# Radiation environment in the interplanetary space and Mars orbit during the declining phase of 24th and beginning of 25th solar cycles according measurements aboard ExoMars Trace Gas Orbiter

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*Thirteenth Workshop "Solar Influences on the Magnetosphere, Ionosphere and Atmosphere" Primorsko, September 12-17, 2021*

# Introduction

**The radiation risk on deep space manned missions is one of the basic factors in planning and designing the mission.**

**Complex radiation environment in free space and Mars orbit:**

**1) Galactic cosmic rays (GCRs);**

**2) Solar particle events (SPE) from flares and coronal mass ejections;**

**3) Secondary radiation from interaction of primary radiation with the spacecraft structures, Mars atmosphere and surface.**

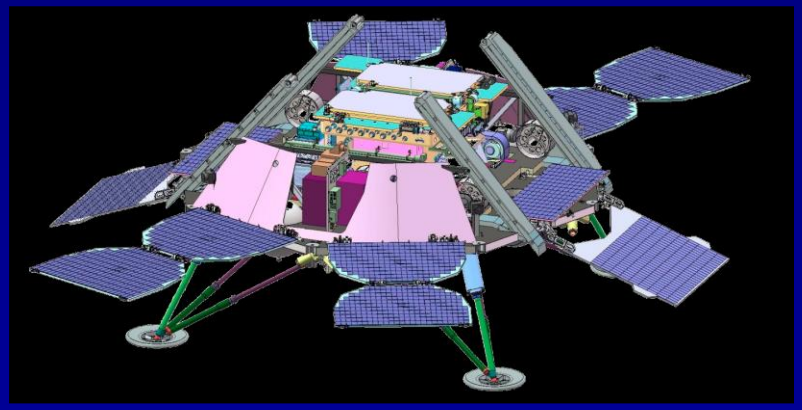
# EXOMARS MISSION

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

The ExoMars programme has been established to investigate the Martian environment.

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 2022.


Trace Gas Orbiter (TGO)
Credit: ESA/Ducros.



