# Neutron Derived Properties of the Martian Soil

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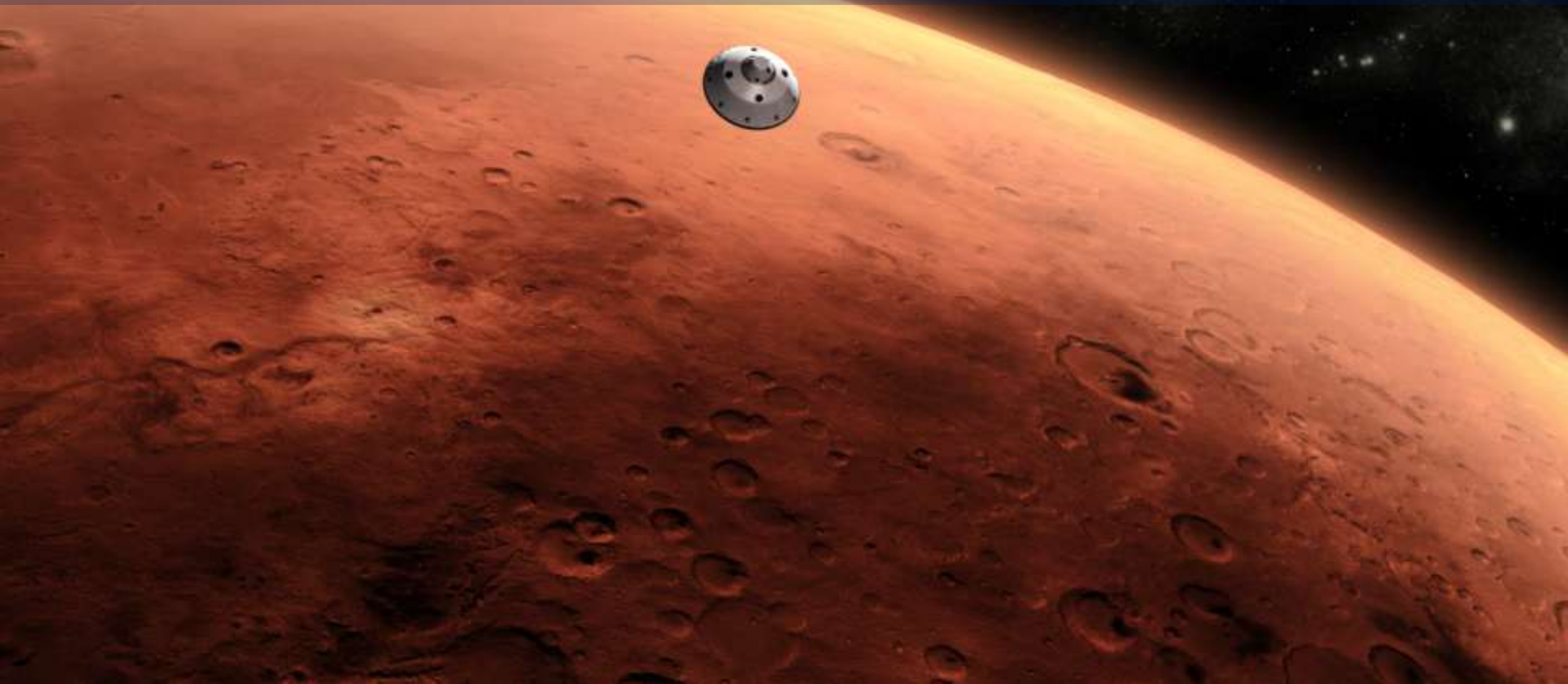



800m
ESA / DLR / FU Berlin (G Neukum)
Image NASA / USGS
13.20 mi
22°21'34.66" S 41°58'48.71" W elev

