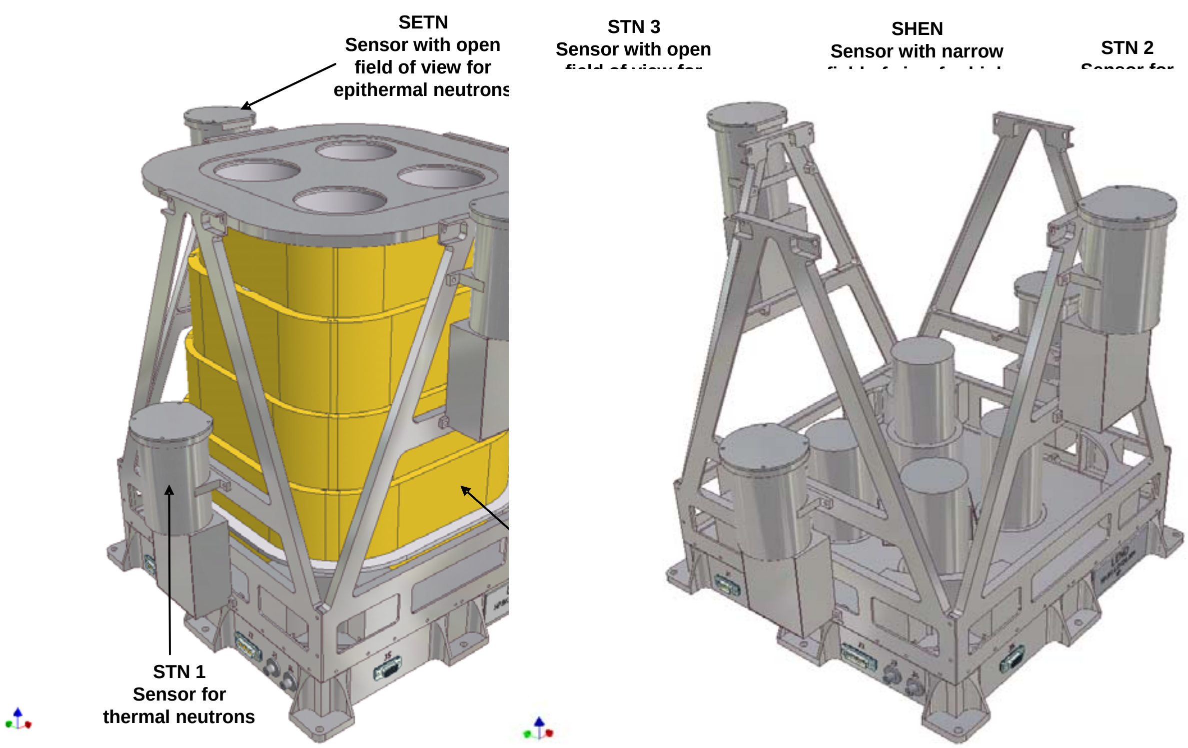


**Fig. 4 LEND Design Concept with four collimated sensors of epithermal neutrons CSETN 1-4, one sensor with narrow FOV for high energy neutrons SHEN and four sensors of thermal STN 1-3 and epithermal SETN neutrons with open fields of view. Left view is LEND with the collimator and right view is LEND without the collimator.**

neutrons with collimated epithermal neutron detectors (see detectors CSETN 1-4 in Figure 4). LEND is able to detect a hydrogen-rich spot at one of the Lunar poles with as little as 100 ppm of hydrogen and a spatial resolution of 10 km (pixel diameter), and to produce global measurements of the hydrogen content with a resolution of 5-20 km. If the hydrogen is associated with water, a detection limit of 100 ppm hydrogen corresponds to ~0.1 % weight water ice in the regolith. High energy neutron data from another LEND sensor (SHEN in Figure 4) could help to distinguish between areas in which hydrogen was implanted by solar wind and potential water ice deposits.

LEND's primary sensor type is the $^3$He counter, used for LEND detectors CSETN 1-4, STN 1-3, and SETN. The $^3$He counter produces an electrical pulse proportional to the number of ions formed. The Cd shield around CSETN 1-4 and SETN absorbs all neutrons with energies below ~0.4 eV, which exclude all thermal neutrons from detection.

