Radiation environment aboard ExoMars Trace Gas Orbiter in Mars science orbit in May 2018-July 2019

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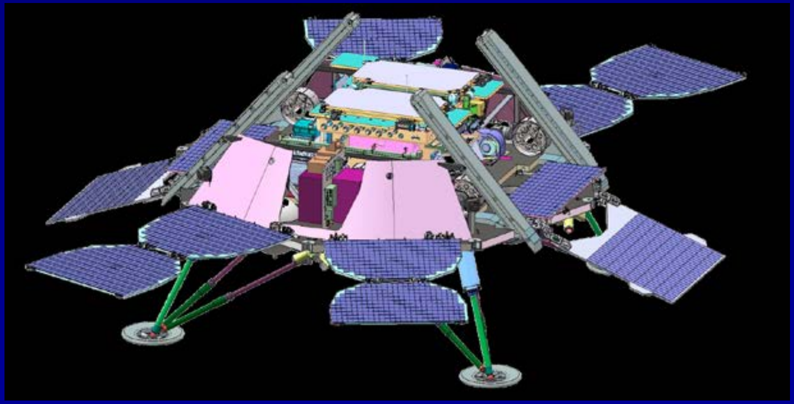
EXOMARS MISSION

ExoMars is a joint investigation of Mars carried out by ESA and Roscosmos.

Two missions are foreseen within the ExoMars programme: one consisting of the Trace Gas Orbiter (TGO), launched on 14 March 2016, and the other, featuring a rover and a surface platform, with a launch date of 2020.



Surface platform
Credit: NPO Lavochkin

Radiation environment investigations onboard ExoMars

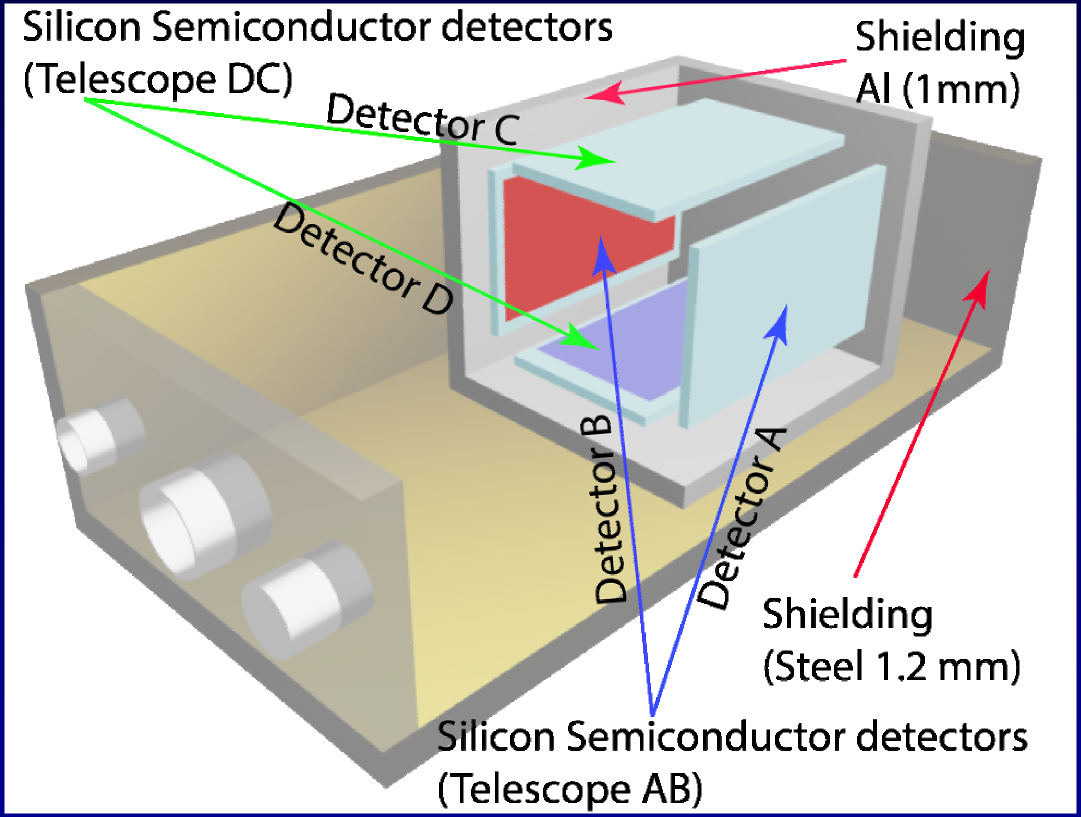
- The dosimeter Liulin-MO *(Semkova et al, 2018)* for measurement the radiation environment onboard the ExoMars 2016 TGO is a module of the Fine Resolution Epithermal Neutron Detector (FREND) onboard TGO *(Mitrofanov et al, 2018).*

