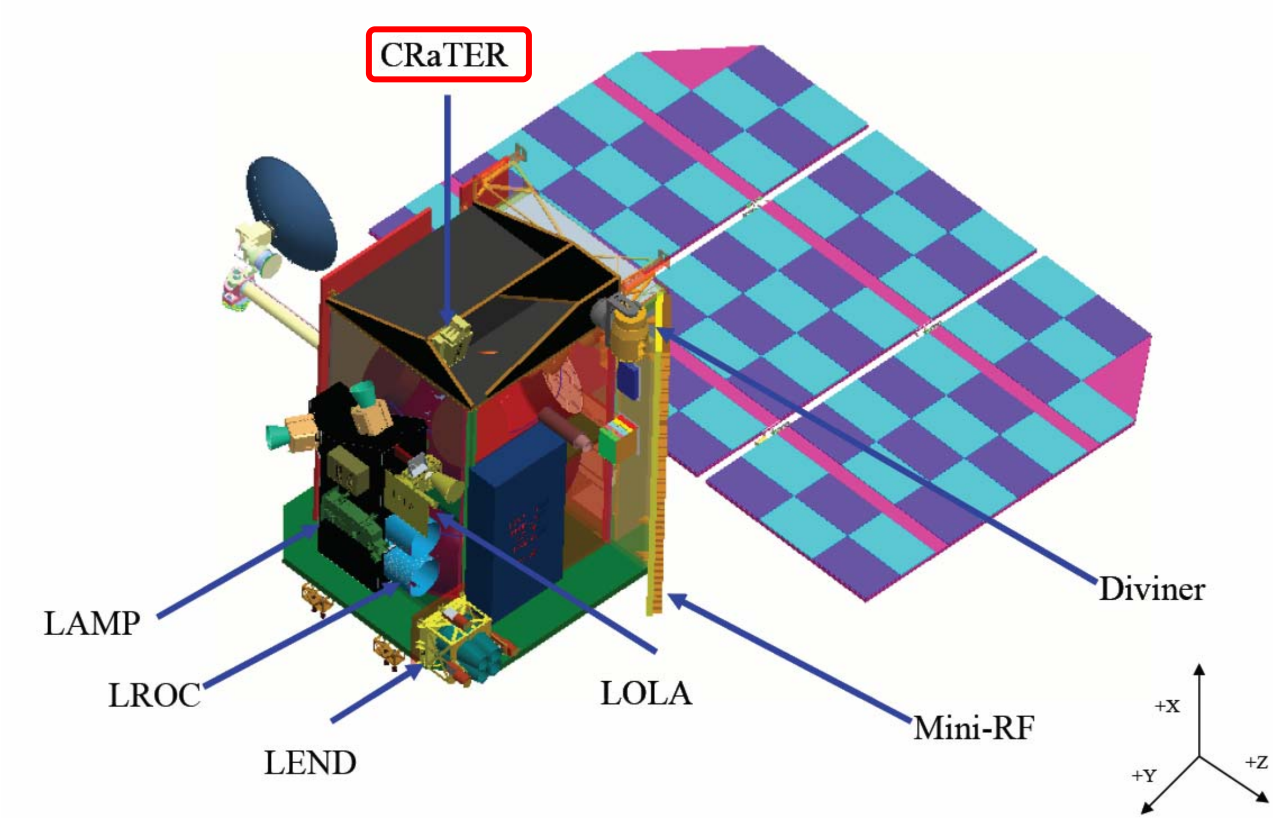
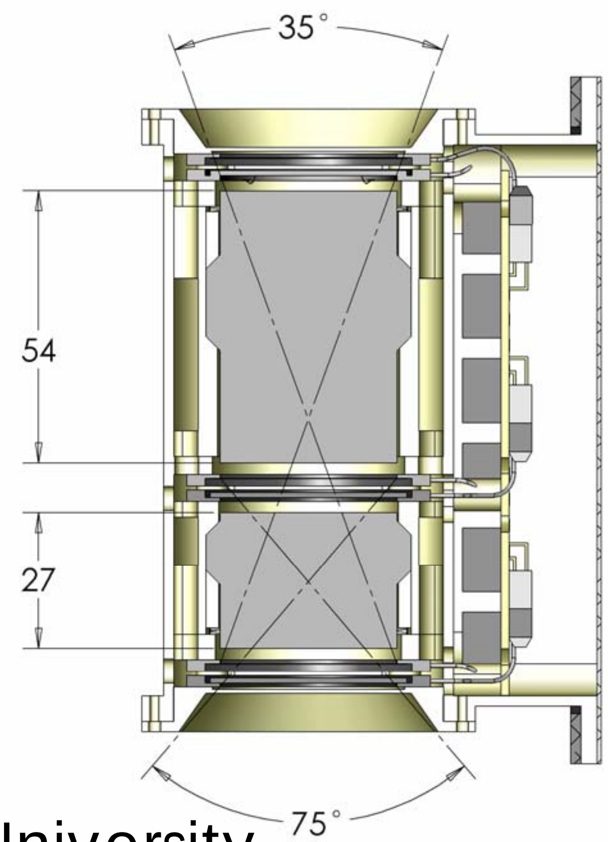
Cosmic Ray Telescope for the Effects of Radiation (CRaTER)

Radiation Detection and Dosimetry Workshop
7 April 2006





Harlan E. Spence, Boston University

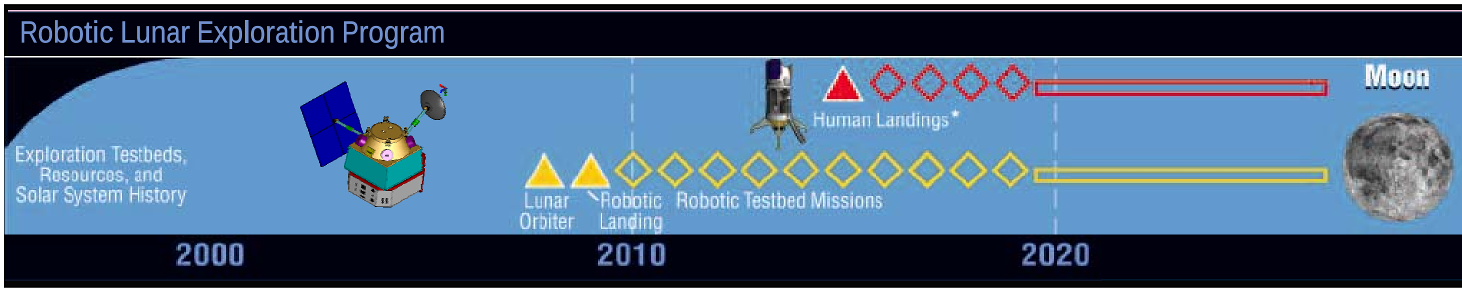
on behalf of the CRaTER Science Team

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

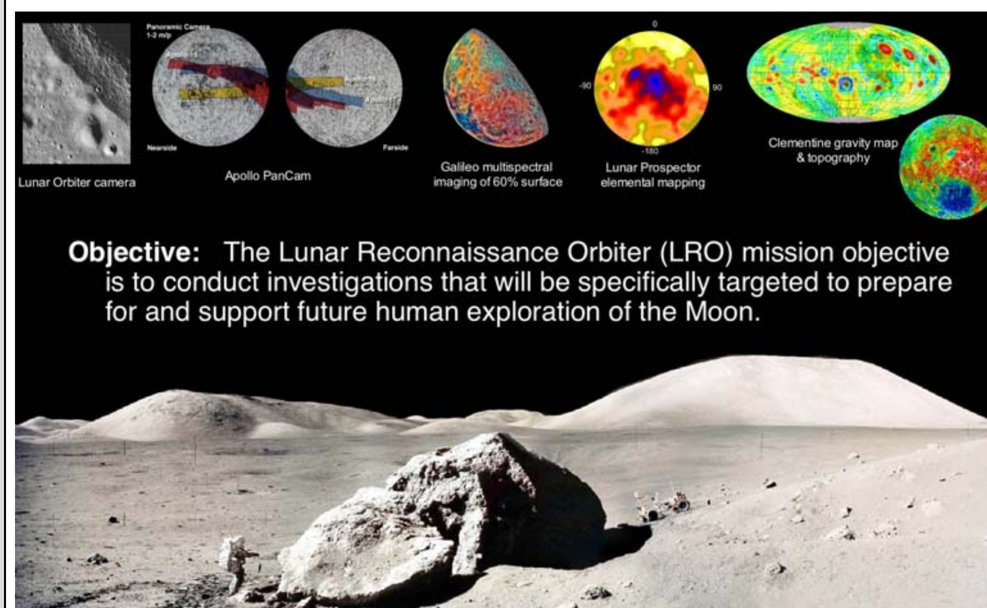
Lunar Reconnaissance Orbiter (LRO)

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

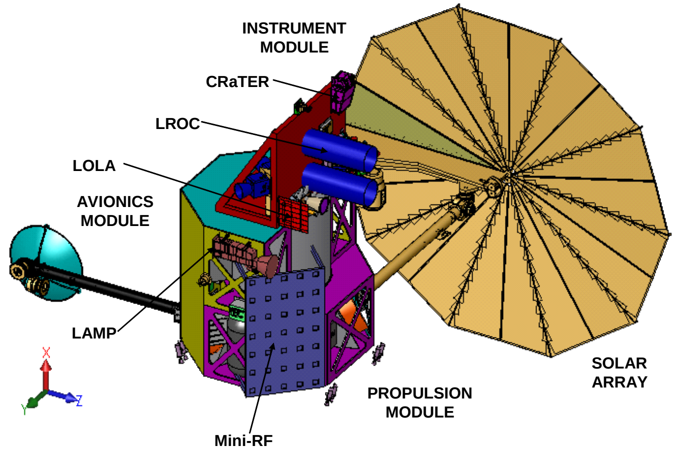


LRO Objectives

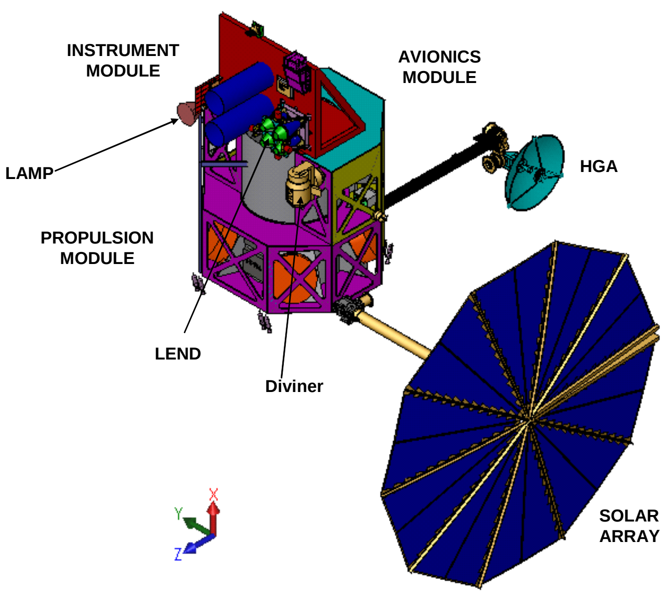
- **Characterization of the lunar radiation environment, biological impacts, and potential mitigation. Key aspects of this objective include determining the global radiation environment, investigating the capabilities of potential shielding materials, and validating deep space radiation prototype hardware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



