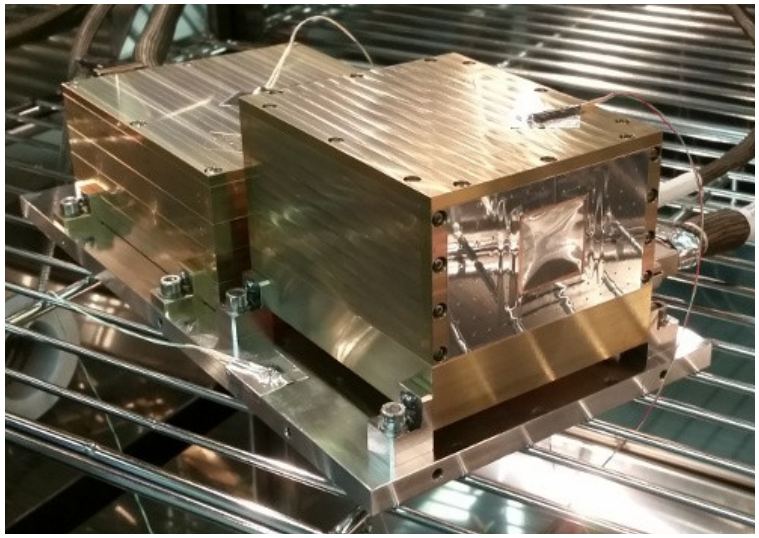
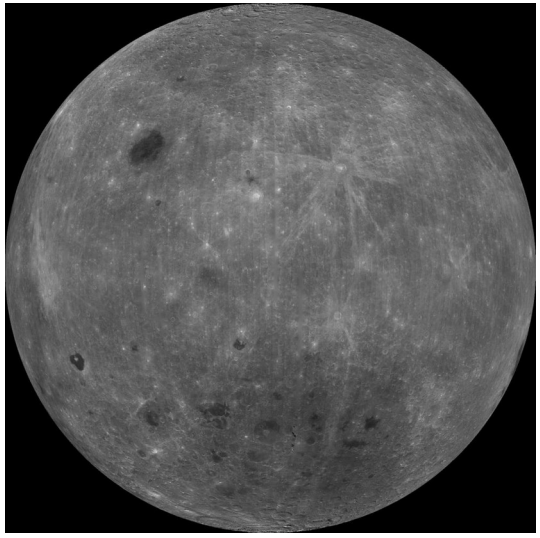
First results from the Lunar Lander Neutron and Dosimetry (LND) Experiment on China's Chang'E 4 mission to the far side of the Moon





Robert F. Wimmer-Schweingruber[1,2], Shenyi Zhang[2], Jia Yu[1], Stephan Böttcher[1], Sönke Burmeister[1], Henning Lohf[1], Bin Yuan[2], G. Shen[2], C. Wang[2], Jingnan Guo[1,3], Zigong Xu[1], Christine Hellweg[4], Thomas Berger[4], Daniel Matthiä[4]
and the LND Team

C | A | U Christian-Albrechts-Universität zu Kiel

DLR

[1]IEAP/CAU, [2]NSSC/CAS, [3]USTC, [4]DLR

Risk Assessments for all Design Reference Missions (DRMs)

Human Spaceflight Risks	In Mission Risk - Operations						Post Mission Risk – Long Term Health					
	Low Earth Orbit	Low Earth Orbit	Deep Space Sortie	Lunar Visit/Habitation	Deep Space Journey/Habitation	Planetary	Low Earth Orbit	Low Earth Orbit	Deep Space Sortie	Lunar Visit/Habitation	Deep Space Journey/ Habitation	Planetary
	6 Months	12 Months	30 Days	1 year	1 Year	3 years	6 Months	12 Months	30 Days	1 year	1 Year	3 years
VIIP	A	A	A	A	RM	RM	A	A	A	A	RM	RM
Renal Stone Formation	A	A	A	A	RM	RM	RM	RM	RM	RM	RM	RM
Inadequate food and nutrition	A	A	A	A	RM	RM	A	A	A	A	A	RM
Risk of Space Radiation Exposure	A	A	A	A	A	A	A	A	A	RM	RM	RM
Medications Long Term Storage	A	A	A	A	A	RM	A	A	A	A	A	RM
Acute and Chronic Carbon Dioxide	A	A	A	A	RM	RM	A	A	A	A	A	A
inflight Medical Conditions	A	A	A	RM	RM	RM	A	A	A	A	RM	RM
Cognitive or Behavioral Conditions	A	A	A	A	RM	RM	A	A	A	RM	RM	RM
Risk of Bone Fracture	A	A	A	A	A	A	A	A	A	A	A	RM
Team Performance Decrements#	A	A	A	A	RM	RM	A	A	A	A	A	A
Reduced Muscle Mass, Strength	A	A	A	A	A	RM	A	A	A	A	A	A
Reduced Aerobic Capacity	A	A	A	A	A	RM	A	A	A	A	A	A
Sensorimotor Alterations	A	A	A	A	A	RM	A	A	A	A	A	RM
Human-System Interaction Design#	A	A	A	RM	RM	RM	A	A	A	A	A	A
Injury from Dynamic Loads	A	A	RM	RM	RM	RM	A	A	RM	RM	RM	RM
Sleep Loss	A	A	A	A	RM	RM	A	A	A	A	RM	RM
Altered Immune Response	A	A	A	A	RM	RM	A	A	A	A	A	RM
Celestial Dust Exposure	N/A	N/A	A	TBD	TBD	TBD	N/A	N/A	A	TBD	TBD	TBD
Host-Microorganism Interactions	A	A	A	A	RM	RM	A	A	A	A	A	RM
Injury due to EVA Operations	A	A	A	RM	A	RM	A	A	A	RM	RM	RM
Decompression Sickness	A	A	A	A	RM	A	A	A	A	RM	A	RM
Toxic Exposure	A	A	A	A	A	A	A	A	A	A	A	A
Hypobaric Hypoxia	A	A	A	A	A	A	A	A	A	A	A	A
Space Adaptation Back Pain	A	A	A	A	A	A	N/A	N/A	N/A	N/A	N/A	N/A
Urinary Retention	A	A	A	A	A	A	A	A	A	A	A	A
Hearing Loss Related to Spaceflight	A	A	A	A	A	A	A	A	A	A	A	A
Orthostatic Intolerance	A	A	A	A	A	A	A	A	A	A	A	A
Injury from Sunlight Exposure - retired	A	A	A	A	A	A	A	A	A	A	A	A
Risk of electrical shock - Retired	A	A	A	A	A	A	A	A	A	A	A	A

Radiation!

A – Accepted

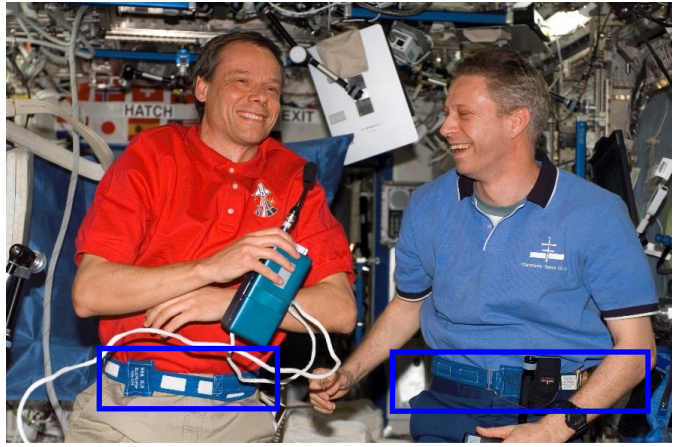
RM- Requires Mitigation

Green – controlled

Yellow – partially controlled

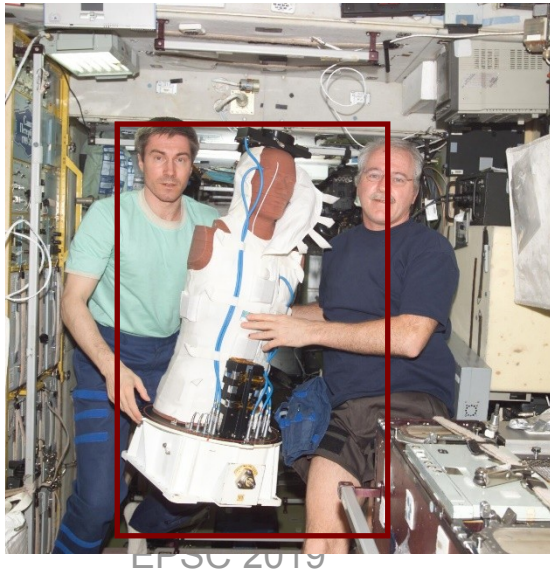
Red - uncontrolled

Radiation Protection in Space



Personal Dosimeters

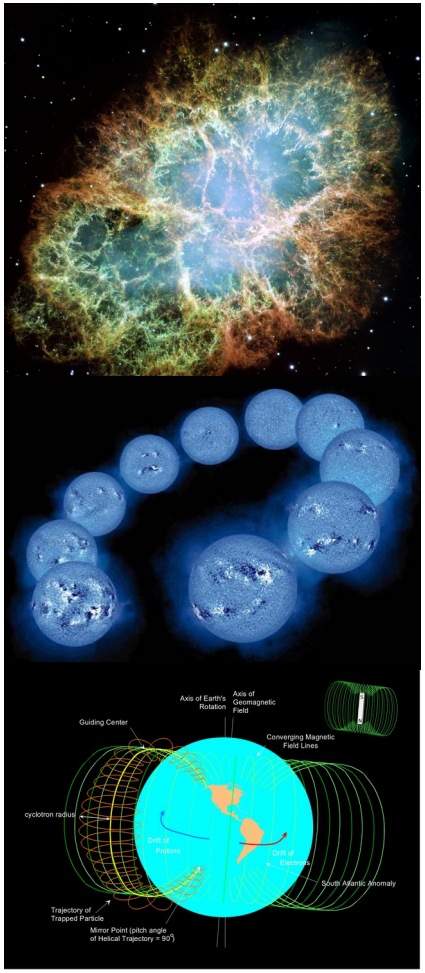
Radiation is *the* long-lasting risk for astronauts. Radiation damage can persist after the end of a long-duration space flight.
Radiation must be measured!