# An Examples of Present Space Missions

- **Mars Reconnaissance Orbiter**

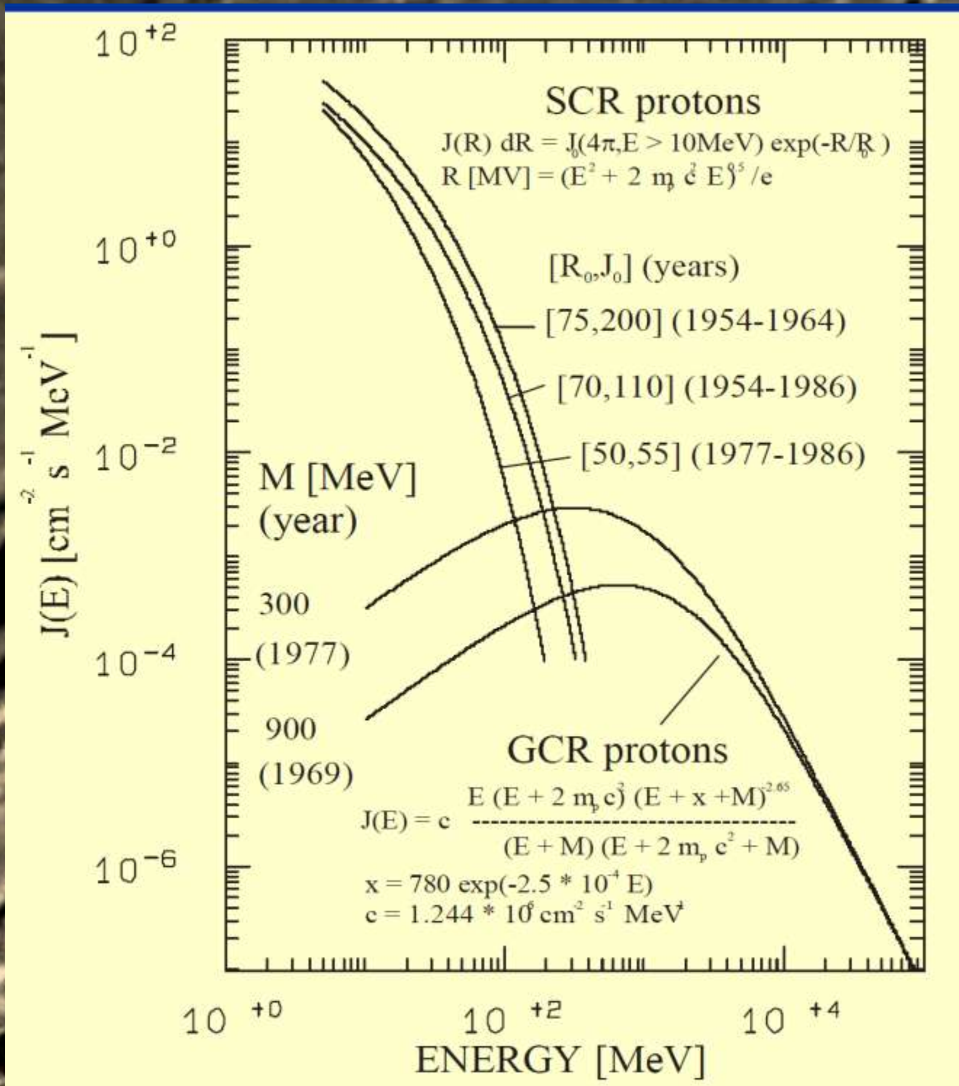
- **Mars Odyssey 2001**

- **International Space Station**

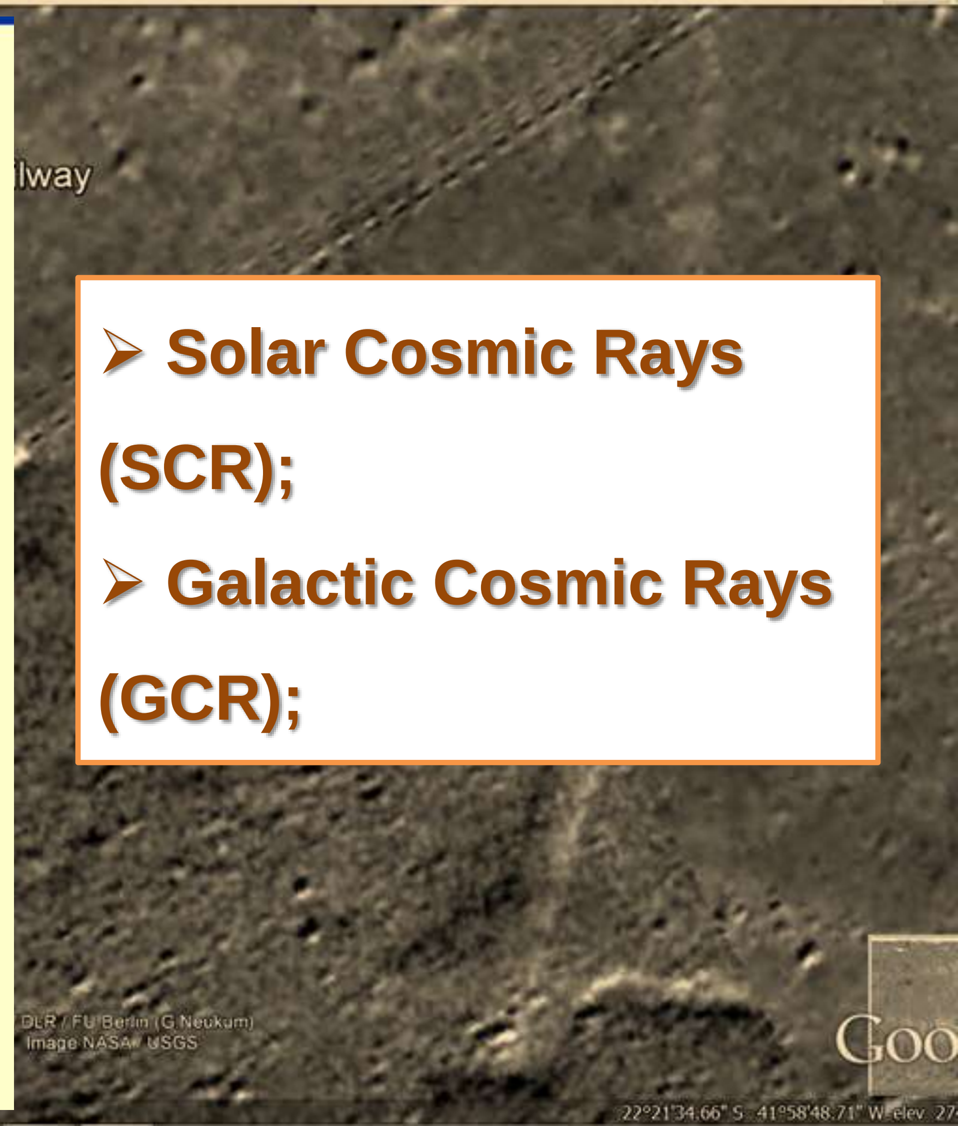
- **Lunar Reconnaissance Orbiter**

ESA/ DLR / FU Berlin (G Neukum)
Image NASA / USGS

# The Origin of Gamma and Neutron Radiation at Space

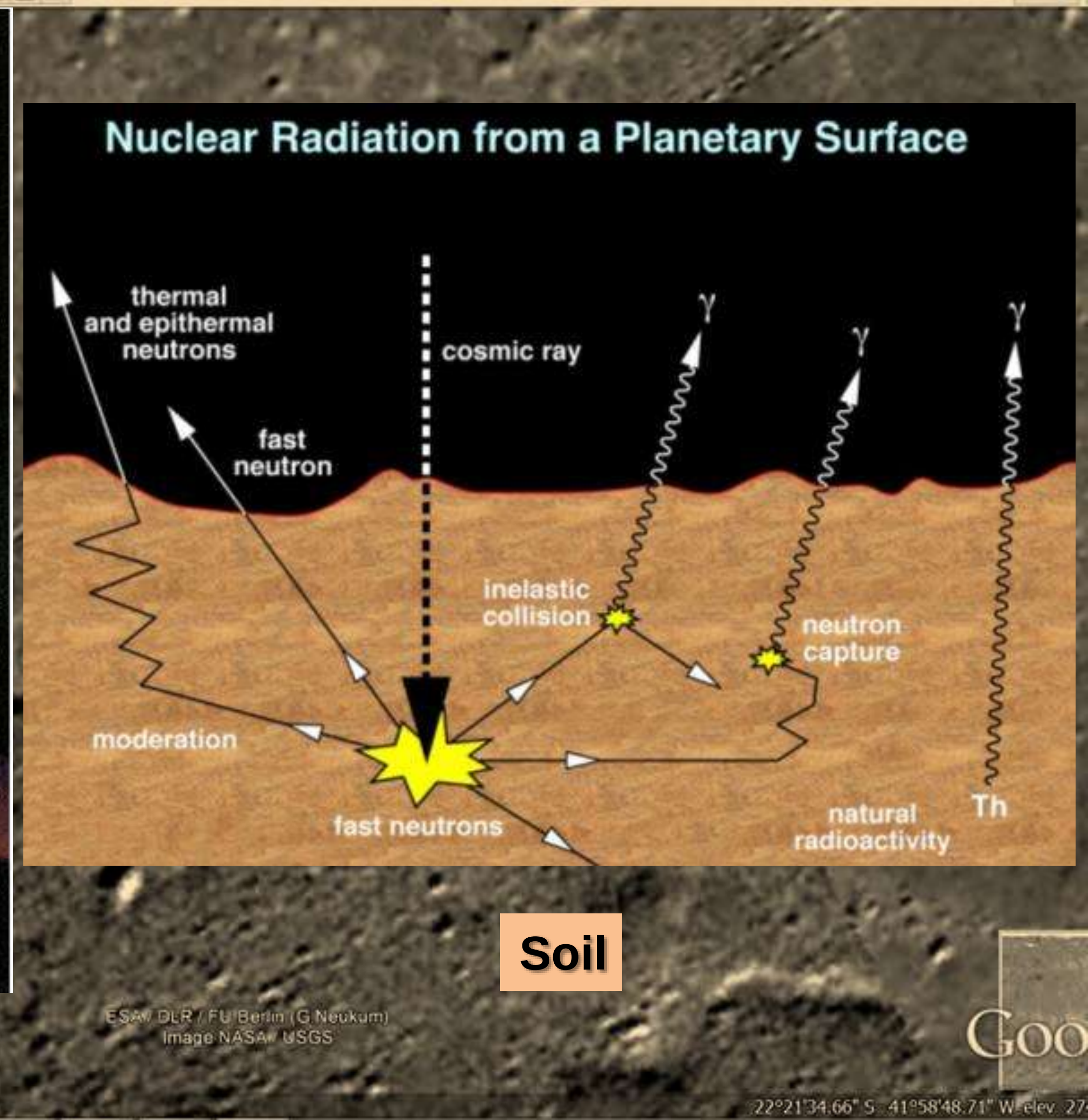



- **Solar Cosmic Rays (SCR);**
- **Galactic Cosmic Rays (GCR);**



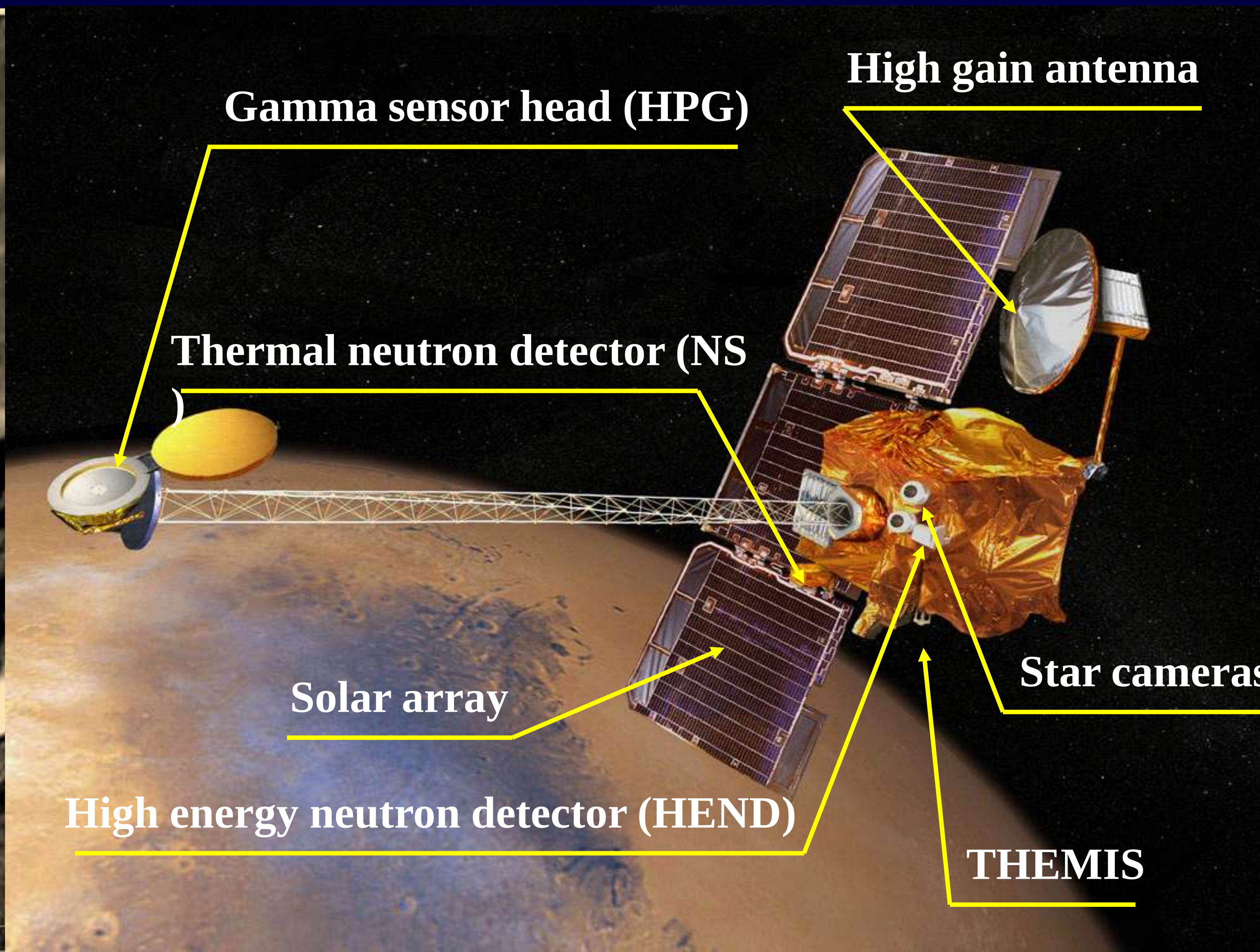
# SCR & GCR Interaction with Planets

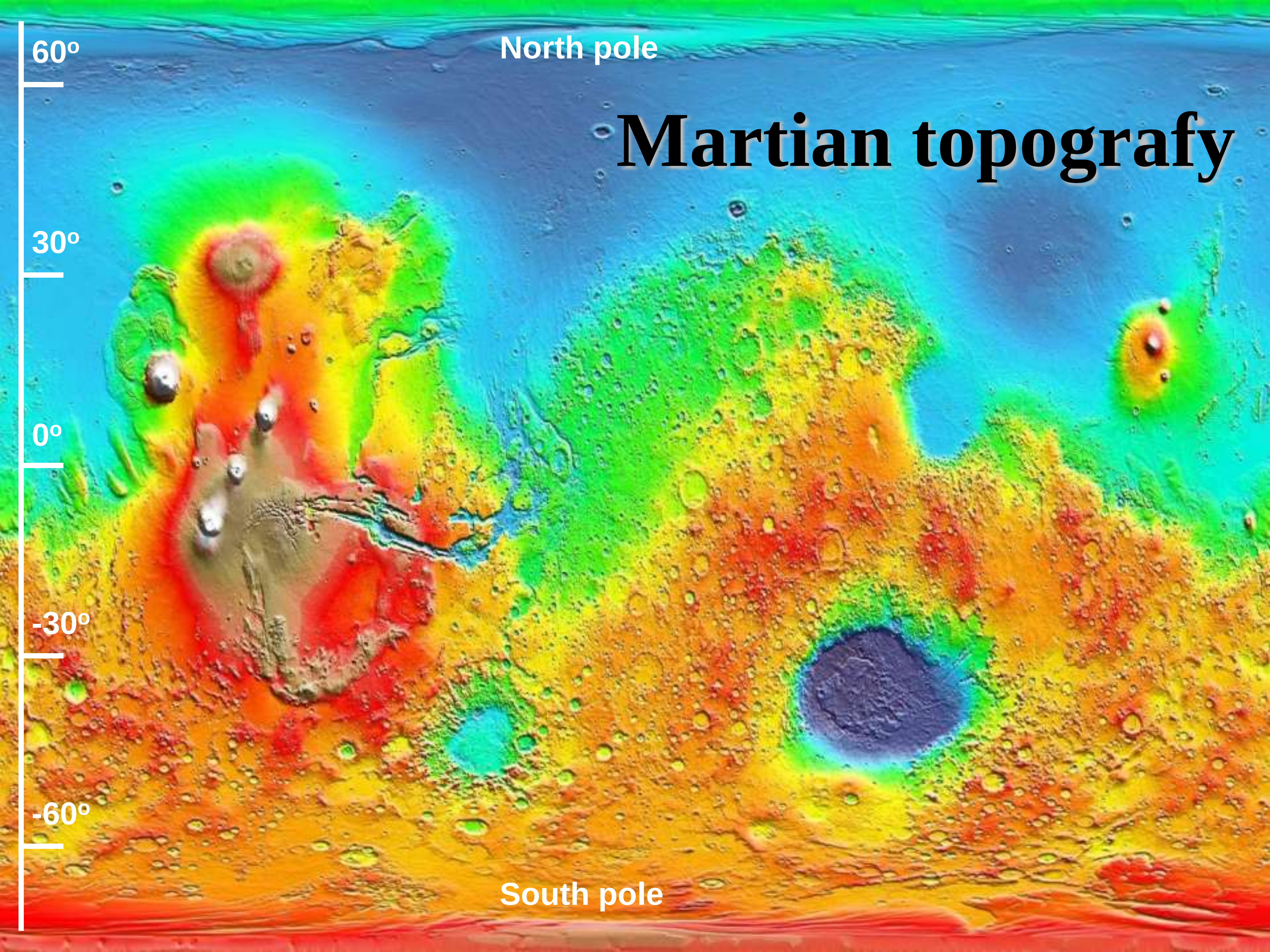
**Atmosphere**

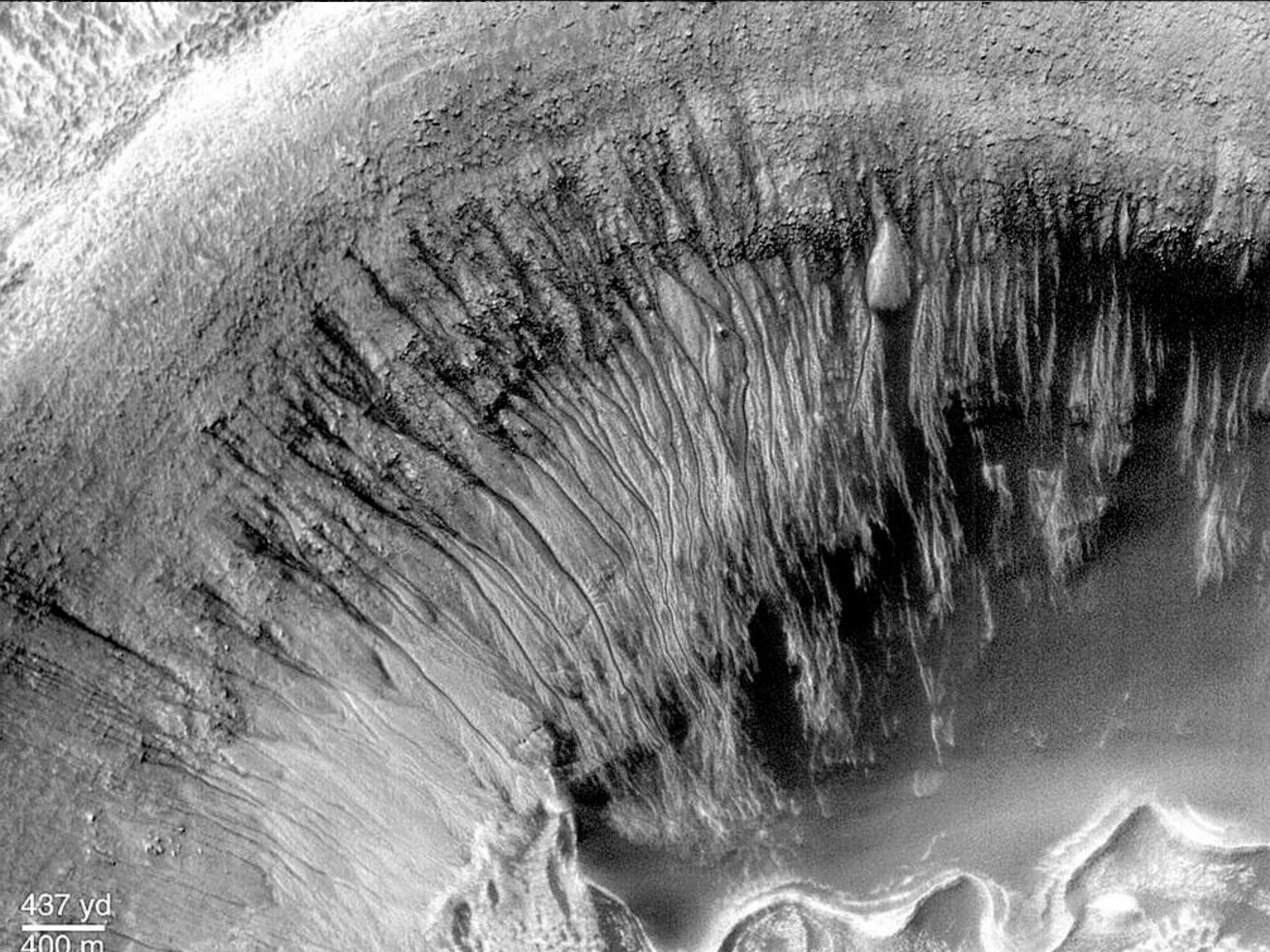



**Soil**

# Mars Odyssey 2001




Martian topografy
North pole
South pole
60°
30°
0°
-30°
-60°


437 yd
400 m

# HEND Creation

**Participants:**

Rosaviakosmos
RSRI
RSRI SDB
SNIIP
JINR
VIMS
e.a.