LRO Mission Overview: Orbiter



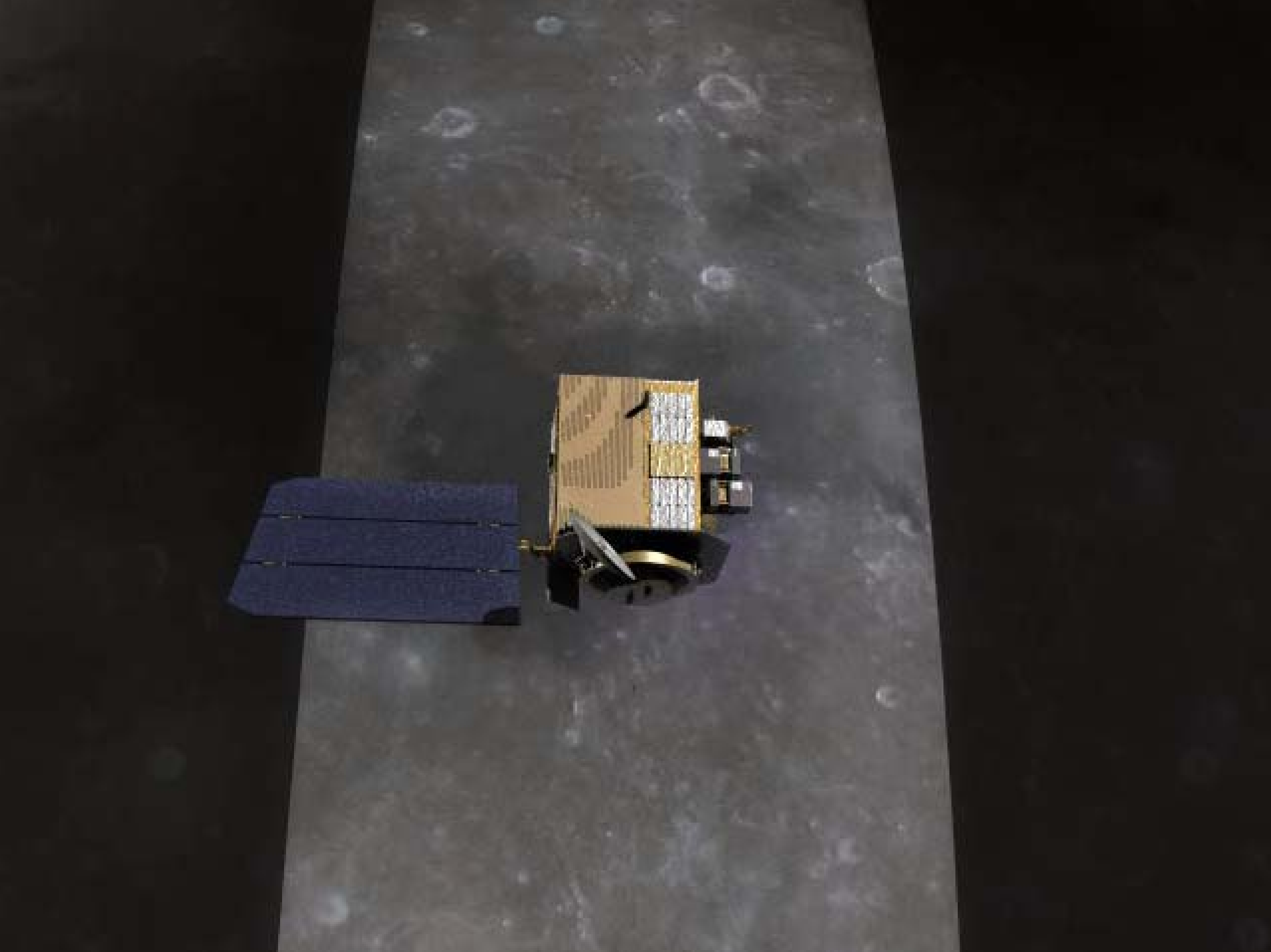
LRO Preliminary Design



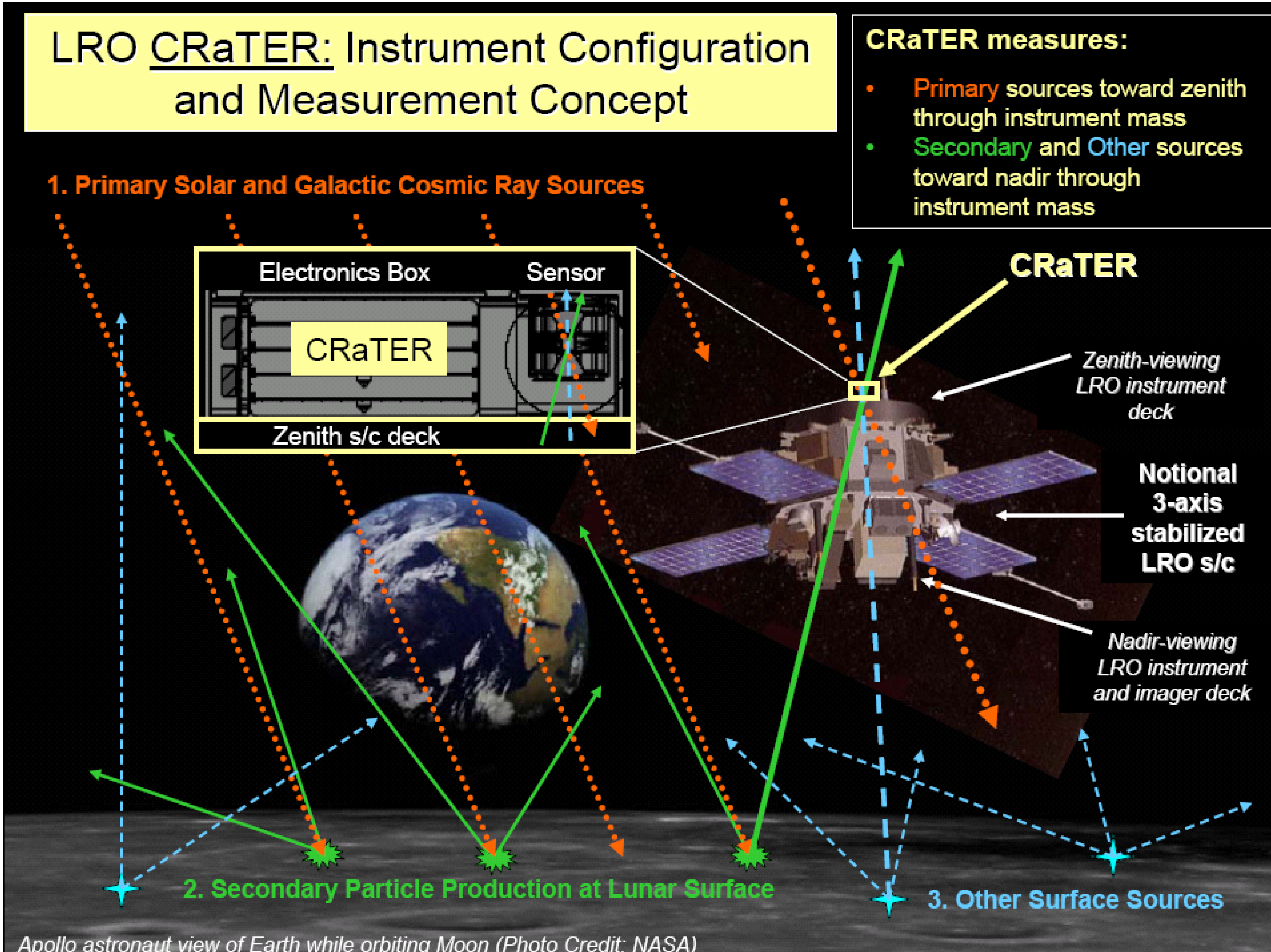
LRO Instruments

- **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.

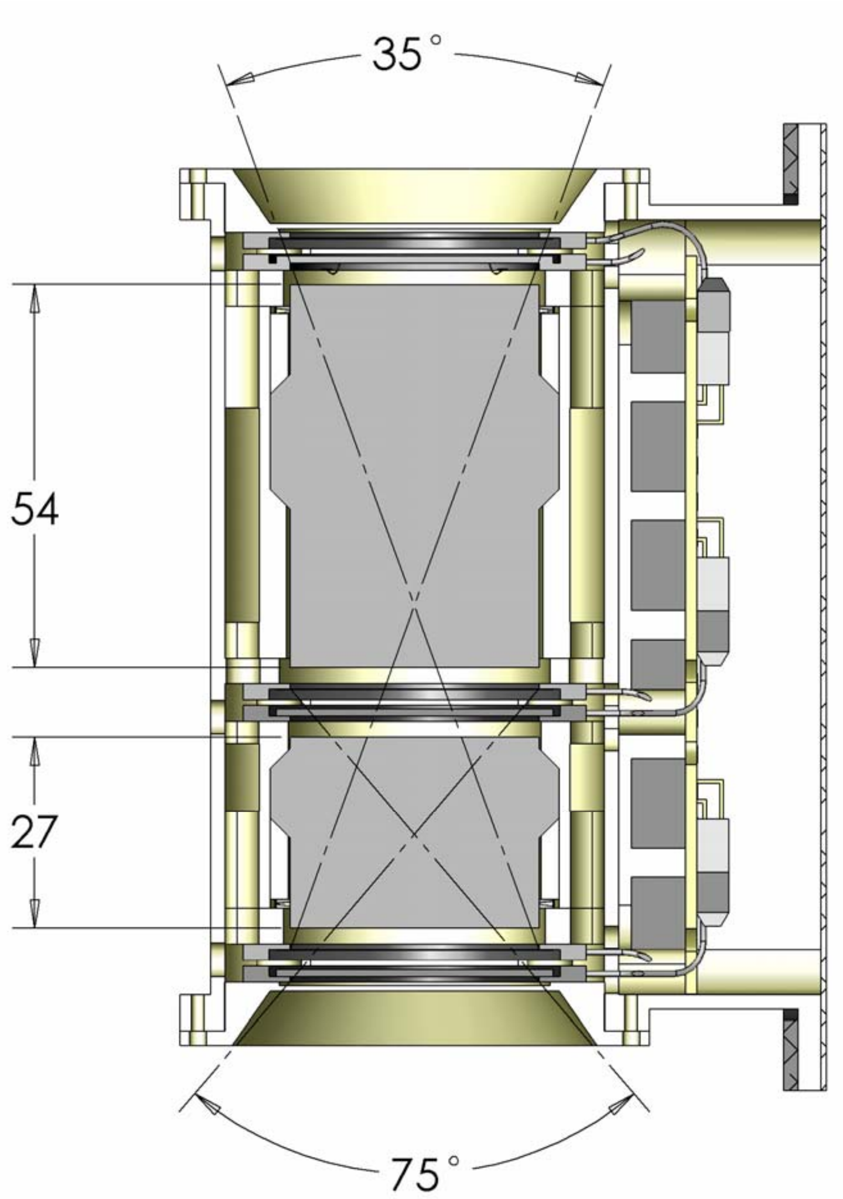
Preliminary LRO Characteristics		
Mass	1317 kg	Dry: 603 kg
		Fuel: 714 kg
Power	745 W	
Measurement Data Volume	575 Gb/day	

