Model for Particle Transport through Planetary Magnetospheres and Atmospheres

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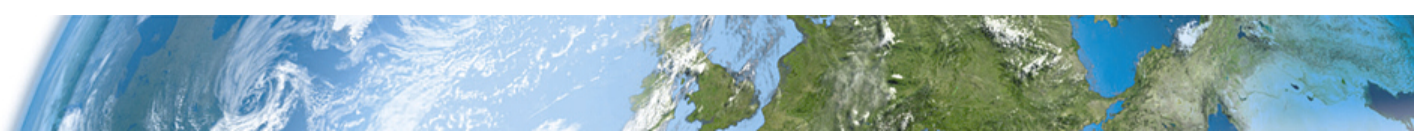
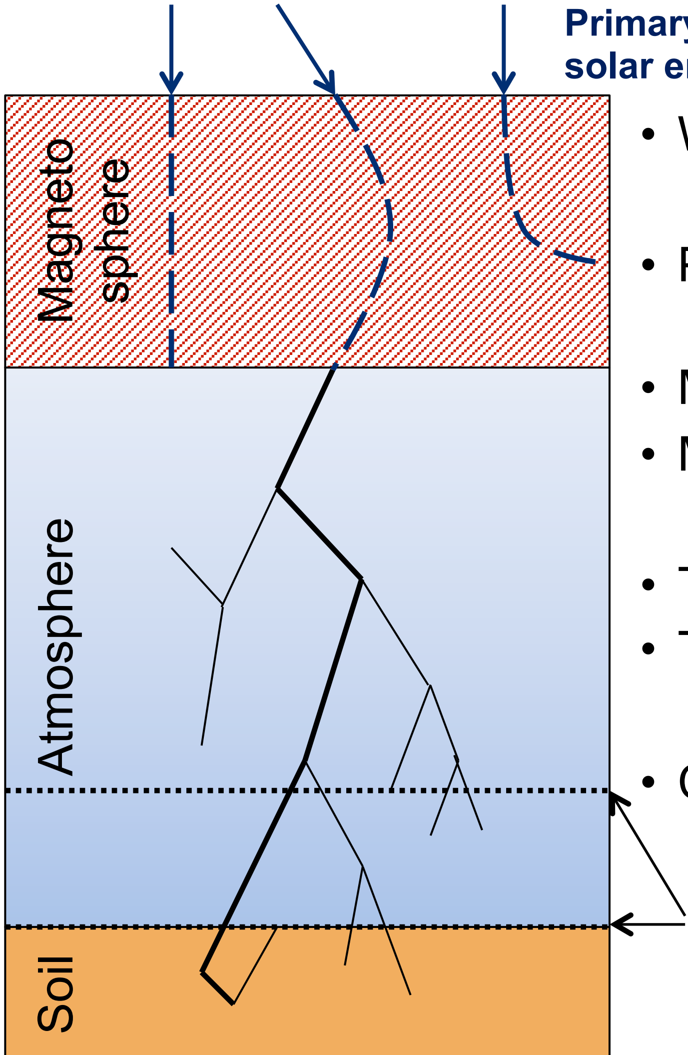
Overview

- Description of the model
- Applications
- Status



Working principle



Primary particles, e.g. Galactic cosmic radiation, solar energetic particles, …

- What do we need:
- Primary particle spectra (model or measurements)
- Model of the magnetosphere
- Model of the atmosphere

} PLANETOCOSMICS

- Transport through the magnetosphere
- Transport through the atmosphere

} GEANT4

- Conversion to dose rate (conversion factors)

Particle spectra at altitude or ground
→ convert to dose rate

Transport tools

- GEANT4 (https://geant4.web.cern.ch):
  “Geant4 is a toolkit for the simulation of the passage of particles through matter.”

  - Arbitrary particles and energies
  - Large number of physics lists / interaction models
  - Monte-Carlo simulation: long computation times

- PLANETOCOSMICS (http://cosray.unibe.ch/~laurent/planetocosmics/):
  “PLANETOCOSMICS is a simulation framework based on Geant4 that allows to compute the hadronic and electromagnetic interactions of cosmic rays with the Earth, Mars and Mercury. For each planet it is possible to take into account the presence of the magnetic field, atmosphere and soil.”

