Galactic cosmic rays radiation quantities onboard ExoMars Trace Gas Orbiter during the transit and in Mars orbit

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Introduction

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

The estimation of the radiation effects for a long-duration manned space mission requires : i) Knowledge and modeling of the particle radiation environment; ii) Calculation of primary and secondary particle transport through shielding materials; and iii)

Assessment of the biological effect of the dose.

Sources of ionizing radiation in the interplanetary space

Complex radiation environment:

- **GCRs**
- **SEP from flares and CMEs**
- **Secondary radiation from interaction of primary radiation with the spacecraft structures.**

Implications for Future Human Missions to Mars

The Russian and ESA limits allow not more than 1 Sv for the cosmonaut’s, astronaut’s career. NASA's current career effective dose limits are age and gender specific but also about 1Sv.

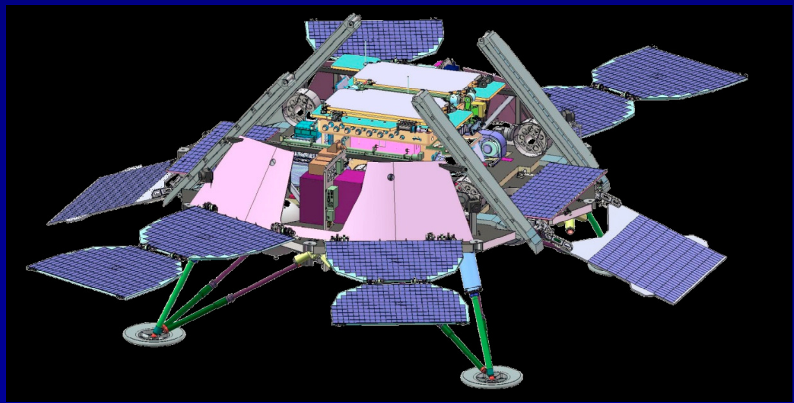
EXOMARS MISSION

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) plus an Entry, Descent and landing demonstrator Module (EDM), launched on 14 March 2016, and the other, featuring a rover and a surface platform, with a launch date of 2020.

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



Surface platform
Credit: NPO Lavochkin

Radiation environment investigations onboard ExoMars

- The dosimeter Liulin-MO for measurement the radiation environment onboard the ExoMars 2016 TGO is a module of the Fine Resolution Epithermal Neutron Detector (FREND) onboard TGO.

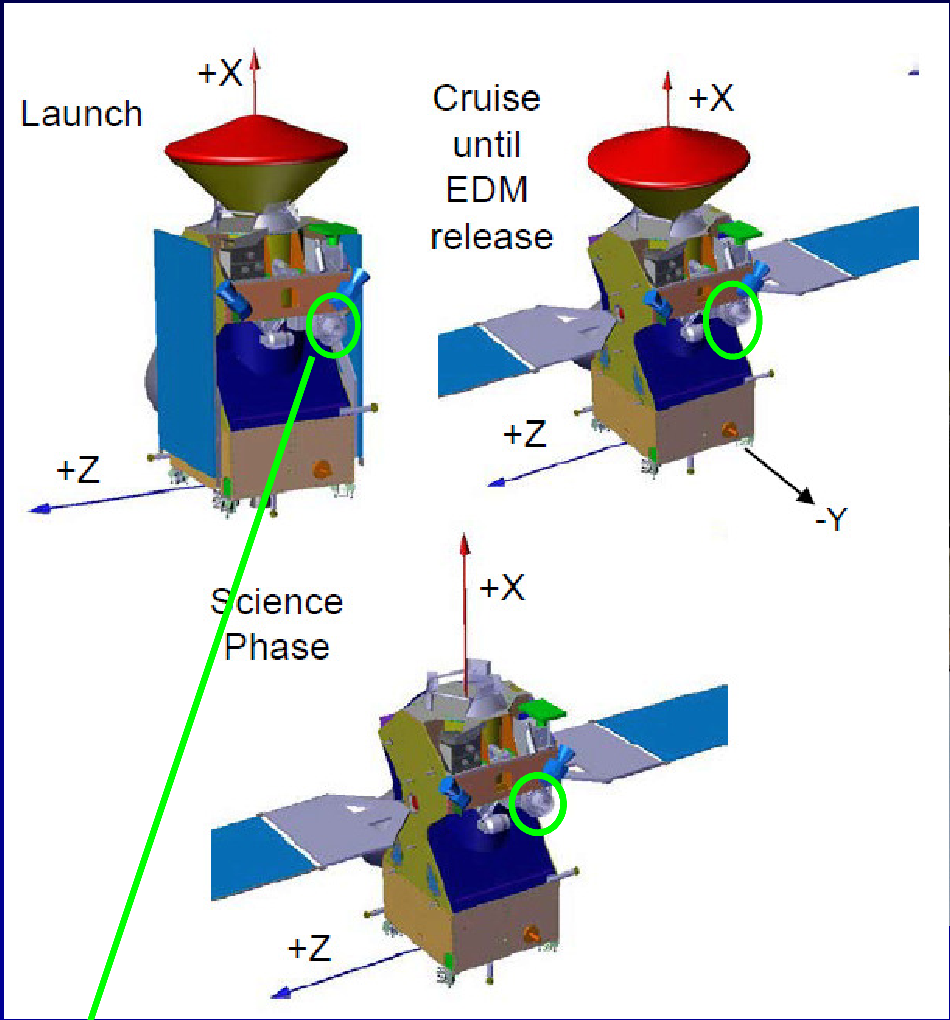
- The second planned experiment for investigation of the radiation environment on Mars surface will be conducted with the Liulin-ML dosemeter as a module of the active detector of neutrons and gamma rays (ADRON) on the surface platform for ExoMars 2020 mission.