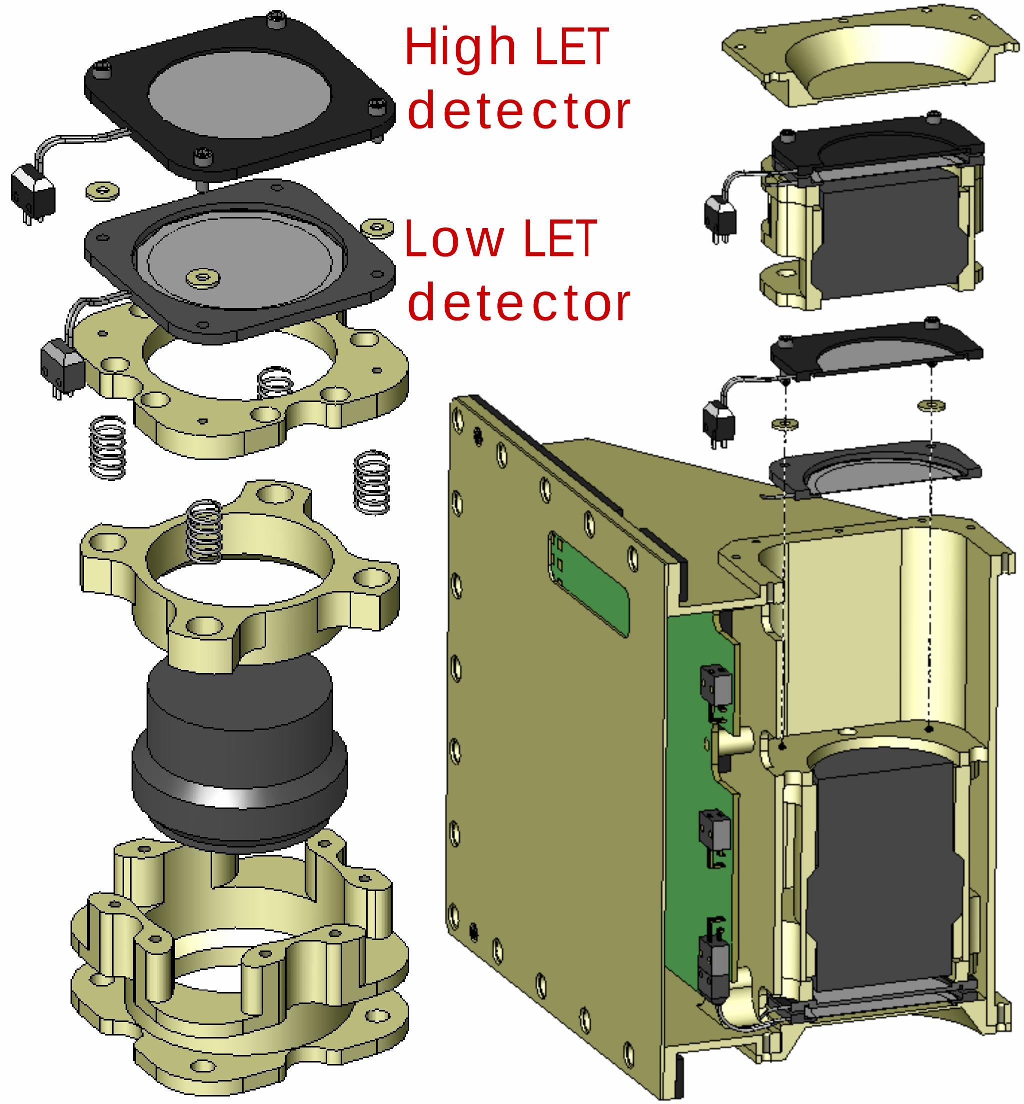


CRaTER Science Measurement Concept

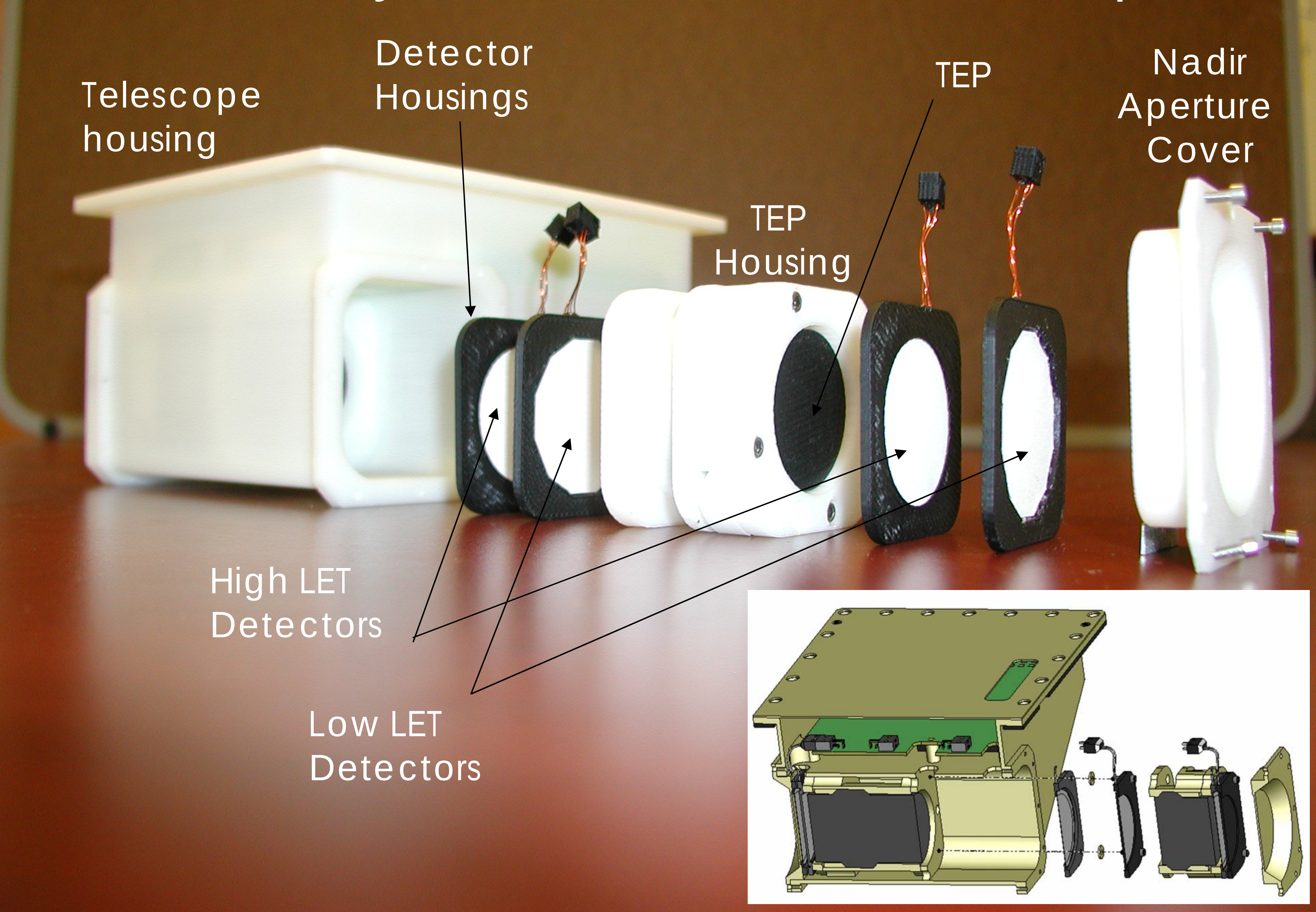


CRaTER Telescope Configuration





Assembly Stack of CRaTER Telescope



CRaTER Science Summary

- **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:

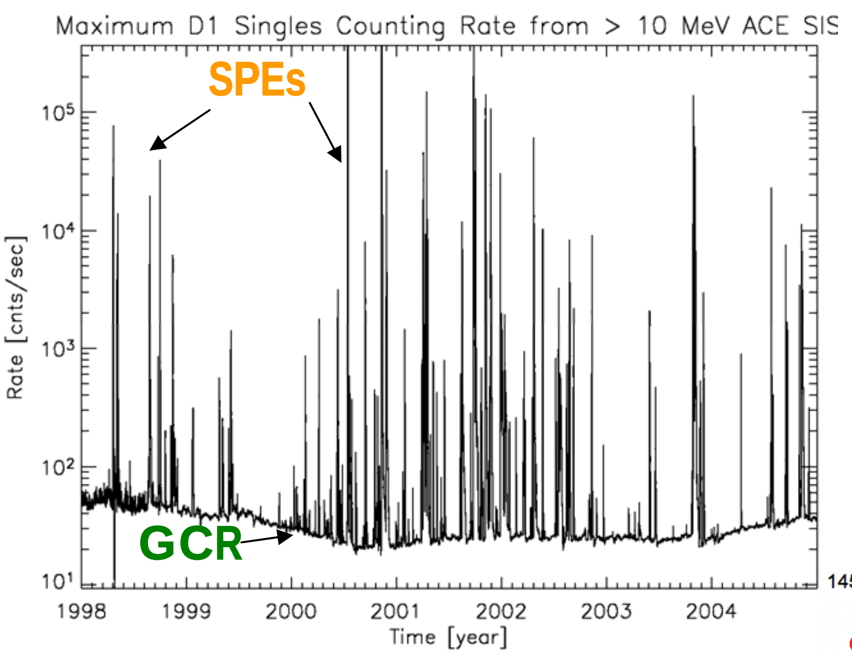
- **200 keV to 100 MeV (low LET detector chains)**
- **2 MeV to 1 GeV (high LET detector chains)**
- **Energy resolution <0.5% (at max energy); GF ~ 0.1 cm^2-sr**

This corresponds to:

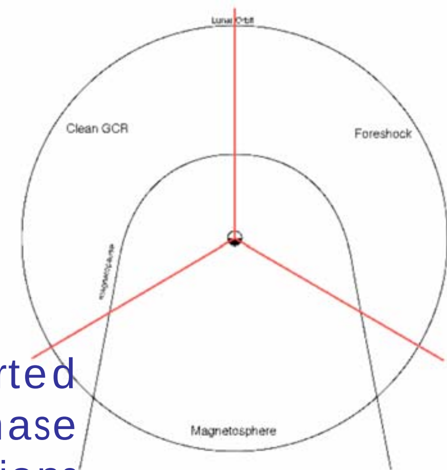
- LET from **0.2 keV/μ to 7 MeV/ μ** (stopping 1 Gev/nuc 56-Fe)
- Excellent spectral overlap in the **100 kev/μ** range (key range for RBEs)

CRaTER Primary Science

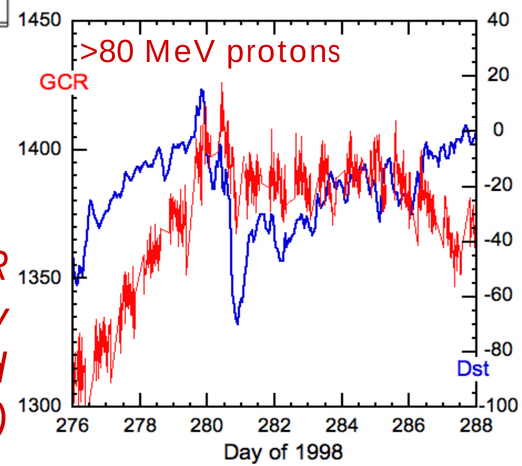
- LET spectra constructed for **GCR**/**SPE** independently, zenith & *nadir*
- Sorted according to lunar phase, LRO orbit phase, and lunar location
- *Will explore GCR fluctuations on **short** time scales (minutes to hours, of interest to LISA mission)*

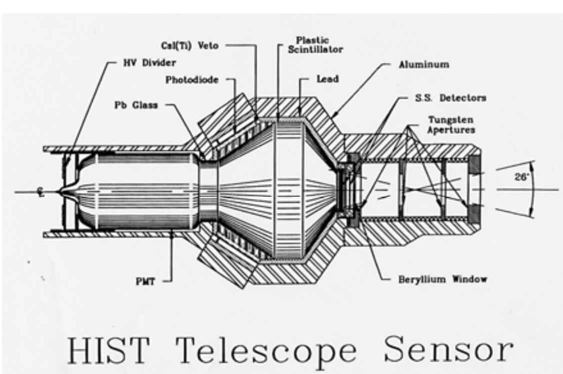


Predicted CRaTER counting rates based on historic GCR (low level, slowly varying) and SPE (intense, rapidly varying) observations



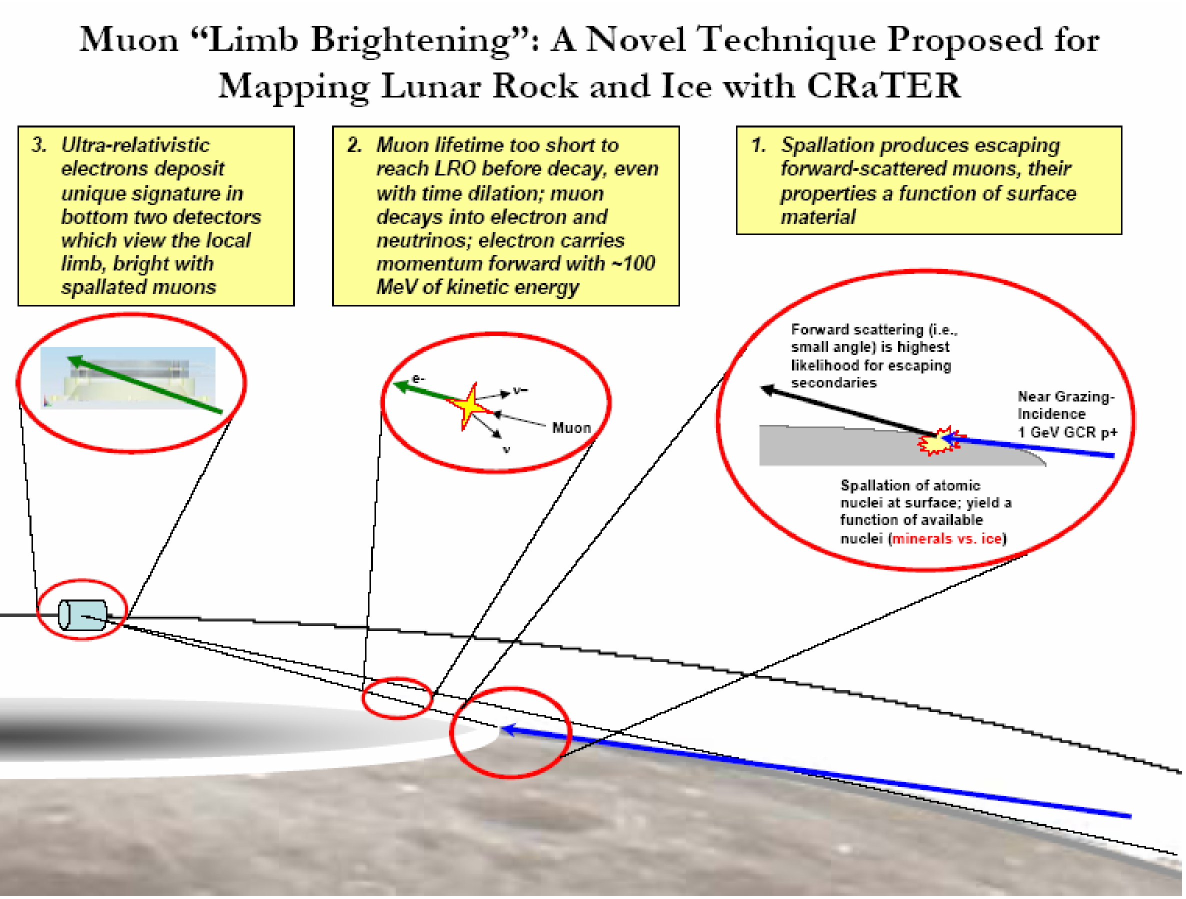
LET spectra sorted according to lunar phase and orbital positions

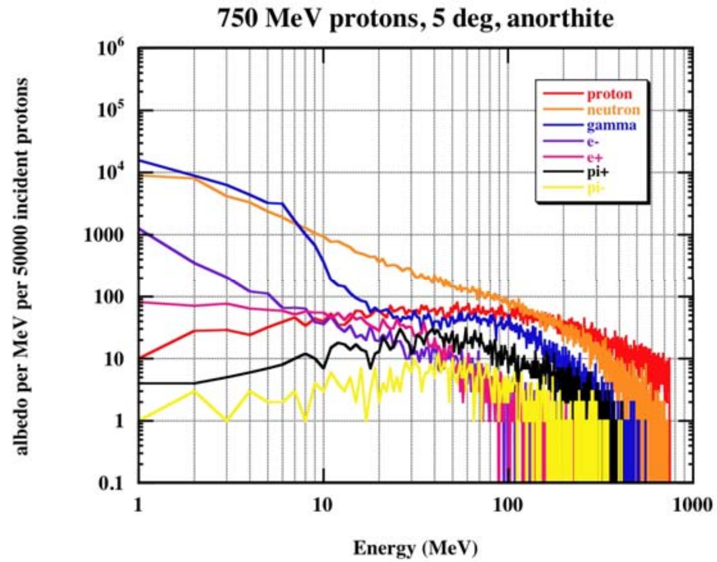


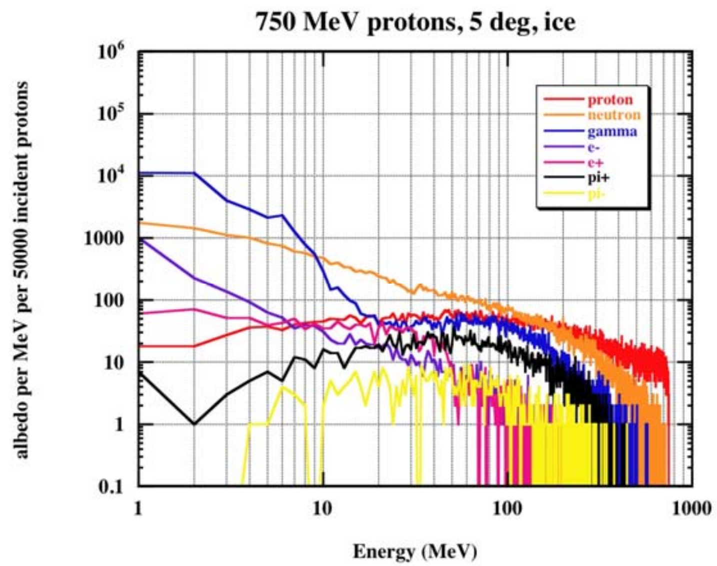


CRaTER will explore rapid GCR variations, discovered recently by NASA/Polar HIST (results presented last month at LISA meeting in UK)

