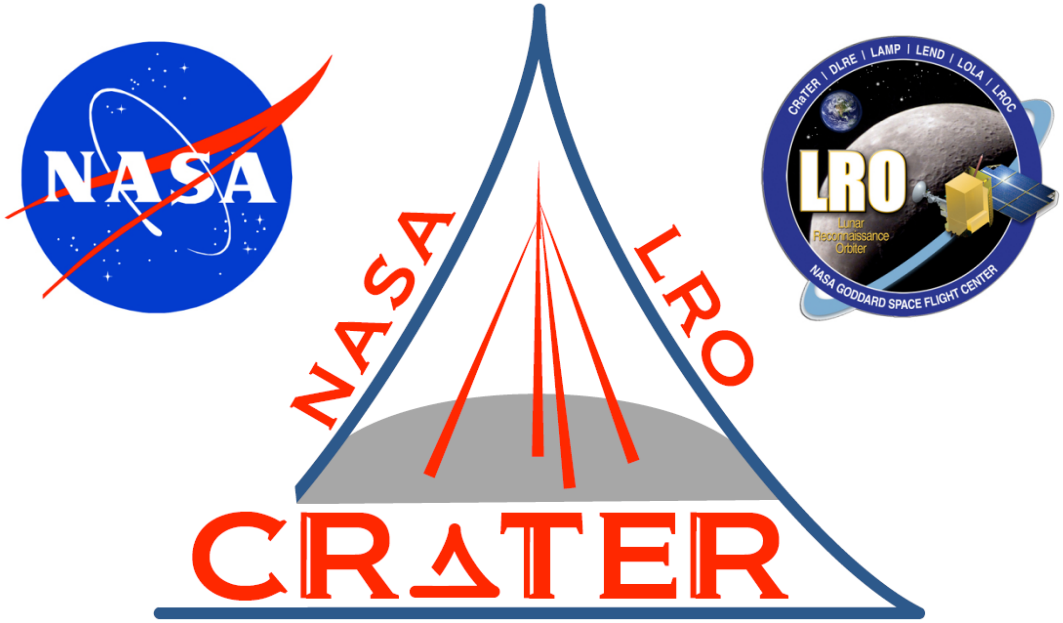
First "Light" from the NASA/LRO Cosmic Ray Telescope for the Effects of Radiation (CRaTER) Investigation

2nd Annual NLSI Lunar Science Forum
NASA/Ames

21 July 2009



Harlan E. Spence
CRaTER Principal Investigator
Boston University, Center for Space Physics

"Luna Ut Nos Animalia Tueri Experiri Possimus"
("In order that we might be able to protect and make trial of living things on the Moon")

CRaTER co-Investigators/Science Team

Harlan Spence	*Boston University (Principal Investigator)*
Justin Kasper	*CfA (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 (Research Associate, GCR variability)*
Eddie Semones	*NASA/JSC, (Collaborator, astronaut safety)*
Timothy Stubbs	*NASA/GSFC (LRO Participating Scientist, dust)*
Cary Zeitlin	*SwRI(LRO Partic. Sci., radiation modeling)*

CRaTER ESMD Measurement Goals

To characterize the global lunar radiation environment and its biological impacts

- Six-element, solid-state detector and tissue-equivalent plastic (TEP) telescope

- Sensitive to cosmic ray particles with energies greater than ~10 MeV, primarily protons, but also heavy ions, electrons, and neutrons
  - *Galactic cosmic rays – GCRs*
  - *Solar energetic particles– SEPs*

- Measure spectrum of Linear Energy Transfer (LET = energy per unit path length deposited by cosmic rays as they pass through or stop in matter) behind different amounts of TEP

- Accurate LET spectrum is missing link needed to constrain radiation transport models and radiation biology

CRaTER Performance Specifications

CRaTER's design has thick/thin detector pairs at 3 points through TEP:

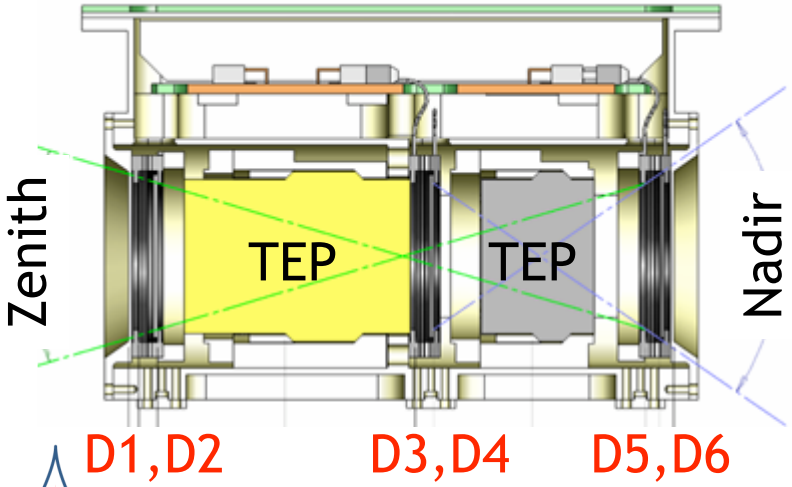
- 3 "low LET" thick detectors (D2,D4,D6)
- 3 "high LET" thin detectors (D1,D3,D5)

nergy resolution <0.5% (at max energy); GF ~1 cm^2-sr (typical)