- The second planned experiment for investigation of the radiation environment on Mars surface will be conducted with the Liulin-ML dosemeter as a module of the active detector of neutrons and gamma rays (ADRON-EM) on the surface platform for ExoMars 2020 mission.

Science objectives of the Liulin-MO and Liulin-ML investigation

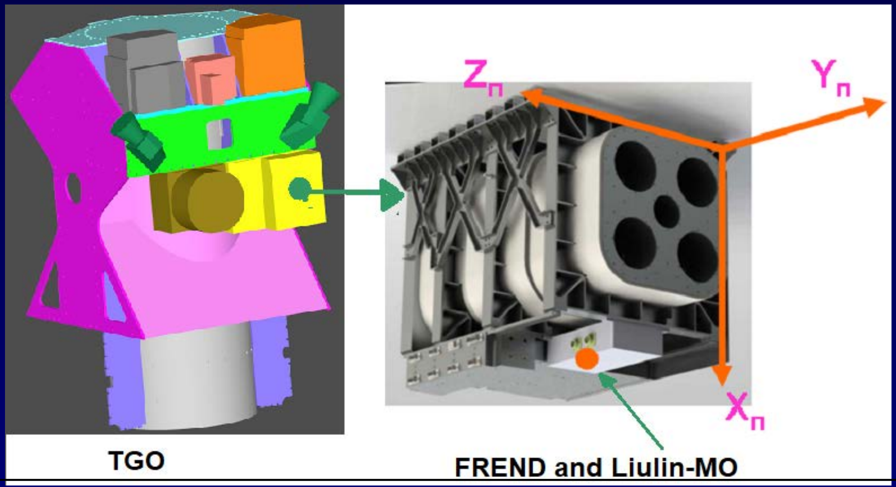
- To measure dose and determine dose equivalent rates for human explorers during the interplanetary cruise, in Mars orbit and on Mars surface.
- Measurement of the fluxes of GCRs, SEPs, secondary charged particles and gamma rays during the transit, in Mars orbit and on Mars surface.
- Together with the neutron detectors of FREND and ADRON-EM to provide data for verification and benchmarking of the radiation environment models and assessment of the radiation risk to the crewmembers of future exploratory flights.

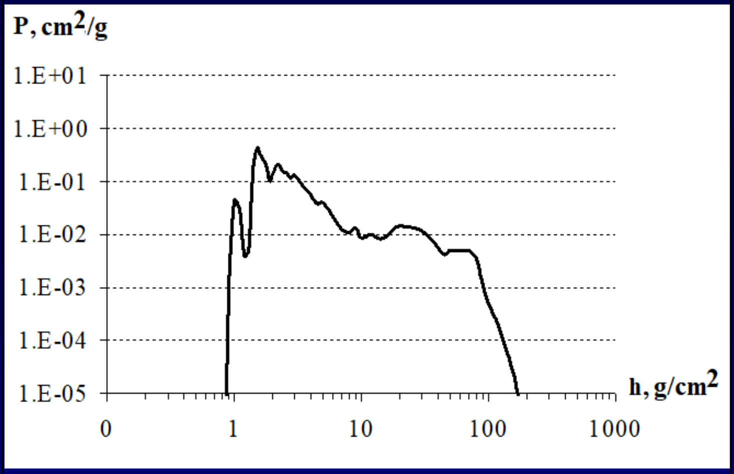
Liulin –MO description



Each pair of the dosimetric telescopes consists of two Si PIN photodiodes. Liulin-MO provides data for the deposited energy spectra, dose rates D, particle fluxes F, LET spectra, radiation quality factor Q, and dose equivalent rates H in 2 perpendicular directions.