Phantom experiments
MATROSHKA

(Photos courtesy G. Reitz)

Radiation Sources Close to Earth



Galactic Cosmic Rays:

Very high energies, H through U

Solar modulation, predictable

Highly penetrating

Solar Energetic Particles:

High energies

Solar activity, unpredictble

High dose rate variability (up to ~10^4)

Can be shielded

Trapped Radiation (Radiation Belts):

Very high energies, protons, electrons

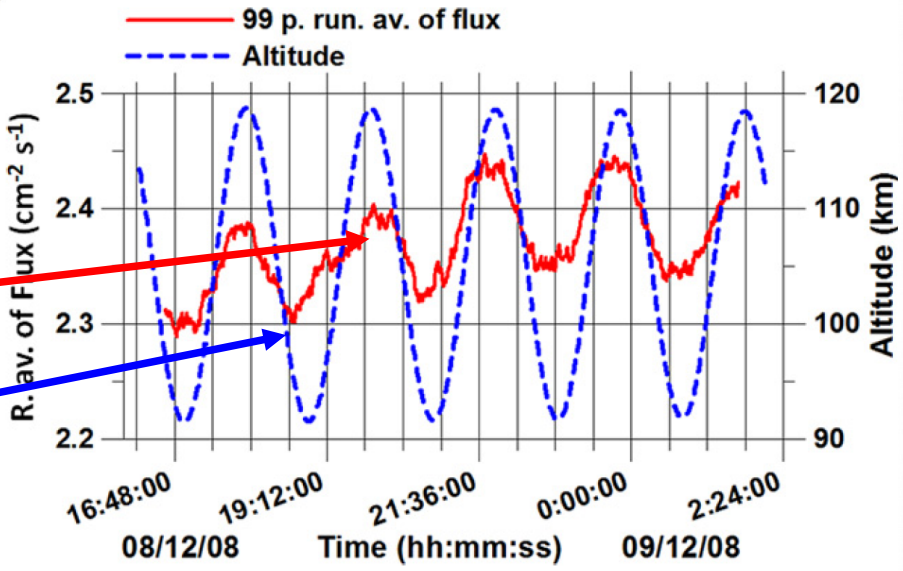
Very high dose rate

Highly penetrating

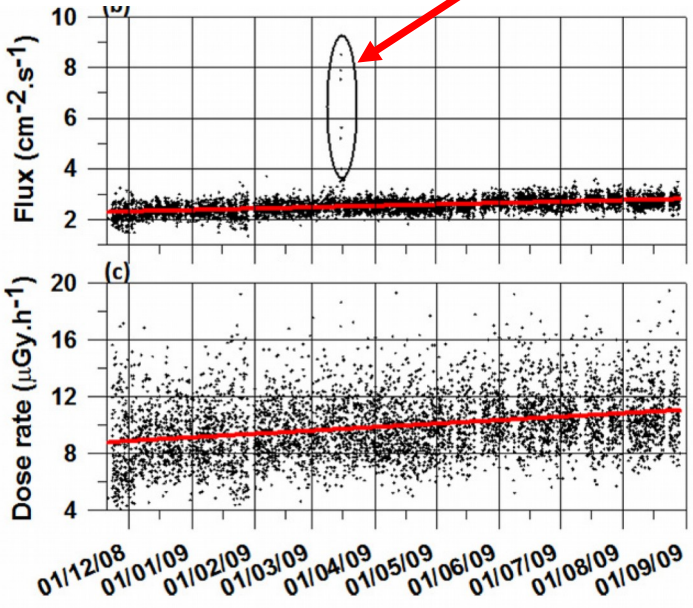
Dose Rate Measurements at the Moon?

Radiation

altitude



Solar Particle Event



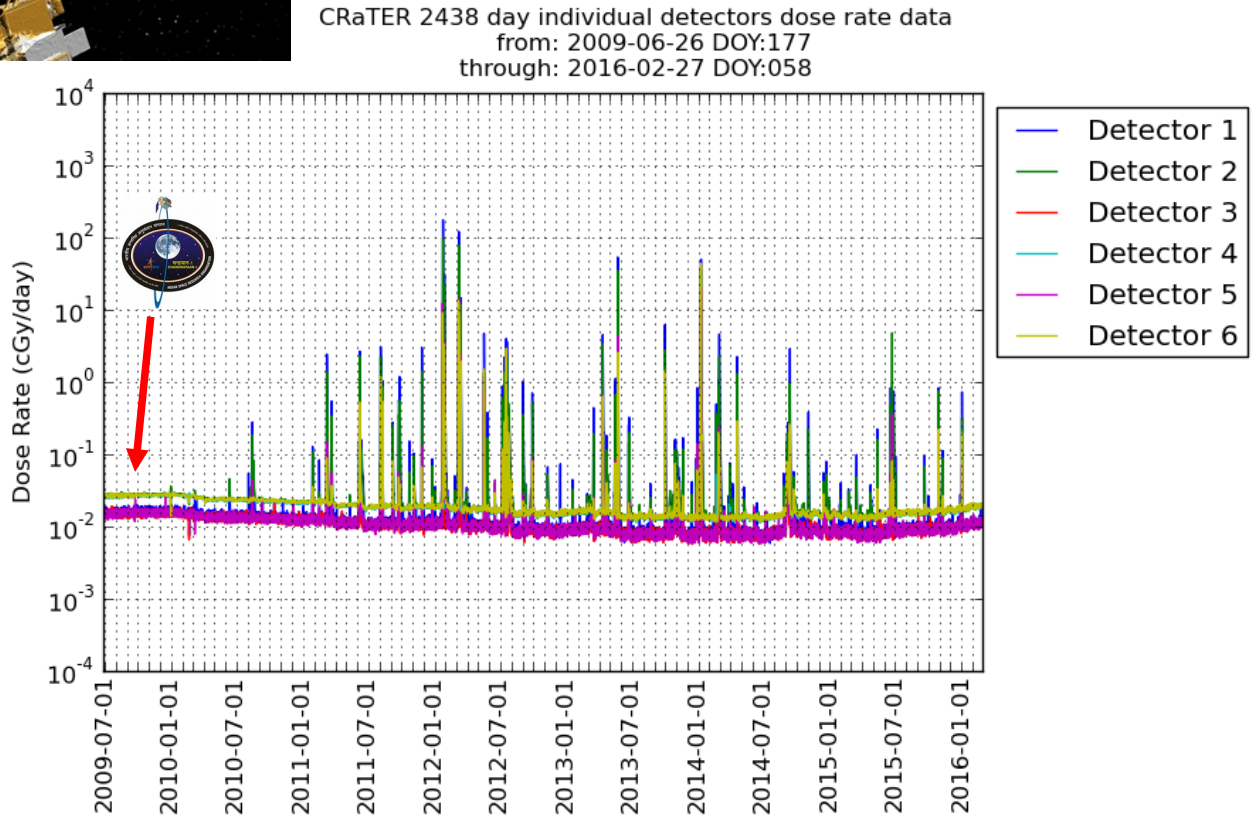
Dose rates vary with orbital height due to shielding by the Moon:
At ~ 100 km: 227 μGy/d; at ~ 200 km : 257 μGy/d

(Dachev et al., ASR, *48 (2011) 779-791)*

Dose Rate Measurements at the Moon?

Due to rising solar activity CRaTER saw a large number of solar particle events.

Solar activity is a critical driver, dose rates vary by 4 orders of magnitude!

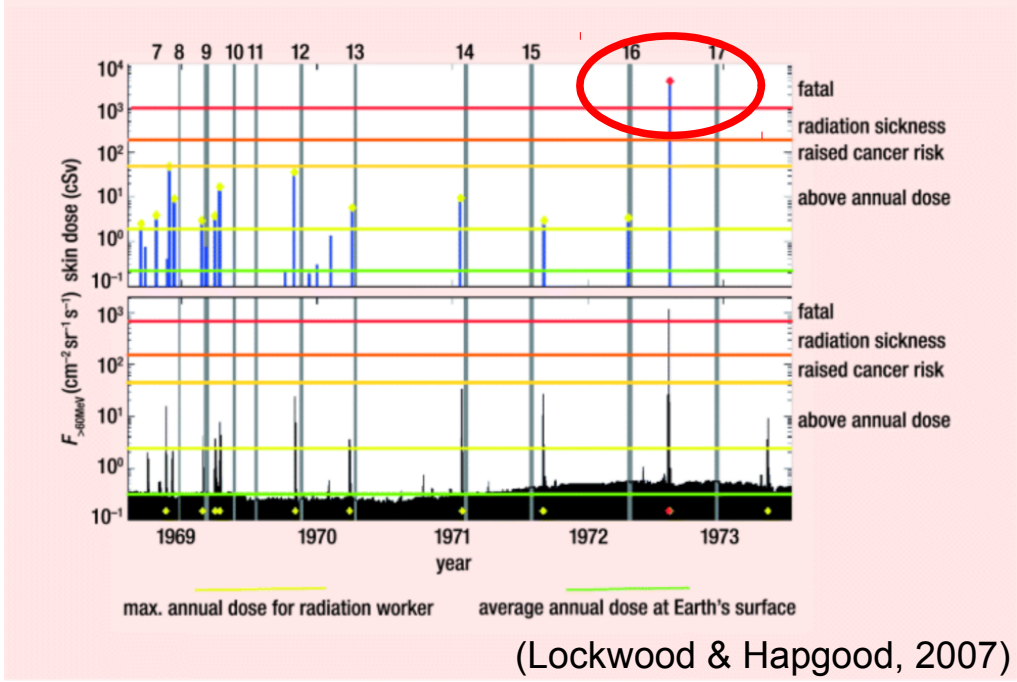


Dose Rate Measurements on the Moon?