This corresponds to:

ET from **0.2 keV/μ to 2 MeV/ μ**

xcellent spectral overlap in the **100 kev/μ** range (key range for RBEs)



CRaTER Status Summary

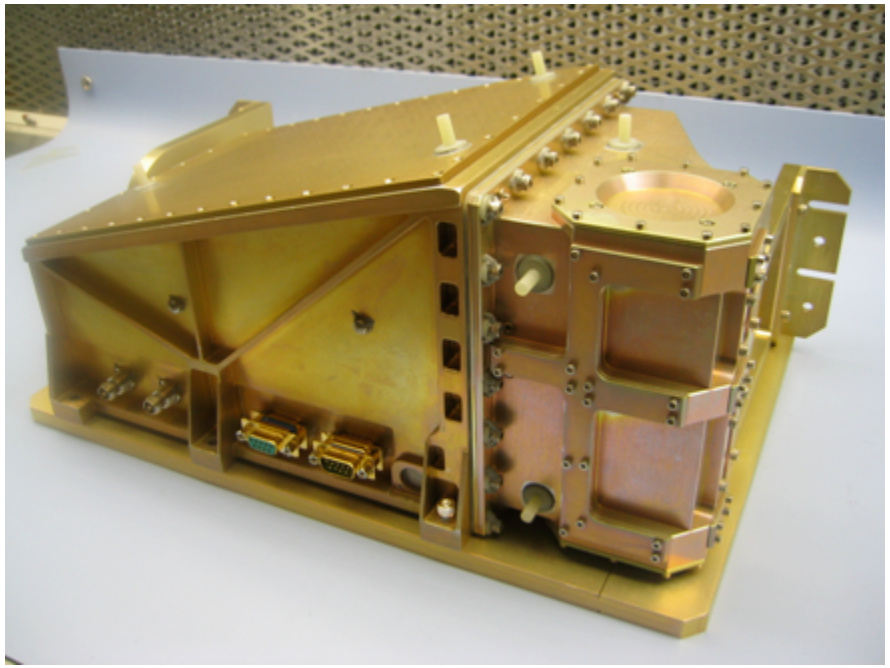
- **CRaTER primary science data quality is excellent and all systems are behaving as designed; off to great start in meeting ESMD Level 1 requirements as well as CRaTER secondary science goals**

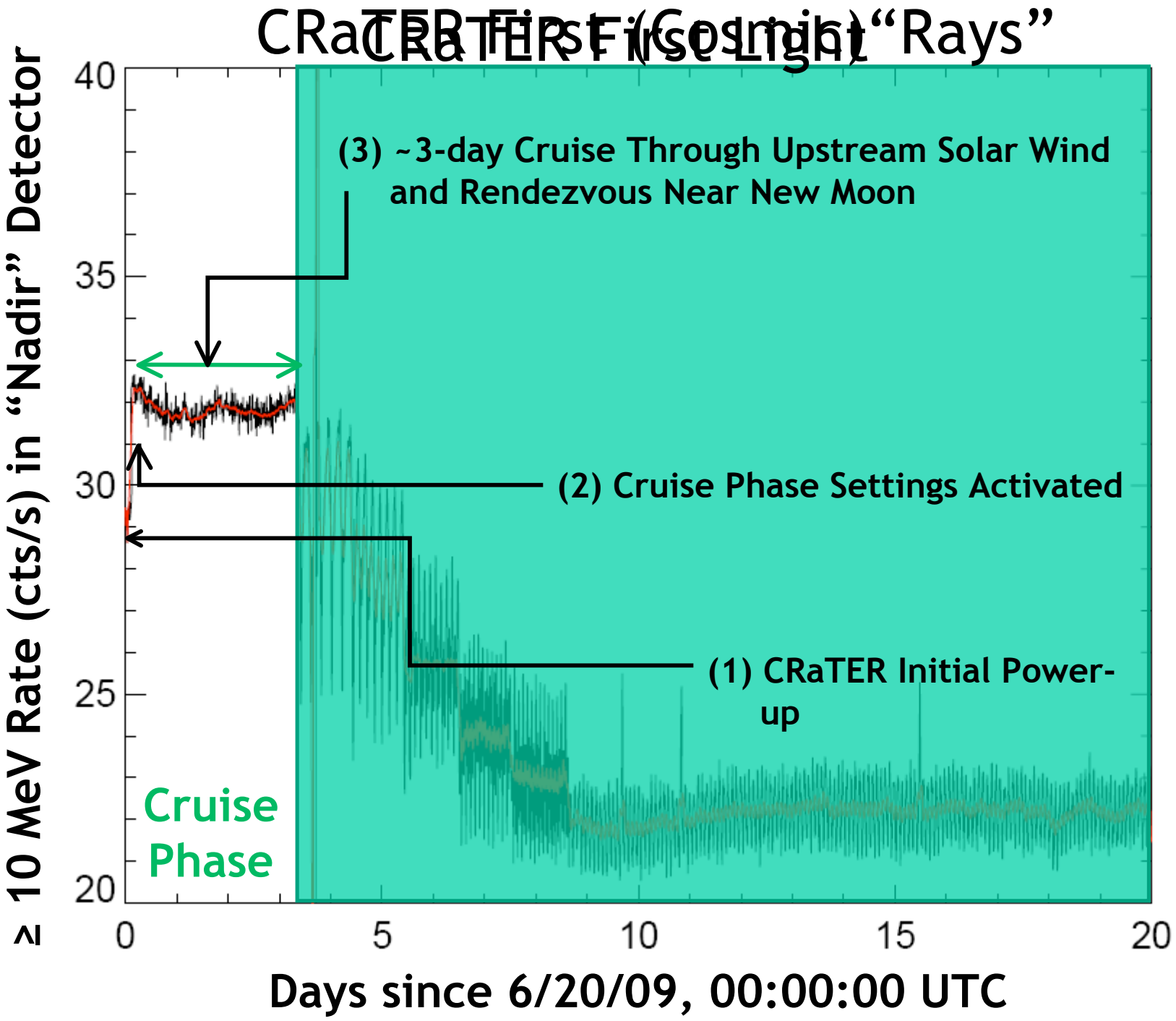
- Primary science data has been flowing into the CRaTER Science Operations Center (SOC) continuously since initial power-up on 6/20/09 (approximately one-day post-launch)