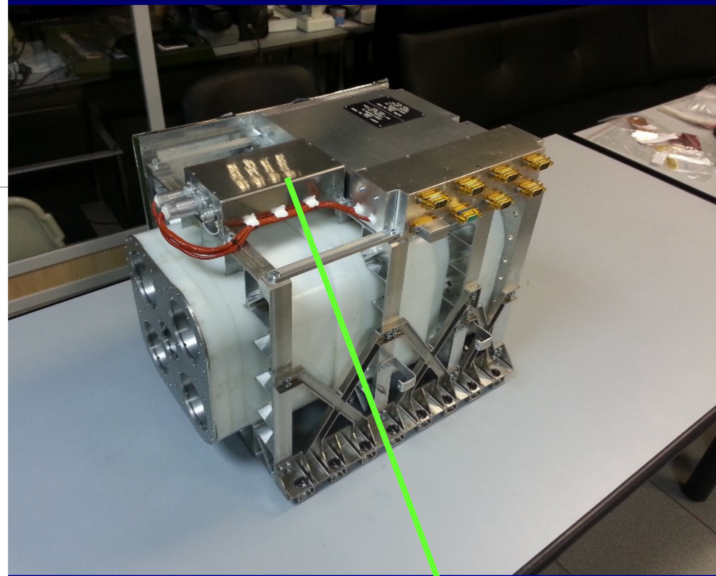
Science objectives of the Liulin-MO and Liulin-ML investigation

- 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 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.

ExoMars TGO mission represents an unique opportunity to conduct measurements of the radiation characteristics during the declining phase of the 24th Solar Cycle.

FREND with Liulin-MO

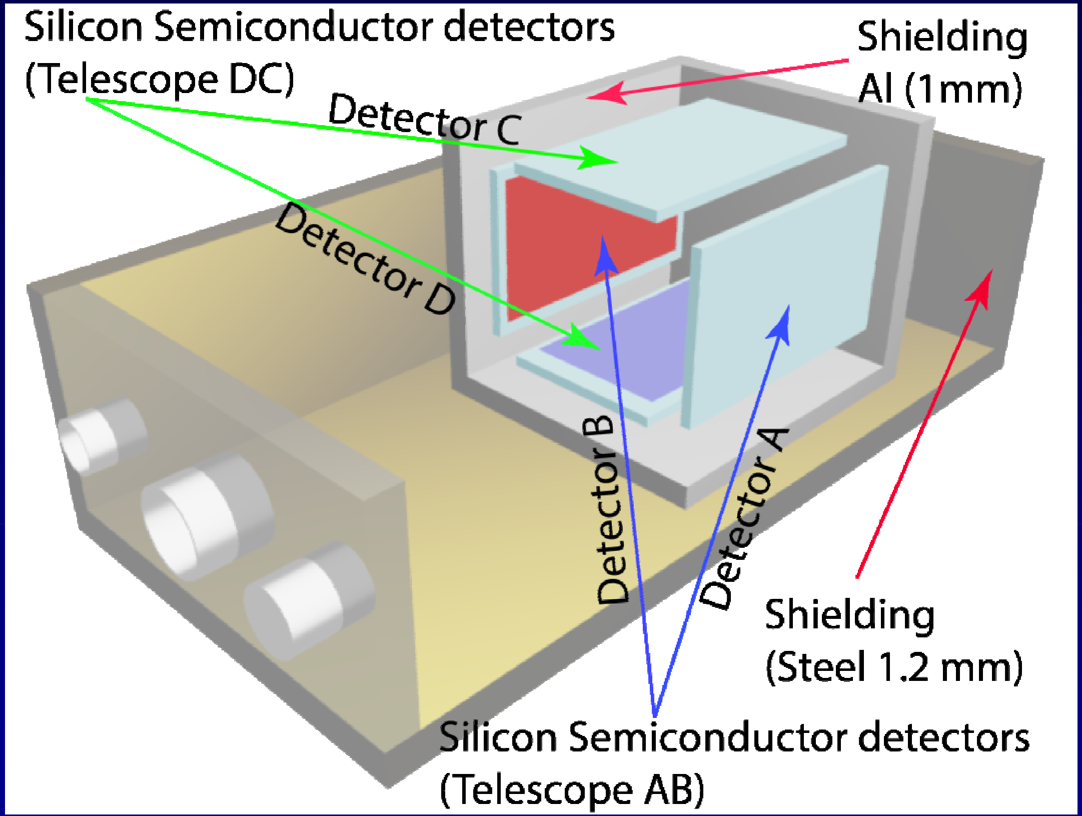




FREND on TGO

FREND instrument with Liulin-MO *Credit: ESA/Roscosmos/FREND/IKI* .

Liulin –MO description



Each pair of the dosimetric telescopes consists of two Si PIN photodiodes. The distance between the parallel Si PIN photodiodes is 20.8 mm. Liulin-MO provides data for the dose rates D, particle fluxes F, LET spectra, radiation quality factor Q, and dose equivalent rates H in 2 perpendicular directions.

