Modeling Planetary Radiation Environments with Geant4

Patrícia Gonçalves
LIP, Portugal

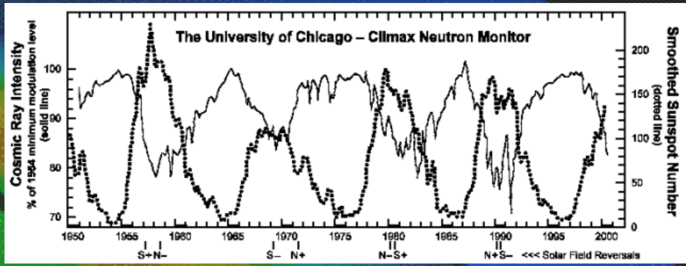
How to model Planetary Radiation Environment?

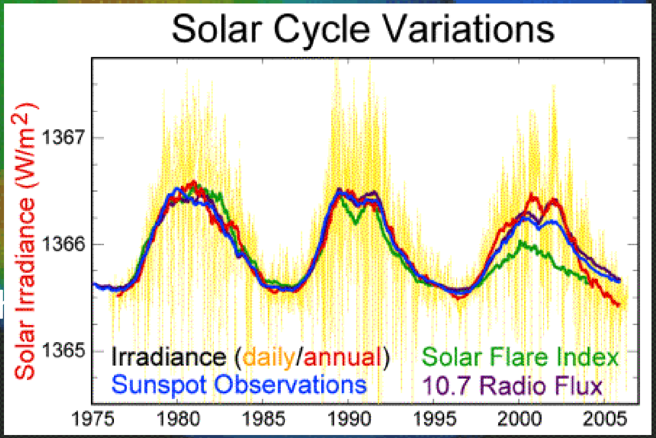
Magnetosphere or crustal magnetic fields? : Structure and strength of the B field

Solar Cycle : minimum/maximum SEP?

Soil: composition Water ?

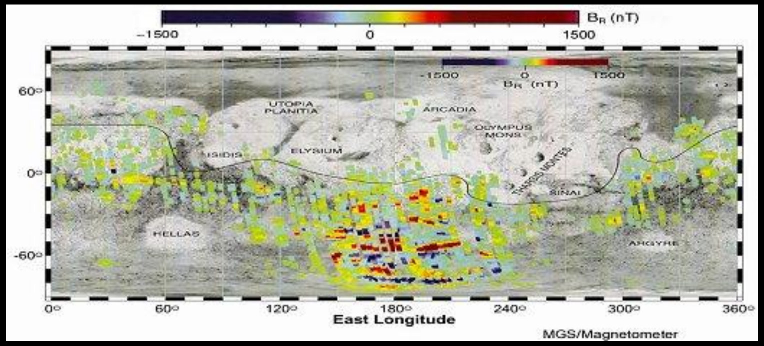
Atmosphere?
Composition
Depth
seasonal & day-night variations

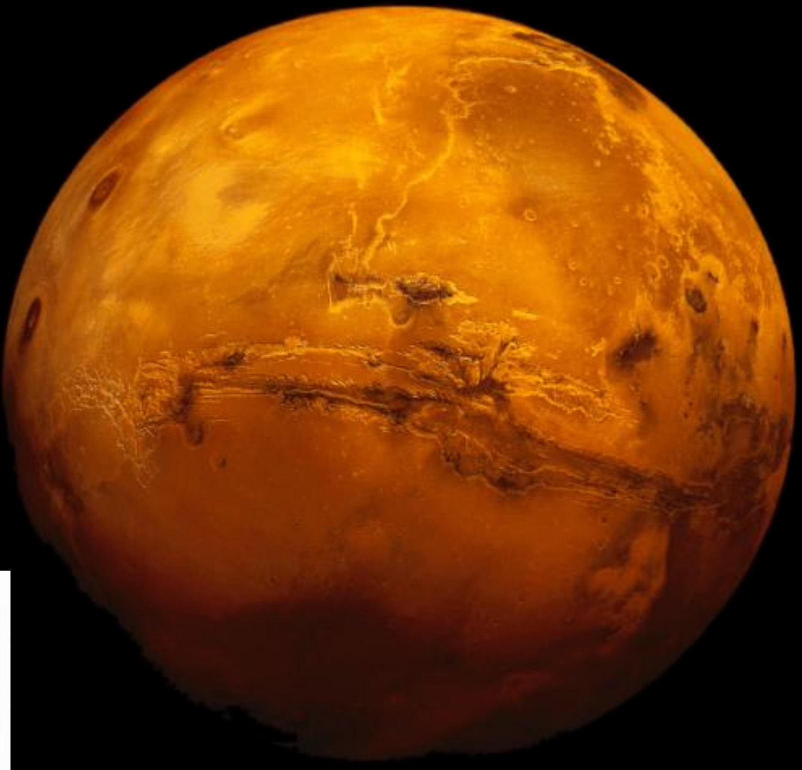




Mars

- **Atmospheric depth and composition**
  - **> 95% CO_2,**
  - **0.01 Earth's atmospheric depth**
- **Localized crustal magnetic fields**
  - **(umbrellas)**





- **Radiation environment**
  - **SEP and GCR @ ~1.5 AU**
  - **Albedo neutrons (modulated by soil composition)**
  - **No radiation belts**
  - **"umbrella" electrons/ low energy protons**

MarsREM:
the Mars Energetic Radiation Environment Models

dMEREM :
detailed Mars Energetic Radiation Environment Model

eMEREM :
engeneering Mars Energetic Radiation Environment Model

- interfaced to SPEs , GCR (p,α, ions)
- to be used by mission designers and planners and by radiation experts
- web-based and interfaced with existing radiation shielding and effects simulation tools

LIP developed dMEREM, a Geant4 based model for the radiation environment on Mars, Phobos and Deimos, including local treatment of surface topography and composition, atmospheric composition and density (including diurnal + annual variations) and local magnetic fields.

