CRaTER: COSMIC RAY TELESCOPE FOR THE EFFECTS OF RADIATION

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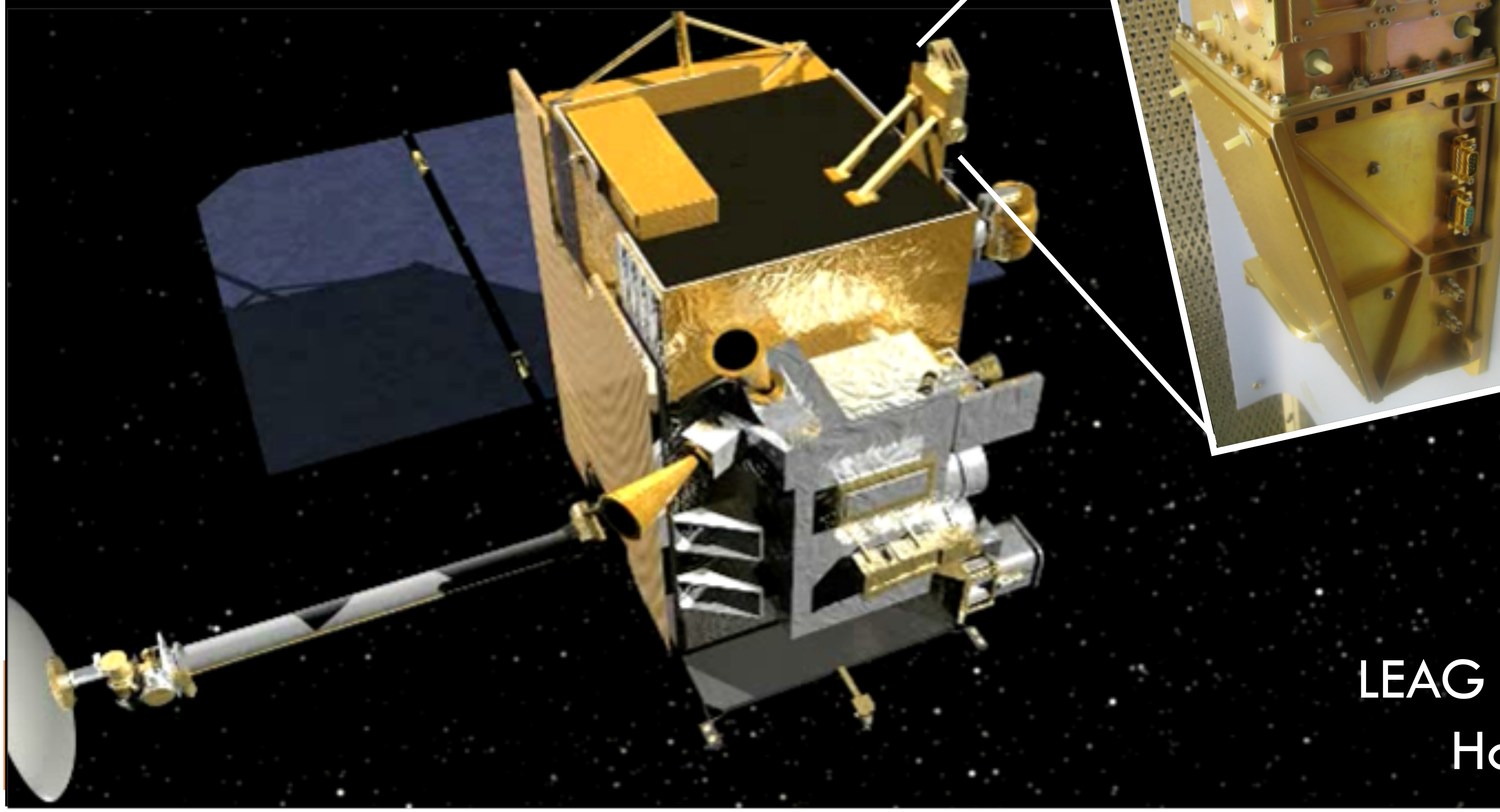
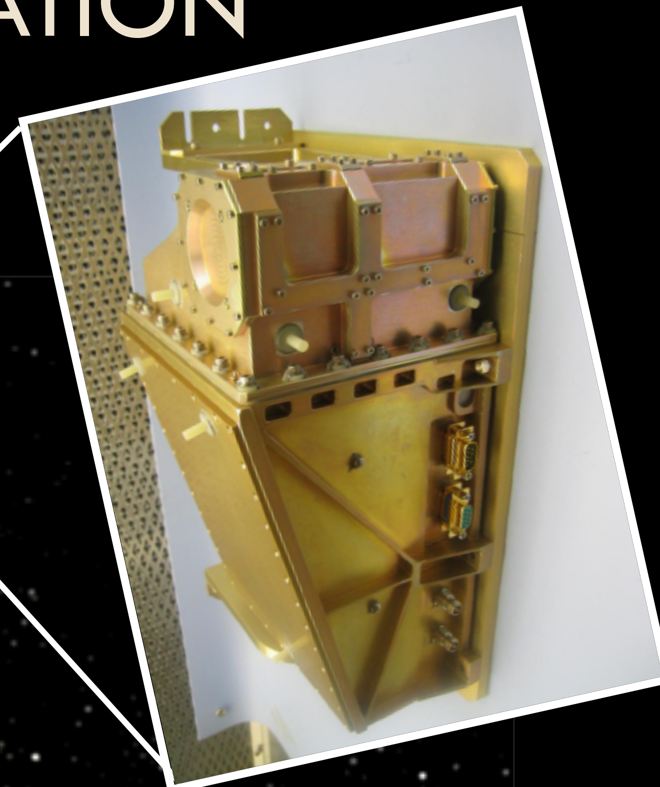




LEAG 2009
Houston

Outline

- The purpose of CRaTER is to directly characterize the lunar ionizing radiation environment and to validate radiation propagation models
- Accomplish this with accurate detailed measurements of propagation of incident energetic particles though detectors and human tissue equivalent plastic
- Team
- Background and Motivation
- Instrument Design
- Performance and Early results

CRaTER Science Team

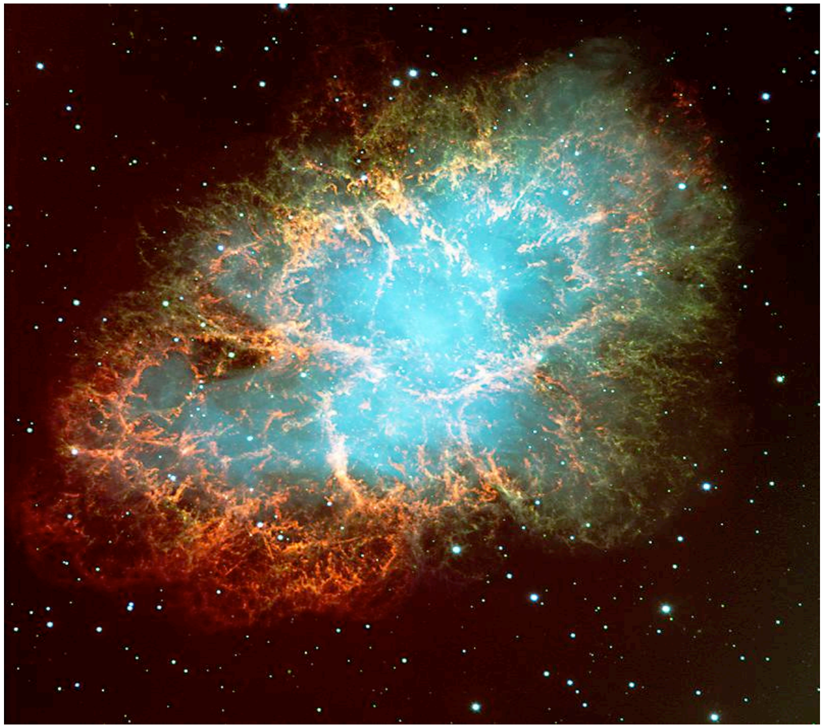
Harlan Spence	Boston University (Principal Investigator)
Justin Kasper	Harvard Smithsonian (Project Scientist)
Michael Golightly	BU (Deputy Project Scientist, SOC lead)
J. Bernard Blake	Aerospace Corp. (co-I, radiation physics)
Joseph Mazur	Aerospace Corp. (co-I, SEP/GCR physics)
Larry Townsend	UT Knoxville (co-I, radiation transport lead)
Terrence Onsager	NOAA/SWPC (co-I, space weather effects)

