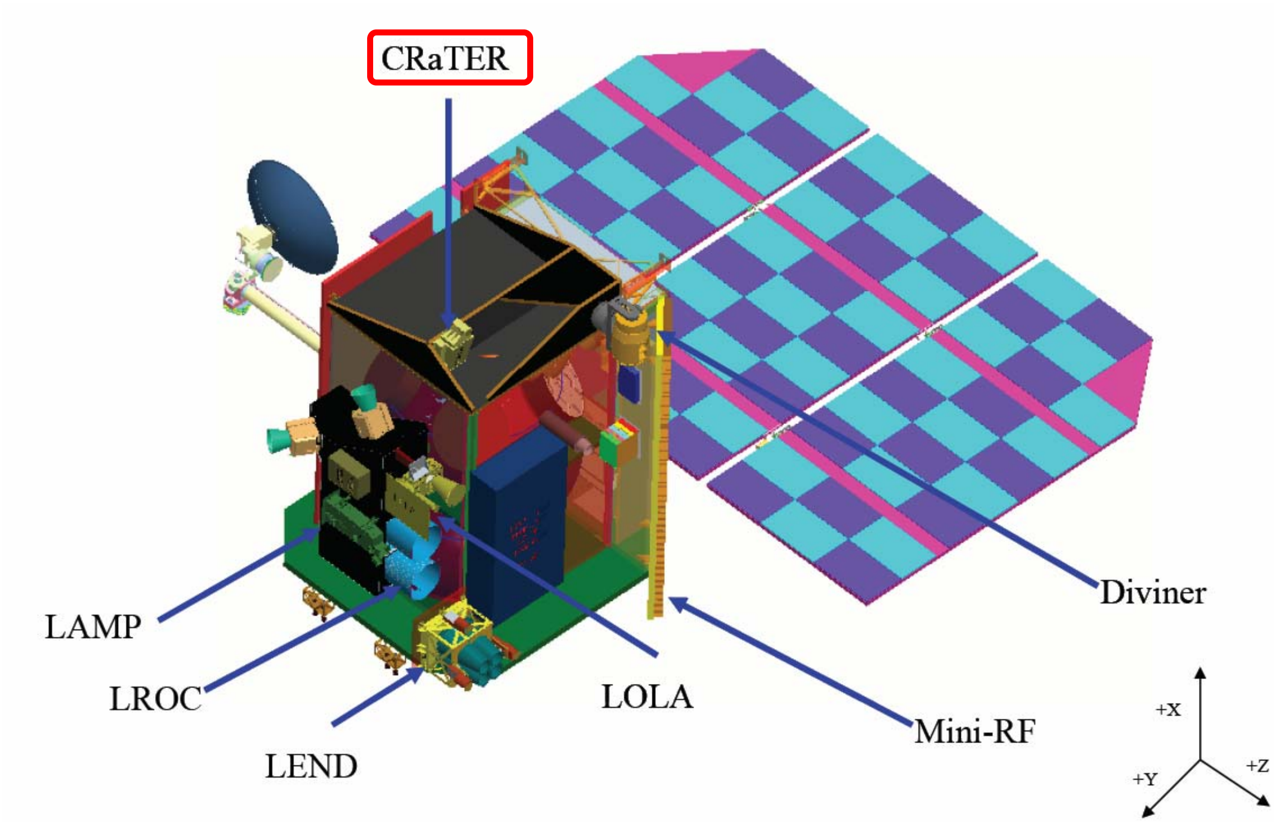
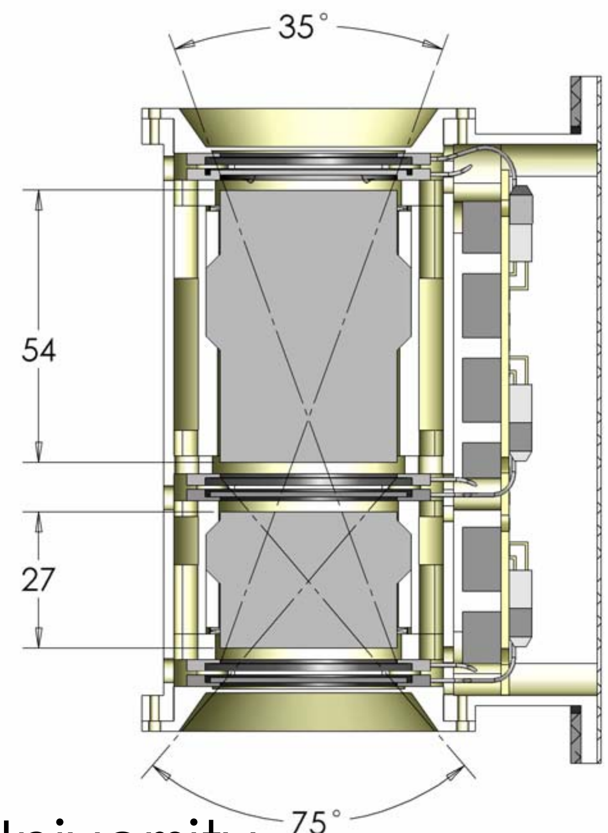
Cosmic Ray Telescope for the Effects of Radiation (CRaTER)

Space Weather Week, Boulder, CO

28 April 2006





Harlan E. Spence, Boston University

on behalf of the CRaTER Science Team

Outline

- CRaTER Team and Overview
- RLEP and LRO Mission Overview
- CRaTER Objectives
- Principles of Operation
- Science Summary
- Status Report
- Summary

CRaTER Science Team and Key Personnel

Name	Institution	Role
Harlan E. Spence	BU	PI
Larry Kepko	" "	Co-I (E/PO, Cal, IODA lead)
Justin C. Kasper	MIT/BU	Co-I (Project Scientist)
J. Bernard Blake	The Aerospace Corp	Co-I (Detector lead)
Joe E. Mazur	" "	Co-I (GCR/SPE Environment lead)
Larry Townsend	UT Knoxville	Co-I (Transport code modeling lead)
Michael J. Golightly	AFRL	Collaborator (Radiation Effects lead)
Terry G. Onsager	NOAA/SEC	Collaborator (CR measurements, Space weather lead)
Rick Foster	MIT/BU	Project Manager
Bob Goeke	MIT	Systems Engineer
Brian Klatt	" "	Q&A
Chris Sweeney	BU	Instrument Test Lead

Cosmic Ray Telescope for the Effects of Radiation (CRaTER):

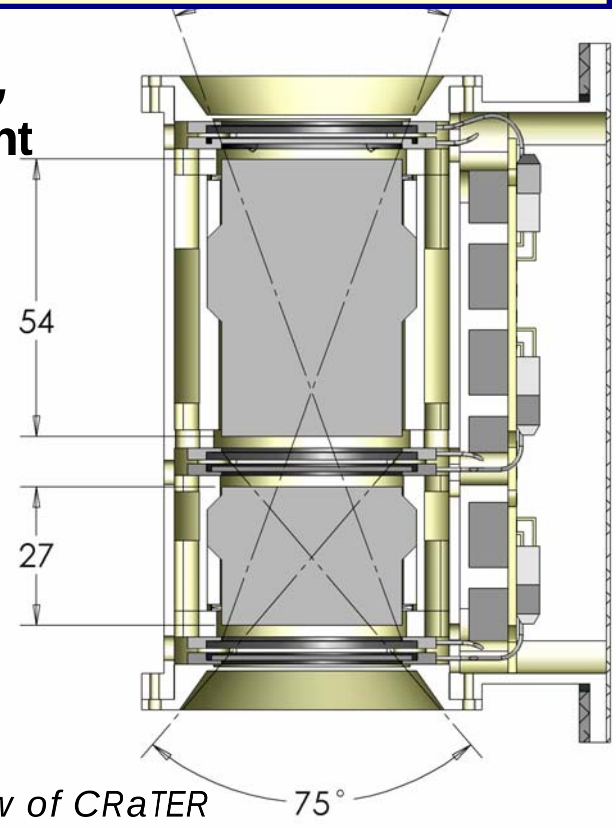
An **Interdisciplinary** Experiment for NASA's Lunar Reconnaissance Orbiter (LRO)

Harlan E. Spence, *Principal Investigator, BU Center for Space Physics (**crater.bu.edu**)*

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

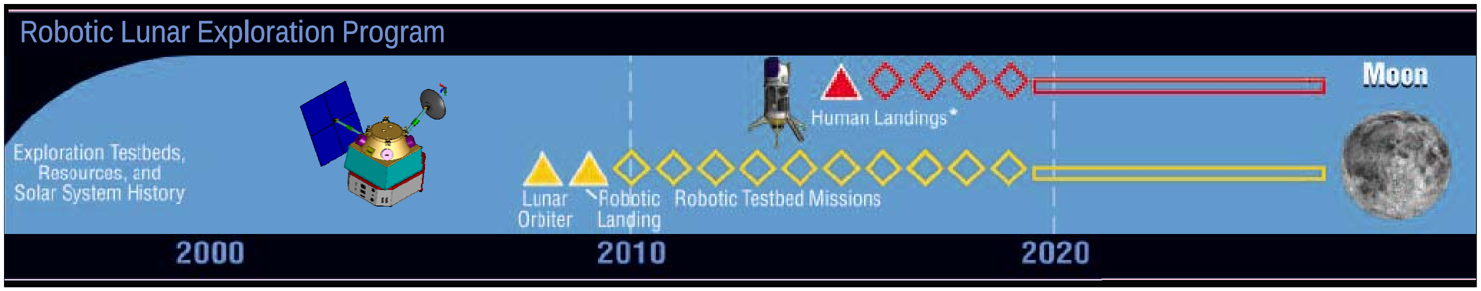
"…to address the prime LRO objective and to answer key questions required for enabling the next phase of human exploration in our solar system."