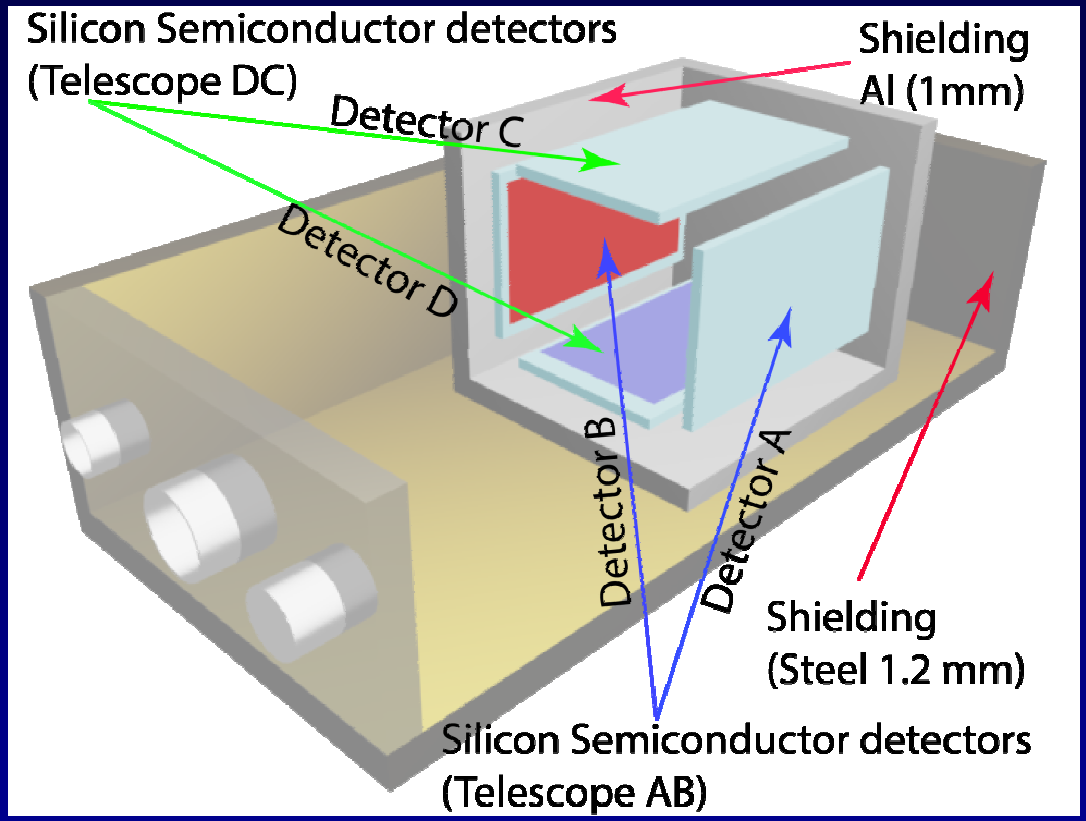
Surface platform
Credit: NPO Lavochkin

# 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).***

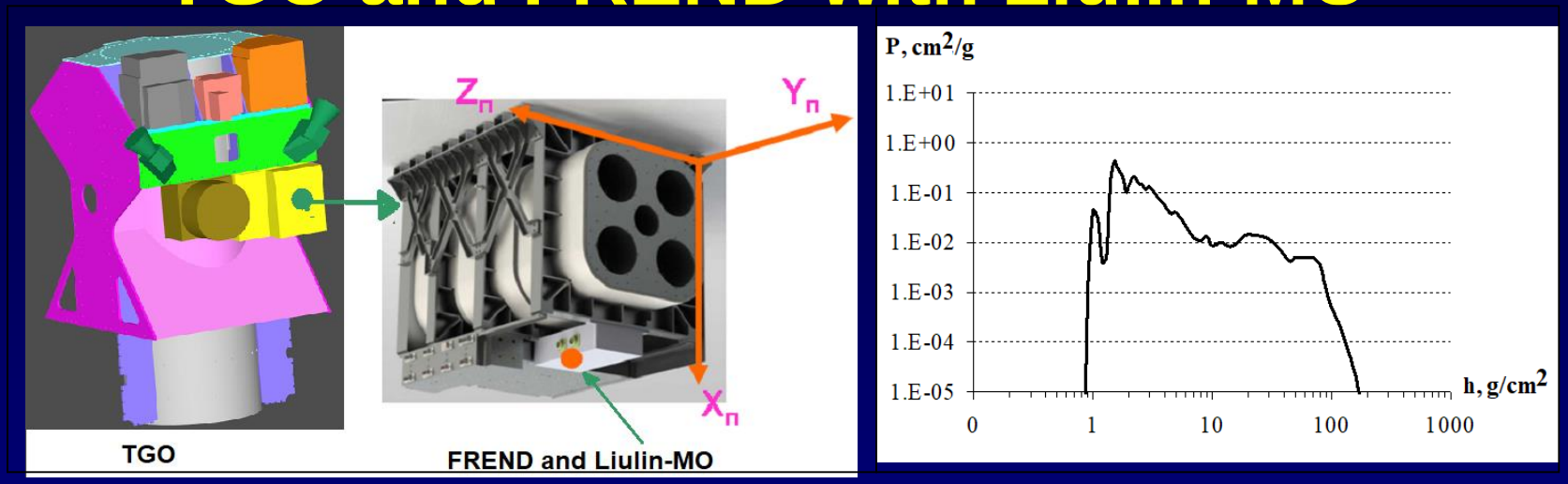
**The data will be used for benchmarking og the existing radiation environment modddels and for assessment of the radiation risk to future manned missions to Mars.**

