Radiation Exposure in the Vicinity of a Simple Crater on the Moon

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Image Credit: NASA / GSFC / Arizona State University

Motivation

- The Moon's harsh radiation environment poses risk to exploration
- Implications for understanding of lunar regolith space weathering processes
- Exposure level depends on space radiation incident above local horizon
- Radiation dose characterization will allow planning of safer surface operations for future mission (e.g., the Artemis program)

The Moon

- No global magnetic field
- No dense atmosphere
- Direct exposure to space radiation

- Radiation from energetic particles
  - Galactic Cosmic Rays (GCRs)
    - High energy, low flux
    - From Galactic sources
  - Solar Energetic Particles (SEPs)
    - Low energy, High flux
    - From the Sun

- On average these sources are isotropic

Image Credit: NASA / GSFC / Arizona State University

Lunar Reconnaissance Orbiter (LRO)

- LRO's primary mission was to characterize the lunar environment in preparation for future lunar exploration
- Cosmic Ray Telescope for the Effects of Radiation (CRaTER) measures radiation environment
- In lunar orbit since June 2009

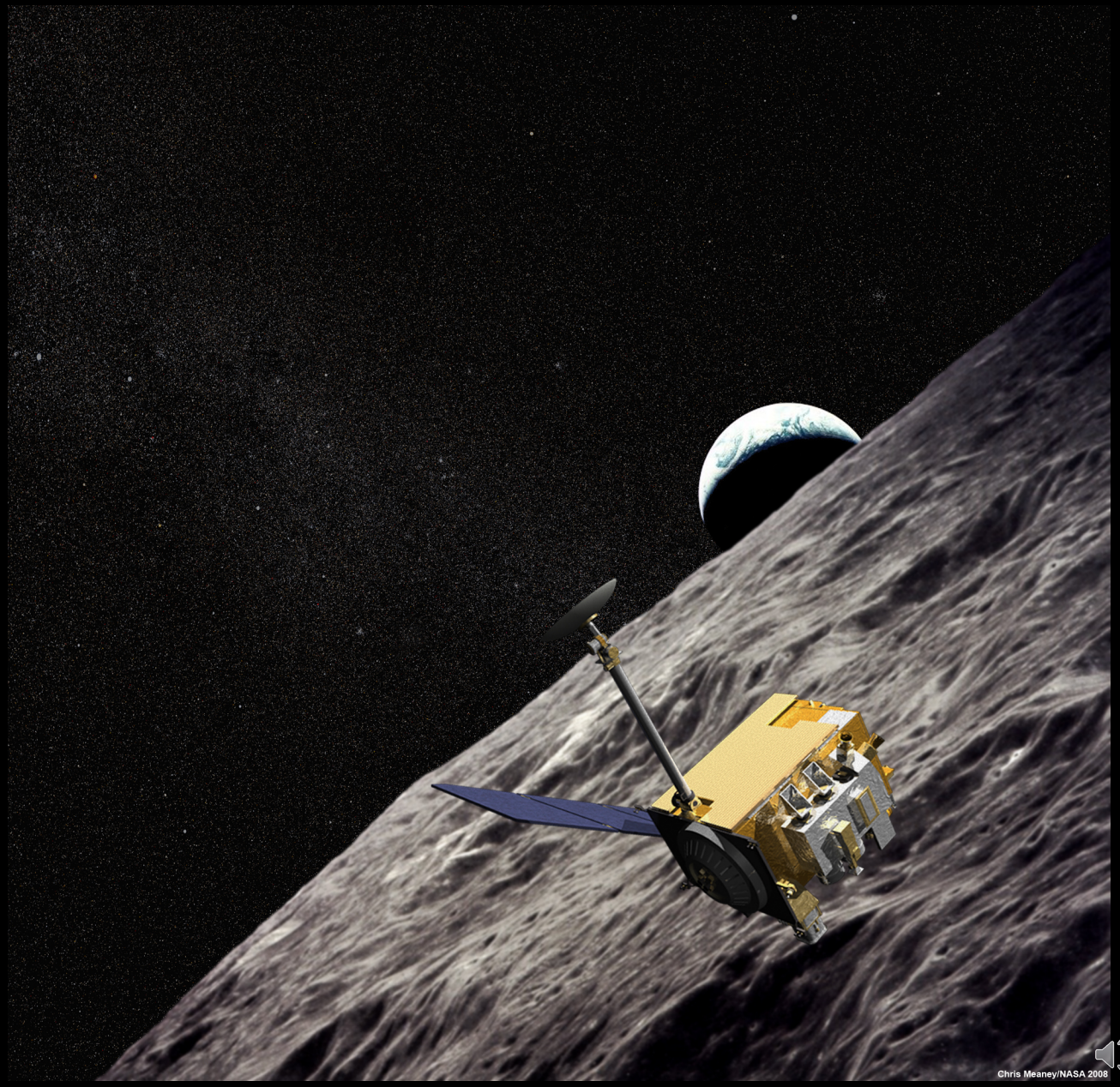
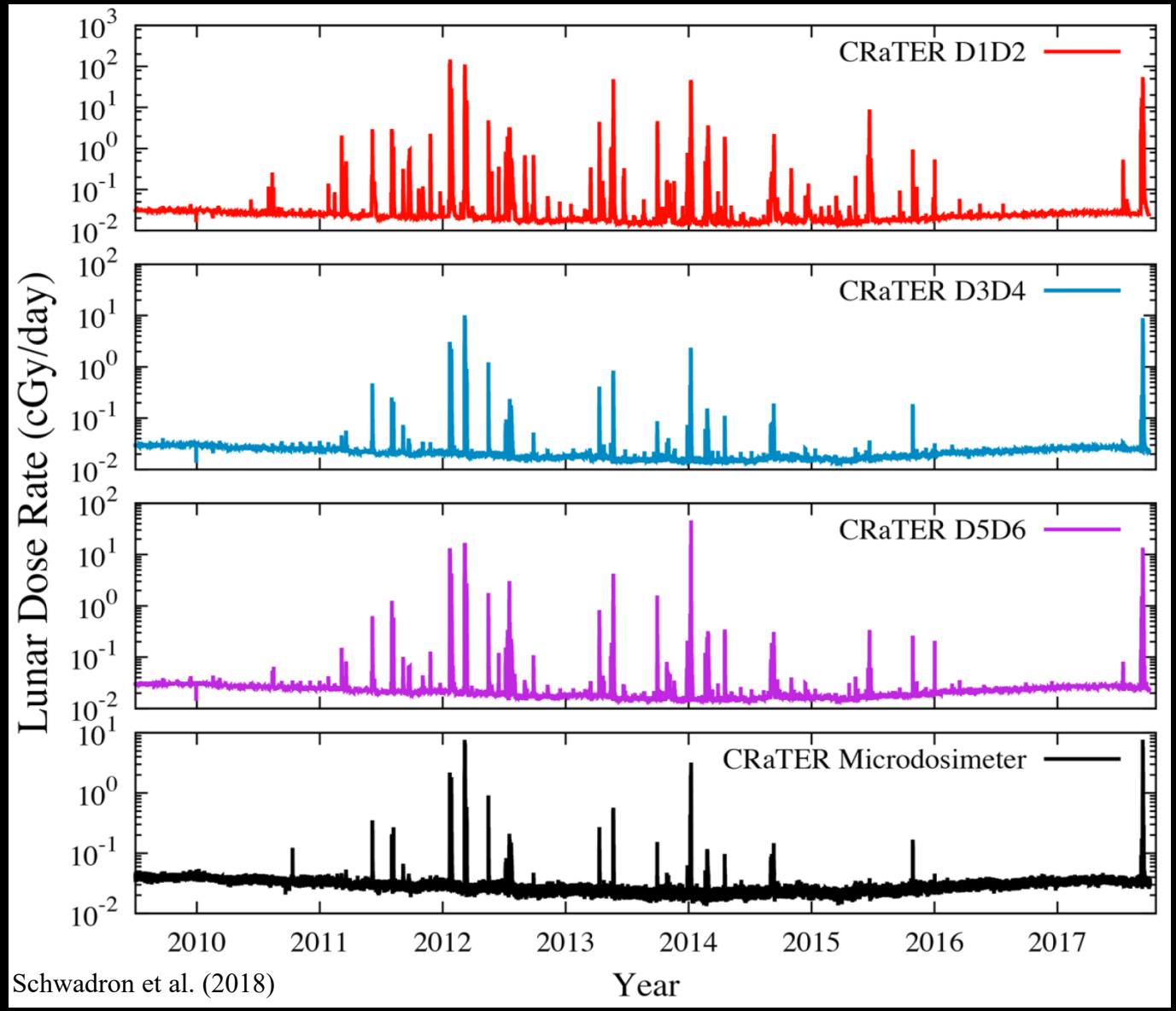


Image Credit: Chris Meaney/NASA 2008

LRO's Cosmic Ray Telescope for the Effects of Radiation(CRaTER) Instrument

- GCRs provide steady radiation dose with peak at solar minimum
- SEP events are episodic with high dosage over short period of time. More frequent around solar maximum.



Schwadron et al. (2018)

CRaTER measures radiation from orbit, but what about at the surface?