- **BU-led, multi-institution (*BU, MIT, The Aerospace Corp., Univ. of Tennessee, NOAA/SEC, AFRL*) NASA spaceflight instrument project**
- **CRaTER's interdisciplinary science team comprises:**
  - space plasma physicists
  - nuclear physicists
  - cosmic ray physicists
  - solar and heliospheric scientists
  - lunar scientists
  - space radiation biology and radiation effects experts
  - space weather modelers and astronaut safety experts



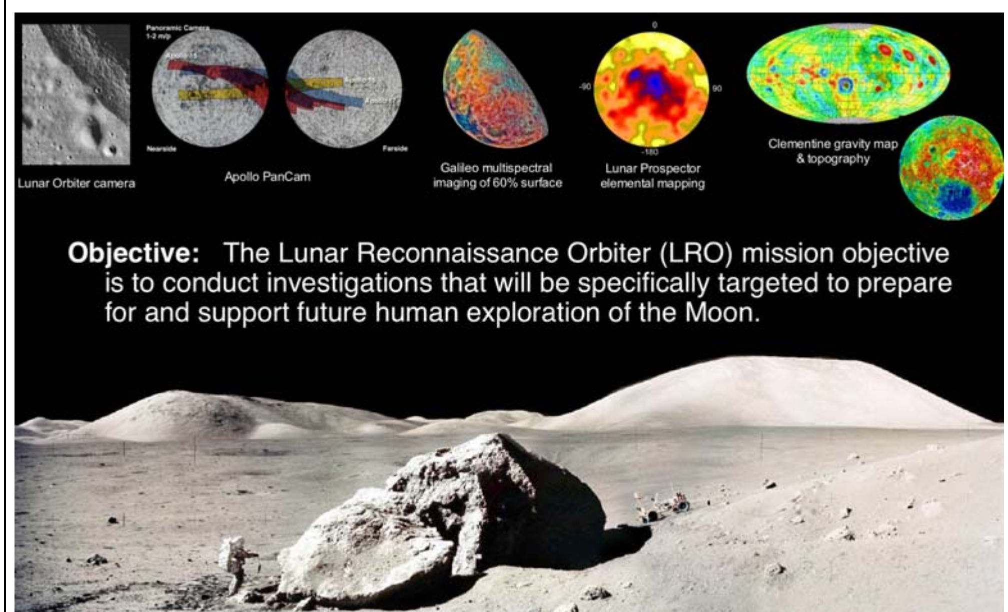
Cutaway view of CRaTER

1st Step in the Robotic Lunar Exploration Program – Launch: Oct 2008

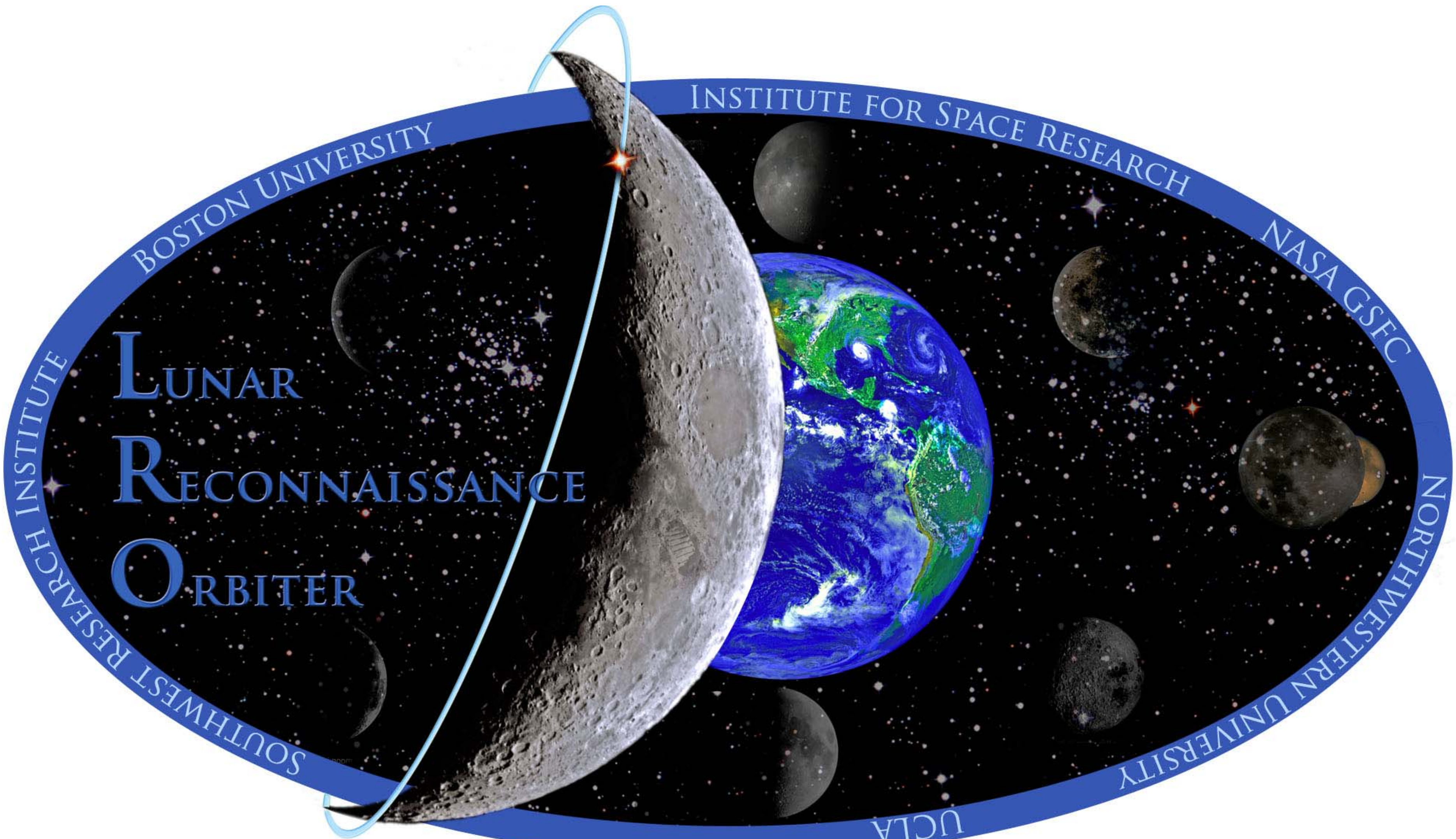


LRO Objectives

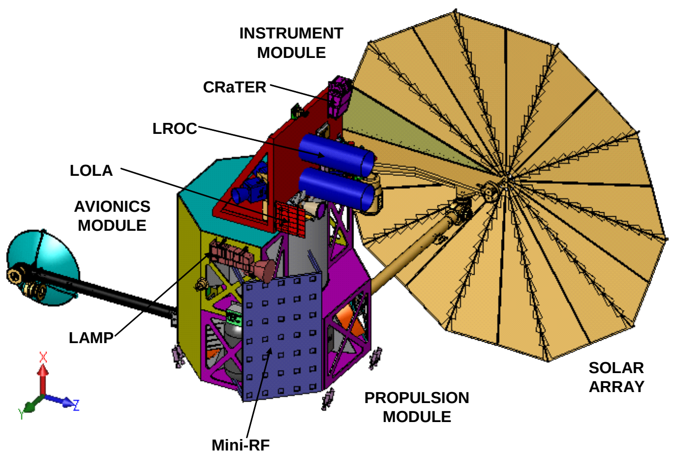
- **Characterization of the lunar radiation environment, biological impacts, and potential mitigation. Key aspects of this objective include determining the global radiation environment, investigating the capabilities of potential shielding materials, and validating deep space radiation prototype hardware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



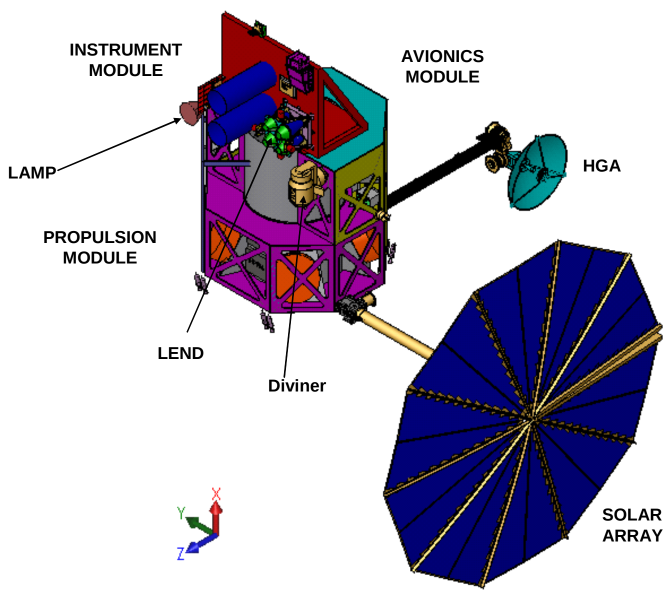
Lunar Reconnaissance Orbiter (LRO)