Tony Case	BU (Graduate student, CRaTER science)
Elly Huang	BU (Research Associate, GCR/SEP modeling)
Andrew Jordan	BU (Graduate Student, GCR variability)
Brian Larsen	BU (Research Associate, Instrument modeling)
Eddie Semones	NASA/JSC, (Collaborator, astronaut safety)
Timothy Stubbs	NASA/GSFC (LRO Participating Scientist, dust)
Cary Zeitlin	SwRI(LRO Partic. Sci., radiation modeling)

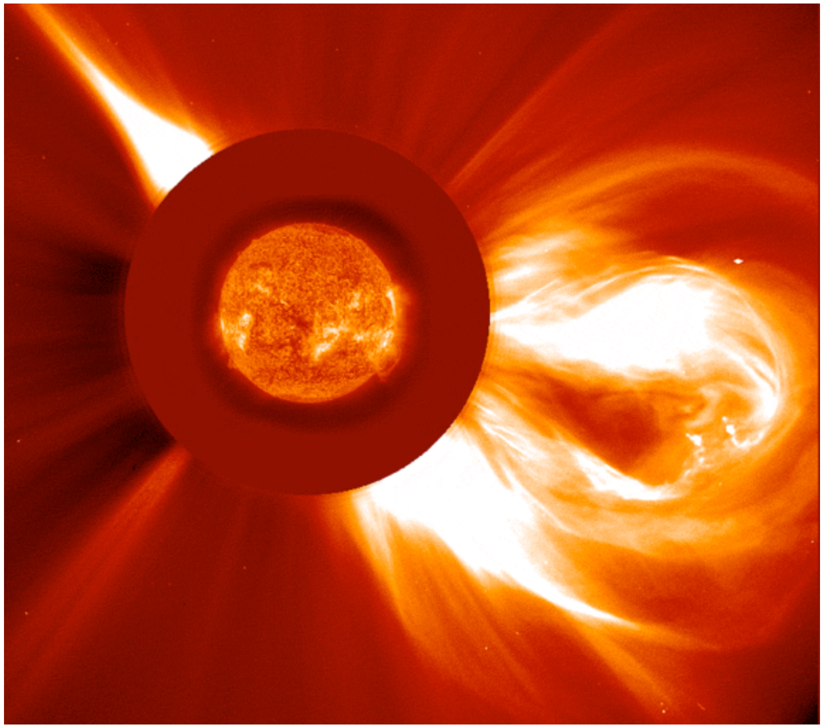
Motivation

Ionizing Radiation in Space

Galactic Cosmic Rays (GCRs)



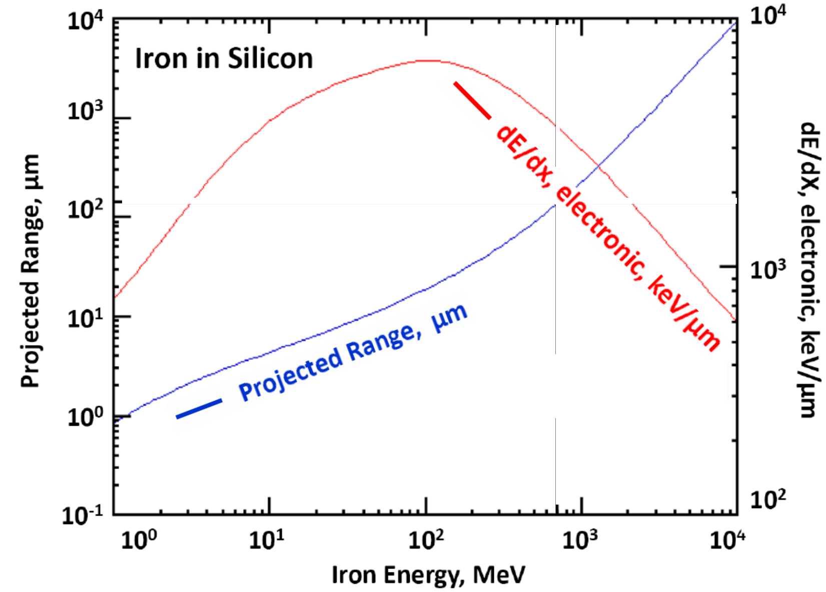
Solar Energetic Particles (SEPs)

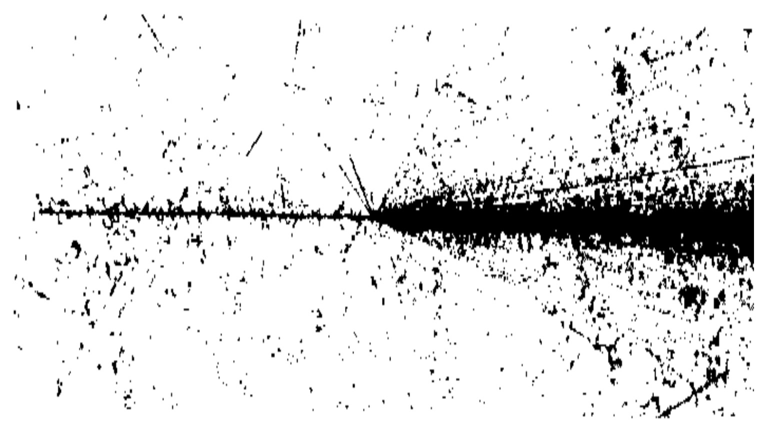


+ Interaction of the above with the lunar surface…

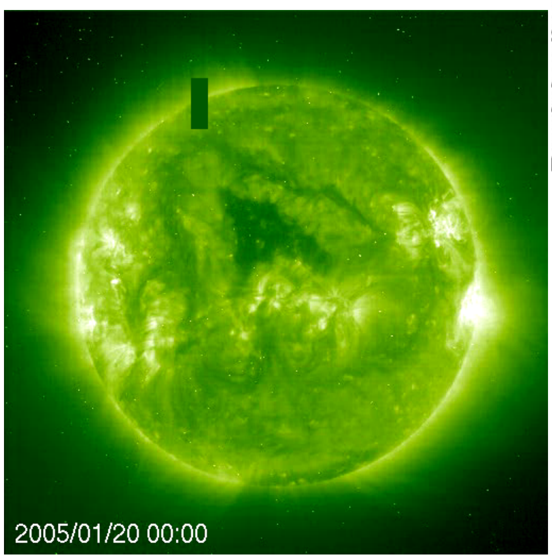
Effects of ionizing radiation

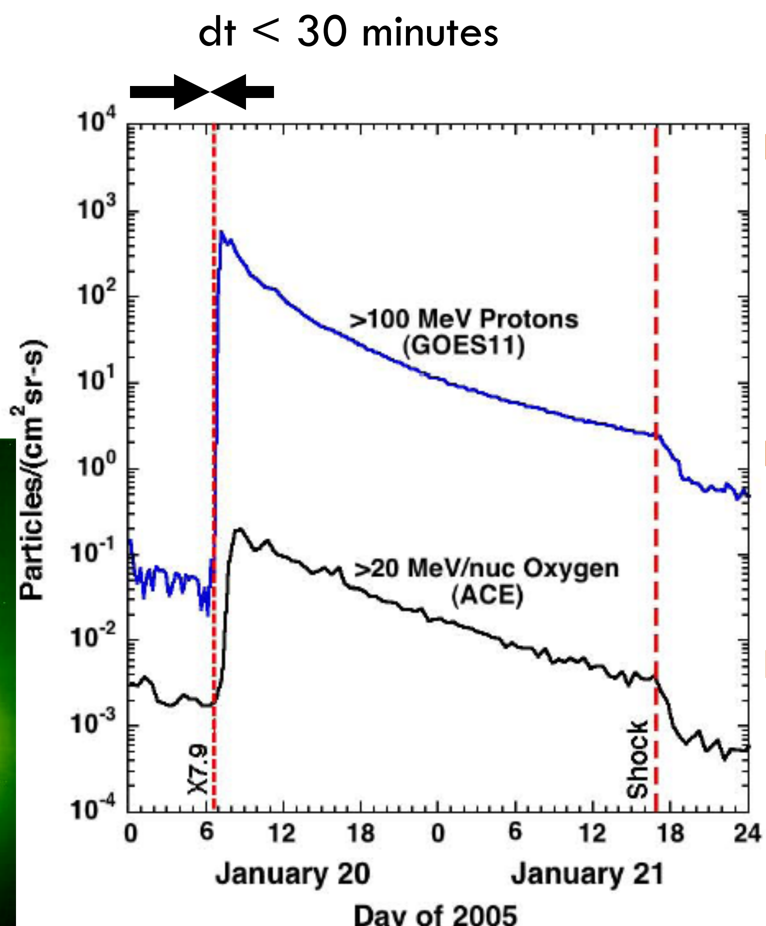
- Ionizing energy loss in matter
  - Damage ~ rate of energy deposition dE/dx
  - Rate of energy deposition dE/dx ~ z^2
  - Also nuclear interactions, fragmentation, showers
- Protecting electronics
  - Memory corruption, CPU errors, part failure
- Protecting humans
  - Keep risk of chronic dose low, i.e. lifetime cancer risk due to integrated dose over mission(s) below mandated level
  - Protect against serious injury from acute dose due to prompt radiation from Sun