University of Arizona
NASA JPL
LMA
NASA KSC

**December 1999**

**September 2000**

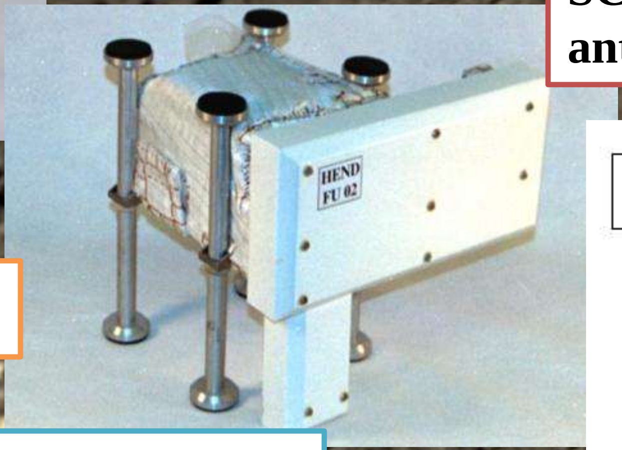
**April 7, 2001**

**February 19, 2001**

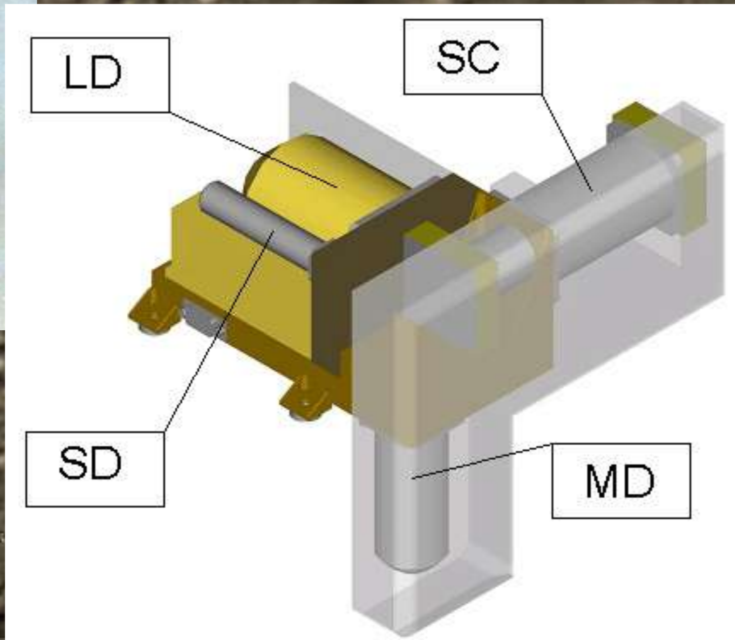
# Russian High Energy Neutron Detector (HEND)

**Total weight: 3.695 kg    Power supply: 5.7 watt**

**SD, MD, LD – $^{3}$He proportional counters enveloped with PE of different thickness**




**SC – stilbene scintillator with CsI anticoincidence counter**




**Pulse height analysis**

**5 sensors = 6 signals:**
**1-4 – neutrons 0.001 – 10 MeV**
**γ – 50-2000 keV**
**GCR and solar protons**

# "2001 Mars Odyssey" mission

*Space port "Cape Canaveral" (Florida, USA),*

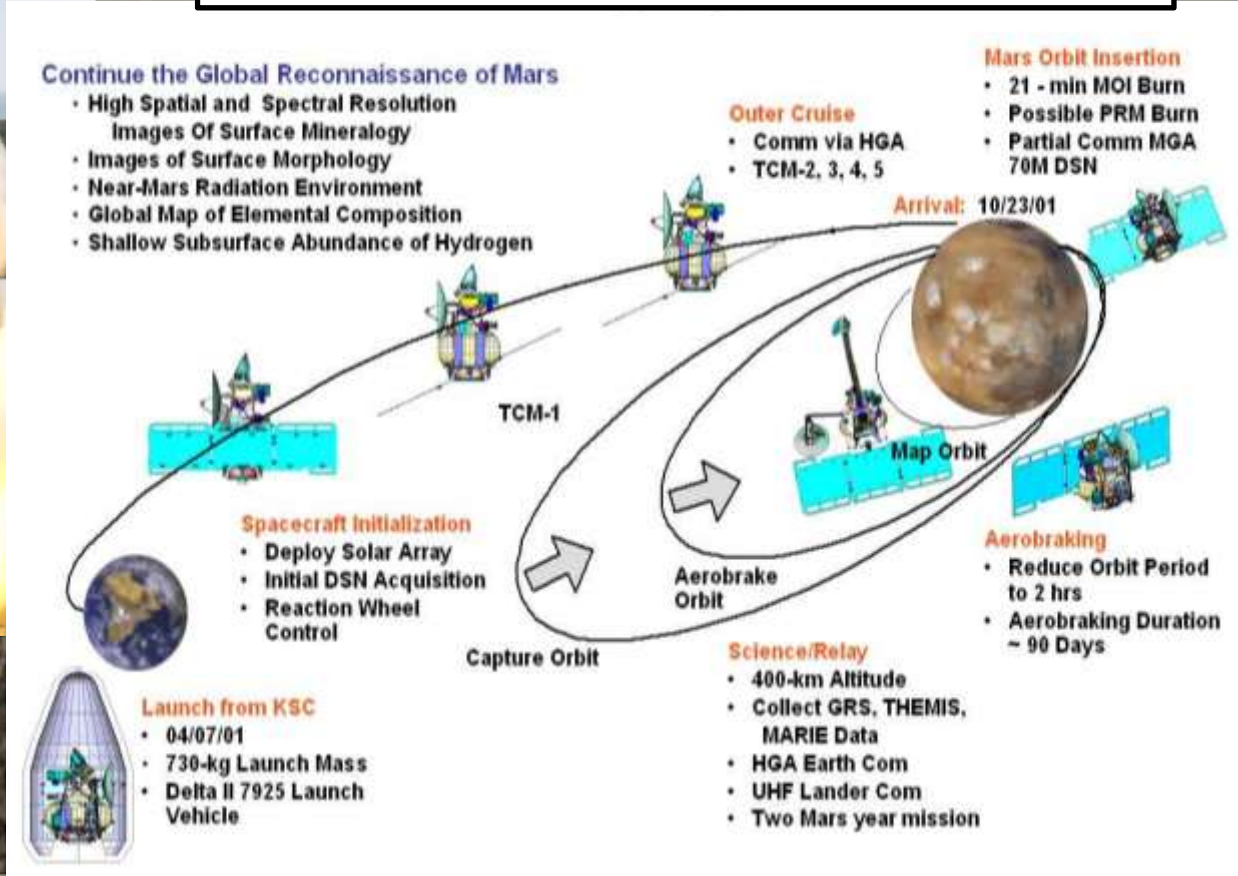
*04.07.2001*

*Arrival to Mars: 10.23.2001*

***Purpose of expedition:*** ***exploration of Martian surface (research of chemical composition of the surface and search for water);***

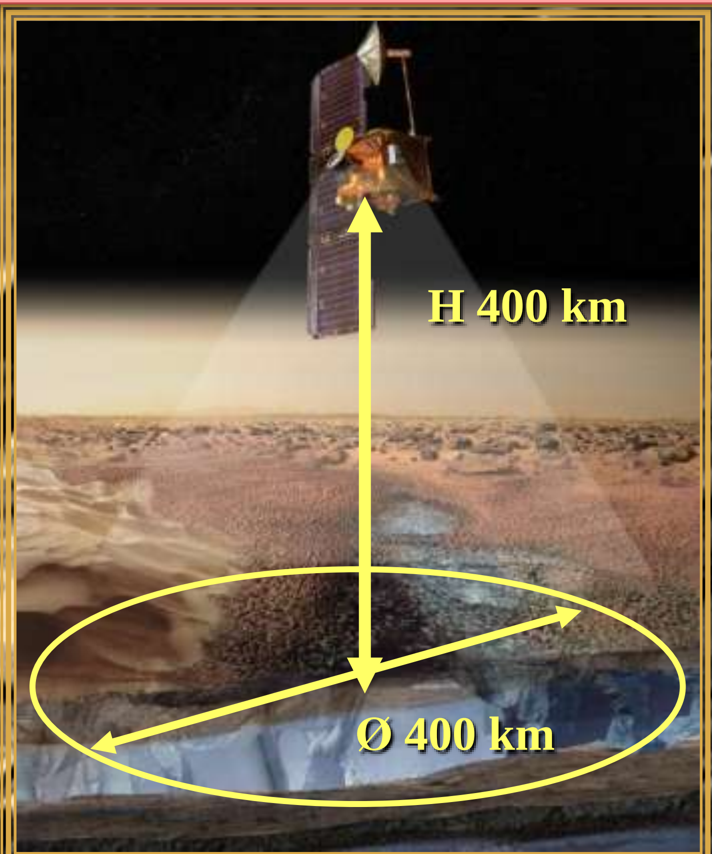
***Scientific equipment:*** ***HPG gamma-ray spectrometer (GRS), low energy neutron spectrometer (NS); high-energy neutrons detector (HEND); thermal emission imaging system (THEMIS); radiation environment measuring system (MARIE);***

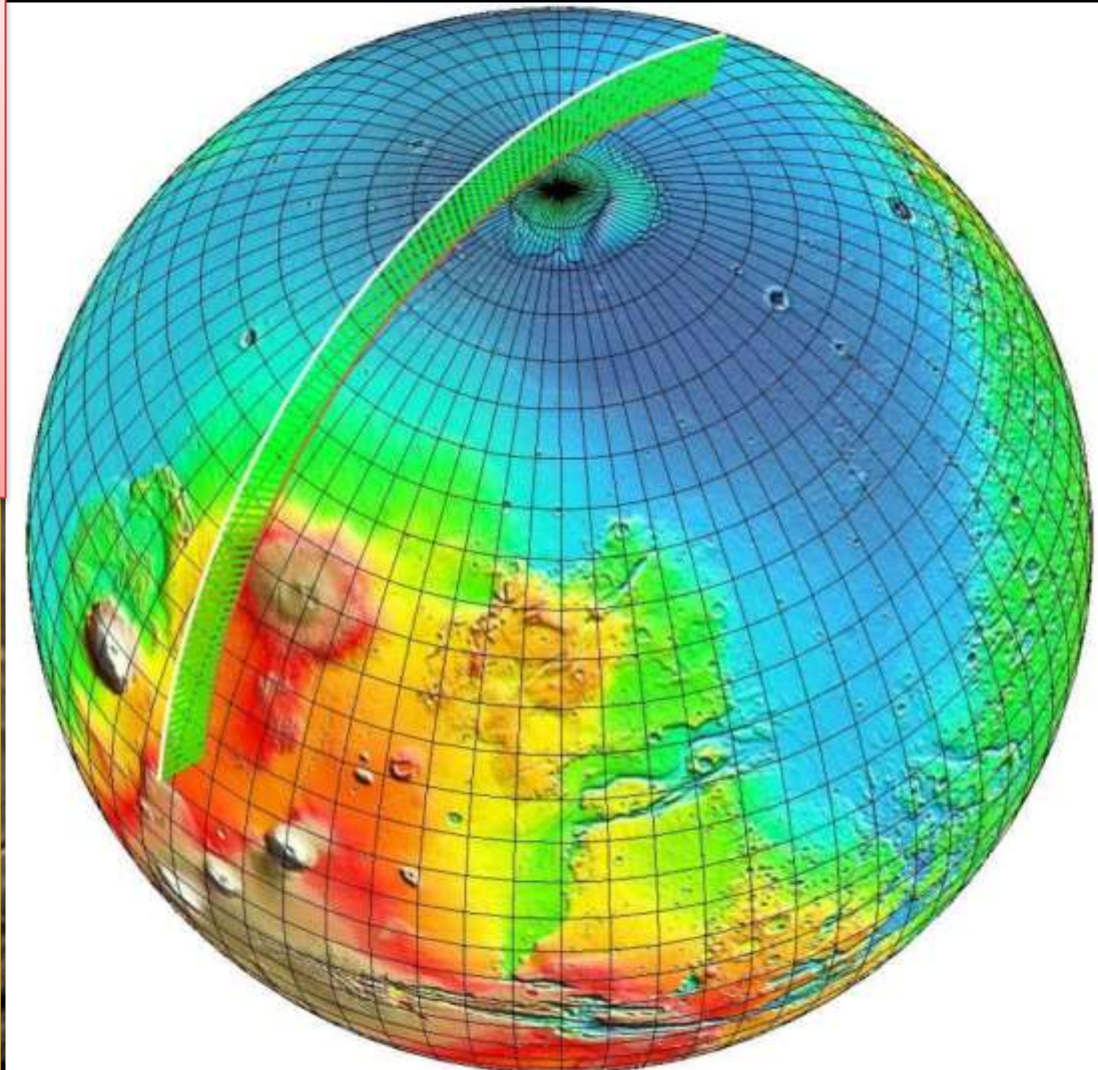
***Total mass of a scientific equipment:*** ***44.5 kg***



**Building the Map**

On the surface of planet making a mesh with selected size of pixels. In each pixel independently accumulating counts and exposure time. Selecting a time interval, detector and set of channels to create map.



