Radiation investigations onboard ExoMars missions. Results for radiation parameters during TGO cruise to Mars

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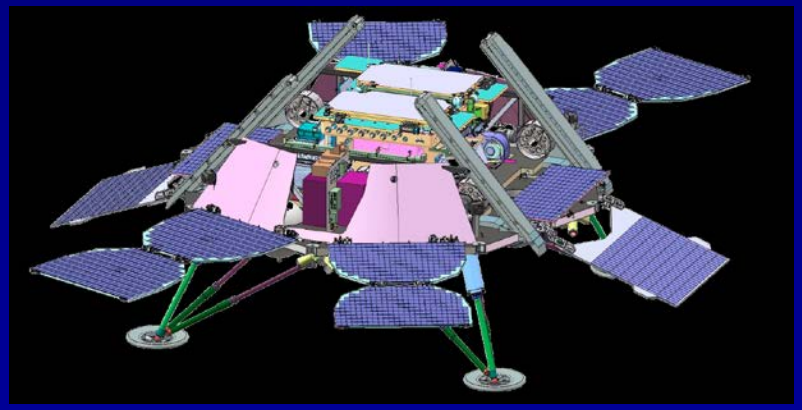
EXOMARS MISSION

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

The ExoMars programme has been established to investigate the Martian environment and to demonstrate new technologies paving the way for a future Mars sample return mission.

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 dosimetric telescope and the experiment Liulin-MO for measurement the radiation environment onboard the ExoMars 2016 TGO is a part of the Fine Resolution Epithermal Neutron Detector (FREND) onboard TGO.

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

Primary 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.

LIULIN–MO DOSIMETER OF FREND INSTRUMENT ONBOARD EXOMARS TGO

Detailed Liulin –MO Objectives on TGO (1)

- **Measurements during the cruise phase and in Mars orbit:**

➢ **Energy Deposition Spectra, Dose Rate & Particle flux - then Absorbed Dose *D* in 2 perpendicular directions.**

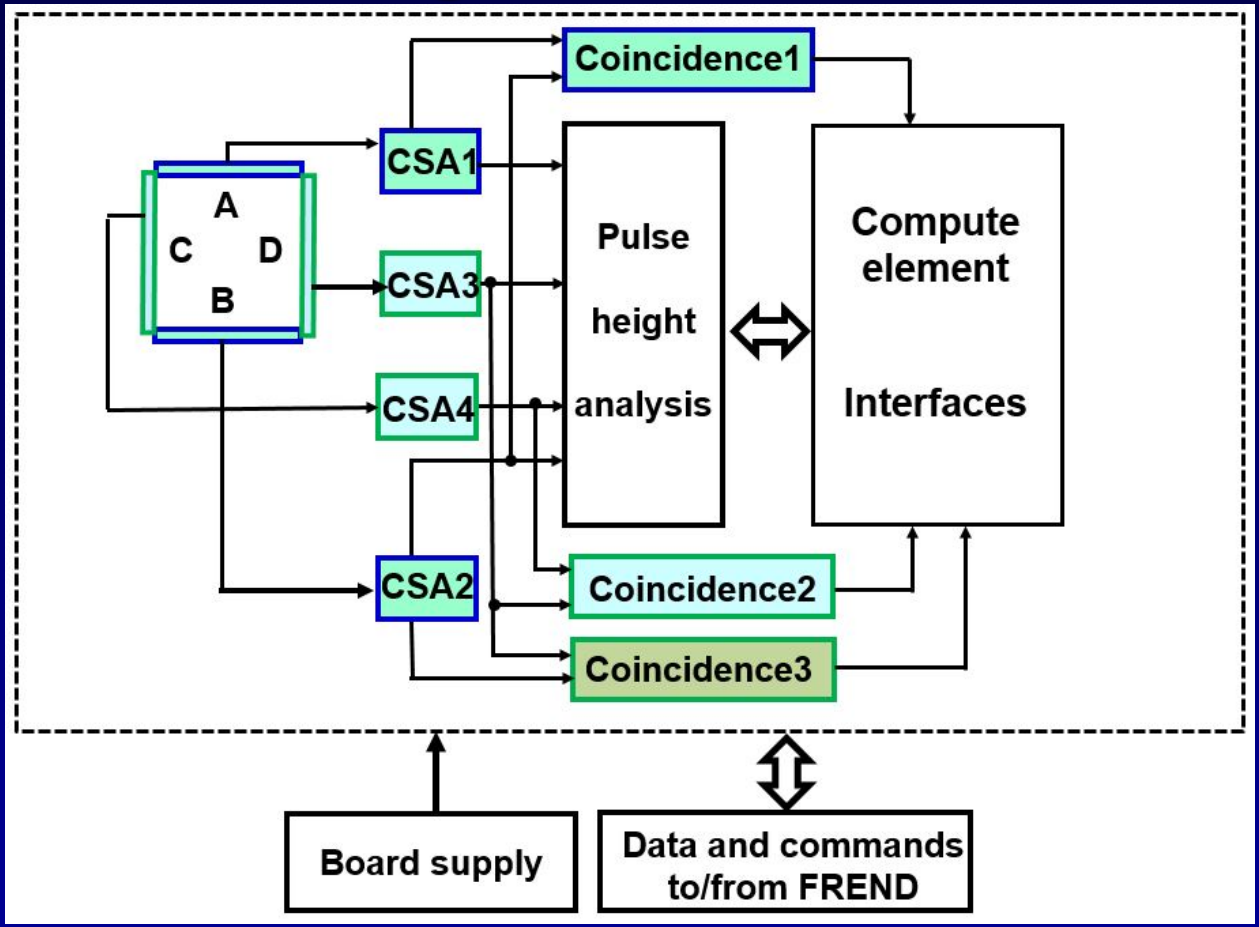
➢ ***dE/dX* spectra in silicon (in 2 perpendicular directions) – then assessment of LET(H_2O), Q=f(LET), given in ICRP-60 and Dose Equivalent H; H=DxQave.**

- **Measurements of GCR flux and dose rate in dependence on the heliocentric distance.**
- **Investigation of the dependence of the GCR radiation parameters in Mars orbit on the distance to Mars.**

Detailed Liulin –MO Objectives on TGO (2)