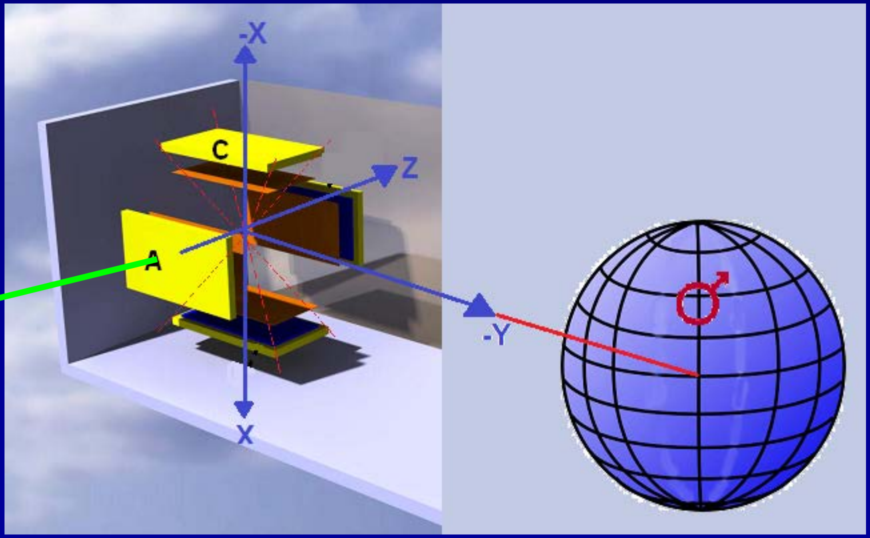
TGO and FREND with Liulin-MO





Left- Liulin-MO on TGO, under FREND neutron detector; Right – probability of shielding Liulin-MO detectors' central point.

Location of Liulin-MO detectors and axes to nadir direction in MSO. In nadir the angles of the dosimeter axes to the nadir are 90^0.



Available Liulin-MO data

• **Cruise phase**. From from 22.04 to 15.09.2016 Liulin-MO was turned on periodically.

• **MCO1**. TGO was inserted into Mars orbit on 19.10.2016. FREND, turned on 31.10.2016 ÷ 17.01.2017 in Mars high elliptic orbit (MCO1:98 000 ÷230 km, 0^0 inclination to the equator, 4.2 days orbit period).

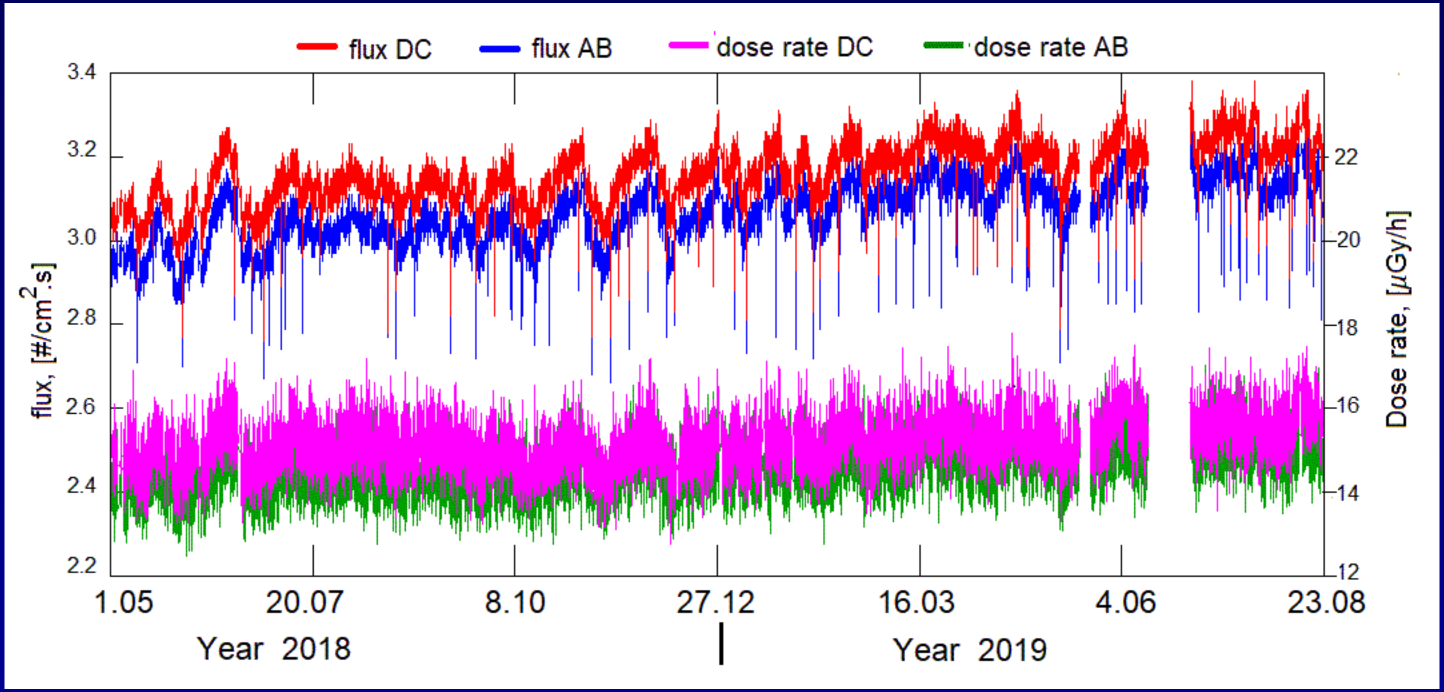
• **MCO2**. From 24.02 to 07.03.2017 FREND turned on in MCO2: 37150 ÷200 km, 74^0 inclination, 24h 39 min orbit period.