Work sponsored by the ESA Technology Research Programme
(http://reat.space.qinetiq.com/marsrem) **concluded in 2009**

dMEREM inputs

Inputs
as a function of latitude, longitude, in a 5 x 5 degree grid, and season.

- Atmosphere composition from EMCD (Eurpean Mars Climate Database) or MarsGRAM (NASA)

- Topography from Mars Laser Altimeter aboard Mars Global Surveyor.

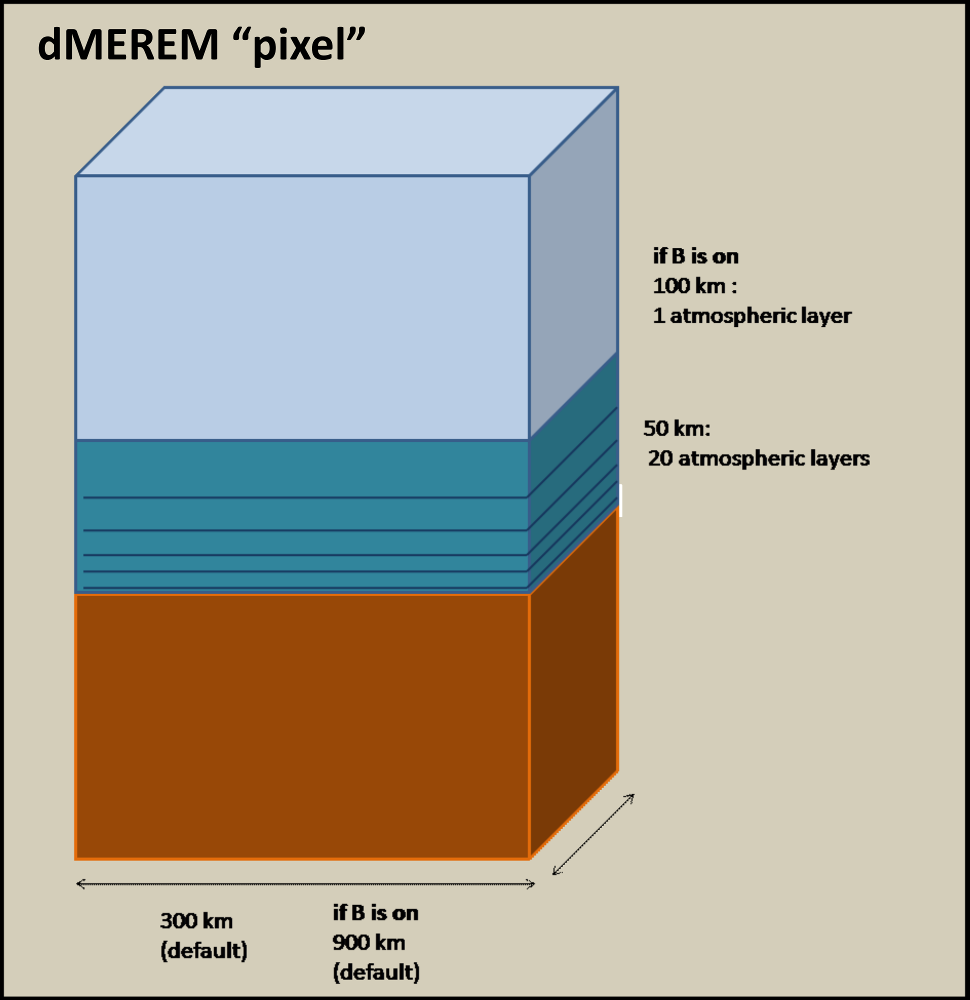
- Soil Composition from analysis of data from Gamma Ray Spectrometer aboard Mars Odyssey, including water content and CO_2 ice.

- Magnetic Field Models , from PLANETOCOSMICS (L. Desorgher)

