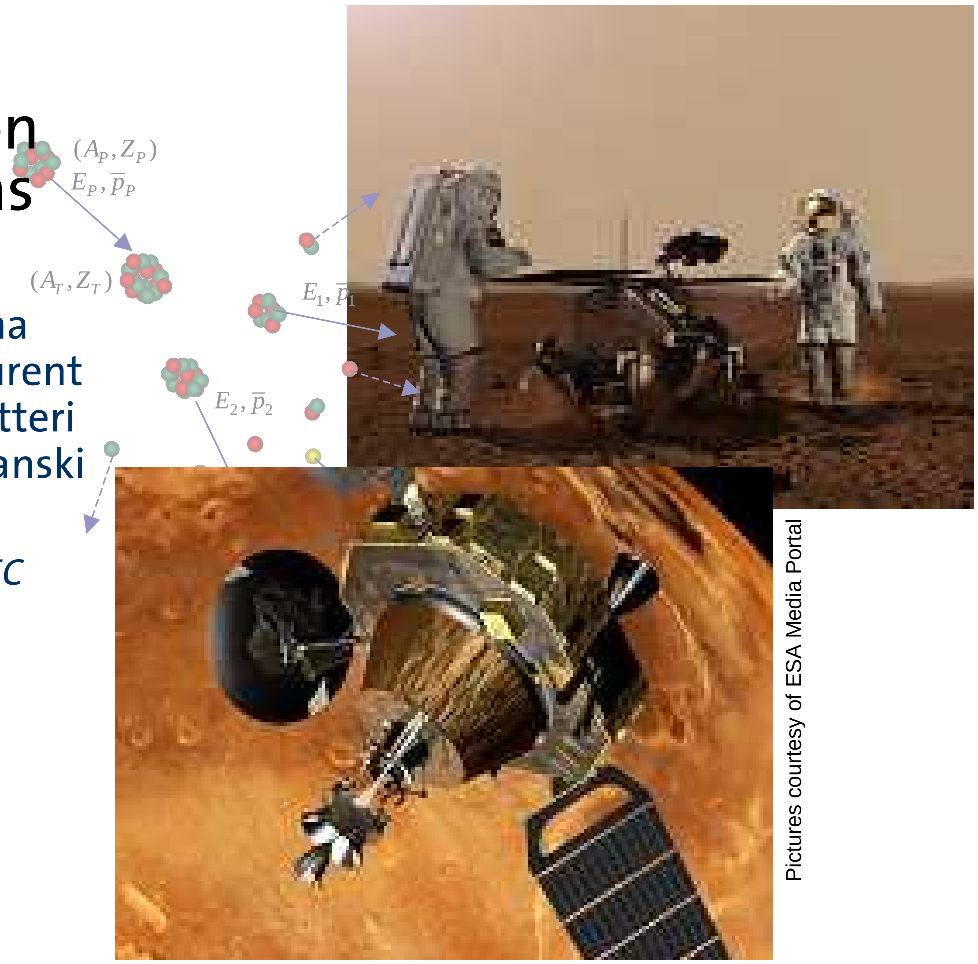
eMEREM and dMEREM: New Models to Predict the Radiation Environment for Mars Missions



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Background on Mars Radiation Environment

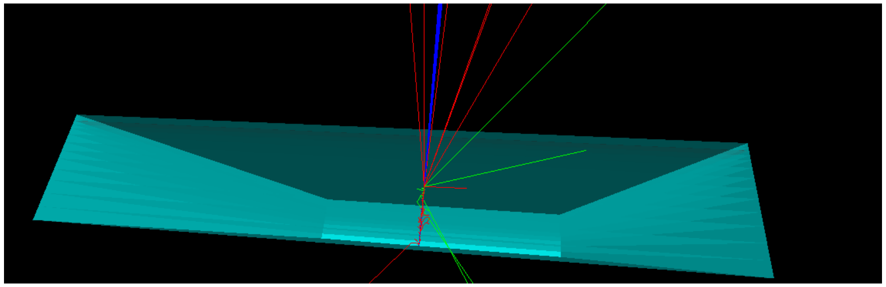
- Interplanetary missions to Mars carry with them significant risk from long-term exposure to ionising radiation
- Almost all experience for manned space-flight accumulated from LEO missions
- Galactic cosmic ray ions and solar energetic particles principal risk for interplanetary space
- Shielding can have limited or even a detrimental effect:
  - leads to the generation of high multiplicity of lower-energy (and more ionising) secondaries
  - Need to have strategies to slow and stop energetic heavy ions with minimal production of highly ionising nuclear fragments
- Once at Mars, risk is not diminished:
  - Tenuous atmosphere means secondary particle production maximises just beneath the surface of the planet – radiation dose at surface of planet can be worse
- Radiation threat needs accurate assessment to understand trade-off space in mission/spacecraft design
- Need easy-to-use tools to be used by mission designers and planners as well as radiation experts, to assess radiation received for different mission profiles and mitigation strategies
- Applicable to surface/sub-surface conditions or in the atmosphere of Mars, as well as for orbital spacecraft, and Phobos/Deimos landers