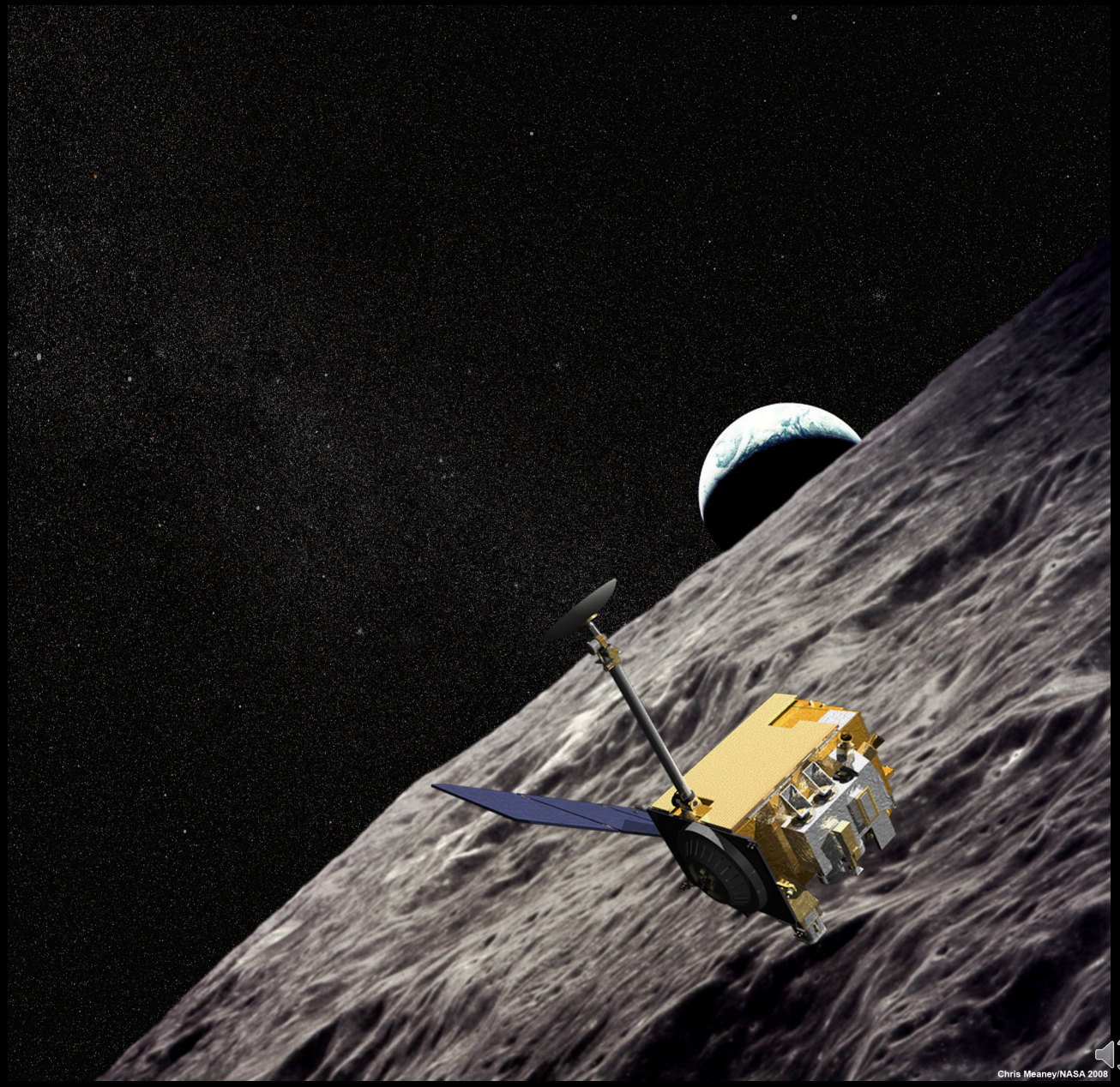


Image Credit: Chris Meaney/NASA 2008

Artemis Mission

Image Credit: NASA

Artemis Mission

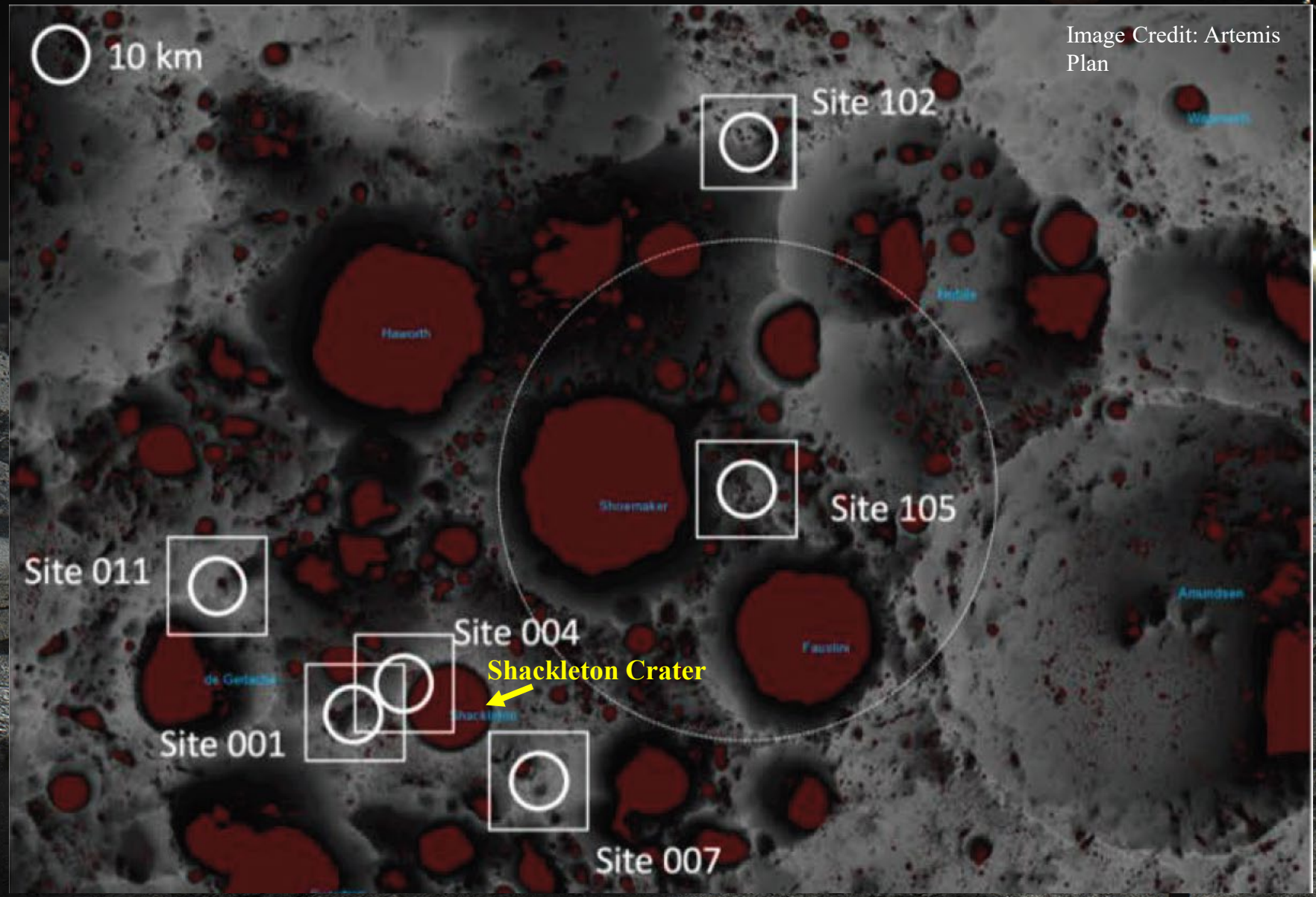


Image Credit: Artemis Plan