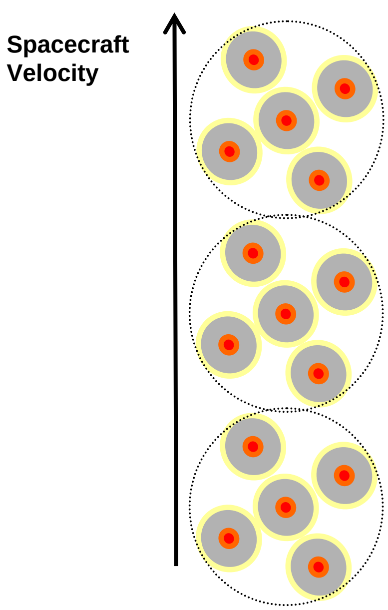


**Fig. 5. Pulse Detection Time-of-Flight Altimeter 5-spot Pattern Red represents the laser spots on the ground while the grey circles represent the receiver FOV.**

The major difference between LEND and HEND, is the collimation of neutron flux before detection. Collimating modules around the $^3$He counters of CSETN 1-4 effectively absorb neutrons that have large angles with respect to the normal on the Moon's surface (Figure 4), leading to spatial resolution of 10 km full width at half maximum signal from the nominal 50 km orbit. This is the first time this method of "neutronography" will be used to map another planet with high spatial resolution.

3.5 *Lunar Orbiter Laser Altimeter.* LOLA has two primary objectives. First, it will produce a high-resolution global topographic model and geodetic framework that will assist with precise targeting, safe landing, and surface mobility for future scientific and exploration activities. LOLA will also characterize the polar illumination environment and image the Moon's PSRs to identify possible locations of surface ice crystals in shadowed polar craters. To achieve these primary objectives, LOLA will make three measurements: 1) the distance between the surface and the spacecraft, 2) the spreading of the returned laser pulse, and 3) the transmitted and returned laser energies. LOLA is a pulse detection time-of-flight altimeter that incorporates a five-spot pattern that measures the precise distance to the lunar surface at 5 spots simultaneously, thus providing 5 profiles across the lunar surface. Each spot within the five-spot pattern has a diameter of five meters; the spots are 25 meters apart, and form a cross pattern (Figure 5). The 5-spot pattern enables the surface slope to be derived in the along-track and across track directions.

LOLA's instrument design (Figure 6) is similar to the designs of the Mars Orbiter Laser Altimeter [6] and the Mercury Laser Altimeter [7]; however, it has five laser beams and five receiver channels.

Because LOLA will make global observations, the LOLA altimetry data can be used to improve the spacecraft orbit, and our knowledge of far side lunar gravity – which is currently extremely poorly known but is required for precise landing and low-altitude navigation.

3.6 *Lunar Reconnaissance Orbiter Camera* The 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* anywhere on the Moon; and 2) Acquire multi-temporal synoptic imaging of the poles every orbit to *characterize the polar illumination environment* (on a 100 m scale), identifying regions of permanent shadow and permanent or near-permanent illumination over a full lunar year. The LROC consists of two narrow-angle cameras (NACs) (see Figure 7a) to provide 0.5 m scale panchromatic images over a 5 km swath, a wide-angle camera component (WAC) (see Figure 7b) to provide images at a scale of 100 m in seven color bands over a 100 km swath in black and white mode and 60 km in color mode, and a common Sequence and Compressor System (SCS).

In addition to acquiring the two LRO prime measurement sets, LROC will return six other high-value datasets that support LRO goals, the LPRP, and basic lunar science. These additional datasets include:

- Meter-scale imaging of regions of permanent or near-permanent illumination.