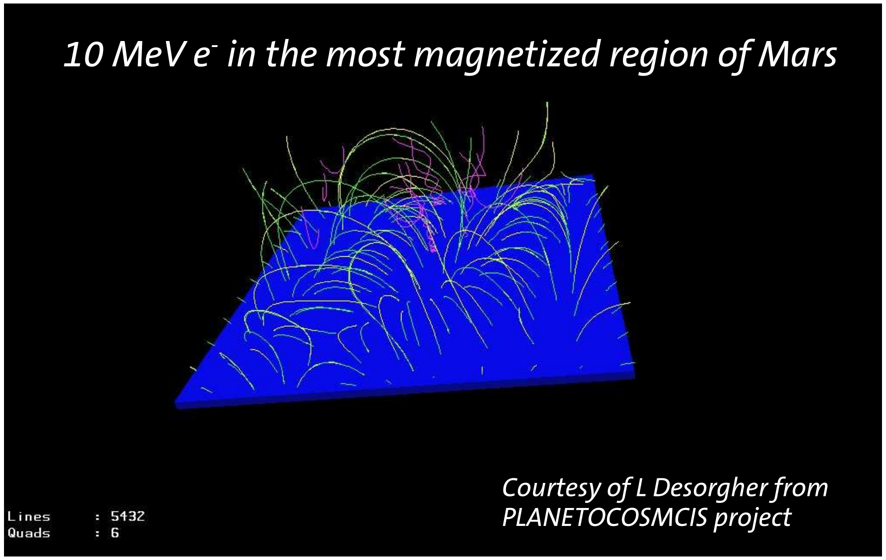
MarsREM activities

- Created **two radiation environment models** for future Mars missions
- Detailed Martian Energetic Radiation Environment Model (**dMEREM**)
  - Merge and extend MarsREC & Mars-Planetocosmic models for the Mars, Phobos and Deimos, including treatment of surface topology and composition, subsurface, atmospheric composition and density (including diurnal and annual variations), and local magnetic fields.
- Engineering Martian Energetic Radiation Environment Model (**eMEREM**)
  - Base also on approach used in QinetiQ Atmospheric Radiation Model for Earth (http://qarm.space.qinetiq.com)
- **SEP** (different models), **GCR** (alpha, proton, HI) and **X-ray**
- Tools are for **use by mission designers and planners** as well as radiation experts
- Web-based and interfaced with existing radiation shielding and effects simulation tools at the SPENVIS web-site
- Assess the requirements gaps in **Geant4 energetic nuclear-nuclear simulations**, and implemented into Geant4 interface to **DPMJET-II.5** model

Detailed Mars Energetic Radiation Environment Model (dMEREM)

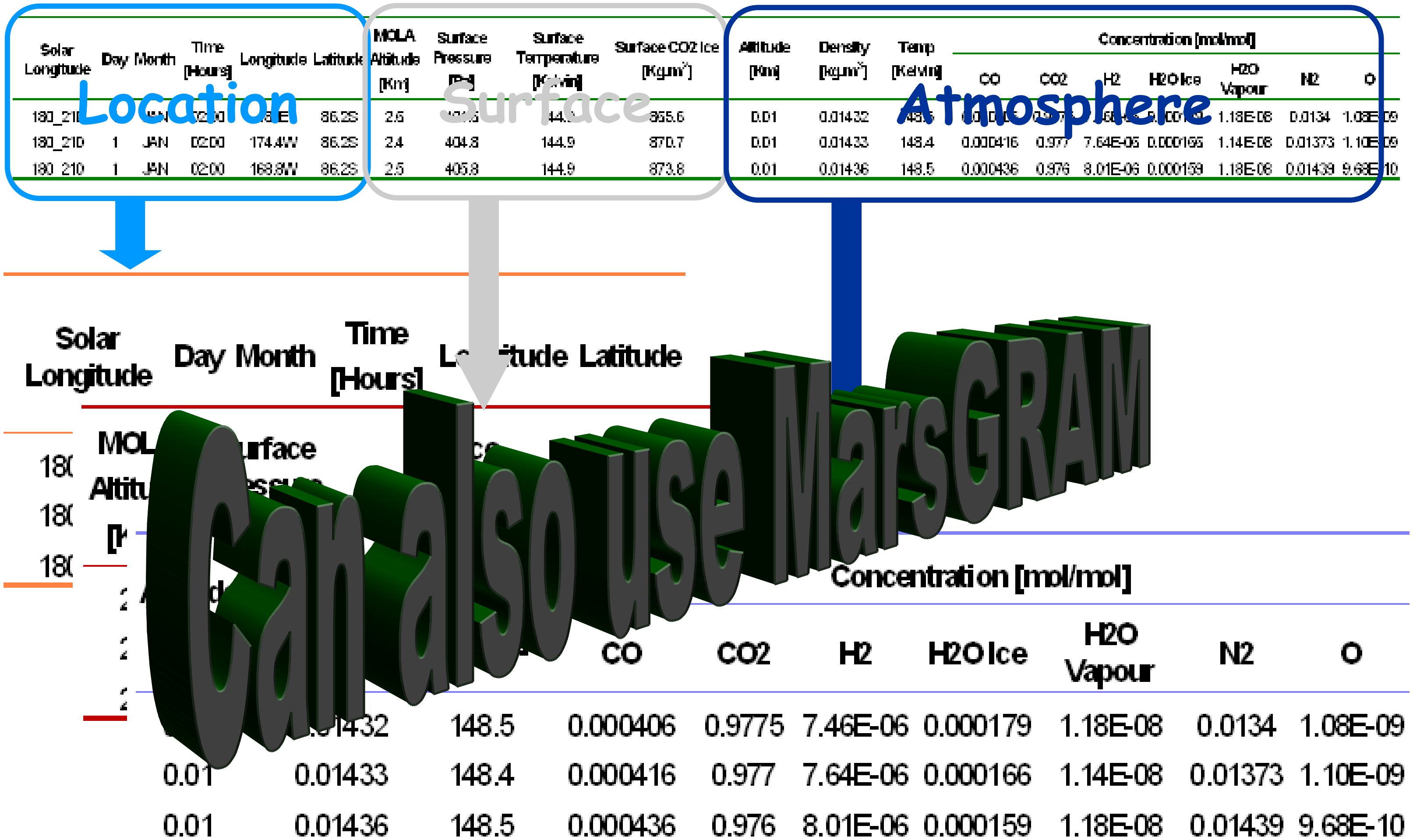
- dMEREM is a **Geant4-based** application to simulate GCR and SEP (protons and heavier ions) and X-ray propagation through the Martian atmosphere and soil
- Based on an extension of **MARSREC** and **PLANETOCOSMICS** codes
- Treats point locations above/within Martian atmosphere or subsurface + moons
- Propagation of **all secondaries**
- Treats protons & heavier ions, neutrons, e^-, γ/X-rays, $\mu^{\pm}$, $\pi^{\pm}$
- **Energy** as well as **LET spectra** for Si & H_2O
- Treats internal **magnetic fields**, relevant to energetic electrons