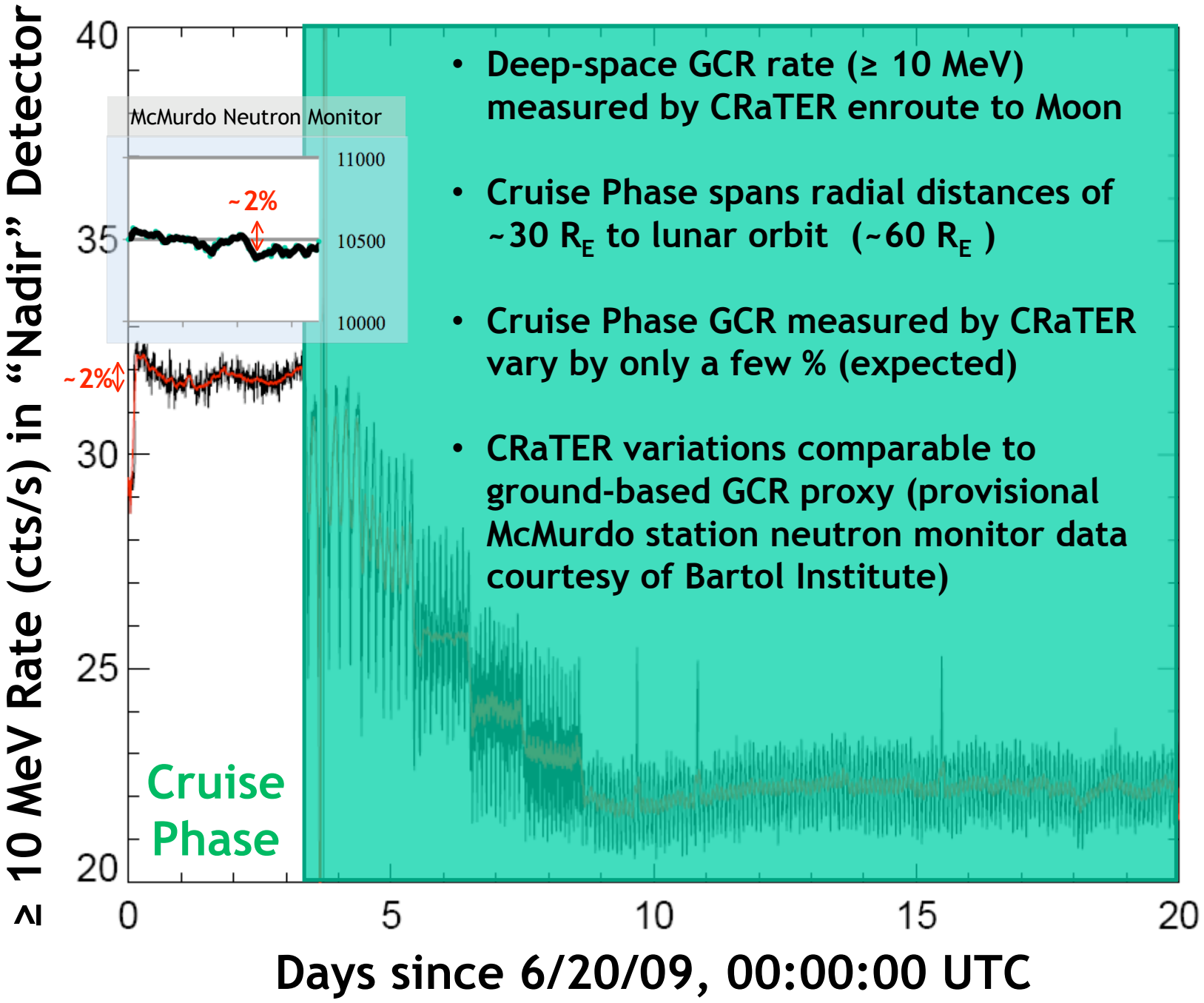
- Well-understood variations seen in fluxes of galactic cosmic rays (GCR) during (no SEPs yet…):
  - Cruise Phase
  - Lunar Orbit Insertion (LOI)
  - Commissioning Phase