dMEREM DetectorConstruction

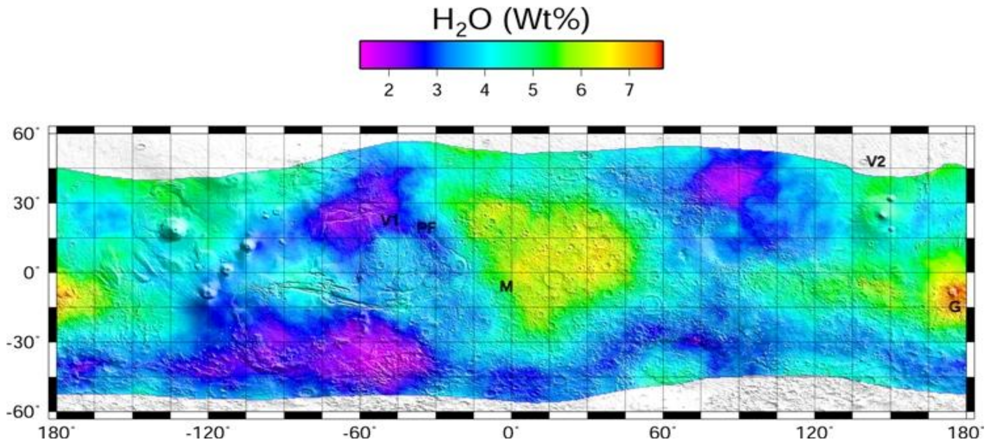
Detector

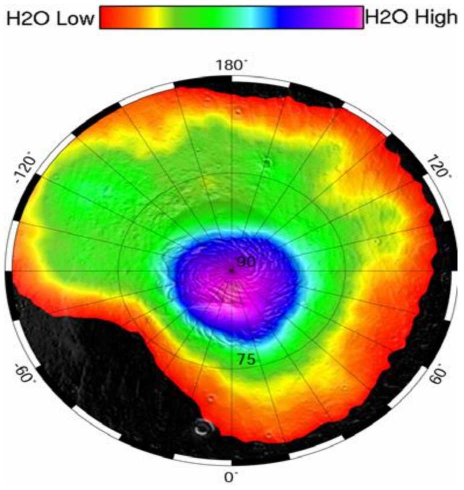
- Size:
  - 300 x 300 km pixel,
  - 50 km altitude (100 km if B is on)
- Atmosphere:
  - 20 constant depth (g/cm2) layers
  - composition and ρ from EMCD /MARSGRAM (including CO2 ice)
- Soil:
  - top layer with composition and density from GRS data analysis (including water content)

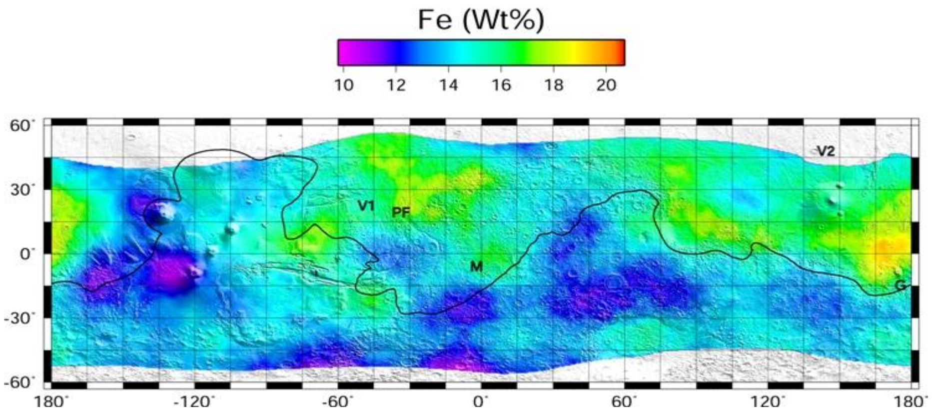


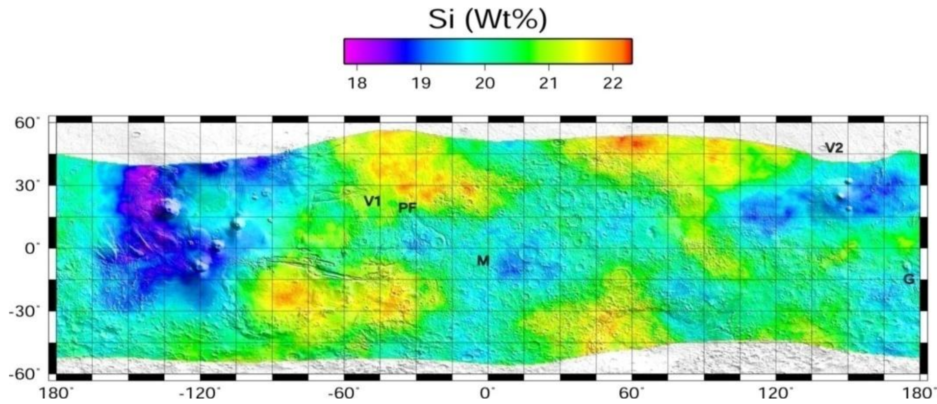
GRS data

- Soil Composition from analysis of data from Gamma Ray Spectrometer aboard Mars Odyssey, including water content and CO_2 ice.