Courtesy of L Desorgher from PLANETOCOSMCIS project

Atmospheric Table (MACLIDIG5) based on Mars Climate Database (MCD)



Solar Longitude	Day	Month	Time [Hours]	Longitude	Latitude	MOLA Altitude [Km]	Surface Pressure [Pa]	Surface Temperature [Kelvin]	Surface CO2 Ice [Kg/m²]	Altitude [Km]	Density [kg/m³]	Temp [Kelvin]	CO	CO2	H2	H2O Ice	H2O Vapour	N2	O
180_210	[illegible]	[illegible]	[illegible]	[illegible]	86.2S	2.6	[illegible]	[illegible]	865.6	0.01	0.01432	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1.18E-08	0.0134	1.08E-09
180_210	1	JAN	02:00	174.4W	86.2S	2.4	404.8	144.9	870.7	0.01	0.01433	148.4	0.000416	0.977	7.64E-06	0.000166	1.14E-08	0.01373	1.10E-09
180_210	1	JAN	02:00	168.8W	86.2S	2.5	405.8	144.9	873.8	0.01	0.01436	148.5	0.000436	0.976	8.01E-06	0.000159	1.18E-08	0.01439	9.68E-10

Altitude [Km]	Density [kg/m³]	Temp [Kelvin]	CO	CO2	H2	H2O Ice	H2O Vapour	N2	O
[illegible]	[illegible]	148.5	0.000406	0.9775	7.46E-06	0.000179	1.18E-08	0.0134	1.08E-09
0.01	0.01433	148.4	0.000416	0.977	7.64E-06	0.000166	1.14E-08	0.01373	1.10E-09
0.01	0.01436	148.5	0.000436	0.976	8.01E-06	0.000159	1.18E-08	0.01439	9.68E-10

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Pre-Processor (SOILCOMPI) results summary

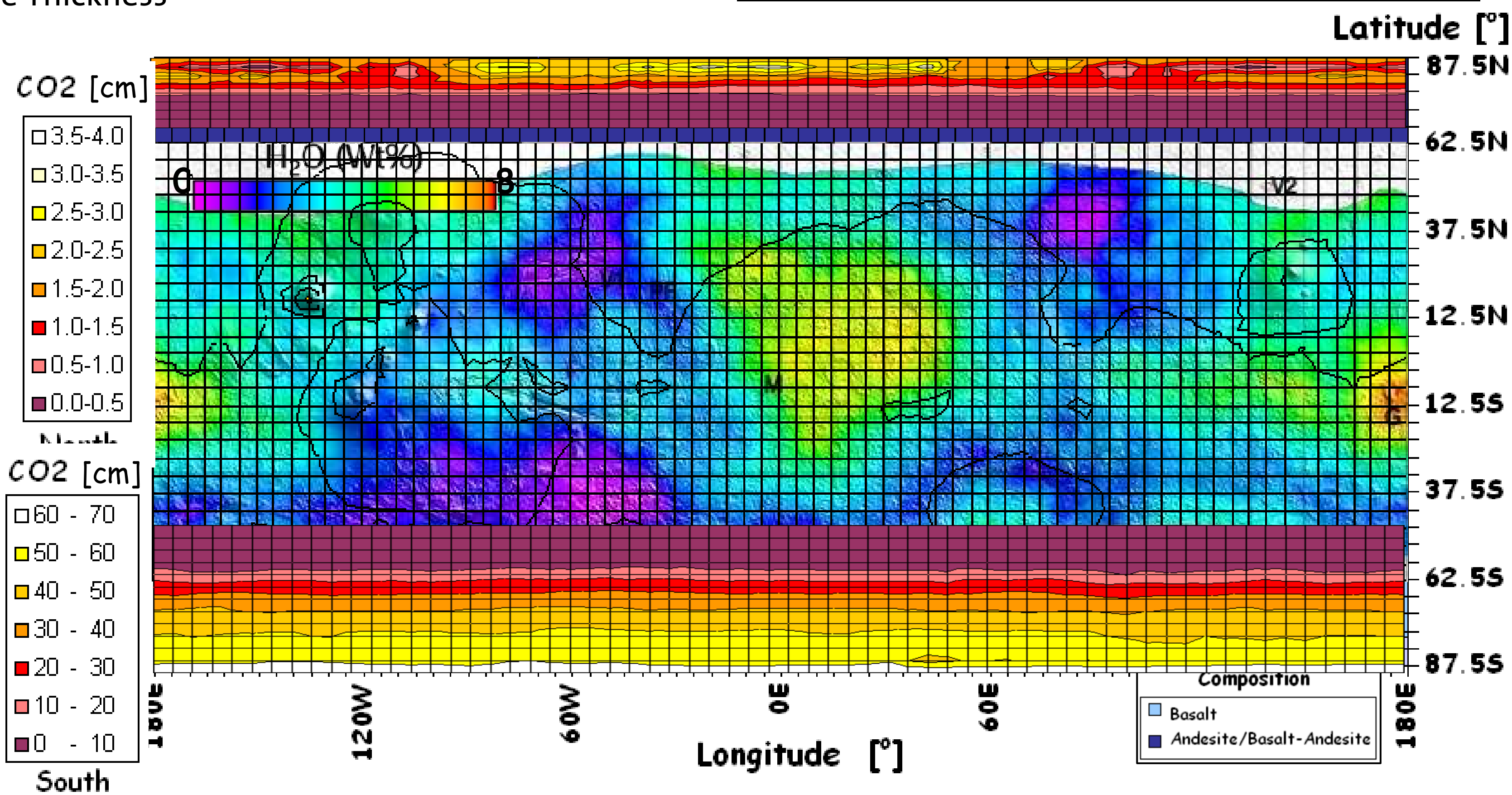
Fe2O3 [Wt%]