• **Mars science orbit.** Beginning 16.04.2018- after >1 year aerobreaking. Circular orbit, 400 km altitude from Mars, 74^0 inclination, 2 hours orbit period. Liulin-MO turned on almost continuously.

•*Since now the dosimeter has measured the dosimetric parameters of GCR. SPE were not registered.*

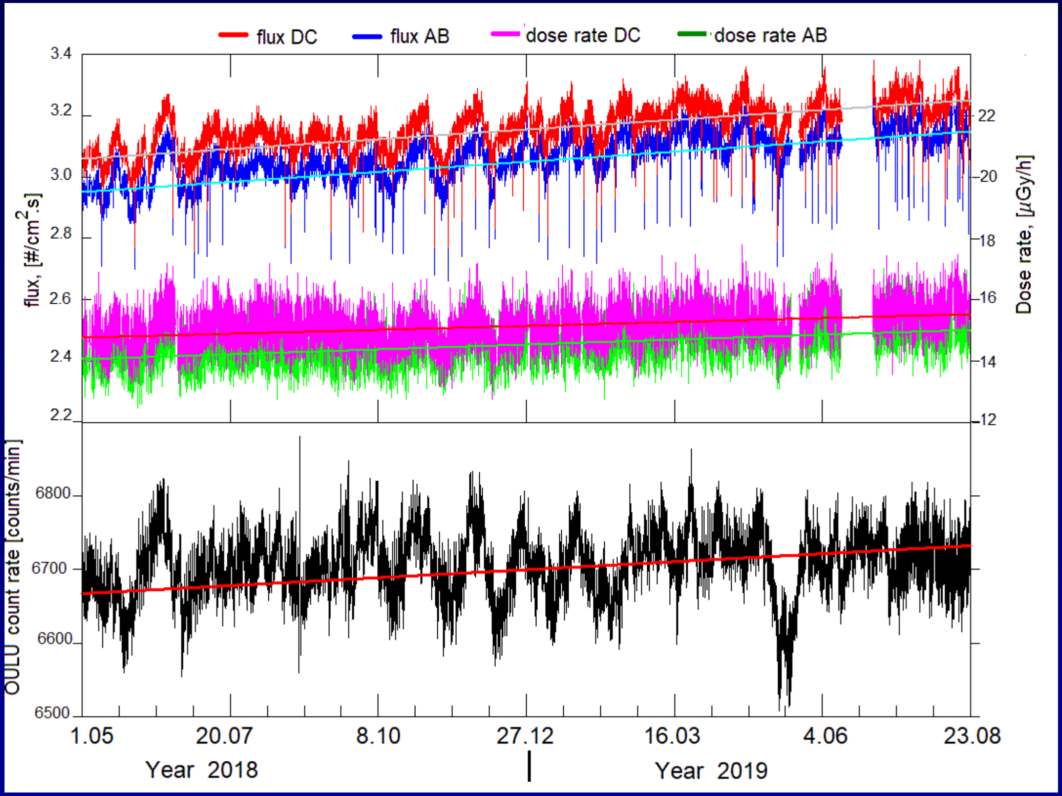
Results during TGO science phase

Flux and absorbed dose rates in 2 perpendicular directions, 01.05.2018-22.08.2019



Upper-flux, bottom- dose rate. Short term modulations of GCR fluxes by interaction with the corotating interaction region of the solar wind.