LRO Mission Overview: Orbiter



LRO Preliminary Design

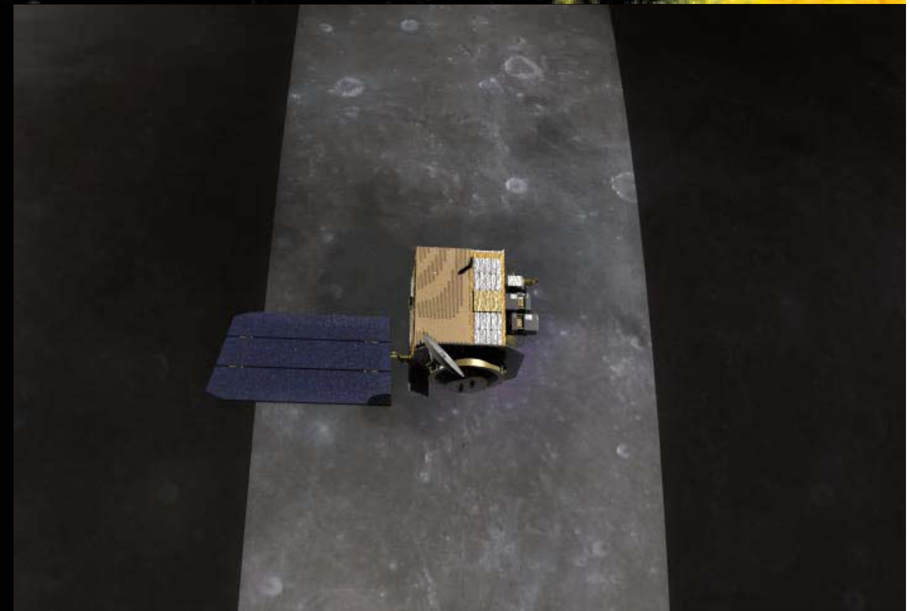


LRO Instruments

- **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		
Mass	1317 kg	Dry: 603 kg
		Fuel: 714 kg
Power	745 W	
Measurement Data Volume	575 Gb/day	

- One of only 6 scientific instruments selected competitively for LRO
- Galactic and solar cosmic ray radiation measured behind human "tissue-equivalent plastic"; Physics of particle acceleration studied
- Launch: Oct.-Nov. 2008



- Global maps of lunar radiation environment constructed from data collected over >1 year in low altitude lunar orbit
- NASA will use CRaTER data to assess deep space radiation dose rates and risks to astronauts

Motivation and Measurement Objectives

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

CRaTER's energy spectral range:

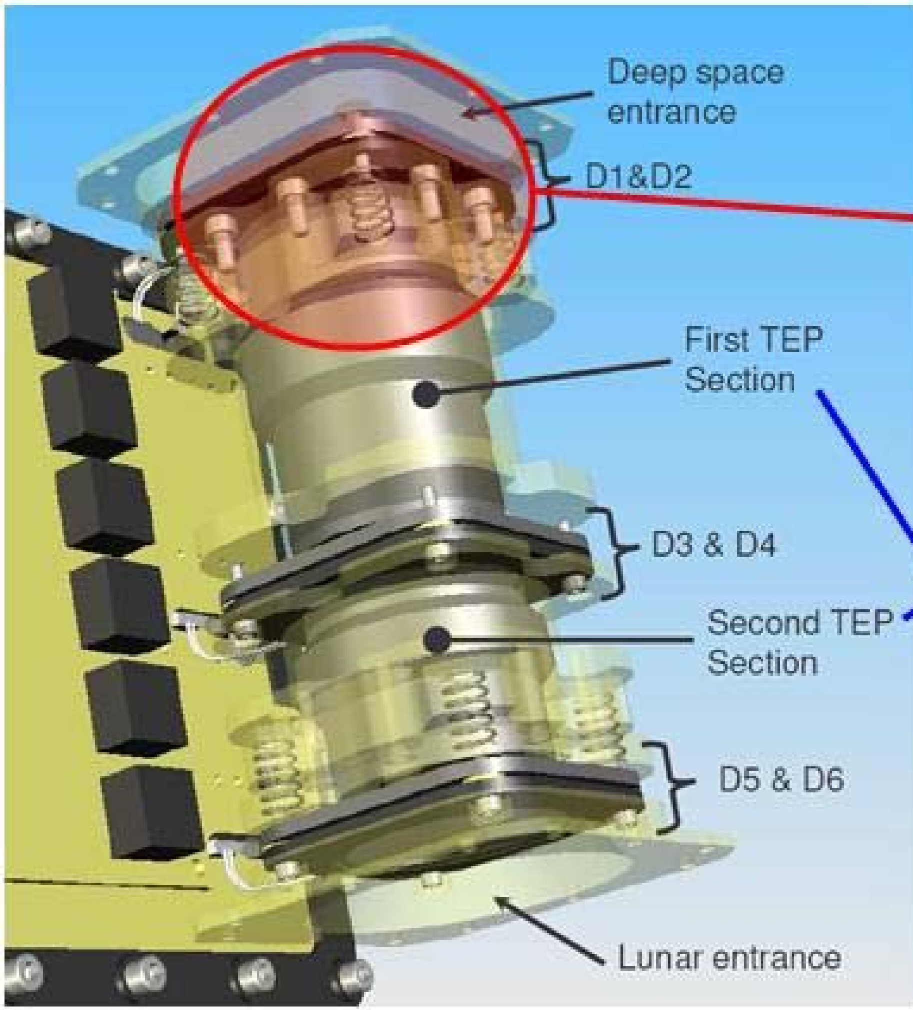
- **200 keV to 100 MeV (low LET detector chains)**
- **2 MeV to 1 GeV (high LET detector chains)**
- **Energy resolution <0.5% (at max energy); GF ~ 0.1 cm^2-sr**

This corresponds to:

- LET from **0.2 keV/μ to 7 MeV/ μ** (stopping 1 Gev/nuc 56-Fe)
- Excellent spectral overlap in the **100 kev/μ** range (key range for RBEs)

CRaTER Science Measurement Concept

Theory of Operation

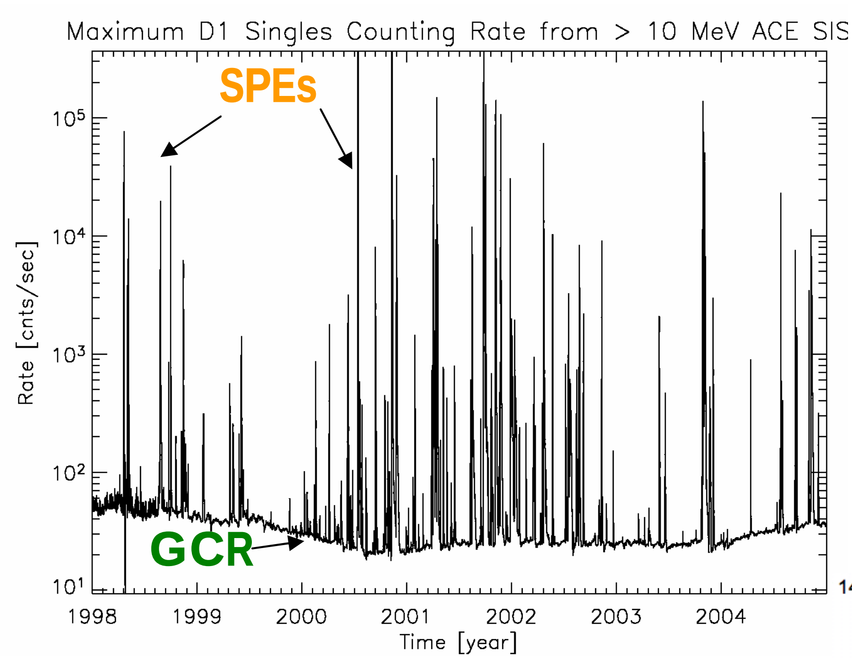


Pairs of thin and thick Silicon detectors

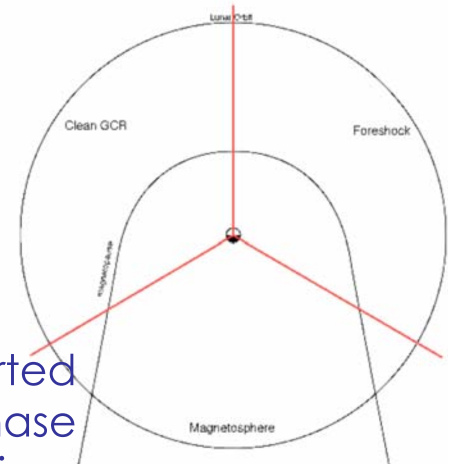
A-150 Human tissue equivalent plastic (TEP)

CRaTER Primary Science

- LET spectra constructed for **GCR**/**SPE** 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)*

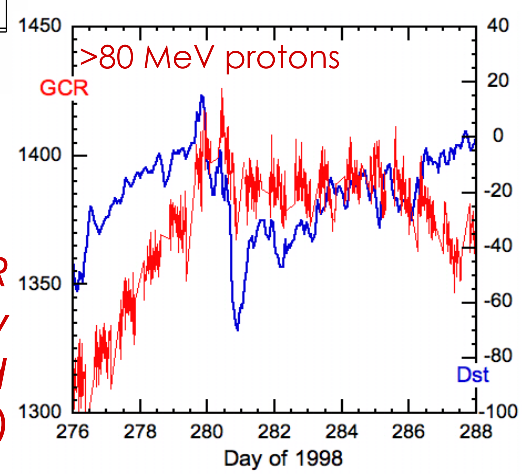


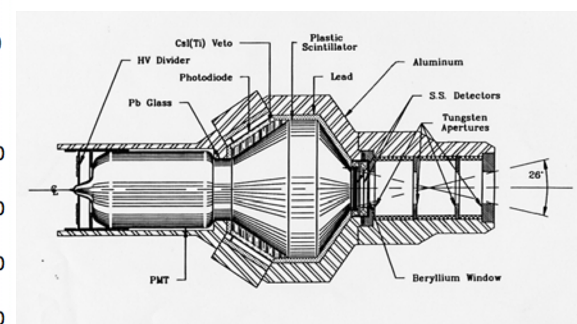
Predicted CRaTER counting rates based on historic GCR (low level, slowly varying) and SPE (intense, rapidly varying) observations