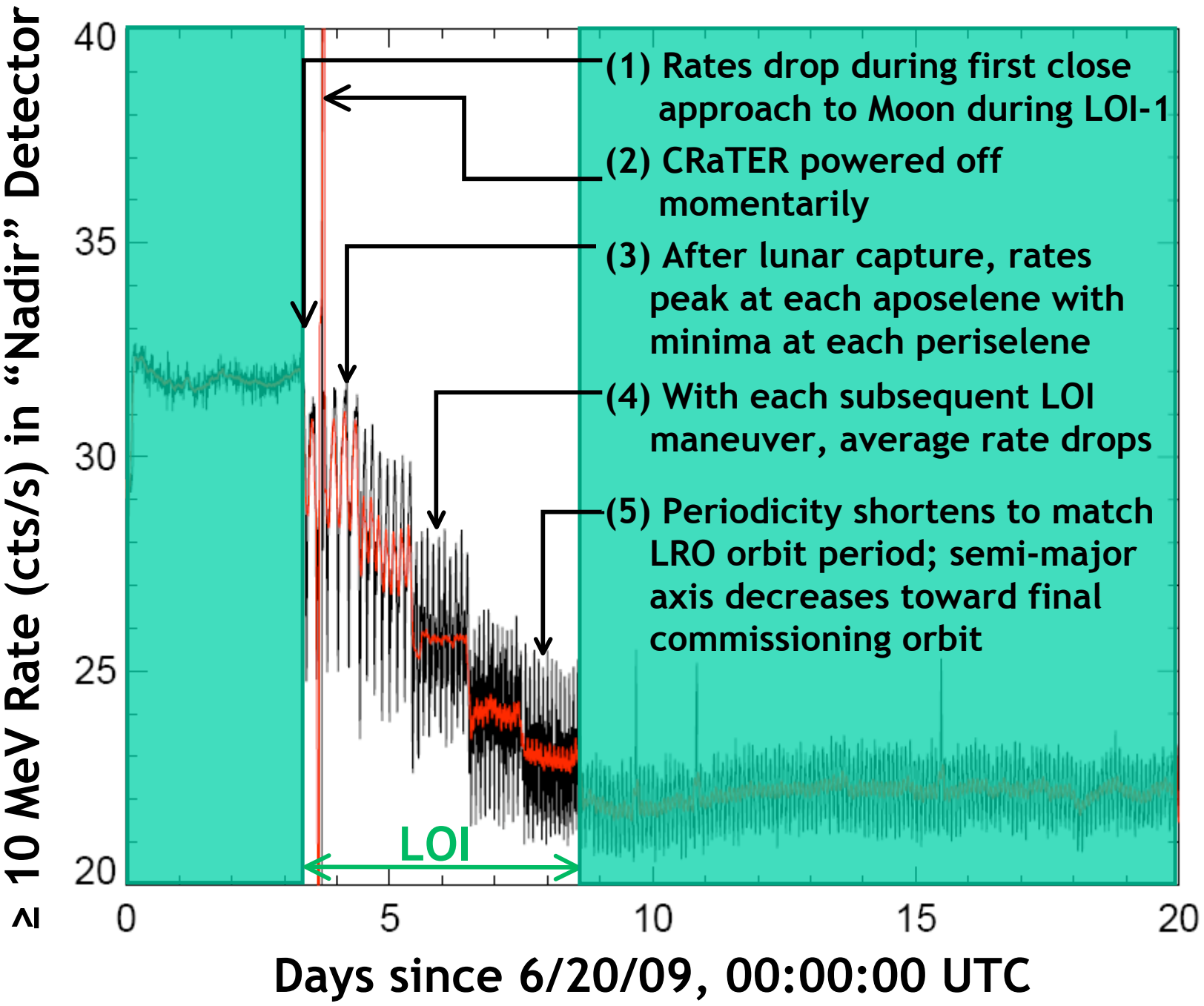
- CRaTER commissioning calibration begins officially on 7/25/09