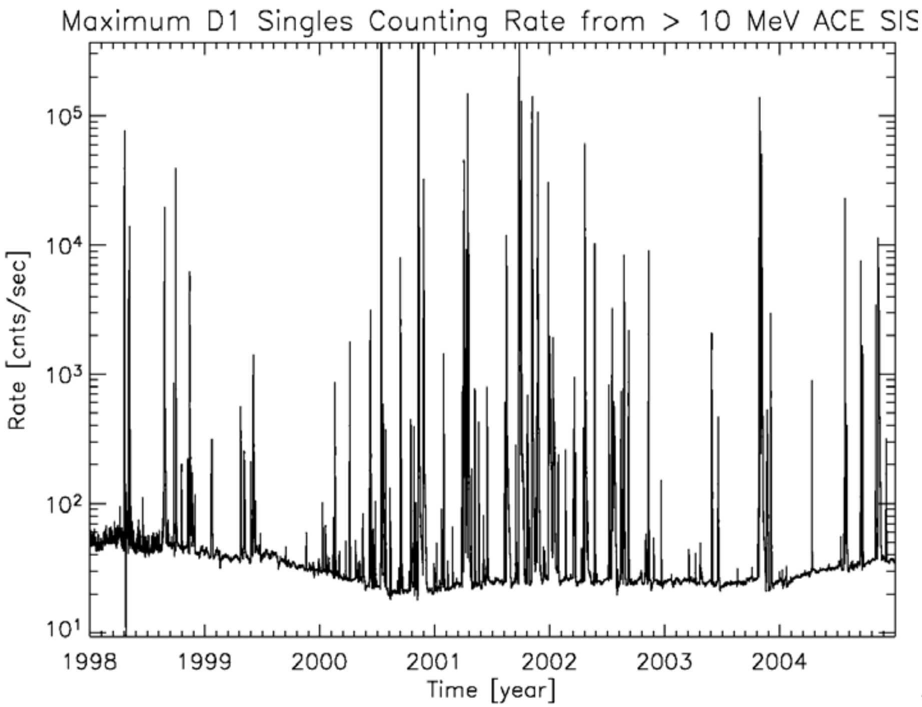
CRaTER *Secondary* Science – Muon “Limb Brightening” through Spallation

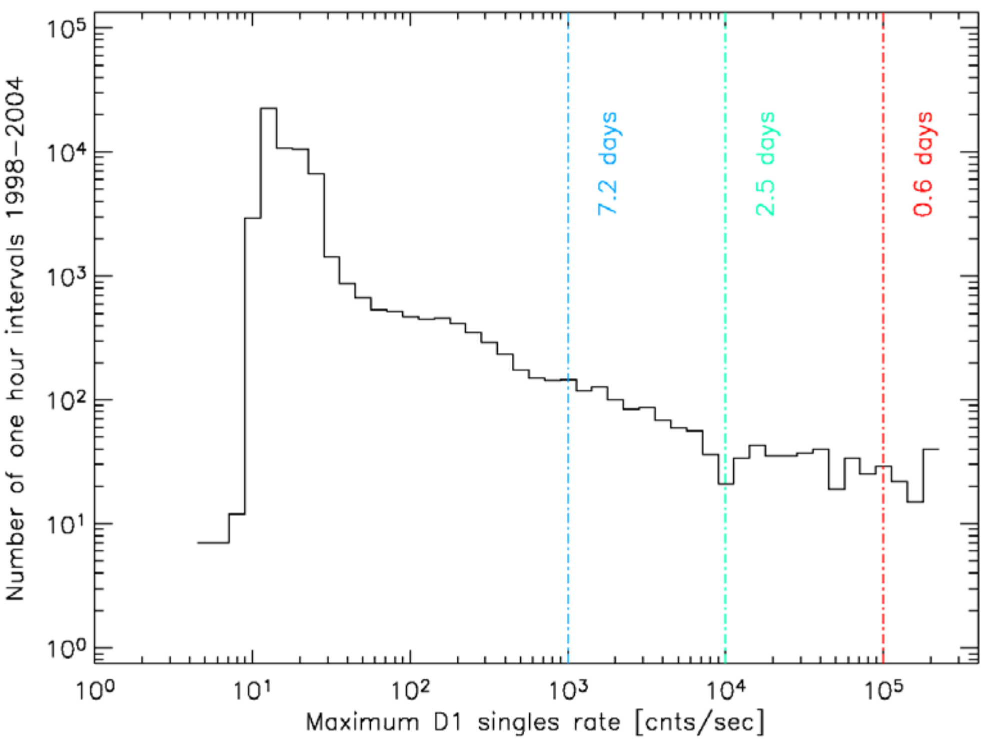






Maximum singles detector rates
CRaTER gets **100 kbits/sec**!!



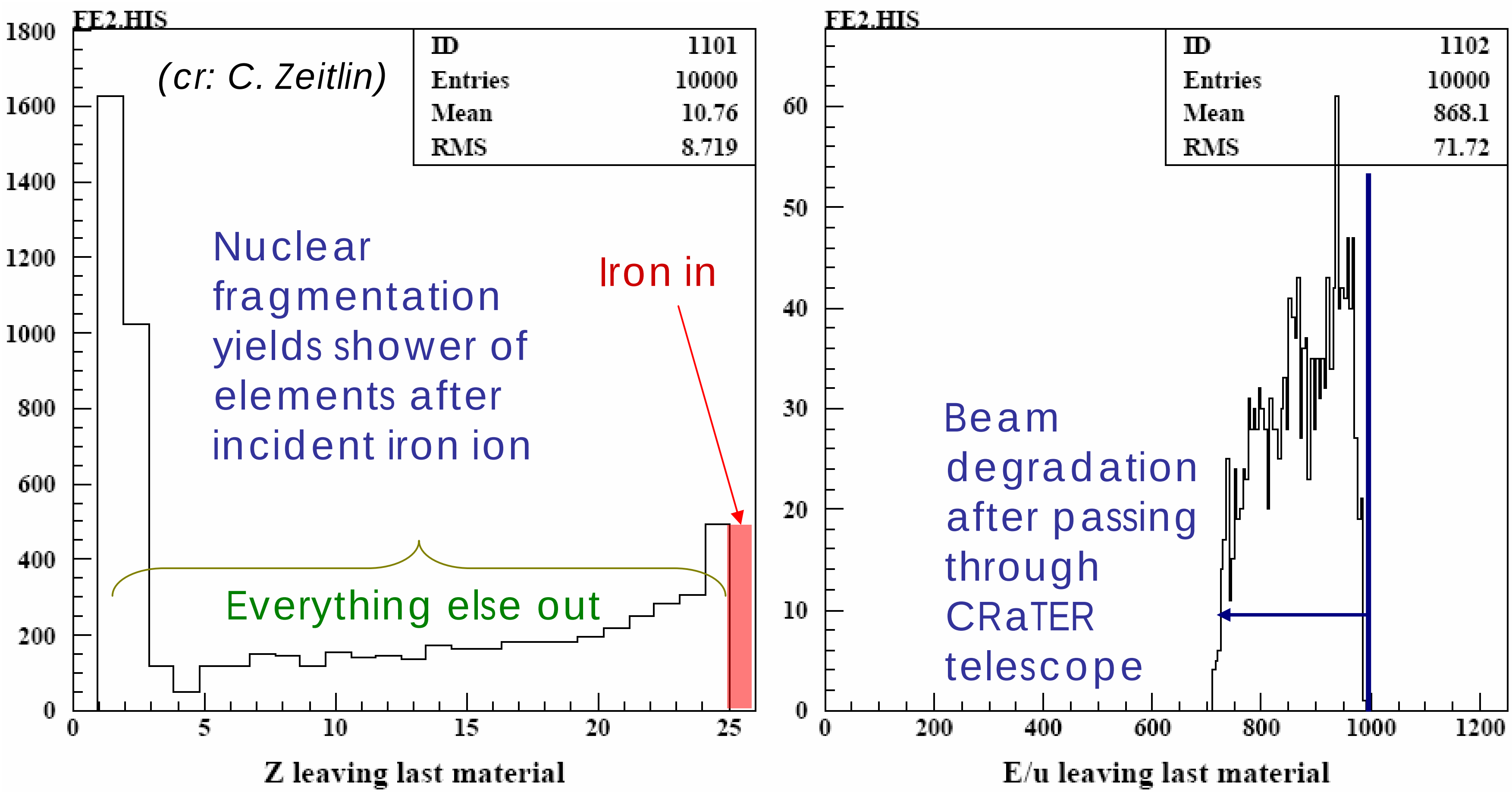


Recent CRaTER Beam Validation/Modeling

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**
June 2006	E/M CRaTER beam validation at **BNL** (56-Fe, 0.6 GeV/n) – 4 more hours of beam time