Prompt solar radiation January 2005

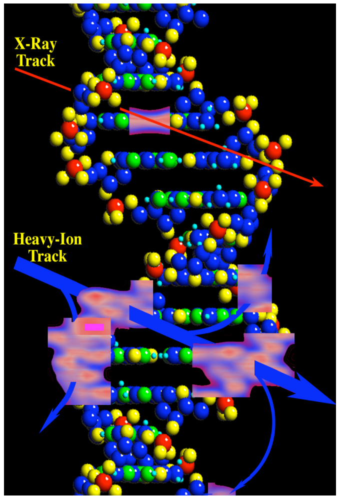




- ISS: 1 REM (1 REM ~ 1 CAT Scan)
  - Scintillations, shelter
- Spacesuit on moon 50 REM (Radiation sickness)
  - Vomiting, Fatigue, Low blood cell counts
- 300 REM+ suddenly
  - Fatal for 50% within 60 days
- 10 October 1972 flare
  - Derived dosage 400 REM

Challenges

- Protect astronauts and equipment during transit to and habitation of lunar surface
  - Understand the lunar environment, optimize shielding design, accurate predictions of biological effects
- Primary spectrum of radiation is variable (time, energy, composition)
- Effect of radiation depends on properties of the radiation
  - Total energy deposited in the body
  - Rate of radiation dose
  - Particles with higher rate of energy deposition dE/dx may do more damage ($dE/dx \sim z^2$)
  - Particles fragment and scatter (focused damage)

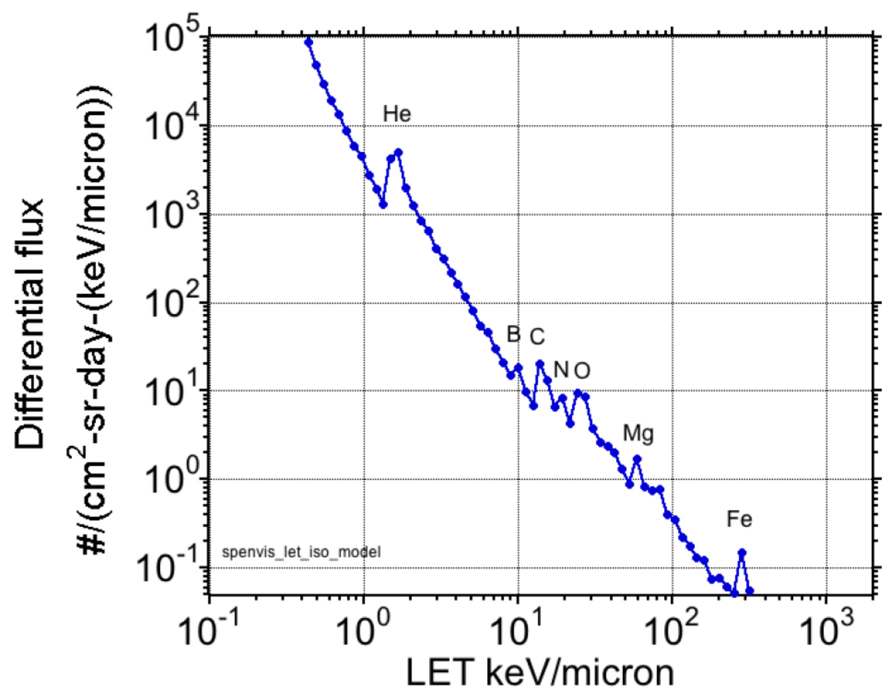


(Courtesy, Mark Weyland, NASA Johnson Space Center, Space Radiation Analysis Group)

CRaTER Measurement Objectives

- Directly measure the LET spectrum: the differential flux (time^{-1} solid angle^{-1}) of ionizing radiation as a function of LET
- Characterize the LET of the lunar radiation environment as a function of time and determine typical and extreme conditions on the surface
- Measure how this spectrum evolves through different depths of tissue equivalent plastic (TEP) in order to:
  - Directly measure biological impact of lunar radiation
  - Produce precise detailed constraints for validation of radiation transport models

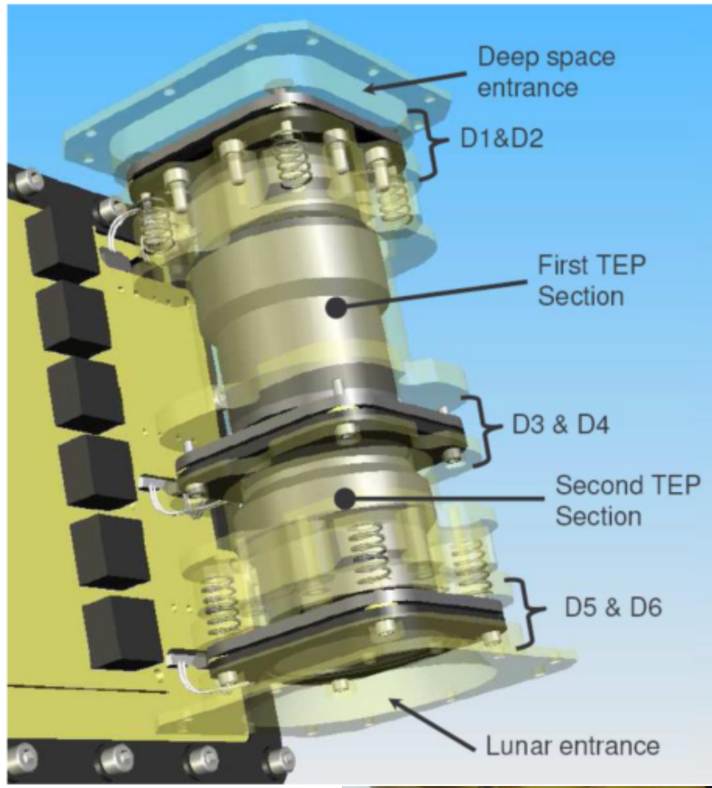
Hazard = Integral of (LET * Biological impact)