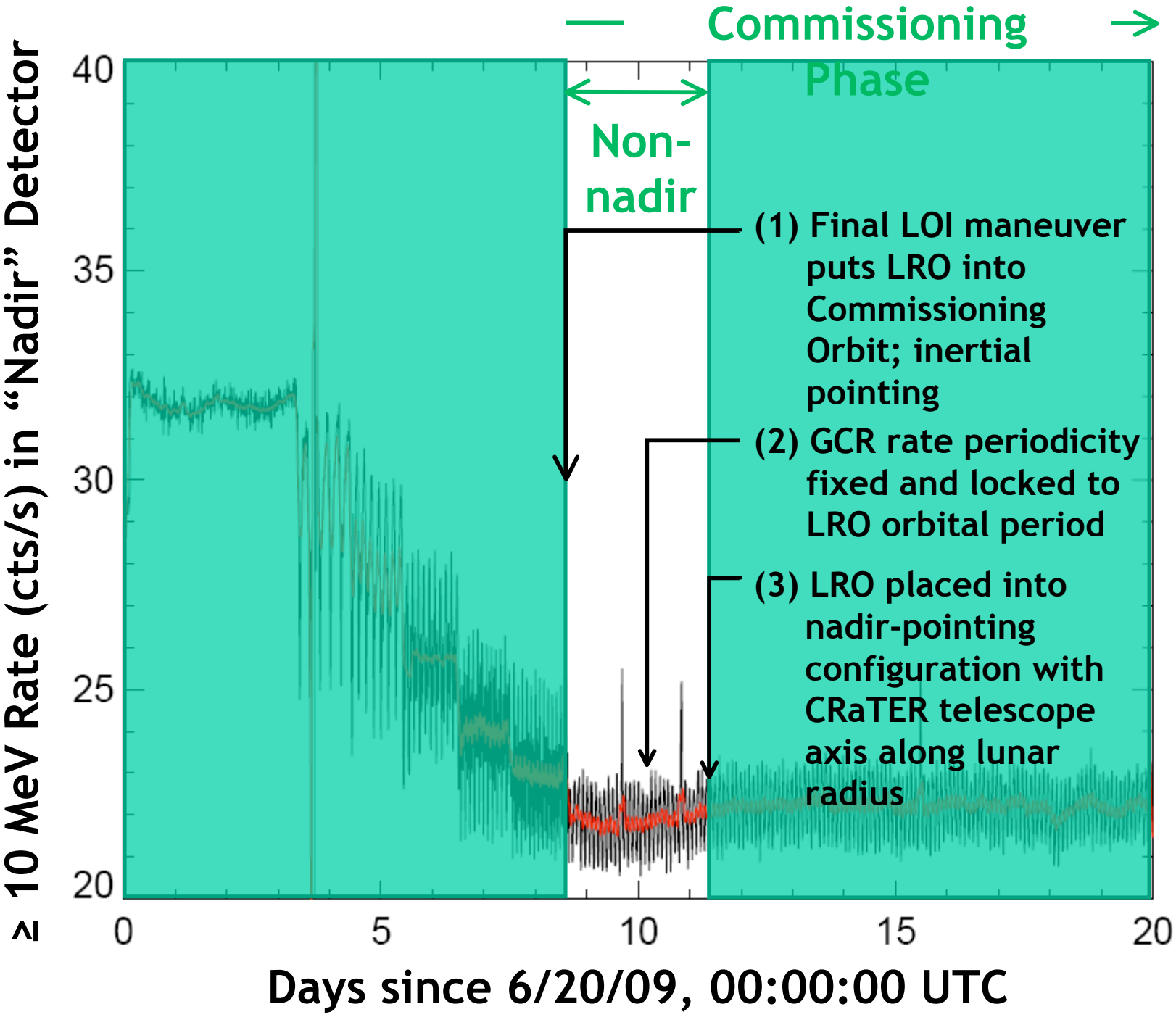
- Next…a preview of the first 20 days!