Available Liulin-MO data

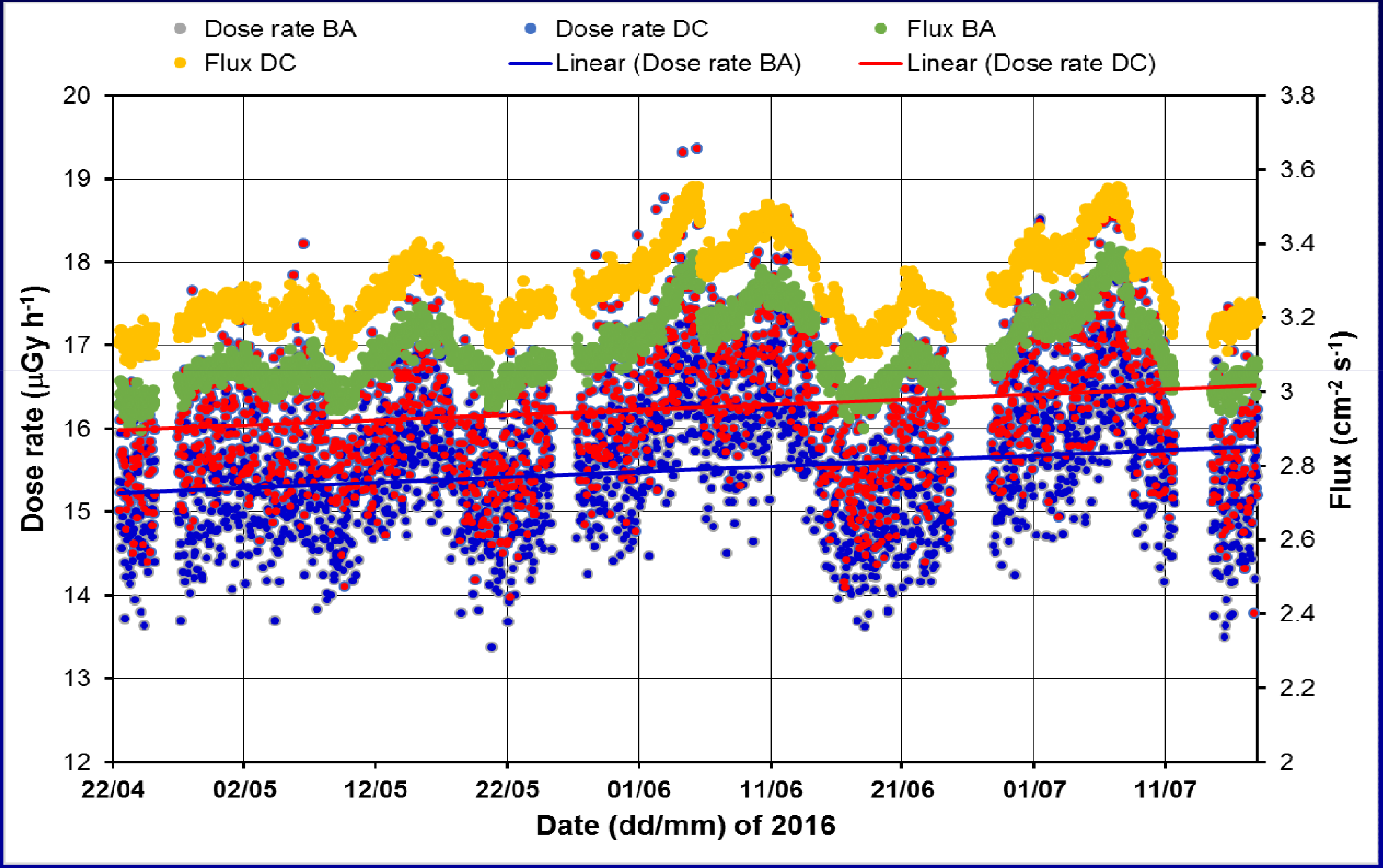
- **Cruise phase. From from 22.04 to 18.07.2016 one of the ^{3}He, the scintillate detectors and Liulin-MO were turned on almost continuously. Since 11.08.2016 ÷ 15.09.2016 Liulin-MO was turned on periodically.**

- **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.**

- ***During that time the dosimeter has measured the dosimetric parameters of GCR. SPE were not registered.***

Fluxes and dose rates recorded in the perpendicular detectors B(A) and D(C) of Liulin-MO