Image Credit: NASA

Radiation Shielding by Lunar Terrain

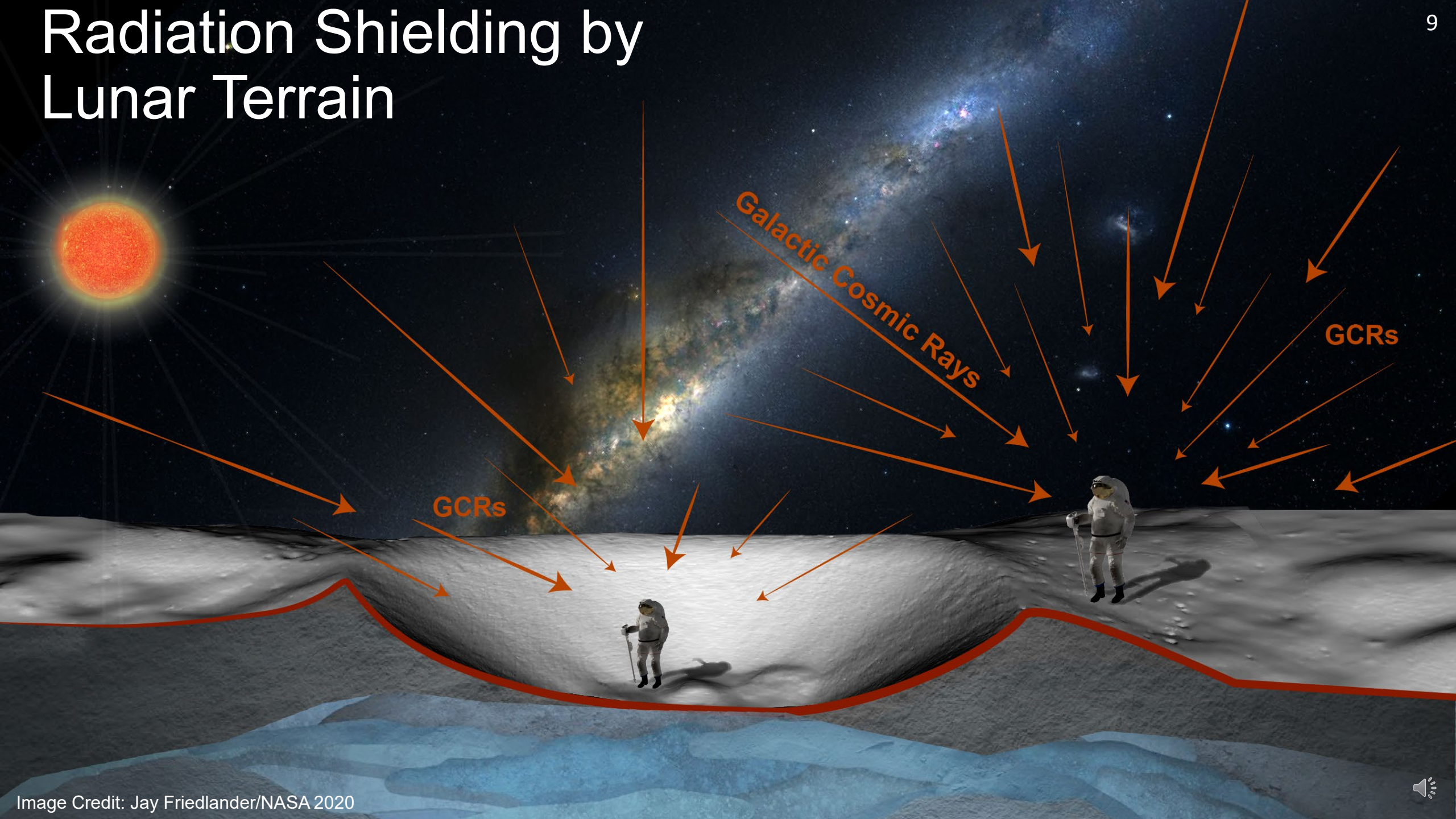
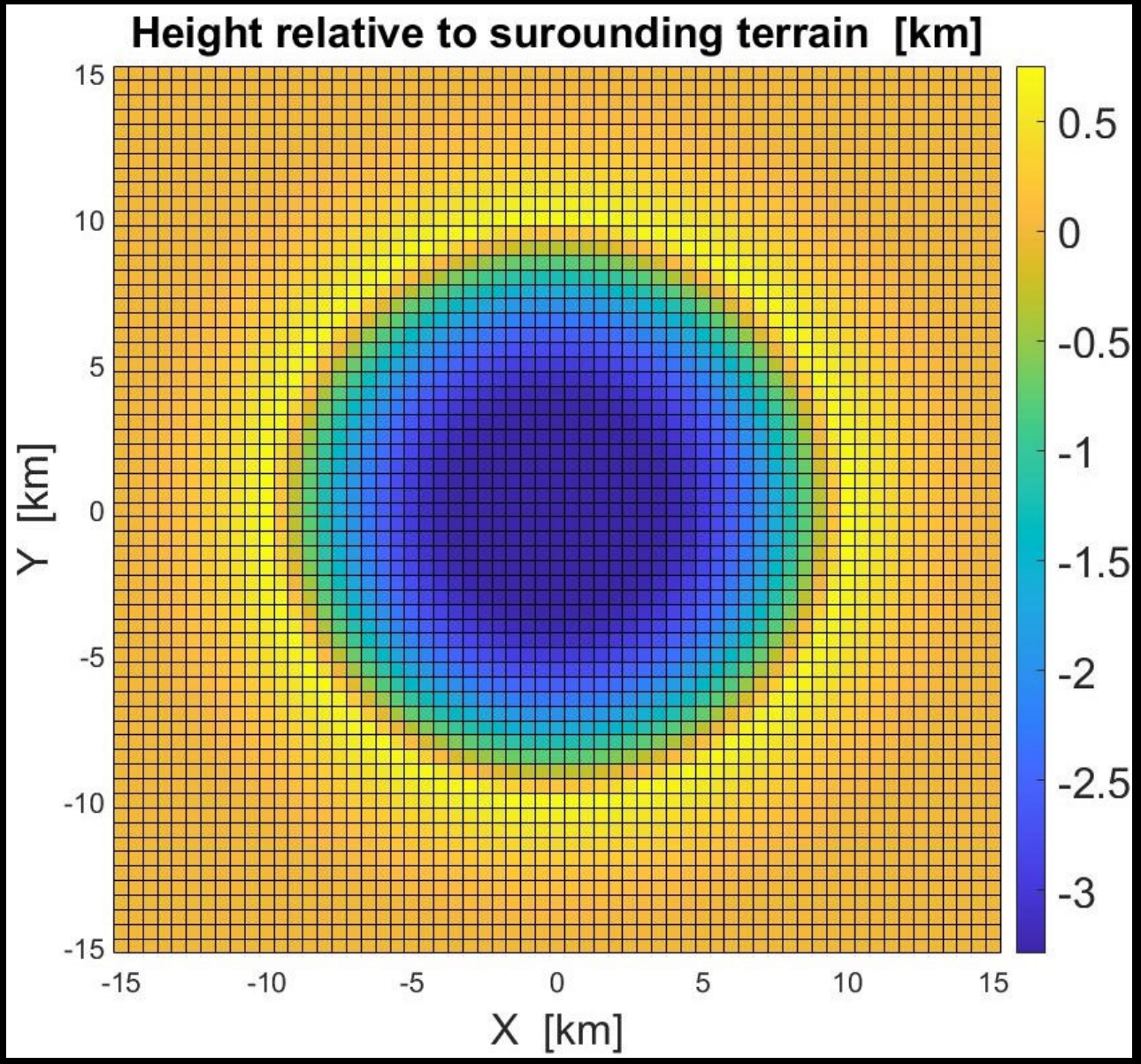
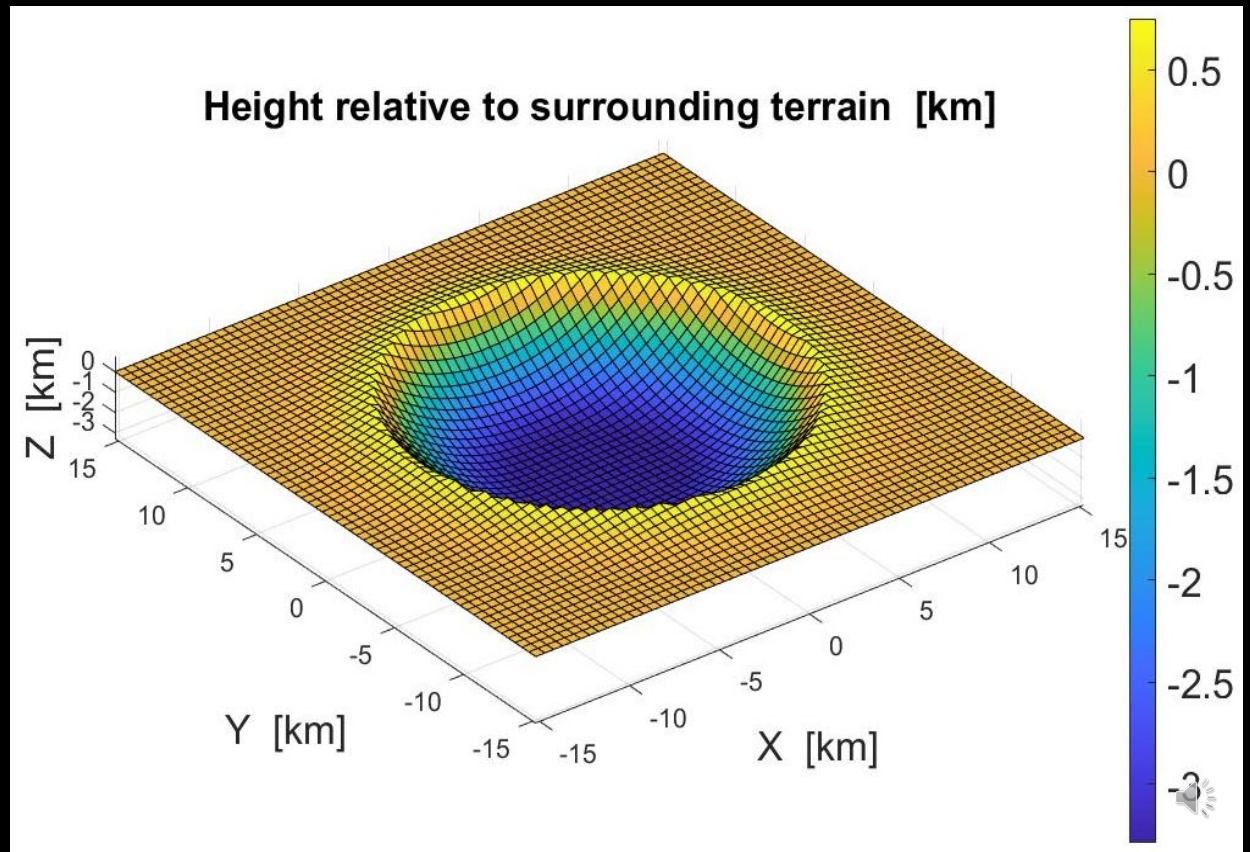