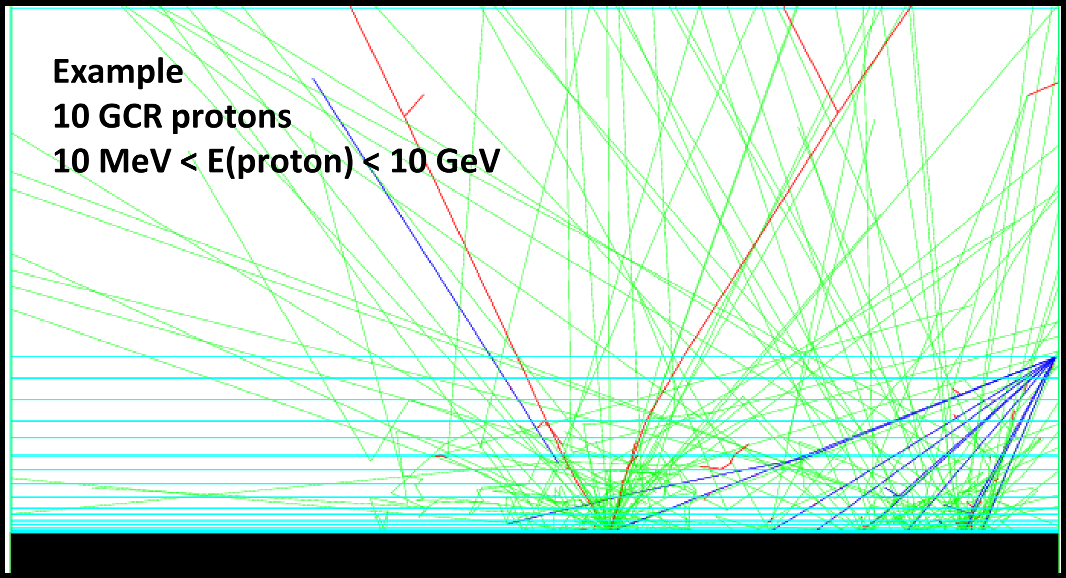




dMEREM PrimaryGeneration

- **GCR (proton,nuclei) and SEP proton with Energy between 10 MeV to 1 TeV**

  log-log binned input spectra



- **Position**

  generation at a fixed point: $(0, (d_{pixel}/2)-1km, H_{max})$

  $d_{pixel}/2$ is half of the pixel side [150 km]

  H_{max} is the maximum atmospheric altitude [50 km]

- **Direction**

  θ between 0º and $\theta_{max}=atan((dpixel/2-1km)/H_{max})$ [80.5º]

  φ fixed to a single value [90º]

Benchmark Physics Scenarios

With Geant4.9.1

	Standard EM.	Low Energy EM	Hadronic	HP neutron
1-Full: had+leem+ ln	no	yes	yes	yes
2-Standard: had+em+ln	yes	No	yes	yes
3-Fast: had+em+ln	e/gamma>100 keV	No	yes	yes
4-EM: leem	no	yes	no	no

- **Full :**
  detailed description of the electromagnetic and hadronic component
  very time consuming
- Standard:
  standard em physics + HP neutrons
- Fast:
  for a preliminary evaluation of hadronic (p+n) interactions-> dose
- EM:
  gamma studies

dMEREM outputs

For any location on Mars surface, atmosphere, underground or at Phobos and Deimos surface:

Particles are detected in Sensitive detectors placed at a single altitude for detailed analysis or at different atmospheric depths for profile analysis.

The outputs are given in the form of csv files.

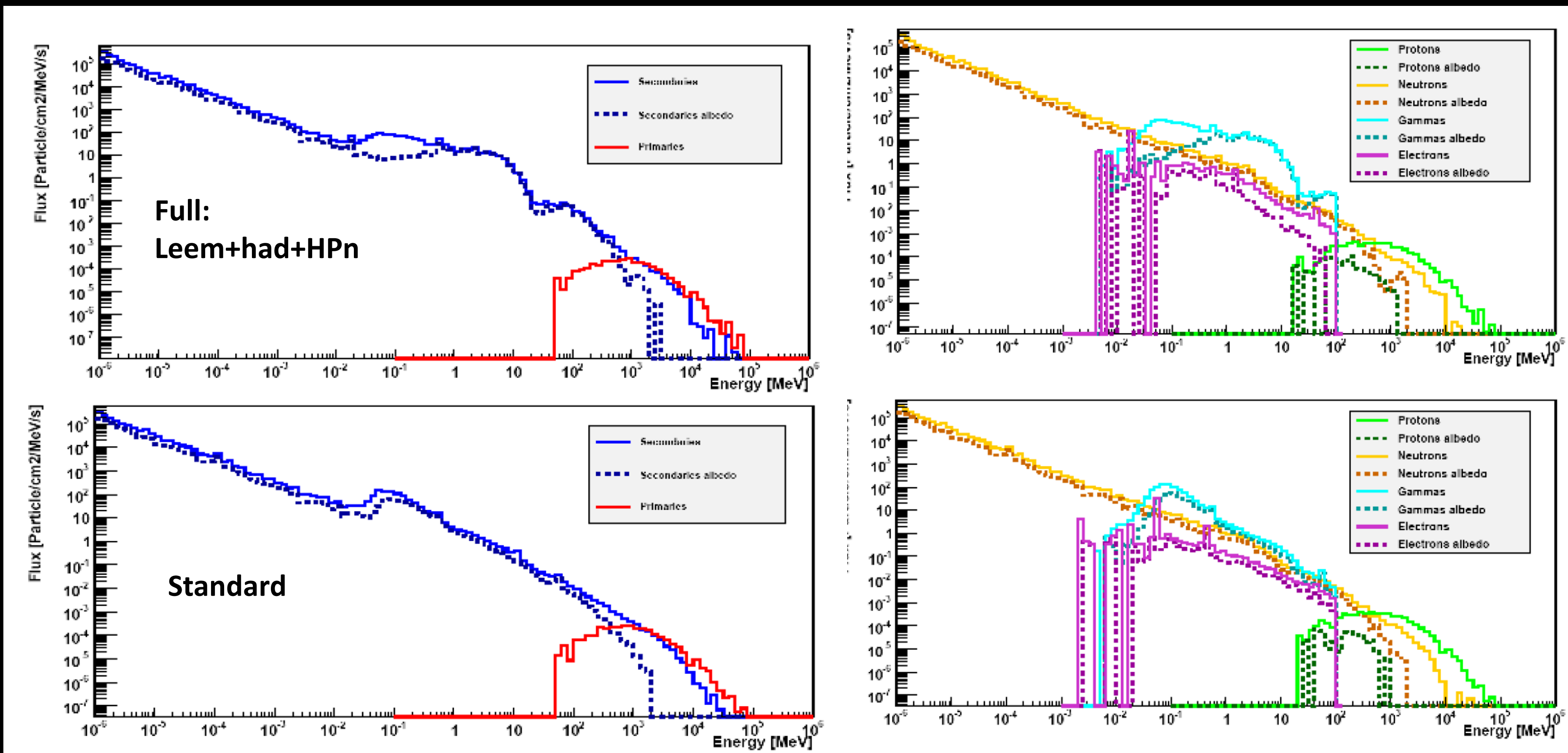
Ouputs:

- Particle energy spectra for primaries and secondaries
- Particle energy spectra for p,n,α, e,gamma,π, μ and ions
- LET spectra im Si and H_2O
- Effective dose (*)
- Ambient Dose Equivalent (*)

(*) using fluence to ED conversion factors interfaced with G4 (Pelliccioni)

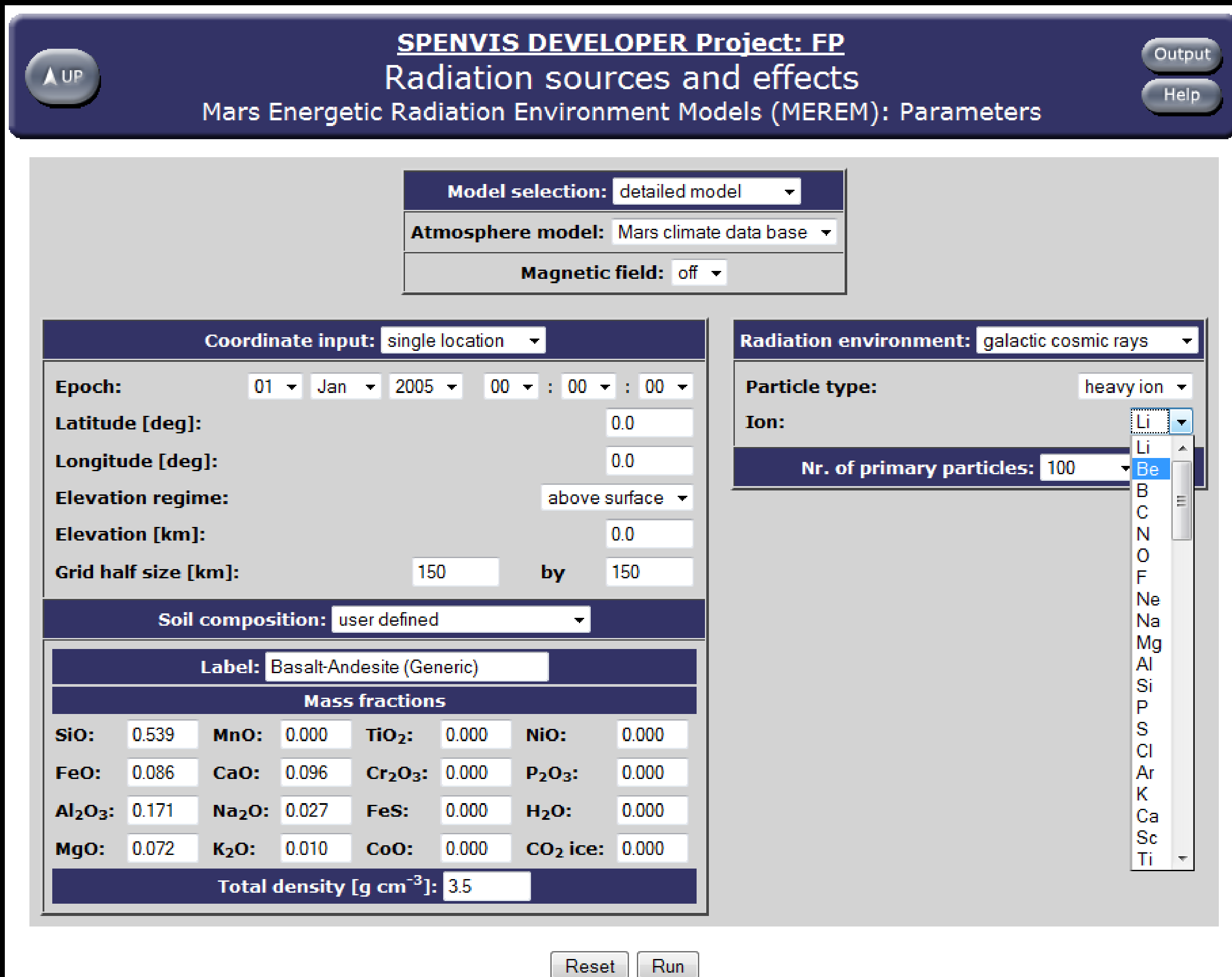
dMEREM results

Spectra of primaries and secondaries and different particle species at a given location on Mars surface and for a given epoch, due to GCR, including albedo component.