***Main parameters of orbit:***

***Altitude – 400 km;***

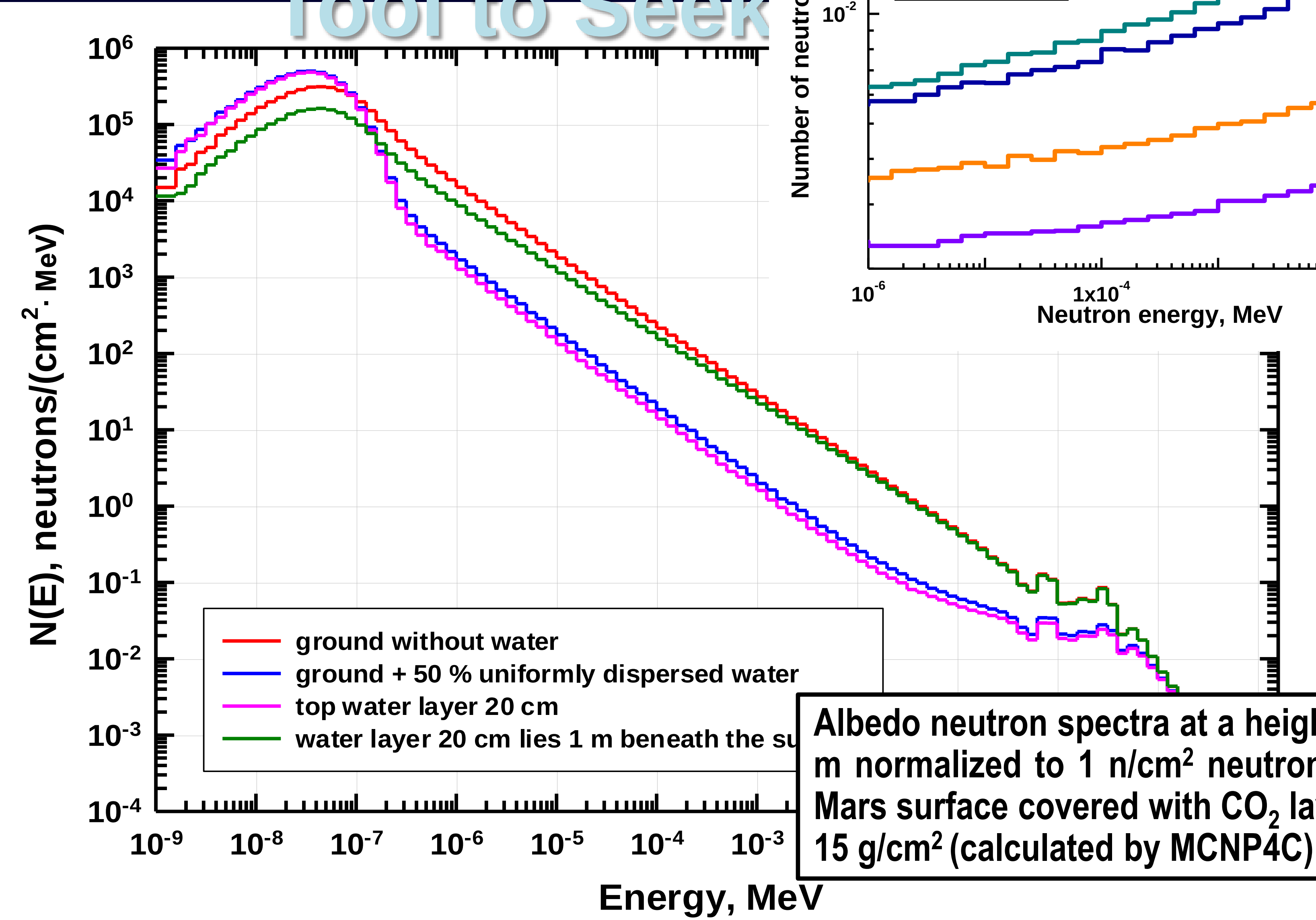
***Orbital period – 2 hours;***

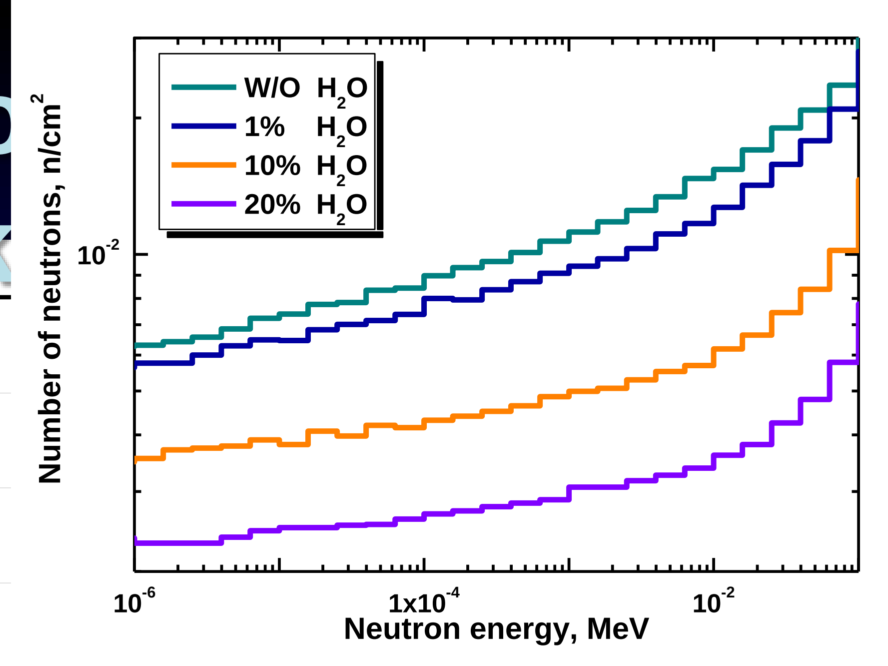
***Orbit inclination – 93.1$^{0}$***



22°21'34.66" S 41°58'48.71" W elev 27

# Neutron Detecto
# Tool to Seek

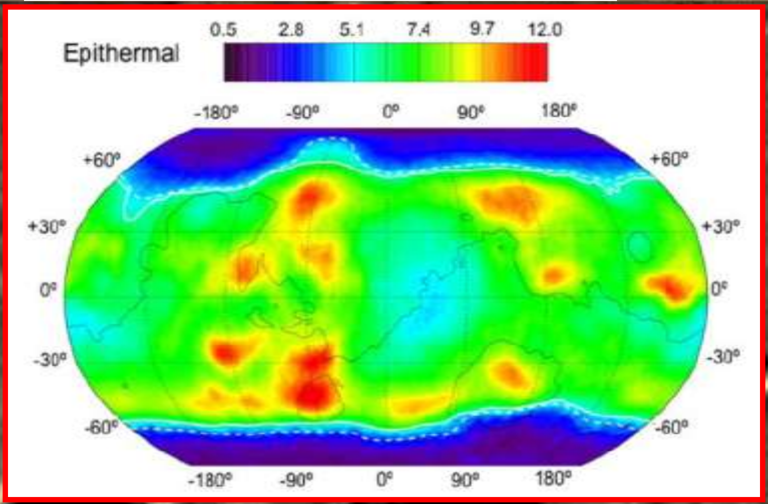


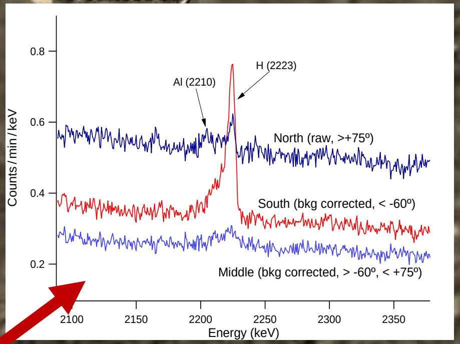

Albedo neutron spectra at a height of 400 km normalized to 1 n/cm$^2$ neutron flux from Mars surface covered with $CO_2$ layer 15 g/cm$^2$ (calculated by MCNP4C)

# Water Ice on Mars – Data from Three Detectors

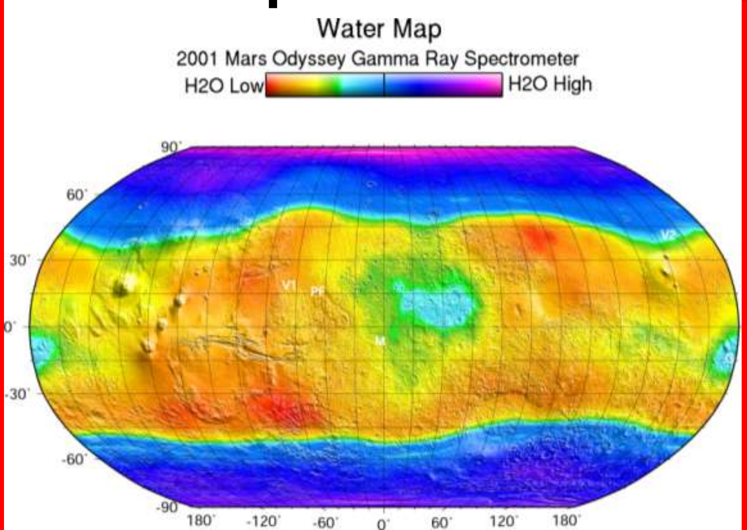
**Neutron Spectrometer**



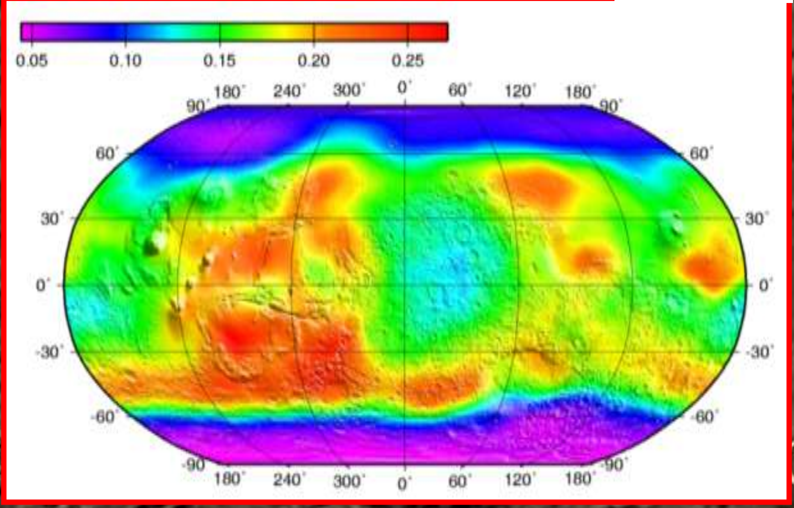

**Results of Mars surface scanning. Comparison of NS, GRS and HEND readings.**




**Gamma Spectrometer**




**HEND**




# mposition

# APXS on Pathfinder

ELEMENTAL COMPOSITION:

Table 3.1. *Foley* et al. (2003b) *X-ray mode results* ($\pm 1\sigma$)

| Soils | $Na_2O$* | MgO | $Al_2O_3$ | $SiO_2$ | $P_2O_5$ | $SO_3$ | Cl | $K_2O$ | CaO | $TiO_2$ | $Cr_2O_3$ | MnO | $Fe_2O_3$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **A-2** Deploy | 3.2 ± 0.7 | 8.7 ± 2.0 | 10.4 ± 0.8 | 40.9 ± 0.8 | 0.9 ± 0.2 | 6.0 ± 1.2 | 0.7 ± 0.2 | 0.50 ± 0.04 | 6.1 ± 0.4 | 0.7 ± 0.2 | 0.3 ± 0.1 | 0.5 ± 0.1 | 21.2 ± 0.9 |
| **A-4** Next to Yogi | 3.2 ± 0.7 | 8.0 ± 1.9 | 10.6 ± 0.8 | 41.0 ± 0.9 | 1.2 ± 0.2 | 6.9 ± 1.4 | 0.8 ± 0.2 | 0.50 ± 0.07 | 5.6 ± 0.4 | 1.0 ± 0.3 | 0.4 ± 0.1 | 0.4 ± 0.1 | 20.4 ± 0.8 |
| **A-5** Dark Next to Yogi | 3.2 ± 0.6 | 7.1 ± 1.7 | 10.4 ± 0.8 | 40.7 ± 0.9 | 0.6 ± 0.1 | 5.7 ± 1.1 | 0.8 ± 0.2 | 0.50 ± 0.05 | 6.1 ± 0.4 | 0.6 ± 0.1 | 0.5 ± 0.1 | 0.20 ± 0.06 | 23.7 ± 1.0 |
| **A-9** Disturbed Soil by Scooby | 2.6 ± 2.4 | 6.4 ± 1.6 | 10.2 ± 0.9 | 41.7 ± 0.9 | 0.8 ± 0.2 | 6.6 ± 1.4 | 1.2 ± 0.3 | 0.70 ± 0.09 | 6.4 ± 0.5 | 0.8 ± 0.2 | 0.2 ± 0.1 | 0.1 ± 0.1 | 22.2 ± 1.0 |
| **A-10** Lamb | 1.8 ± 0.7 | 7.5 ± 1.7 | 9.8 ± 0.7 | 41.3 ± 0.9 | 0.6 ± 0.1 | 6.4 ± 1.3 | 0.8 ± 0.2 | 0.40 ± 0.04 | 6.0 ± 0.4 | 0.8 ± 0.2 | 0.3 ± 0.1 | 0.4 ± 0.1 | 24.0 ± 1.0 |
| **A-15** Mermaid | 2.7 ± 0.8 | 6.7 ± 1.6 | 9.9 ± 0.8 | 43.2 ± 1.0 | 0.6 ± 0.1 | 5.2 ± 1.1 | 0.8 ± 0.2 | 0.70 ± 0.07 | 5.5 ± 0.4 | 0.8 ± 0.2 | 0.3 ± 0.1 | 0.3 ± 0.1 | 23.2 ± 1.0 |
| **Indurated soil** | | | | | | | | | | | | | |
| **A-8** Scooby Doo | 3.1 ± 0.8 | 6.4 ± 1.5 | 10.5 ± 0.8 | 45.0 ± 1.0 | 0.5 ± 0.1 | 5.5 ± 1.1 | 0.9 ± 0.2 | 0.80 ± 0.06 | 7.0 ± 0.5 | 0.7 ± 0.2 | 0.1 ± 0.1 | 0.3 ± 0.1 | 19.1 ± 0.8 |
| **Rocks** | **$Na_2O$*** | **MgO** | **$Al_2O_3$** | **$SiO_2$** | **$P_2O_5$** | **$SO_3$** | **Cl** | **$K_2O$** | **CaO** | **$TiO_2$** | **$Cr_2O_3$** | **MnO** | **FeO** |
| **A-3** Barnacle | 3.2 ± 0.5 | 2.1 ± 0.5 | 12.8 ± 0.9 | 54.1 ± 1.1 | 0.7 ± 0.1 | 2.0 ± 0.4 | 0.5 ± 0.1 | 1.1 ± 0.07 | 5.7 ± 0.4 | 0.6 ± 0.1 | 0.10 ± 0.04 | 0.3 ± 0.1 | 16.7 ± 0.7 |
| **A-7** Yogi | 4.9 ± 0.8 | 5.2 ± 1.2 | 11.2 ± 0.9 | 47.4 ± 1.1 | 0.5 ± 0.1 | 4.4 ± 0.9 | 0.8 ± 0.2 | 0.70 ± 0.06 | 6.6 ± 0.5 | 0.7 ± 0.2 | 0.10 ± 0.1 | 0.4 ± 0.1 | 17.1 ± 0.7 |
| **A-16** Wedge | 4.9 ± 0.9 | 4.1 ± 1.0 | 11.5 ± 0.8 | 48.0 ± 1.1 | 0.6 ± 0.1 | 3.0 ± 0.6 | 0.6 ± 0.1 | 0.80 ± 0.07 | 6.9 ± 0.5 | 0.7 ± 0.2 | 0.00 ± 0.04 | 0.3 ± 0.1 | 18.6 ± 0.8 |
| **A-17** Shark | 3.6 ± 0.8 | 3.9 ± 1.0 | 10.7 ± 0.8 | 53.9 ± 1.2 | 0.5 ± 0.1 | 1.7 ± 0.4 | 0.5 ± 0.1 | 0.80 ± 0.09 | 7.7 ± 0.6 | 0.5 ± 0.2 | 0.10 ± 0.1 | 0.4 ± 0.1 | 15.8 ± 0.7 |
| **A-18** Half Dome | 4.0 ± 0.7 | 3.4 ± 0.8 | 12.3 ± 0.9 | 50.0 ± 1.1 | 0.6 ± 0.1 | 3.0 ± 0.6 | 0.7 ± 0.2 | 1.0 ± 0.08 | 6.0 ± 0.5 | 0.7 ± 0.2 | 0.10 ± 0.1 | 0.4 ± 0.1 | 17.9 ± 0.7 |

Key: All X-ray $Na_2O$* values are calculated from $\alpha$-proton mode $Na_2O/SiO_2$ values except for A-9, disturbed soil by Scooby Doo, which is derived from X-ray. Errors are the statistical and laboratory combined error, at the $1\sigma$ level. Sulfur is assumed to have +6 oxidation state because of its high abundance, and because of the Viking soil analyses which support this oxidation state (Toulmin *et al.*, 1977). Fe is assumed to have +3 oxidation state in the soils and +2 oxidation state in the rocks based on IMP (Imager for Mars Pathfinder) red/blue ratios which indicate more oxidized iron in the soils than the rocks (McSween *et al.*, 1999).

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- Флеров Г.Н., Алексеев Ф.А. – Использование радиоактивных излучений при разведке и разработке нефтяных месторождений – Доклад на сессии АН СССР по мирному использованию атомной энергии 1-5 июля 1955 г., М.: Издательство АН СССР, 1955.
- Флеров Г.Н., Алексеев Ф.А., Ерозолимский Б.Г. – Перспективы использования радиоактивных излучений в геологии при поиске и разведке полезных ископаемых – Труды Всесоюзной научно-технической конференции по применению радиоактивных изотопов и излучений в народном хозяйстве и науке. М.: Гостоптехиздат, 1958, с.17-28.
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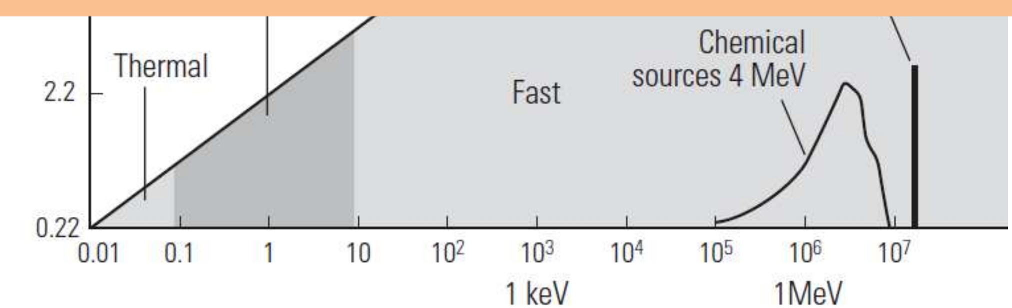
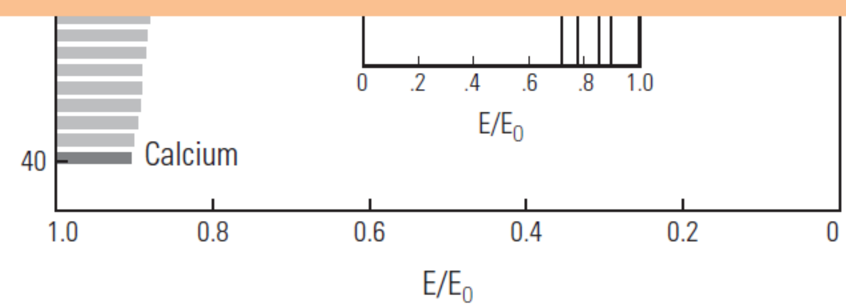
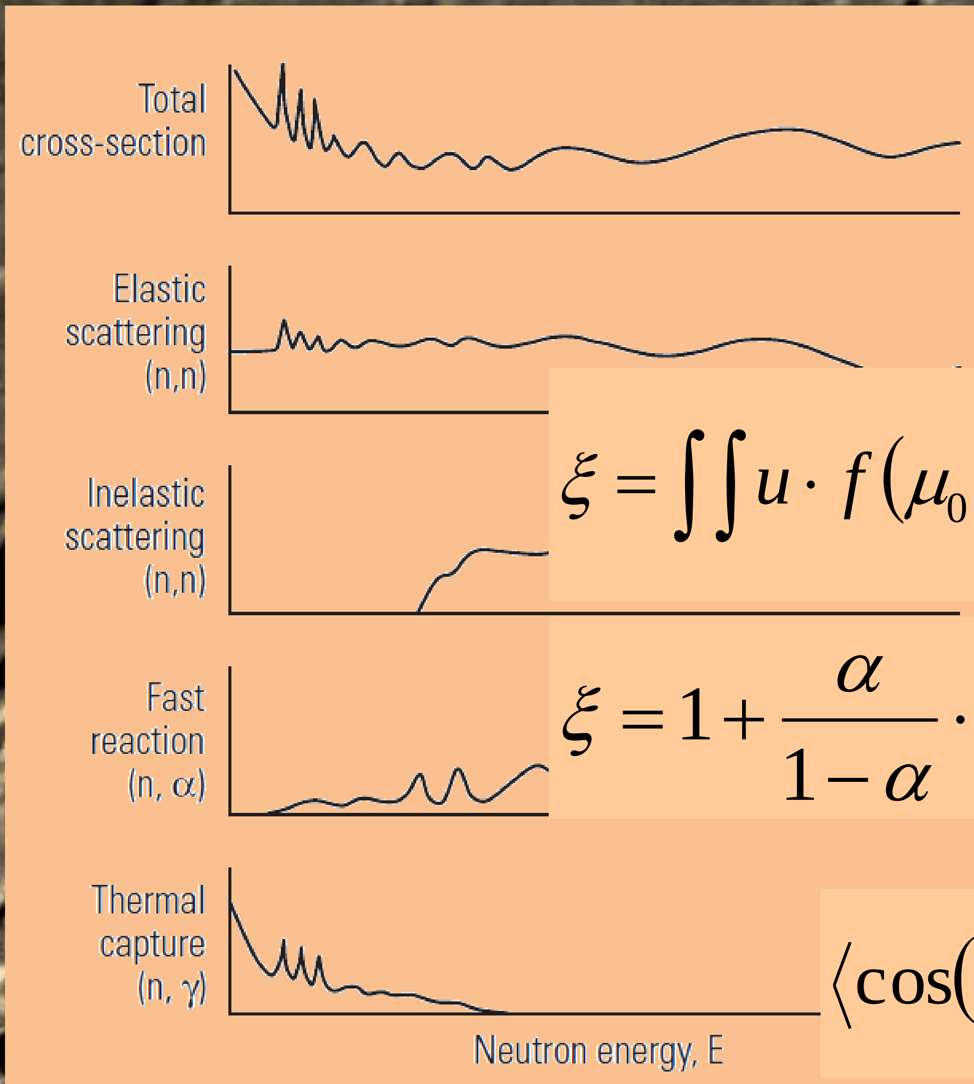