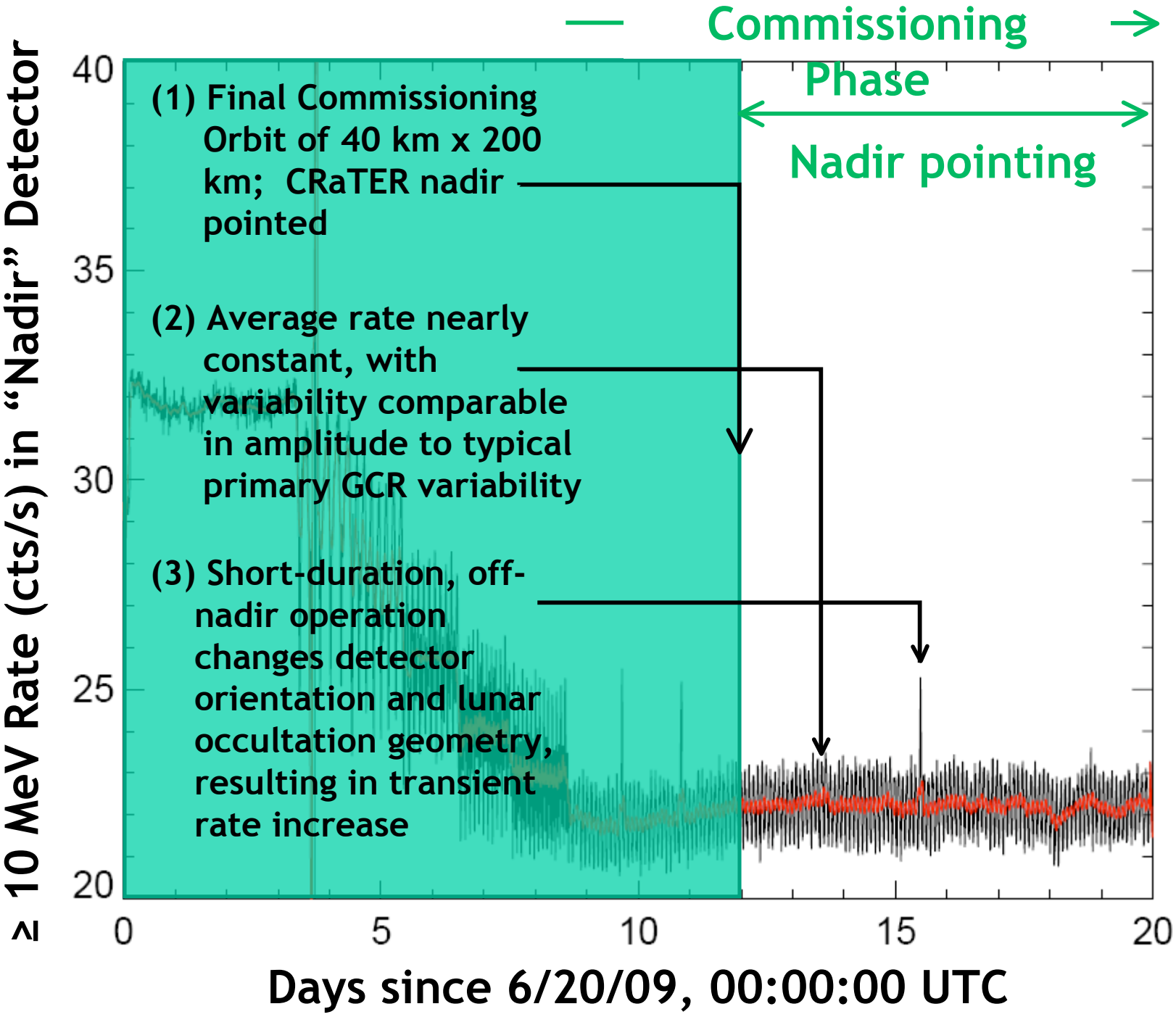


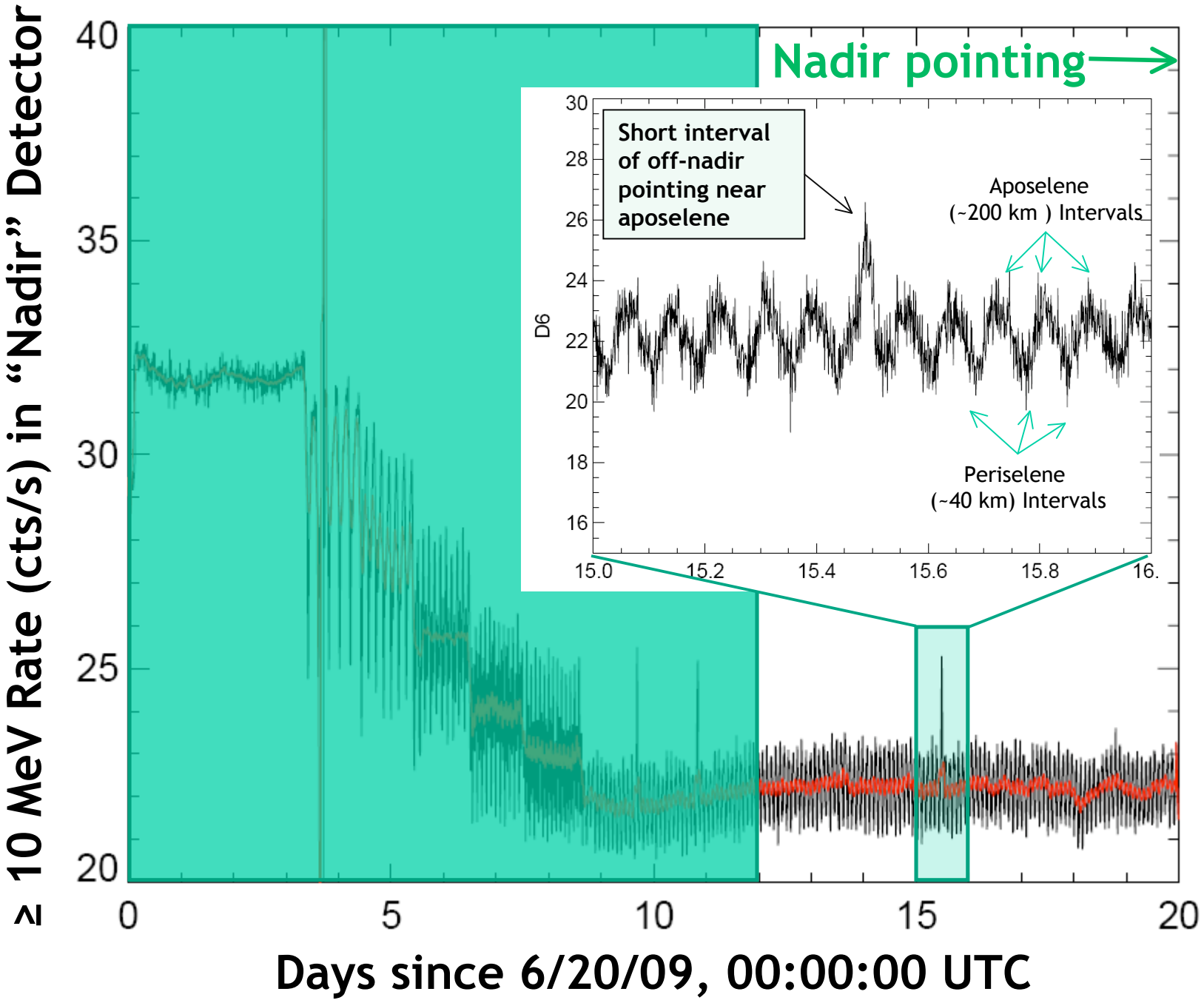

CRaTER First Cosmic "Rays"
CRaTER First Light
(3) ~3-day Cruise Through Upstream Solar Wind and Rendezvous Near New Moon
(2) Cruise Phase Settings Activated
(1) CRaTER Initial Power-up
Cruise Phase
≥ 10 MeV Rate (cts/s) in "Nadir" Detector
40
35
30
25
20
0
5
10
15
20
Days since 6/20/09, 00:00:00 UTC