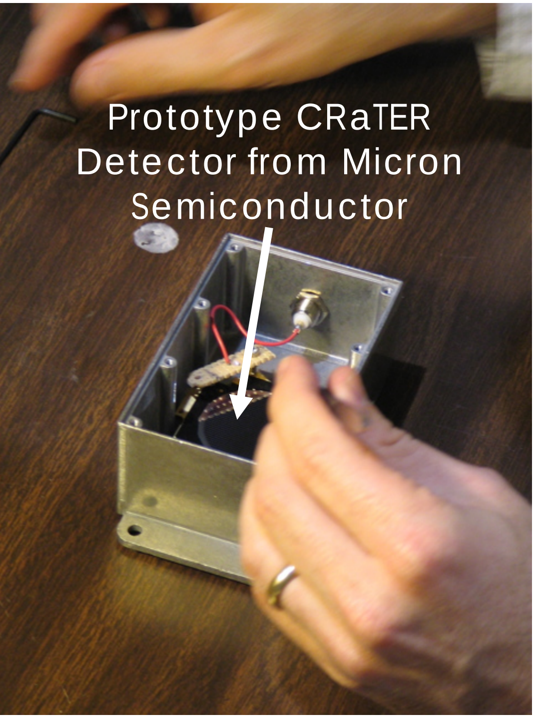
Fragmentation of 1 GeV/nuc Fe in CRaTER

- 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

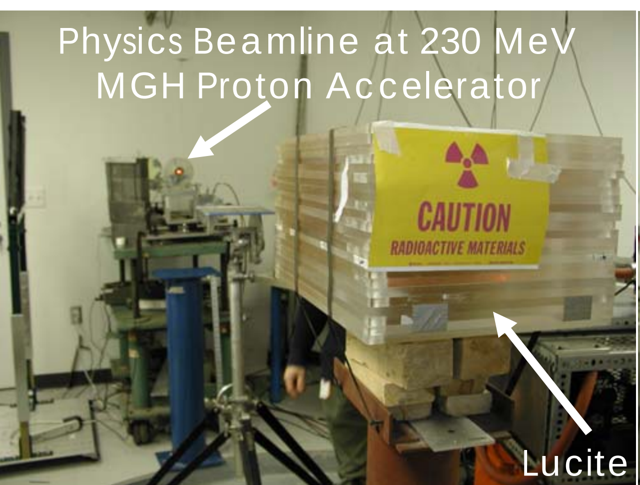


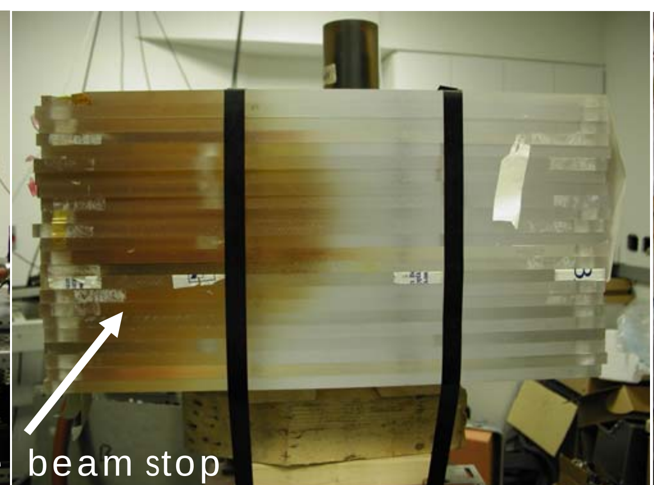
CRaTER Beam Runs at LBNL and MGH

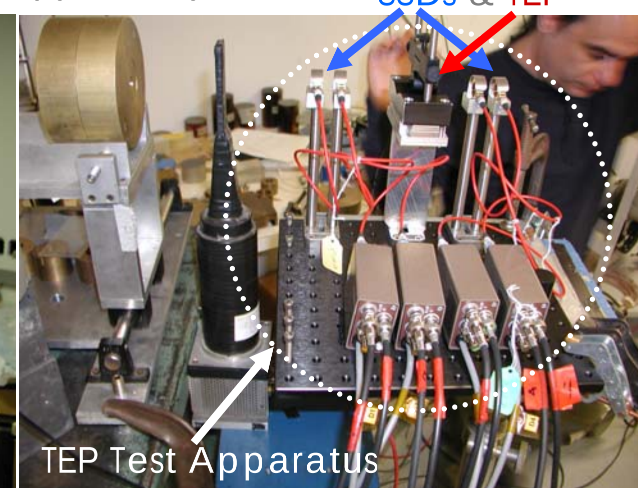
12 September 2005 – LBNL 88” cyclotron



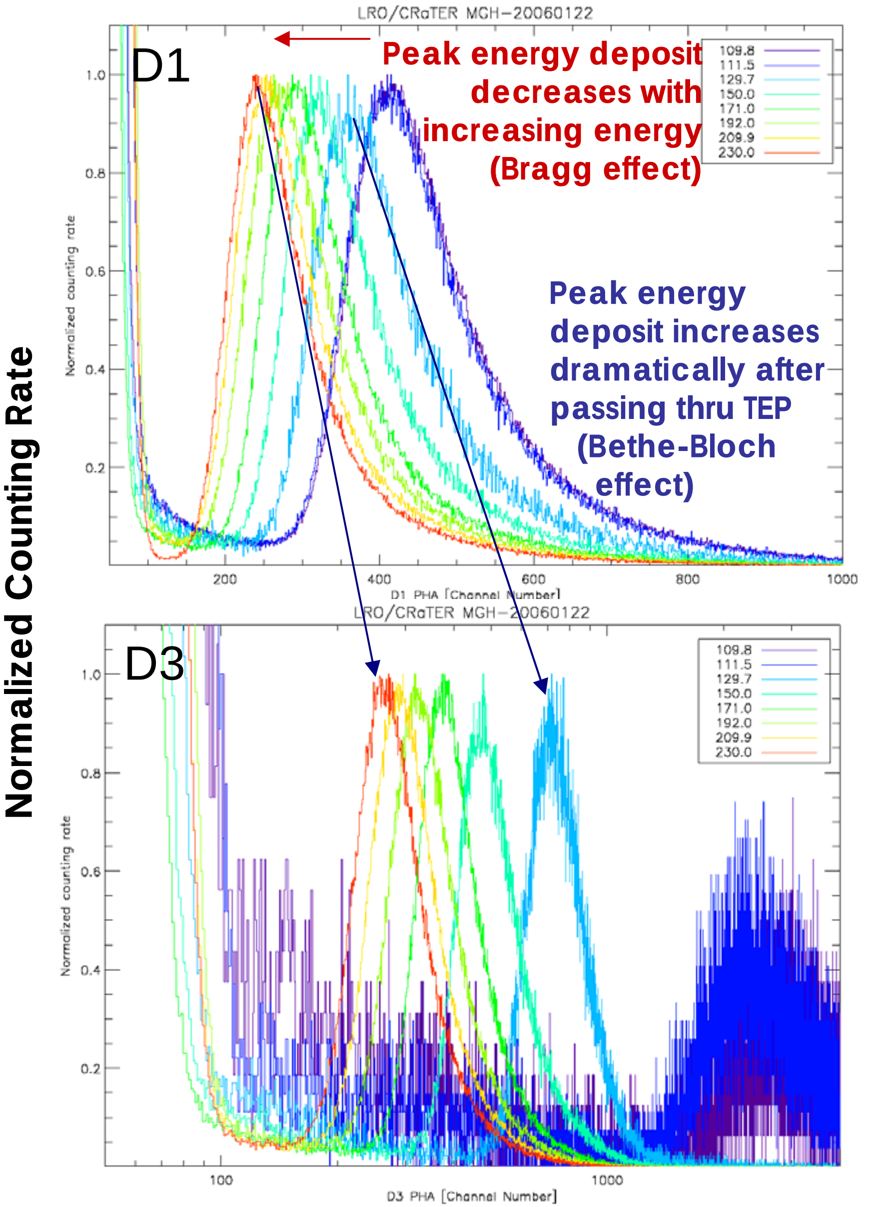
22 January 2006 – MGH Proton Radiation Therapy Facility



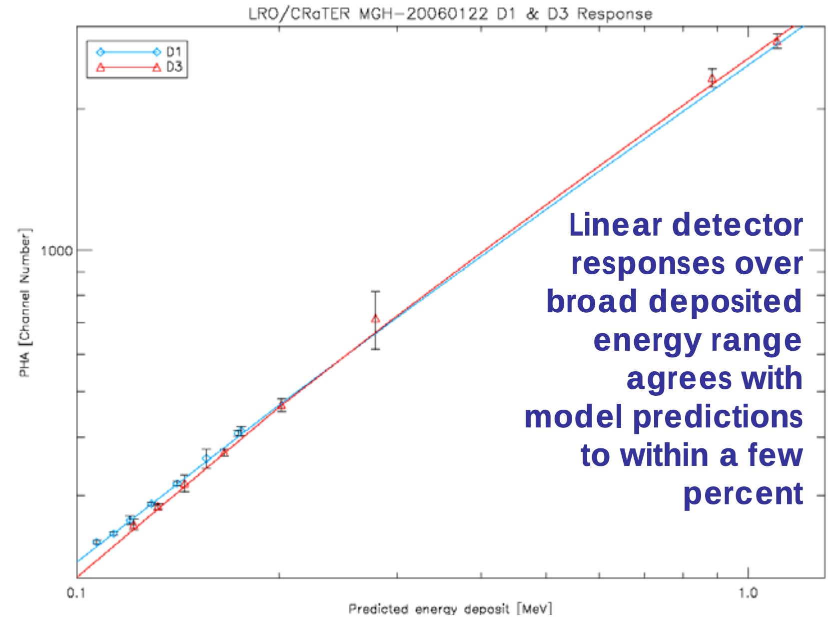


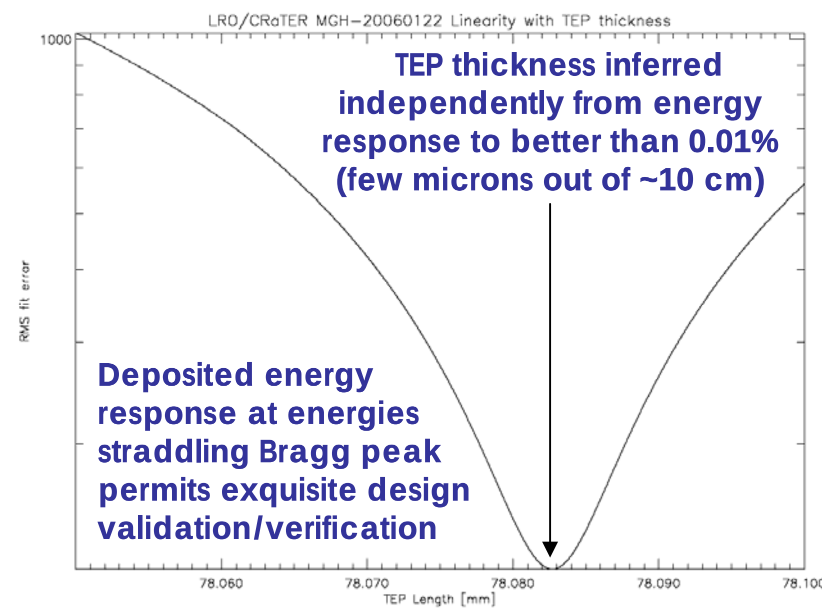


CRaTER Design Validation: MGH Results



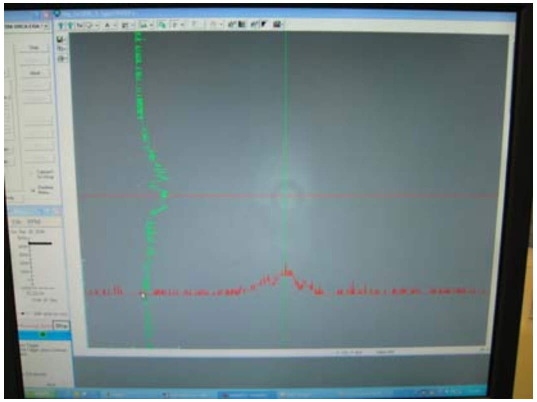
D1 and D3 Energy response to 110-230 MeV p+