LET spectra sorted according to lunar phase and orbital positions

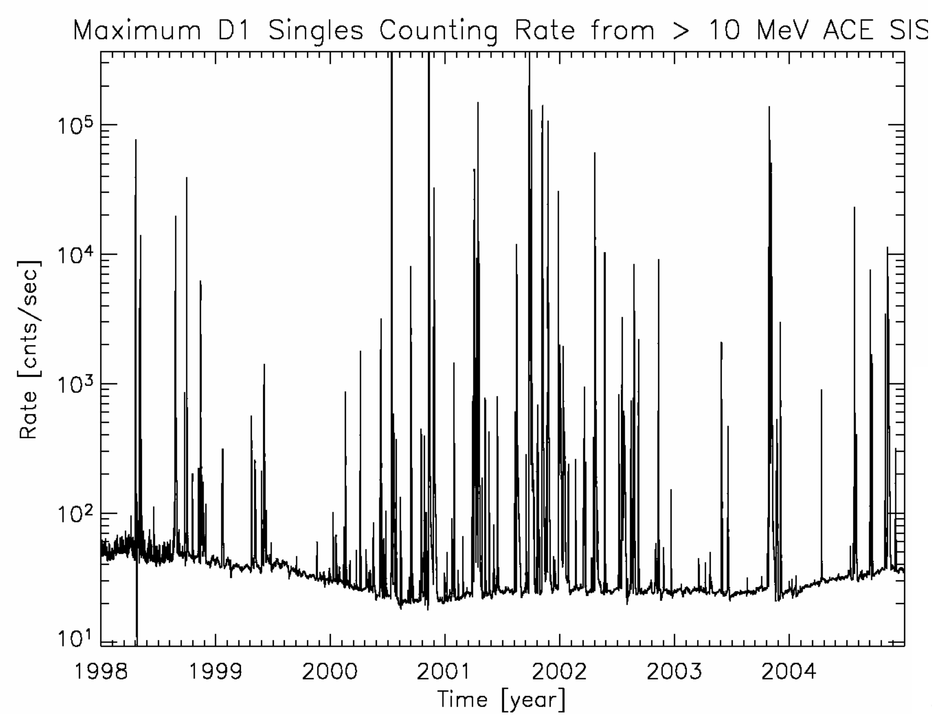
CRaTER will explore rapid GCR variations, discovered recently by NASA/Polar HIST (results presented last month at LISA meeting in UK)

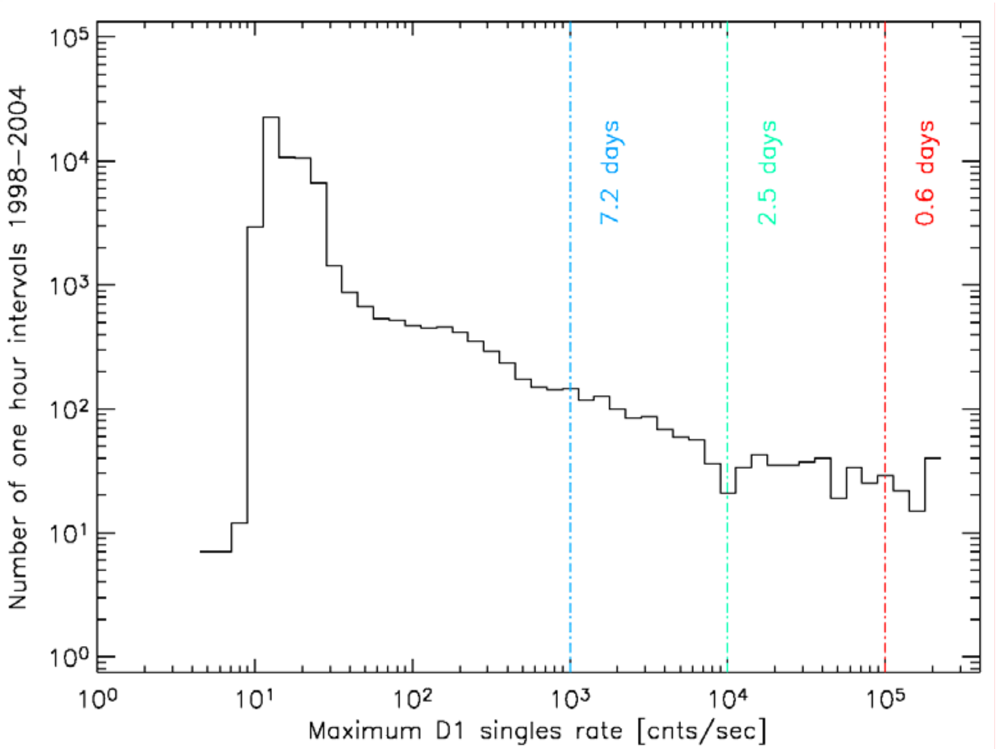




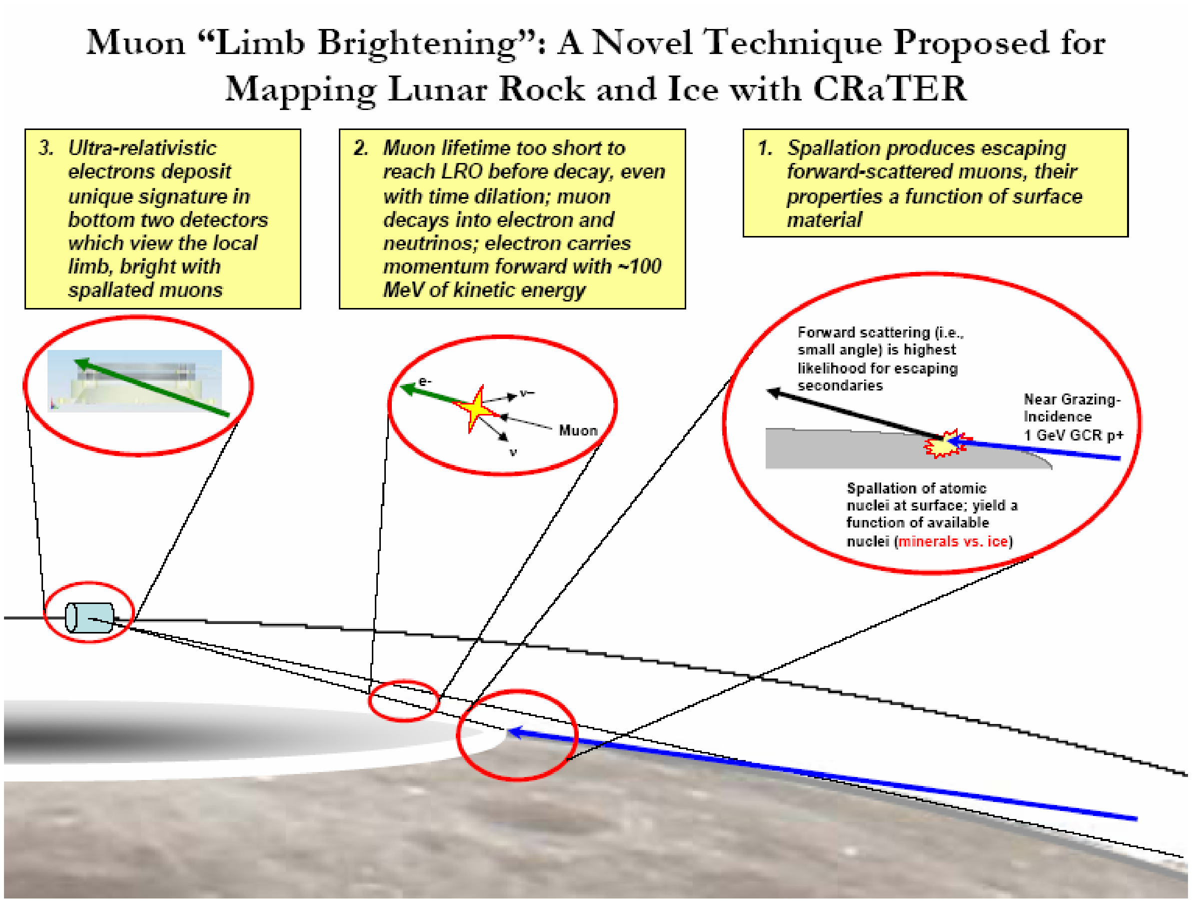
HIST Telescope Sensor

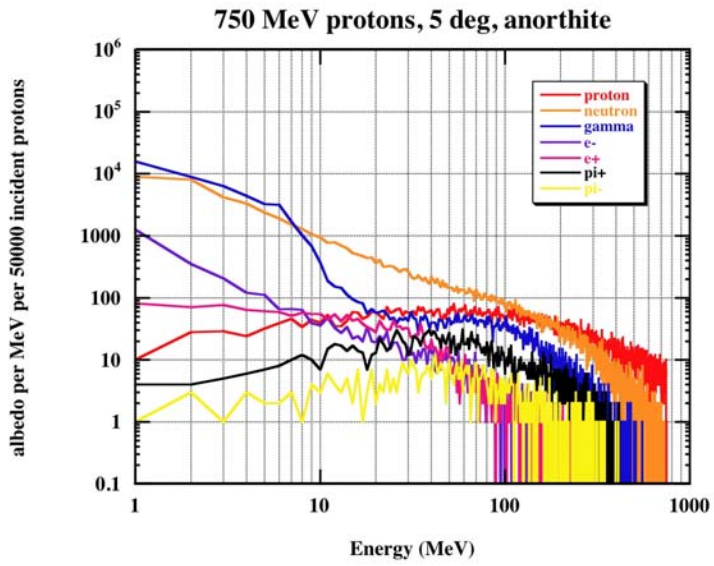
Maximum singles detector rates; CRaTER gets **100 kbits/sec**!