Image Credit: Jay Friedlander/NASA 2020

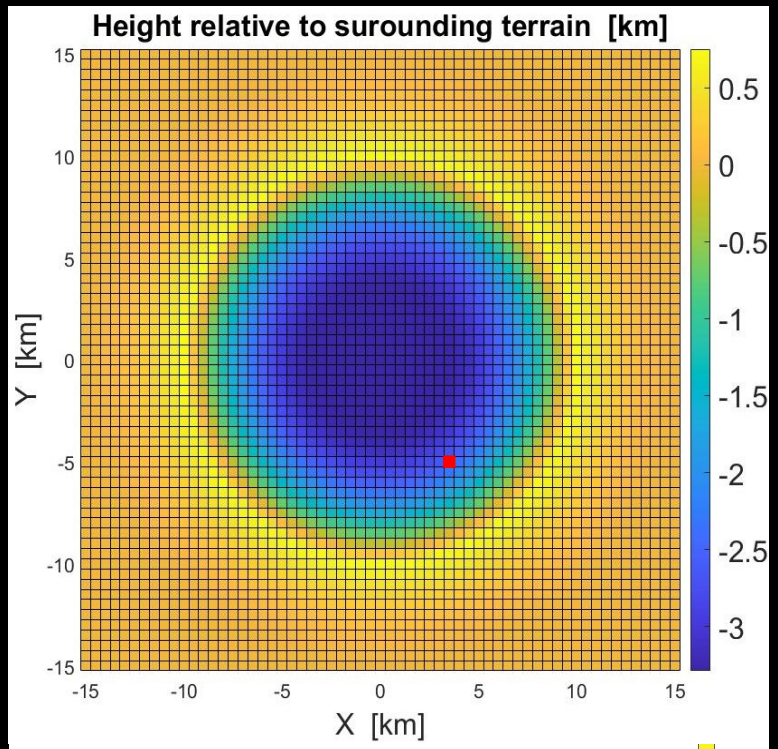
Height Profile for Simple Lunar Crater

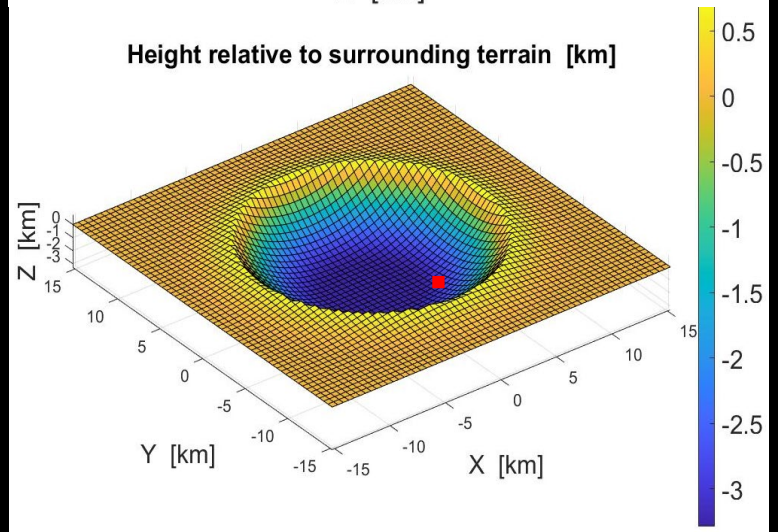


- 20 km crater similar to Shackleton
  - 0.5 km resolution
  - ~64 pix/deg Digital Elevation Model (DEM)



Exposure to Space at a Simple Lunar Crater





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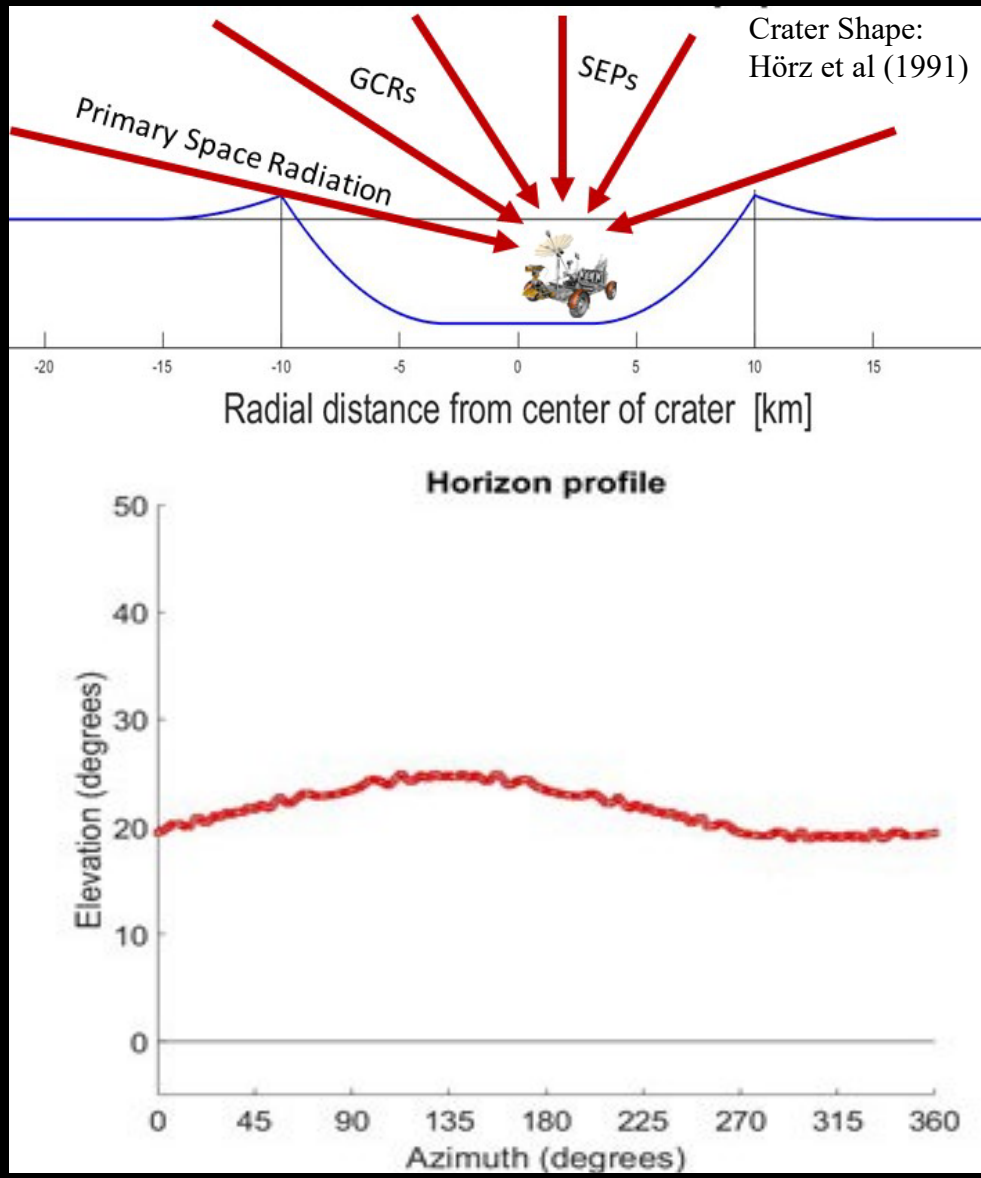