SiO2 [Wt%]

H2O [Wt%]

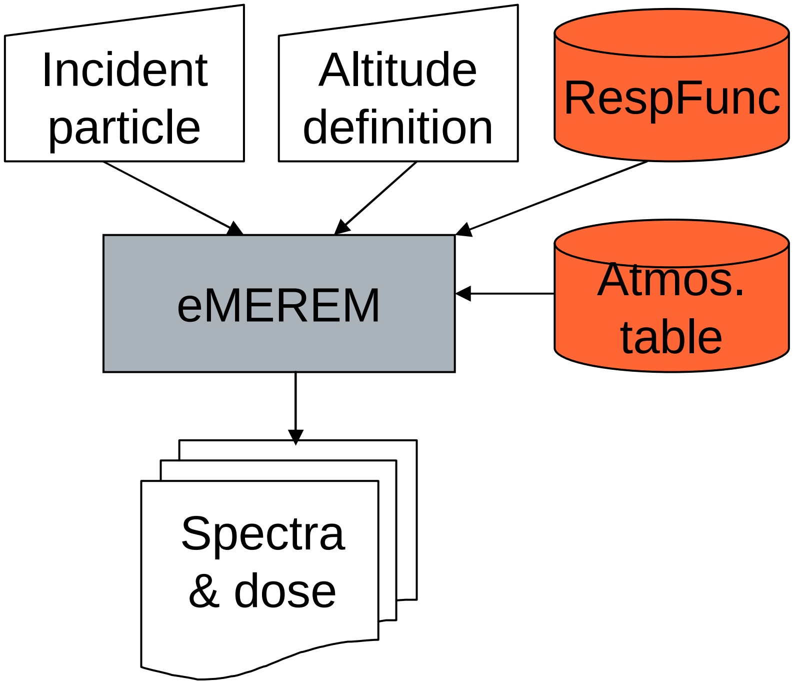
CO2 ice Thickness

Composition	Basalt-Andesite (adapted from Generic) [Weight percentage (%)]
Si_2O	51.2
Fe_2O_3	9.3
Bulk ($Al_2MgCa\ Na_2\ K_2O_7$)	32.1
FeS	0.0
H_2O	7.4
Total	100.0



Engineering Mars Energetic Radiation Environment Model (eMEREM)

- Based on the same principles as the **QinetiQ Atmospheric Radiation Model**
- Uses a series of **response function data bases** which quantify the particle flux in the atmosphere/soil per unit incident monoenergetic flux at the top of the atmosphere
  - 50 energies from 10MeV/n to 1TeV/n
- **Atmosphere**: 22 g/cm^2 in 22 layers ($1 g/cm^2$ per layer), extend to 50 km altitude (based on MCD)