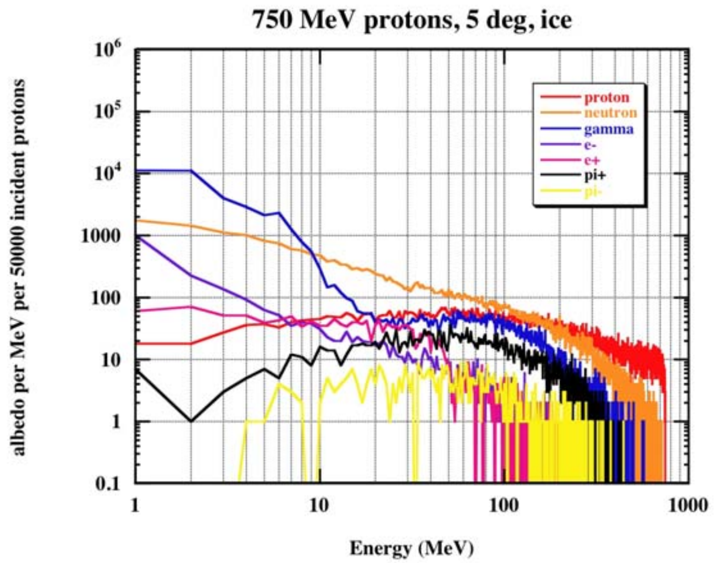




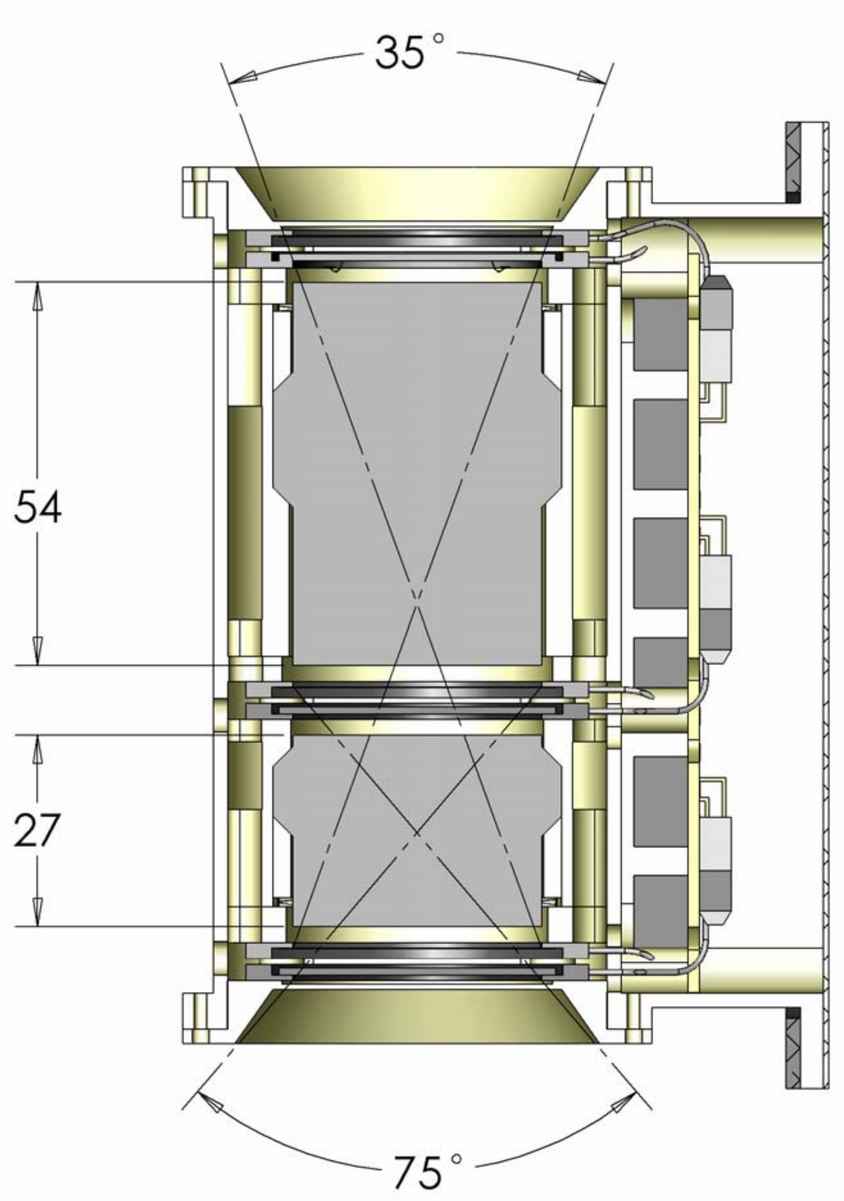
CRaTER *Secondary* Science – Muon "Limb Brightening" through Spallation