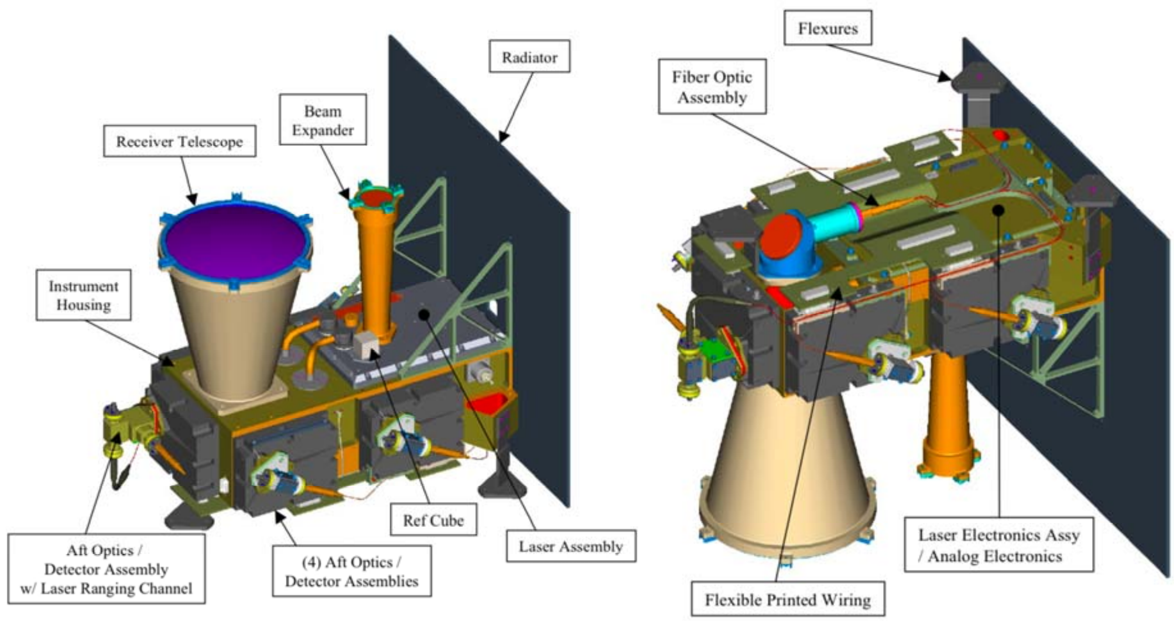


**Fig.6 LOLA Instrument Design**

- Multiple co-registered observations of portions of potential landing sites and elsewhere for derivation of high-resolution topography through stereogrammetric and photometric stereo analyses.

- A global multispectral map in 7 wavelengths (315-680 nm) useful for mapping potential lunar resources, in particular ilmenite.

- A global 100-m/pixel basemap with incidence angles (60-80°) favorable for morphologic interpretations.

- Sub-meter imaging of a variety of geologic units to characterize physical properties, variability of the regolith, and key science questions.

- Meter-scale coverage overlapping with Apollo era Panoramic images (1-2 m/pixel) to document the number of small impacts since

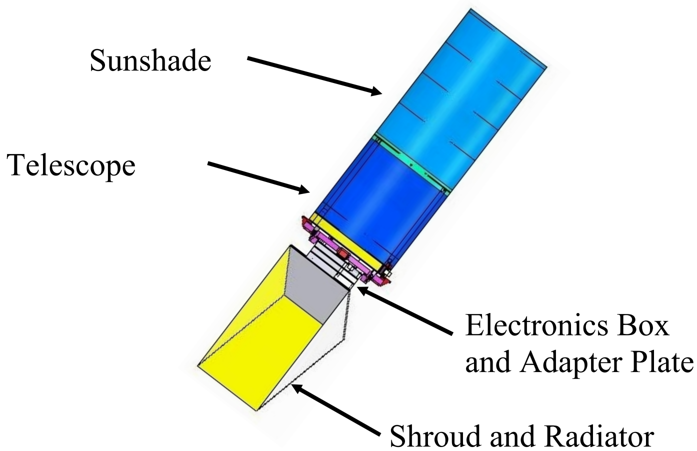


**Fig. 7a LROC Narrow Angle Component, 70 cm length by 24 cm diameter**

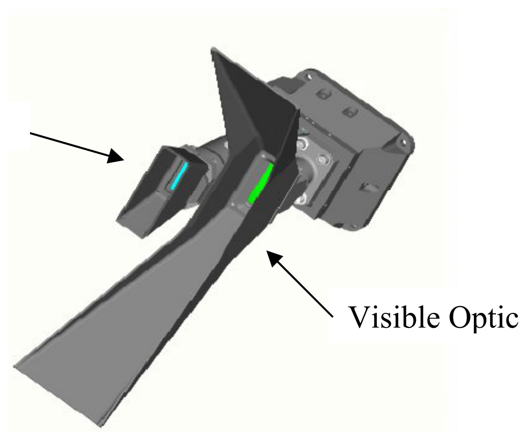


**Figure 7b LROC Wide Angle Component, 14.5 cm by 9.2 cm by 7.6 cm**

1971-1972, to ascertain hazards for future surface operations and interplanetary travel.