dMEREM in SPENVIS

dMEREM and eMEREM operate as standalone applications but were integrated into the Space Environment Information System (SPENVIS)

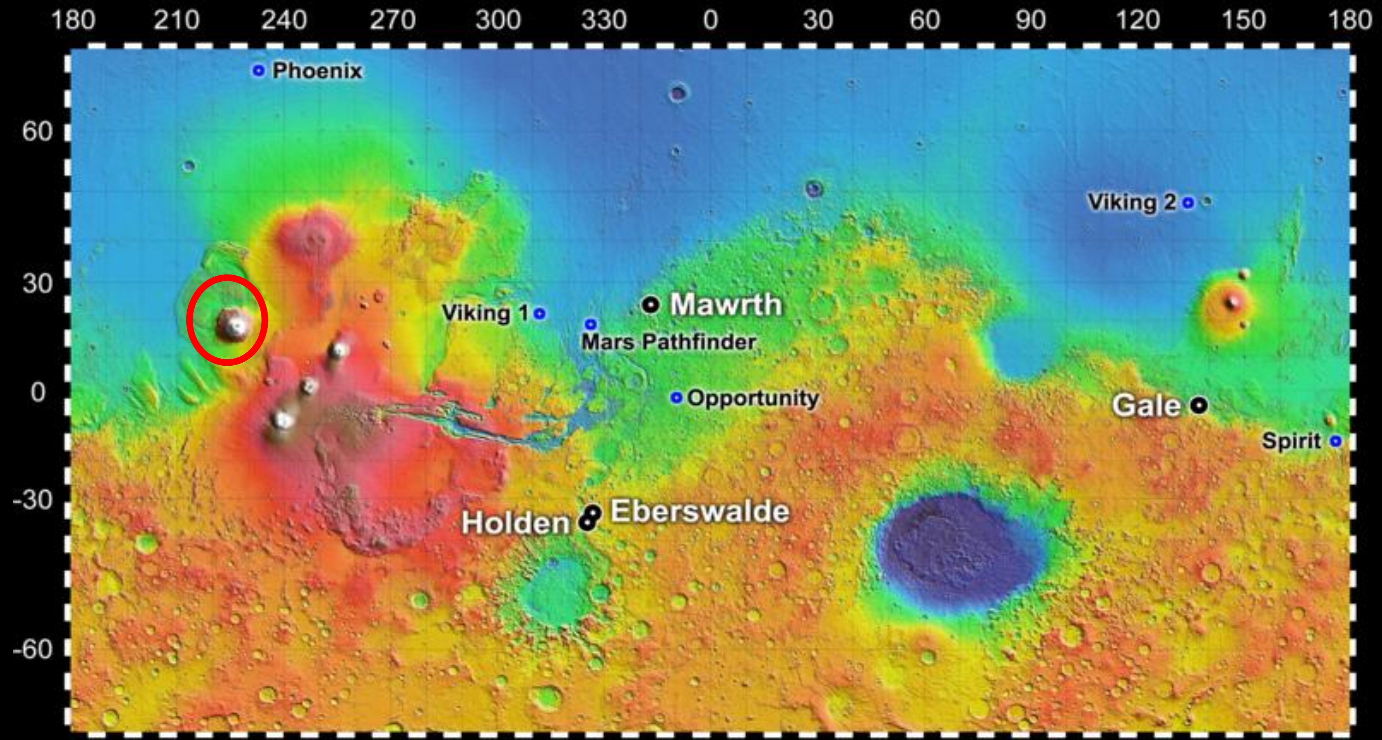


Location Radiation Enviroment Study with dMEREM

"Characterization of the Martian radiation environment on selected locations using the ESA Mars Energetic Radiation Environment Models",

Icarus 218 (2012) 723–734

S. McKenna-Lawlor[1], P. Gonçalves[4], A. Keating[4], B.Morgado[4], D. Heynderickx[2], P. Nieminen[3], G. Santin[3], P, P. Truscott[5], F. Lei[5], B. Foing[6], and J. Balaz[1,7].