Conversion of particle spectra to dose *x*

$$x=\sum_{s}\sum_{i=0}^{N} c_x^s(E_i)\cdot F^s(\Delta E_i)$$

$s=$ secondary particle type

$F^s(\Delta E_i)=$ secondary particle fluence in the energy interval ΔE_i

$c_x^s(E_i)=$ fluence to dose x conversion facto

$$F^s(\Delta E_i)=\sum_{j=0}^{M} f_{\Delta E_j}^s(\Delta E_i)\cdot F(\Delta E_j)$$

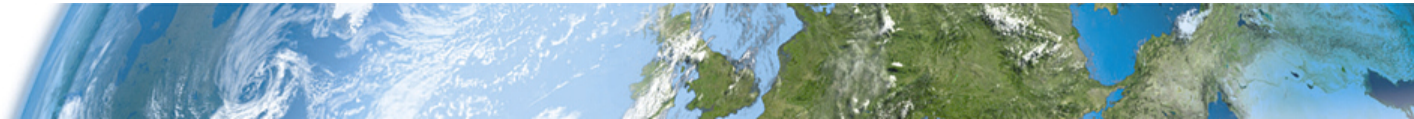
$$g_x(\Delta E_j)=\sum_{i=0}^{N} c_x^s(E_i)\cdot f_{\Delta E_j}^s(\Delta E_i)$$

$$x=\sum_{j=0}^{M} g_x(\Delta E_j)\cdot F(\Delta E_j)$$

$F(\Delta E_j)=$ primary particle fluence in ΔE_j

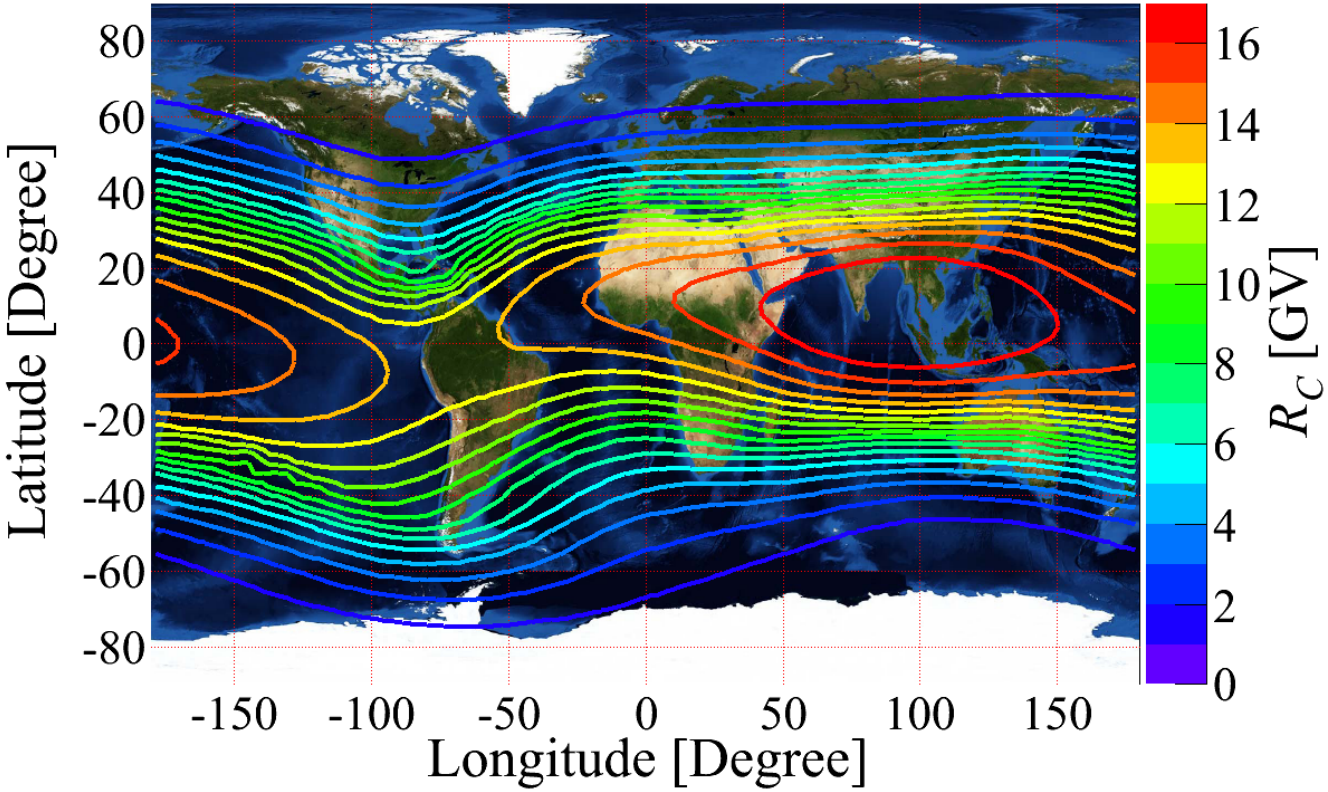
$f_{\Delta E_j}^s(\Delta E_i)=$ secondary particle fluenc induced by a primary from ΔE_j