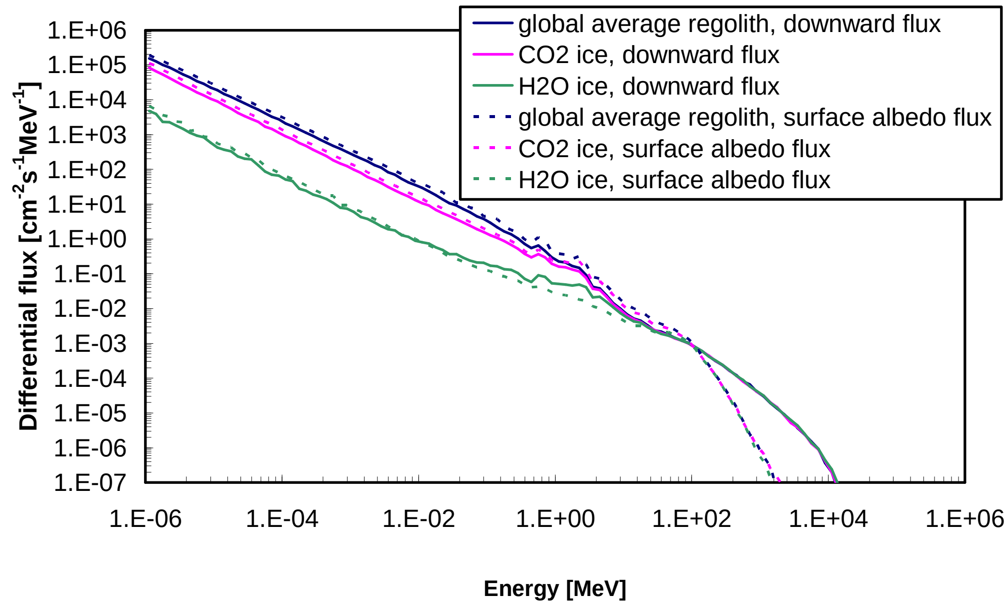
- **Regolith**: 14 spherical layers total thickness to 5000 g/cm^2; composition uses data from dMEREM preprocessor
  - Globally averaged, Equatorial average, Water ice (>80°), Dry-ice (>80°)

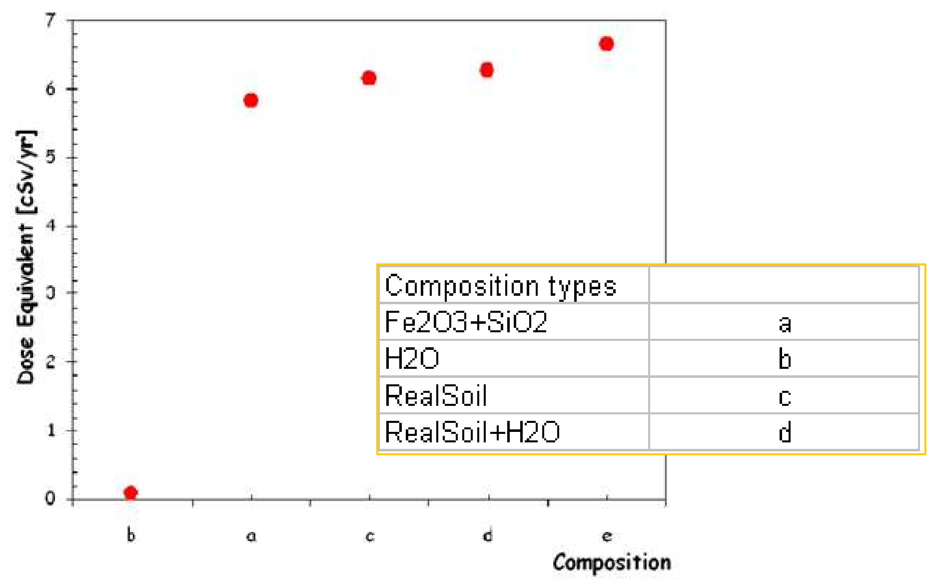
$$\psi(t,E,P) = \int_{E'=10MeV/nuc}^{E'=1TeV/nuc} \Psi(t,E,E',P)\cdot\Phi(E')dE'$$