Apollo 16:
Launched 16th Apr 1972, 17:54
Landed on Moon 21st Apr 1972, 02:23

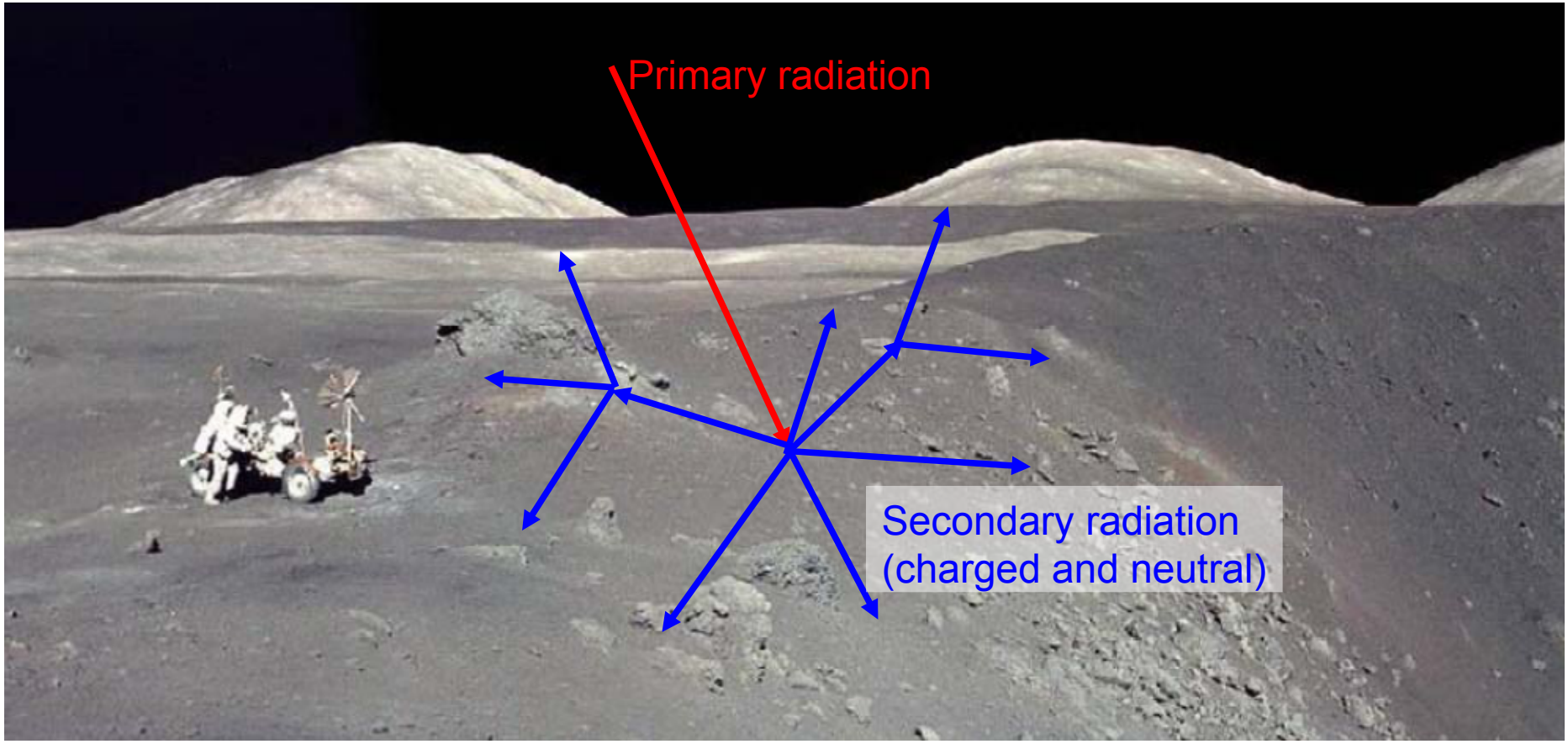
In between:
an enormous solar particle event!

Apollo 17:
Launched 7th Dec 1972, 05:33
Landed on Moon 11th Dec 1972, 19:55



(Lockwood & Hapgood, 2007)

Dose Rate Measurements on the Moon?

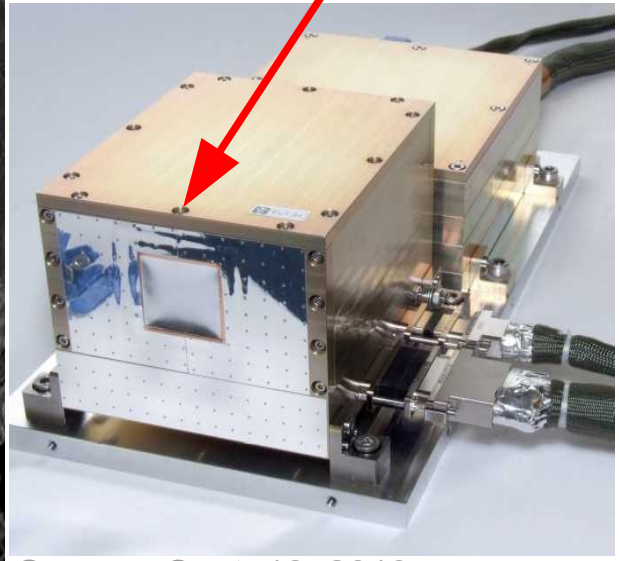


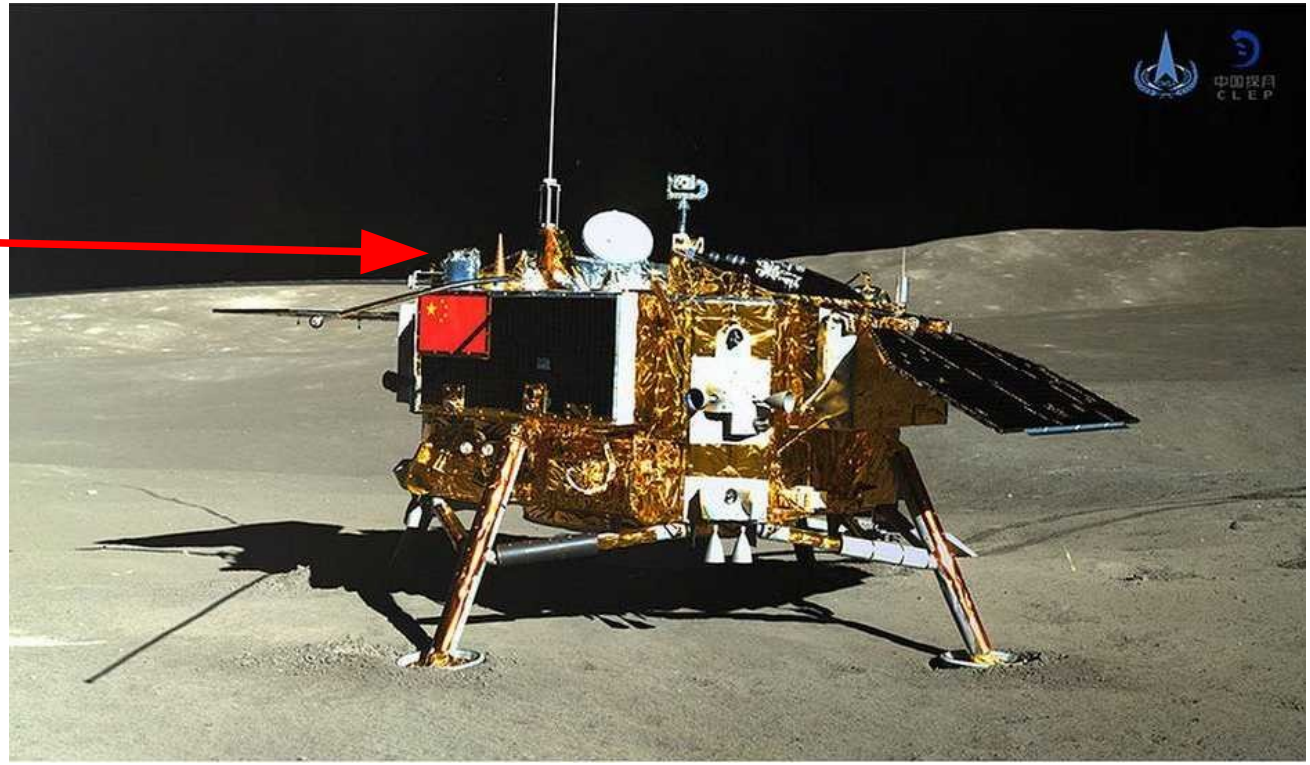
Dose Rate Measurements on the Moon?

Dose Rate Measurements on the Moon?