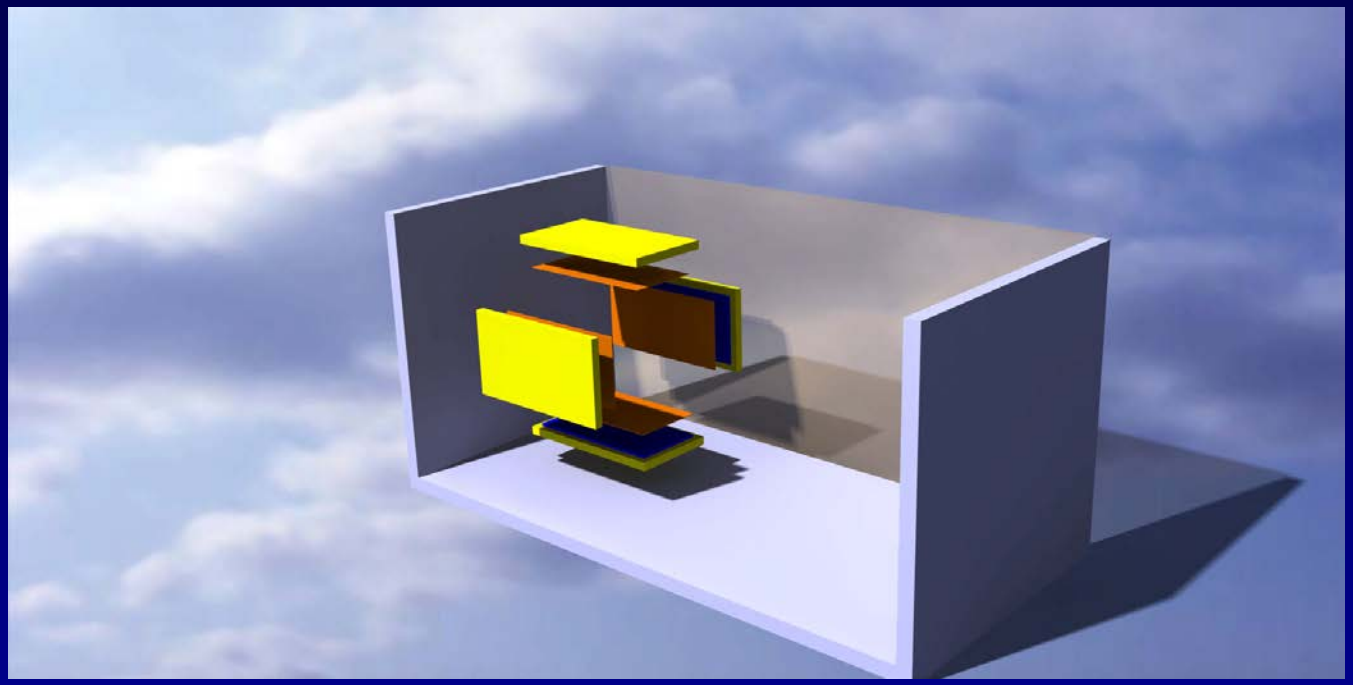
- Simultaneous registration of SEP events together with other space instruments providing radiation data .
- Assessment of both the charged particle and the neutron fluxes and dose rates during periods of quiet Sun and during SEP events combining data from the dosimeter and the neutron detectors of FREND.
- Allow comparison of orbital and surface radiation data provided by Liulin-MO on TGO, and Liulin-ML on the ExoMars 2020 surface platform.
- An additional goal of Liulin-MO is to increase the accuracy of the neutron measurements by providing information about radiation fluctuations from charged particles that can have an impact on the signals from the neutron detectors of FREND.

Configuration of Liulin –MO



Two dosimetric telescopes (A&B) and (C3&D) in perpendicular directions. Each telescope consists of two Si PIN photodiodes. A coincidence technique for the associated with each dosimetric telescope signals is applied to obtain LET .

Liulin-MO detector's location



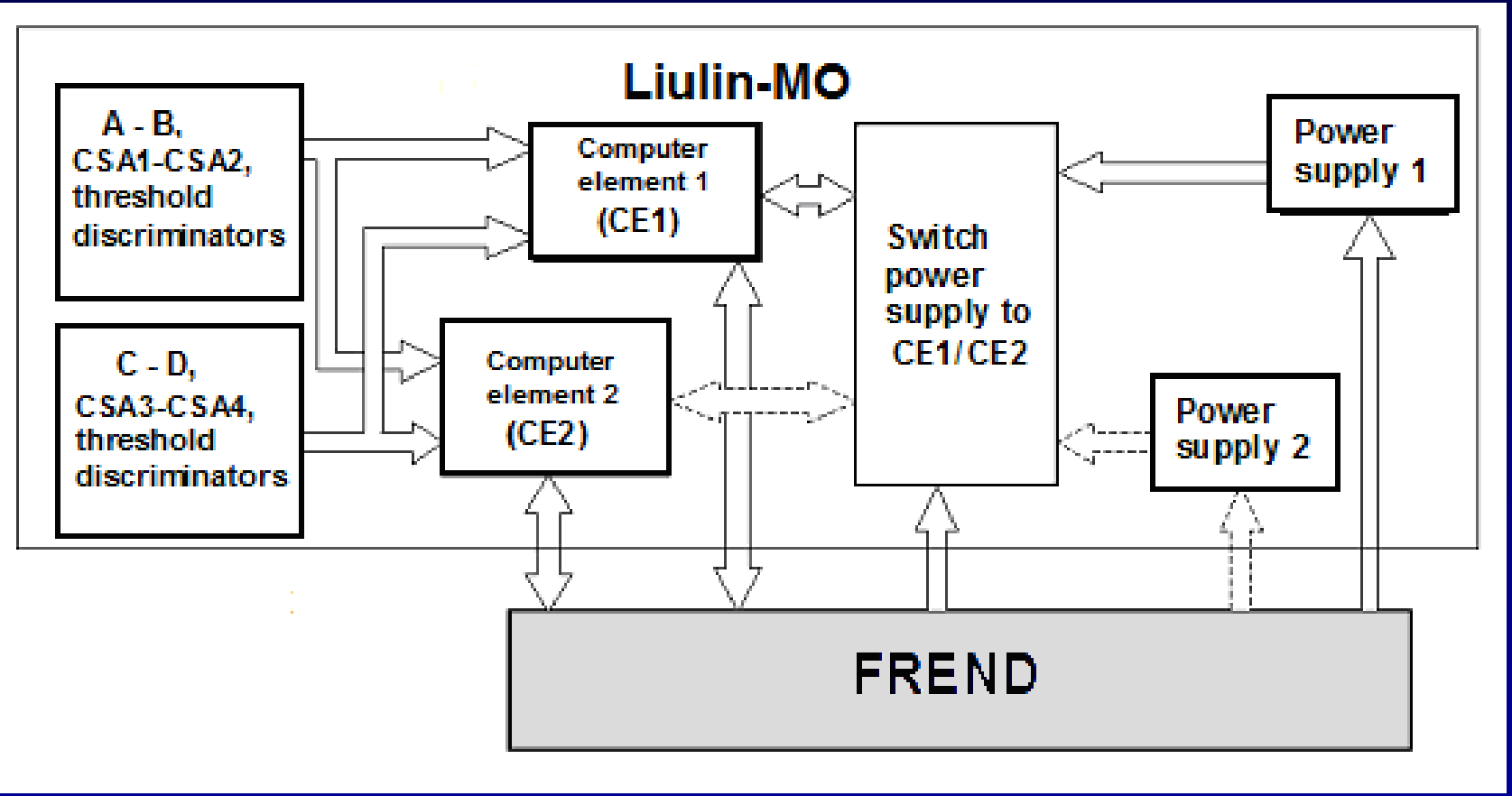
Each pair of the dosimetric telescopes consists of two 300 μm thick, 20x10 mm area rectangular Si PIN photodiodes. The distance between the parallel Si PIN photodiodes is 20.8 mm.