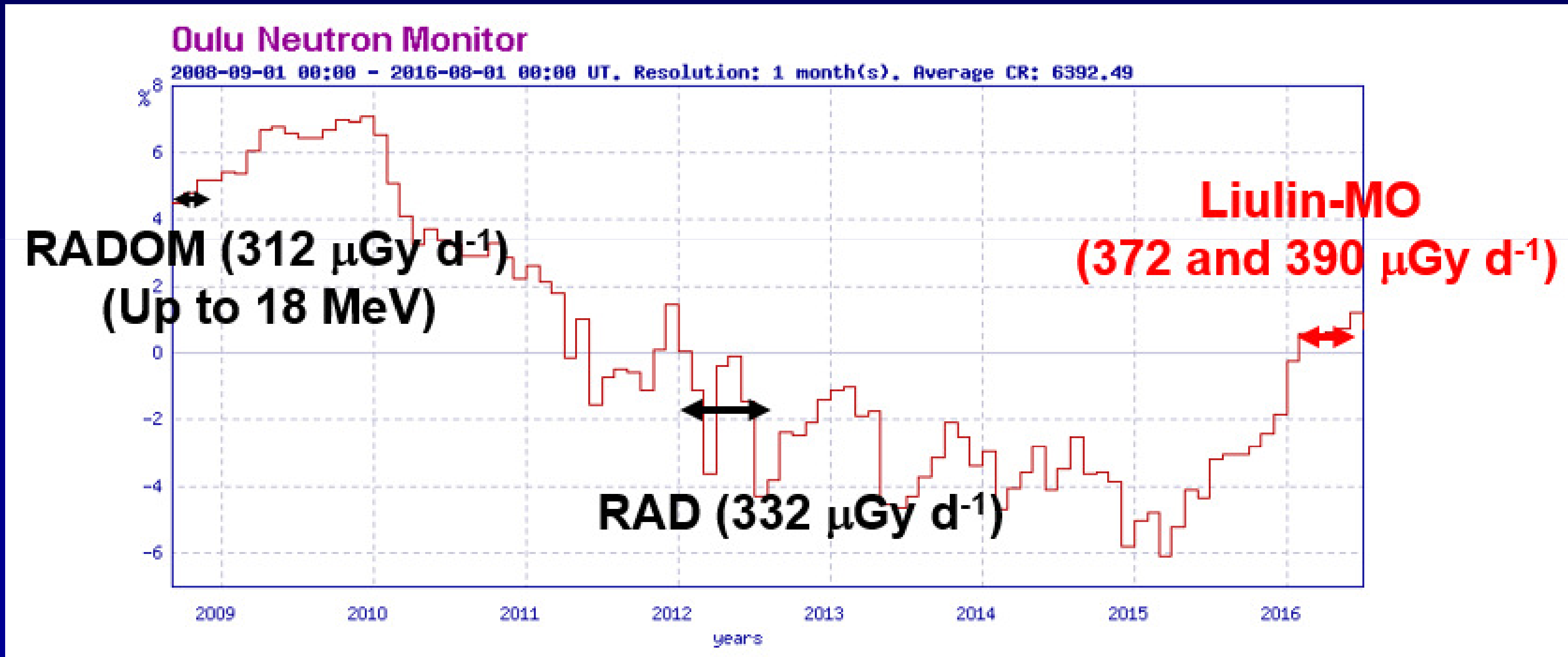
Data for 22.04 ÷ 18.07. 2016

Comparison with RAD during MSL cruise

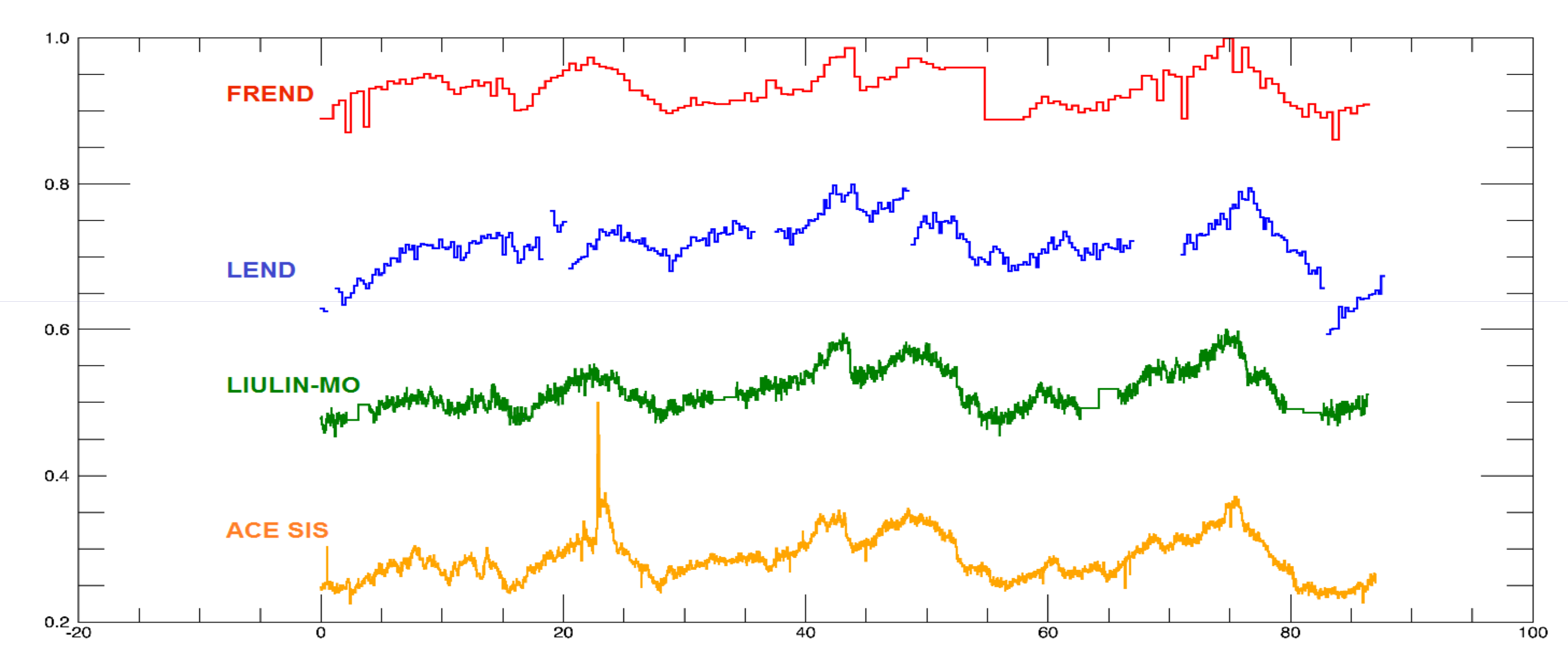
RAD (MSL cruise)	Liulin –MO (TGO cruise)
Data for GCR dose rate in Si 06.12.2011÷14.7. 2012	Data for for GCR dose rate in Si 22.04 ÷ 15.09.2016
332 ± 23 μGy/day *(Zeitlin et al, 31 MAY 2013 VOL 340 SCIENCE)*	372 ± 37 μGy d^{-1} in B(A); 390 ± 39 μGy d^{-1} in D(C).