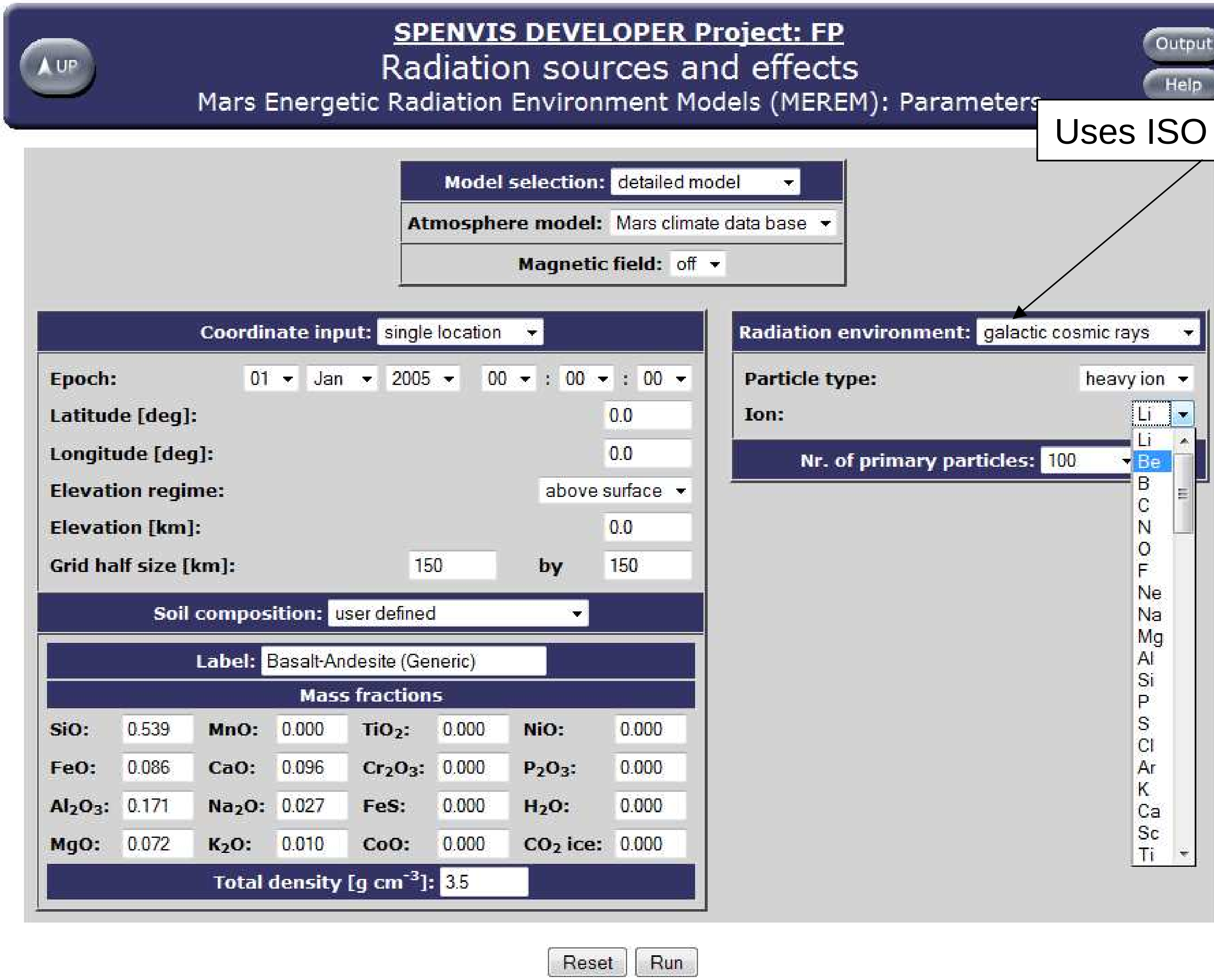
Where $\Psi(t,E,E',P)$: the response function matrix
$\Phi(E')$: the incident particle spectrum

Engineering Mars Energetic Radiation Environment Model eMEREM – response function database

- Current response database uses FLUKA results, but could use Geant4/dMEREM
- Currently protons and α-particle sources treated up to 1TeV/nuc
- Radiation particle type recorded: Up/downwards particle energy spectra at layer boundaries
  - 100 keV (1 eV, n) – 1 TeV
  - e, γ, p, n, μ±, π±, α,
- LET(Si), LET(H_2O), ambient dose eqv. and effective dose
- Scoping calculations performed to assess validity of some of these approximations
  - Little effect of ground density and composition except
  - WATER IS VERY IMPORTANT







Uses ISO 15390

Tool developed by

UP

SPENVIS DEVELOPER Project: FP

Radiation sources and effects

Mars Energetic Radiation Environment Models (MEREM): Parameters

Output
Help

Model selection: engineering model

Coordinate input: single location

Epoch:	01 Jan 2005 00 : 00 : 00
Latitude [deg]:	0.0
Longitude [deg]:	0.0
Elevation regime:	subsurface
Depth [g cm^{-2}]:	2.0

Soil composition: user selection

Composition:	global (global, equatorial, dry ice, water ice)

Radiation environment: solar energetic protons

Definition:	ESP total fluence
Confidence level [%]:	95.0
Prediction period [years]:	10.0
Distance from the Sun [AU]:	1.5
Distance scaling:	*R*^ -2