The geometry factor of the telescope for isotropic radiation is ~ 1,38 cm^2sr. The geometry factor of a single detector is ~ 12,56 cm^2 sr.

Technical characteristics of Liulin-MO

- Weight 0. 700 kg.
- Power consumption 2.2 W.
- Absorbed dose rate $\Rightarrow 10^{-7} \div 0.1$ Gy/h.
- Particle flux $\Rightarrow 0 \div 10^{4}$ particle/s.
- LET spectrum (in H_2O) $\Rightarrow$ 0.1 ÷ 200 keV/μm.
- Resolution: Dose rate and particle flux $\Rightarrow$ 60s, spectra $\Rightarrow$ 60 min.
- Telemetry rate $\Rightarrow$ 2 Mbits/day.

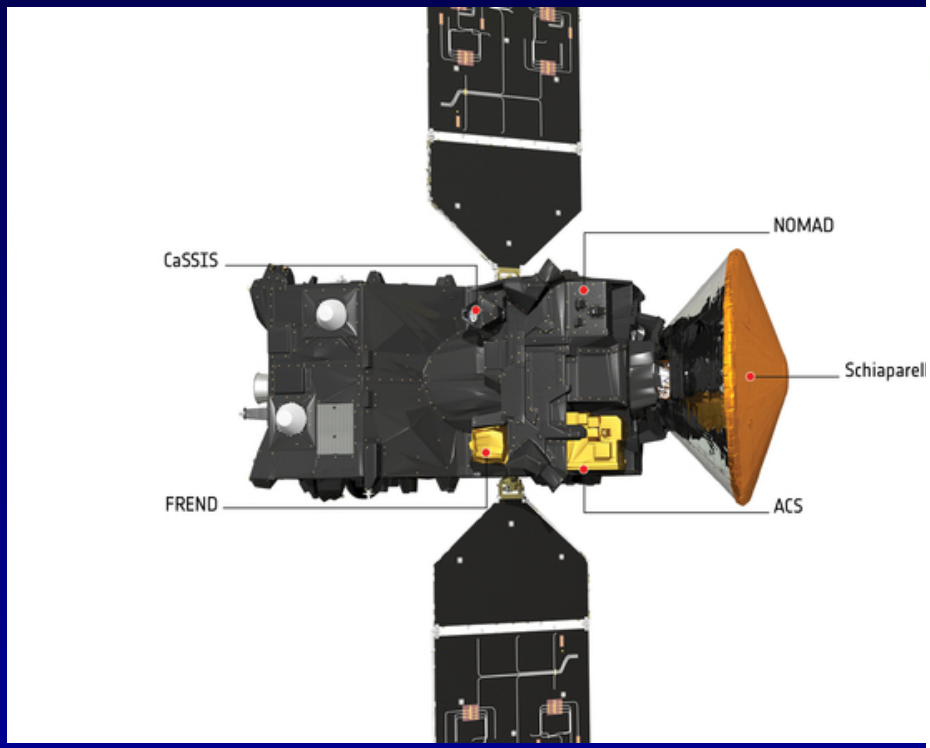
Liulin-MO Block-diagram



Nominal and redundant side of the dosimeter

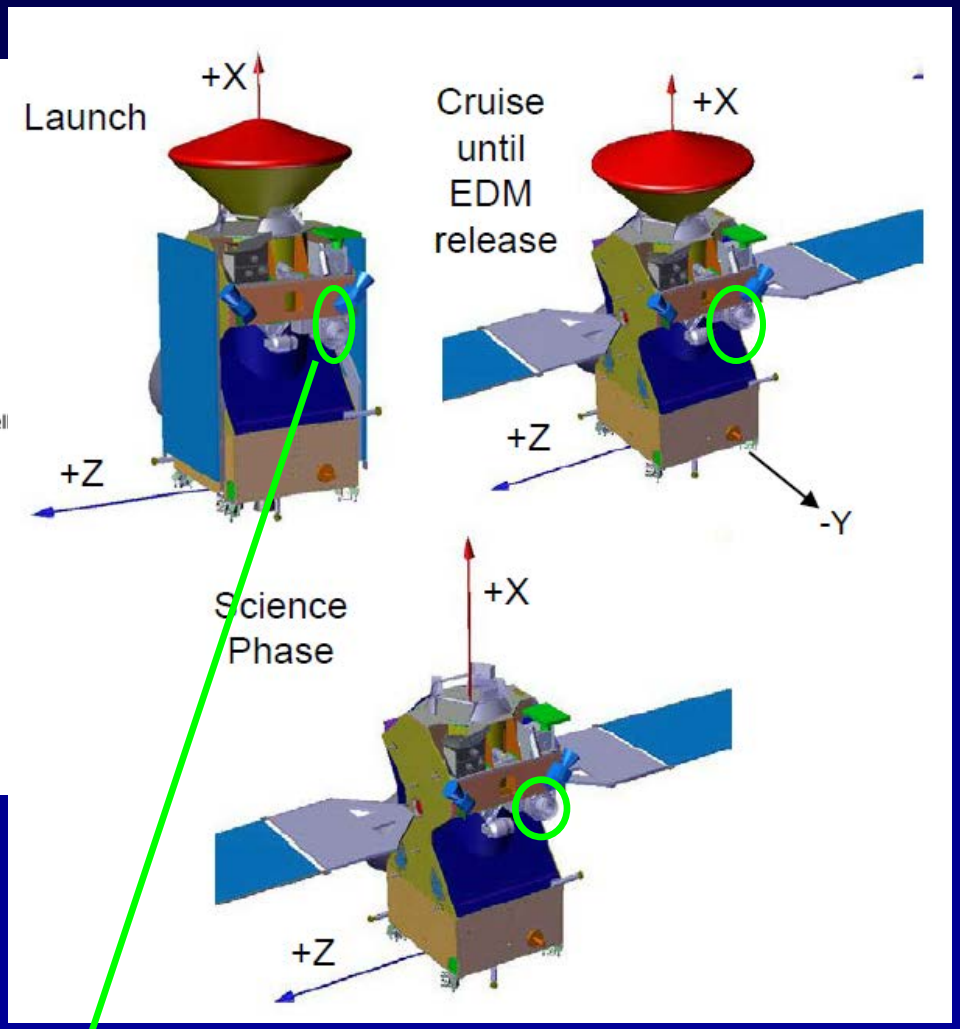
FREND onboard ExoMars TGO

http://exploration.esa.int/science-e/www/area/index.cfm?fareaid=118



Scientific instruments accommodation on the TGO.
http://exploration.esa.int/mars/48523-trace-gas-orbiter-instruments/?fbodylongid=2217