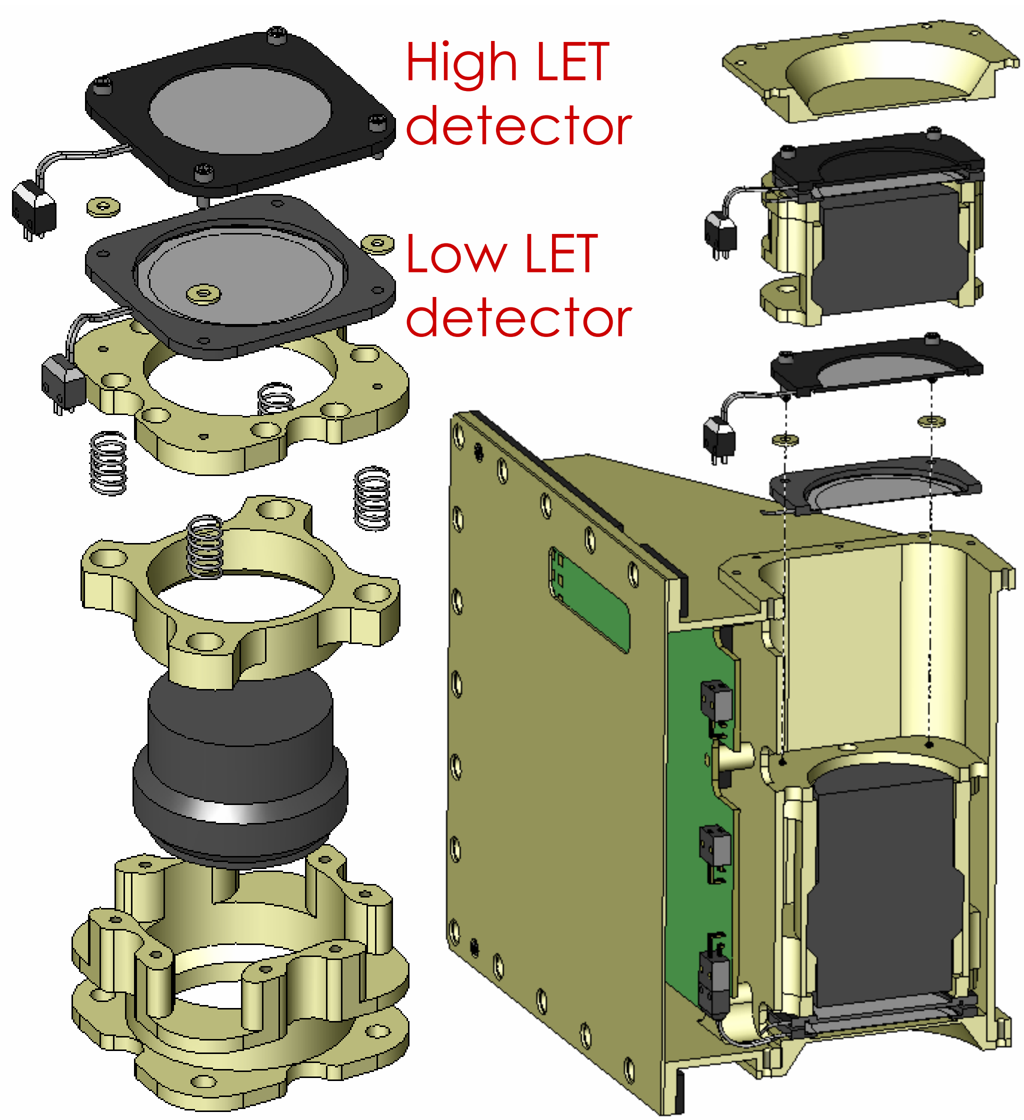




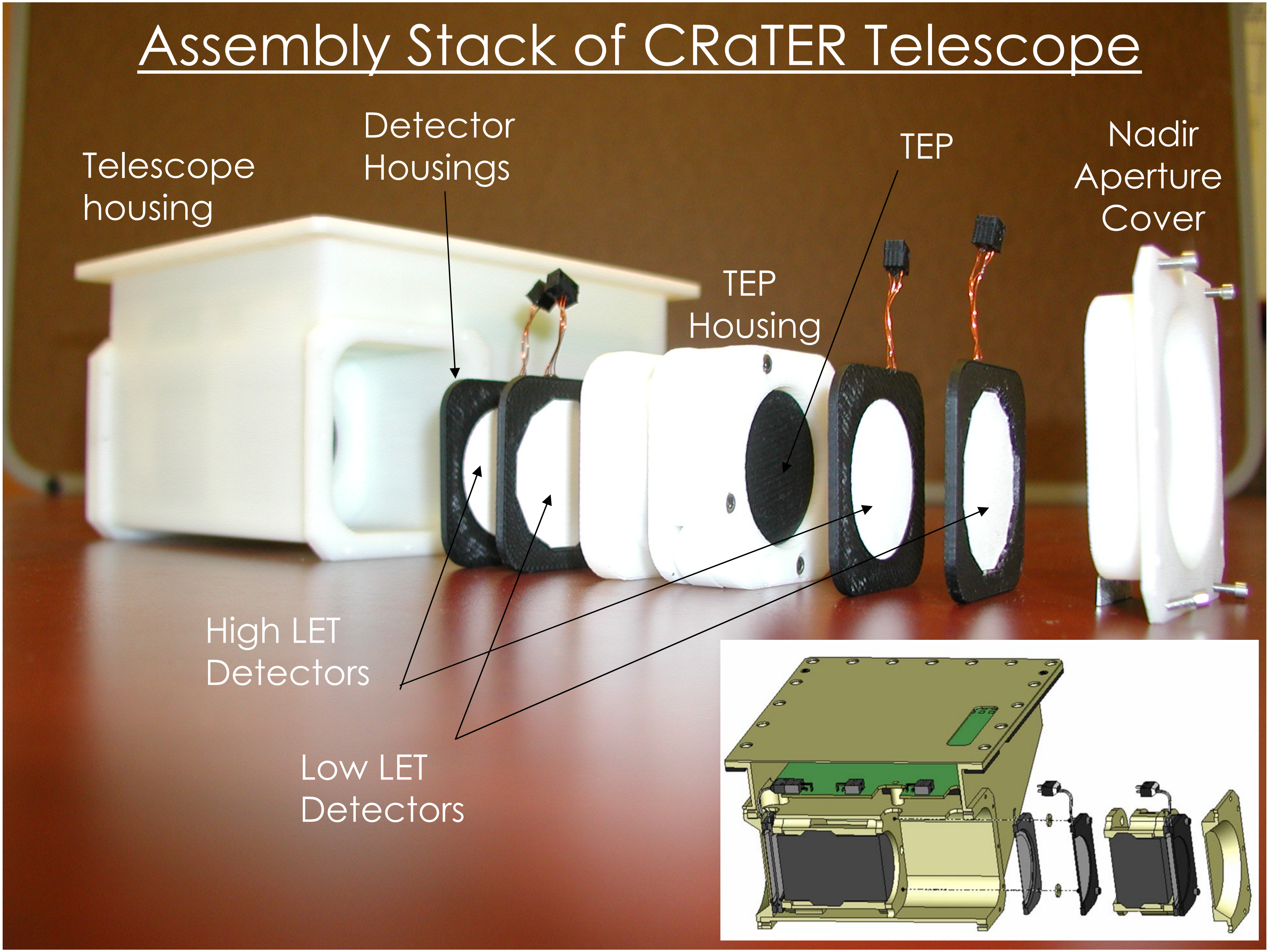


CRaTER Telescope Configuration





Assembly Stack of CRaTER Telescope

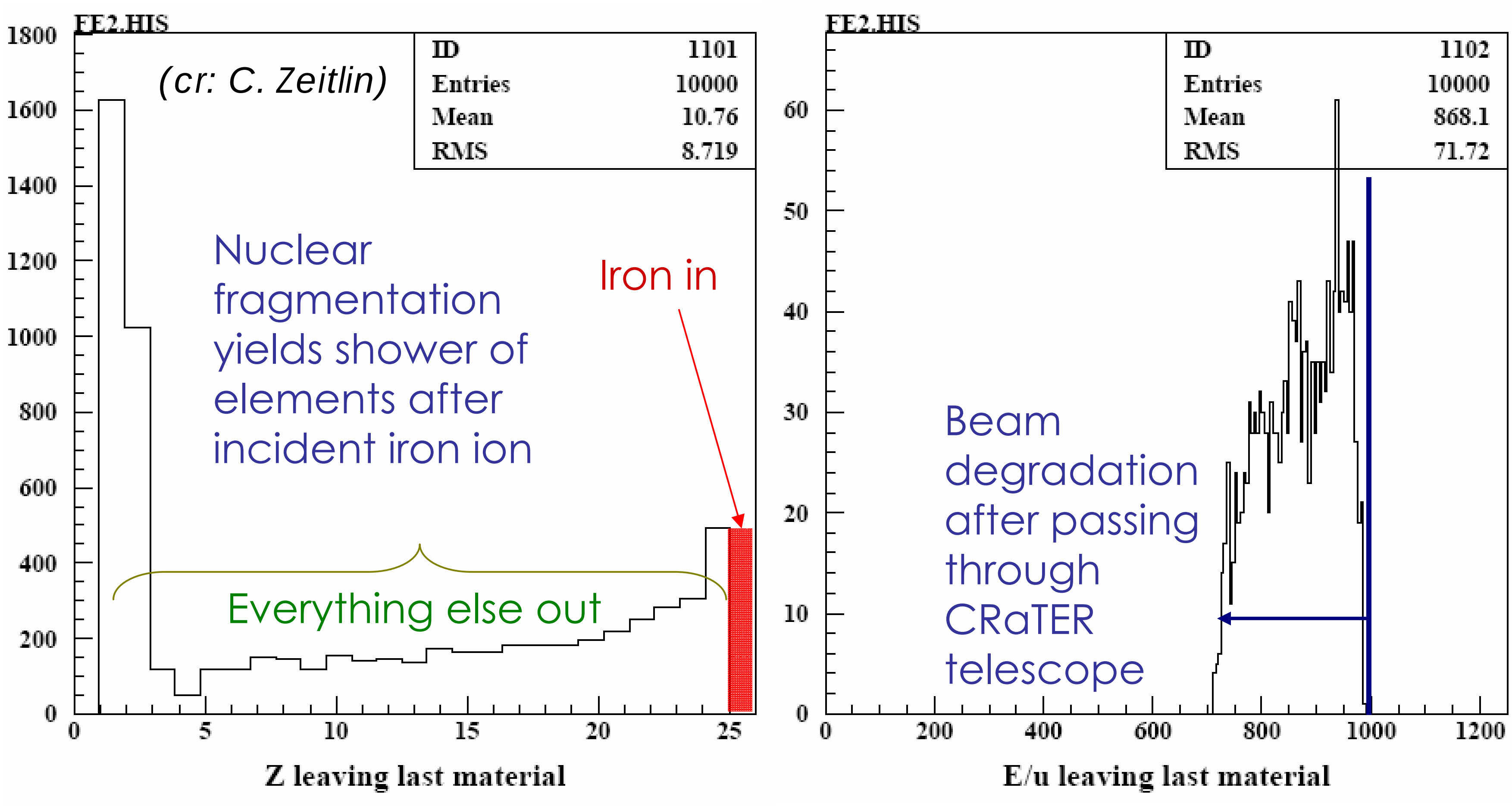


Recent CRaTER Beam Validation/Modeling

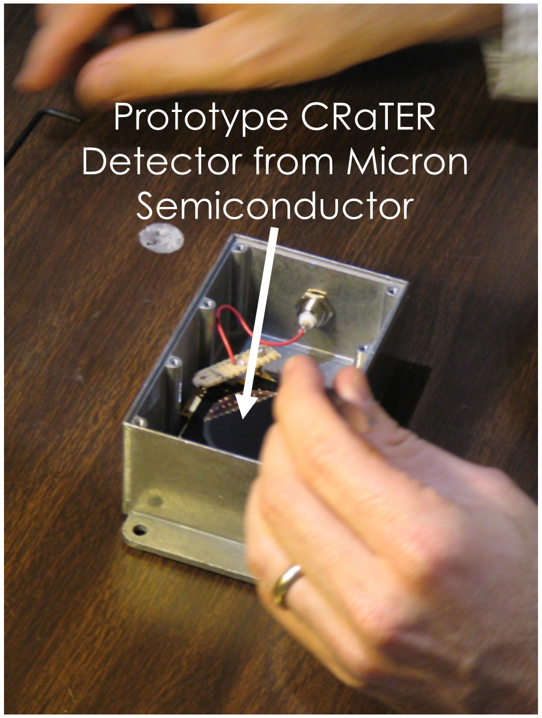
Modeling	**SRIM, GEANT4, BBFRAG, HETC-HEDS, FLUKA, HZTRAN**
Beam Validation	
12 September 2005	Detector prototype characterization at **LBNL** 88" cyclotron
22 January 2005	TEPTA response to p+'s at **MGH** proton accelerator (10 - 230 MeV)
13 March 2006	Prototype detector/TEP characterization at **LBNL** (light ions)
27 March 2006	TEPTA response to heavy ions at **BNL** (56-Fe, 0.3 & 1 Gev/n) – 4 hours of beam time
May/June 2006	E/M detector testing at **LBNL** and **MGH**
September 2006	E/M CRaTER beam validation at **BNL** (56-Fe, 0.6 GeV/n) – 4 more hours of beam time

Fragmentation of 1 GeV/nuc Fe in CRaTER

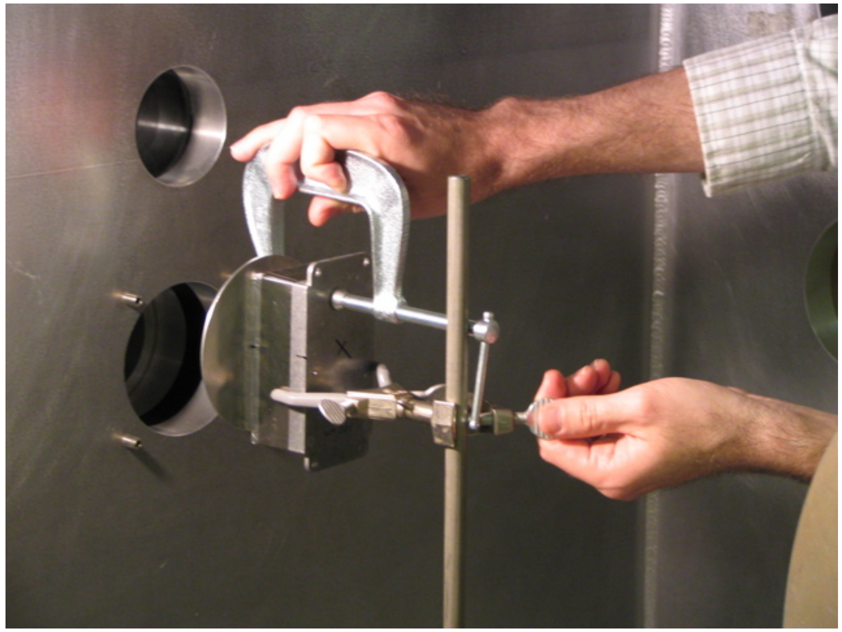
- State-of-the-art in-development physics codes used for most complex interactions (energetic heavy ions) – these are codes that we hope CRaTER data products will ultimately improve
- HETC-HEDS & **BBFRAG** (see example below) used to constrain extremes
- Lab validation of TEP test apparatus and E/M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