LROC has high heritage from the Mars Reconnaissance Orbiter (MRO) Context Camera (CTX) and Mars Color Imager (MARCI) instruments [8], with modifications needed to meet the primary measurement requirements. Each NAC has a 700 mm-focal-length, Ritchey-Chretien telescope that images onto a 5000-pixel CCD line-array, providing a cross-track field-of-view (FOV) of 2.86°. WAC has two short-focal-length lenses imaging onto the same 1000 x 1000 pixel, electronically shuttered CCD area-array, one imaging in the visible/near Infrared (EFL=6.0mm), and the other in the UV (EFL=4.5mm). The optical systems have a cross-track FOV of 90° and 60° respectively. From the nominal 50 km orbit, the WAC will provide a nadir, ground sample distance of 100 m/pixel in the visible, and a swath width of ~100 km. The seven-band color capability of the WAC is provided by a color filter array mounted directly over the detector, providing different sections of the CCD with different filters acquiring data in the seven channels in a "pushframe" mode.

3.7 *Miniature Radio Frequency Technology Demonstration* The Mini-RF system primary purpose is technical demonstration in the lunar environment of a unique miniaturized multi-mode radar observatory. Its synthetic aperture radar (SAR) imaging modes are most relevant to the scientific and exploratory roles of LRO. The mini-RF SAR baseline modes include: two frequencies – S-

**Table I Instrument Performance Parameters**

| Instru-ment | Instrument Classification | Characteristic Range | Characteristic Resolution | Spatial Resolution (from 50 km) | Spatial Coverage | Data Rate Gbits/day |
|---|---|---|---|---|---|---|
| LOLA | Laser Altimeter | Range Window 20-70 km | 10 cm vertical | Five 5 m laser spots, 25 m spacing | Polar Grid 0.001° latitude 0.04° longitude | 1.4 |
| LROC NAC | High Resolution Camera | Broadband Centered at 550 nm | ± 150 nm | 50 cm/pixel | Targeted >10% Lunar Surface 100% > 85.5° lat. | 515 |
| LROC WAC | MultiSpectral Camera | 315 - 680 nm | spectral filters centered at 315 nm 360 nm, 415 nm, 560 nm, 600 nm, 640 nm, 680 nm | 100 m/pixel vis 400 m/pixel UV | Full lunar surface at each wave-length and various lighting angles | 41 |
| LEND | Neutron Detector | thermal to 15 MeV | Four Bands<br>Thermal < 0.4 eV<br>Epithermal 0.4 eV - 10 keV<br>Fast 10 keV - 1 MeV<br>Energetic 1 MeV - 15 MeV | Epithermal 10 km FWHM (see test for other bands) | Full lunar surface and deep space | 0.26 |
| DLRE | Radiometer | 30 K to 400 K | 5 K | 400 m | Full Lunar Surface Day/Night Temperatures | 3.5 |
| LAMP | UV Imaging Spectrograph | 52 to 187 nm | 3.5 nm | 260 m | Full Lunar Surface | 2 |
| CRaTER | Primary and albedo cosmic ray sensor | LET spectra 0.2 keV/µm to 7 MeV/µm | < 3% | 77 km | Full lunar surface and deep space | 7.8 (peak) |
| mini-RF | X- and S-band Synthetic Aperture Radar | 4 cm (X-band)<br>12 cm (S-band) | Sensitivity:<br>-30 dB (S-band)<br>-25 dB (X-band) | 75 m/pixel, 7.5 m/pixel (zoom) | limited during the nominal mission | 7.7* |

*mini-RF 7.7 Gbits for 4 min. data collection interval band (13 cm) and X-band (4 cm); two resolutions – baseline (150 m/75-m pixels) and zoom (15 m/7.5-m pixels); and dual-polarization – transmit on one and receive on like and orthogonal polarizations. The nominal incidence is 45° side-looking; swath widths vary by mode from ~ 4 km to ~ 6 km. The primary data products will be multi-mode Stokes parameters (or their primitives), which will be a major step forward in space-based radar astronomy [9,10]. In addition, there is an experimental two-pass interferometric mode (single polarization), and the possibility of bistatic radar experiments. The instrument mass is about 12 kg, and the antenna measures 1.8 m long and 0.6 m high.

**4. Conclusions** Over the next few years as many as four spacecraft will be orbiting the moon simultaneously, equal to the total number of orbiting spacecraft in the previous three decades. Naturally there is some overlap in the data products produced be each mission but different emphasis assures that the moon will be well covered by a robust instrument set that covers broad array of interesting explorative and scientific measurement sets. The Lunar Reconnaissance Orbiter's emphasis is on preparation for follow on lander missions. It will bring high resolution imaging and altimetry to bear on moon, particularly in the polar regions where it will search for lunar resources and assess the lunar radiation environment.

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