If we know what we want to know (*x*) we can pre-calculate the $g_x(\Delta E_j)$ and derive the quantity for arbitrary primary input spectra by a simple summation.



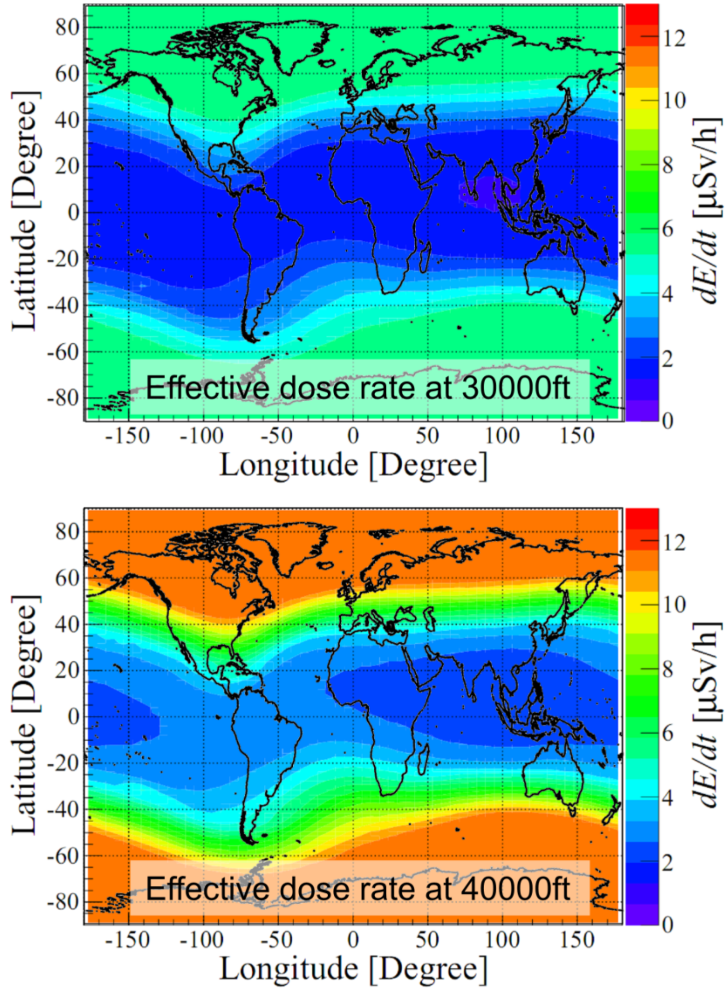
Applications: Magnetospheric transport, cut-off rigidity R_C

- rigidity: $R = p/q$ = momentum/charge



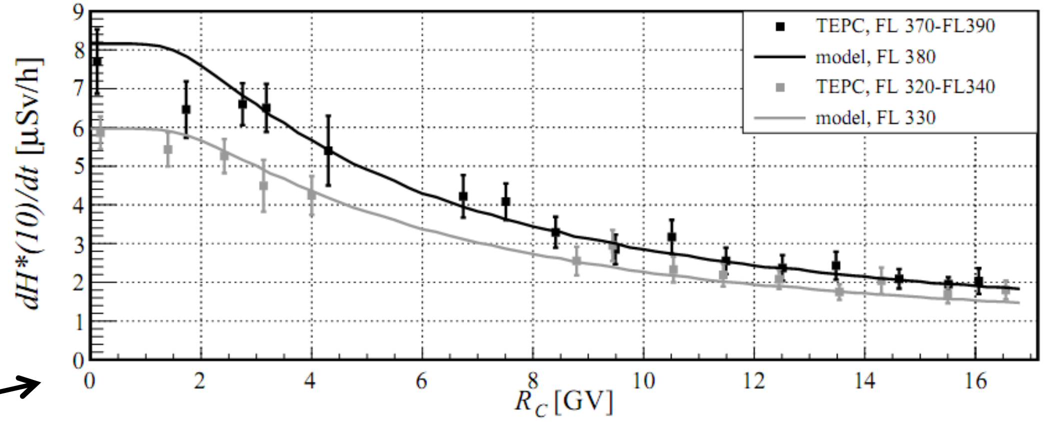
Applications:
Dose rates at aviation altitudes (PANDOCA)