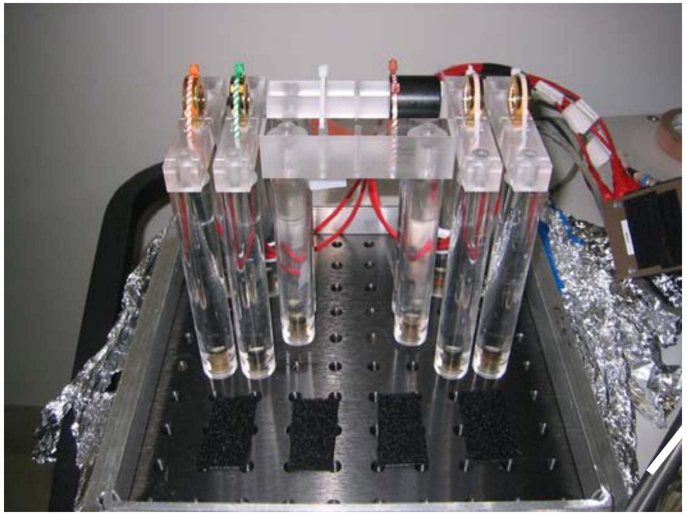


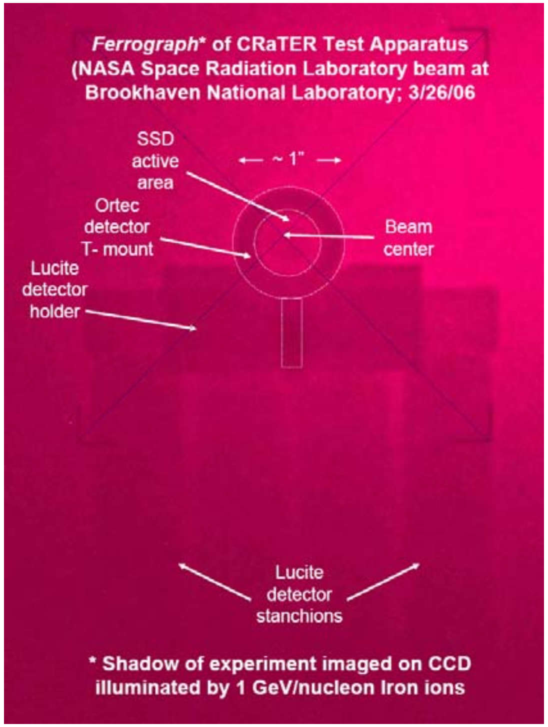


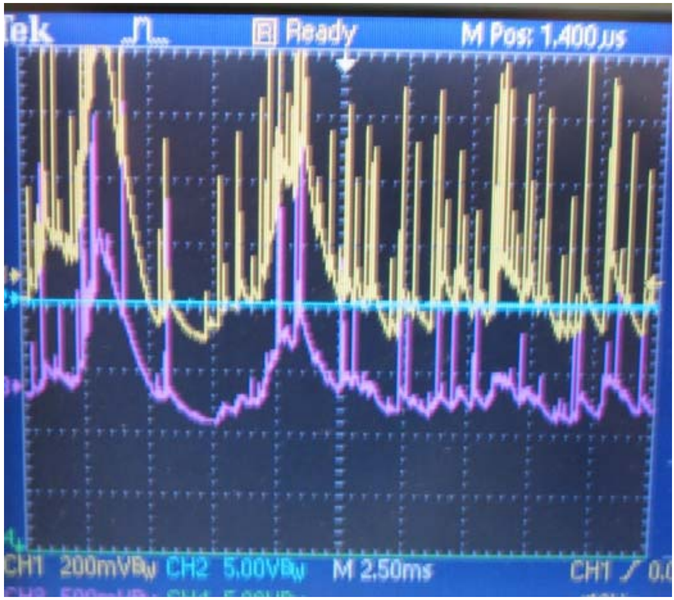
CRaTER Beam Runs at BNL/NSRL

26 March 2006

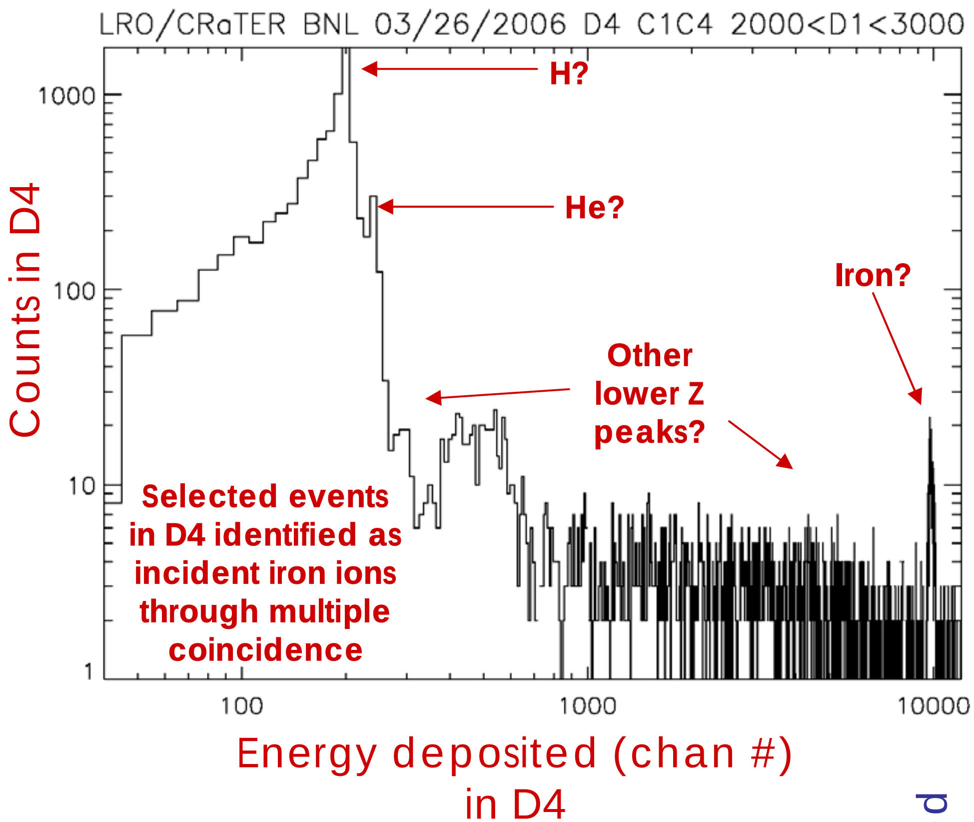


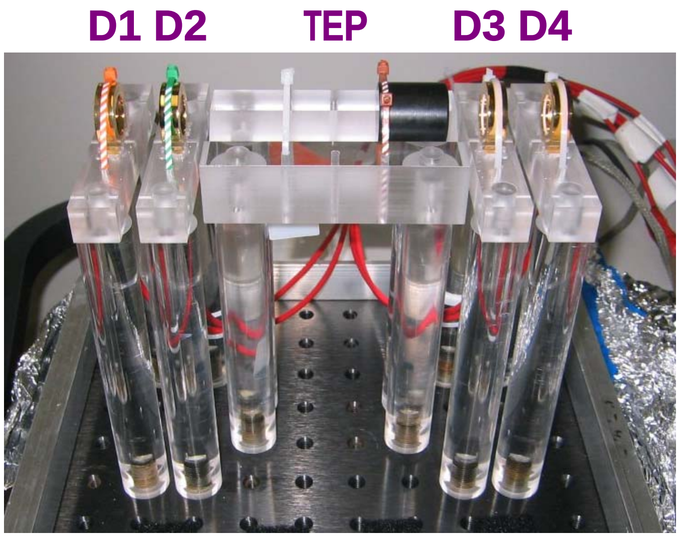




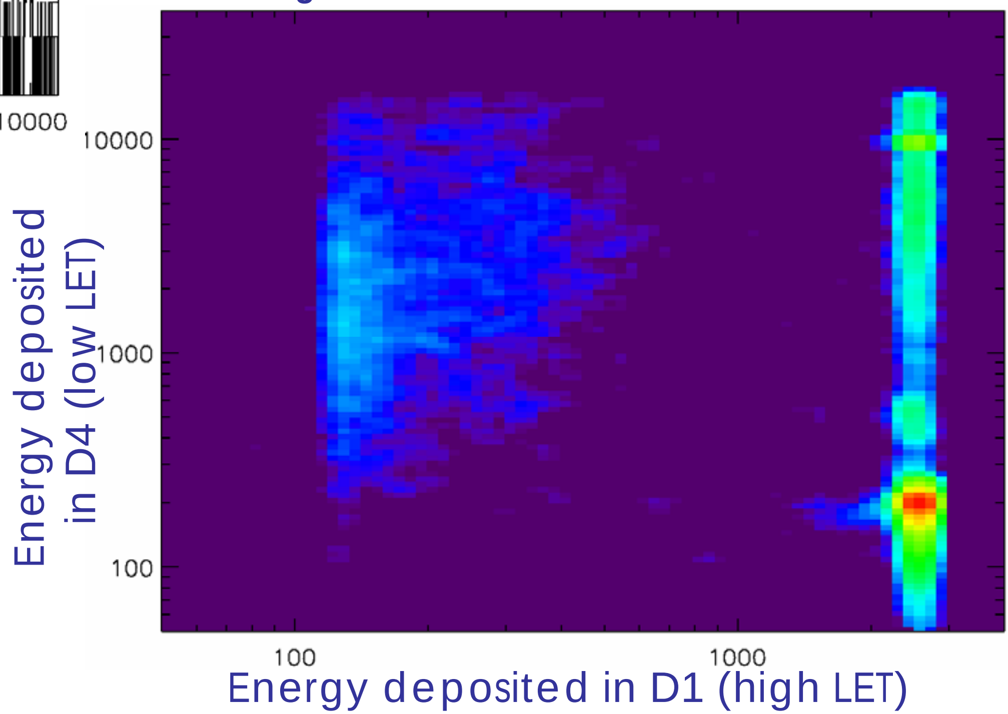


Very Preliminary CRaTER BNL/NSRL "Results"





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



PRELIMINARY, RAW DATA!
Warning: Species identified might actually be "Spuronium" (Sp)!

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 (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; Need to discuss details of their needs/requirements/desirements

SRAG wants real data experience in operationally supporting manned lunar missions; CRaTER is a highly relevant instrument of interest at Moon

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

Proposed meeting with SRAG personnel with CRaTER team at Space Weather Week in late April

Web pages constantly in development at:

crater.bu.edu
(science site)

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

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)

PDF Adobe

2006 NSREC paper describing the instrument.

Annotated drawing of our current instrument design.

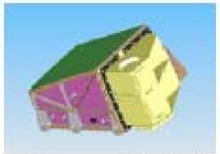
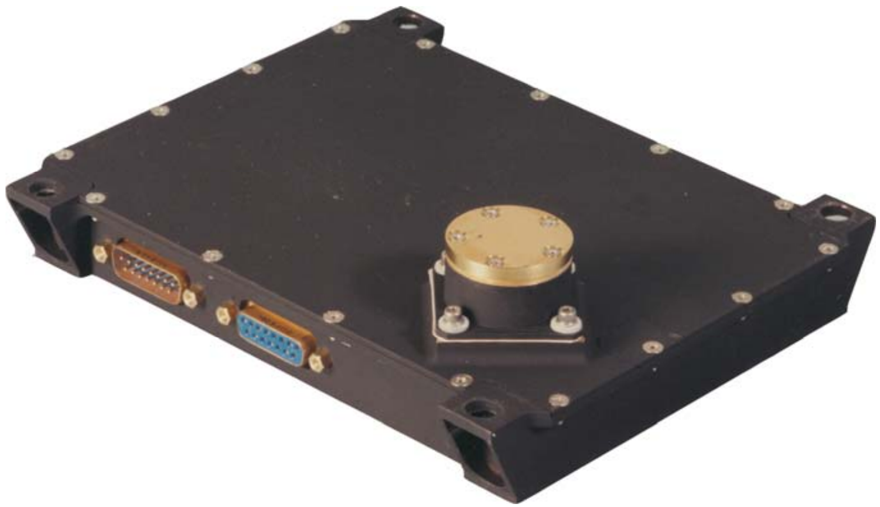


Image of our current box design.

Space Radiation “Dosimeter on A Chip”

W. R. Crain, Jr, D. J. Mabry, and J. B. Blake
Space Science Applications Laboratory
The Aerospace Corporation

Advanced Dosimeter Evolution



MCM package

+

ASIC

Heritage Dosimeter
Box-level Design

5.5” x 7” x 1.9” (73 in^3)
1.6 lbs
1.0 Watts @ 28V
Digital interface to host
Moderate host accommodation

Advanced Dosimeter
Device-level design

1.5” x 1.5” x 0.3” (0.67 in^3)
< 0.1 lbs
< 0.28 Watts @ 28V
Thermistor-type interface
Minimal host accommodation

1st Advanced Dosimeter Result

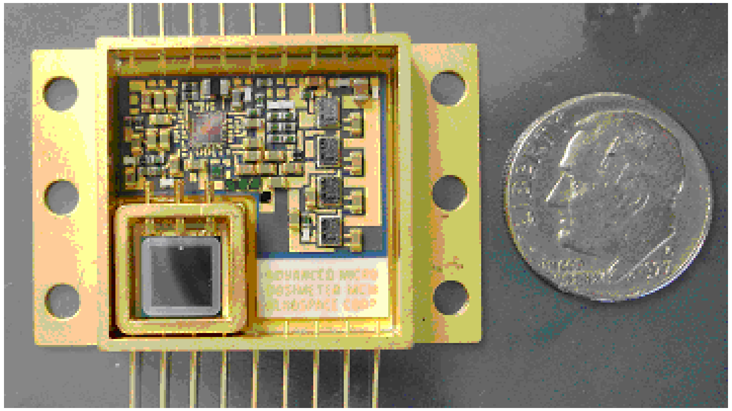
- Apogee   36,000 feet
- Perigee   10 fathoms of seawater

Advanced Radiation Dosimeter-on-a-Chip

Project Objective:

Develop very small, spaceflight devices to monitor total radiation dose to spacecraft.

Description:



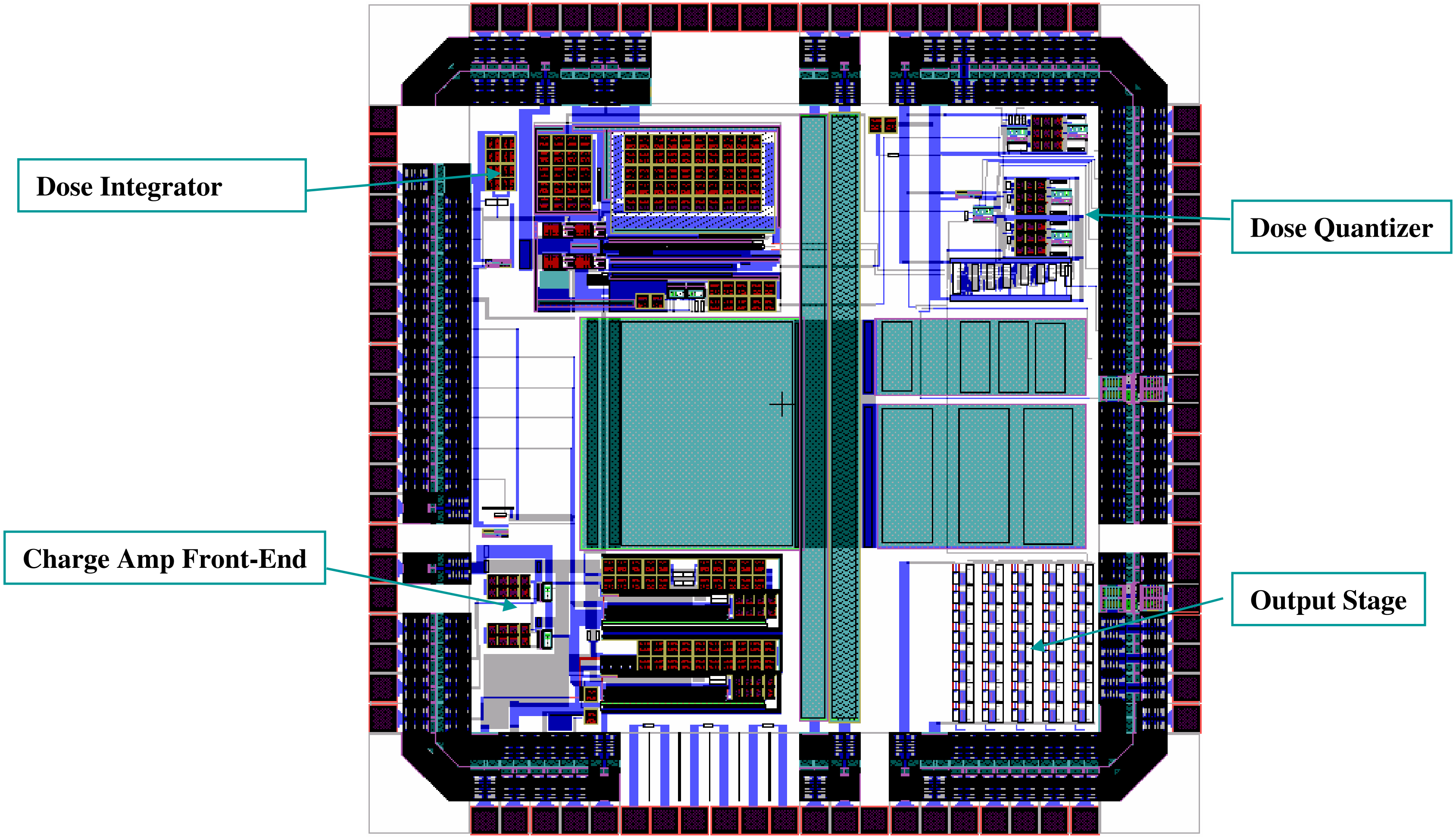
Approach:

Provide monitoring in real time of radiation dose using housekeeping level spacecraft resources. Enable the use of many dosimeters to provide dose at all critical locations.