# Neutron Moderation in Soil




**Neutron lethargy (logarithmic decrement)**

$$u \equiv \ln\left(\frac{E_0}{E}\right)$$

**Average logarithmic decrement**

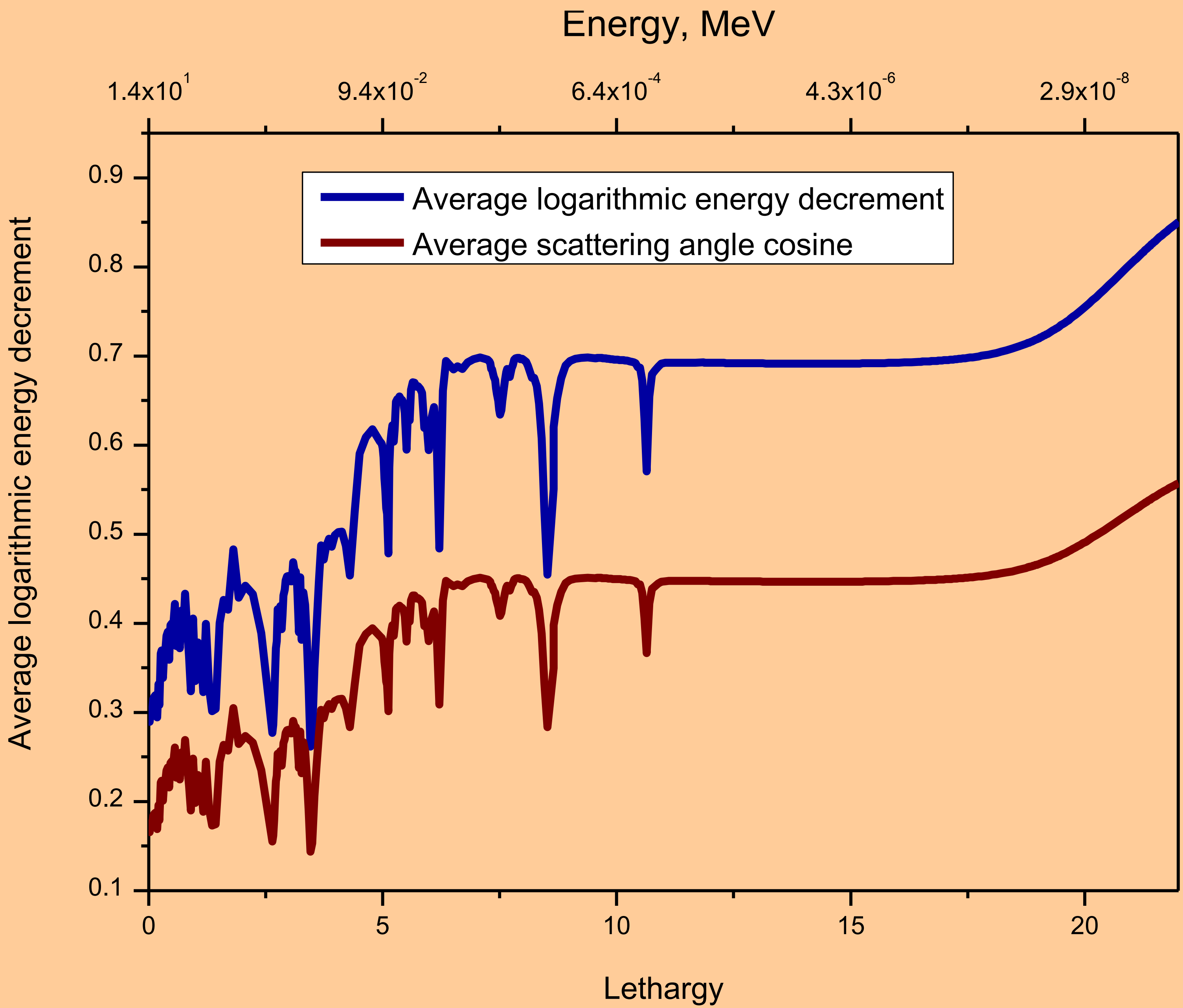
$$\xi = \int\int u \cdot f(\mu_0, u)\, du\, d\overline{\Omega} = \frac{1}{1-\alpha}\int_0^{u_{max}} u \cdot \exp(-u)\, du$$

$$\xi = 1 + \frac{\alpha}{1-\alpha} \cdot \ln(\alpha)$$

$$\alpha \equiv \left(\frac{A-1}{A+1}\right)^2$$

$$\langle \cos(\psi) \rangle = \frac{2}{3A}$$

**Average cosine of the scattering angle**


Energy, MeV
1.4x10^1
9.4x10^-2
6.4x10^-4
4.3x10^-6
2.9x10^-8
Average logarithmic energy decrement
Average scattering angle cosine
Average logarithmic energy decrement
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
5
10
15
20
Lethargy

# Some History

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Final Report

NEUTRON DIE-AWAY EXPERIMENT FOR
LUNAR AND PLANETARY SURFACE ANALYSIS

July 26, 1966 through March 26, 1967

Prepared by

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and
W. W. Givens
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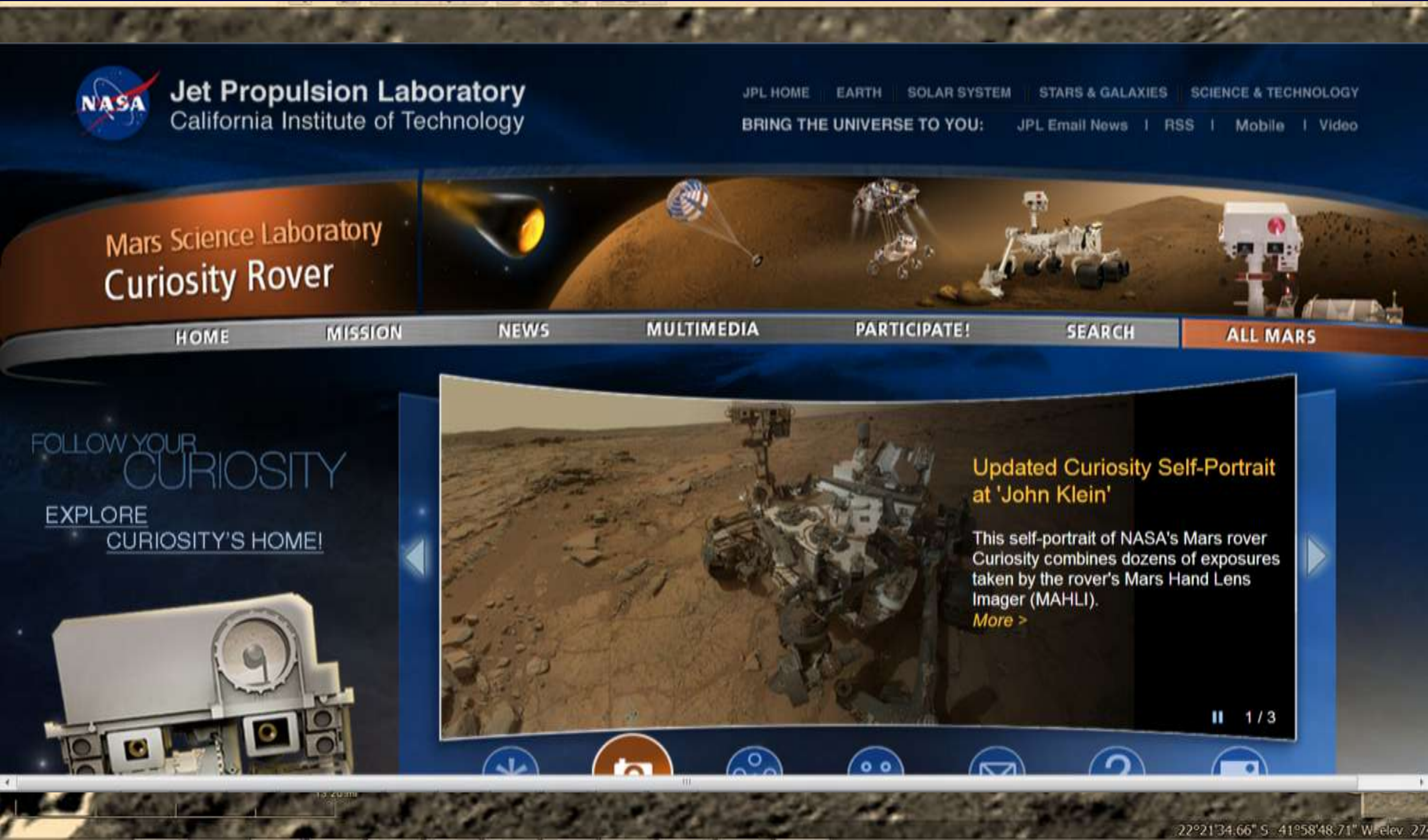
Field Research Laboratory
3600 Duncanville Road
Dallas, Texas 75211

for

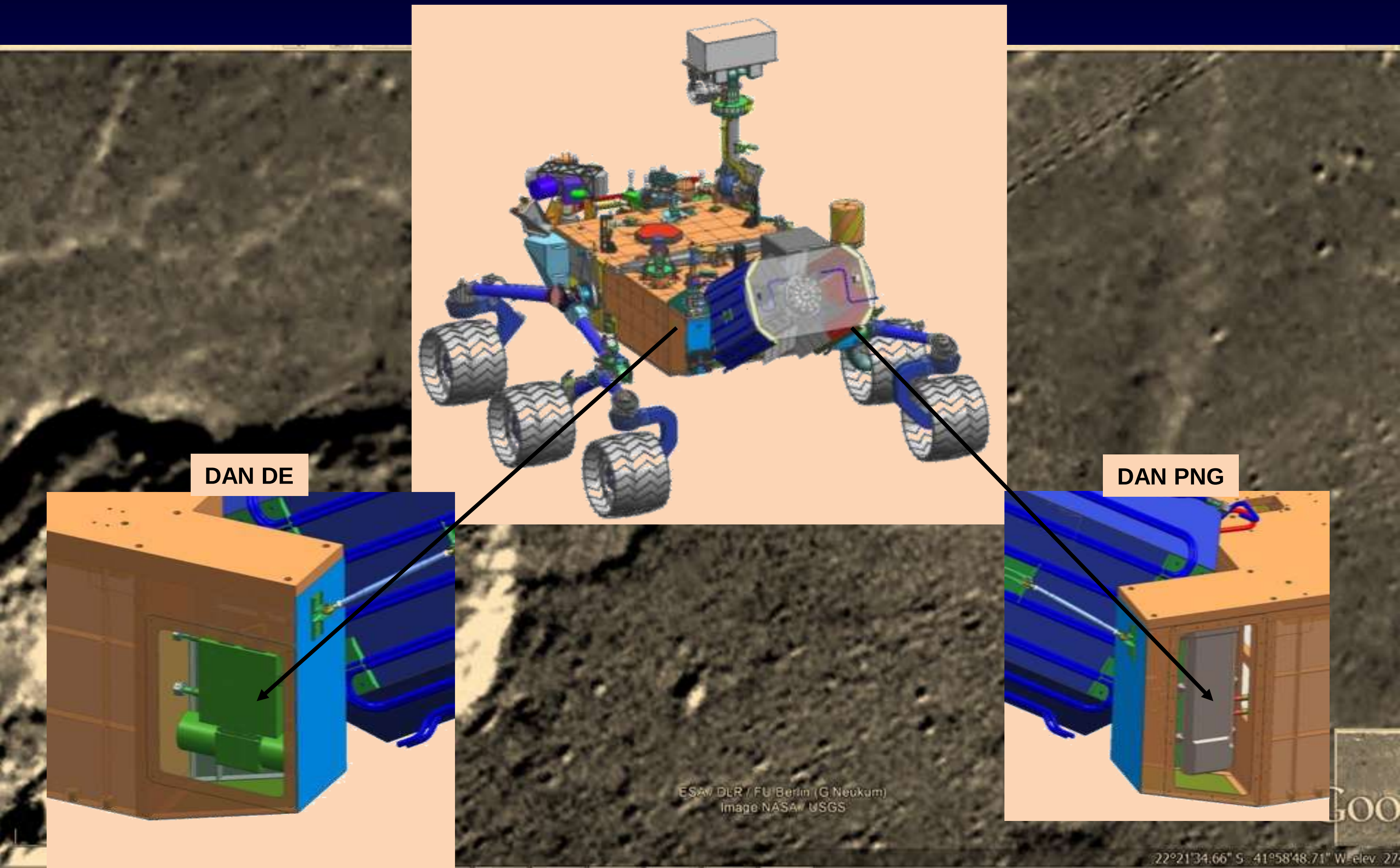
Dr. Martin J. Swetnik
Code SL
National Aeronautics and Space Administration
Washington, D.C. 20546