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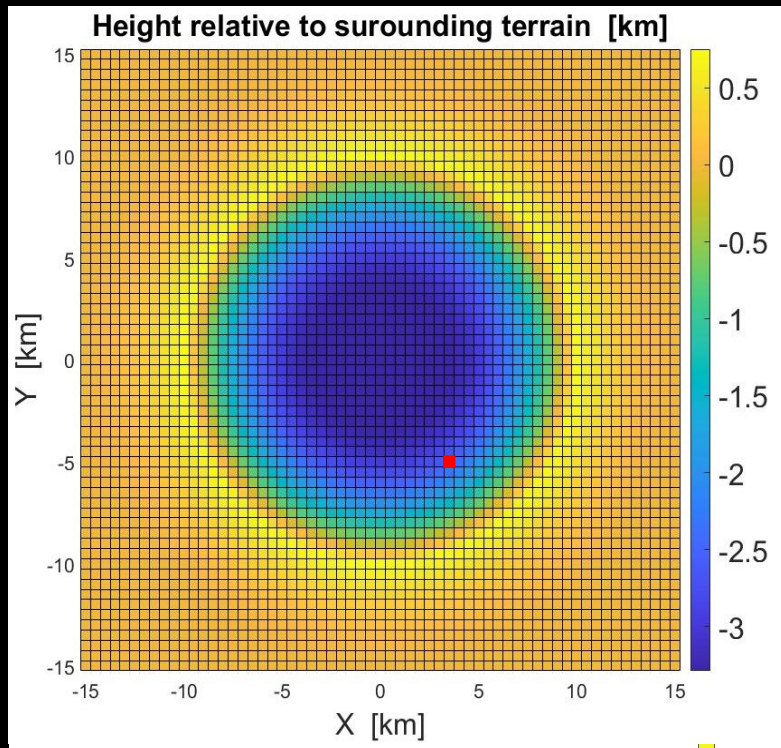
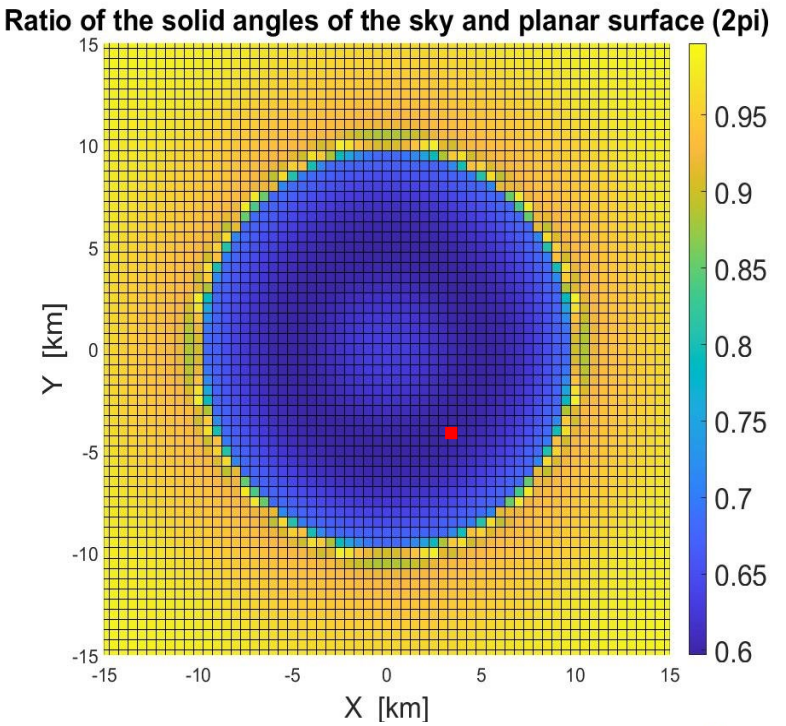
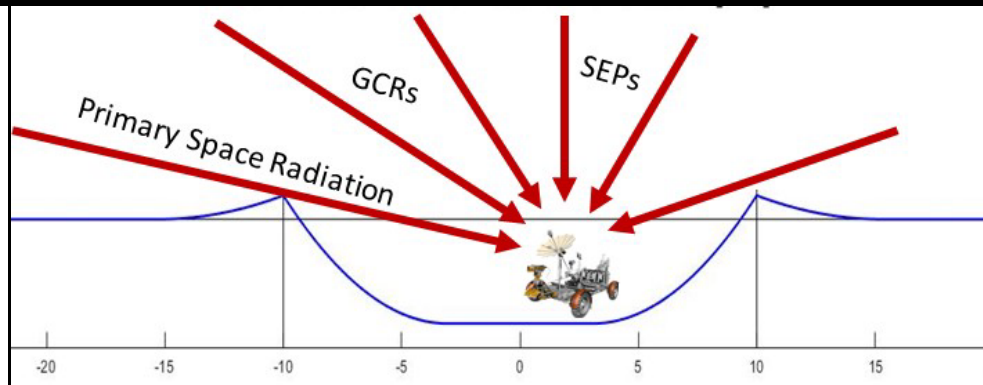
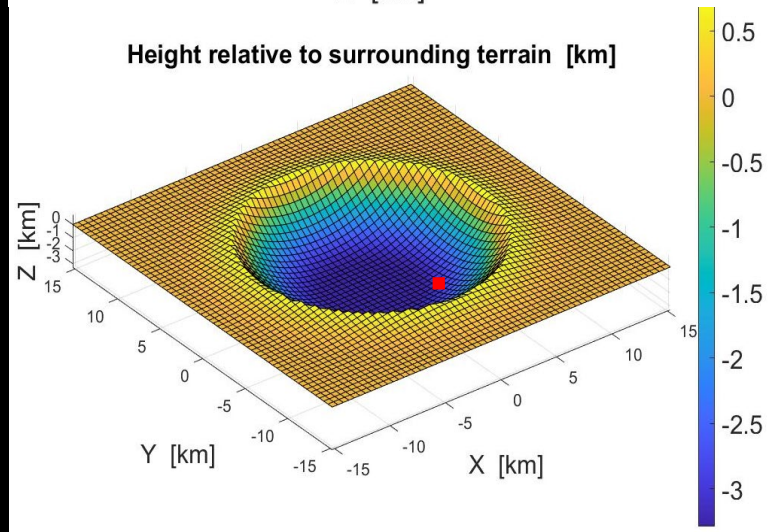
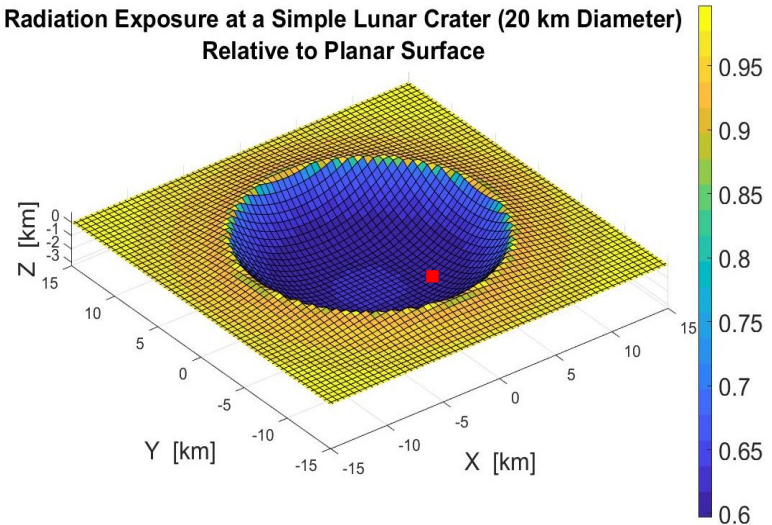
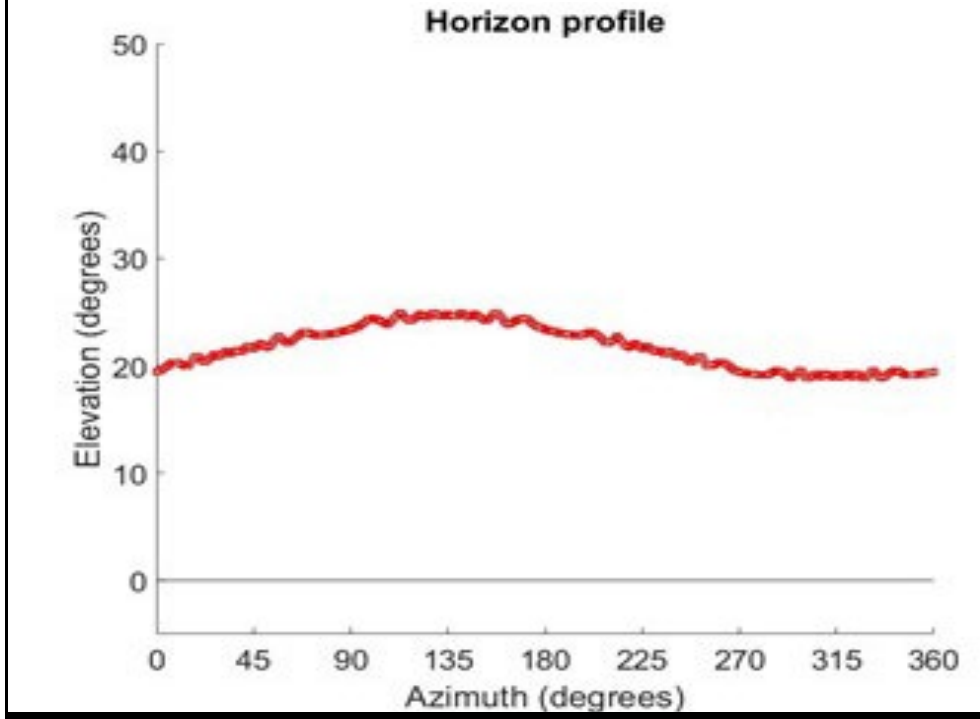








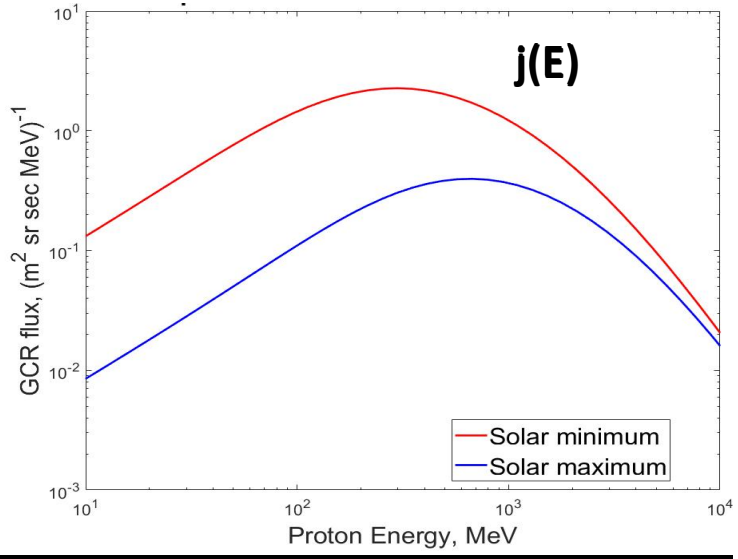




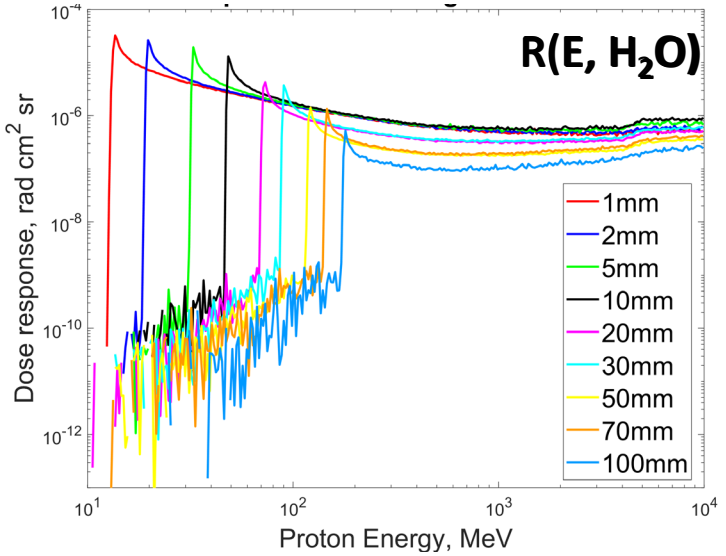
Geant4 Radiation Modeling

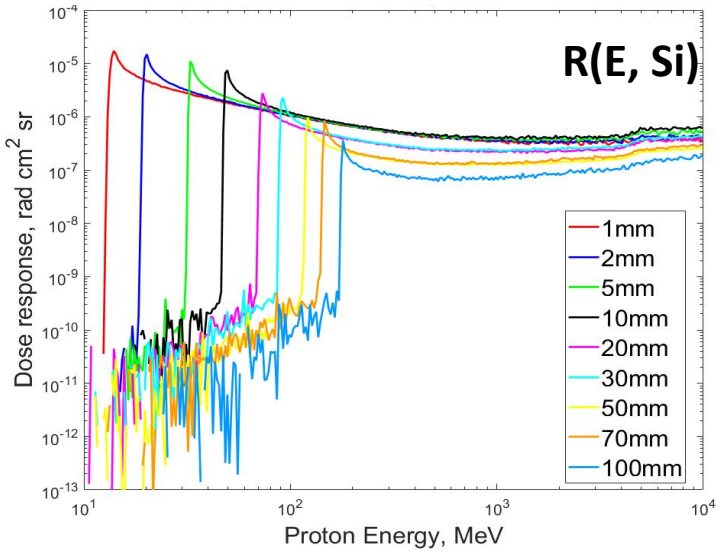
$$\int j(E)\ R(E)\ dE = D\ all\ sky\ dose\ rate\ (rads\ \mathrm{sec}^{-1})$$