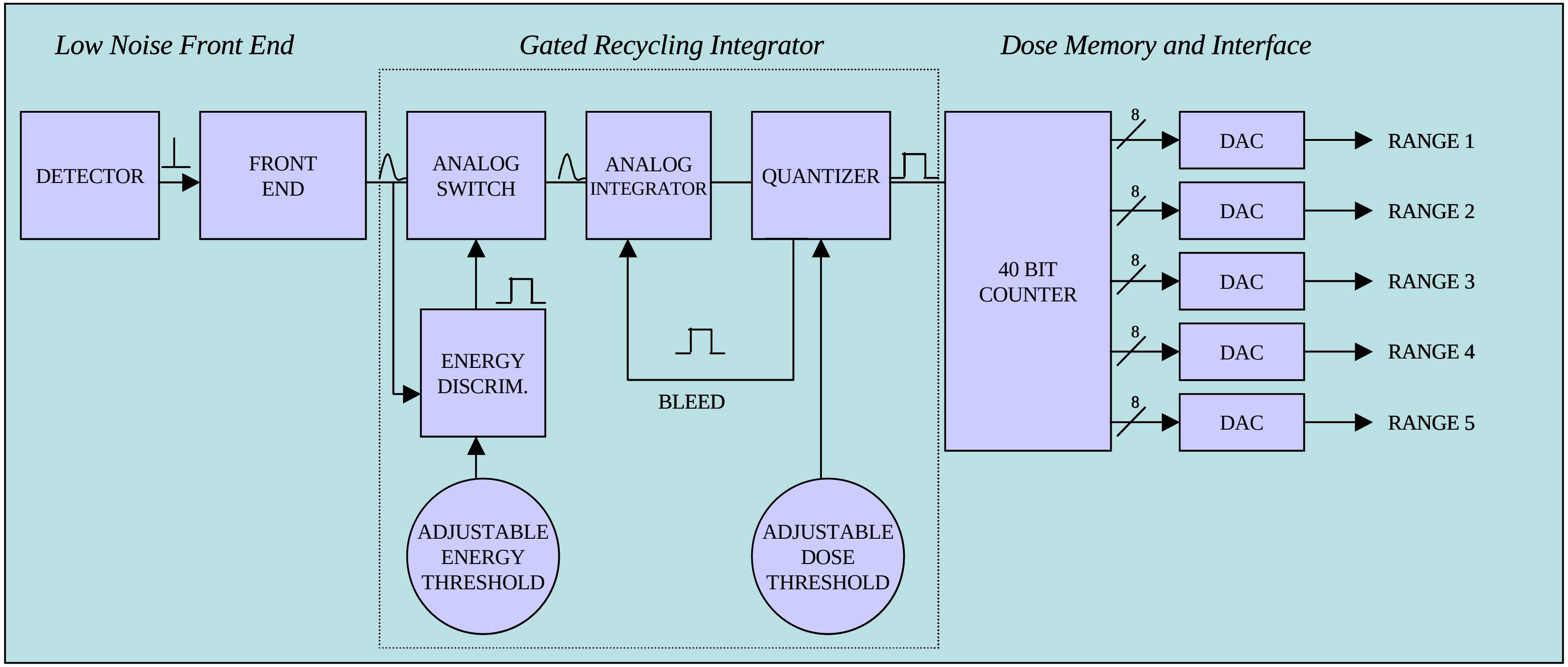
Key Milestones:

- **Dosimeter test at LBL88 (Mar 06)**
- **LRO/CRaTER mission agreement**
- **Enhanced ASIC fabrication and test**
- **Enhanced dosimeter fabrication**

DosASIC Version 5 Layout



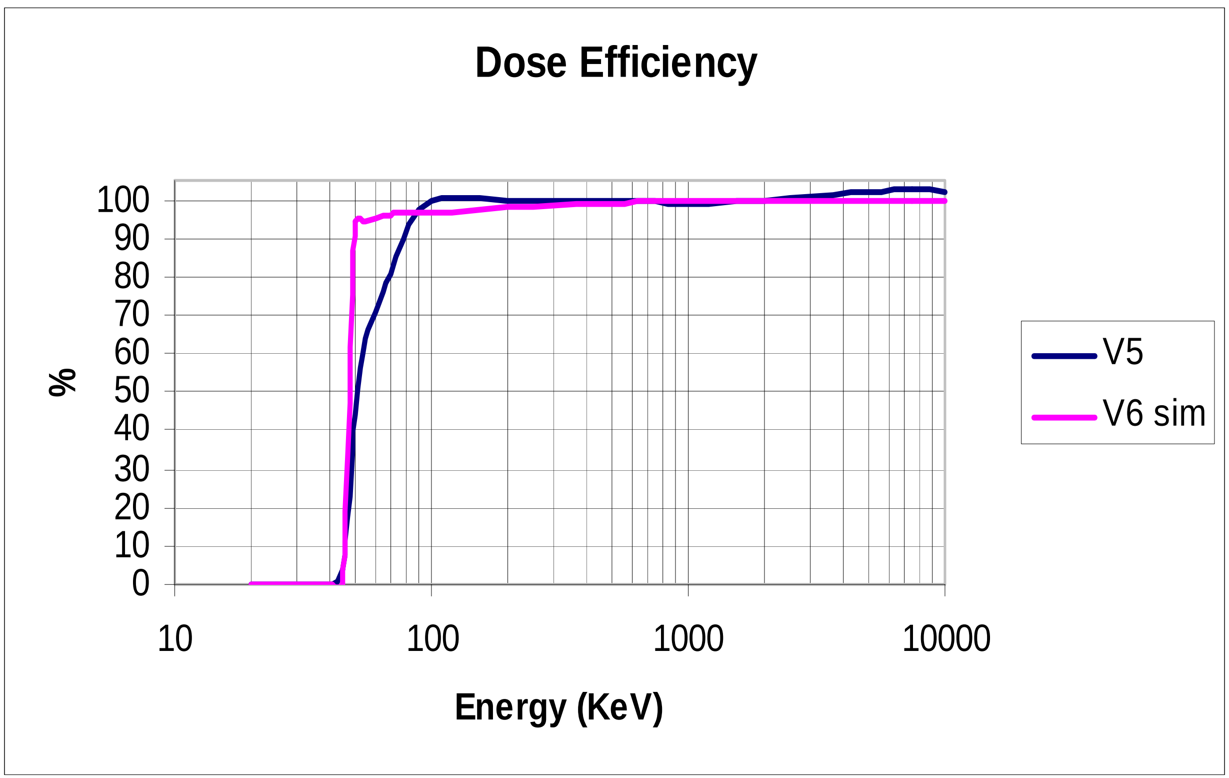
- Particle energy-rate approach gives accurate and repeatable measurements
  - Single energy deposit from 50 keV to 10 MeV
  - Dose rates from 1 μRad/sec. to 10 mRad/sec.
  - 20 μRad resolution



Results to date: 1 of 2

- Version 5 ASIC testing completed in FY05 resulted in development of a new integrator architecture for improved radiation dose measurement in V6 chip

Preliminary V06 Simulation Results



Improvements

1. Sharper Threshold
2. Temperature Stable
3. No tuning required

Results to date: 2 of 2

- Demonstrated end-to-end functional performance using Am^{241} alpha source (FY06)
- Other measurements

Resource	Goal	Actual	Comment
Weight	45 g	20 g	Margin for shielding
Size	1.5”x1.5”x0.3”	1.0”x1.5”x0.3”	In-spec but could be smaller
Power @ 28V	280 mW	390 mW	Diagnostic features account for half of growth
Interface	Analog Temp	Analog Temp	As planned
Rec. Costs	$5,000	$2,500	Not including screening

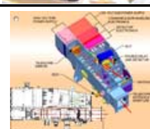
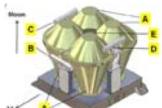
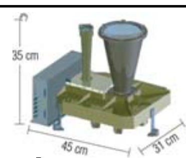
Milestones and Progress Report

- Assembled 5 advanced dosimeter devices (FY05) and completed initial electrical and functional performance tests (Nov 05)
- Two patent applications submitted (Jan 06)
  - S/C radiation dosimeter device
  - Radiation dosimeter system for wide area total dose profiling
- Interface agreement in place for ride-of-opportunity on NASA/LRO CRaTER mission (Jan 06)
- Dosimeter test at Lawrence Berkeley Lab (March 06)
  - Compare three dosimeter device results with laboratory dosimeters on same proton beam
- Submit v.6 ASIC design with enhancements (July 06)
- Target radhard process release (October 06)

To the Moon, Alice!
Thank you, all.

Backup Slides

Competitively Selected LRO Instruments Provide Broad Benefits

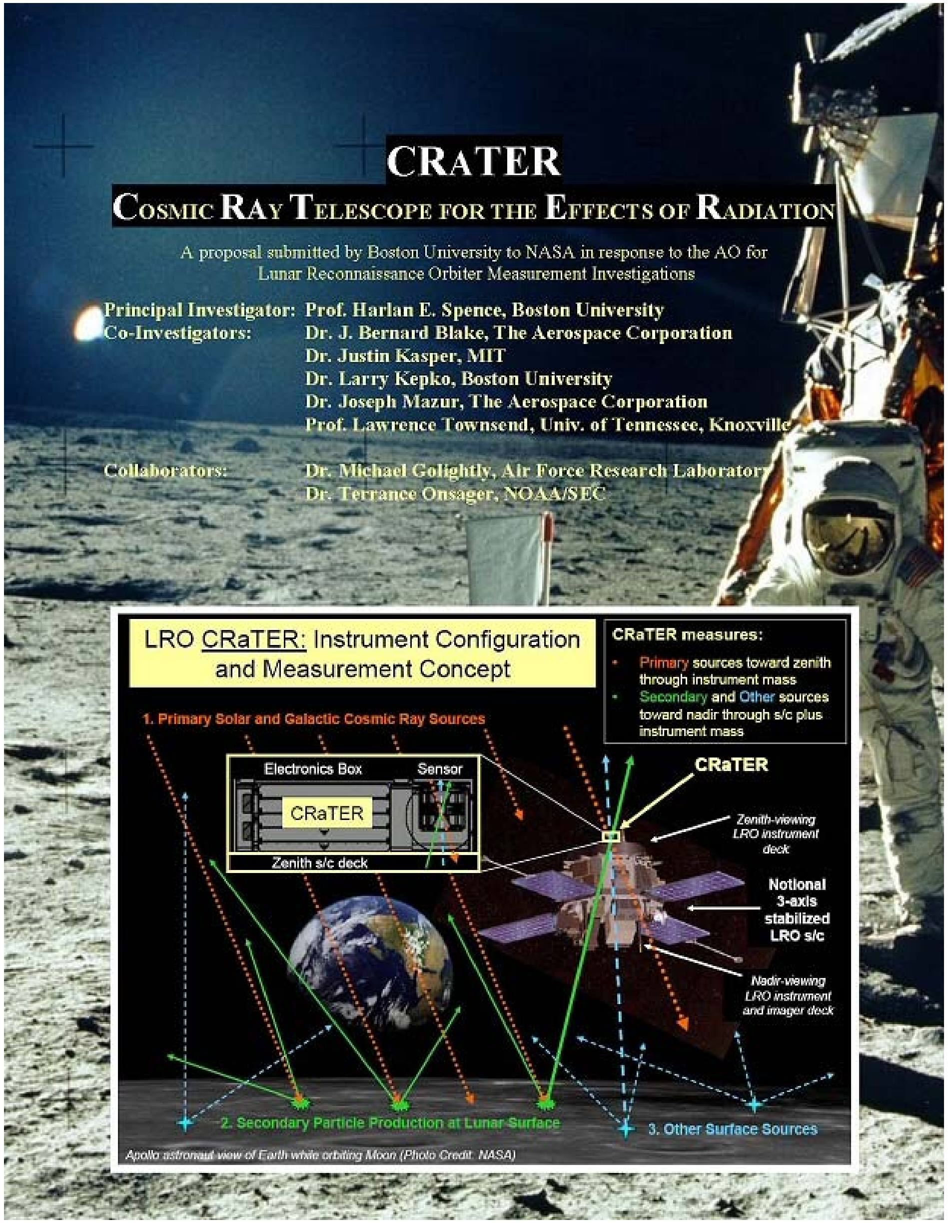
INSTRUMENT	Measurement	Exploration Benefit	Science Benefit
CRaTER  (BU+MIT) Cosmic Ray Telescope for the Effects of Radiation	***Tissue equivalent response to radiation***	***Safe, lighter weight space vehicles that protect humans***	***Radiation conditions that influence life beyond Earth***
Diviner  (UCLA)	***300m scale maps of Temperature, surface ice, rocks***	***Determines conditions for systems operability and water-ice location***	***Improved understanding of volatiles in the solar system - source, history, migration and deposition***
LAMP  (SWRI) Lyman-Alpha Mapping Project	***Maps of frosts in permanently shadowed areas, etc.***	***Locate potential water-ice (as frosts) on the surface***	
LEND  (Russia) Lunar Exploration Neutron Detector	***Hydrogen content in and neutron radiation maps from upper 1m of Moon at 5km scales, Rad > 10 MeV***	***Locate potential water-ice in lunar soil and enhanced crew safety***	
LOLA  (GSFC) Lunar Orbiter Laser Altimeter	***~50m scale polar topography at < 1m vertical, roughness***	***Safe landing site selection, and enhanced surface navigation (3D)***	***Geological evolution of the solar system by geodetic topography***
LROC  (NWU+MSSS) Lunar Recon Orbiter Camera	***1000's of 50cm/pixel images (125km^2), and entire Moon at 100m in UV, Visible***	***Safe landing sites through hazard identification; some resource identification***	***Resource evaluation, impact flux and crustal evolution***

Science/Measurement Overview

<u>CRaTER Objectives</u>:

"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. "



CRaTER Traceability Matrix

Four CRaTER Measurement Goals

Measurement Parameters-->	Pointing	Energy Range (MeV)	Energy resolution (keV)	Time resolution (sec)	Collection duration	Geometric Factor (cm^2-sr)	Number of Sensing Elements	Spectra Behind How Many Shielding Depths	Simultaneous GCR/SCR Spectra
Measure primary and secondary source lunar LET spectra	Zenith (primary) and nadir (lunar albedo and other)	<1 (as low as practical) to >100 (as high as practical)	30	1 (nominal)	> 1 year (to map possible secondary source surface locations)	As large as possible	> 2	Surfacial and at several depths	-
Simple, compact sensor with sufficient temporal, spectral sensitivity	-	> 10	> noise floor	60 (nominal)	> 1 year (to obtain several SEP events)	As small as possible	> 2, but as few as possible	As many as feasible	-
Investigate effect of shielding and tissue absorption at various relevant depths	-	~1 to > 100	30	1 (nominal)	> 1 year (to obtain several SEP events)	>0.1 cm^2-sr	≥ 5	Behind thin "hull" and behind several depths centered on ~5 gm/cm^2 "tissue"	Ancillary from GOES/ACE
Test models of LET spectra	-	~1 to >100	30	1 (nominal)	> 1 year (to obtain several SEP events)	>0.1 cm^2-sr	As many as possible	Behind thin "hull" and behind several depths centered on ~5 gm/cm^2 "tissue"	Ancillary from GOES/ACE
Aggregate --> Measurement Requirements	Zenith (primary) and nadir (lunar albedo and other)	0.3 to 140	30	1 (nominal)	> 1 year	~0.3 cm^2-sr	5	Behind thin "hull" and behind several depths centered on ~5 gm/cm^2 "tissue"	Ancillary from GOES/ACE