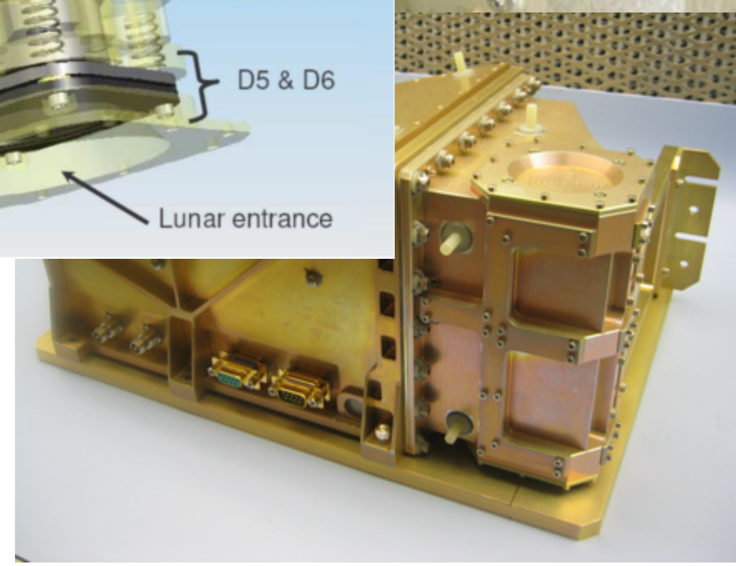


Instrument

CRaTER Overview

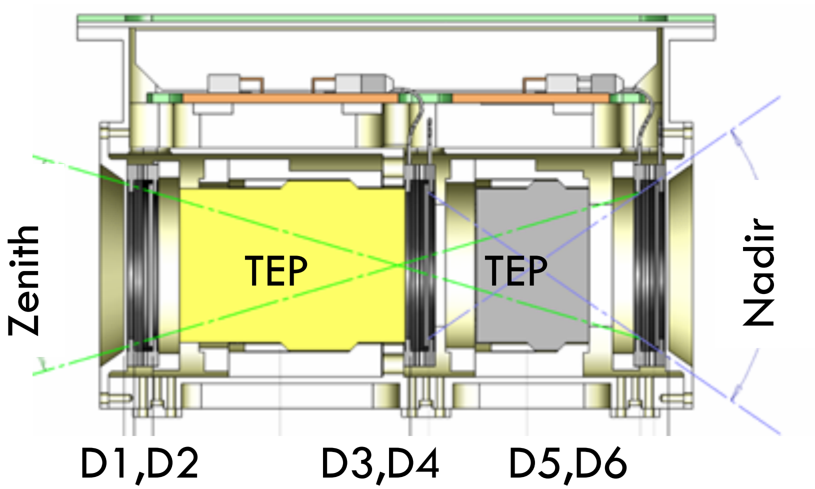
- A "telescope"
  - Three pairs of silicon detectors measure dE/dx
  - Thin detector low gain (large dE/dx)
  - Thick detector high gain (low dE/dx)
  - Two blocks of A150 TEP
- Programmable minimum dE/dX to trigger an event
- Process up to 300,000 events/sec
  - 4096-channel dE/dx
  - < 0.3% accuracy
- Send first 1,200 events/sec to Earth
- Reconfigures automatically for flares

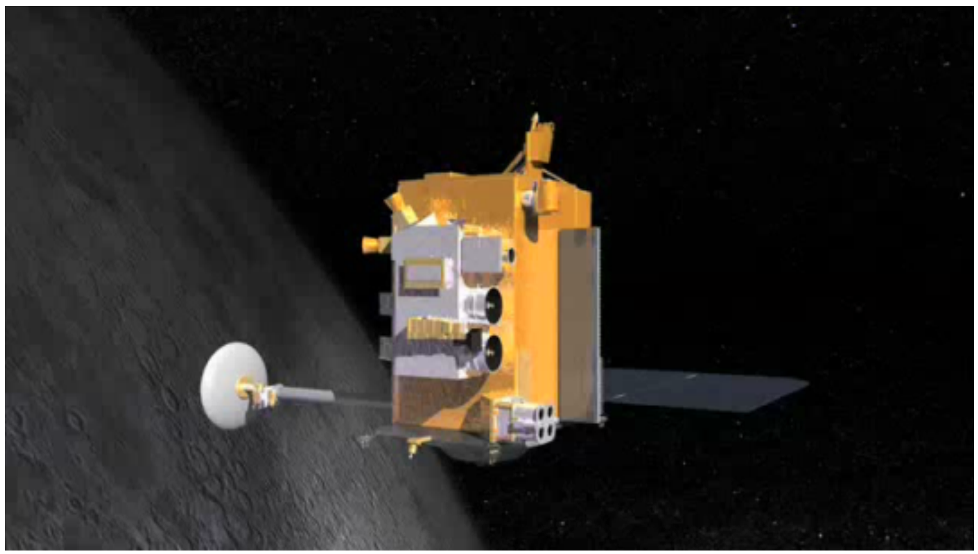




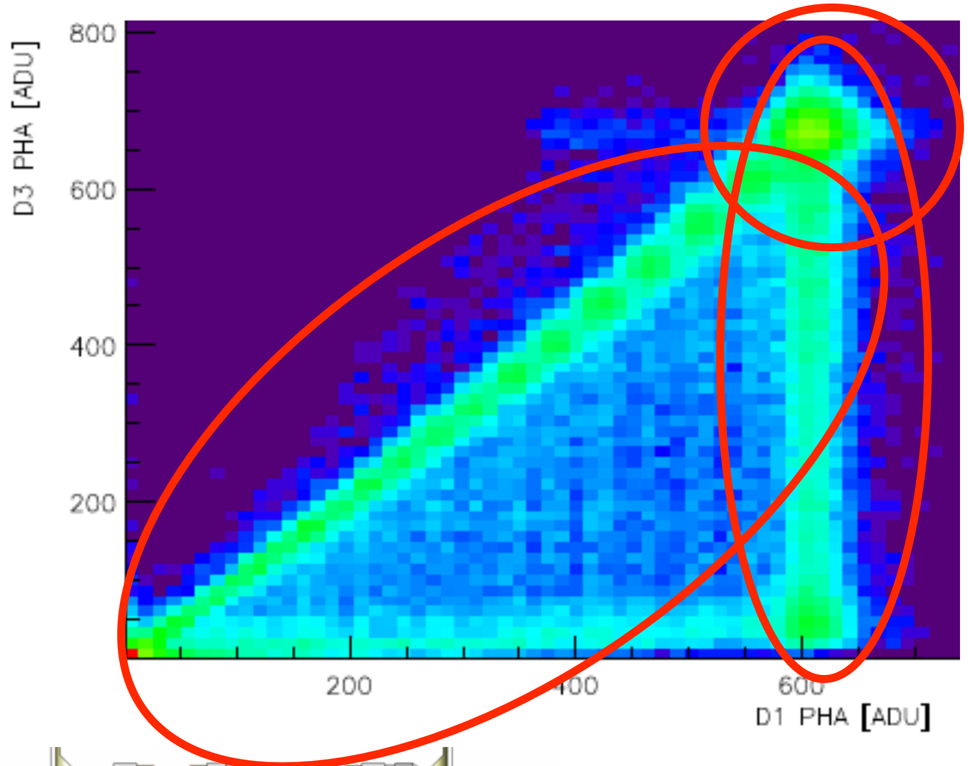
CRaTER Performance Specs

- Three thick low LET detectors 200 keV-100 MeV
- Three thin high LET detectors 2 MeV – 300 MeV
- Overall LET range 0.2 keV/μm to 2 MeV/ μm
- Digitize energy loss in each detector at 0.3% accuracy
- Send back up to 1200 events/second
- Detector rates, single chip dosimeter





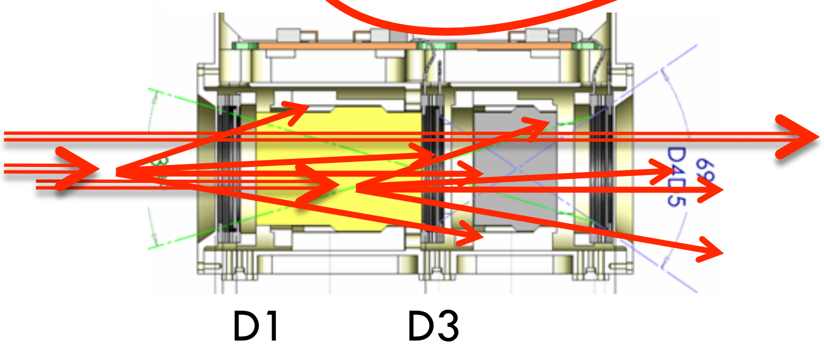
Extreme example 1 GeV/nuc Fe at Brookhaven



An iron enters the instrument and passes through it

Iron passed through the first detector but broke up in the TEP ($dE/dx \sim z^2$)