Flux, absorbed dose rates and Oulu NM count rates 01.05.2018-22.08.2019

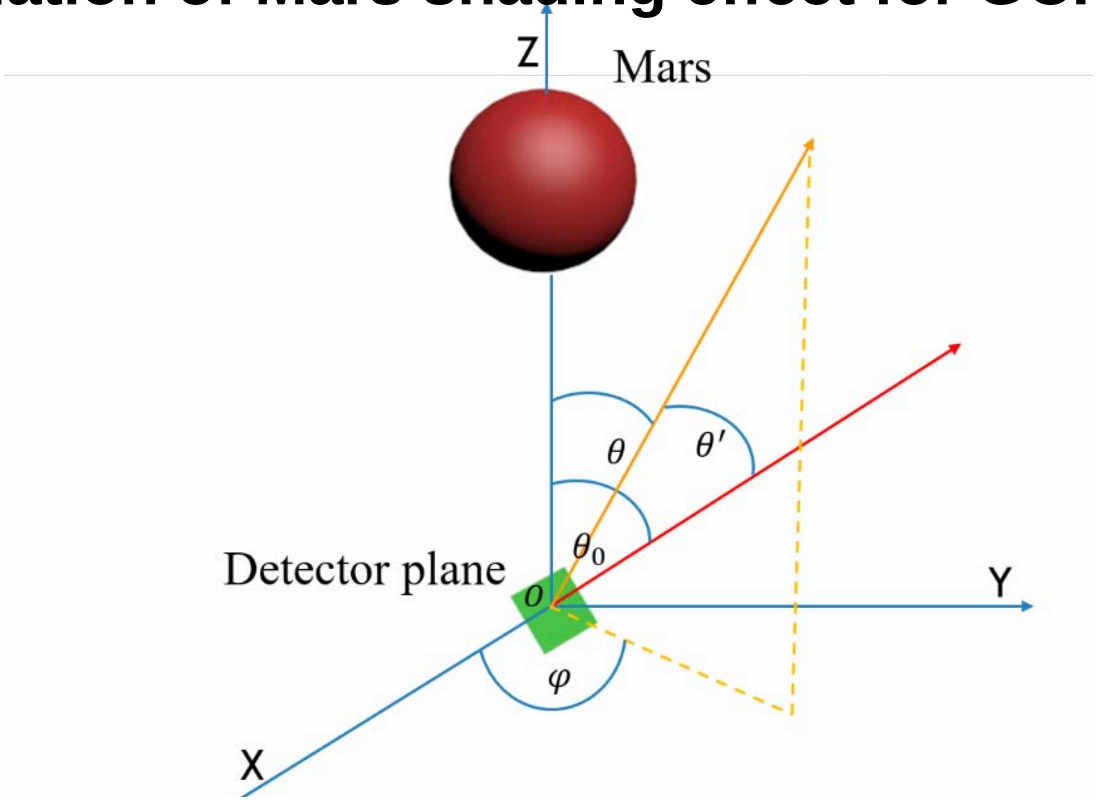


Increasing of all quantities -slightly different for the different parameters. SA modulates strongly the low energy GCR. Their flux rises, but they leave little energy in matter, thus the dose rates grow less than the flux. Oulu is situated at 64.5^0 geomagnetic latitude and its effective cut off rigidity is ~ 0.8 GV, so the most sensitive to the SA low energy GCR do not reach it. The decrease in Oulu count rate around May 10th, 2019 is due to two CME arriving at Earth but not at Mars.