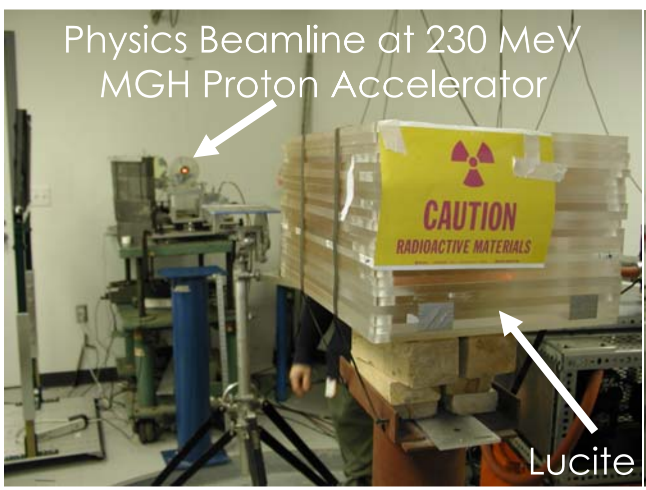
CRaTER Beam Runs at LBNL and MGH

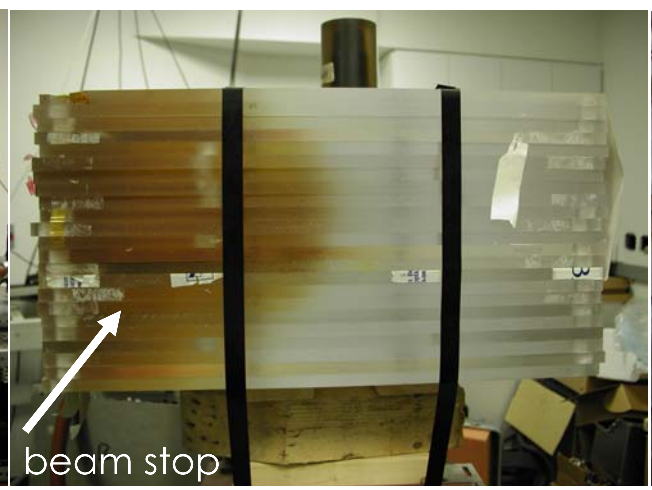


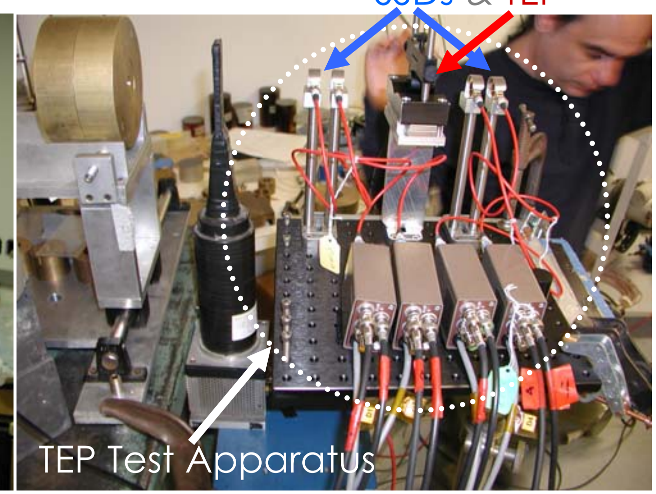
12 September 2005 – LBNL 88" cyclotron



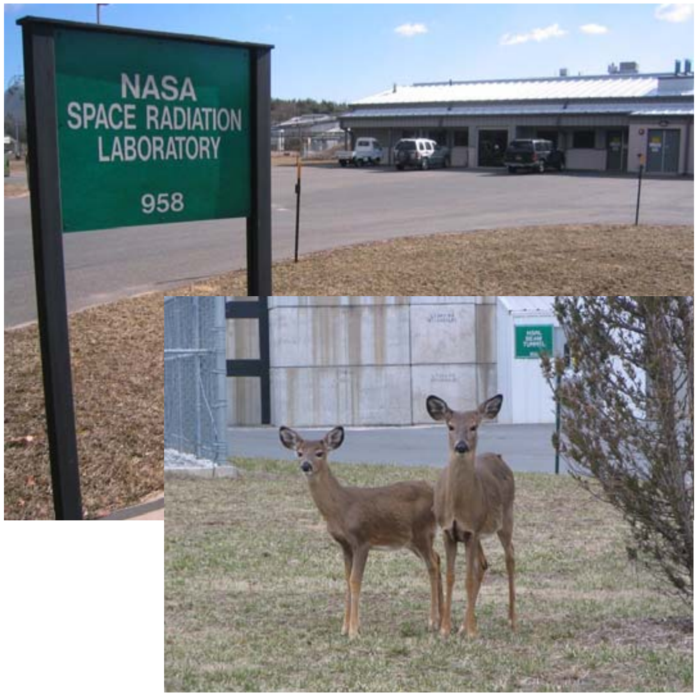
22 January 2006 – MGH Proton Radiation Therapy Facility