# Liulin –MO description



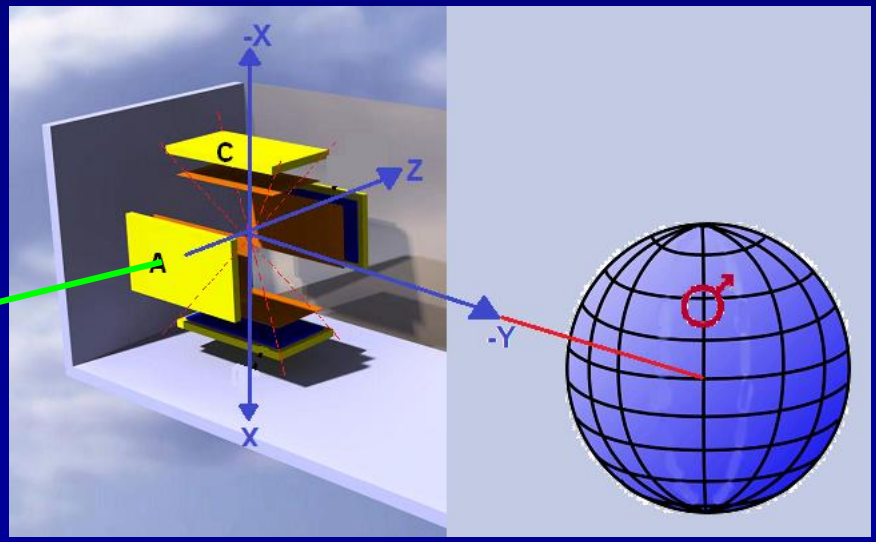

***Each pair of the dosimetric telescopes consists of two Si PIN photodiodes. Liulin-MO provides data for the deposited energy spectra, dose rates, particle fluxes , LET spectra, radiation quality factor Q, and dose equivalent rates of the charged particles in 2 perpendicular directions. We register the parameter of electrons >1 MeV, Protons >30 MeV, iron ions >5,6 GeV***

# TGO and FREND with Liulin-MO




***Left- Liulin-MO on TGO, under FREND neutron detector; Right – density shielding distribution probability of 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.**

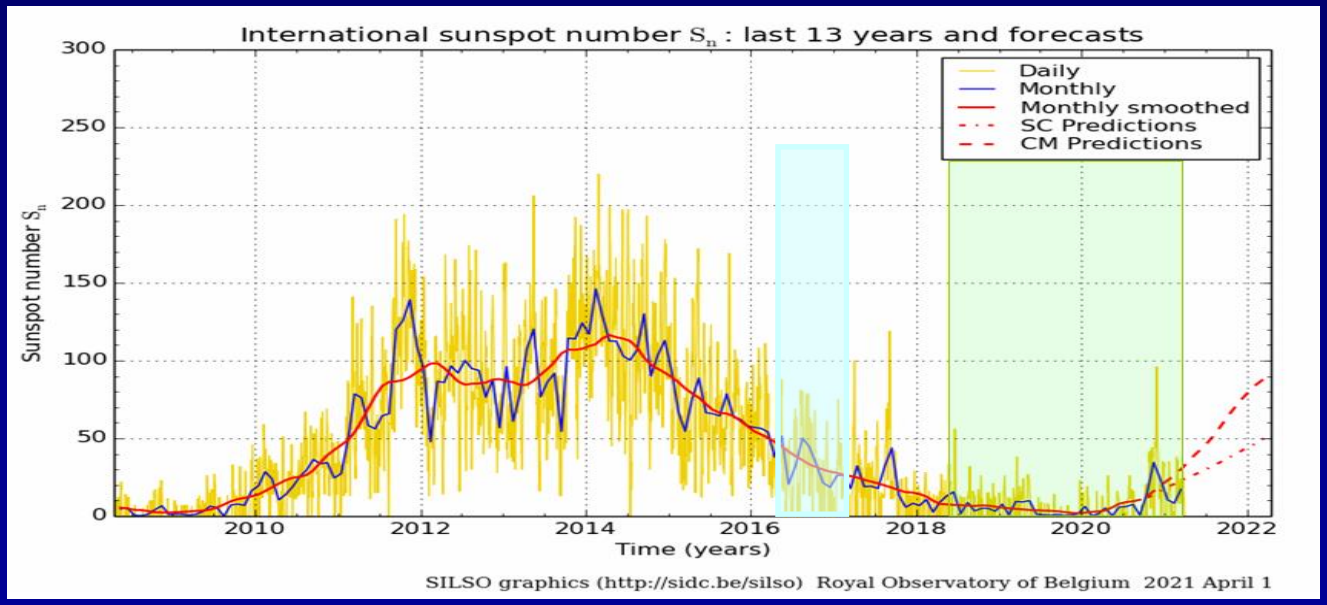
• **MCO1. TGO was inserted into Mars orbit on 19.10.2016. FREND, turned on 31.10.2016 ÷ 17.01.2017 in Mars high elliptic orbit (MCO1:98 000 ÷230 km, $0^0$ inclination to the equator, 4.2 days orbit period).**