GCR proton spectrum
Badhwar-O'Neill 2010

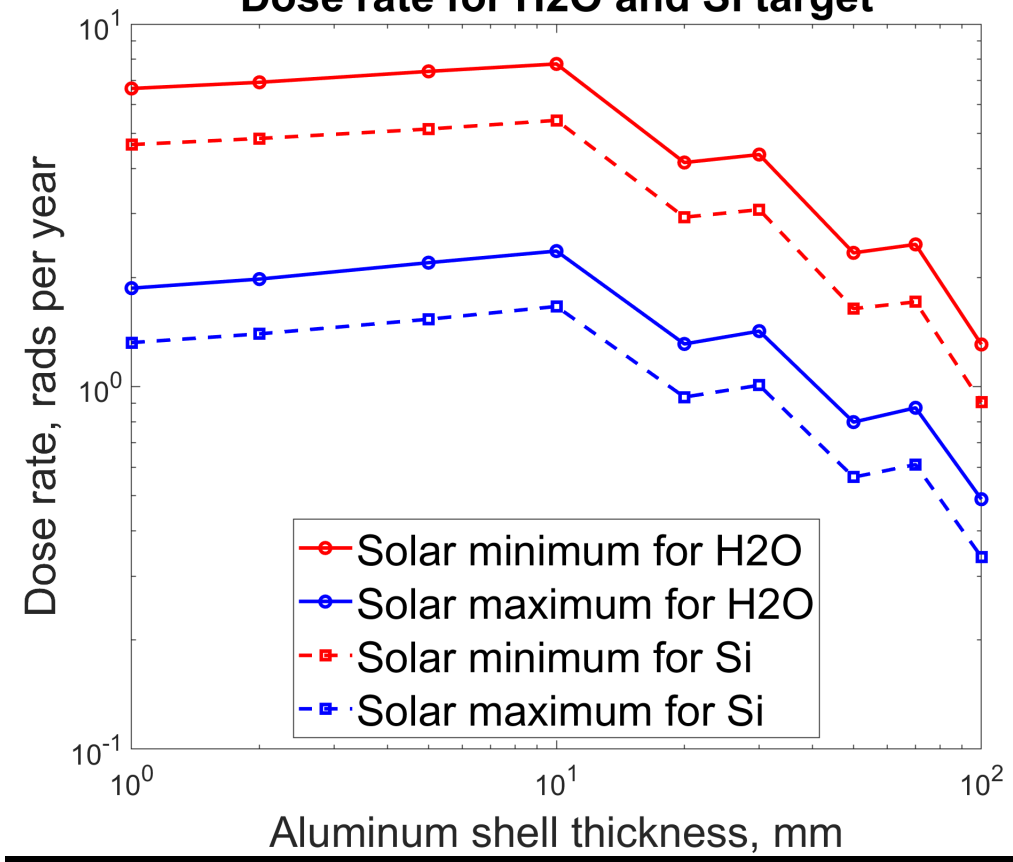


Dose Response H_2O (top) Si(bottom)





Dose rate for H2O and Si target



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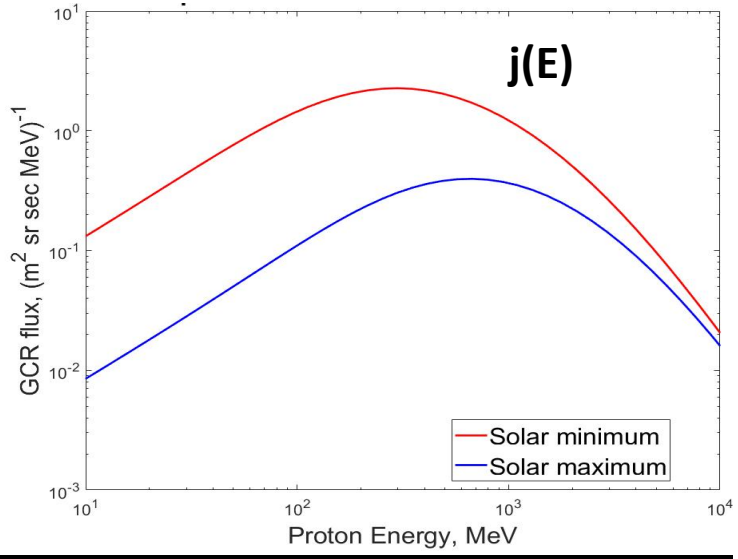

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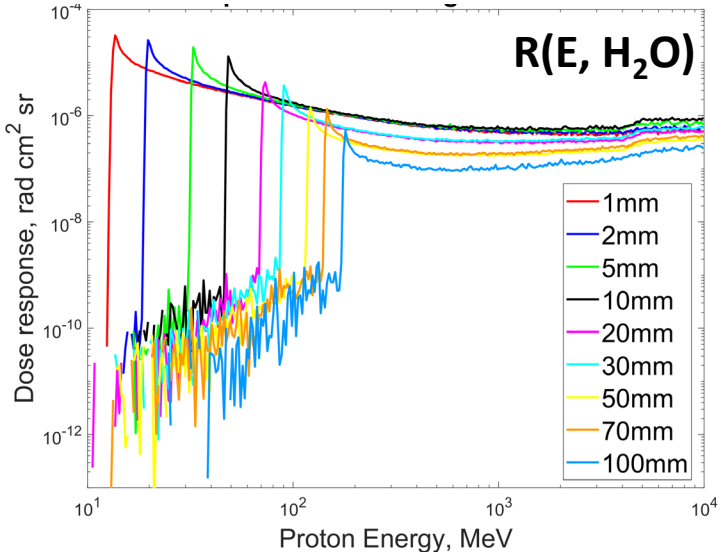

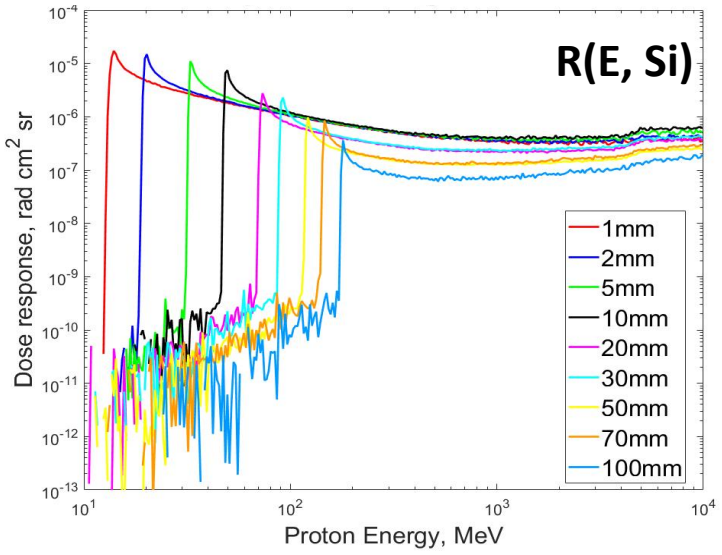

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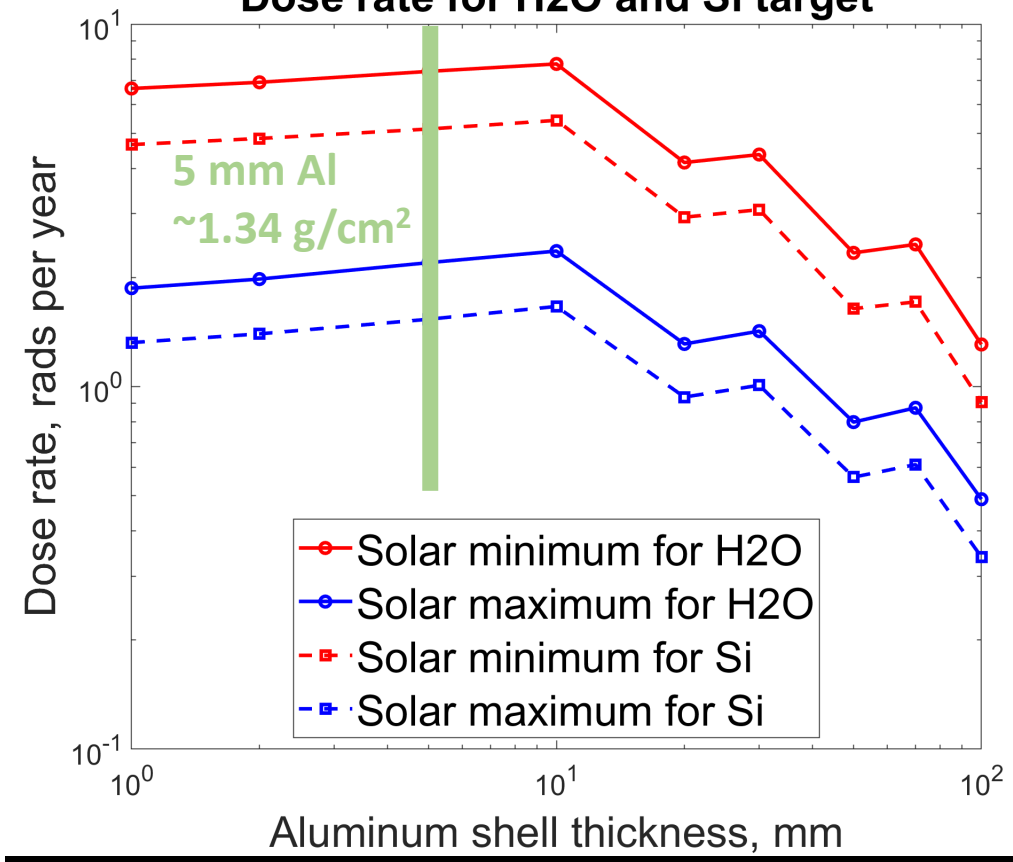


Si and H_2O Dose Rates

- For 5 mm Al shielding the proton 4π dose rates in Si are:
  - 5.14 rads/year (solar minimum)
  - 1.53 rads/year (solar maximum)