Iron broke up before it reached CRaTER



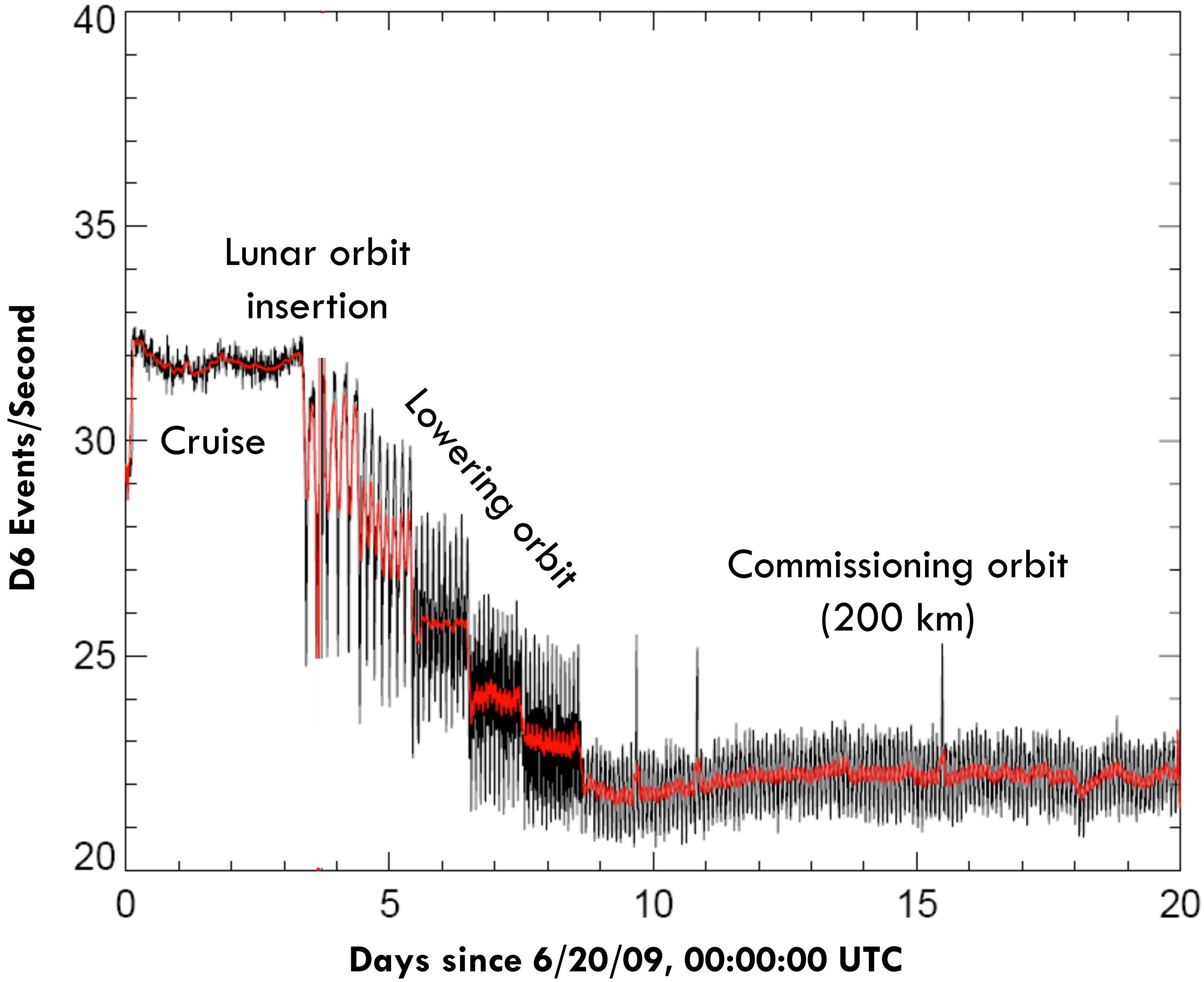
CRaTER Results

- Performance since launch
- Initial results

Overview of initial results

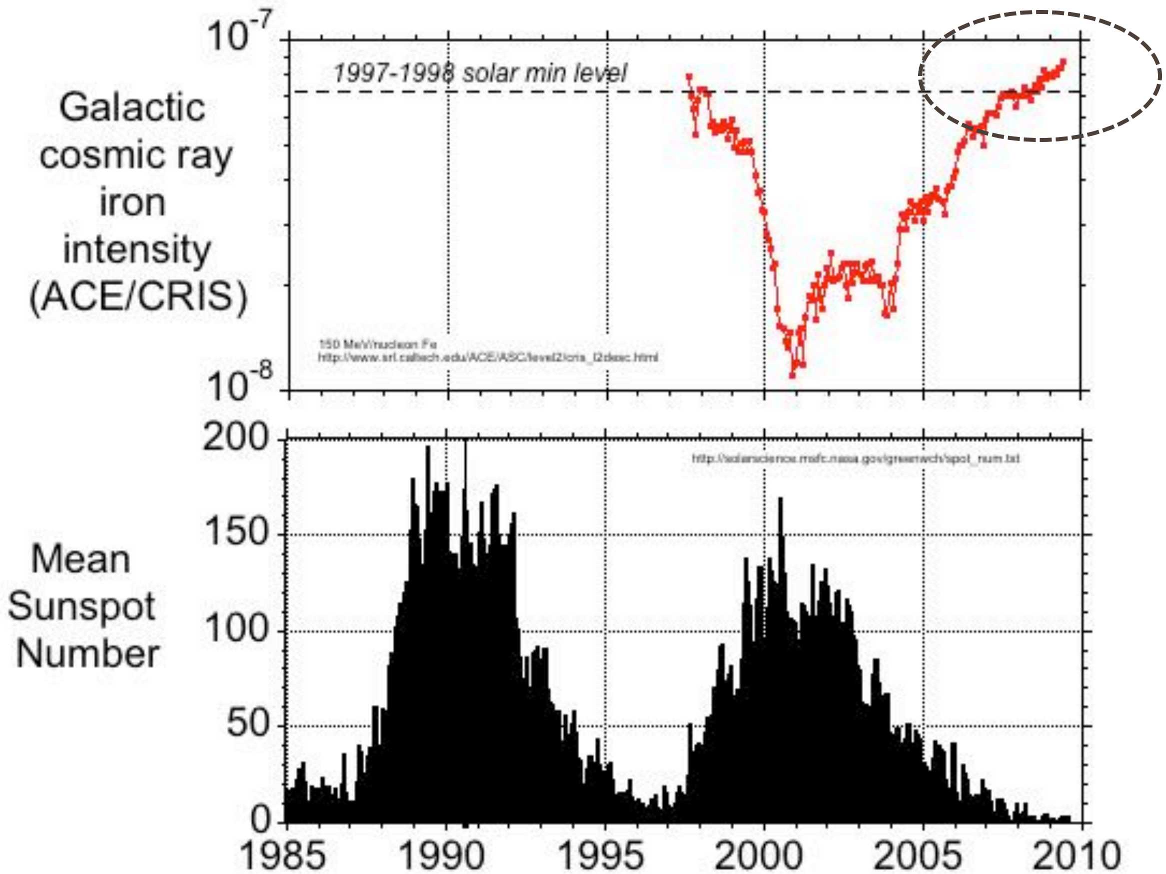
- CRaTER is performing as expected
  - Noise levels are low
  - Insensitive to temperature over orbit
- Continuous data taking since turn on one day after launch
- Rates are much higher than originally estimated
  - Rarest events (> 100 MeV, punch through whole telescope) seen once a second
  - The unprecedented solar minimum has led to the highest GCR fluxes and dose rates in the history of human space exploration
- Integrated LET spectra showing presence of nuclear interactions, inelastic scatterings, other deviations from simple radiation transport
- GCR rates drops as we approach moon (due to blocking increasing fraction of the sky) until 500 km altitude
  - Rate does not fall at expected rate as we get closer to moon
  - Ionizing radiation > 10 MeV from lunar surface – possibly due to interactions between GCR and surface
  - Lunar surface radiation dose higher than expected as a result

First observations…



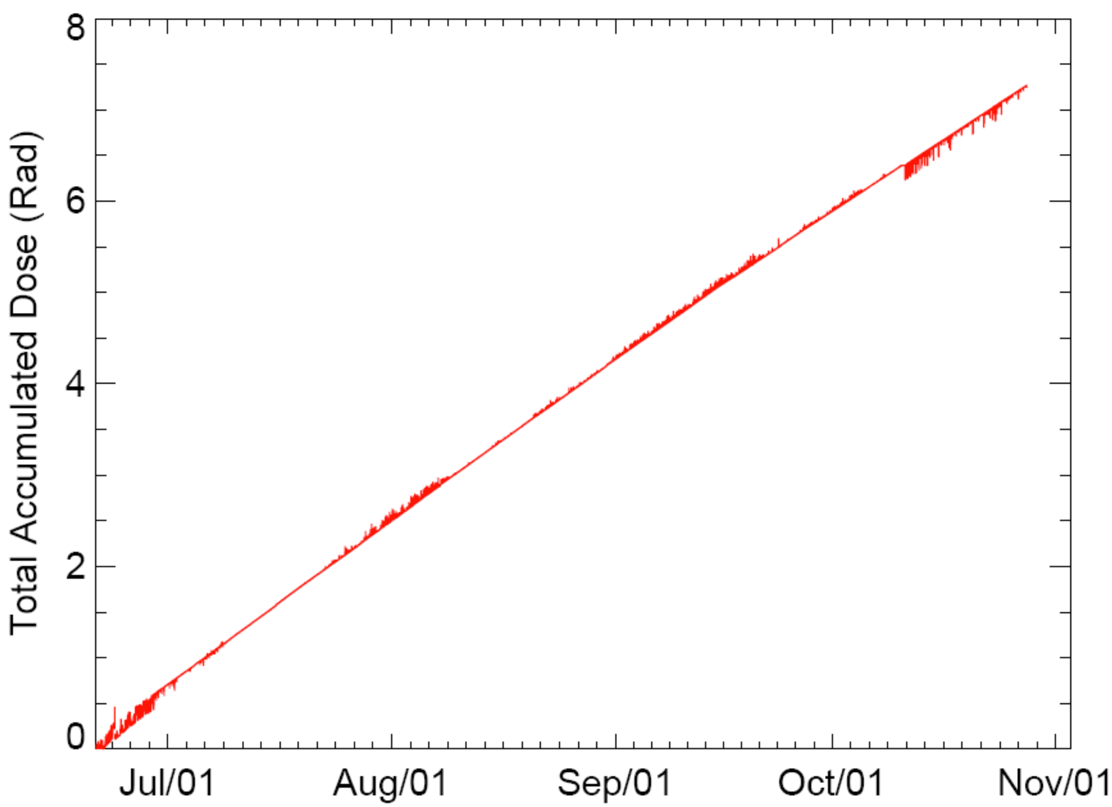
- Instrument turned on one day after launch
- Three days of cruise phase observations
- Shown are rates of valid events (> 10 MeV) observed in nadir-most detector
- Variations in fluxes of galactic cosmic rays (GCR) seen during:
  - Cruise Phase
  - Lunar Orbit Insertion (LOI)
  - Commissioning Phase