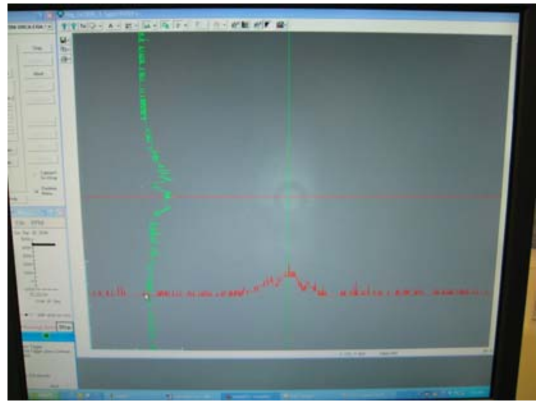


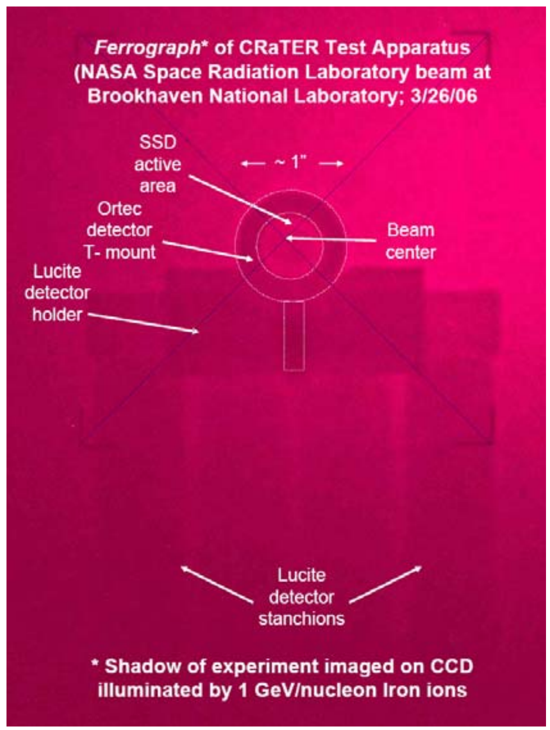


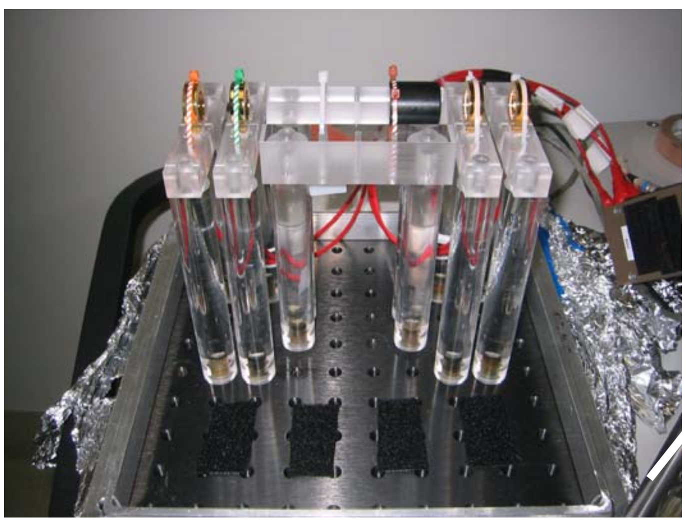
CRaTER Beam Runs at BNL/NSRL

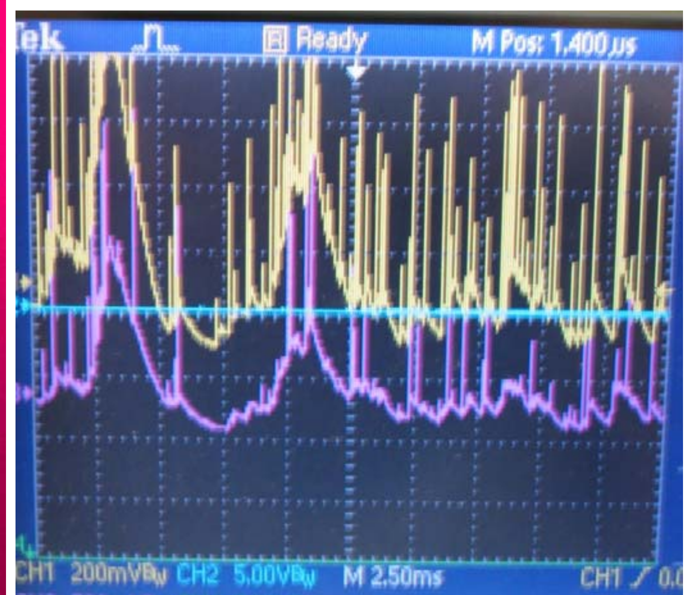


26 March 2006

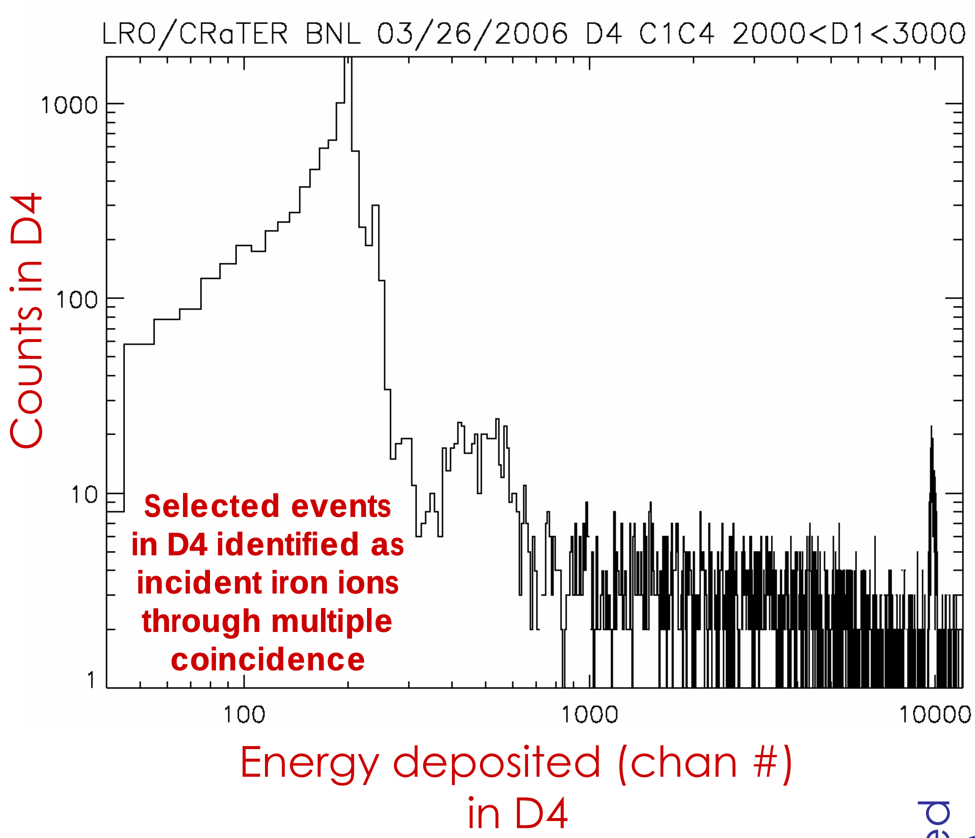


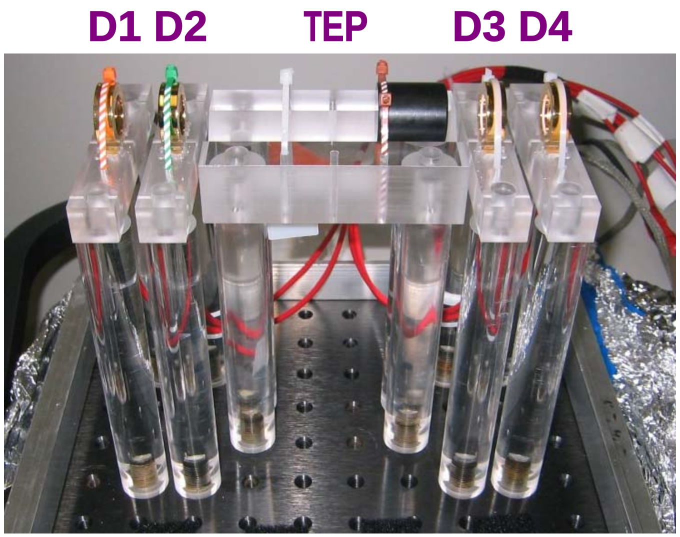




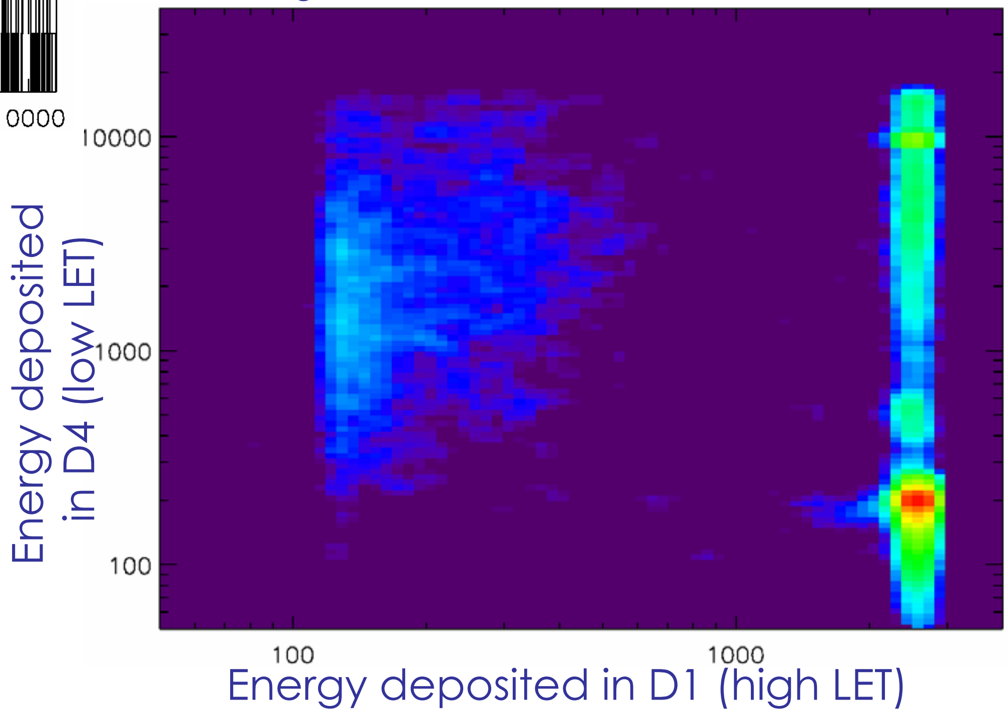


Preliminary CRaTER BNL/NSRL "Results"





2-D histogram of all coincident events between D1/D4



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

CRaTER Data Level Definitions

Data Level	Description
Level 0	Unprocessed instrument data (pulse height at each detector, plus secondary science) and housekeeping data.
Level 1	Depacketed science data, at 1-s resolution. Ancillary data pulled in (spacecraft attitude, calibration files, etc.)
Level 2	Pulse heights converted into energy deposited in each detector. Calculation of Si LET
Level 3	Data organized by particle environment (GCR, foreshock, magnetotail). SEP-associated events identified and extracted.
Level 4	Calculation of incident energies from modeling/calibration curves and TEP LET spectra

- Additional user-motivated data products might include: "Surface", "Tissue", and "Deep Tissue" Dose Rates (working with JSC's SRAG to identify key tailored data products to support their operations)

- 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.

Web pages (*constantly in development*) at:

crater.bu.edu
(science site)

snebulos.mit.edu/projects/crater
(engineering site)

CRaTER
Cosmic Ray Telescope for the Effects of Radiation

About CRaTER | News | Instrument | Science | Public Data

- Instrument Overview
- Solid State Detectors
- Tissue Equivalent Plastic

The investigation hardware consists of a single, integrated sensor and electronics box with simple electronic and mechanical interfaces to the spacecraft. The CRaTER sensor frontend design is based on standard stacked-detector, cosmic ray telescope systems that have been flown for decades, using detectors developed for other NASA flight programs. The analog electronics design is virtually identical to the robust and flight-proven design of the NASA/POLAR Imaging Proton Spectrometer that has been operating flawlessly on orbit since 1996. The digital processing unit is a simple and straightforward design also based on similar instruments with excellent spaceflight heritage. No new technology developments or supporting research are required for the final design, fabrication, and operation of this instrument.

The CRaTER telescope consists of five ion-implanted silicon detectors (red areas), mounted on four detector boards (green areas), and separated by three pieces of tissue-equivalent plastic, hereinafter referred to as TEP (tan areas). All five of the silicon detectors are 2 cm in diameter. Detector 1 is 20 micrometers thick; the other four are 300 micrometers thick. TEP (such as A-150 manufactured by Standard Imaging) simulates soft body tissue (muscle) and has been used for both ground-based as well as space-based (i.e., Space Station) experiments.

Low LET detectors	9.6 cm^2 circular, 1000 microns thick. 0.2 MeV threshold
High LET detectors	9.6 cm^2 circular, 140 microns thick. 2 MeV threshold
TEP absorber 1	5.4 cm cylinder
TEP absorber 2	2.7 cm cylinder
Zenith FOV	35 degrees, 6-detector coincidence
Nadir FOV	75 degrees, for D3D4D5D6 coincidence
Geometry factor	0.1 cm^2 sr (D1D2 events)
LET range	0.2 - 7 MeV/micron (Si)
Incident particle energy range	>20 MeV (H) >87 MeV/nucleon (Fe)

2006 NSREC paper describing the instrument.

Annotated drawing of our current instrument design.

Image of our current box design.


Thank you.