- For 5 mm Al shielding the proton 4π dose rates in H_2O are:
  - 7.41 rads/year (solar minimum)
  - 2.20 rads/year (solar maximum)

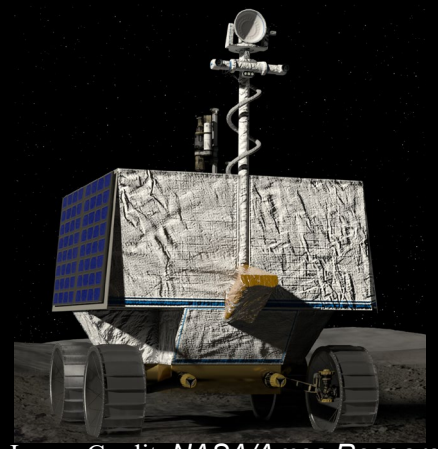
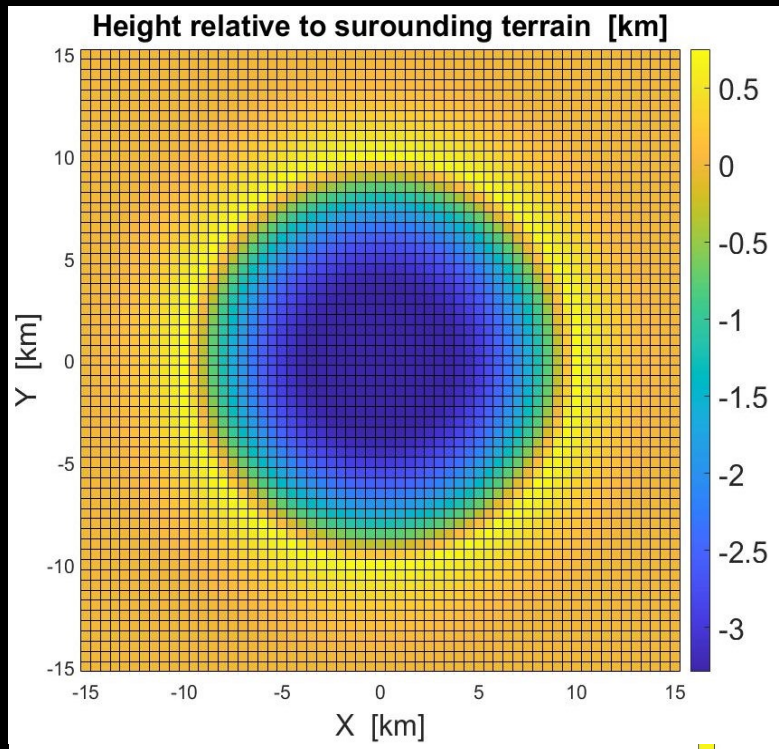
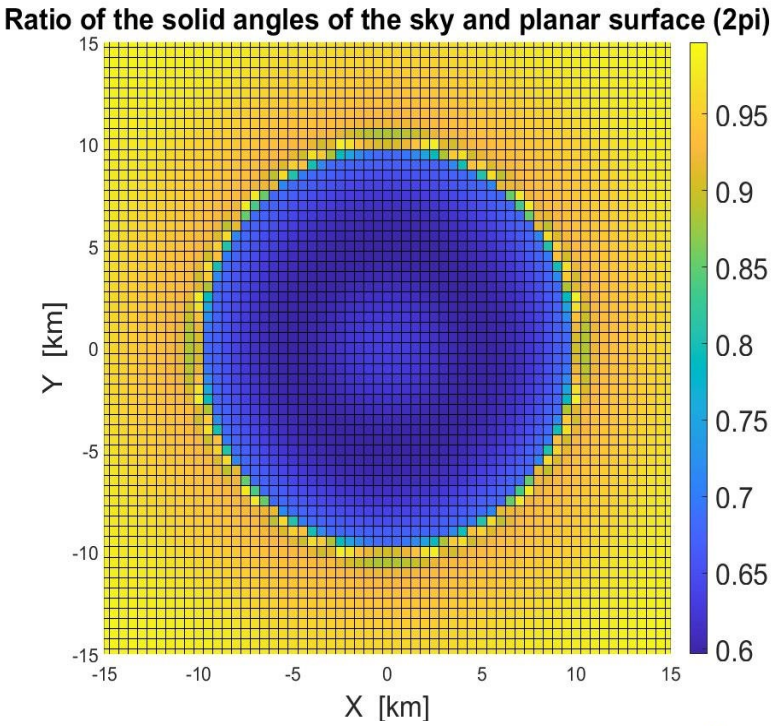


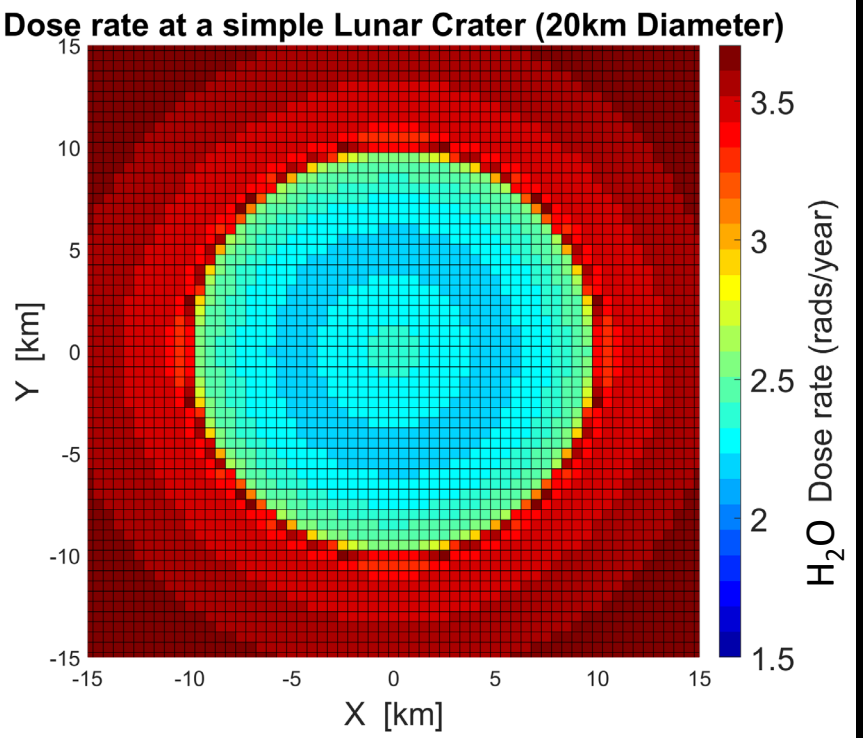
Image Credit: *NASA/Ames Research Center /Daniel Rutter*

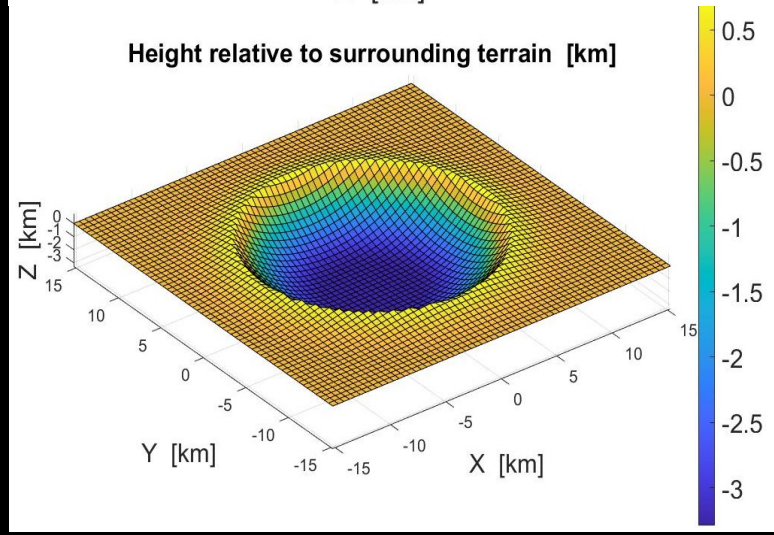
Image Credit: *NASA/ Bill Stafford*

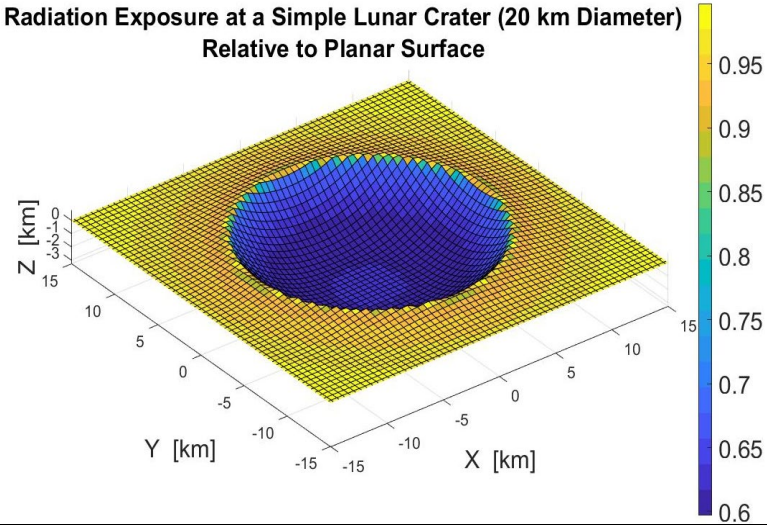
Radiation Exposure at a Simple Lunar Crater