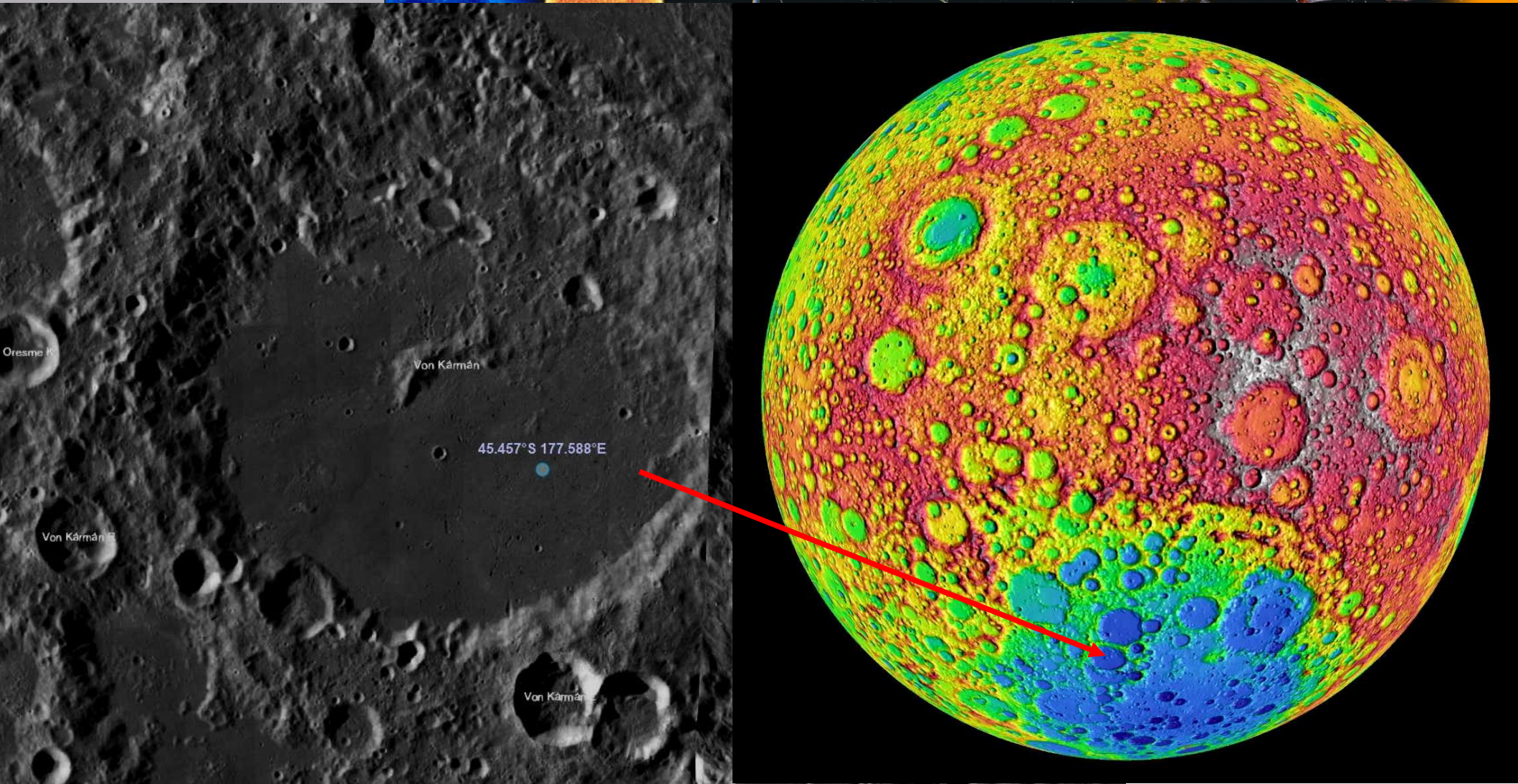
None!

Dose Rate Measurements on the Moon?





Lunar Neutron and Dosimetry (LND) Experiment on Chang'E-4 now provides such measurements

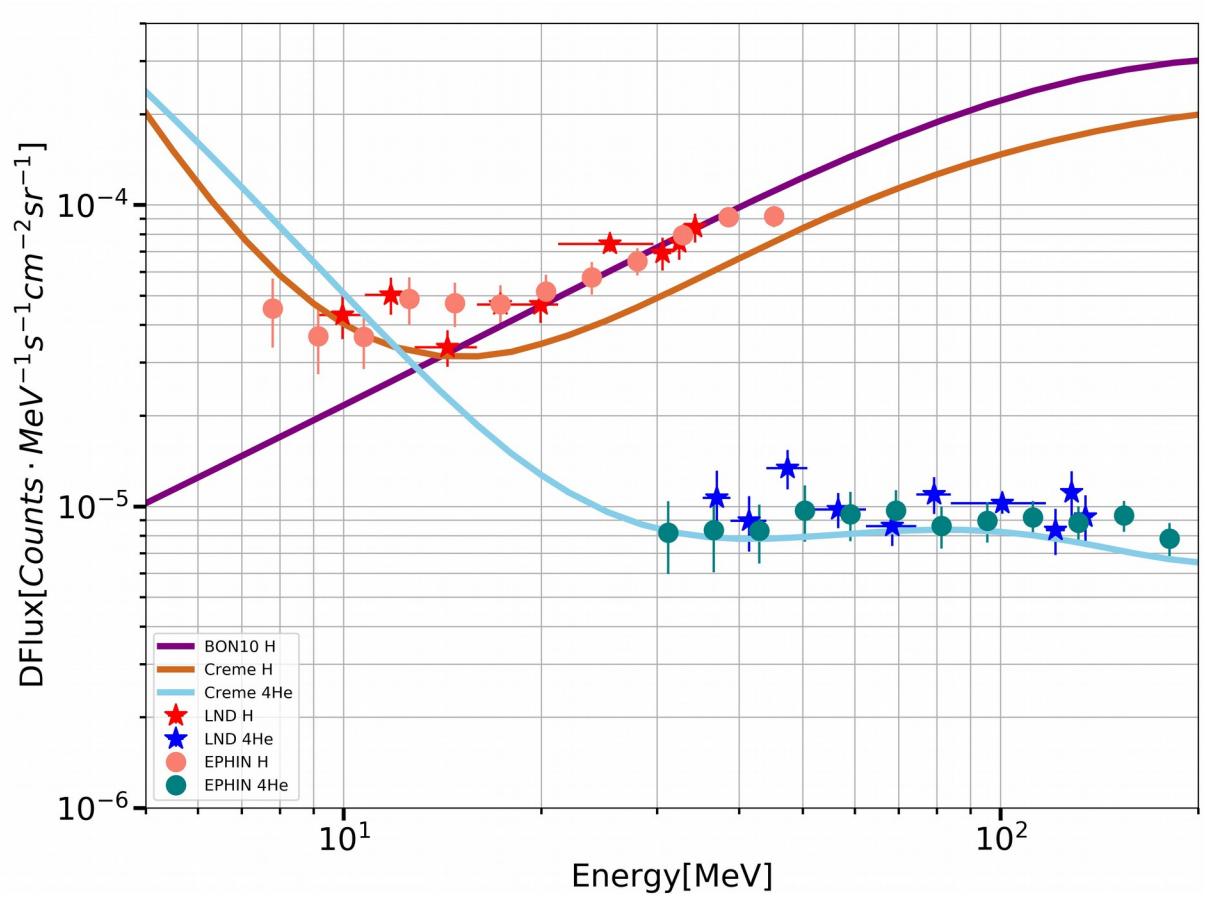

Oresme K
Von Kármán
45.457°S 177.588°E
Von Kármán B
Von Kármán

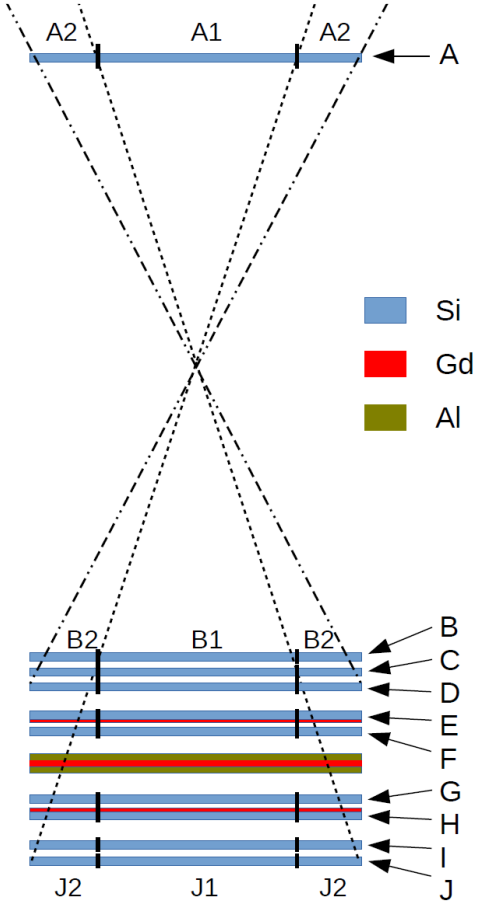
LND Science Objectives

- **Dosimetry for human exploration of the Moon**
  - Time series of the *charged and neutral* particle dose rate in Si
  - LET-spectra in the range 0.1 − 430 keV/µm
  - *Fast neutron* spectra in the energy range of $10 < E_n < 20$ MeV
  - *Composition* of the radiation, which is important for dosimetry
  - Charged particle spectra
  - Count rates of *thermal neutrons*