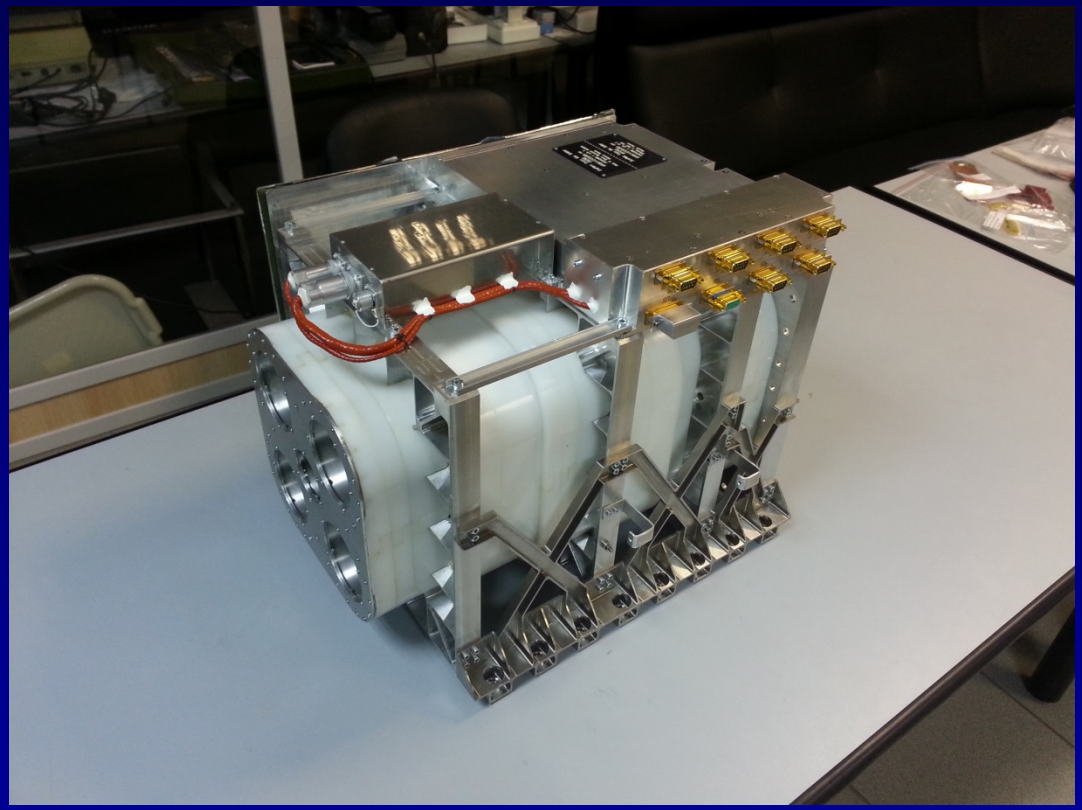
Credit:ESA/ATG medialab



FREND with Liulin-MO on TGO

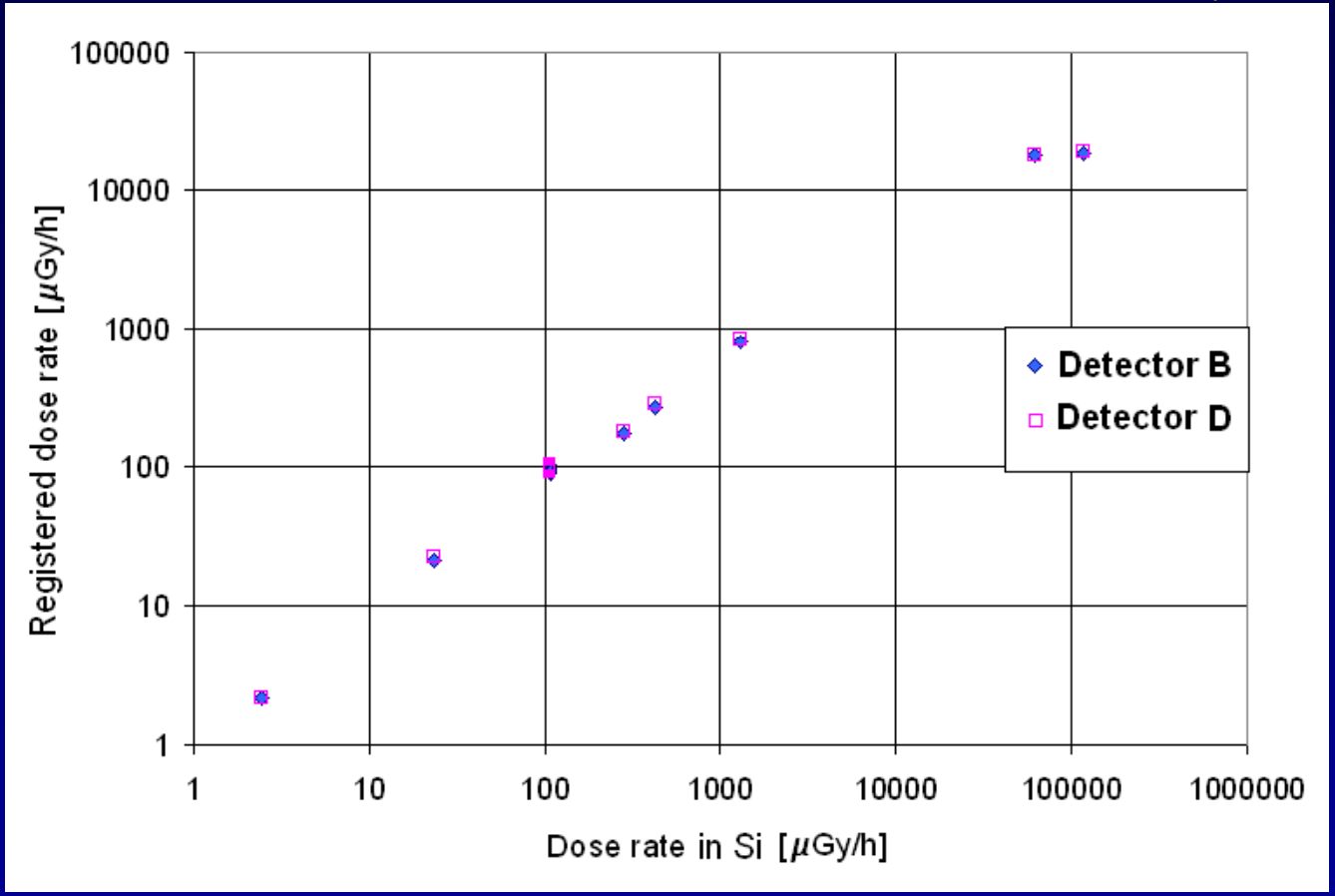
FREND with Liulin-MO

Liulin-MO.



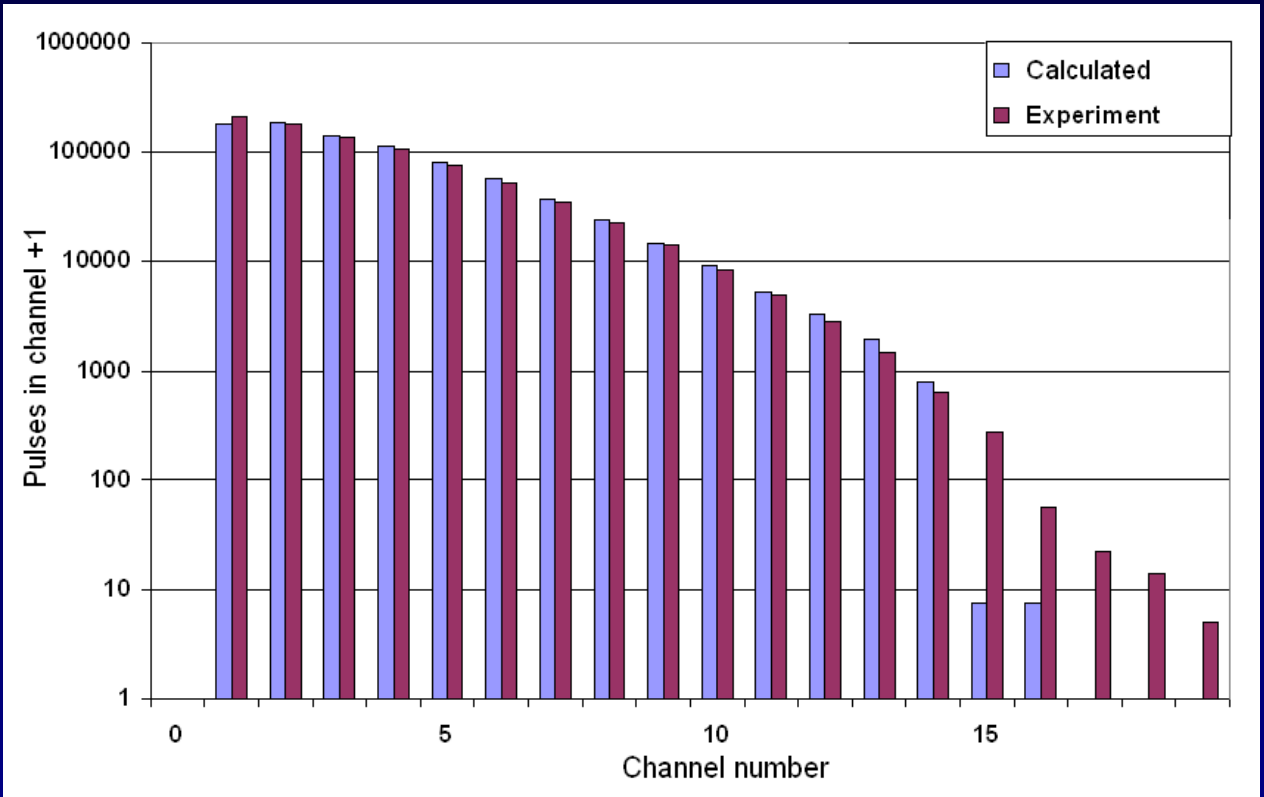
FREND with Liulin-MO.

Liulin-MO calibration with standard γ-sources



Calibrations at the Research Department of Ionising Radiation Metrology – Russia by means of standard ^{60}Co and ^{137}Cs sources.

Calibration curve of dose rate measurements in detectors B and D. On the X-axis is the dose rate of the source (estimated at the point between all 4 detectors, located at equal distances from the detectors) , on the Y-axis is the measured dose.



Comparison between measured during the physical calibration and simulated (GEANT4) energy deposition spectra of γ-sources in detector B of Liulin-MO

A model of the detector unite of Liulin-MO was developed. Simulated was irradiation of the detector unit with γ-rays of energy 0.661 MeV (^{137}Cs) and γ-rays with energies 1.17 MeV and 1.33 MeV (^{60}Co).

The received spectrum, as expected, is due mainly to Compton electrons with energies less than 0.477 MeV for ^{137}Cs and 1.116 MeV for ^{60}Co.