• **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. 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.***

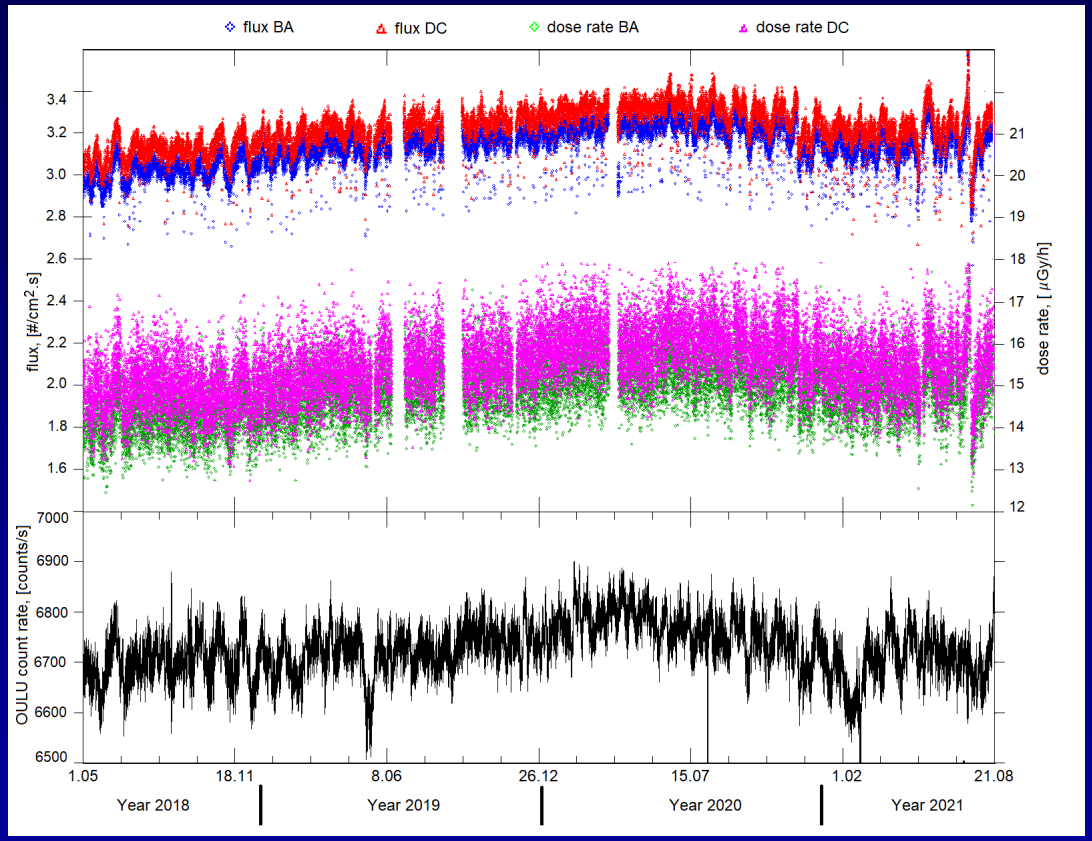
# Solar cycle sunspot number progression and imposed on it periods of Liulin-MO measurements in the interplanetary space and Mars orbit




During Solar minimum - GCR maximum intensity, SEP - rare, if any. During Solar maximum - GCR minimum intensity, SEP - unpredictable

# Results during TGO science phase

# Flux and absorbed dose rates in 2 perpendicular directions and comparison with Oulu count rates, 01.05.2018-20.08.2021




In Mars orbit the planet shades detectors' field of view, thus cutting part of GCR flux. TGO orientation can vary by $180^0$ . The narrow sharp drops of the flux coincide with the increases of the shading effect when the angle between detector's axis and Mars direction approaches zero. The absorbed dose depends insignificantly on the change of the shading.