Liulin-MO dose rate is 12 ÷ 17% >RAD dose rate

Comparison of Oulu NM GCR counts for the time of measurements with RAD and Liulin-MO

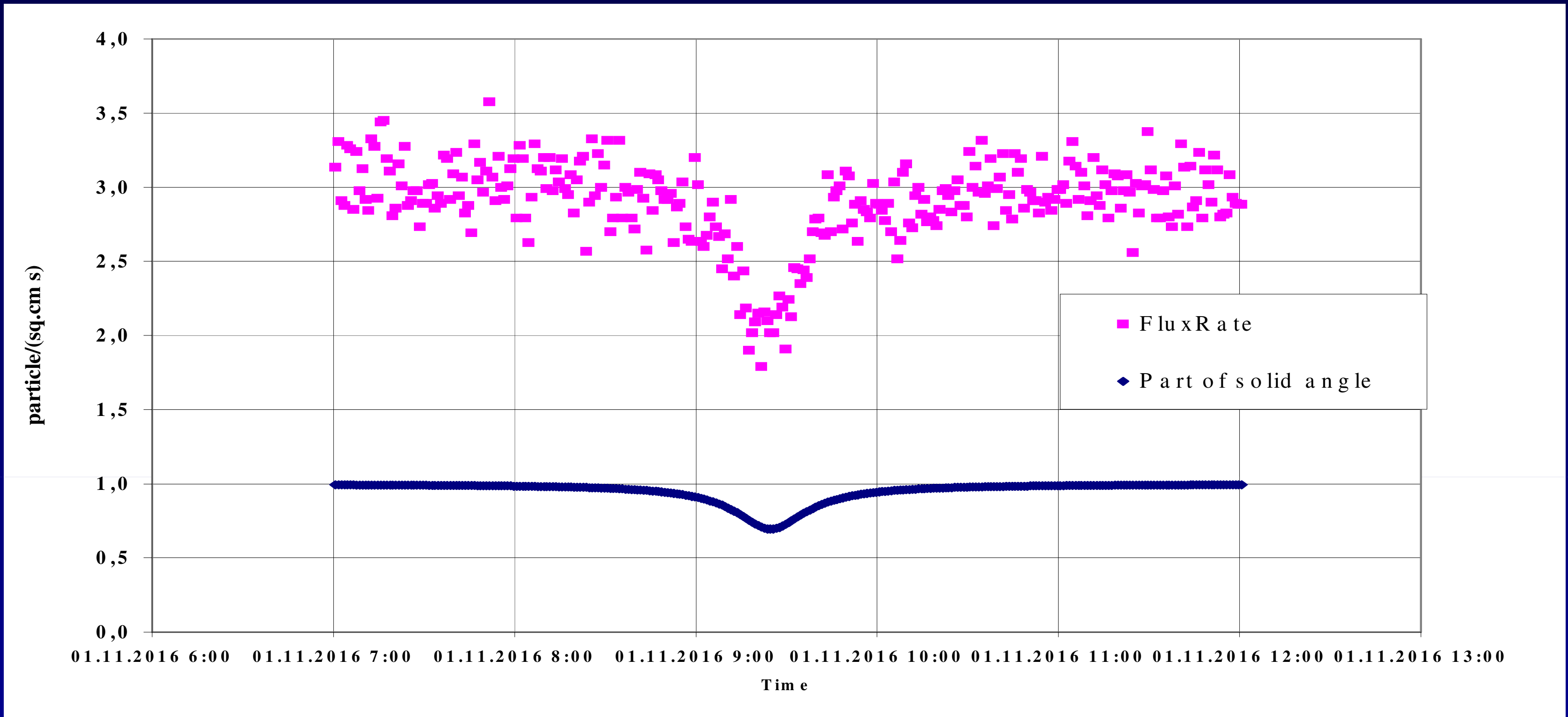


Comparison of SIS-ACE, FREND dosimeter, LEND, FREND neutron detectors fluxes and counts

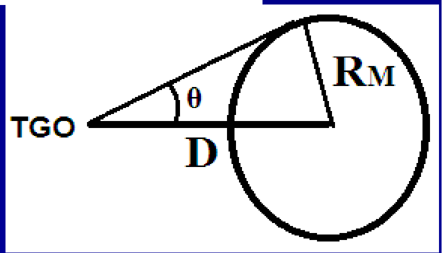


Charged particle counts (in arbitrary units) by : 1) SIS-ACE protons with energies ≥ 30 MeV, 2) Liulin-MO protons with energies ≥ 30 MeV and other charged particles 3) LEND - LRO GCR on (in blue), 4) FREND –neutron detectors GCR

Data in Mars orbit (98 000 ÷250 km)