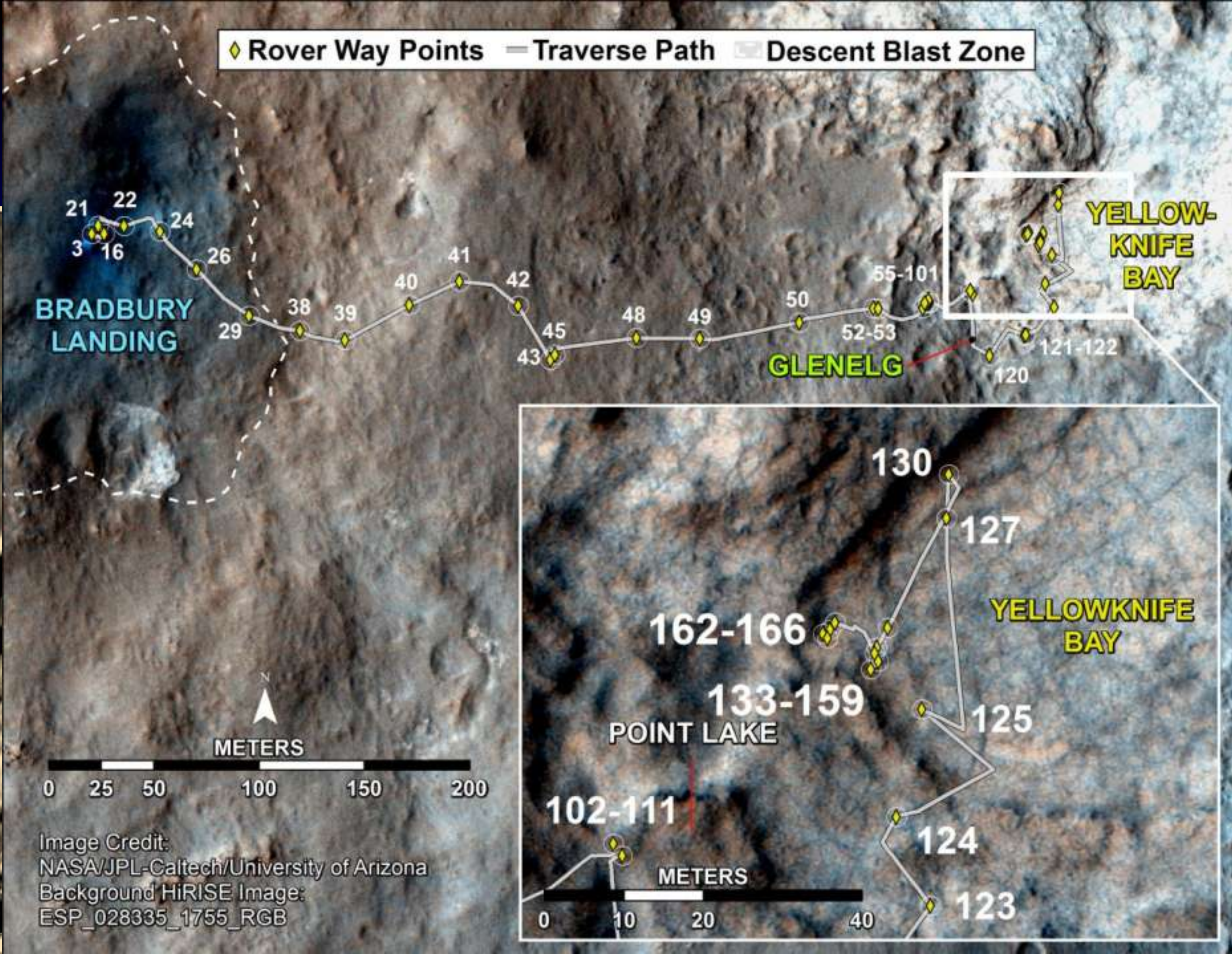
April 26, 1967

# Experiment DAN onboard Curiosity Rover



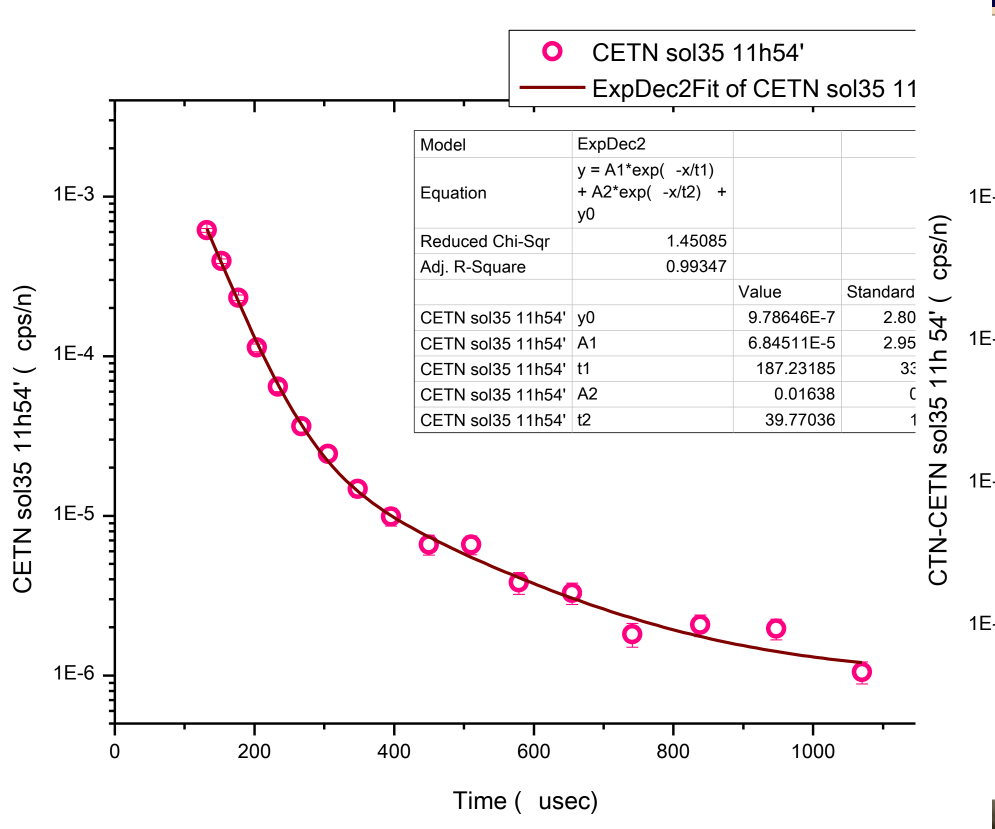
# DAN PNG and DE Allocation



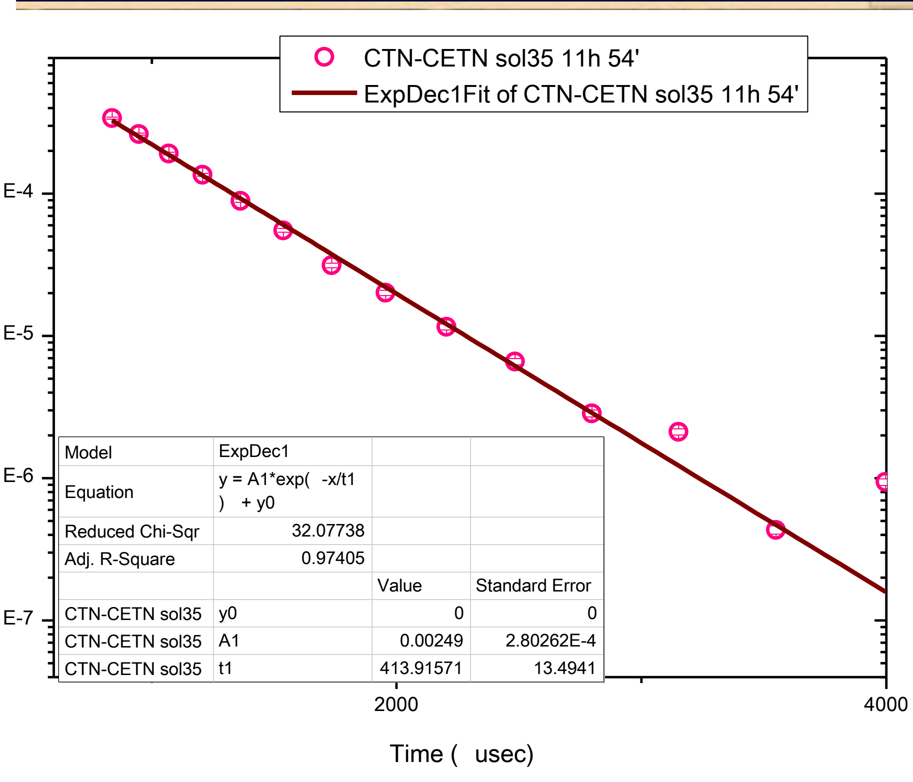


Rover Way Points
Traverse Path
Descent Blast Zone
BRADBURY LANDING
21 22 3 16 24 26 29 38 39 40 41 42 43 45 48 49 50 52-53 55-101
GLENELG
120
121-122
YELLOW-KNIFE BAY
N
METERS
0 25 50 100 150 200
Image Credit: NASA/JPL-Caltech/University of Arizona
Background HiRISE Image: ESP_028335_1755_RGB
130
127
162-166
YELLOWKNIFE BAY
133-159
125
POINT LAKE
102-111
124
METERS
0 10 20 40
123