Current energy spectral range:

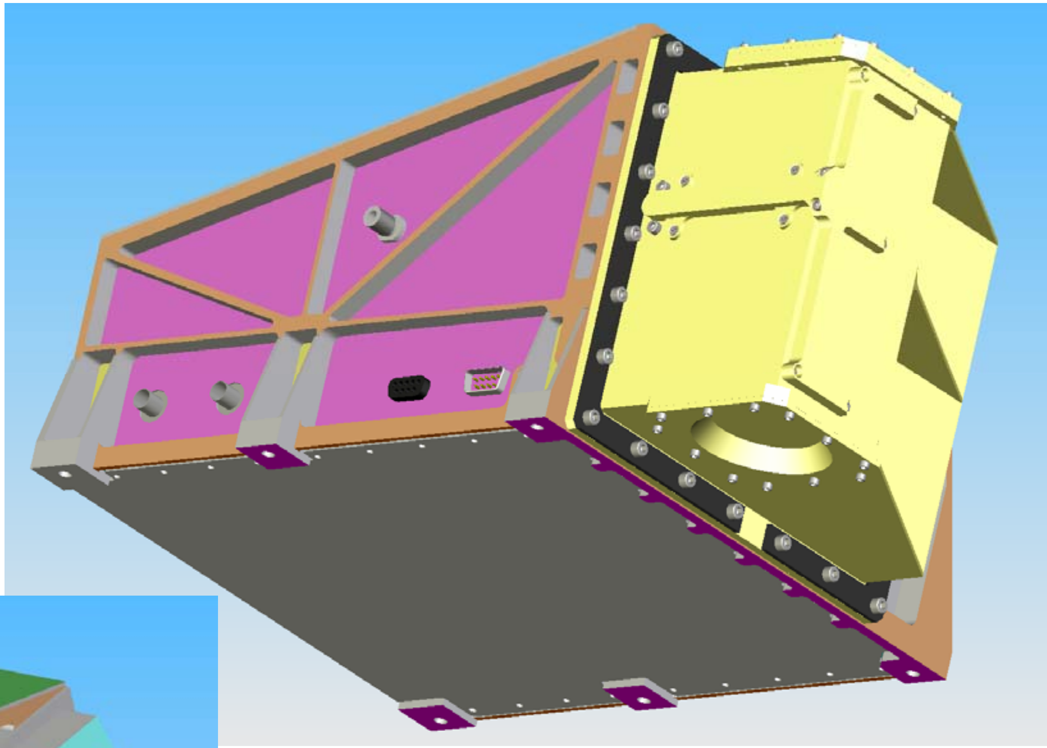
- **200 keV to 100 MeV (low LET); and**
- **2 MeV to 1 GeV (high LET)**

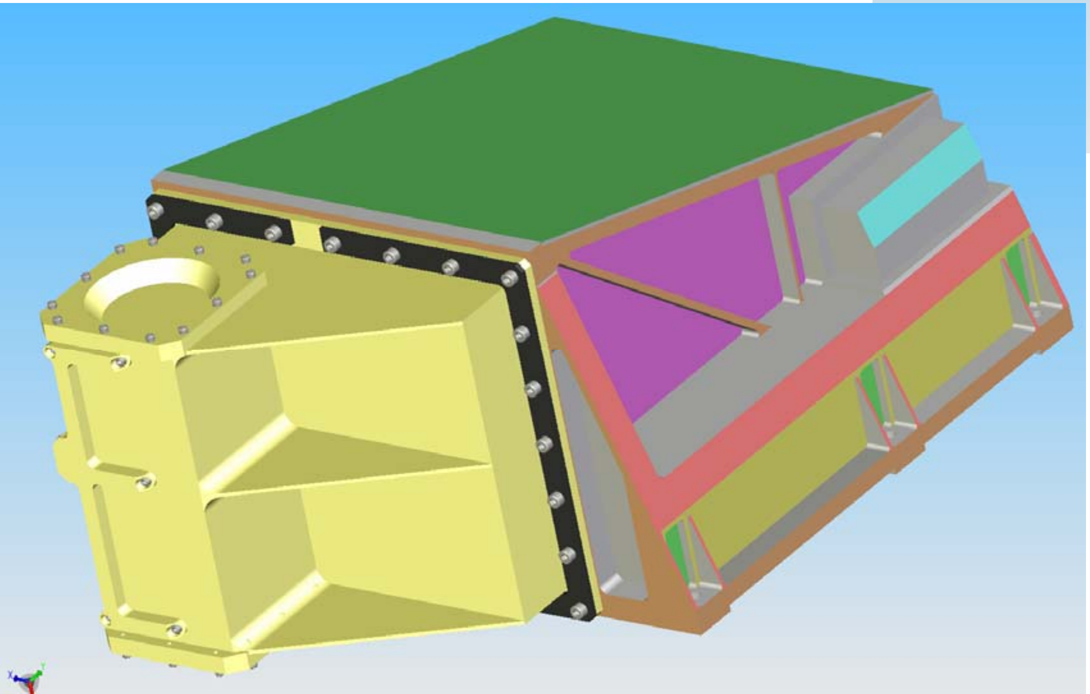
This corresponds to:

- **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)**

Engineering Status Report

- Minor design modifications pre-I-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")

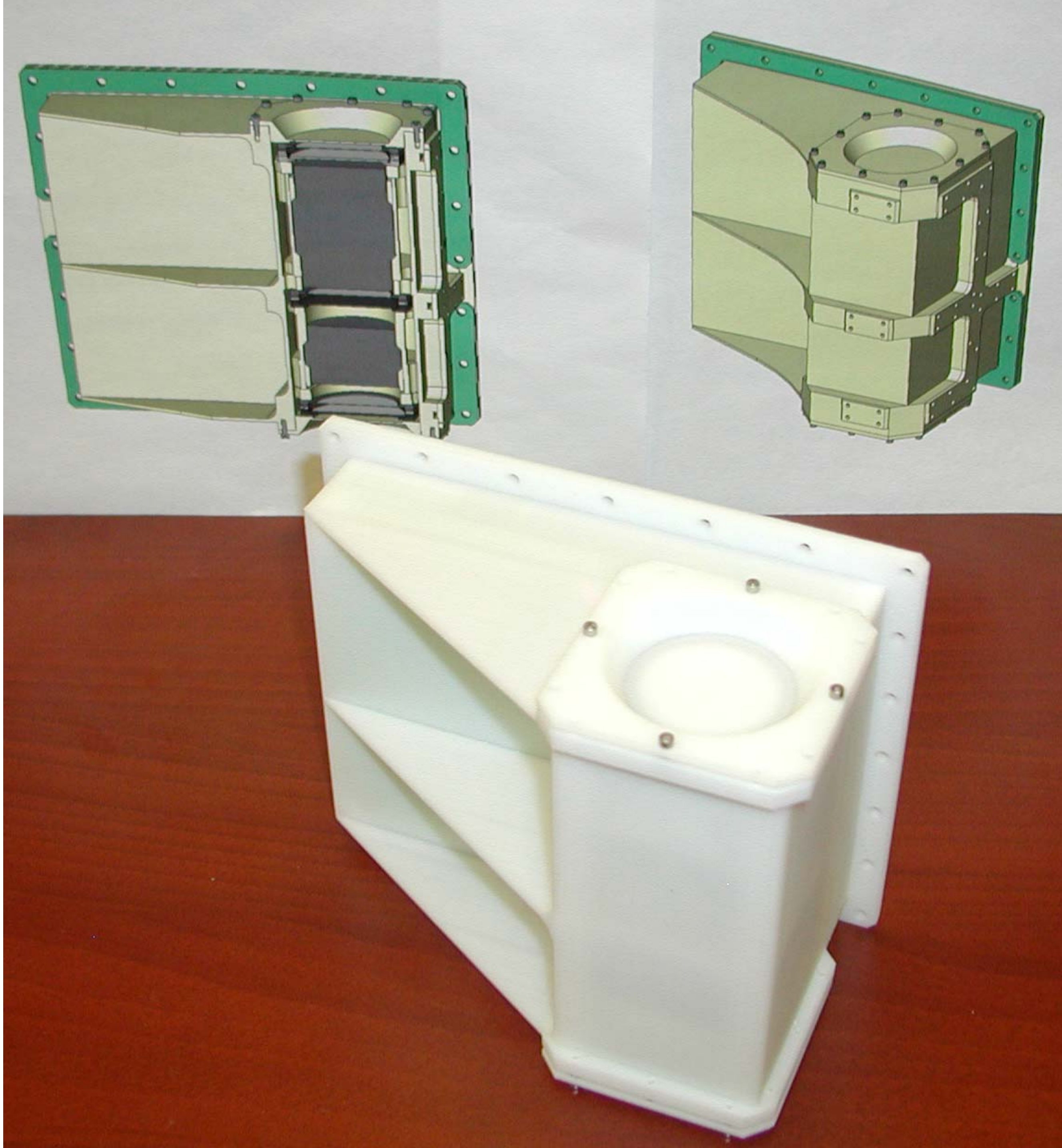




- First batch of E/M detectors (procured using "flight rules") to arrive in April '06 (second batch no later than June '06)
- CRaTER telescope simulator tested and design validated
- Goal to perform end-to-end test of E/M in a beam before June '06 CDR still achievable

Rapid prototype model of CRaTER Telescope Assembly, Rev 3 *(or so…)*

16 January 2006



3.0 Level 2 Traceability Matrix

The matrix in this section traces the flow down from the Level 1 requirements and data products stated in ESMD-RLEP-0010 and outlined in Section 2 to the CRaTER Level 2 requirements. The individual CRaTER Level 2 requirements, with detailed explanations of the rationale for each value, are provided in Section 4.

Item	Sec	Requirement	Quantity	Parent
CRaTER-L2-01	4.1	Measure the Linear Energy Transfer (LET) spectrum	LET	RLEP-LRO-M10
CRaTER-L2-02	4.2	Measure change in LET spectrum through Tissue Equivalent Plastic (TEP)	TEP	RLEP-LRO-M20
CRaTER-L2-03	4.3	Minimum pathlength through total TEP	> 60 mm	RLEP-LRO-M10, RLEP-LRO-M20
CRaTER-L2-04	4.4	Two asymmetric TEP components	1/3 and 2/3 total length	RLEP-LRO-M20
CRaTER-L2-05	4.5	Minimum LET measurement	0.2 keV per micron	RLEP-LRO-M10, RLEP-LRO-M20
CRaTER-L2-06	4.6	Maximum LET measurement	7 MeV per micron	RLEP-LRO-M10, RLEP-LRO-M20
CRaTER-L2-07	4.7	Energy deposition resolution	< 0.5% max energy	RLEP-LRO-M10, RLEP-LRO-M20
CRaTER-L2-08	4.8	Minimum full telescope geometrical factor	0.1 cm^2 sr	RLEP-LRO-M10

Table 3.1: CRaTER Level 2 instrument requirements and LRO parent Level 1 requirements.

5.0 Level 3 Traceability Matrix

The table in this section traces the flow down from the CRaTER Level 2 requirements to the individual CRaTER Level 3 requirements. The individual CRaTER level 3 requirements, with detailed explanations of the rationale for each value, are described in section 6.

Item	Ref	Requirement	Quantity	Parent
CraTER-L3-01	6.1	Thin and thick detector pairs	140 and 1000 microns	CRaTER-L2-01, CRaTER-L2-05, CRaTER-L2-06, CRaTER-L2-07
CraTER-L3-02	6.2	Minimum energy	< 250 keV	CRaTER-L2-01
CraTER-L3-03	6.3	Nominal instrument shielding	> 1524 micron Al	CRaTER-L2-01
CraTER-L3-04	6.4	Nadir and zenith field of view shielding	<= 762 micron Al	CRaTER-L2-01
CraTER-L3-05	6.5	Telescope stack	Shield, D1D2, A1, D3D4, A2, D5D6, shield	CRaTER-L2-01, CRaTER-L2-02, CRaTER-L2-04
CraTER-L3-06	6.6	Pathlength constraint	< 10% for D1D6	CRaTER-L2-01, CRaTER-L2-02, CRaTER-L2-03
CraTER-L3-07	6.7	Zenith field of view	<= 34 degrees D2D5	CRaTER-L2-01, CRaTER-L2-02
CraTER-L3-08	6.8	Nadir field of view	<= 70 degrees D4D5	CRaTER-L2-01
CraTER-L3-09	6.9	Calibration system	Variable rate and amplitude	CRaTER-L2-07
CraTER-L3-10	6.10	Event selection	64-bit mask	CRaTER-L2-01
CraTER-L3-11	6.11	Maximum event transmission rate	>= 1000 events/sec	CRaTER-L2-01
CraTER-L3-12	6.12	Telemetry interface	32-02001	
CraTER-L3-13	6.13	Power interface	32-02002	
CraTER-L3-14	6.14	Thermal interface	32-02004	
CraTER-L3-15	6.15	Mechanical interface	32-02003	

Table 5.1: CRaTER Level 3 instrument requirements and parent Level 2 requirements.

9.2 CRaTER data product table

Data Level	Description
Level 0	Unprocessed instrument data (pulse height at each detector, plus secondary science) and housekeeping data in CCSDS packets.
Level 1	Data extracted from CCSDS packets, with primary 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 using calibration conversion. 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

Table 9.1: Overview of the CRaTER data products.