Cosmic Ray Telescope for the Effects of Radiation (CRaTER):
10 February 2006 LRO PSWG Status Report

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on behalf of the CRaTER Science Team
(J. B. Blake, M. Golightly, J. Kasper, L. Kepko, J. Mazur, T. Onsager, L. Townsend)
• Minor design modifications pre-l-PDR to optimize science (5 det., 3 TEP configuration is now a 6 det., 2 TEP configuration)
• Prototype detectors procured from flight vendor, testing began in September 2005;
• Performance question at PDR fully resolved (it was a beam, not detector, “feature”)

• First batch of E/M detectors (procured using “flight rules”) to arrive in April ‘06 (second batch no later than June ‘06)
• CRaTER telescope simulator tested and design validated
• Goal to perform end-to-end test of E/M in a beam before June ‘06 CDR still achievable
Rapid prototype model of CRaTER Telescope Assembly, Rev 3 (or so...)

16 January 2006
CRaTER Telescope Configuration
CRAgTER Science Summary

- **GCR/SEP** parent spectra measured by other spacecraft during mission
- Biological assessment requires not incident CR spectrum, but linear energy transfer (LET) spectra behind tissue-equivalent material
- LET spectra are a missing link, currently derived from models; experimental measurements required for critical ground truth – CRAgTER will provide this key data product

CRAgTER’s energy spectral range:
- 200 keV to 100 MeV (low LET)
- 2 MeV to 1 GeV (high LET)

This corresponds to:
- LET from 0.2 keV/µ to 7 MeV/µ (stopping 1 GeV/nuc 56Fe)
- Excellent spectral overlap in the 100 keV/µ range (key range for RBEs)
- Endorsed enthusiastically by radiation biologists, transport code modelers, and JSC/SRAG personnel at recent VSE meeting
C RaTER Primary/Secondary Science

- LET spectra constructed for GCR/SEP independently, zenith & nadir
- Sorted according to lunar phase, LRO orbit phase, and lunar location
- Will explore GCR fluctuations on short time scales (minutes to hours, of interest to LISA mission)

Predicted C RaTER counting rates based on historic GCR (low level, slowly varying) and SEP (intense, rapidly varying) observations

LET spectra sorted according to lunar phase and orbital positions

C RaTER will explore rapid GCR variations, discovered recently by NASA/Polar HIST (results presented this week at LISA meeting in UK)
C RaTER Team Presentations/Publications

16 October 2005  Vision for Space Exploration Workshop, Wintergreen, VA – Spence, Townsend (C RaTER included in NRC report)

6 February 2006  LISA Solar, Cosmic Ray, and Environmental Physics Workshop, London, UK – Blake

4 March 2006  2006 IEEE Aerospace Conference, Big Sky, MT – Townsend (IEEE publication on C RaTER modeling pending)

3 April 2006  NASA Radiation Detection Workshop, Houston, TX – Spence, Golightly

28 April 2006  Space Weather Week, Boulder, CO – Townsend, Spence, Golightly

16 July 2006  COSPAR(*) Beijing, China – Kasper, Townsend (several potential Advances in Space Research publications)

17 July 2006  IEEE Nuclear and Space Radiation Effects Conference, Ponte Vedra Beach, FL – Mazur (Paper submitted)

1 August 2006  SHINE Workshop, Zermatt, Utah – Spence, Kasper, Blake, Mazur

(*) Relevant LRO/CRaTER sessions at COSPAR include:
B0.1  The Moon: Recent Results, Science, Future Robotic and Human Exploration
D2.4/E3.4  The Radiation Environment of the Inner Heliosphere
F2.1  Space Radiation Biology
F2.2  Physical & Biophysical Models & Simulation Codes for Space Radiation Risk Assessment
F2.3  Recent Radiation Measurements and Calibration Results
# CRaTER Beam Validation/Modeling

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<th>Modeling</th>
<th>SRIM, GEANT4, BBFRAG, HETC-HEDS, FLUKA, HZTRAN</th>
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<td><strong>Beam Validation</strong></td>
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<td>12 September 2005</td>
<td>Detector prototype characterization at <strong>LBNL</strong> 88” cyclotron</td>
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<td>22 January 2005</td>
<td>TEPTA response to p+’s at <strong>MGH</strong> proton accelerator (10 - 230 MeV)</td>
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<td>13 March 2006</td>
<td>Prototype detector/TEP characterization at <strong>LBNL</strong> (light ions)</td>
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<tr>
<td>27 March 2006</td>
<td>TEPTA response to heavy ions at <strong>BNL</strong> (56-Fe, 0.3 &amp; 1 Gev/n) – 4 hours of competitive beam time</td>
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<tr>
<td>May/June 2006</td>
<td>E/M detector testing at <strong>LBNL</strong></td>
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<tr>
<td>June 2006</td>
<td>E/M CRaTER beam validation at <strong>BNL</strong> (56-Fe, 0.6 GeV/n) – 4 hours of competitive beam time</td>
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</table>
Modeled Evolution of 10 GeV p+ in CRaTER

- **High LET Detectors** - GEANT4
- **Low LET Detectors** - GEANT4

- **SRIM**
  - Solid – Low LET
  - Dashed – High LET

- **GEANT4**
  - Simple, standard models used for simplest interactions
  - SRIM and GEANT4

