Cosmic Ray Telescope for the Effects of Radiation (CRaTER)

Harlan E. Spence, Principal Investigator
Boston University
Department of Astronomy and Center for Space Physics
# CRaTER Science Team and Key Personnel

<table>
<thead>
<tr>
<th>Name</th>
<th>Institution</th>
<th>Role</th>
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<tbody>
<tr>
<td>Harlan E. Spence</td>
<td>BU</td>
<td>PI</td>
</tr>
<tr>
<td>Larry Kepko</td>
<td>“</td>
<td>Co-I (E/PO, Cal, IODA lead)</td>
</tr>
<tr>
<td>Justin Kasper</td>
<td>MIT</td>
<td>Co-I (Project Scientist)</td>
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<tr>
<td>Bern Blake</td>
<td>Aerospace</td>
<td>Co-I (Detector lead)</td>
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<tr>
<td>Joe Mazur</td>
<td>“</td>
<td>Co-I (GCR/SCR lead)</td>
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<tr>
<td>Larry Townsend</td>
<td>UT Knoxville</td>
<td>Co-I (Modeling lead)</td>
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<tr>
<td>Michael Golightly</td>
<td>AFRL</td>
<td>Collaborator (Biological effects)</td>
</tr>
<tr>
<td>Terry Onsager</td>
<td>NOAA/SEC</td>
<td>Collaborator (CR measurements)</td>
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<tr>
<td>Rick Foster</td>
<td>MIT</td>
<td>Project Manager</td>
</tr>
<tr>
<td>Bob Goeke</td>
<td>“</td>
<td>Systems Engineer</td>
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<tr>
<td>Brian Klatt</td>
<td>“</td>
<td>Q&amp;A</td>
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<tr>
<td>Chris Sweeney</td>
<td>BU</td>
<td>Instrument Test Lead</td>
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2008 Lunar Reconnaissance Orbiter (LRO)
First Step in the Robotic Lunar Exploration Program

LRO Objectives

• Characterization of the lunar radiation environment, biological impacts, and potential mitigation. Key aspects of this objective include determining the global radiation environment, investigating the capabilities of potential shielding materials, and validating deep space radiation prototype hardware and software.

• Develop a high resolution global, three dimensional geodetic grid of the Moon and provide the topography necessary for selecting future landing sites.

• Assess in detail the resources and environments of the Moon’s polar regions.

• High spatial resolution assessment of the Moon’s surface addressing elemental composition, mineralogy, and Regolith characteristics.

Objective: The Lunar Reconnaissance Orbiter (LRO) mission objective is to conduct investigations that will be specifically targeted to prepare for and support future human exploration of the Moon.
LRO Mission Overview

**Orbiter**

**LRO Instruments**

- **Lunar Orbiter Laser Altimeter (LOLA) Measurement Investigation** – LOLA will determine the global topography of the lunar surface at high resolution, measure landing site slopes and search for polar ices in shadowed regions.

- **Lunar Reconnaissance Orbiter Camera (LROC)** – LROC will acquire targeted images of the lunar surface capable of resolving small-scale features that could be landing site hazards, as well as wide-angle images at multiple wavelengths of the lunar poles to document changing illumination conditions and potential resources.

- **Lunar Exploration Neutron Detector (LEND)** – LEND will map the flux of neutrons from the lunar surface to search for evidence of water ice and provide measurements of the space radiation environment which can be useful for future human exploration.

- **Diviner Lunar Radiometer Experiment** – Diviner will map the temperature of the entire lunar surface at 300 meter horizontal scales to identify cold-traps and potential ice deposits.

- **Lyman-Alpha Mapping Project (LAMP)** – LAMP will observe the entire lunar surface in the far ultraviolet. LAMP will search for surface ices and frosts in the polar regions and provide images of permanently shadowed regions illuminated only by starlight.

- **Cosmic Ray Telescope for the Effects of Radiation (CRaTER)** – CRaTER will investigate the effect of galactic cosmic rays on tissue-equivalent plastics as a constraint on models of biological response to background space radiation.

**Preliminary LRO Characteristics**

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<tbody>
<tr>
<td>Mass</td>
<td>1317</td>
<td>Dry: 603 kg</td>
</tr>
<tr>
<td></td>
<td>kg</td>
<td>Fuel: 714 kg</td>
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<tr>
<td>Power</td>
<td>745 W</td>
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<tr>
<td>Measurement Data Volume</td>
<td>575 Gb/day</td>
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### Competitively Selected LRO Instruments Provide Broad Benefits