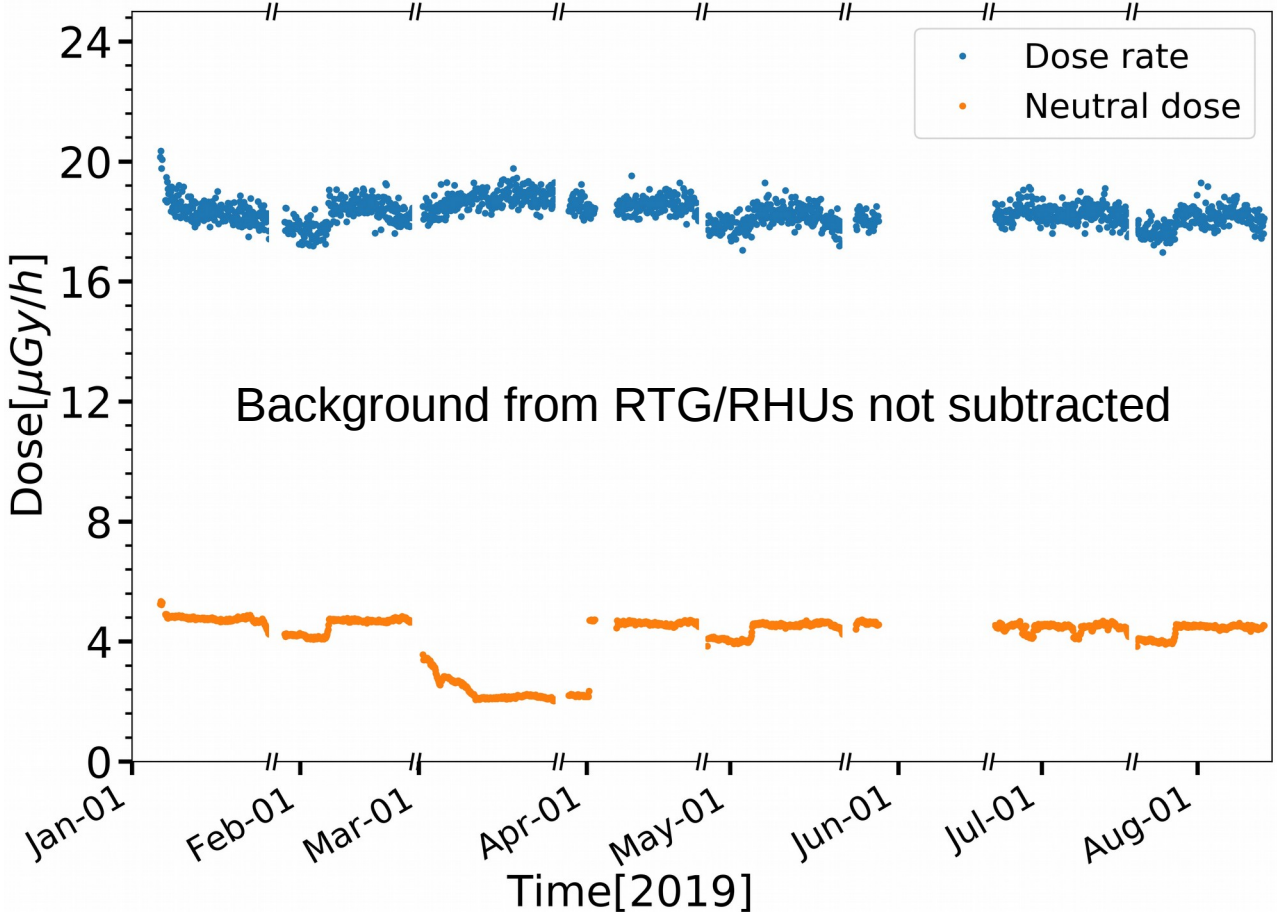
- **Contribution to heliospheric sience:**
  - Time series of the charged and neutral particle dose rate in Si at a cadence of 1 minute
  - Coarse proton and electron spectra at a cadence of up to 1 minute
  - Composition of radiation

First LND Science Results: Charged Particle Spectra

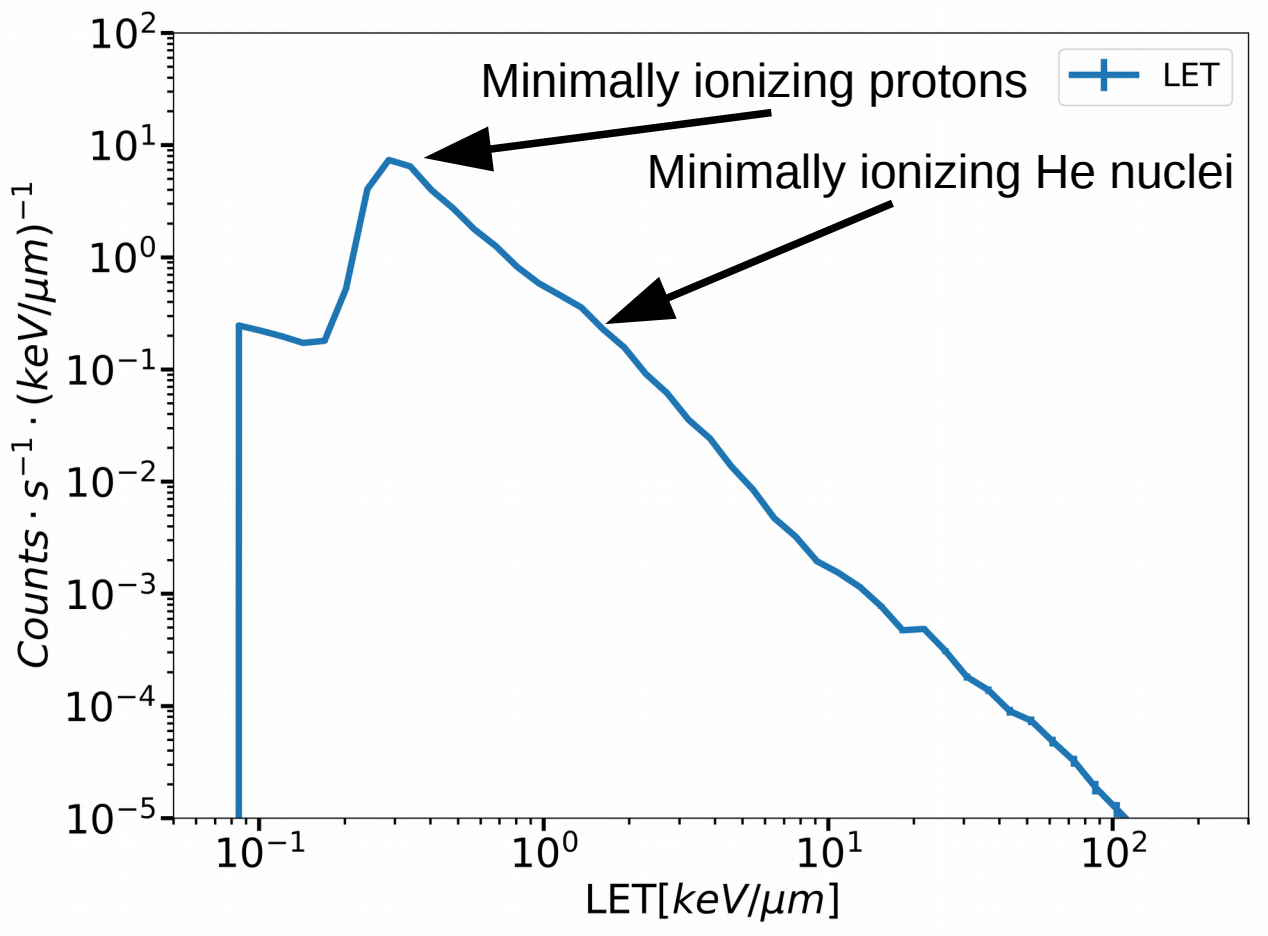




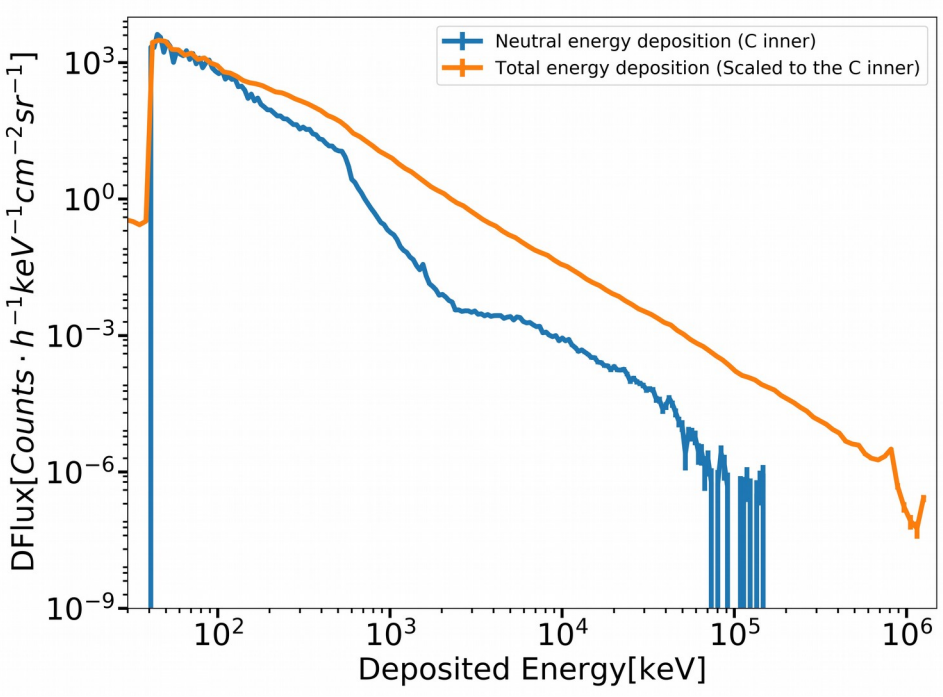
First LND Science Results: Dosimetry – Dose Rate

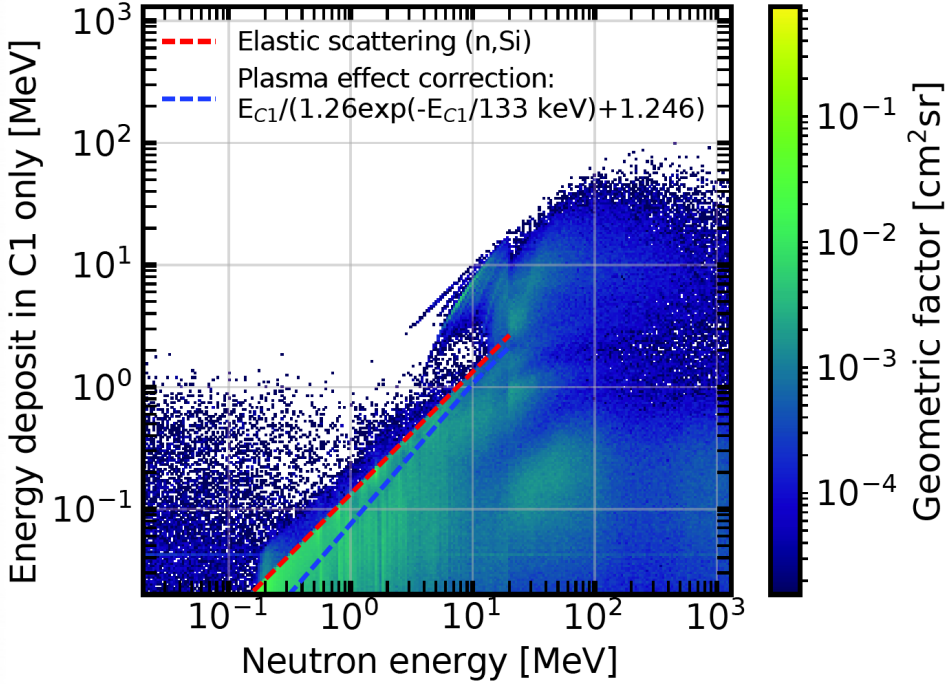


First LND Science Results: Dosimetry – LET spectrum



First LND Science Results: Total Energy Deposition and Fast Neutron Spectra





The Lunar Lander Neutron and Dosimetry (LND) Experiment

Conclusions:

- Chang'E-4 is a technically challenging mission
- LND providing the first measurements of the radiation environment on the Moon
  - Dose rate and dose equivalent rate for *charged and neutral* component
  - Time series, composition, particle spectra
- LND uses well-established measuring techniques for charged particles, ...
- … but new, innovative ones for the secondary, neutral radiation component
- Several papers submitted

謝謝

Supported by:
Federal Ministry of Economics and Technology
on the basis of a decision by the German Bundestag
DLR
C | A | U Christian-Albrechts-Universität zu Kiel
NSSC

Backup Slides

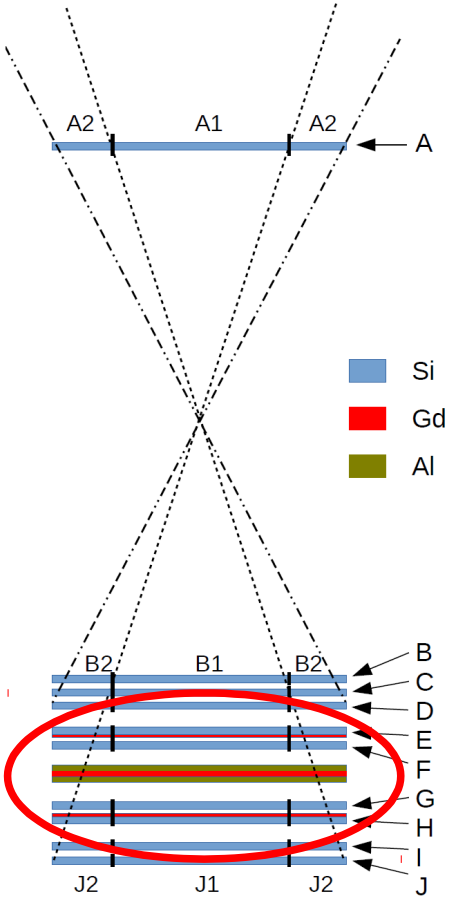
LND Science Objectives

- LND has **two main** and **two bonus** science objectives.
- Science Objective 1:
- **Dosimetry for Human Exploration of the Moon**
- Science Objective 2:
- **Contribution to Heliospheric Science**
- ~~Bonus Science Objective 1:~~ TRL
- **Determine the Subsurface Water Content in the South-Pole Aitken Basin (SPA)**
- ~~Bonus Science Objective2:~~ TRL
- **Determine the FeO content in the SPA**
- (Bonus science objectives are enabled by thermal neutron measurements)

LND TRL Objectives (previous Bonus Science Objectives)

Determine the subsurface water and FeO content in the SPA Basin (also used orbit insertions time period, no RTG!)

-



Determine ratio of thermal neutrons from above and below.

Chang'E-4 mission to the far side of the Moon

Relay satellite launched May 20, 2018
Relay satellite orbit insertion June 13, 2018
Launch December 8, 2018
Landed January 3, 2019

Science Payload:

- Biology experiment (students)
- Ground-penetrating radar
- IR spectrometer
- Low frequency radio
- **LND**
- Lunar dust
- Lunar electric field
- Miniature optical imager
- Neutral atom detector
- Plasma and magnetic field
- Panoramic camera
- Seismometer
- VLF radio interferometer

Dose Rate Measurements at the Moon?

-Only results from two missions in Lunar orbit avaible (CRaTER and RADOM) with dose values of around 200 – 300 µGy/d (depending on altitude)

- ***T.P. Dachev et al.*** *An overview of RADOM results for earth and moon radiation environment on Chandrayaan-1 satellite, Advances in Space Research 48 (2011) 779-791*
- ***Spence H. E. (CRaTER Science Team)****, An Overview of Results from the Lunar Reconnaissance Orbiter (LRO) Cosmic Ray Telescope for the Effects of Radiation (CRaTER), Annual Meeting of the Lunar Exploration Analysis Group, Washington D.C. September 14-16, 2010*
- ***J.E. Mazur et al.*** *New Measurements ot total ionizing dose in the lunar environment, Space Weather, 9, S07002, doi:10.1029/2010SW000641*

-Calculations show an Effective Dose of 600 µSv/day taking into account Solar Minimum conditions and a 0.5 g/cm² space suit (GCR)

- *NASA-TP-2003-212158, "Analysis of a Radiation Model of the Shuttle Space Suit"*
- ***D. Matthiae****, T. Berger, G. Reitz: DLR – Updated GCR Model / Moon calculations, 2012*

-„Safe haven" to prevent exposures due to SPE needs approx. 80 cm of lunar regolith

- ***D. Matthiae****, T. Berger, G. Reitz: DLR – Updated GCR Model / Moon calculations, 2012*

NO MEASUREMENTS on the LUNAR surface available --> needed as input

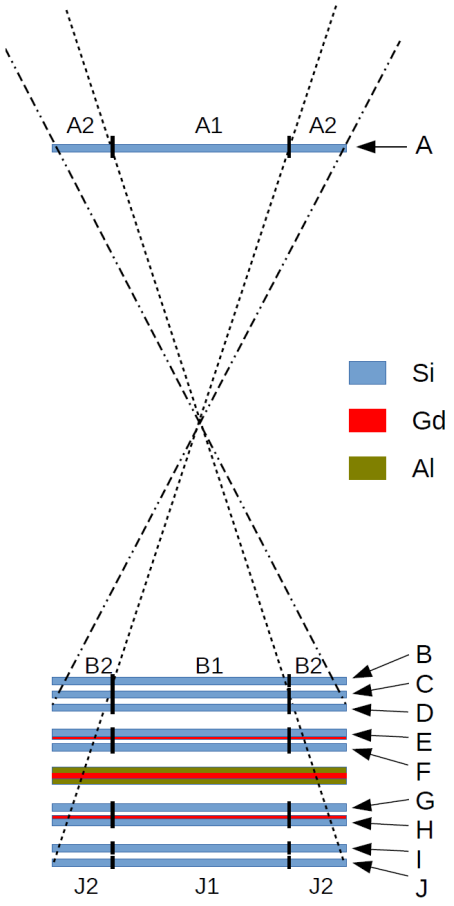
a) benchmarking of radiation transport codes

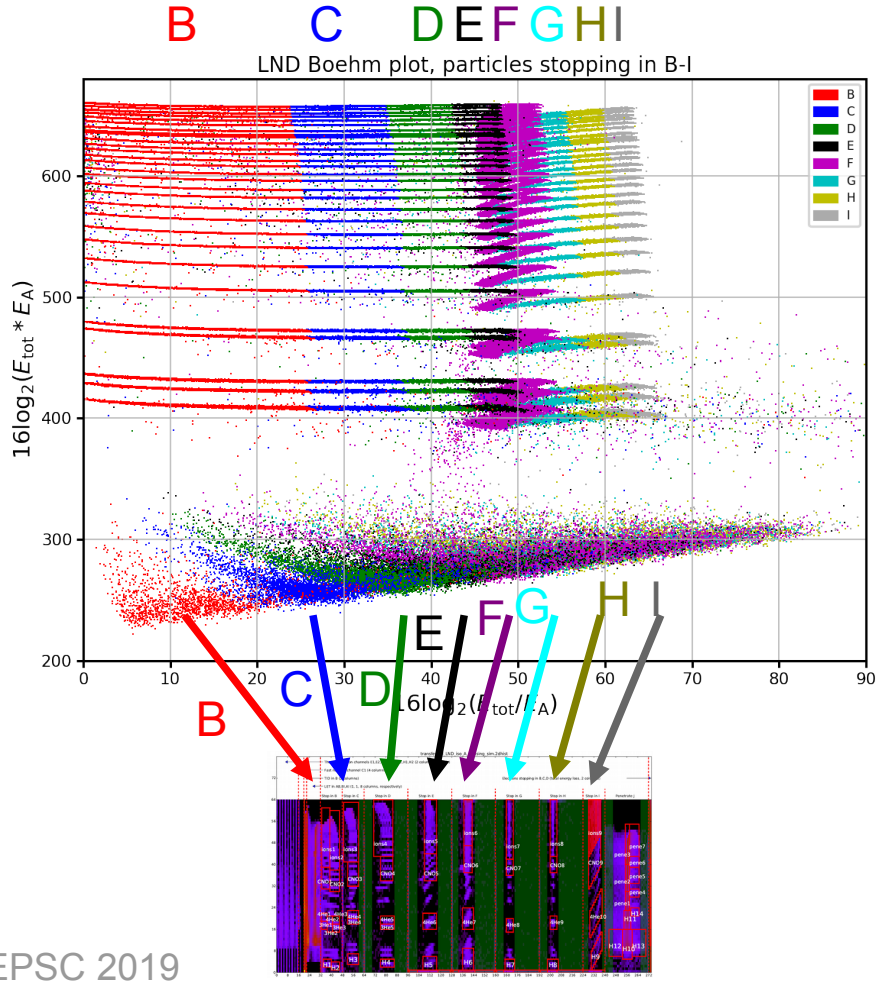
b) prerequisite for future human presence on the Moon