≥ 10 MeV Rate (cts/s) in "Nadir" Detector
40
35
30
25
20
0
5
10
15
20
Days since 6/20/09, 00:00:00 UTC
McMurdo Neutron Monitor
11000
10500
10000
~2%
~2%
Cruise Phase
• Deep-space GCR rate (≥ 10 MeV) measured by CRaTER enroute to Moon
• Cruise Phase spans radial distances of ~30 R_E to lunar orbit (~60 R_E)
• Cruise Phase GCR measured by CRaTER vary by only a few % (expected)
• CRaTER variations comparable to ground-based GCR proxy (provisional McMurdo station neutron monitor data courtesy of Bartol Institute)

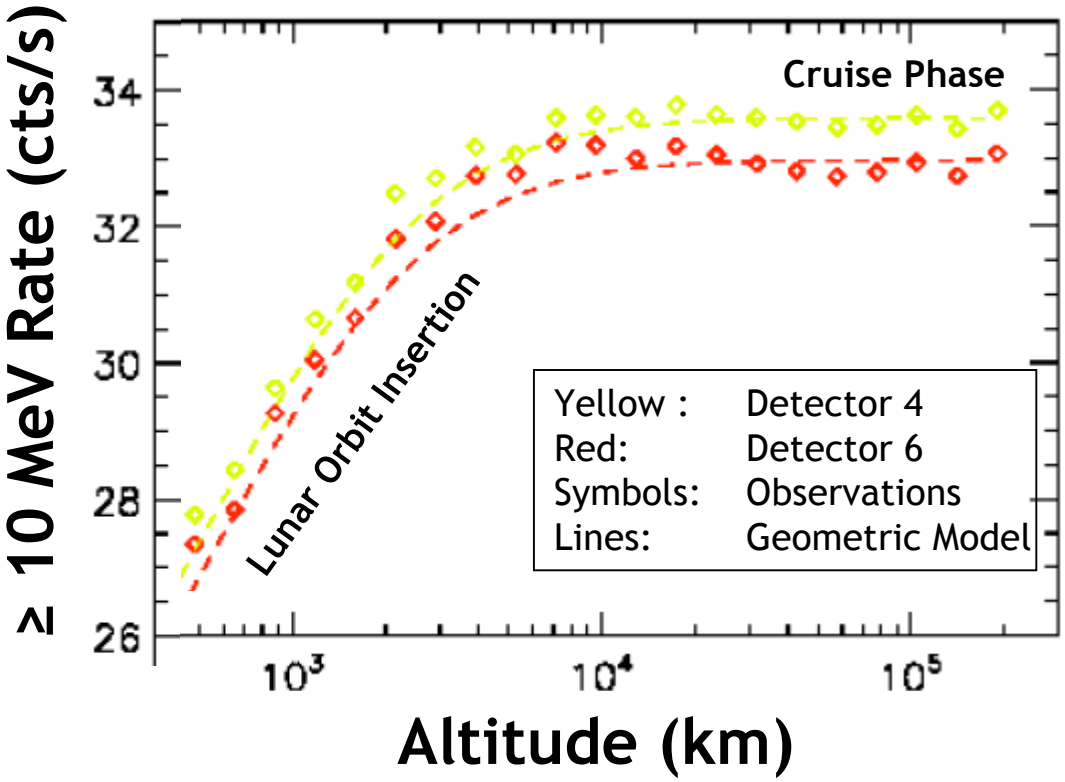

≥ 10 MeV Rate (cts/s) in "Nadir" Detector
40
35
30
25
20
0
5
10
15
20
Days since 6/20/09, 00:00:00 UTC
(1) Rates drop during first close approach to Moon during LOI-1
(2) CRaTER powered off momentarily
(3) After lunar capture, rates peak at each aposelene with minima at each periselene
(4) With each subsequent LOI maneuver, average rate drops
(5) Periodicity shortens to match LRO orbit period; semi-major axis decreases toward final commissioning orbit
LOI

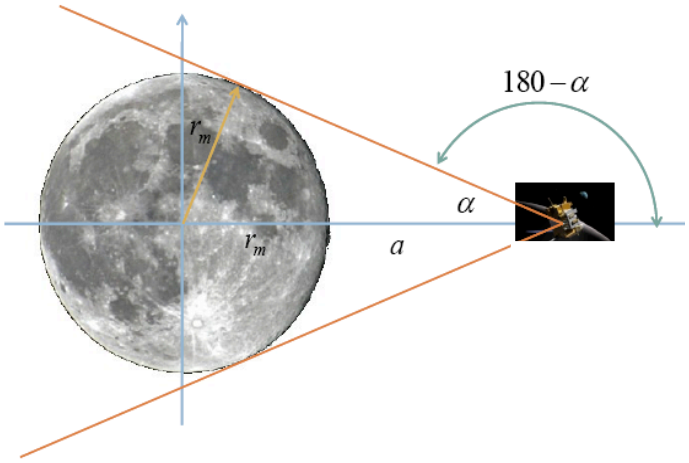

Commissioning Phase
Non-nadir
(1) Final LOI maneuver puts LRO into Commissioning Orbit; inertial pointing
(2) GCR rate periodicity fixed and locked to LRO orbital period
(3) LRO placed into nadir-pointing configuration with CRaTER telescope axis along lunar radius
≥ 10 MeV Rate (cts/s) in "Nadir" Detector
40
35
30
25
20
0
5
10
15
20
Days since 6/20/09, 00:00:00 UTC