- Galactic cosmic radiation (GCR)
  - Effective dose rate *E*
  - Ambient dose equivalent rate *H*(10)*
- Aviation altitudes: ≈ 200-300 g/cm^2
- Mars surface: ≈ 16-17 g/cm^2

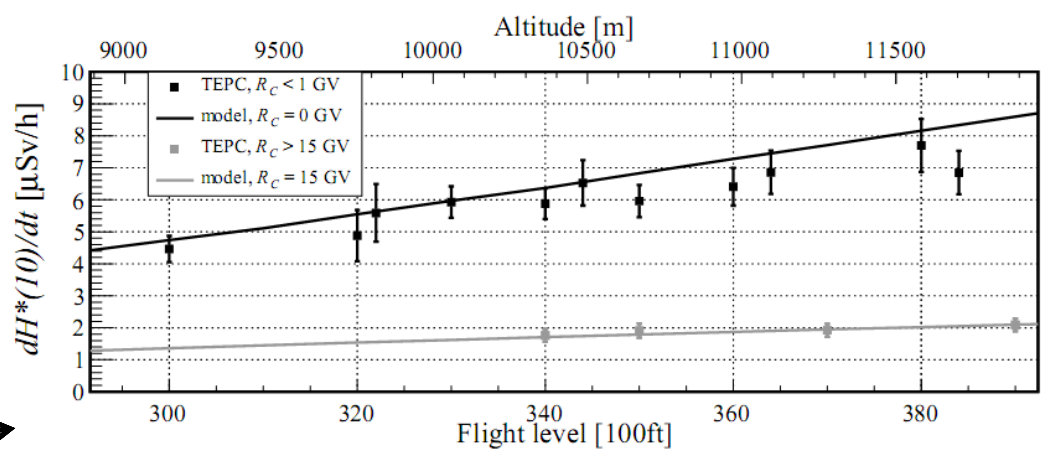


Applications: Dose rates at aviation altitudes (PANDOCA)

- Validated against (among others) TEPC (tissue equivalent proportional counter) measurements