F, D(Si), and H during different periods in TGO science orbit

Time frame	F (AB)/ F (DC) $\#cm^{-2}s^{-1}$	D(Si) (AB)/ D(Si) (DC) $\mu Gy\ h^{-1}$	H (AB)/ H (DC) $mSv\ h^{-1}$
01.05.2018-31.07.2018	3/3.1	14.26/14.97	64.33/67.14
01.08.2018-31.10.2018	3.02/3.12	14.35/14.98	64.92/67.77
01.11.2018-31.01.2019	3.06/3.16	14.47/14.98	65.27/67.38
01.02.2019-30.04.2019	3.11/3.2	14.78/15.32	67.06/69.31
01.05.2019-31.07.2019	3.15/3.24	14.91/15.46	67.65/69.94

Calculation of Mars shading effect for GCR flux



$$F_{sh} = \int_0^{2\pi} \int_0^{\theta_1} J(\theta,\varphi)|\cos\theta'|\sin\theta\, d\theta\, d\varphi \qquad \sin\theta_1 = \frac{\text{Mars radius}}{\text{Distance to Mars}}$$

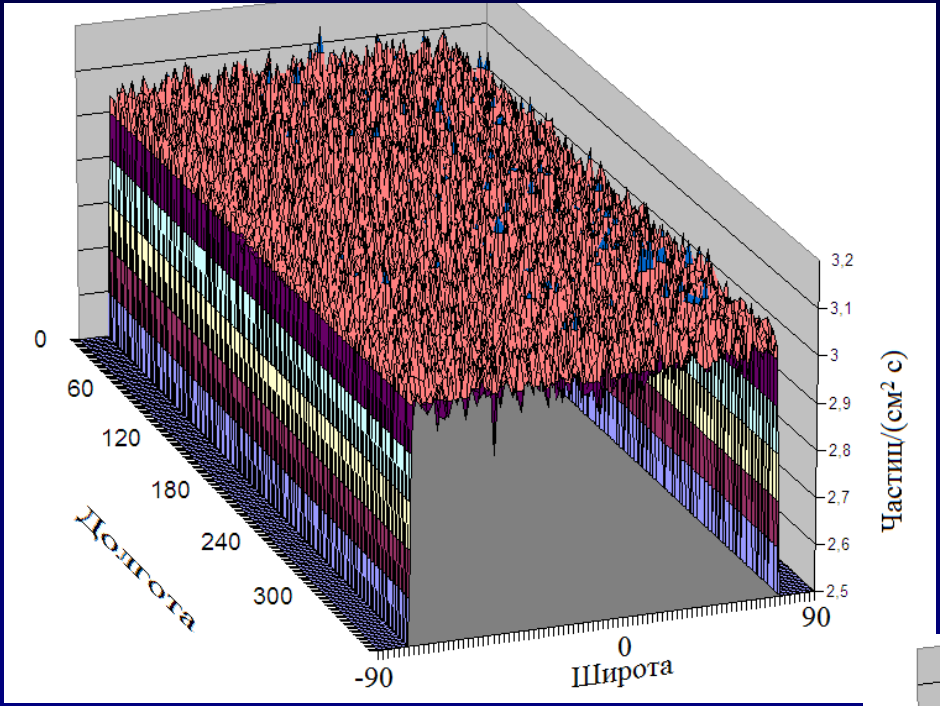
J(θ,φ) -differential flux and F_{sh} - the part of GCR flux shaded by Mars. θ' is the angle between the normal to the plane of the detector and the differential flux. θ_0 is the angle between the normal and the Mars direction. Red line -the normal to the detector plane .

Mars shading effect on flux in dependence on the distance from Mars and the angle between Liulin-MO axis and the nadir

From top to bottom: Liulin-MO flux, part of flux shadowed; angle between Liulin-MO axis and nadir; distance of TGO from Mars. Data for 5-10.07.2018.

Mars shading effect on absorbed dose rate (1)