*GCR fluxes (top) and dose rates (middle) measured by Liulin-MO in Mars science orbit and Oulu neutron monitor (http://cosmicrays.oulu.fi) count rates (bottom) in the period 01.05.2018 – 20.08.2021.*

# Dosimetric parameters in Mars orbit

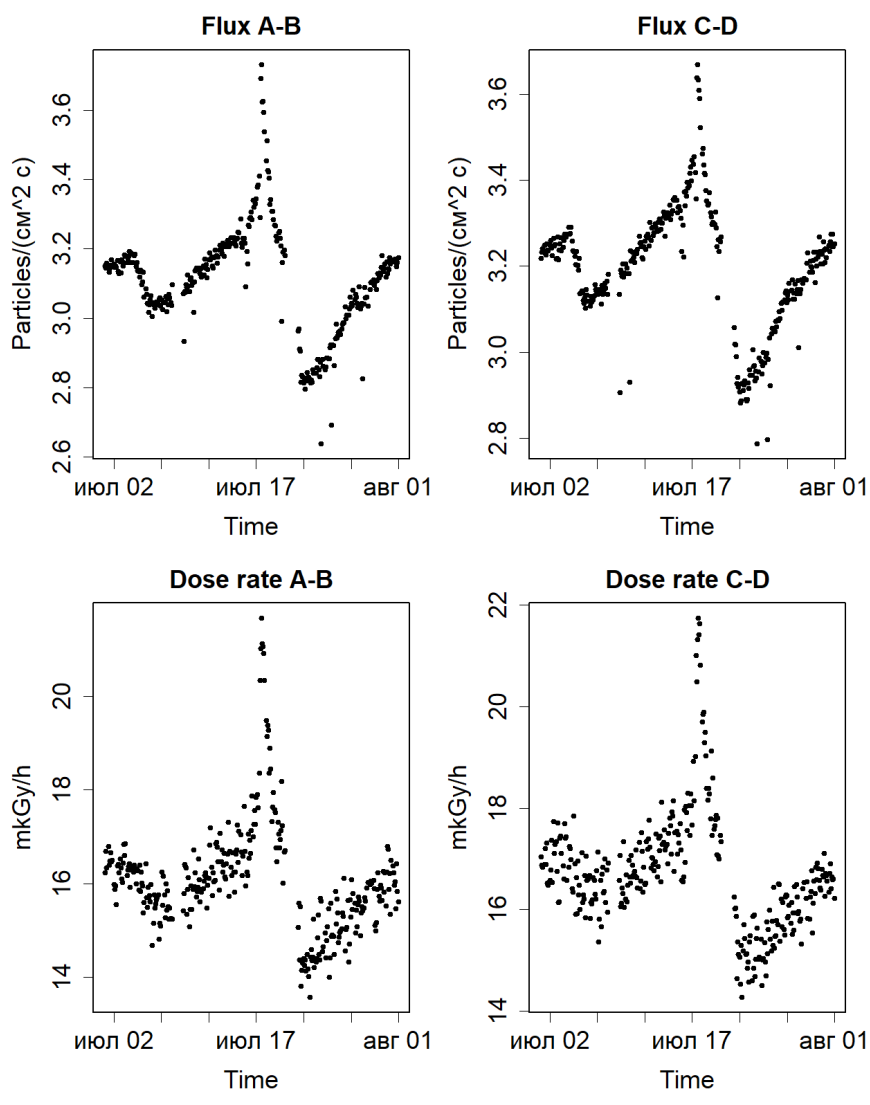
- An increase of the dose rates and fluxes is observed from May 2018 to February 2020 in TGO orbit which corresponds to the increase of GCR intensity during the declining of the solar activity in $24^{th}$ solar cycle; The averaged dose rate for the period is 14.7/15.3 $\mu Gy*h^{-1}$ at two perpendicular directions and the averaged particle flux is 3.09/3.19 $cm^{-2}*s^{-1}$ at two perpendicular directions.