# Neutrons Die-Away Spectra from DAN

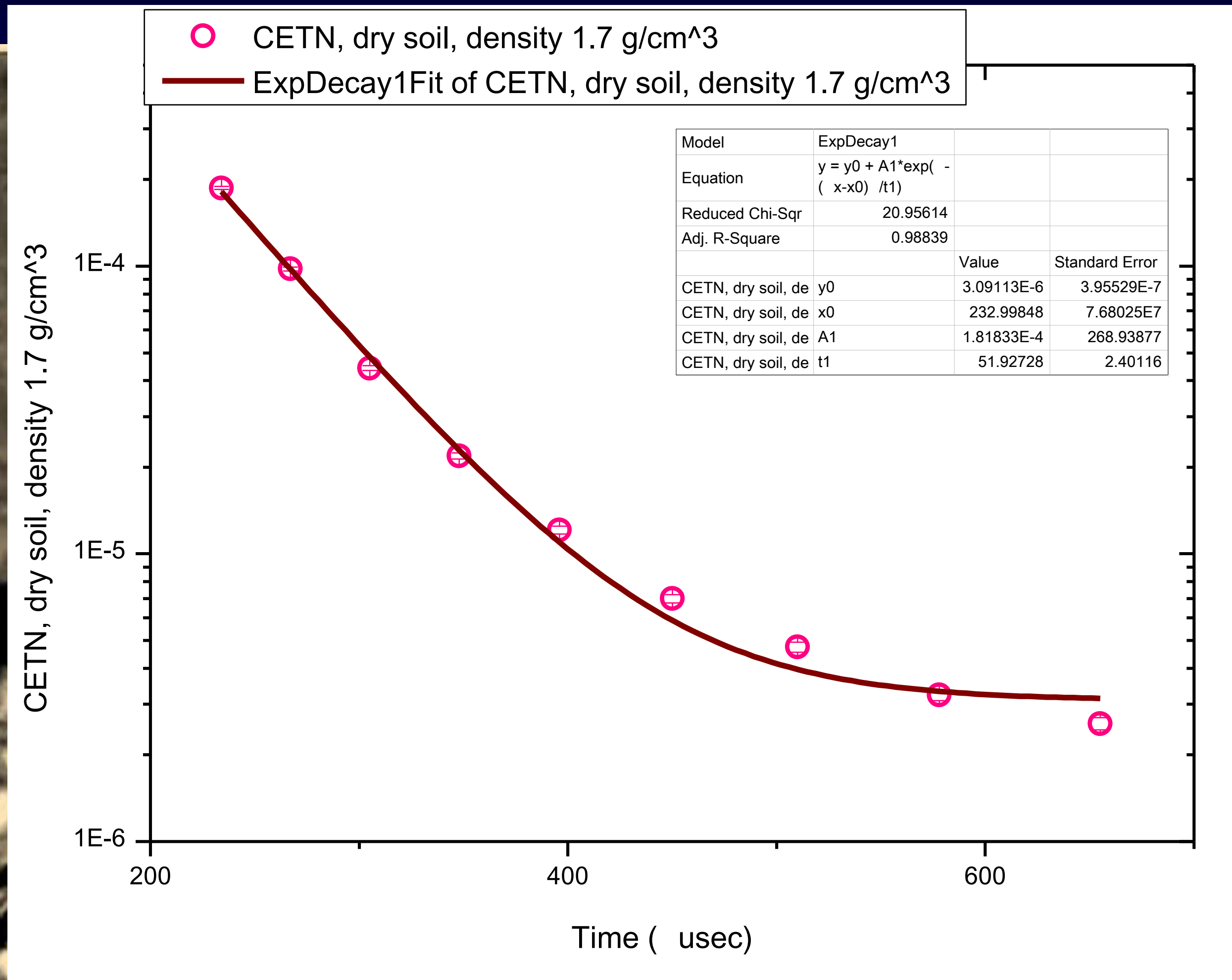



CETN



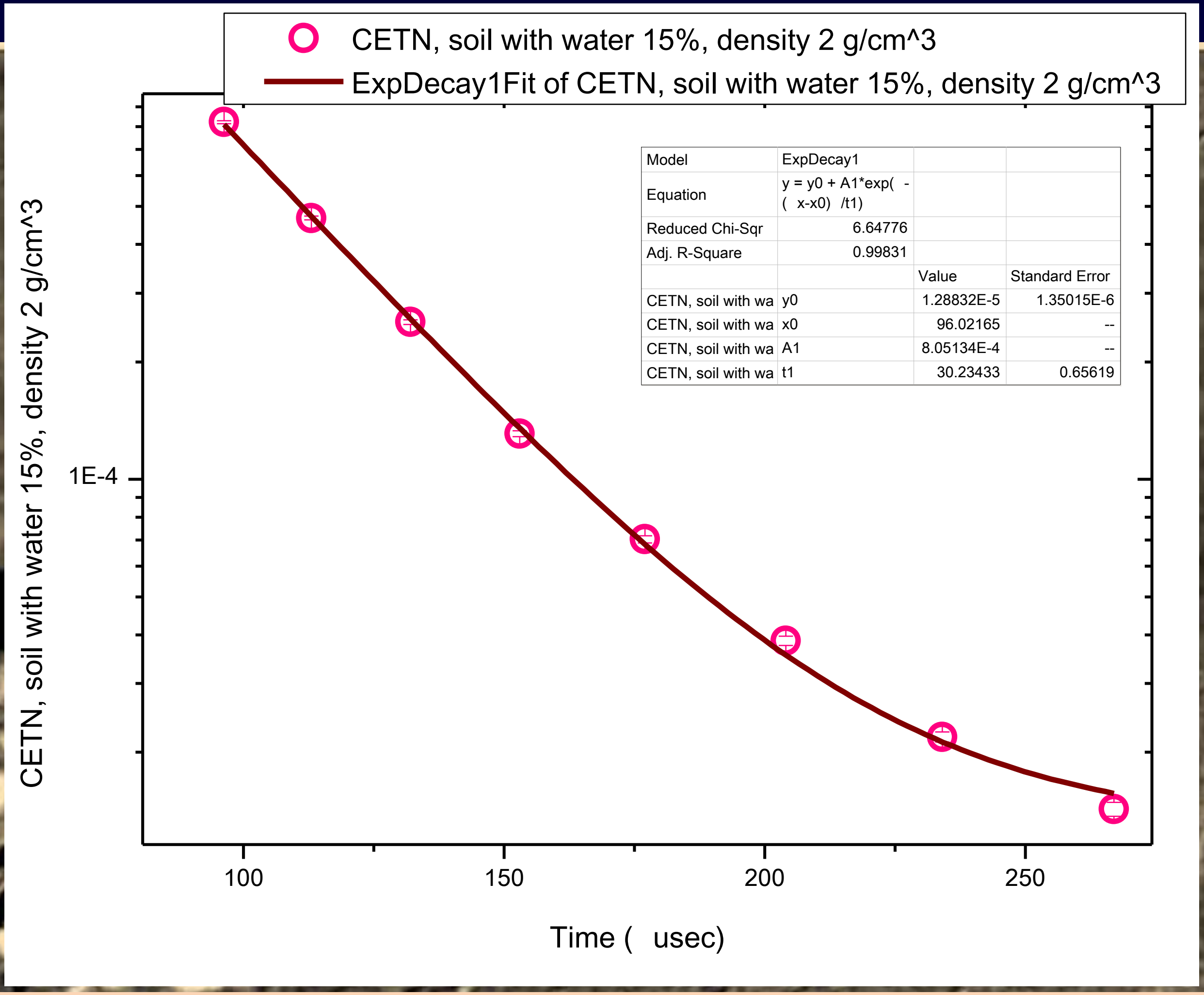

CTN-CETN

# MCNP Simulations



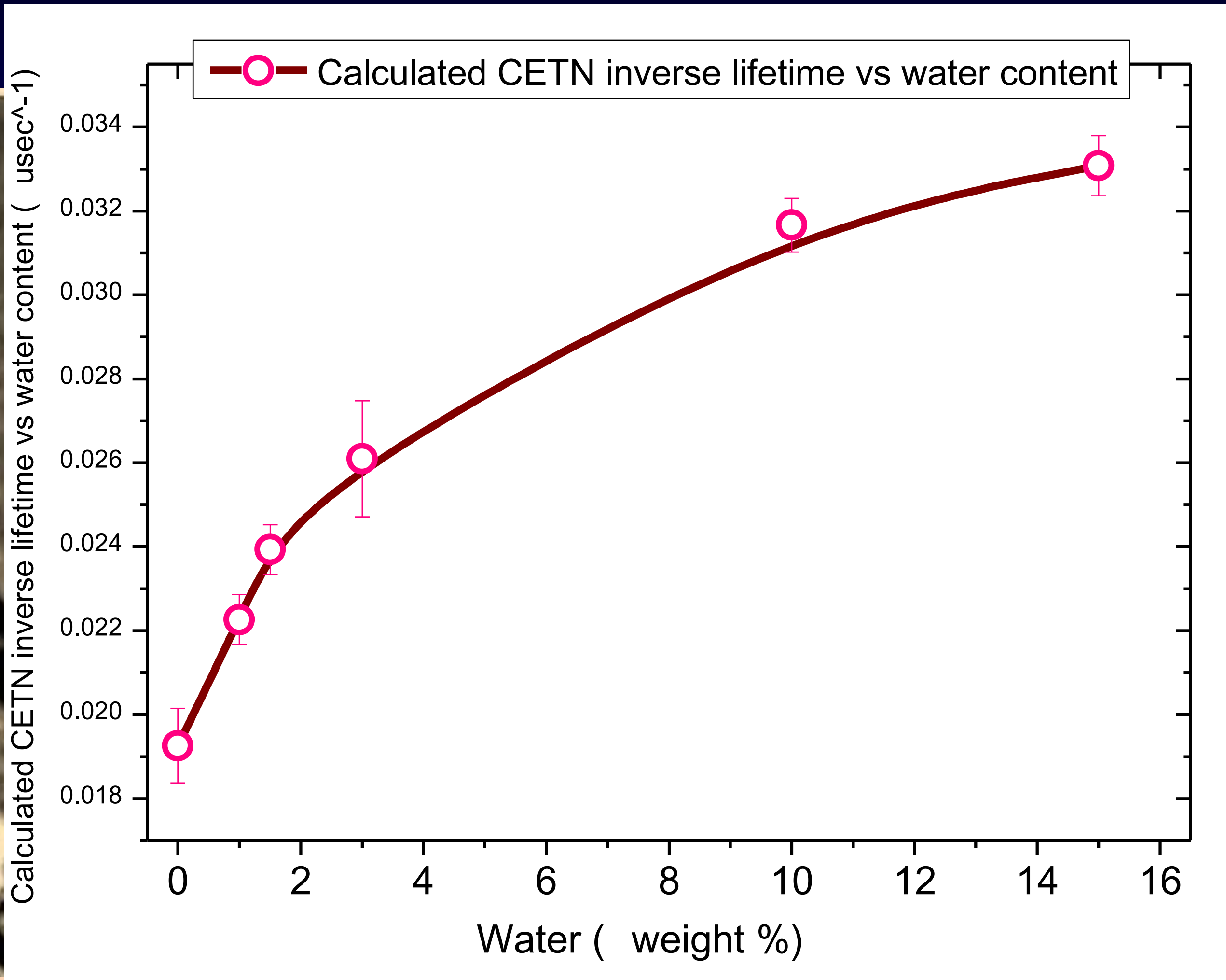

**CETN calculated, dry soil, τ=52 s**

# MCNP Simulations



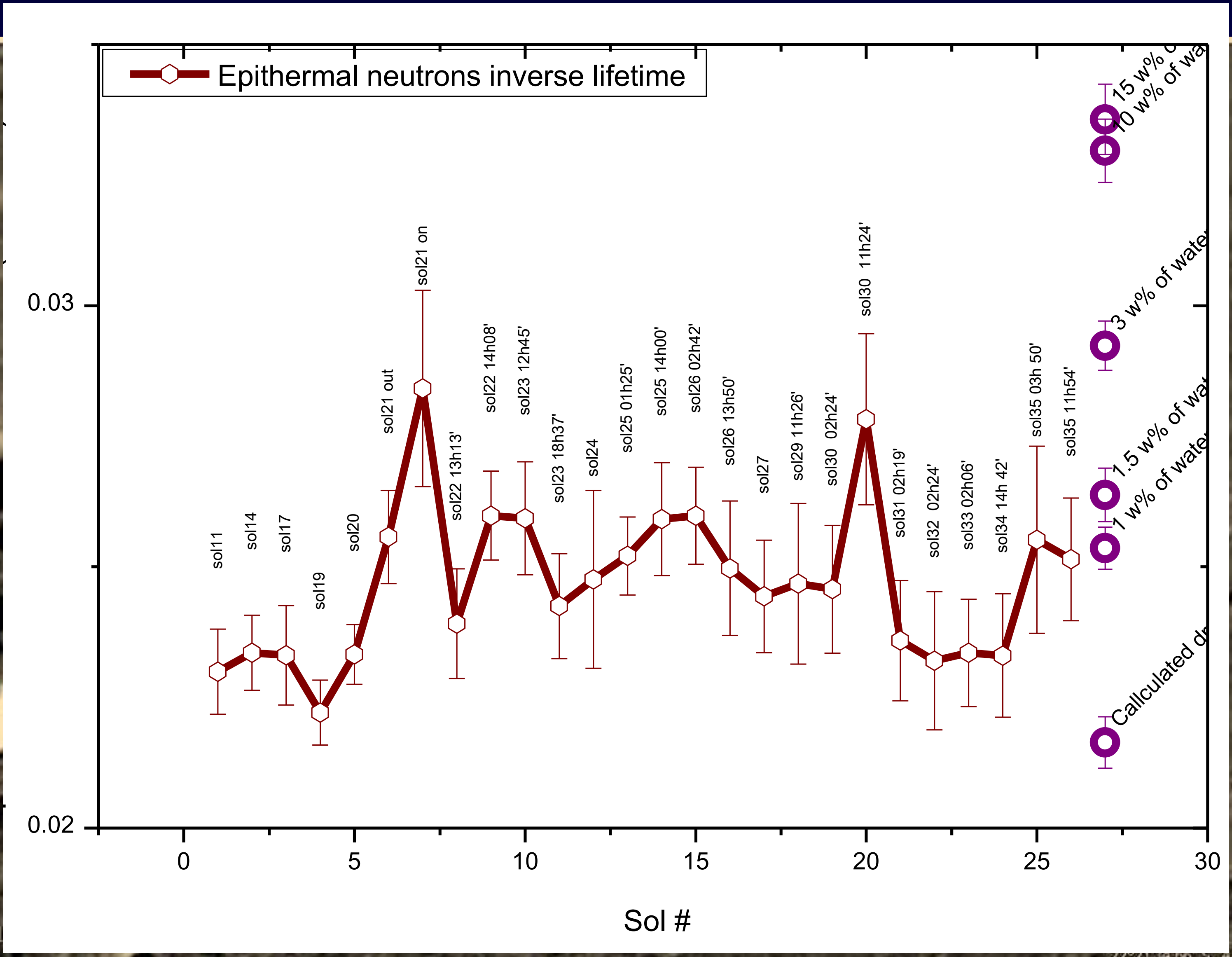

**CETN calculated, 15% water soil, τ=30 s**

# MCNP Simulations

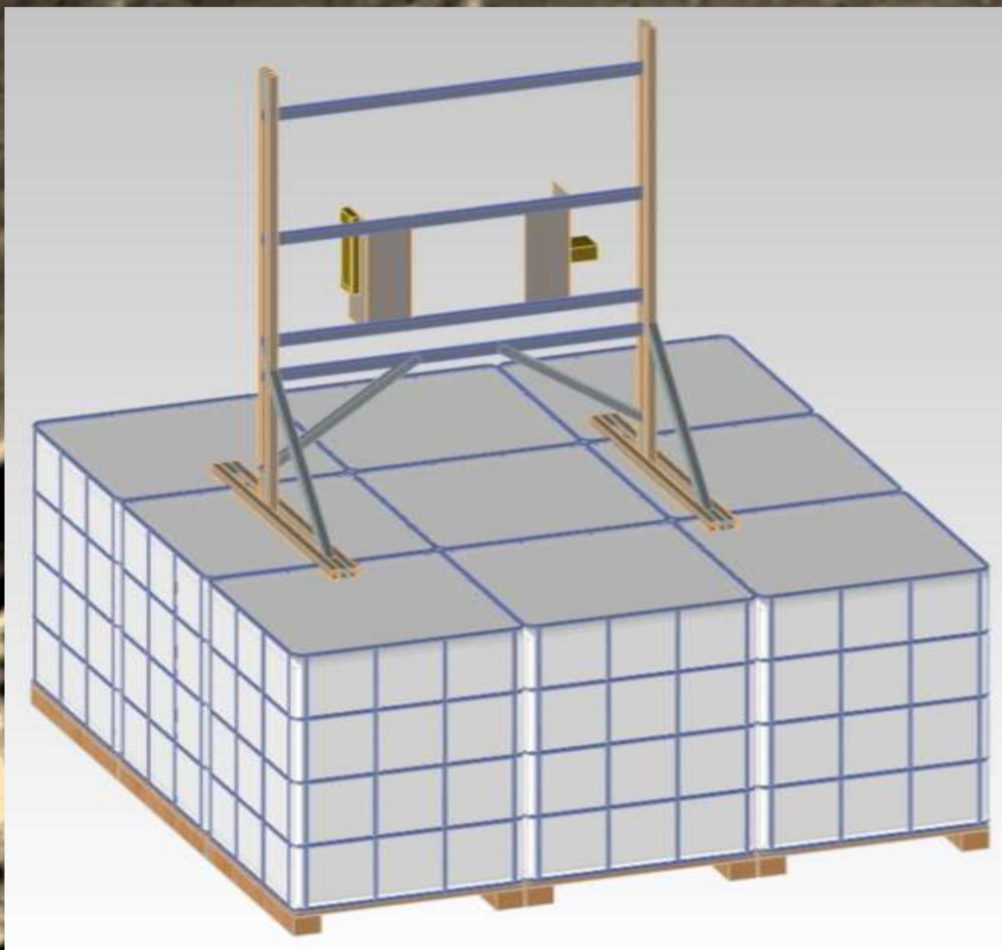



**Epithermal neutrons inverse lifetime vs water content**

# Epithermal Neutrons Inverse Lifetime Variations



# Proving Ground for Martian Soil Simulation



**Plastic containers filled with glass balls with addition of $Fe_2O_3$, CaO, MgO, $Al_2O_3$ and variable H concentration.**

**Plans for 2013-2014**

# Conclusion

- Neutron logging with pulsed source was successfully implemented on the Martian rover spacecraft;
- The sensitivity to the water content on the level of few percents demonstrated;
- More detailed MCNP simulations and physical modeling of the Martian soil is underway;