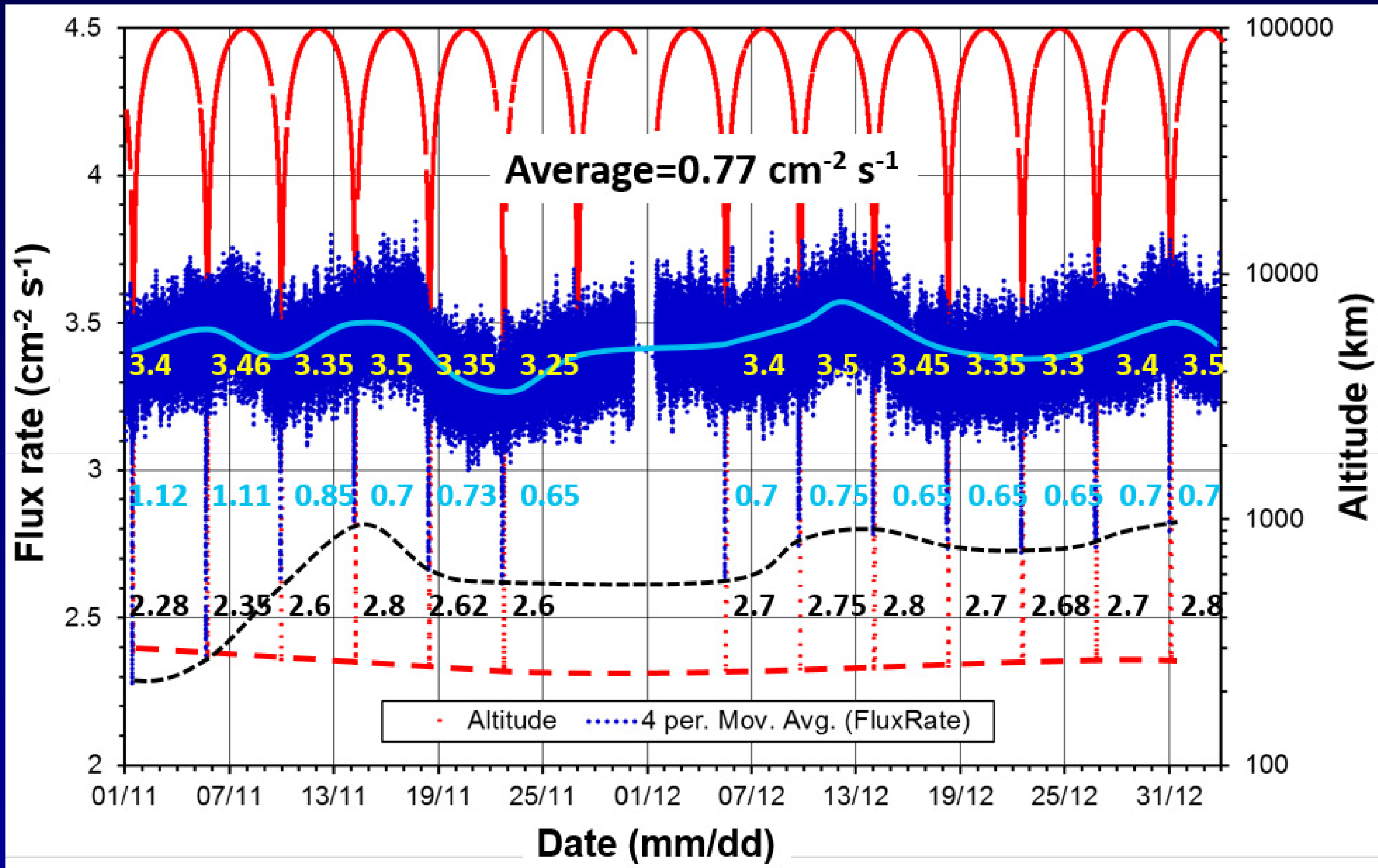


part η of the angle not shadowed by Mars is calculated as: $\eta = [1 - \cos(\Theta)]/2$



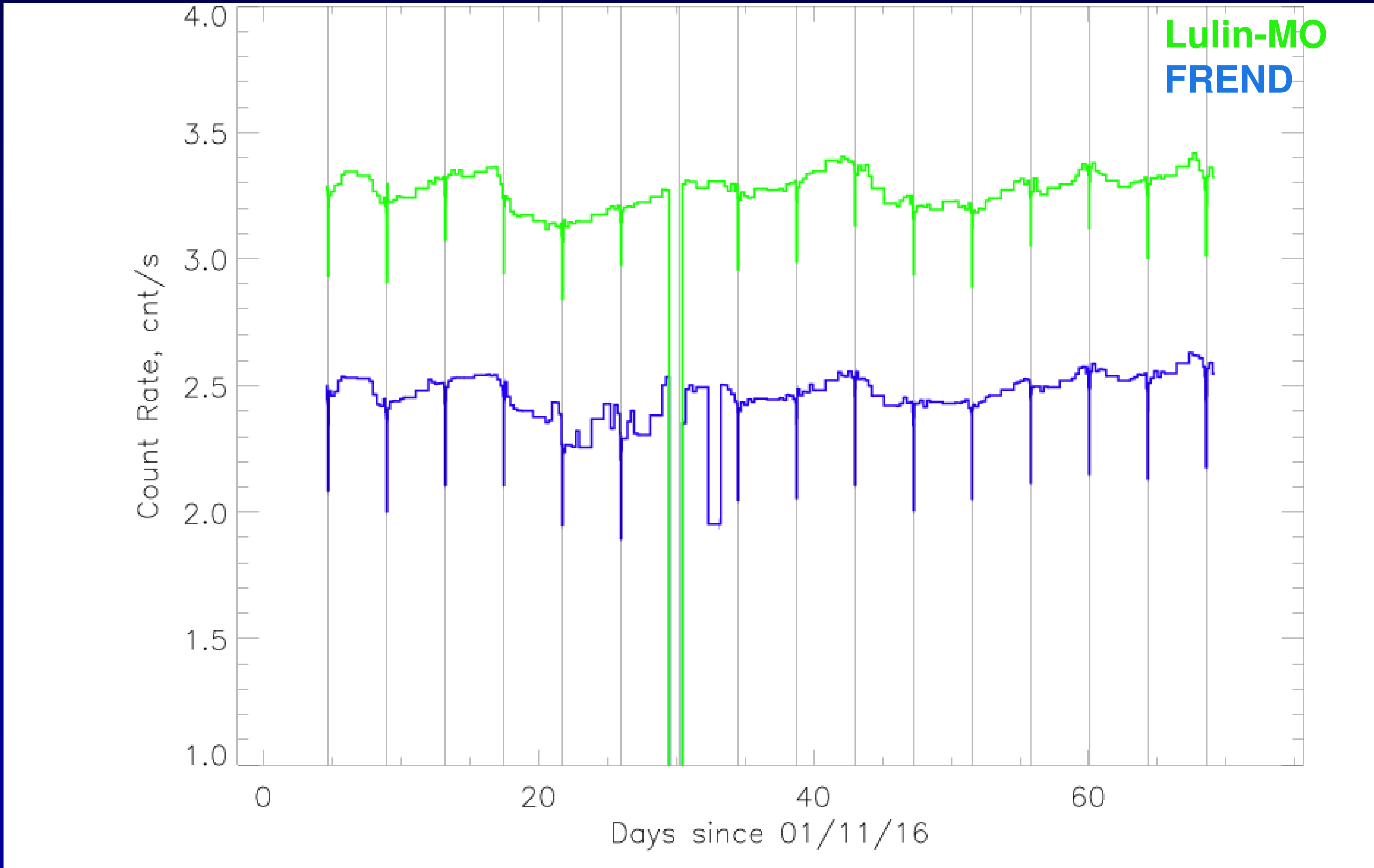
Top- data for the particle flux rate near the pericenter. Bottom-part of the TGO solid angle not shadowed by Mars . The effect of the shadowing of the flux by Mars is observed from the pericenter to 1500 ÷ 3000 km from the planet.