Commissioning Phase
Nadir pointing
(1) Final Commissioning Orbit of 40 km x 200 km; CRaTER nadir pointed
(2) Average rate nearly constant, with variability comparable in amplitude to typical primary GCR variability
(3) Short-duration, off-nadir operation changes detector orientation and lunar occultation geometry, resulting in transient rate increase
≥ 10 MeV Rate (cts/s) in "Nadir" Detector
40
35
30
25
20
0
5
10
15
20
Days since 6/20/09, 00:00:00 UTC


≥ 10 MeV Rate (cts/s) in "Nadir" Detector
Days since 6/20/09, 00:00:00 UTC
Nadir pointing
Short interval of off-nadir pointing near aposelene
Aposelene (~200 km) Intervals
Periselene (~40 km) Intervals
D6

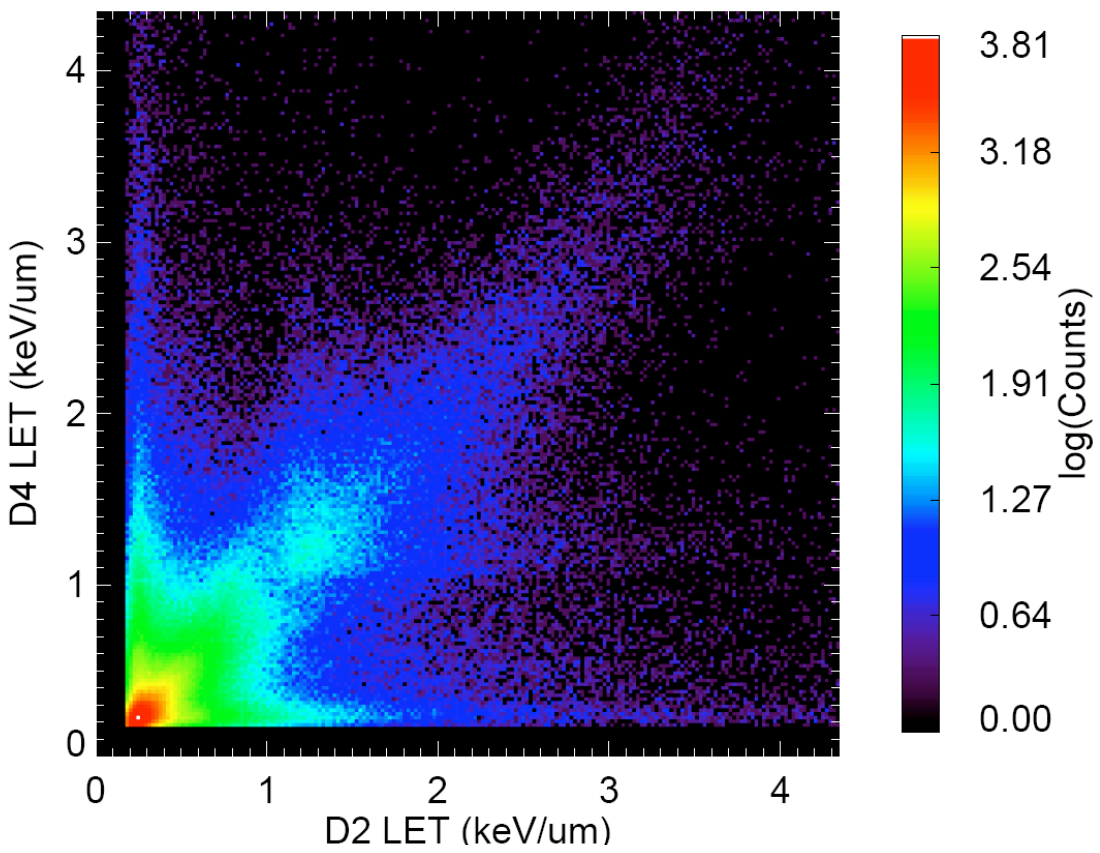
The GCR Absorbing Moon





- Singles rates in each of six detectors varies as predicted geometrically (two of six detector responses shown) as a function of altitude
- Altitude dependence a simple geometric consequence of Moon blocking more or less of the primary GCR
- **Relative to deep space (no absorbing Moon), GCR which produces ionizing radiation is reduced by ~20% at ~500 km lunar altitudes**

Other Early Results/Plans



- Over 150 million(!) cosmic ray detections thus far, including a large fraction of high LET deposits

- Preliminary LET spectra reveal well-resolved heavy ion GCR species:
  - One of deepest solar minima in recorded history
  - GCR rates historically high and thus of great scientific interest
- Awaiting rise to maximum and first solar proton event!
- Supporting radiation transport modeling underway
- Official CRaTER calibration commissioning to begin this Saturday

Summary

CRaTER is now characterizing the global lunar radiation environment and assessing its biological impacts

- CRaTER is working as designed and has been operating continuously since ~1 day after launch
- Early LET spectra in all six detectors obtained during Cruise Phase, LOI, and early Commissioning Phase show clear signatures of protons and heavy ions providing confidence that L1 requirements will be met
- Variations in GCR population well understood in terms of natural variations in the interplanetary medium and in terms of LRO-specific altitude dependence around an absorbing Moon
- Science team is preparing to complete Commissioning Phase and release validated data to the heliophysics and lunar science communities!