The Lunar Ionising Radiation Environment
A Benchmark Model

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LABORATÓRIO DE INSTRUMENTAÇÃO
E FÍSICA EXPERIMENTAL DE PARTÍCULAS
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Lunar Radiation Environment

Particle	Energy (eV)
GCRs	10^8 to 10^{20}
SEPs	10^8 to 10^9
Albedo Particles	Up to 10^8
Other sources	

SEPs fluxes can exceed background GCRs fluxes by factors of 10^3 or more!

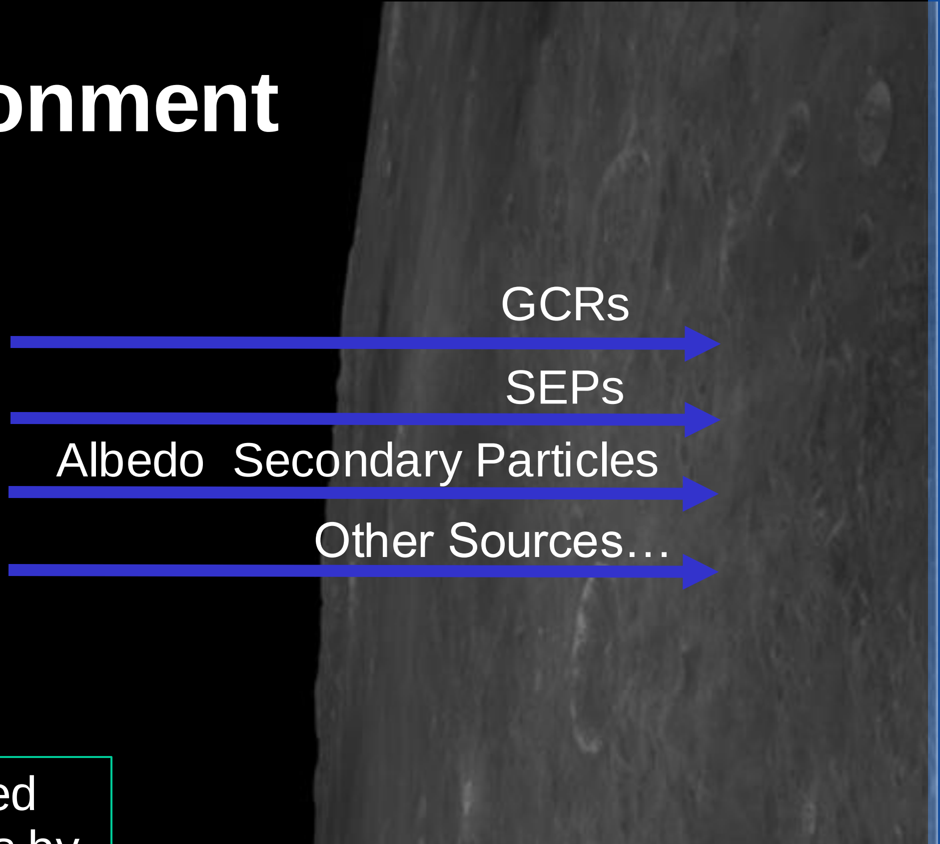

Figure 2: Juice NavCam view of the Moon
Credits: ESA/Juice/NavCam
Acknowledgements: Airbus

From Mars to the Moon

dMEREM

dMEREM
(Mars Model)

Adapting to the Moon:

- Replace Mars' atmospheric/soil models with lunar-specific data.
- Include lunar-specific radiation sources.
- Validate with existing mission data.

Developed by LIP's **SpaceRad** group using **Geant4**.

Simulates radiation environment at different Mars locations.

Figure 3: "Mars true-color generated image using OSIRIS"
CREDIT: ESA & MPS for OSIRIS Team MPS/UPD/LAM/IAA/RSSD/INTA/UPM/DASP/IDA

From Mars to the Moon

dLEREM

Task 1: Characterize lunar radiation environment

Task 2: Develop a computational model (Geant4-based)

Task 3: Validate model against real mission data

Task 4: Assess astronaut radiation risks

Figure 4: “Full Moon as photographed from on board the International Space Station
CREDIT: NASA/Astronaut Jeff Williams