Flux rate and TGO altitude vs. time

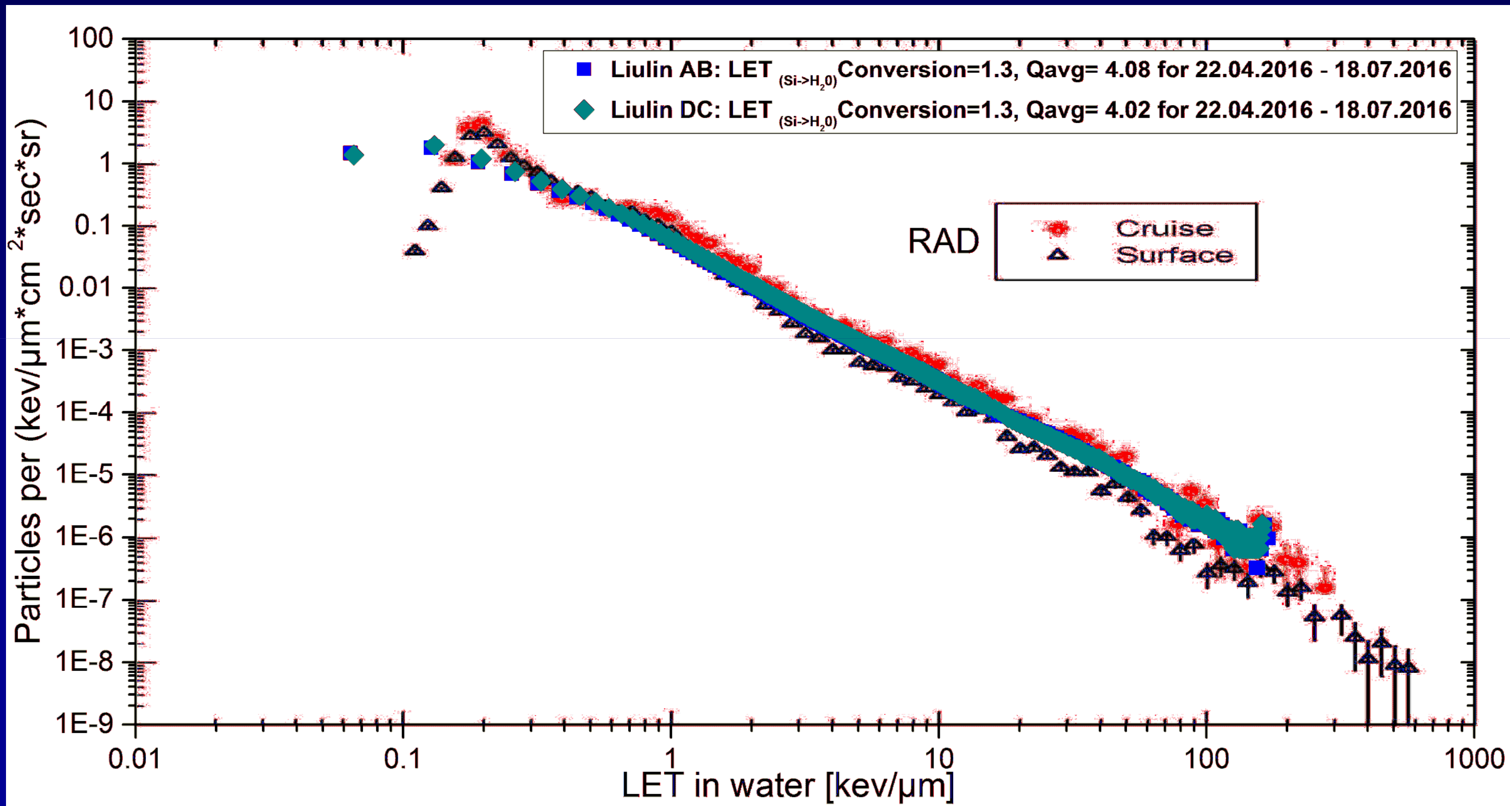


Data for 01.11.2016 ÷ 04.01.2017. The average particle flux is 3.26 cm^{-2} s^{-1} in BA and 3.42 cm^{-2} s^{-1} in DC. The average decrease of the flux in the pericenter is 0.77cm^{-2} s^{-1}

FREND GCRs Count Rate and Lulin-MO GCRs Flux in high elliptic Mars orbit



LET spectra, Q and H for 22.04 ÷ 15.09.2016. Comparison with RAD Data for GCR during the transit *(Guo et al, 2015)*. Preliminary !