Rates higher than expected



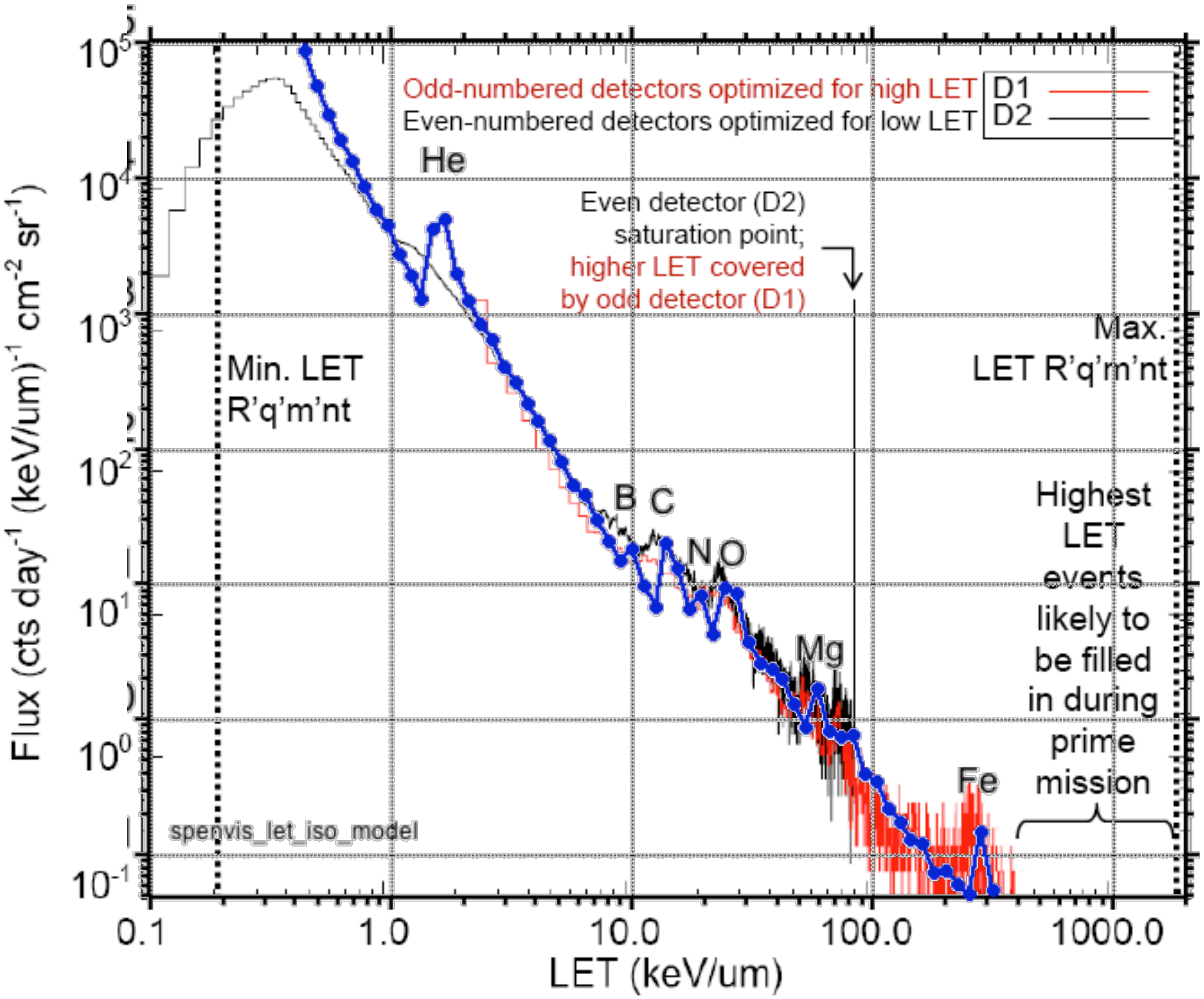
- Rarest events are > 100 MeV/ nucleon particles that pass through center of telescope and hit every detector
- See one of these events per second
- Almost 10x higher than anticipated

Total dose since launch

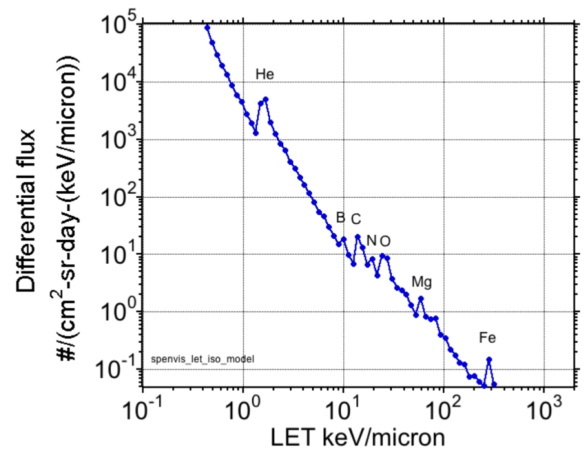


- Measured dose embedded in housekeeping
- 16-second cadence
- In real time during tracking periods
- Still making some tweaks to processing pipeline
- Current dose at 30 km 24 Rad/year