<table>
<thead>
<tr>
<th>INSTRUMENT</th>
<th>Measurement</th>
<th>Exploration Benefit</th>
<th>Science Benefit</th>
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<tbody>
<tr>
<td>CRaTER (BU+MIT)</td>
<td>Tissue equivalent response to radiation</td>
<td>Safe, lighter weight space vehicles that protect humans</td>
<td>Radiation conditions that influence life beyond Earth</td>
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<tr>
<td>Diviner (UCLA)</td>
<td>300m scale maps of Temperature, surface ice, rocks</td>
<td>Determines conditions for systems operability and water-ice location</td>
<td>Improved understanding of volatiles in the solar system - source, history, migration and deposition</td>
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<tr>
<td>LAMP (SWRI)</td>
<td>Maps of frosts in permanently shadowed areas, etc.</td>
<td>Locate potential water-ice (as frosts) on the surface</td>
<td>Locate potential water-ice in lunar soil and enhanced crew safety</td>
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<tr>
<td>LEND (Russia)</td>
<td>Hydrogen content in and neutron radiation maps from upper 1m of Moon at 5km scales, Rad &gt; 10 MeV</td>
<td>Locate potential water-ice in lunar soil and enhanced crew safety</td>
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<tr>
<td>LOLA (GSFC)</td>
<td>~50m scale polar topography at &lt; 1m vertical, roughness</td>
<td>Safe landing site selection, and enhanced surface navigation (3D)</td>
<td>Geological evolution of the solar system by geodetic topography</td>
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<tr>
<td>LROC (NWU+MSSS)</td>
<td>1000’s of 50cm/pixel images (125km²), and entire Moon at 100m in UV, Visible</td>
<td>Safe landing sites through hazard identification; some resource identification</td>
<td>Resource evaluation, impact flux and crustal evolution</td>
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Science/Measurement Overview

CRaTER Objectives:

“To characterize the global lunar radiation environment and its biological impacts.”

“...to address the prime LRO objective and to answer key questions required for enabling the next phase of human exploration in our solar system.”
## Relationship of CRaTER Measurement Goals to LRO Mission Objectives

<table>
<thead>
<tr>
<th>Highest-priority LRO Objective</th>
<th>CRaTER Objective</th>
<th>CRaTER Measurement Goals</th>
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| 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. | To characterize the global lunar radiation environment and its biological impacts. | 1. Measure and characterize that aspect of the deep space radiation environment, LET spectra of galactic and solar cosmic rays (particularly above 10 MeV) and their secondaries, most critically important to the engineering and modeling communities to assure safe, long-term, human presence in space.  
2. Develop a novel instrument, steeped in flight heritage, that is simple, compact, and comparatively low-cost, but with a sufficiently large geometric factor needed to measure LET spectra and its time variation, globally, in the lunar orbit.  
3. Investigate the effects of shielding by measuring LET spectra behind different amounts and types of areal density, including tissue-equivalent plastic.  
4. Test models of radiation effects and shielding by verifying/validating model predictions of LET spectra with LRO/CRaTER measurements, using high-quality GCR and SCR spectra available contemporaneously on ongoing/planned NASA (ACE, STEREO, SAMPEX) and other agency spacecraft (NOAA-GOES). |
GCR/SEP parent spectra will be measured by other spacecraft during LRO mission.

Biological assessment requires not the incident CR spectrum, but the LET spectra behind tissue-equivalent material.

LET spectra are a missing link, currently derived largely by models; we require experimental measurements to provide critical ground truth – CRaTER will provide information needed for this essential quantity.

Rationale for LET Spectra
Classical ionizing radiation

- Energy loss: Electromagnetic (electrons and nucleus) and nuclear (spallation)
- Nuclear interactions occur in a fraction of events
- Above plots are from a SRIM-2003 simulation of 50 MeV protons in human tissue
Science Measurement Concept

LRO CRaTER: Instrument Configuration and Measurement Concept

1. Primary Solar and Galactic Cosmic Ray Sources

2. Secondary Particle Production at Lunar Surface

3. Other Surface Sources

CRaTER measures:
- Primary sources toward zenith through instrument mass
- Secondary and Other sources toward nadir through instrument mass
**Current energy spectral range:**
- 200 keV to 100 MeV (low LET); and
- 2 MeV to 1 GeV (high LET)

This corresponds to:
- a range of LET from 0.2 keV/µ to 7 MeV/ µ (stopping 1 Gev/nuc Fe-56)
- good spectral overlap in the 100 kev/µ range (key range for RBEs)
CRaTER Telescope Configuration
Nuclear fragmentation of 1 GeV/nuc Fe

Iron in; Everything out!
Evolution of proton spectrum through stack

Proton flux $[\text{p cm}^{-2} \text{s}^{-1} \text{sr}^{-1} (\text{MeV/nuc})^{-1}]$

January 20 2005

Energy deposited in component $[\text{MeV}]$
Maximum singles detector rates

CRaTER gets 100kbits/sec!!

- LET spectra will be constructed for GCR and SEP independently
- Will be sorted according to lunar phase (plasma regime) and LRO orbit location
• **What we know**
  • “Unmoderated” GCR and SEP spectra @ 1AU (well enough) in lunar (and other nearly-interplanetary environments)

• **What we don’t know**
  • How GCR/SEP particles are transported through matter and how energy is deposited (e.g., LET), particularly heaviest ions at highest energies – needed to validate transport codes which are currently our only resource for assessing this biologically important ionizing radiation component. What is LET spectrum of GCR/SEP behind “tissue” at moon (and interplanetary space)?

• **What we need**
  • Instruments like CRaTER on LRO providing missing link between model/theory-data closure on radiation effects; *RAD on MSL providing data for validating atmospheric transport codes*
  • State-of-the-art radiation transport modeling efforts like BBFRAG, HETC-HEDS, FLUKA, etc.
  • Better connections of S3C with radiation biology and EE communities to provide measurements of value to their needs