Three Martian landing sites were studied during two significant flares

15 day duration in April 2002 (sol.max) and December 2006 (sol.min)

Results

Dependence of ED and ADE on soil compoisition and epoch

dMEREM	Apr-2002, “Solar maximum” • expect lower ED/ADE (GCR) •Winter on north pole (*)			Dec-2006, “Solar minimum” • expect higher ED/ADE (GCR) • Summer on north pole (*)		
	Viking	Phoenix	Mawrth	Viking	Phoenix	Mawrth
ED (mSv)	11.30	11.00	11.00	20.6	19.10	20.4
ADE (mSv)	6.02	5.49	4.30	10.5	7.8	7.67
ADE(i) / ADE (Viking)	**1.00**	**0.91**	**0.71**	**1.00**	**0.74**	**0.73**
H_2O	**3.0 %**	**50.0 %**	**9.4 %**	**3.0 %**	**50.0 %**	**9.4%**
Dry Ice	**No**	Yes(*)	**No**	**No**	**No (*)**	**No**
Atmospheric depth (g/cm^2)	17.8	19.2	16.5	17.8	17.8	15.1
Soil density (g/cm^3)	1.8	1.2	2.2	1.8	1.2	2.2

Results

- GCR reach the surface of Mars and originate albedo neutrons increasing the ADE values.
- Most SEPs are degraded in the atmosphere and do not reach the surface.
- Both MEREM models agree on GCR but not on SEP prediction

  (difference on e.m. results to be investigated)
- There is a resonable agreement between the MEREM and the HZTERN model used by NASA.

Regolith soil type	Dose Equivalent (mSv)	
	"Solar minimum"	"Solar maximum"
HZETRN (De Angelis et al.,2007)	11.2	4.5
eMEREM – Viking 1*	13.8	8.0
dMEREM – Viking 1*	10.5	6.0

(*) ADE

30 days on Mars

NASA Mars short surface stay scenario

(430 days =   400 cruise+ 30 surface)

30 Day Stay on Surface - solar minimum GCR induced dose	Dose Equivalent (mSv)	
	Skin	BFO
Ionizing Radiation Exposure Limits for LEO (Simonsen et al. ,1993)	1500	250
eMEREM Viking 1/Phoenix/Mawrth *	21.2/ 16.0/21.0	
dMEREM Viking 1/Phoenix/ Mawrth *	21.0/20.3/14.4	

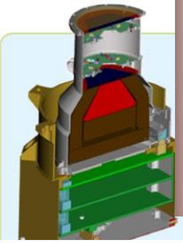
(*) ADE

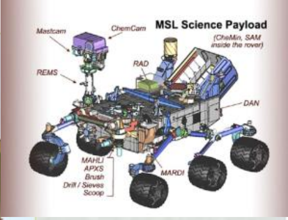
0.5-0.7 mSv/day

Models predictions are that it is possible for Astronauts to remain on Martian surface for months with no serious risk!

For longer permanences shelters are required (GCR never stop...)

Curiosity RAD data
On Gale Crater since August 5, 2012



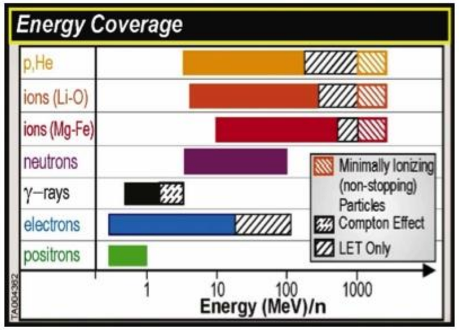


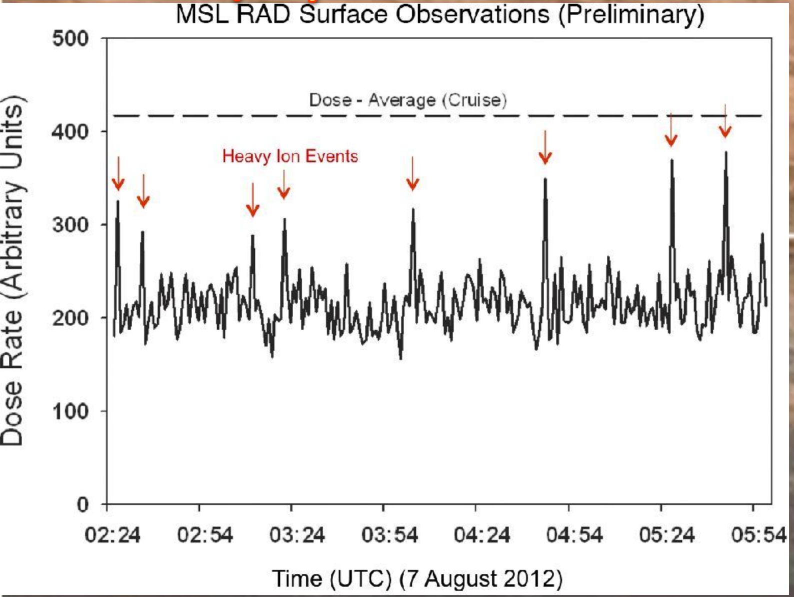
"…preliminary data (…) revealed that levels on the ground are similar to what astronauts encounter on the International Space Station *(…)The astronauts can live in this environment"