Electron Calibration at NSSC, Beijing

The Lunar Lander Neutron and Dosimetry (LND) Experiment

Data Products

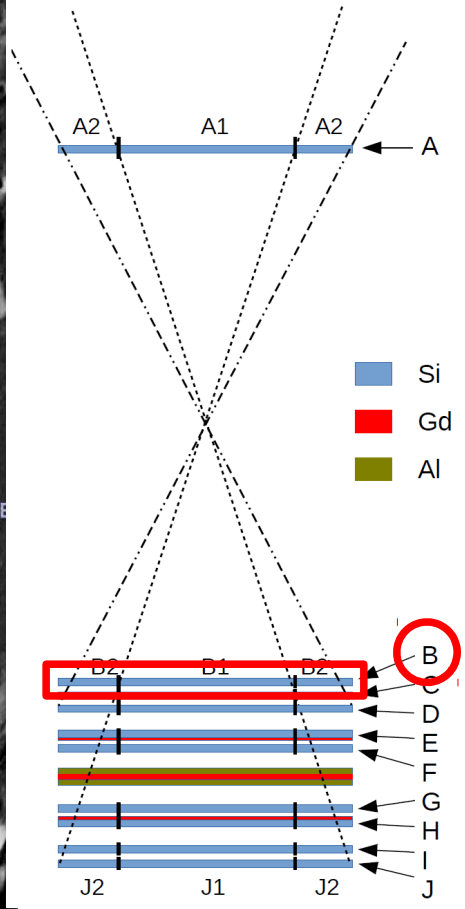




LND in the Lander

The Lunar Lander Neutron and Dosimetry (LND) Experiment

Dosimetric quantities (dose rate and LET)



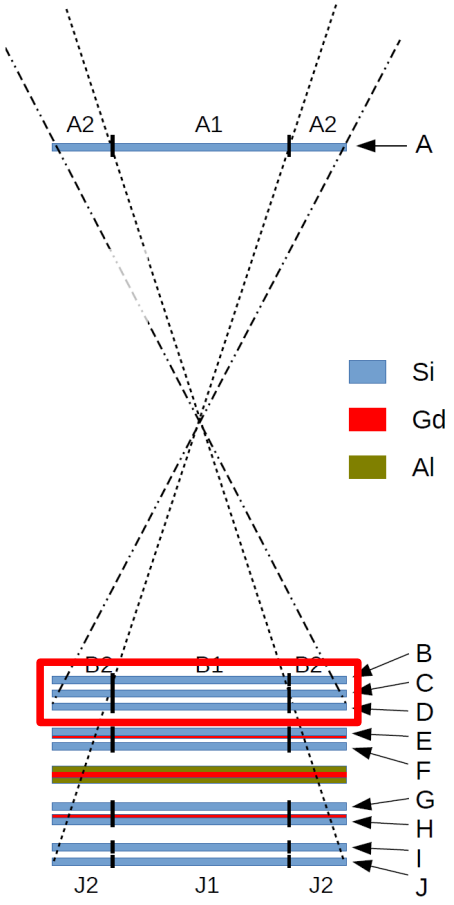
LND triggers its data acquisition with a signal in B

Dose rate is the energy deposit measured in B per unit time

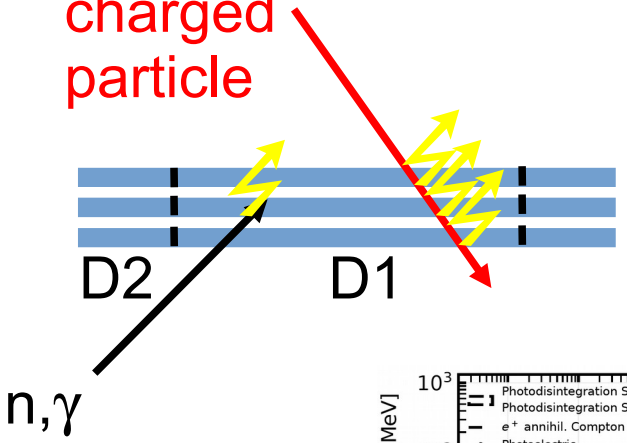
LET is measured in 3 different combinations:
Energy deposit measured in B triggered by:

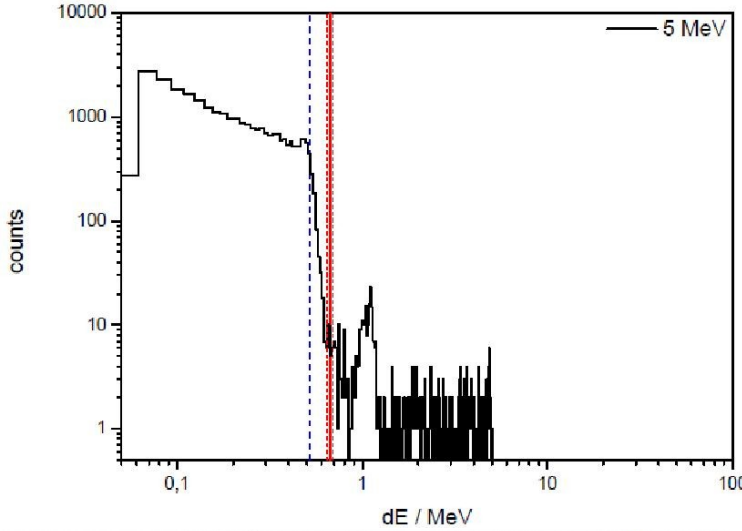
- AB coincidences (medium time and energy resolution)
- AI coinicidences (high energy resolution, low time)
- BI coincidences (high time resolution, low energy)

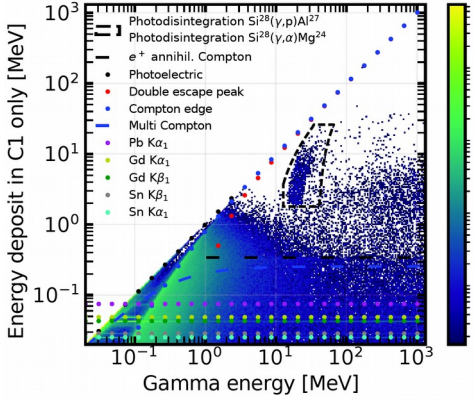
The Lunar Lander Neutron and Dosimetry (LND) Experiment