- From March to August 2020 the measured radiation values are practically equal, corresponding to the minimum of $24^{th}$ sycle and transition to $25^{th}$ cycle. The highest values of the dose rate (15.5/16.2 $\mu Gy*h^{-1}$ at two perpendicular directions) and particle flux (3.24/3.33 $cm^{-2}*s^{-1}$ at two perpendicular directions) are registered in this period.

- Since September 2020 a decrease of the dose rates and fluxes is observed, corresponding to the decrease of GCR intensity during the inclination phase of the $25^{th}$ cycle. In August 2021 the dose rate is 15/15.5 $\mu Gy*h^{-1}$ at two perpendicular directions and particle flux is 3.13/3.22 $cm^{-2}*s^{-1}$ at two perpendicular directions-decrease about 3.3-3.8% compared to the maximum in August 2020.

- A good correlation between Liulin-MO and Oulu neutron monitor measurements in the period May 2018 to March 2021 is observed.

# Increase of the flux and dose rate on July 17, 2021



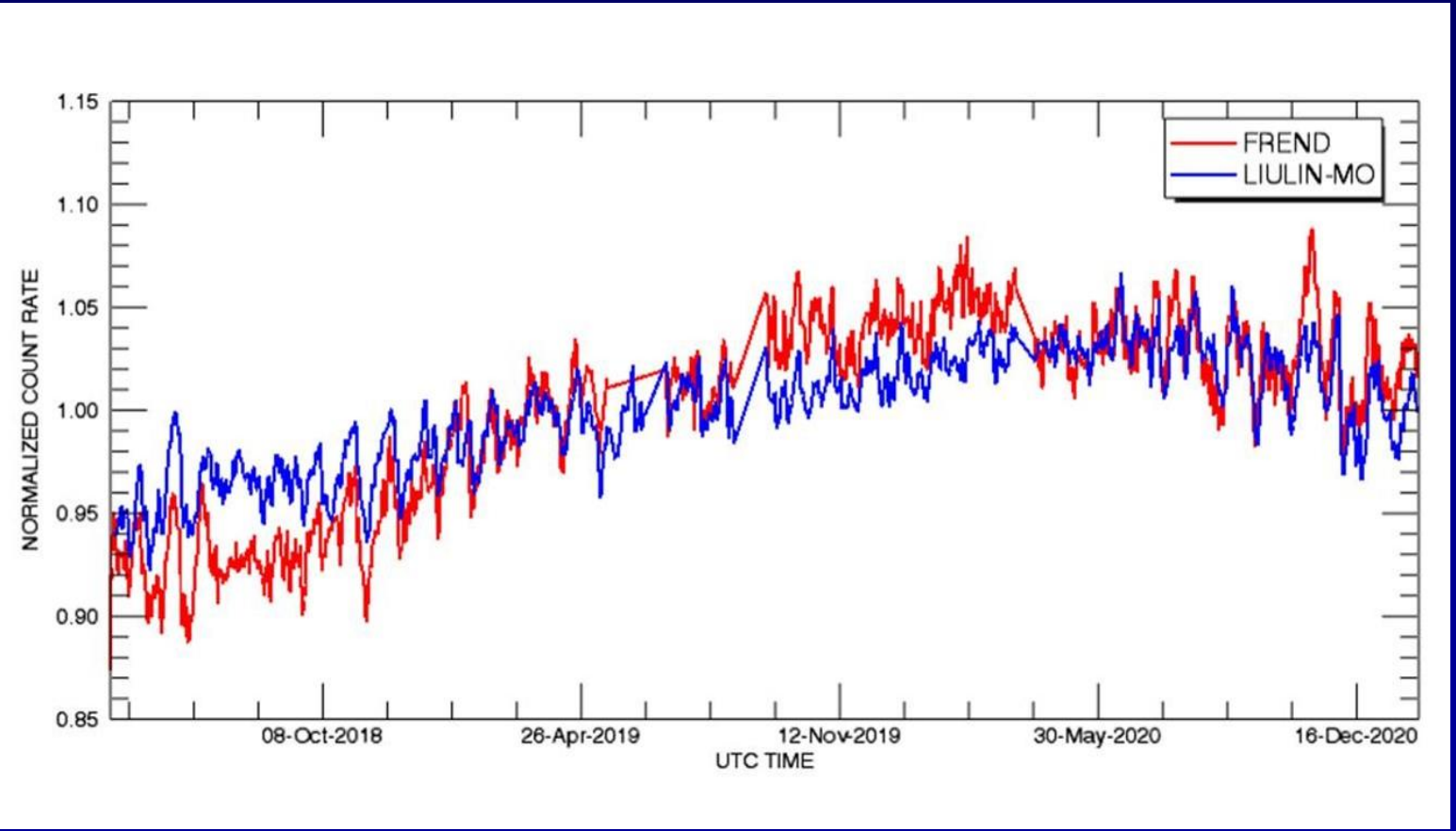

***Increase for about of 24 hours.***

***More details were presented in the poster by Krasimir Krastev et al. at this workshop.***

***Related to 2 CMEs – on 13th 1nd 15th Ju;y 2021.***

***Work in progress***

# Time profiles of GCR daily variations measured by Liulin-MO and FREND neutron detectors in May 2018 – February 2021 in Mars orbit



# Galactic cosmic rays parameters in deep space at about 1.5 AU

**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** ***(Semkova et al, 2021).***

# Worsening of radiation conditions in interplanetary space

- The cosmic ray fluxes and doses measured in Mars orbit are recalculated into values meaningful for the deep interplanetary space at about 1.5 AU.

- The results show that the radiation conditions in the interplanetary space worsen in the minimum of the solar activity in 24$^{th}$ solar cycle. With respect to the values measured during TGO transit to Mars in April-September 2016 *(Semkova et al, 2018),* in August 2020 the particle flux has increased at least by 17.9% (to 3.68 cm$^{-2}$*s$^{-1}$) and the dose rate – by 21.9% (to 18.9 μGy*h$^{-1}$).