Results from the physical calibration and simulations of Liulin-MO

The calibration coefficient that converts the spectral channel number to the deposited energy by a single particle or a photon was obtained experimentally for each of the Liulin-MO detectors.

The results show that the difference between the coefficients obtained from the calculations and calibrations&modeling are not more than 10%.

The calibrations confirm the large dynamic ranges of the flux (up to 10^4 particle cm^{-2} s^{-1}) and the dose rate (10^{-7} Gy h^{-1} ÷ 0.1 Gy h^{-1}) measurements that allow Liulin-MO to measure the fluxes and dose rates both of the relatively low–intensity GCR and the occasional high–intensity powerful SEP events. The instrument has also enough sensitivity to measure the natural radiation background on the Earth surface that was used to control the proper operation of its detectors during the pre - flight tests.

Available Liulin-MO data during the TGO cruise

06.04.2016 –first turned on during NECP:

- **Checked nominal side with nominal power unit & nominal side with redundant power unit.**

- **The dosimeter demonstrated to be in good health and performs valid physical measurements.**

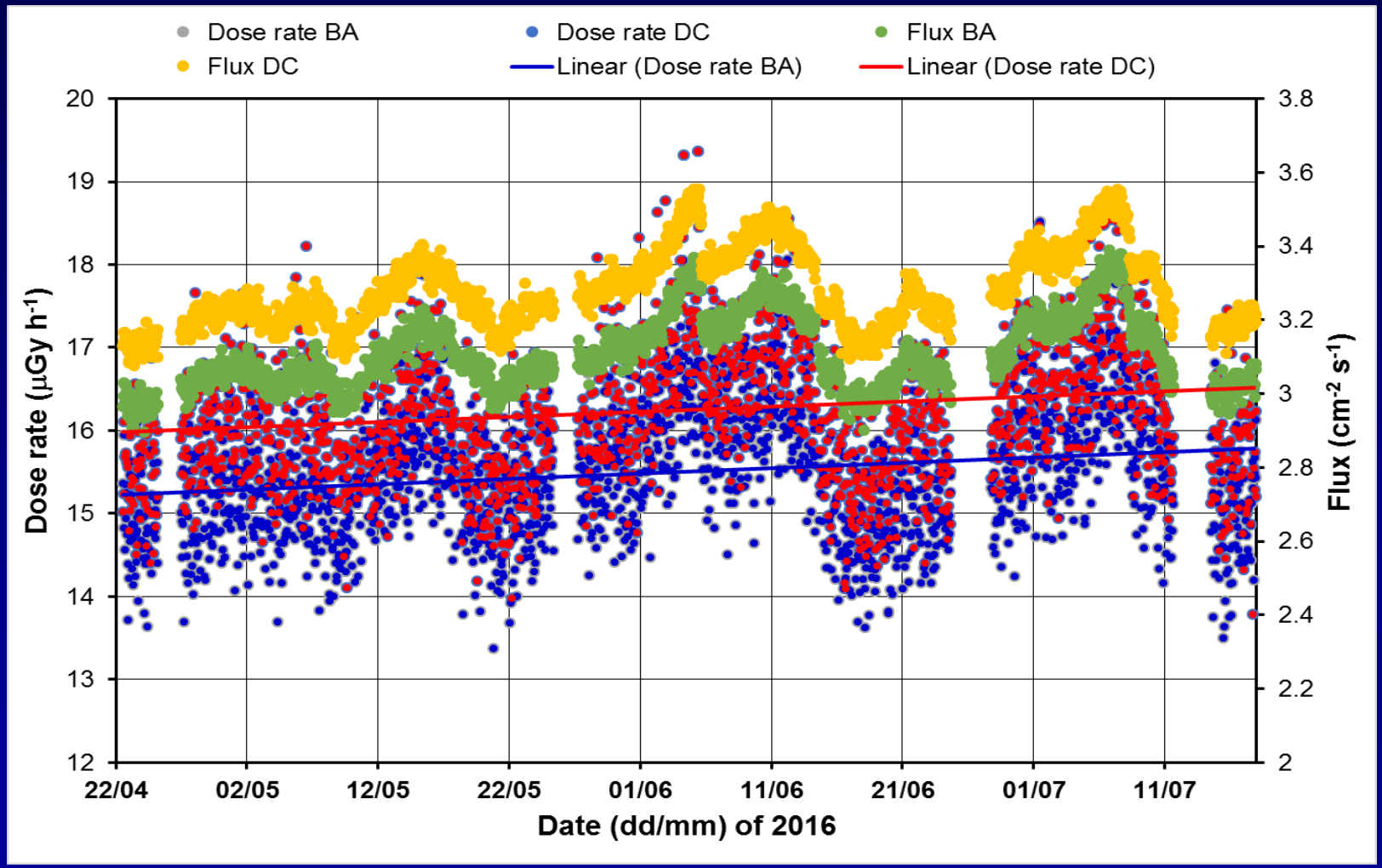
From 22.04 to 18.07 one of the ^{3}He and the scintillate detectors of FREND, as well as Liulin-MO were turned on almost continuously.

From 19.07 to 11.08 during Deep Space Maneuvers of TGO FREND and Liulin-MO were turned off.

Since 12.08.2016-currently Liulin-MO is turned on periodically.