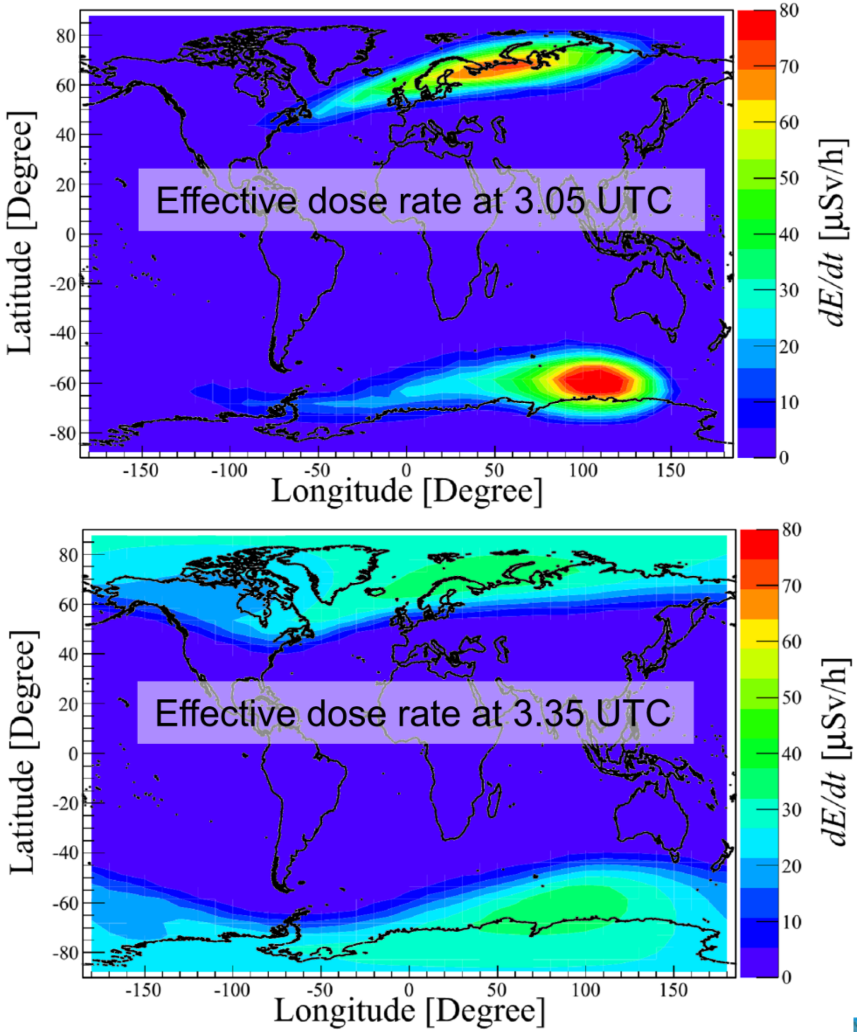
effect of the magnetosphere



effect of the atmosphere

Applications:
Dose rates at aviation altitudes (PANDOCA)

- Dose rates from solar energetic particles (protons):
    - GLE70 (ground level enhancement)



Applications:
Particle spectra and dose rates on the Martian surface

- **Comparison of particle spectra and dose rates, models and MSL-RAD**
  Matthiä et al., J. Space Weather and Space Climate, 6 , A13 (2016)

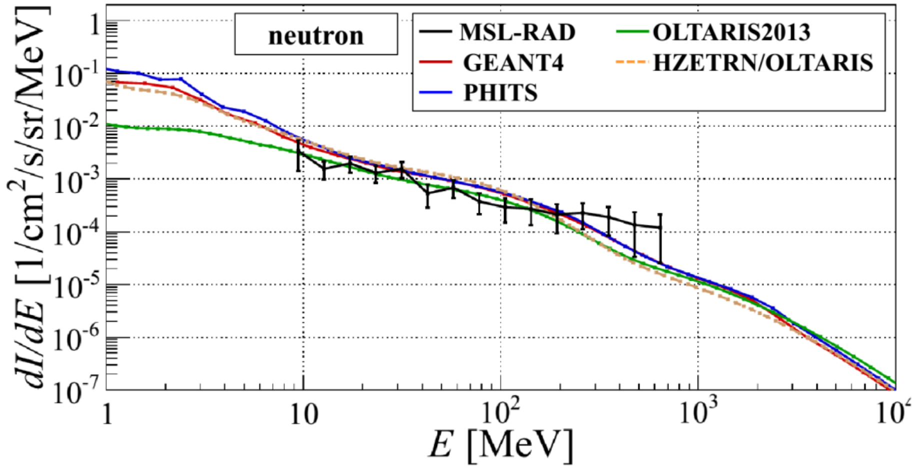
- **Atmosphere:**
  - 22 g/cm^2 (≈ -3000 m, Gale crater)
  - Composition (mass %): 95.7% CO_2, 2.7% N,1.6% Ar (Mars-Gram 2001)
- **Soil:**

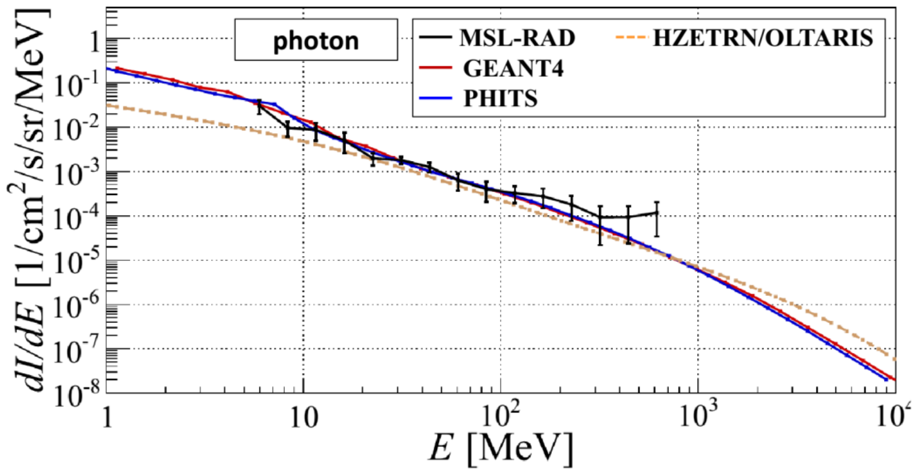
Density: 1.7 g/cm^3

Defined in Terms of Molecular Percentages	
Formula	**Percentage(0 < p <= 100)**
O_2Si	51.2
Fe_2O_3	9.3
$Al_2CaK_2MgNa_2O_7$	32.1
H_2O	7.4
Total	**100.0**