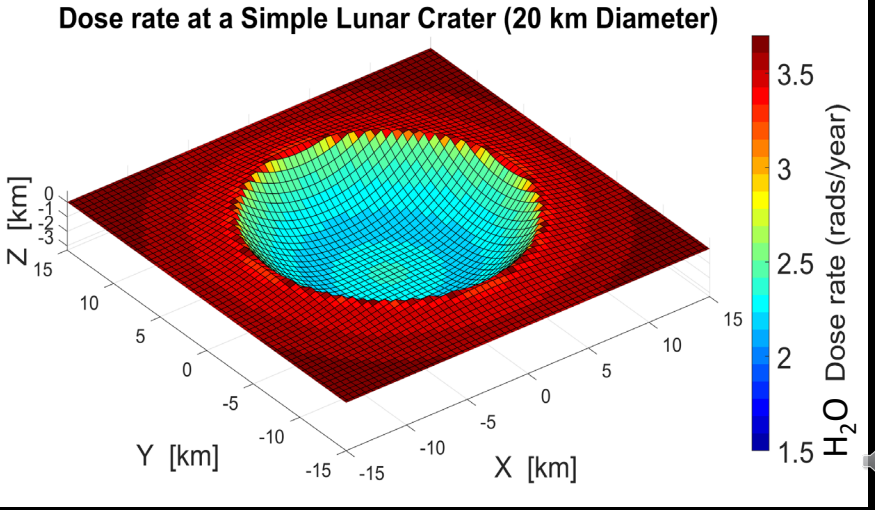




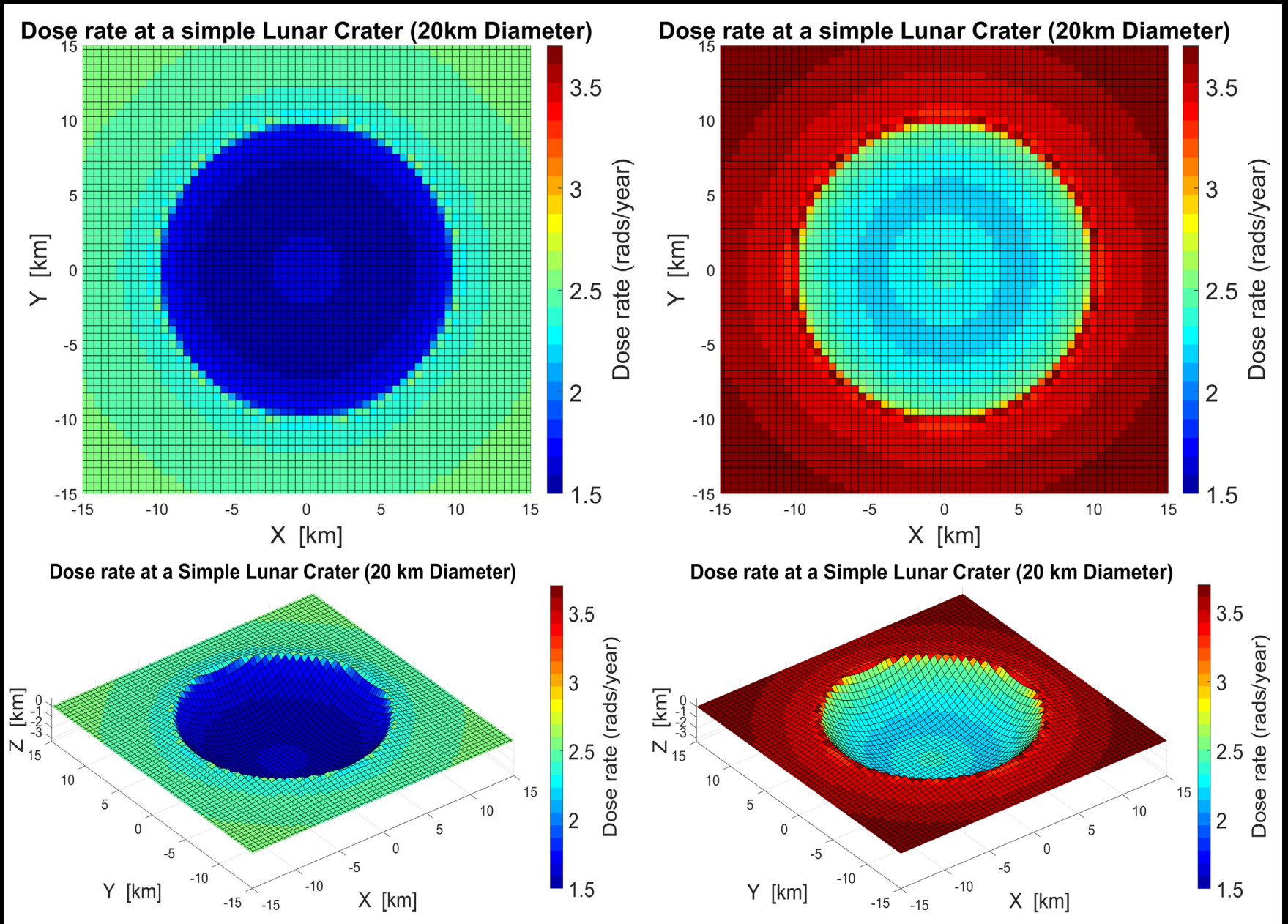






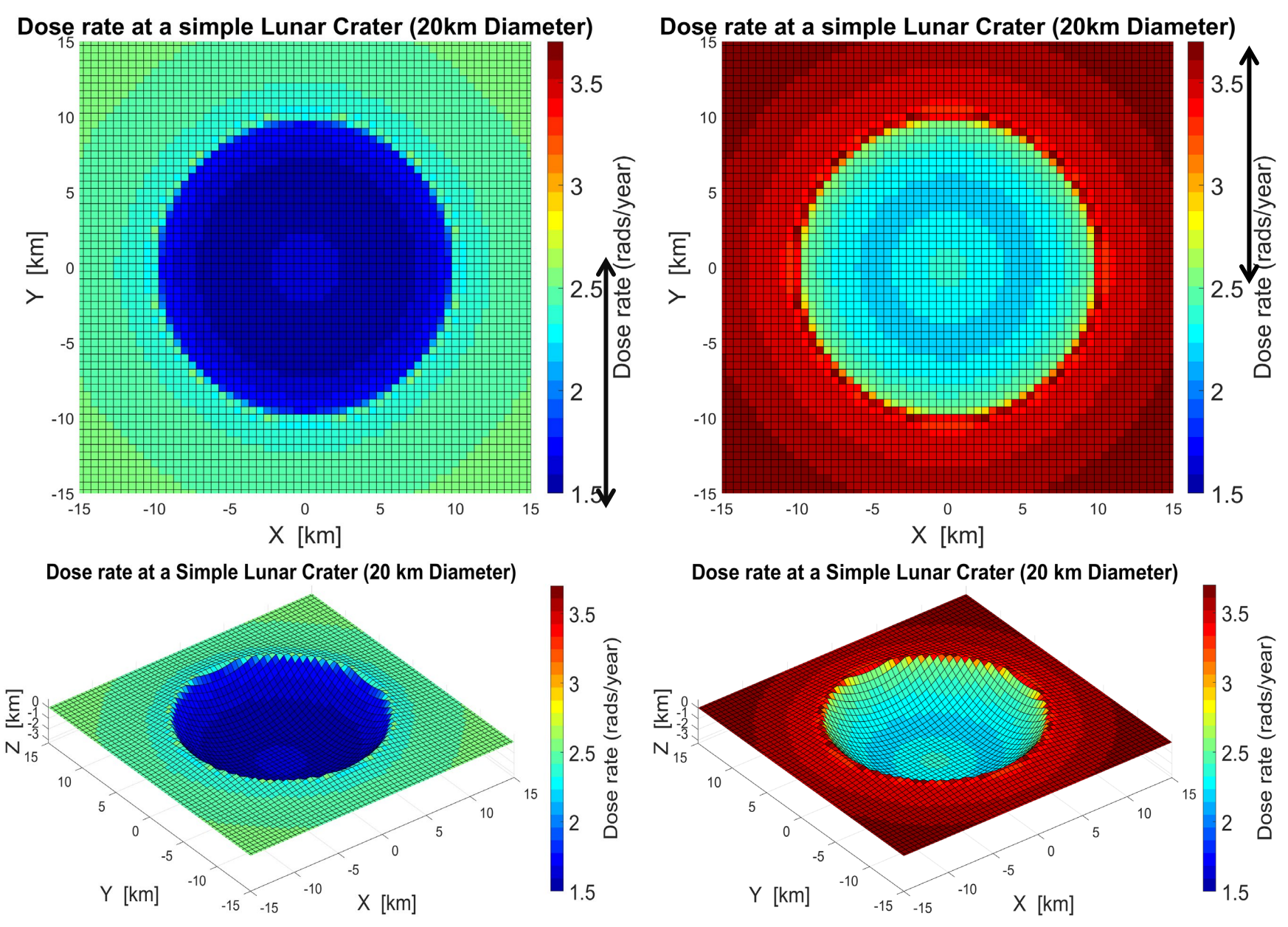


Silicon dose rate Water dose rate



5 mm Al shielding

Silicon dose rate Water dose rate



5 mm Al shielding

Dose rate in mrads/hr 1 rad = 0.01Gy = 0.007Sv	Si		H_2O	
	Solar Min	Solar Max	Solar Min	Solar Max
4 π dose rate for 5 mm Al shielding	0.587	0.175	0.845	0.251
Minimum lunar surface proton dose rates inside a simple 20km crater similar to Shackleton	0.175	0.0525	0.252	0.0742
Lunar surface proton dose rates on rim of Shackleton Crater near site of Artemis Base Camp 004	0.259	0.0776	0.373	0.111
Radiation exposure limits (for 100 rad lens 30 day exposure limit from NASA-STD-3001)	---		139	

Conclusions

- Lunar topography can cut dosage by 40 percent inside crater and by 10 percent rim of Shackleton Crater near site of Artemis Base Camp 004

- During general GCR conditions, dosage is well below the exposure limits of 139 mrad/hr limits (for 100 rad lens 30 day exposure limit from NASA-STD-3001)

- SEP events which have much higher flux (where a maximum rate can be 583 mrad/hr with about 1 g/cm^2 (3.74 mm) Al shielding (Aug 1972 storm presented in Townsend et al ICES 2019 report)) the radiation shielding of topography becomes important