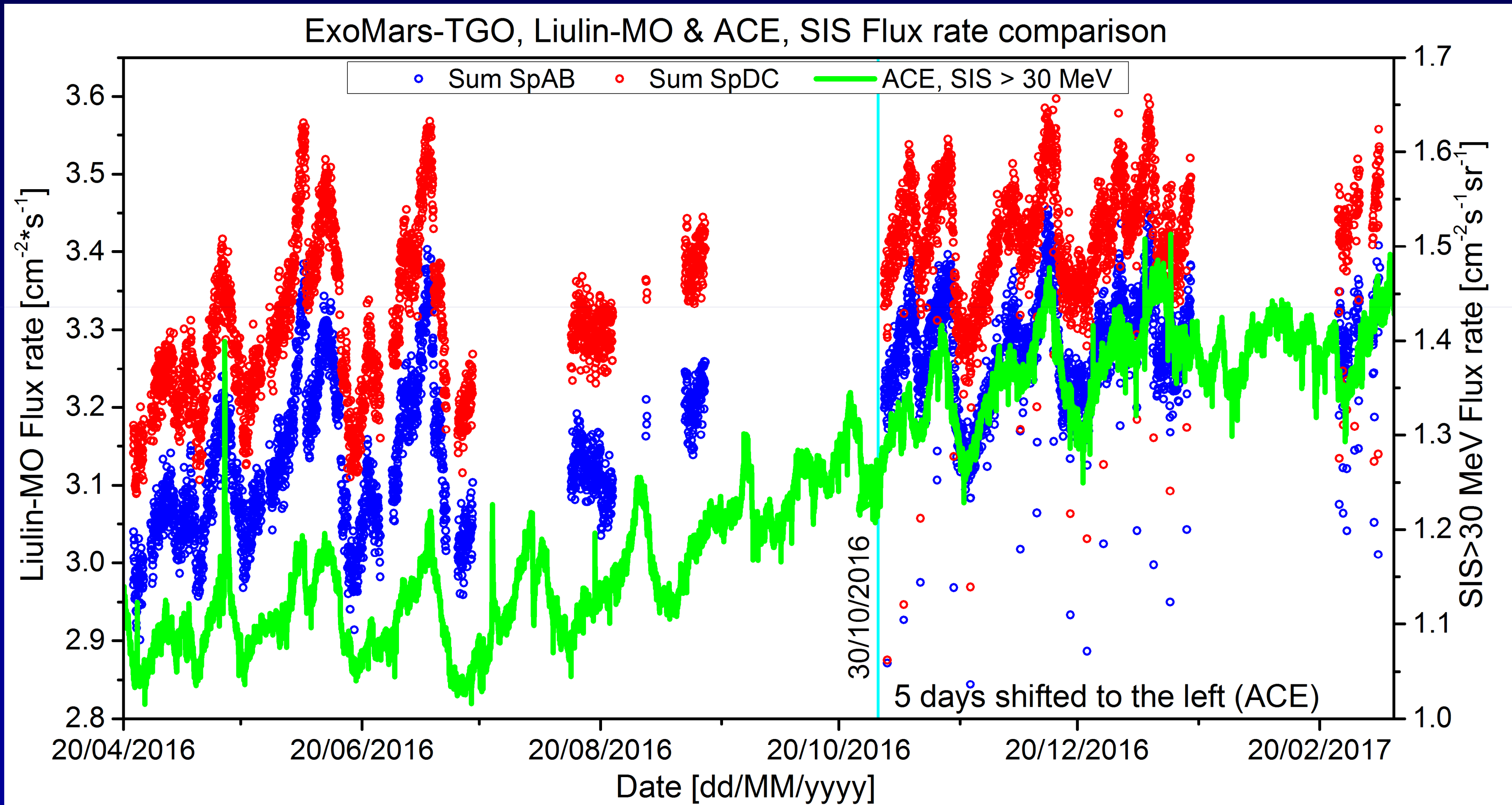
In AB direction Q ~4.08; in DC direction Q~ 4.02 for GCRs, H (AB) =1.97 ± 0.3 mSv d^{-1}, H (DC) = 2.04 ±0.3 mSv d^{-1}. RAD=1.75 ± 0.30 mSvd^{-1}.

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

Time frame	D (Si) (AB) D (Si) (DC) μGy d^{-1}	Q (AB) Q (DC)	H (AB) H(DC) mSv d^{-1}
22.04- 15.09.2016 Cruise	372 ± 37 390 ± 39	4.08 ± 0.3 4.02 ± 0.3	1.97 ±0.4 2.04 ±0.4
01.11.2016- 17.01.2017 MCO1	405.6 ± 41 422.4 ± 42	4.23 ± 0.33 4.12 ± 0.3	2.23 ±0.5 2.26 ±0.5
24.02- 07.03.2017 MCO2	410 ± 41 425 ± 42.5	4.31 ± 0.33 4.17 ± 0.3	2.3 ±0.55

~ 10% increase of dose rate, ~ 15 % increase of dose equivalent rate for 9.5 months flight

Liulin- MO and ACE proton flux > 30 MeV (22.04.2016 to 07.03.2017)



CONCLUSIONS (1)

First results from the Liulin-MO dosimeter of FREND instrument onboard the ExoMars TGO show that:

- **The average measured dose rate in Si from GCR during the transit to Mars for the period 22.04-15.09.2016 is 372 ± 37 μGy d^{-1} and 390 ± 39 μGy d^{-1} in 2 perpendicular directions. The average flux in the interplanetary space is 3.12 cm^{-2} s^{-1} and 3.3 cm^{-2} s^{-1}. This is in good agreement with RAD measurements in the interplanetary space and with current solar activity.**

- **A good agreement between the measurements of GCR count rates taken during the TGO transit by all FREND detectors and measurements by other instruments in different locations in the heliosphere is observed.**

CONCLUSIONS (2)

•In high elliptic Mars' orbit strong dependence of the GCR fluxes near the TGO pericenter on the part of the TGO solid angle not shadowed by Mars is observed.

•The increase of the dose rate and flux from 22.04.2016 to 07.03.2017 corresponds to the increase of GCR intensity during the declining phase of the solar activity.

•The preliminary data shows dose equivalent rates for the transit ~2 ± 0.4 mSv d^{-1} in 2 perpendicular directions. In MCO the dose equivalent rate is ~ 2.2± 0.5 mSv d^{-1} in both directions. This show that during the cruise to Mars and back (taken during the declining of solar activity) the crewmembers of future manned flights to Mars will accumulate at least 60% of the total dose limit for the cosmonaut's, astronaut's career.

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Thank you!