- The dose rate evaluated by our data in free space in 24$^{th}$ cycle minimum is 1.4 times higher than that measured during the previous 23$^{rd}$ solar minimum in 2009/2010 by CRaTER instrument on LRO *(Zeitlin, C., et al., 2016).* The solar minimum in 2009/2010 is considered unusually deep and the dose rates then observed were considered maximal. This demonstrates the peculiarities of the passed 24$^{th}$ solar cycle.

# CONCLUSIONS

**The dose rates and particle fluxes of the charged particles measured by Liulin-MO dosimeter of FREND instrument in ExoMars TGO Mars orbit:**

- **Increase from May 2018 to February 2020 - corresponds to the increase of GCR intensity during the declining of the solar activity in 24$^{th}$ solar cycle;**
- **Show maximal values from March to August 2020 - corresponds to the minimum of 24th cycle and transition to 25$^{th}$ cycle;**
- **Decrease since September 2020 - corresponds to the decrease of GCR intensity during the inclination phase of the 25$^{th}$ cycle;**

**Different instruments located around Mars and on Earth show similar time profiles of GCR count rates in May 2018 – August 2021.**

**The radiation conditions in the interplanetary space worsen in the minimum of the solar activity in 24$^{th}$ cycle.**

**An increase of the flux and dose rate on July 17, 2021 is observed-related to 2 CMEs – on 13$^{th}$ 1nd 15$^{th}$ July 2021. Work in progress.**

# Acknowledgements


- The work in Bulgaria is supported by Project No 129 (Grant KP-06 Russia 24) for bilateral projects of the National Science Fund of Bulgaria and Russian Foundation for Basic Research and by Contract No 4000133961/21/NL/SC funded by the Government of Bulgaria through an ESA Contract under the Plan for European Cooperating States.

- The work in Russia is supported by Grant 19-52-18009 for bilateral projects of the National Science Fund of Bulgaria and Russian Foundation for Basic Research

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