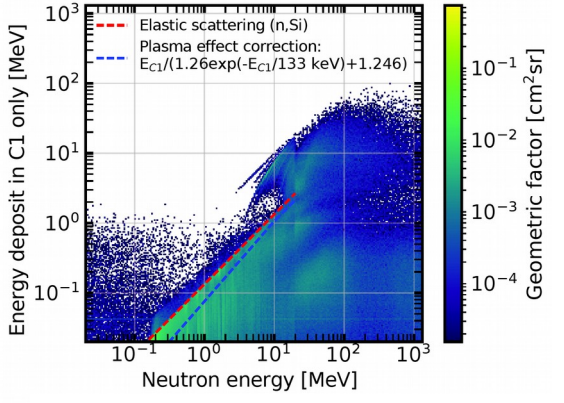


Neutral dose rate & fast neutron spectra



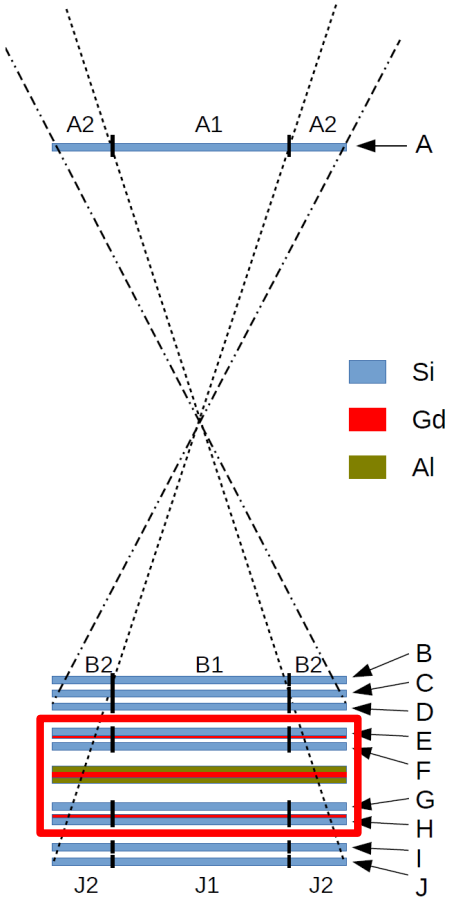


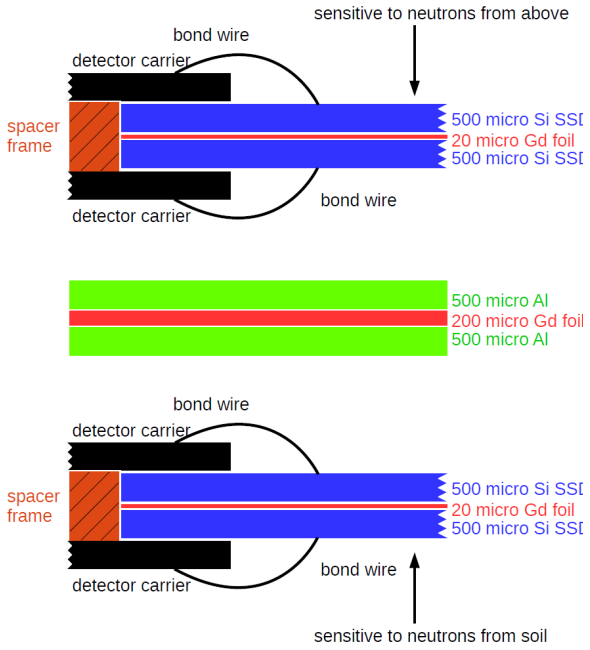




The Lunar Lander Neutron and Dosimetry (LND) Experiment

Thermal neutrons





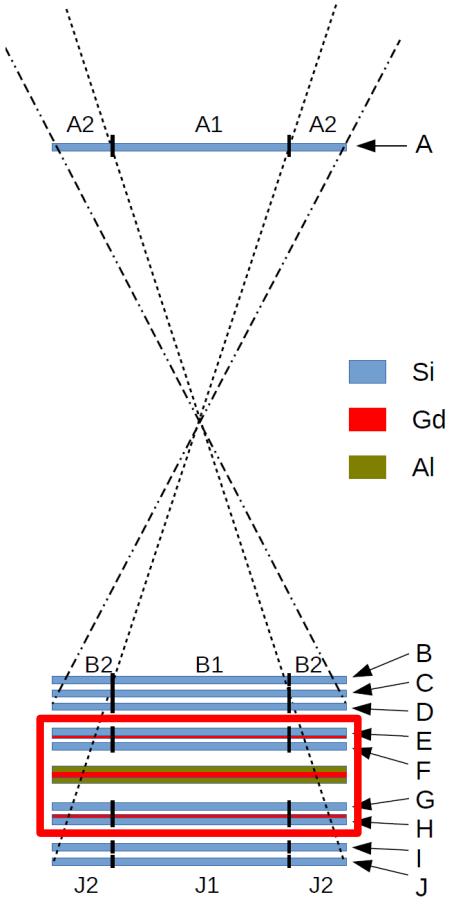
Thermal Capture Cross Sections: A Co

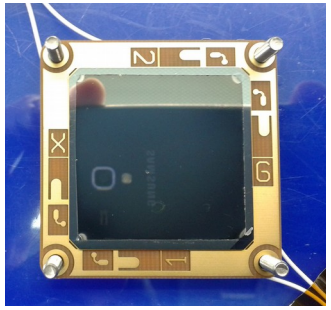
		Thermal Captu	
		ENDF	
Isotope	Abundance	Thermal Capture	Contribution to Elemental
^{152}Gd	0.200	1 050	2.10
^{154}Gd	2.18	85.0	1.85
^{155}Gd	14.80	60 700	8 980
^{156}Gd	20.47	1.71	0.350
^{157}Gd	15.65	254 000	39 800
^{158}Gd	24.84	2.01	0.499
^{160}Gd	21.86	0.765	0.167
Gd	—		48 800

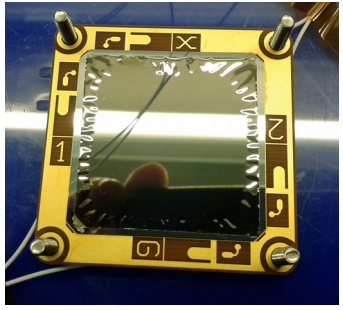
*The units of all cross sections are barns. The units of ab

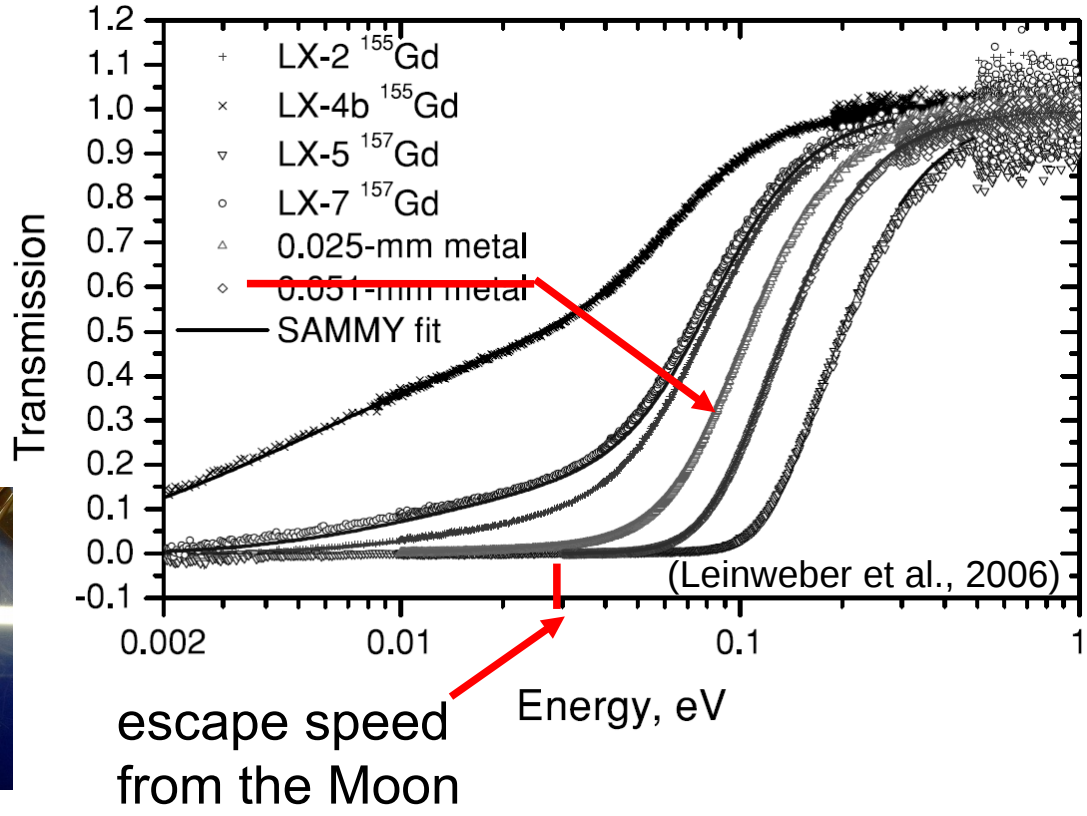
The Lunar Lander Neutron and Dosimetry (LND) Experiment

Thermal neutrons

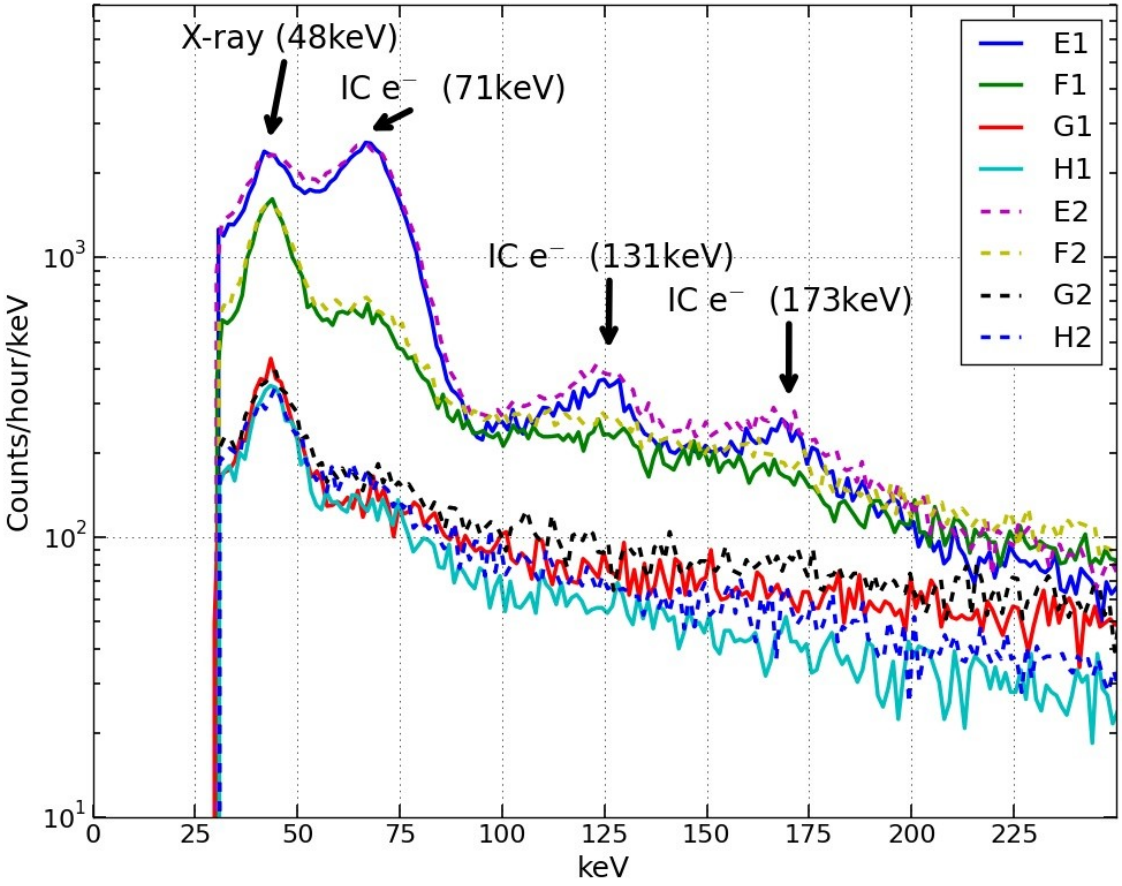


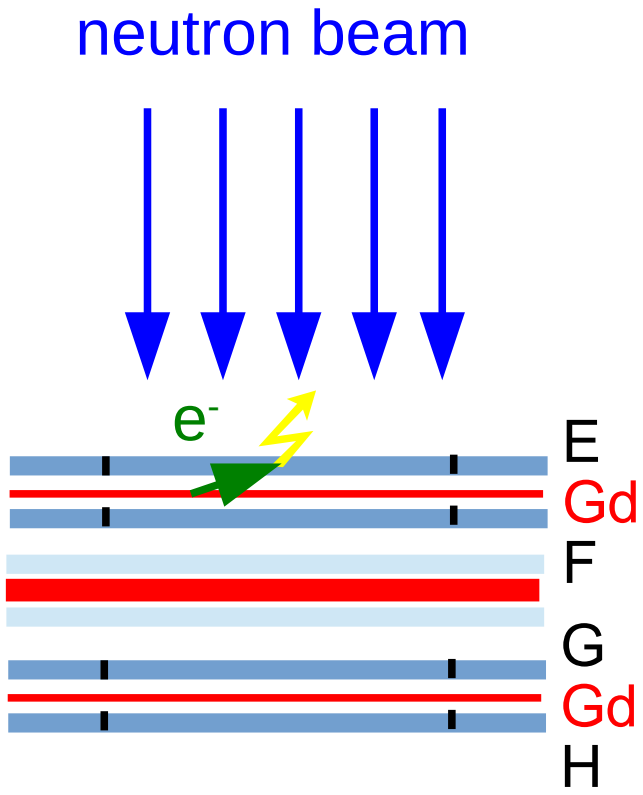






Detection of thermal neutrons using Gd conversion foils





The Lunar Lander Neutron and Dosimetry (LND) Experiment

Data Products