LET Spectra

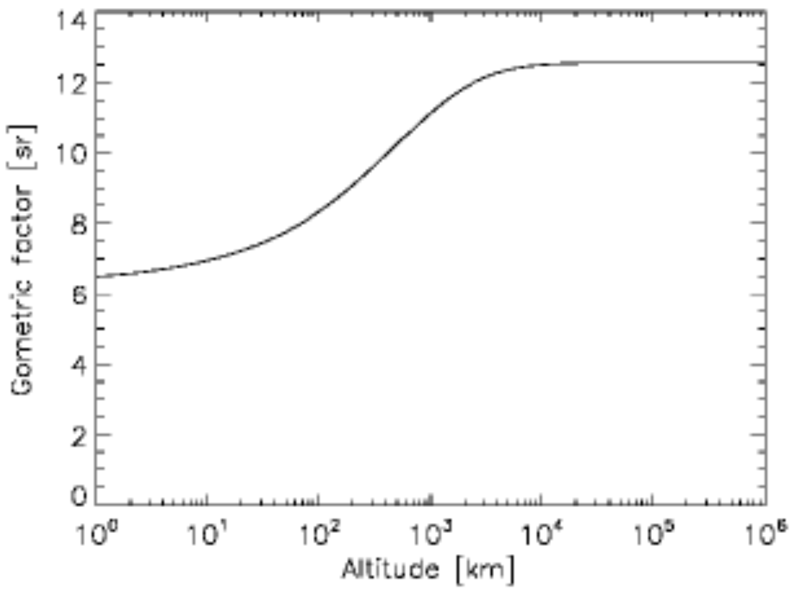


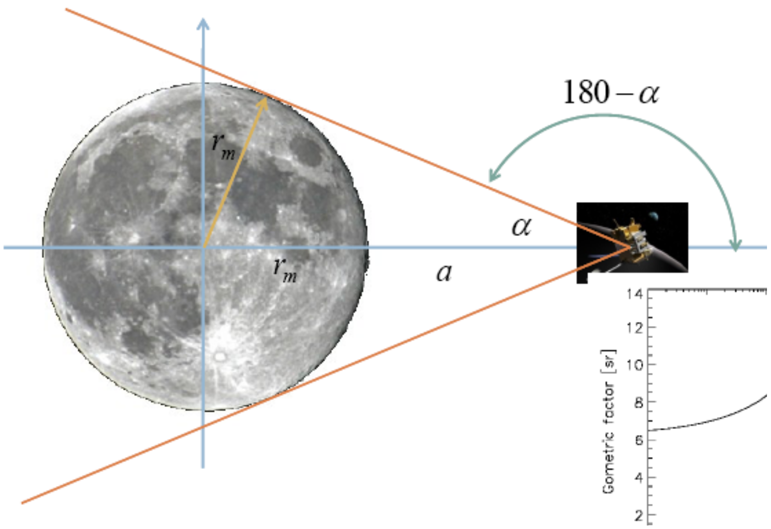
Odd-numbered detectors optimized for high LET
Even-numbered detectors optimized for low LET
D1
D2
He
Even detector (D2) saturation point;
higher LET covered by odd detector (D1)
Min. LET R'q'm'nt
Max. LET R'q'm'nt
B C
N O
Mg
Fe
Highest LET events likely to be filled in during prime mission
spenvis_let_iso_model
Flux (cts day^{-1} (keV/um)$^{-1}$ cm^{-2} sr^{-1})
LET (keV/um)
0.1
1.0
10.0
100.0
1000.0



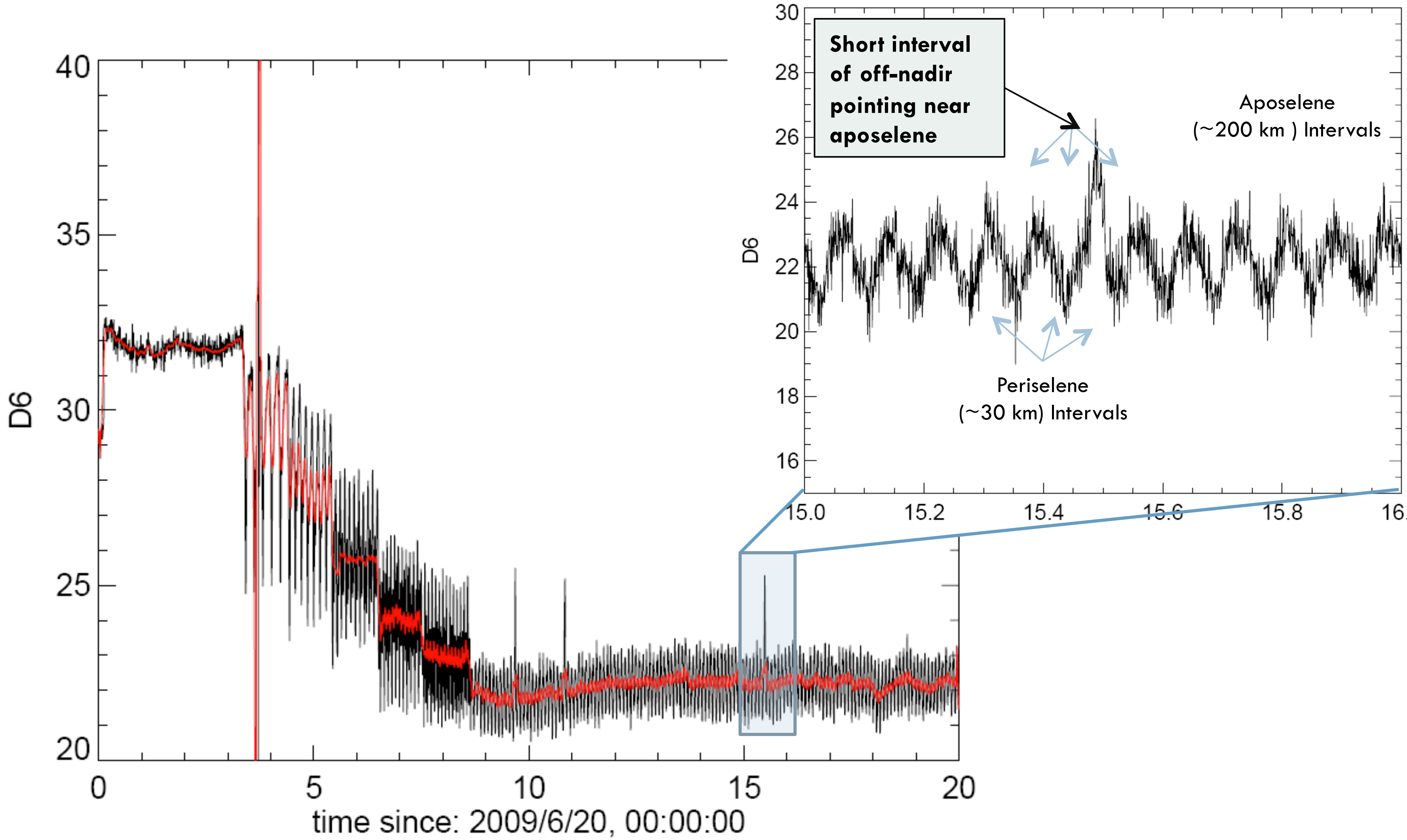
He
B C
N O
Mg
Fe
Differential flux
#/(cm^2-sr-day-(keV/micron))
LET keV/micron