![Graph showing energy deposited vs incident energy with SRIM and GEANT4 models for high and low LET detectors.](image-url)
Fragmentation of 1 GeV/nuc Fe in CRaTER

- State-of-the-art in-development physics codes used for most complex interactions (energetic heavy ions) – these are codes that CRaTER data products will ultimately improve
- HETC-HEDS and BBFRAG (for example) used to constrain extremes
- Lab validation of TEP test apparatus and E/M unit in available beams

Nuclear fragmentation yields shower of elements after incident iron ion
CRaTER Beam Runs at LBNL and MGH

12 September 2005 – LBNL 88” cyclotron

Prototype CRaTER Detector from Micron Semiconductor

22 January 2006 – MGH Proton Radiation Therapy Facility

Physics Beamline at 230 MeV MGH Proton Accelerator

Lucite beam stop

SSDs & TEP

Ion Beam Run at LBNL

TEP Test Apparatus
CRaTER Design Validation: MGH Results

Peak energy deposit decreases with increasing energy (Bragg effect)

Peak energy deposit increases dramatically after passing thru TEP (Bethe-Bloch effect)

D1 and D3 Energy response to 110-230 MeV p+

Deposited energy response at energies straddling Bragg peak permits exquisite design validation/verification

Linear detector responses over broad deposited energy range agrees with model predictions to within a few percent

TEP thickness inferred independently from energy response to better than 0.01% (few microns out of ~10 cm)
CRaTER Data Products

- Data products all related to primary measurement: LET in six silicon detectors embedded within TEP telescope

- CRaTER L0→L4 data products described in table

- Additional user-motivated data products might include: “Surface”, “Tissue”, and “Deep Tissue” Dose Rates (see next slide about JSC’s SRAG data request)

- Calculated LET spectra in each detector, using best available GCR environment specification and one or more transport codes. Calculation done with no a priori knowledge of measurements—a straightforward, quick-look "prediction" using best available modeling capability.

- NOTE: Onboard singles rates in CRaTER T/M can be used by other instruments to identify high rate conditions for possible safing (see in MRD-133, "The flight software shall support monitoring of any telemetry point and initiate stored command in response to pre-defined conditions"). CRaTER to use this feature for autonomous reconfiguration during SEP events.
ESMD/SRAG User Interest in CRaTER Data

Manned side of ESMD expressed interest in direct, early access to CRaTER data during the Level 1 requirements revision approval meeting at HQ in early January 2006 – no closure yet

JSC Space Radiation Analysis Group (SRAG) – ongoing discussions since 10/05 VSE Workshop; SRAG specifically sought us out and we have discussed details of needs/requirements/desirements

SRAG wants real data experience in operationally supporting manned lunar missions; CRaTER is only relevant instrument of interest at Moon for their needs

Measurements from Clementine dosimeter show that lunar radiation environment is not accurately represented by GOES data (i.e., can’t bootstrap from near-Earth environment)

SRAG’s main interest is “real-time” (R/T) data during SEPs; also interested in GCR (but not in R/T)

At a minimum SRAG wants following CRaTER data:

• integrated count rate once per orbit for at least the D1 and D2 detectors in R/T. By R/T they mean within some short time (minutes to tens of minutes) of completion of an orbit.

Additional desired CRaTER data includes:

• temporally resolved (~once per minute) count rates, dumped once per orbit, for at least the D1 and D2 detectors;
• integrated deposited energy (i.e., dose) once per orbit for at least D1 and D2 detectors;
• temporally resolved (~once per minute) deposited energy (i.e., dose), dumped once per orbit, for at least D1 and D2 detectors; and
• cumulative LET spectra once per orbit for at least D1 and D2 detectors.

Possible data flow plan:

• data sent from the LRO MOC to JSC MCC
• CRaTER supplies SRAG with calibration values to convert from L0 data to dose and LET

Upcoming CRaTER meeting with JSC’s Mark Weyland (SRAG lead) in April at Space Weather Week
### CRaTER Science Team and Key Personnel

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<tr>
<th>Name</th>
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<tr>
<td>Harlan E. Spence</td>
<td>BU</td>
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<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>
</tr>
<tr>
<td>Bern Blake</td>
<td>Aerospace</td>
<td>Co-I (Detector lead)</td>
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<tr>
<td>Joe Mazur</td>
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<td>Co-I (GCR/SCR lead)</td>
</tr>
<tr>
<td>Larry Townsend</td>
<td>UT Knoxville</td>
<td>Co-I (Modeling lead)</td>
</tr>
<tr>
<td>Michael Golightly</td>
<td>AFRL</td>
<td>Collaborator (Biological effects)</td>
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<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>
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<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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Science Measurement Concept

LRO CRaTER: Instrument Configuration and Measurement Concept

CRaTER measures:
- **Primary** sources toward zenith through instrument mass
- **Secondary** and **Other** sources toward nadir through instrument mass

1. Primary Solar and Galactic Cosmic Ray Sources

2. Secondary Particle Production at Lunar Surface

3. Other Surface Sources

Zenith-viewing LRO instrument deck
Notional 3-axis stabilized LRO s/c
Nadir-viewing LRO instrument and imager deck

*Apollo astronaut view of Earth while orbiting Moon (Photo Credit: NASA)*
Evolution of proton spectrum through stack

January 20 2005

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

Energy [MeV]

Energy deposited in component [MeV]

Energy [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
- Excellent instrument to measure GCR fluctuations on short time scales (e.g., of interest to LISA)