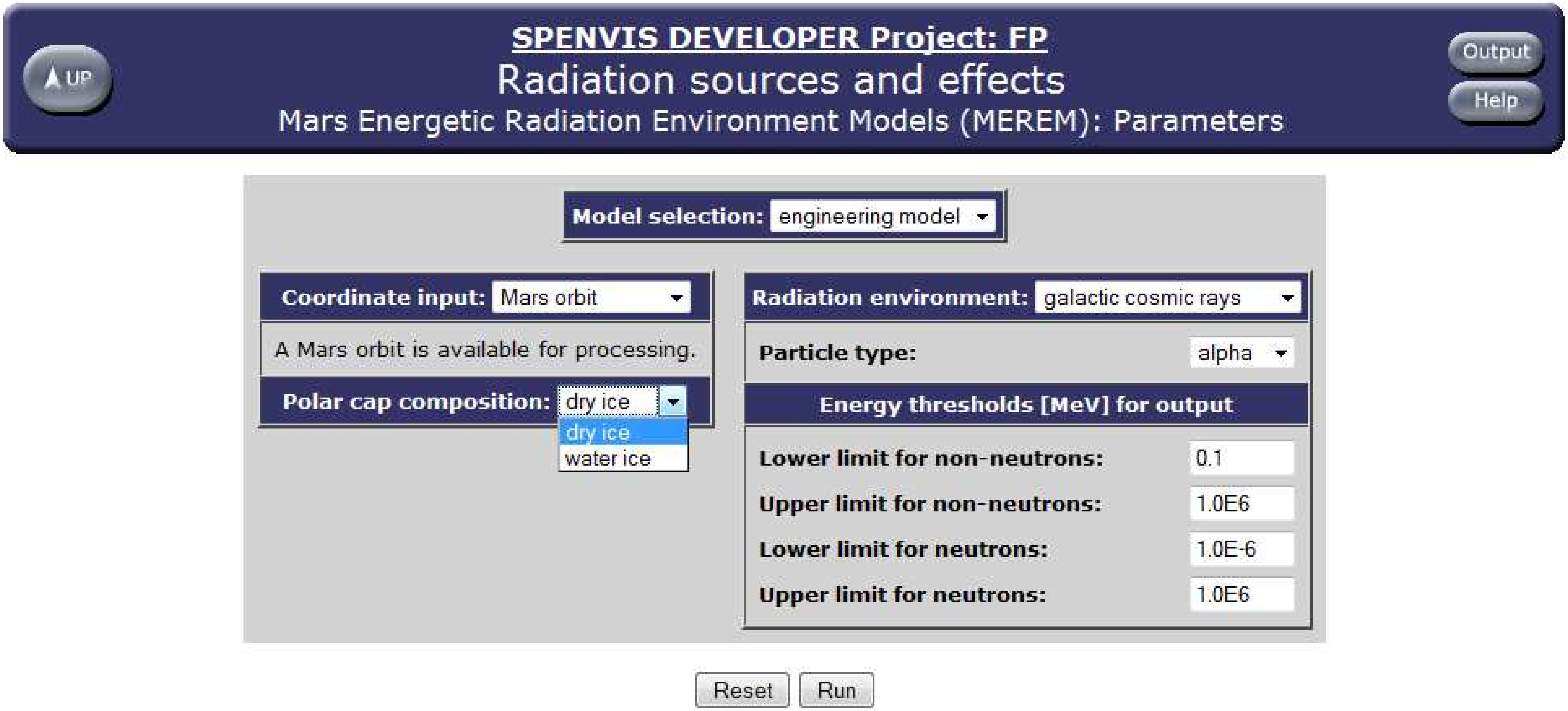
Energy thresholds [MeV] for output

Lower limit for non-neutrons:	0.1
Upper limit for non-neutrons:	1.0E6
Lower limit for neutrons:	1.0E-6
Upper limit for neutrons:	1.0E6