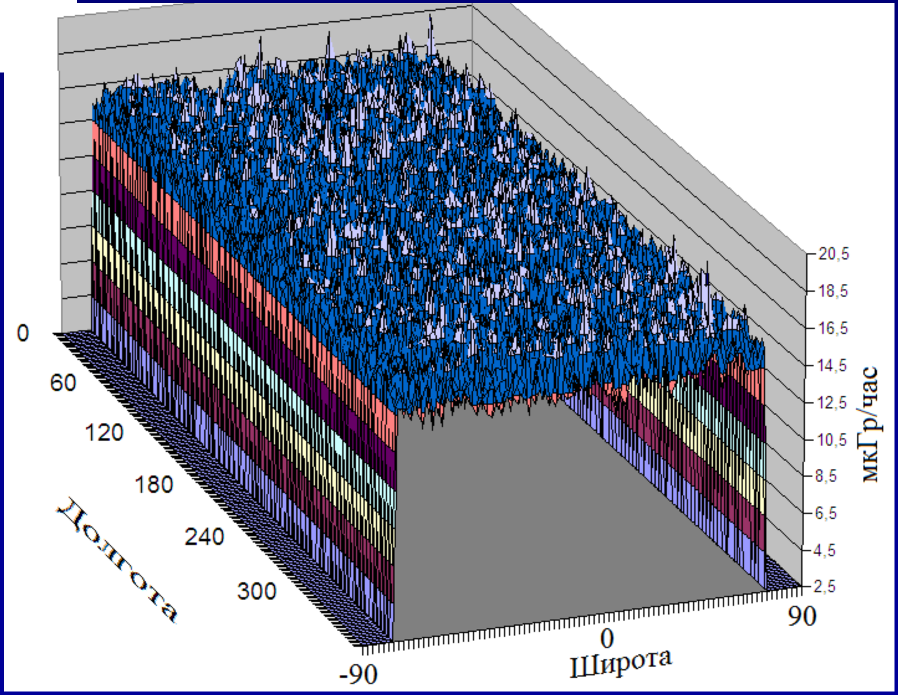
The absorbed dose depends only on the distance. This can be explained by two mutually compensating effects: 1. When the angle between the GCR flux and the detector axis increases, then the number of registered particles per unit time decreases. 2.   At a greater angle, the flux passes a large path into the detector and respectively leaves more energy, so contributes for higher dose.



Planetary distribution of flux and dose rate

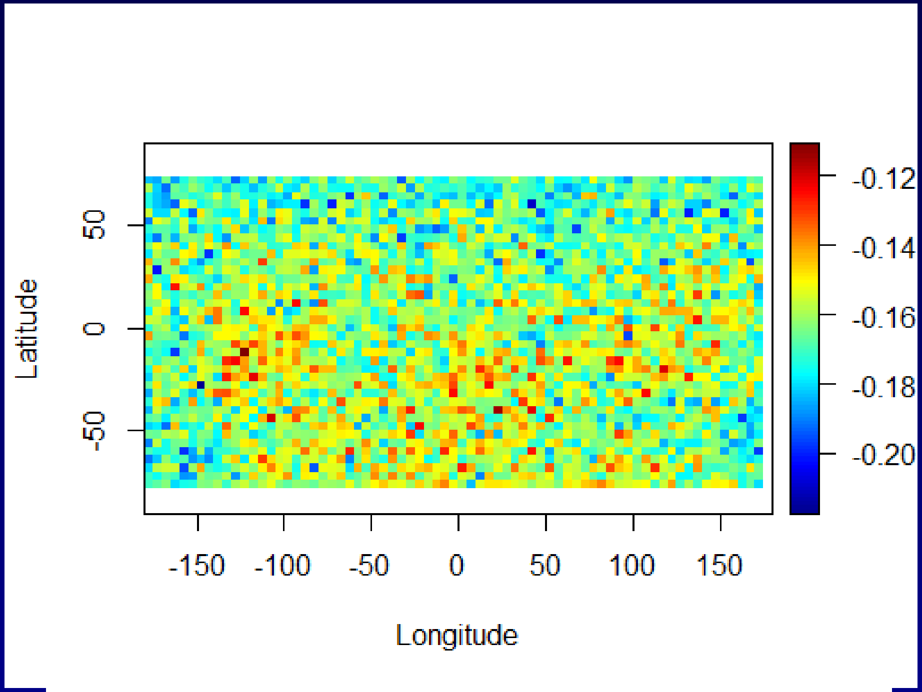
Calculated are average values in bins 2^0 latitude x 2^0 longitude