From Mars to the Moon

dLEREM

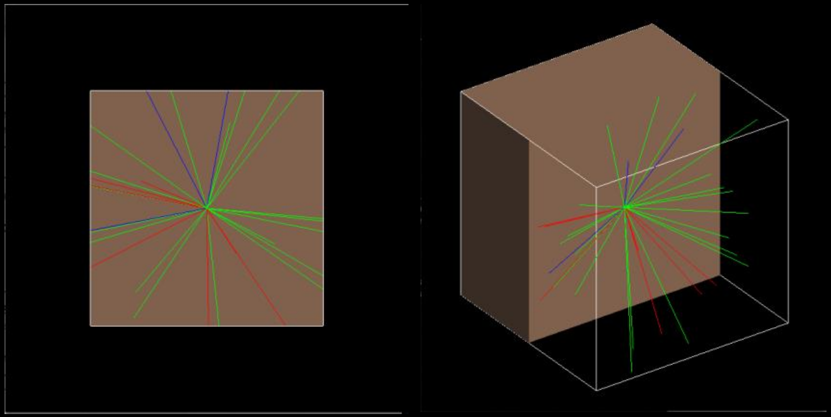

Figure 5: Geant4 Simulation Example with Moon Regolith and Proton Flux of 100 GeV

```
      Position - x (mm)   : -9.120109676571092e-12-9.120132388436999e-12
      Position - y (mm)   : 1.083960349821405e-111.083963049215006e-11
      Position - z (mm)   : 1.479007345873014e-111.479011029067858e-11
      Global Time (ns)    :  0.01143614791999963 0.01143614791999963
      Local Time (ns)     : -7.001454533324725e-14-7.001471969092333e-14
      Proper Time (ns)    : -1.534098534712316e-14-1.534102355087841e-14
      Momentum Direct - x :   0.4453226691461333  0.4453226691461333
      Momentum Direct - y :  -0.5292833130974934 -0.5292833130974934
      Momentum Direct - z :  -0.7221820371769878 -0.7221820371769878
      Momentum - x (MeV/c):    1.013318641254679   1.013318641254679
      Momentum - y (MeV/c):   -1.204368618141755  -1.204368618141755
      Momentum - z (MeV/c):   -1.643303993605095  -1.643303993605095
      Total Energy (MeV)  :    2.332142006503581   2.332142006503581
      Kinetic Energy (MeV):    1.821143096503581   1.821143096503581
      Velocity (mm/ns)    :    292.5074555687947   292.5074555687947
      Volume Name         :             Regolith            Regolith
      Safety (mm)         :                5e-10               5e-10
      Polarization - x    :                    0                   0
      Polarization - y    :                    0                   0
      Polarization - Z    :                    0                   0
      Weight              :                    1                   1
      Step Status         :      AlongStep Proc.     AlongStep Proc.
      Process defined Step:                eIoni               eIoni
   ---------------------------------------------------------------------

  ++List of secondaries generated (x,y,z,kE,t,PID):  No. of secondaries = 0

**PostStepDoIt (after all invocations):
  ++List of invoked processes
   1) Transportation

  ++G4Step Information
   Address of G4Track    : 0x139f1d3f0
   Step Length (mm)      : -5.10009201886219e-17
   Energy Deposit (MeV)  : 0
   ---------------------------------------------------------------------
    StepPoint Information               PreStep            PostStep
   ---------------------------------------------------------------------
      Position - x (mm)   : -9.120109676571092e-12-9.120132388436999e-12
      Position - y (mm)   : 1.083960349821405e-111.083963049215006e-11
      Position - z (mm)   : 1.479007345873014e-111.479011029067858e-11
      Global Time (ns)    :  0.01143614791999963 0.01143614791999963
      Local Time (ns)     : -7.001454533324725e-14-7.001471969092333e-14
      Proper Time (ns)    : -1.534098534712316e-14-1.534102355087841e-14
      Momentum Direct - x :   0.4453226691461333  0.4453226691461333
      Momentum Direct - y :  -0.5292833130974934 -0.5292833130974934
      Momentum Direct - z :  -0.7221820371769878 -0.7221820371769878
      Momentum - x (MeV/c):    1.013318641254679   1.013318641254679
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      Momentum - z (MeV/c):   -1.643303993605095  -1.643303993605095
```

Objectives of dLEREM

Preliminary Validation & Expected Results

Validation Approach: Compare simulated dose rates and spectra to:

- CRaTER (LRO)
- Apollo radiation measurements
- Chandrayaan RADOM instrument
- JUICE RADEM August Earth-Moon Fly by

Expected Findings: Benchmark dLEREM against real lunar measurements.

Assess Accuracy: in predicting realistic lunar exposure conditions.

Applications:

Scientific research: Serve as a benchmark lunar radiation model.

Lunar mission planning: Optimize shielding strategies.

Human spaceflight safety: Provide astronaut radiation risk assessments.

Conclusion

Building a Safer Future for Space Exploration

Unify fragmented radiation data for better **understanding** and **accessibility**.