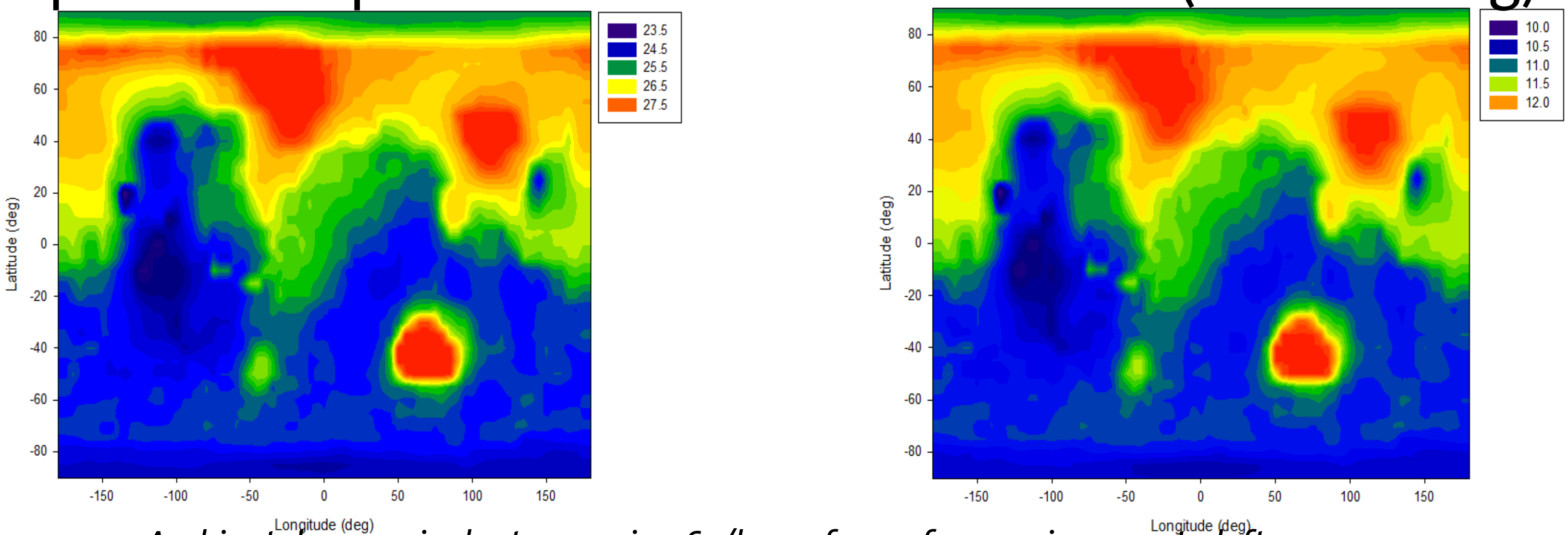
Reset Run

Tool developed by

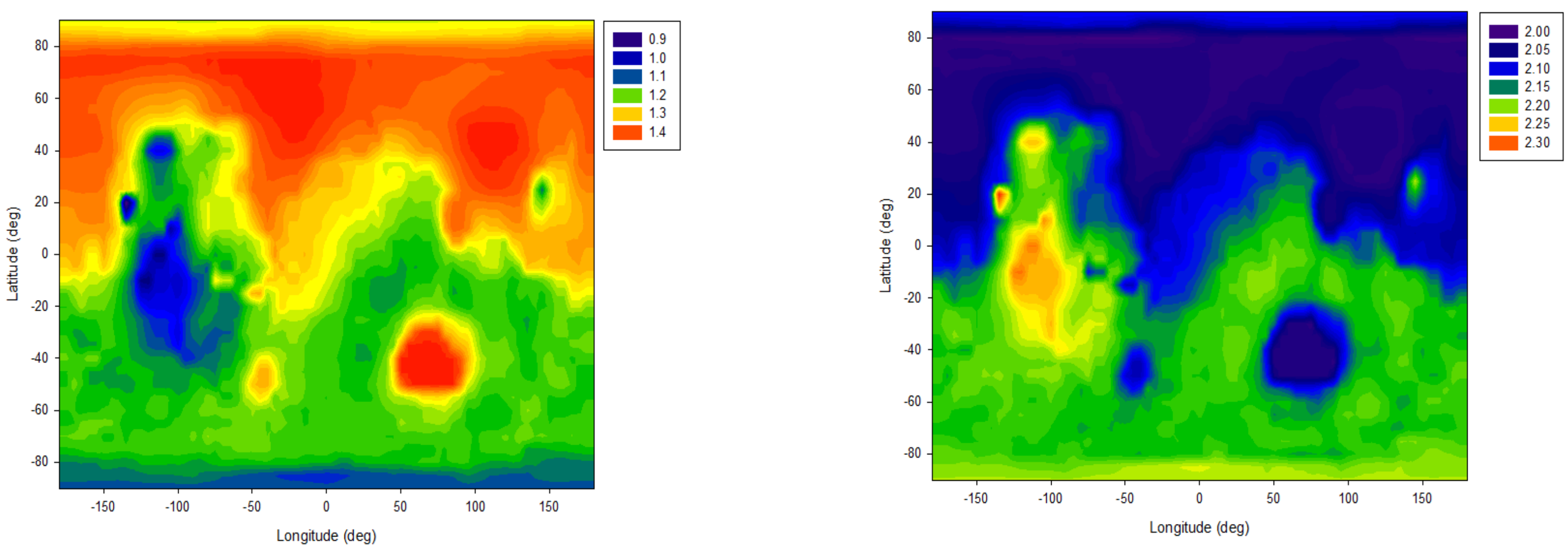
QinetiQ
LIP
DCH
Space IT


UP
SPENVIS DEVELOPER Project: FP
Radiation sources and effects
Mars Energetic Radiation Environment Models (MEREM): Parameters
Output
Help
Model selection: engineering model
Coordinate input: Mars orbit
A Mars orbit is available for processing.
Polar cap composition: dry ice
dry ice
water ice
Radiation environment: galactic cosmic rays
Particle type: alpha
Energy thresholds [MeV] for output
Lower limit for non-neutrons: 0.1
Upper limit for non-neutrons: 1.0E6
Lower limit for neutrons: 1.0E-6
Upper limit for neutrons: 1.0E6
Reset
Run
Tool developed by

GCR proton + α-particle induced environments (no shielding)



Ambient dose equivalent maps, in μSv/hour, for surface environment - left: solar minimum, right: solar maximum



Particle flux maps for surface of Mars at solar minimum:
Left: neutrons >100MeV; Right: protons >100keV. Flux units are particles-cm^{-2}s^{-1}.

	Location	Depth [g/cm²]	Source	Primary species	Ambient dose equiv. [cSv/yr]
dMEREM	Viking 1	17.8	GCR(max.flux) Day / 137°SL	protons	14.5
				alphas	3.5
					18.0
		17.9	GCR(max.flux) Night / 137°SL	protons	20.1
		20.5	GCR (min flux) Day / 253°SL	protons	22.3
				alphas	4.9
					27.2
	MER 2	15.9	GCR(max.flux) Day / 137°SL	protons	20.8
			GCR (min flux) Day / 253°SL		21.5
				alphas	7.0
HZETRN/MOLA			GCR	20-30	

		Elevation	Source	Dose equivalent [cSv/yr]
NASA Langley Research Center Models	Regolith	0 km	GCR Solar maximum	11.8
			GCR Solar minimum	29.3
	Dry Ice	0 km	GCR Solar maximum	6.4
			GCR Solar minimum	16.5
	Ice	0 km	GCR Solar maximum	4.7
			GCR Solar minimum	12.0

Mars Radiation Environment Experiment (MARIE) flown on Mars Odyssey and reported by Saganti:

- Average GCR-induced dose measured by the instrument in orbit during August 2003 was 214 µGy/day
- Of this 120 µGy/day (56%) predicted to be proton & α-induced
- eMEREM prediction for solar max is 71 µGy/day

Conclusions

- **Detailed** and **engineering models**, dMEREM and eMEREM, have been developed to predict the Martian radiation environment (in **atmosphere**, in **orbit**, and on **moons**)
  - Based on Geant4 and FLUKA for accurate physical treatment in 3D
  - Through the Pre-processor, models accurately treat location-dependence of **atmospheric pressure**, **density** and **composition**, and **surface geology** and **topology**
- eMEREM and dMEREM used to **assess variability of environment with solar cycle** and **longitude**, **latitude** and thickness of **atmosphere**
- Results show good agreement with predictions from other models for surface environment and consistent with MARIE measurement data
- MarsREM Web-pages currently online under SPENVIS

Greatly benefit accessibility by the user community
- no other Mars radiation environment model provides this

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