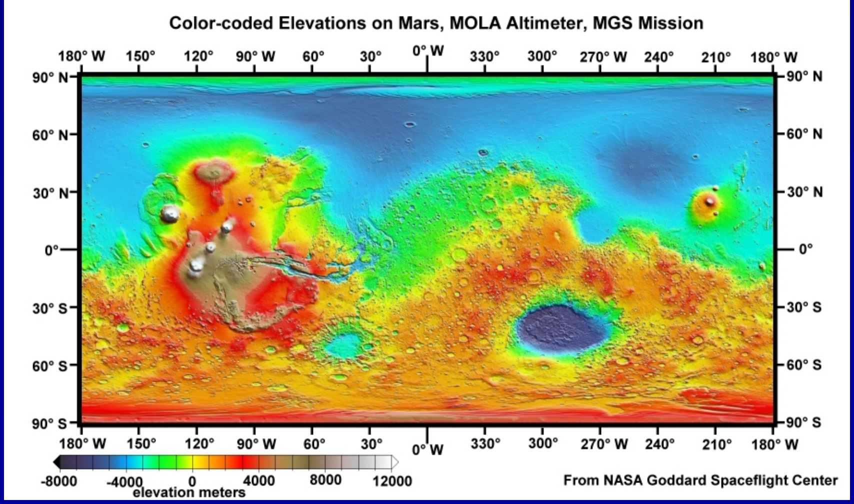
Flux in latitude-longitude coordinates



Dose rate in latitude-longitude coordinates

Planetary distribution of deviations of the flux relatively running average





Running average is calculated for 1 orbit before and 1 orbit after the measurement. Deviations are averaged in bins 5^0 longitude x 4^0 latitude. The flux values are divided by a correction factor, accounting for the TGO altitude. All measurements at angles to horizon > 5^0 are excluded. ***Deviations of the flux relatively the average are < 0.5%-under investigation.***

D(Si), Q and H during different TGO phases

Time frame/TGO phase	D(Si) (AB)/ D(Si) (DC) μGy d^{-1}	Q (AB)/ Q (DC)	H (AB)/ H (DC) mSv d^{-1}
April 22 - September 15, 2016/ Cruise	372 37/ 390 39		
November 01, 2016 - January 17, 2017/ MCO1	405.6 41/ 422 42		
February 24 -March 07, 2017/ MCO2	410 41/ 425 42.5		
April 2018–July 2019/ Mars' Science Orbit	360.5±36, 374.9±37		± ±

~ 10% increase of dose rate, ~ 15 % increase of dose equivalent rate for 10.5 months flight. In Mars' orbit in May 2018-July 2019, dose rate is ~ 87%, dose equivalent rate is ~72% of that in February-March 2017 in MCO2- due to the Mars' shadow.

Worsening of radiation conditions in interplanetary space

To make Liulin-MO results universal we have to recalculate the measured parameters in Mars science orbit for deep space, i.e. to account for Mars shadowing of cosmic rays, the contribution of albedo particles and the effect of detectors' shielding by surrounding materials. As a first approximation the effect of Mars presence – both shadowing and albedo particles, could be removed by dividing the measured flux by 0.88 and the measured dose rates by 0.82 *(see Benghin et al).* Our results are representative for the GCR flux and dose rates under 10 g/cm^2 shielding.

June 2019 to	22.04 – 15.09. 2016 Cruise	1.11.2016– 17.01.2017 MCO1	24.02– 7.03.2017 MCO2	May 2018 Science phase
Flux 3.6 cm^{-2}s^{-1}	11.6 %	7.3 %	7 %	3.5 %
Dose rate 461µGy d^{-1}	18 %	9.4 %	8.7 %	6.5 %

CONCLUSIONS (1)

Recent results (May 2018-July 2019) from the Liulin-MO dosimeter onboard the ExoMars TGO in Mars circular orbit (400 km from Mars), 74^0 inclination show that:

- **A strong dependence of the measured fluxes on the part of the FOV shadowed by Mars and particularly on the orientation of the detectors is observed. *The dependence on the orientation is valid to all measurements near celestial bodies without magnetic field, performed by detectors with planar geometry*.**

- **There is no significant dependence of the absorbed dose rate on the orientation of the detector. The absorbed dose depends only on the distance to Mars.**

- **Slight dependence of flux and dose rate distribution on the Martian latitude and longitude – under investigation.**

CONCLUSIONS (2)

- In Mars' orbit in May 2018-July 2019 the flux is ~ 93%, dose rate is ~ 87%, dose equivalent rate is ~72% of that in February-March 2017 in the deep space- due to Mars shadow.

- A reasonable agreement between GCR count rates from Liulin-MO and Oulu neutron monitor is observed.

- The flux in the deep space in June 2019 is 3.6 $cm^{-2}s^{-1}$, the dose rate is 461 µGy d^{-1}. About 18 % increase of the dose rate and 11.6% of flux from April-September 2016 to June 2019 is observed in the deep space - corresponds to the increase of GCR intensity during the declining of the solar activity.

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Thank you!