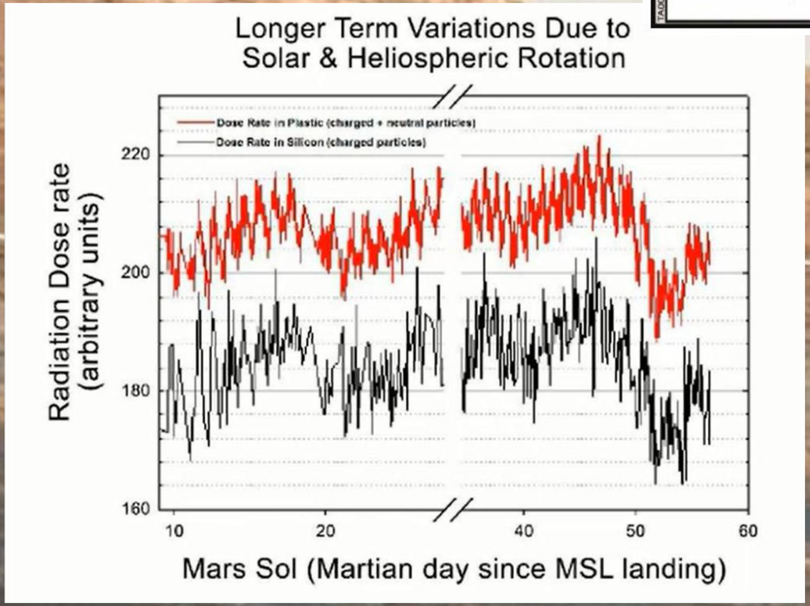
Don Hassler, Curiosity PI - November 2012

http://www.engadget.com/2012/11/17/curiosity-rover-mars-radiation-levels-safe-for-humans/

* ~0.5 mSv/day







Gale Crater predictions with dMEREM are underway !
Curiosity RAD published data awaited for more complete validation of dMEREM with data from Mars surface !

dMEREM review and upgrades

dMEREM last version within MarsREM was delivered in May 2009.
It was compliant with G4.8.1 up to G4.9.1. We are now at G4.9.6.p01!

Requirements should be revisited and the code should be updated to profit from current G4 capabilities:

- **Inputs:** Need more flexible and simple particle spectra input
  use weights as a function of primary spectra and correct at post-processing
  (in spenvis, in particular, more flexibility on input choice would be desirable)

- **generation of primaries:** review of primary generation methodology
  event biasing (reduce execution time) ->
  essential for on-line efficient use (spenvis)

- **Sensitive detector and scoring :** use "recent" scoring capabilities of Geant4 (exec.time?)
  Review fluence to ED and ADE conversion factor

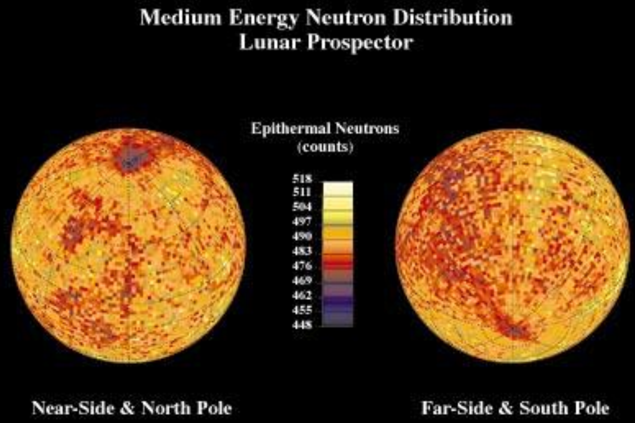
- **Physics lists:** G4 physics lists changed significantly since 2009: update needed !

- **Outputs:** Review of output variables including dosimetric quantities (e.g.: dose equivalent would be useful)

The Moon

Radiation environment: similar to Mars

- **No Atmosphere**
- **Very weak localized crustal magnetic field**
- **Radiation environment**
  - **SEP and GCR @ 1AU**
  - **Albedo neutrons (modulated by H2O)**
  - **No radiation belts**



Measured Neutron spectra
(Lunar Prospector)

Lunar Radiation Environment Model

TO BE DONE

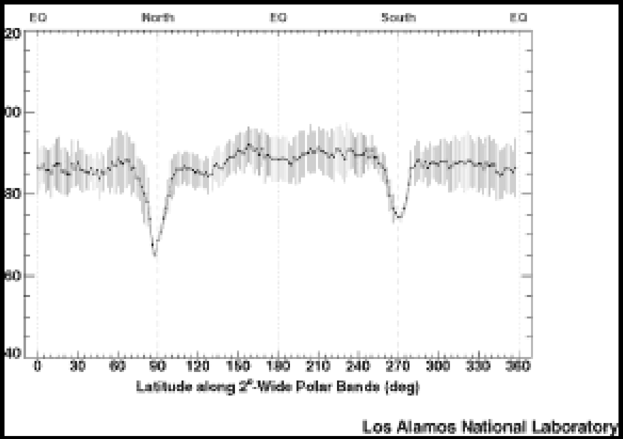
Map the radiation Environment on the Moon as a function of latitude-longitude & season

Inputs:

- data characterizing the topography & the soil composition for the whole moon
  (with good spatial resolution)
- GCR and SEP fluxes @ 1 AU
  (from different data & models)

Validation & **benchmarking**

- **With existing data**
  (instruments in orbiters: LEND, CRATER,RADOM)
- Comparison with other models (Langley, etc.)



Ongoing and planned activites

Review and upgrade dMEREM

Revisit dMEREM, make it more user friendly and faster!

A lot went on inside G4 since v9.1 ...

Validate dMEREM with data from Mars surface

Gale Crater dMEREM prediction analysis is in preparation

Develop a Lunar Energetic Radiation Environment Mode

Radiation map the Lunar radiation environment with a model based on the same strategy as dMEREM

Analyse data from Lunar missions

Assess human Lunar missions hazards and mitigation strategies