- **GCR-Input:** 19. Aug. 2012 (doy 232, 2012) until 17. Feb. 2013 (doy 48, 2013), 182 days

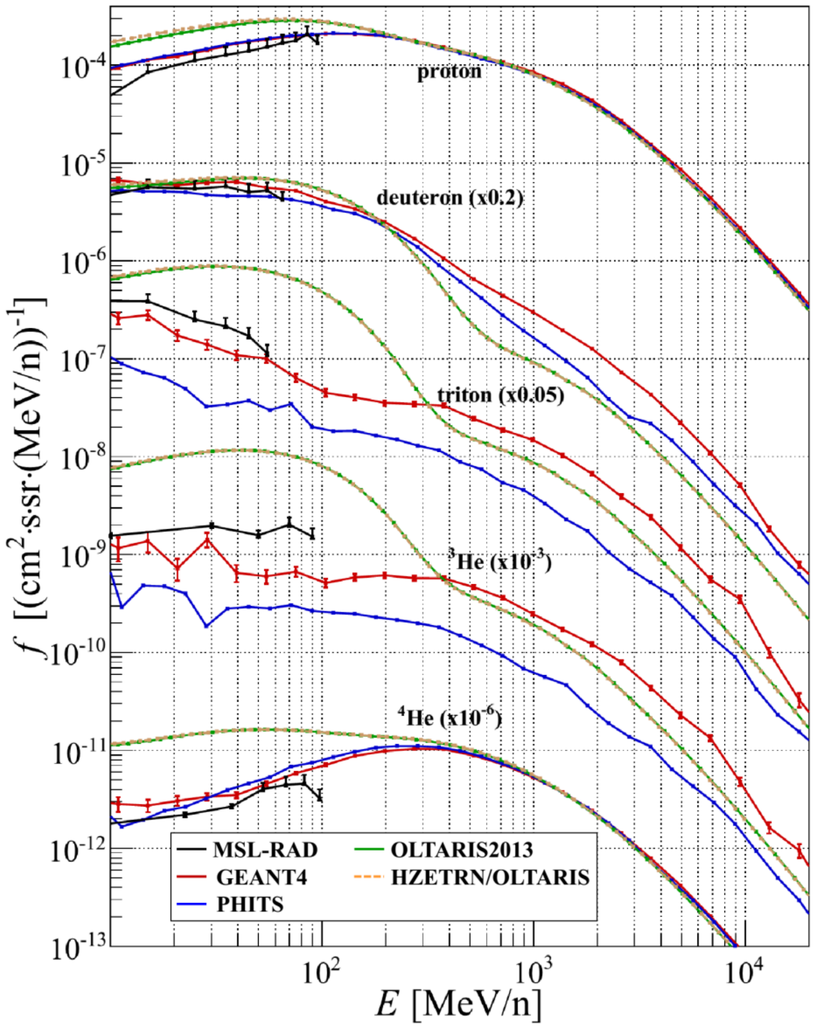
Applications:
Particle spectra and dose rates on the Martian surface





Applications: Particle spectra and dose rates on the Martian surface

- RAD: spectra of stopping charged particles below ≈ 100 MeV/n
- Dose rates measured by RAD (*Hassler et al. 2014*):
  d = 0.21 ± 0.04 mGy/d
  h = 0.64 ± 0.12 mSv/d
- from the model (*Matthiä et al. 2016*):
  d = 0.19 mGy/d
  h = 0.52 mSv/d



Status:

- Validated model for particle transport through Martian atmosphere:
  - Calculation of (integral) particle spectra on the surface
  - Conversion to dose

- We have to define:
  - Primary particle type and energy range
  - Format of the input/interface to other models
  - Output quantities (e.g. dose rate in Si, dose rate in tissue, dose equivalent rates …)

→ Detailed particle transport calculations