Lunar blocking of cosmic rays

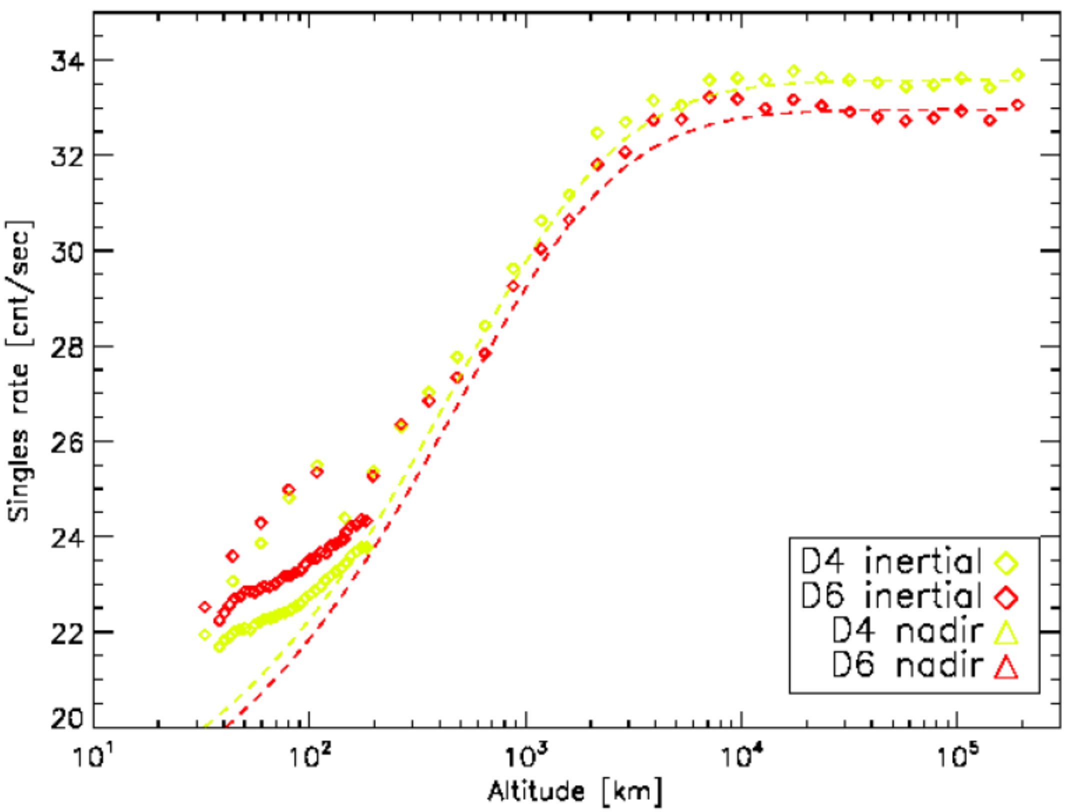




Orbital modulation of cosmic rays

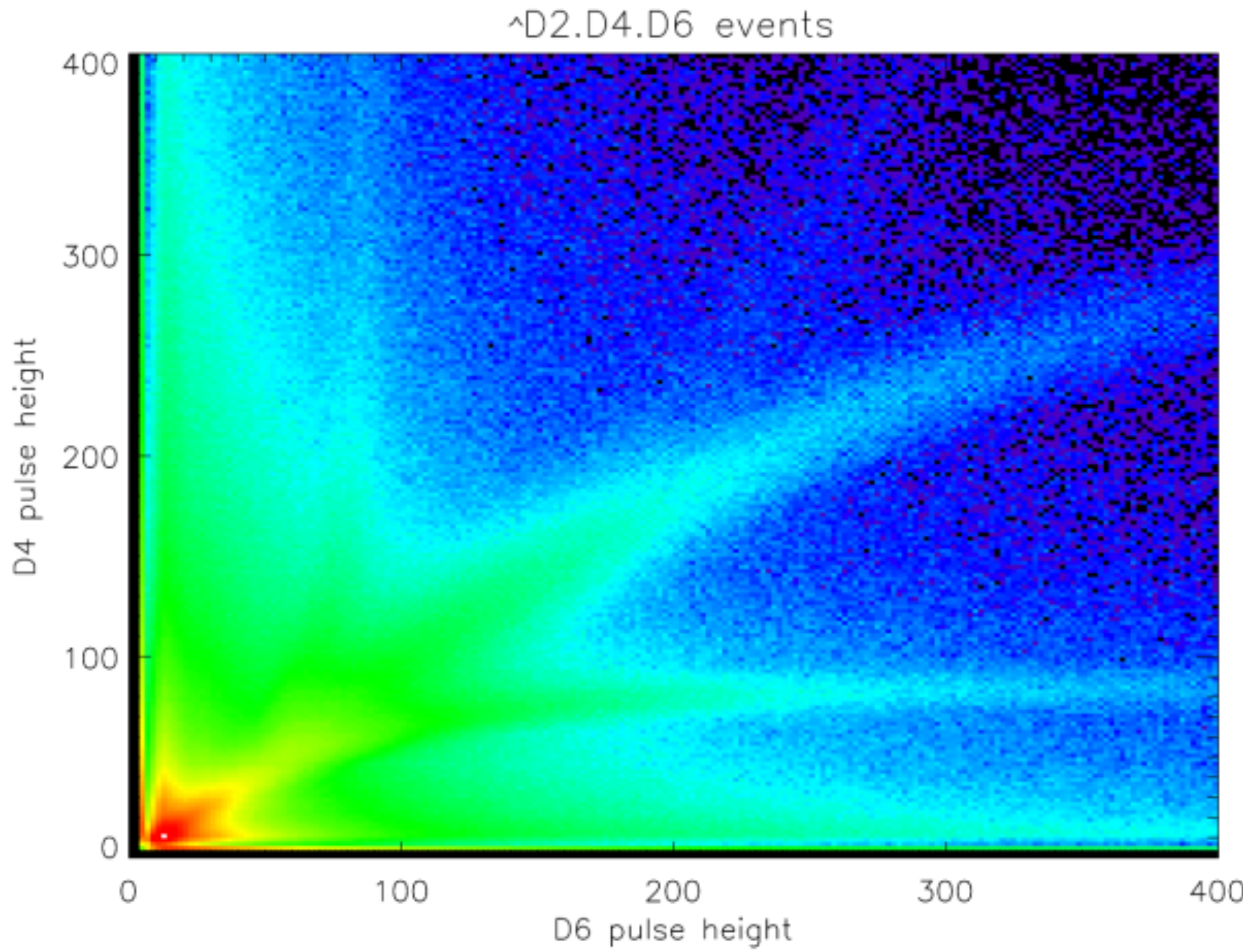


Excess radiation near surface

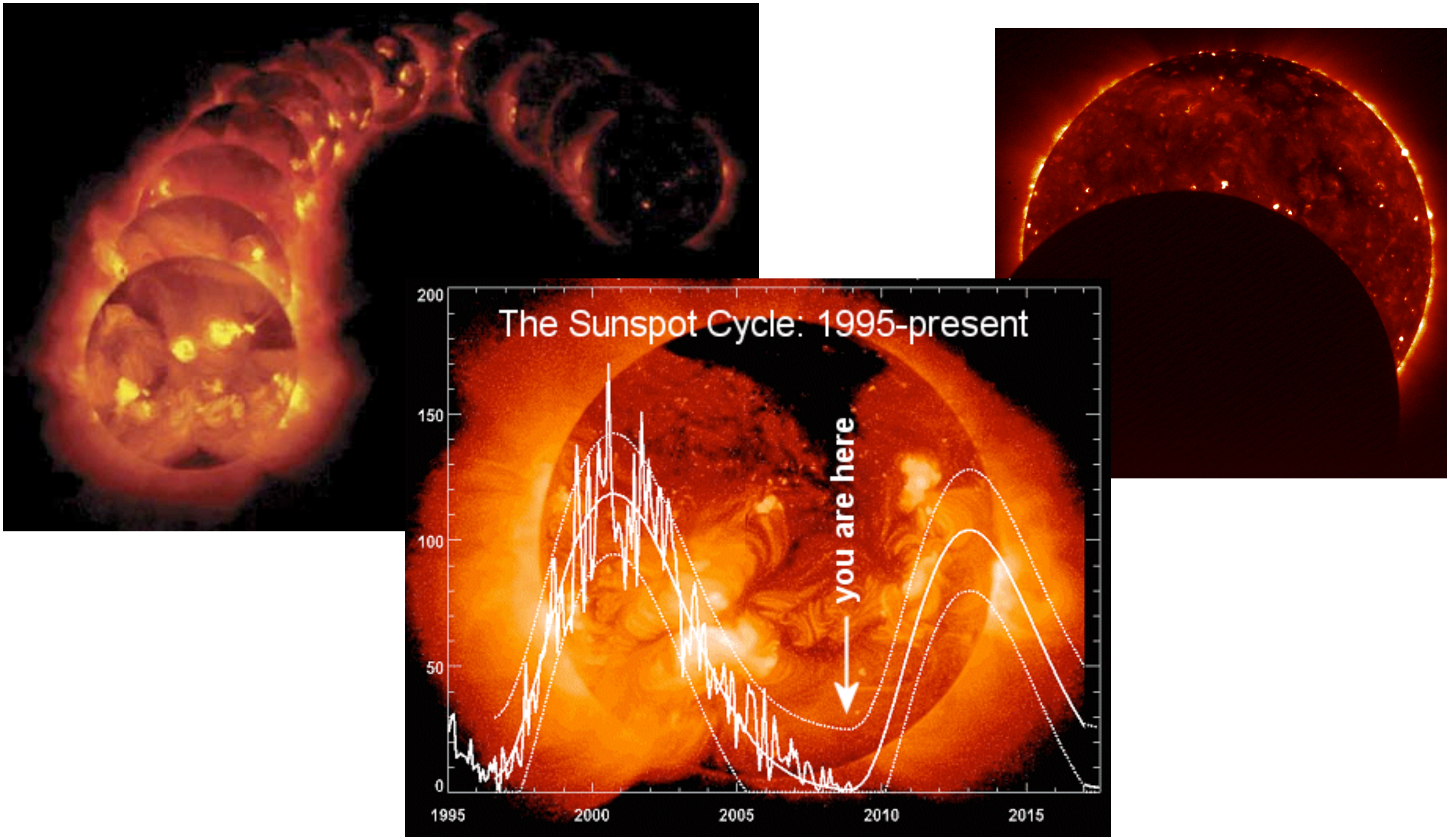


- Observed rate as a function of altitude
- Dashed line is predicted variation of rate with altitude based on geometric model
- Model works well above 800 km
- Flux does not fall off as expected below 800 km
- Additional source of >10 MeV radiation seen at lower altitudes (lunar surface)
- Dose at surface about 25% worse than we'd expected

Composition of lunar radiation



Only one thing missing…



Summary

- CRaTER primary science data quality is excellent and all systems are behaving as designed; off to great start in meeting ESMD Level 1 requirements as well as CRaTER secondary science goals
- Primary science data has been flowing into the CRaTER Science Operations Center (SOC) continuously since initial power-up on 6/20/09 (approximately one-day post-launch)
- Variations seen in fluxes of galactic cosmic rays (GCR) during (no SEPs yet…):
- Cruise Phase
- Lunar Orbit Insertion (LOI)
- Commissioning Phase
- Main ESMD Mission Phase
- Prime ESMD data (LET spectra) of high quality, and are allowing new science of GCR and their interaction with the Moon.