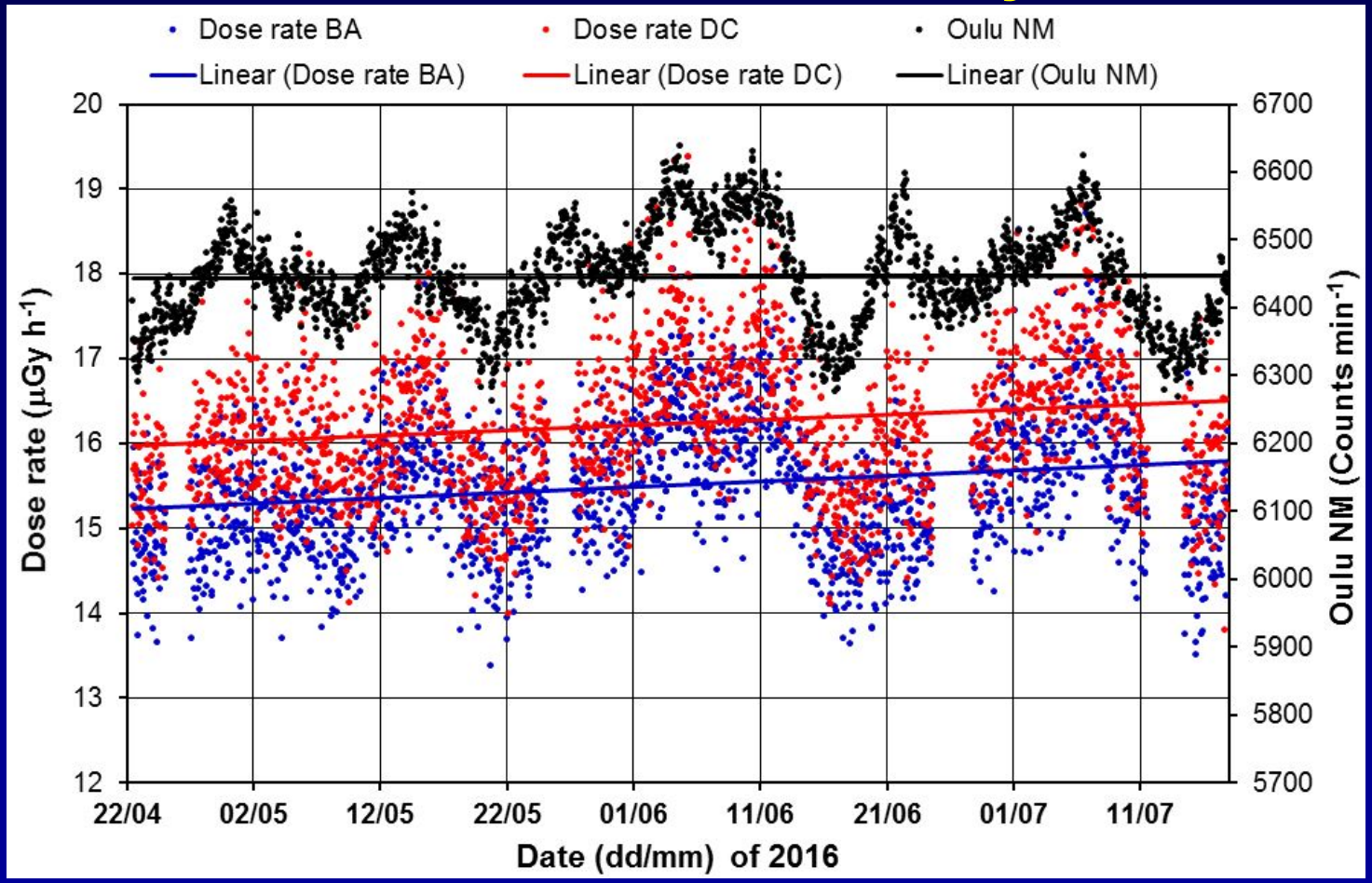
- ***During that time the dosimeter has measured the dosimetric parameters of GCR.***

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



Data for 22.04 ÷ 18.07. 2016

Dose rates recorded in the perpendicular detectors B(A) and D(C) of Liulin-MO and the Oulu Neutron Monitor cosmic ray count rate



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 ÷ 18.07.2016
332 ± 23 μGy/day *(Zeitlin et al, 31 MAY 2013 VOL 340 SCIENCE)*	372 ± 30 μGy d^{-1} in B(A); 390 ± 31 μGy d^{-1} in D(C).

Comparison with RADOM on Chandrayan-1 during the cruise to Moon

RADOM measures in the low-energy deposition range (~ 0.08 ÷ 18 MeV) of Liulin-MO.

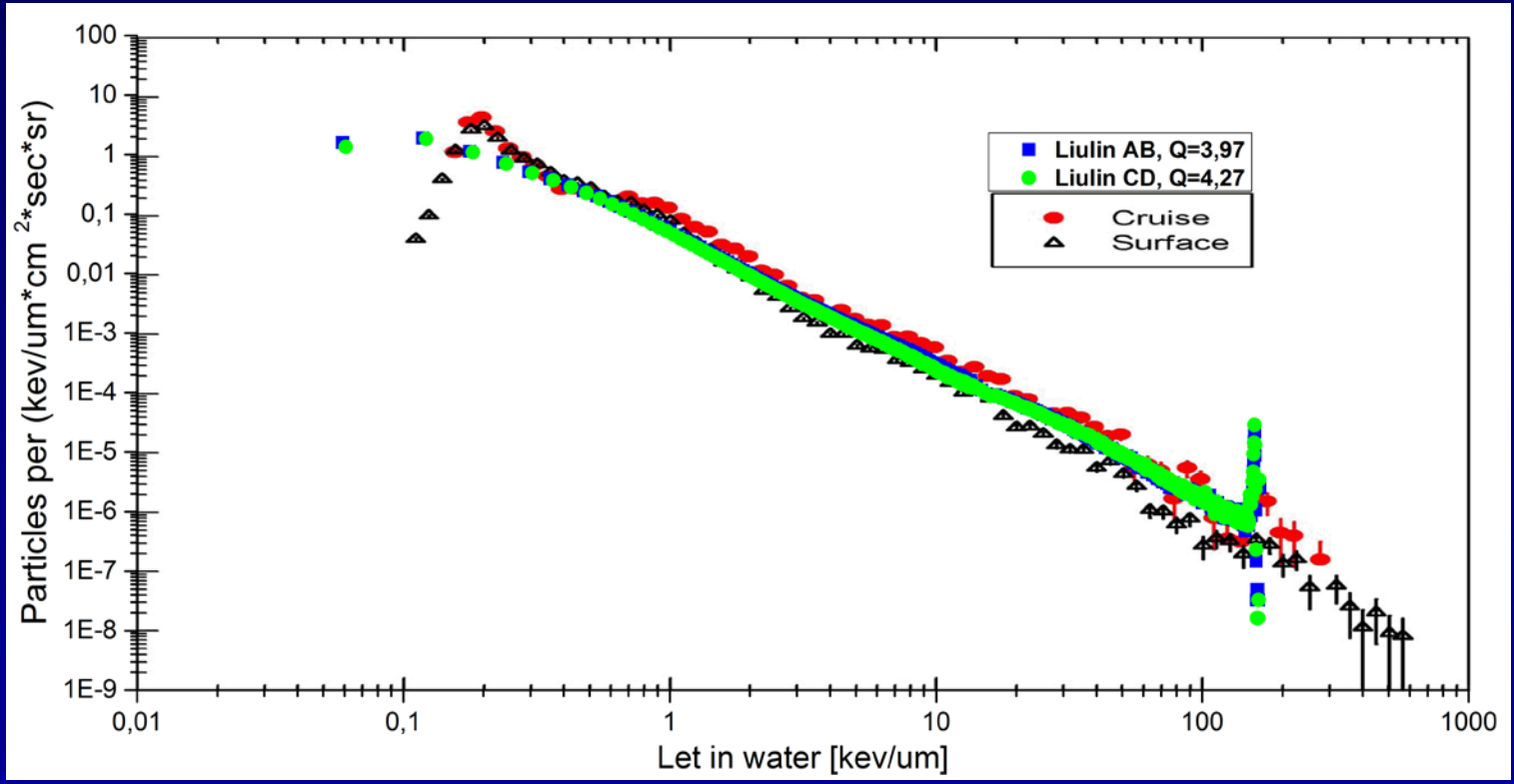
The doses in those ranges are:

- **RADOM: ~ 312 μGy/day (4-6.11.2008).**
- **Liulin-MO: ~ 312 μGy/day in B detector;**

~328,8 μGy/day in D detector (22.04-18.07.2016).

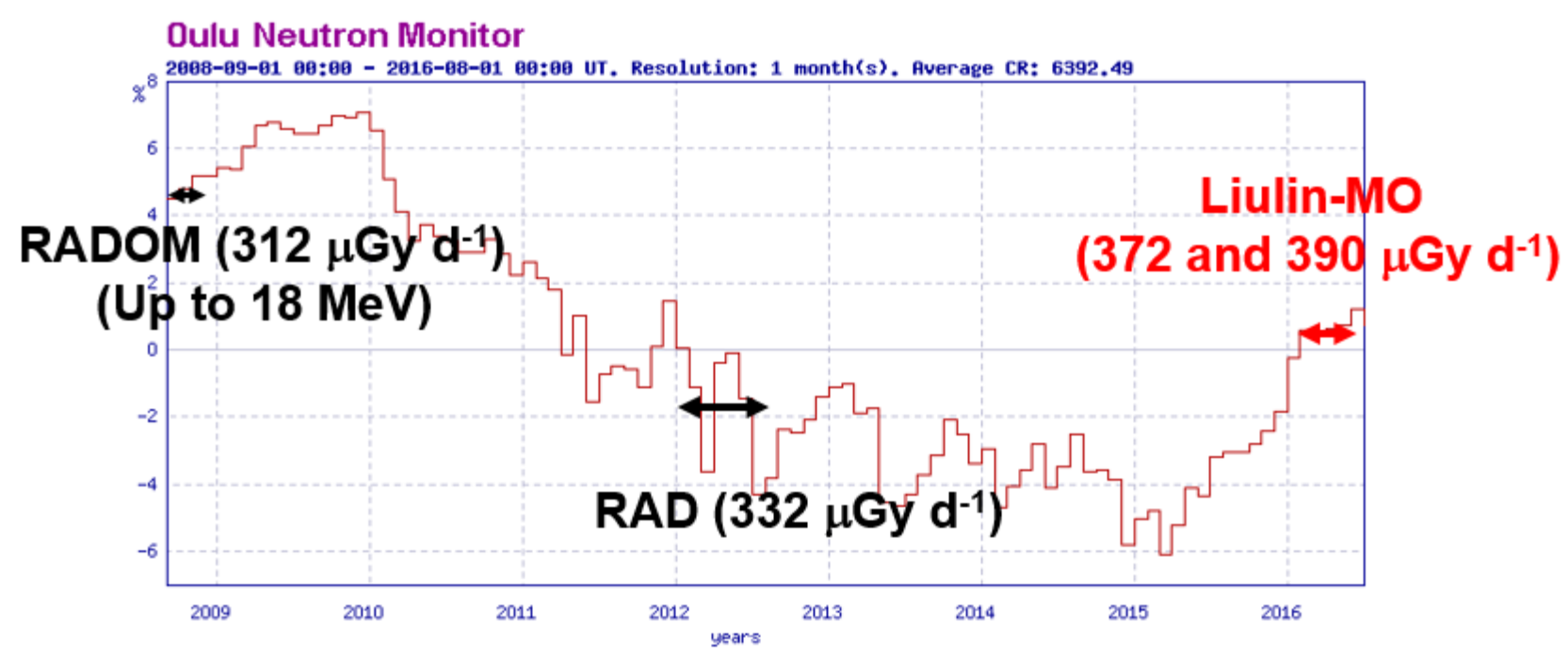
LET spectrum, Q and H for 22.04 ÷ 18.07.2016. Comparison with RAD Data for GCR during the transit *(Hasler et al, Science 343, 2014)*.

Preliminary !



In AB direction Q ~3.97; in DC direction Q~ 4.27 for GCRs, H (AB) =1.8 ± 0.3 mSv d^{-1}, H (DC) = 2 ±0.3 mSv d^{-1}. RAD=1.84 ± 0.30 mSv d^{-1}

Comparison of Oulu NM data for the time of measurements with RADOM, RAD and Liulin-MO



CONCLUSIONS (1)

•New dosimetric telescope Liulin-MO for measuring the radiation environment as a part of FREND neutron instrument has been launched onboard the ExoMars 2016 Trace Gas Orbiter satellite.

• The dynamic range of the LET allows assessment of the contribution to the absorbed dose and to the dose equivalent of the electrons, protons and the high energy particles in the heavy ion cosmic component, and the secondary charged particles and gamma radiation.

•The large dynamic ranges of the flux and the dose rate measurements allows measuring the fluxes and dose rates both of the relatively low–intensity GCR and the occasional high–intensity powerful SEP events.

CONCLUSIONS (2)

- The average measured dose rate in Si from GCR during the transit to Mars for the period 22.04-18.07.2016 is 372 ± 30 μGy d^{-1} and 390 ± 31 μGy d^{-1} in 2 perpendicular directions. This is in good agreement with previous radiation dose measurements in interplanetary space and with current solar activity.

- The preliminary data shows dose equivalent rates for the same period 1.8 ± 0.3 mSv d^{-1} and 2 ± 0.3 mSv d^{-1} in 2 perpendicular directions.

- A similar instrument Liulin-ML for investigation of the radiation environment on Mars as a part of the active detector of neutrons and gamma rays (ADRON-EM) on the Surface Platform is under preparation for ExoMars 2020 mission.

Acknowledgements

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Thank you!