Figure 6: LUNA recreates the Moon's surface on Earth, located next to ESA's Astronaut Centre (EAC) in Cologne, Germany.
CREDITS: ESA-L. Breggion

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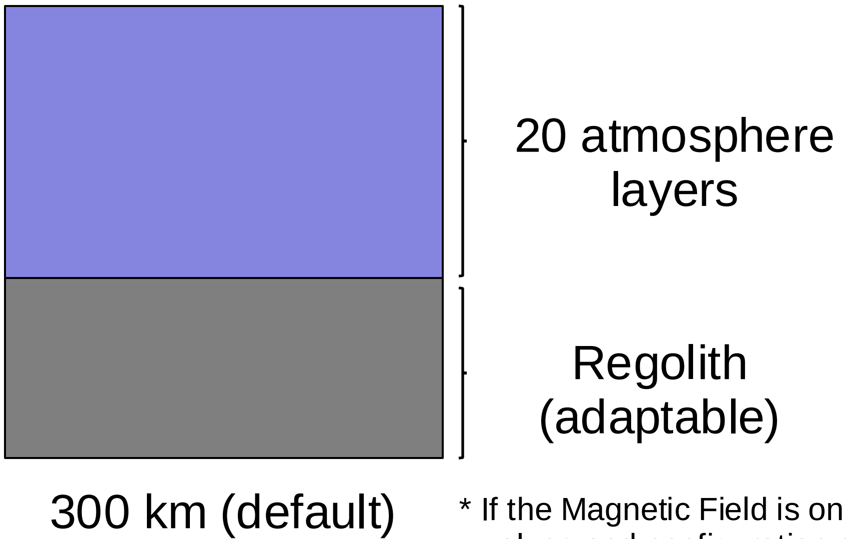
Extra Slides

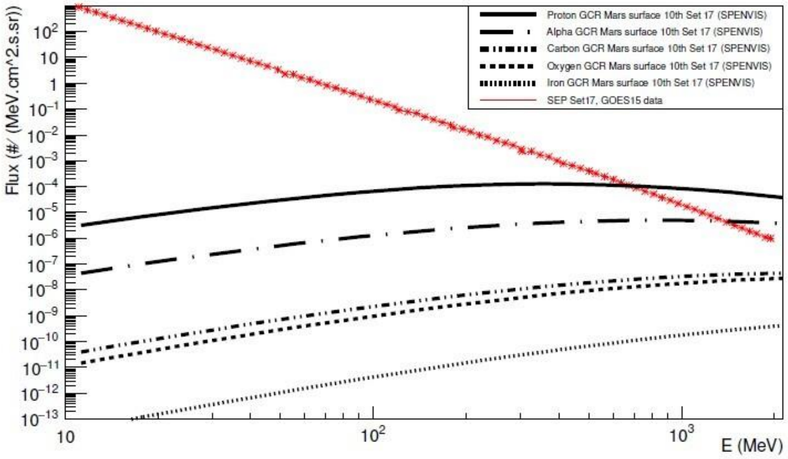
dMEREM



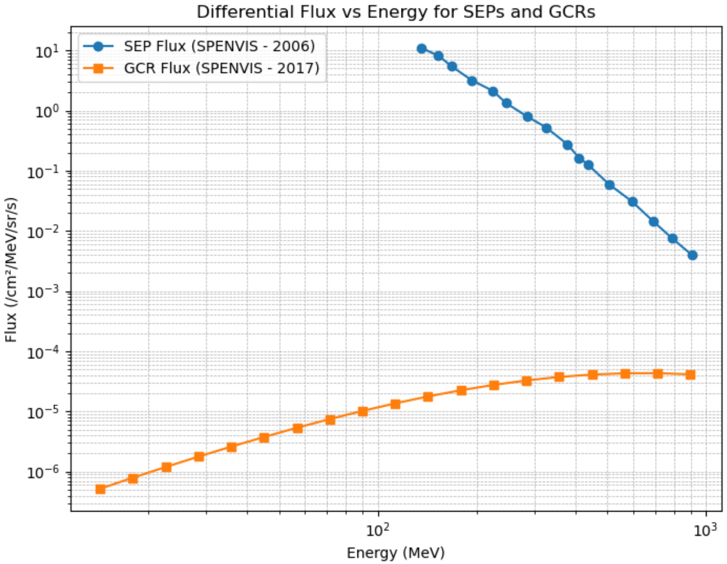
* If the Magnetic Field is on, the values and configuration are different

- ❑ Geometry Definition and Materials;
- ❑ Primary Particle Generation;
- ❑ Event Generation & Simulation;
- ❑ Physics Processes & Interactions;
- ❑ Sensitive Detectors & Scoring Mechanisms;
- ❑ Tracking & Data Collection;
- ❑ Output & Visualization.

Radiation Spectra Simulation



Differential flux as a function of kinetic energy (GCR)



Comparative flux spectra of GCRs and SEPs extracted from SPENVIS