Comparison of Liulin-MO dosimeter radiation measurements during ExoMars 2016 TGO Mars circular orbit with dose estimations based on galactic cosmic ray models.

V. Benghin[1], V. Shurshakov[1], J. Semkova[2], T. Dachev[2], St. Maltchev[2], B. Tomov[2], Yu. Matviichuk[2], P. Dimitrov[2], R. Koleva[2], K. Krastev[2], I. Mitrofanov[3], L. Zelenyi[3], A. Malakhov[3], M. Mokrousov[3], A. Sanin[3], M. Litvak[3], A. Kozyrev[3], V. Tretyakov[3], D. Golovin[3], S. Nikiforov[3], S.G. Drobyshev[1].

[1] *Institute of Biomedical Problems, Russian Academy of Sciences*

[2] *Space Research and Technologies Institute-BAS;*

[3] *Space Research Institute, Russian Academy of Sciences,*

Diagram of steps for comparison

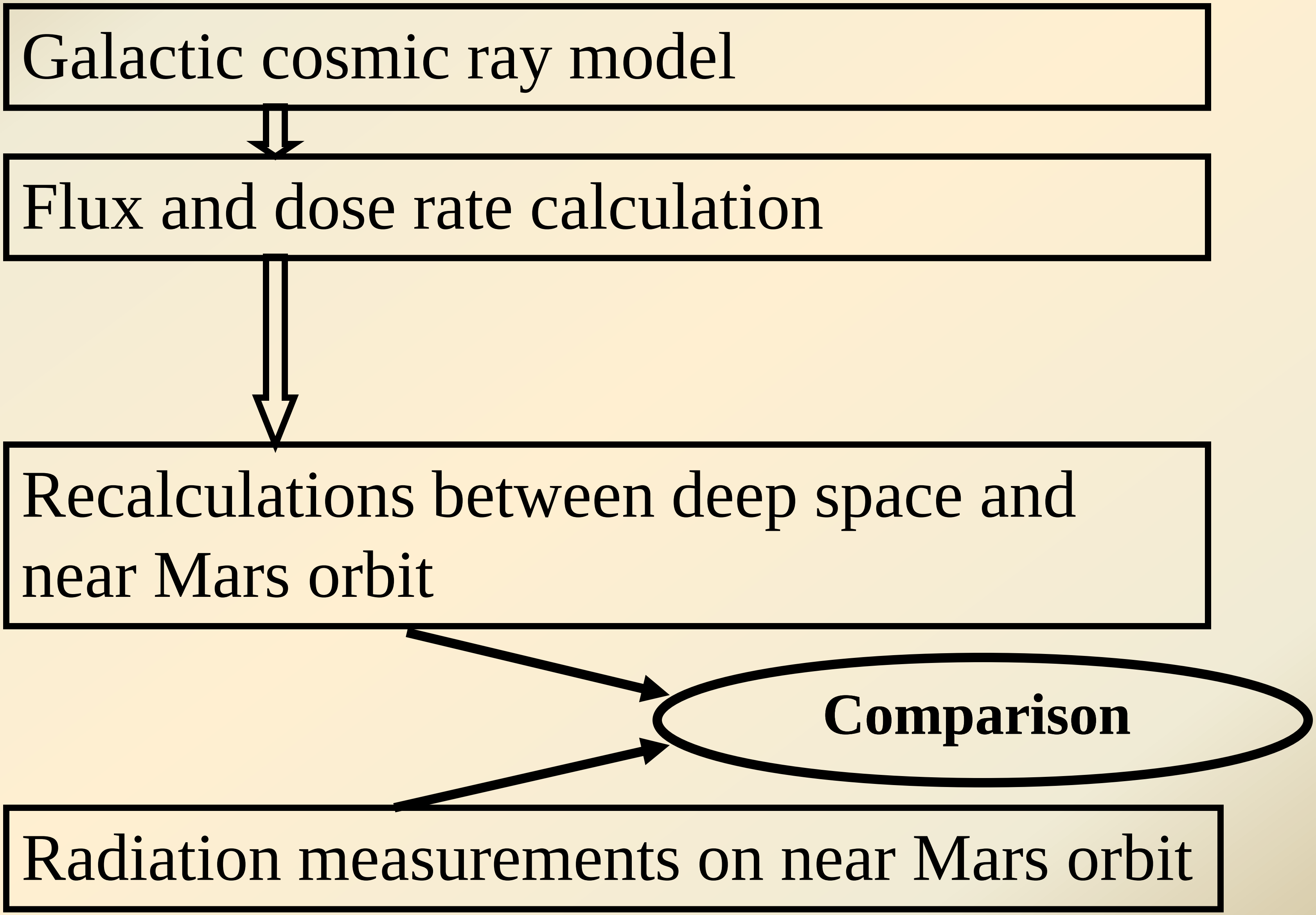
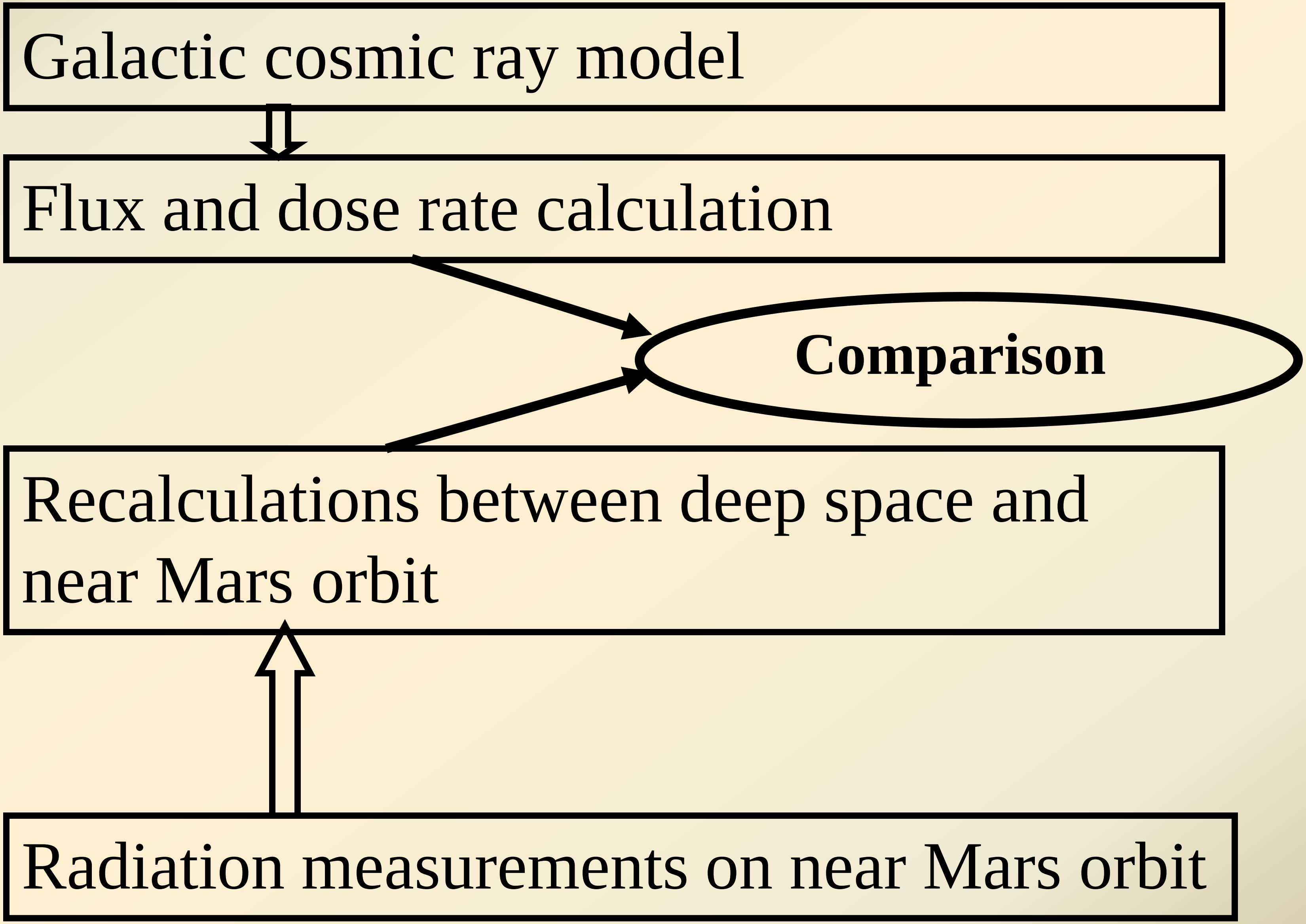


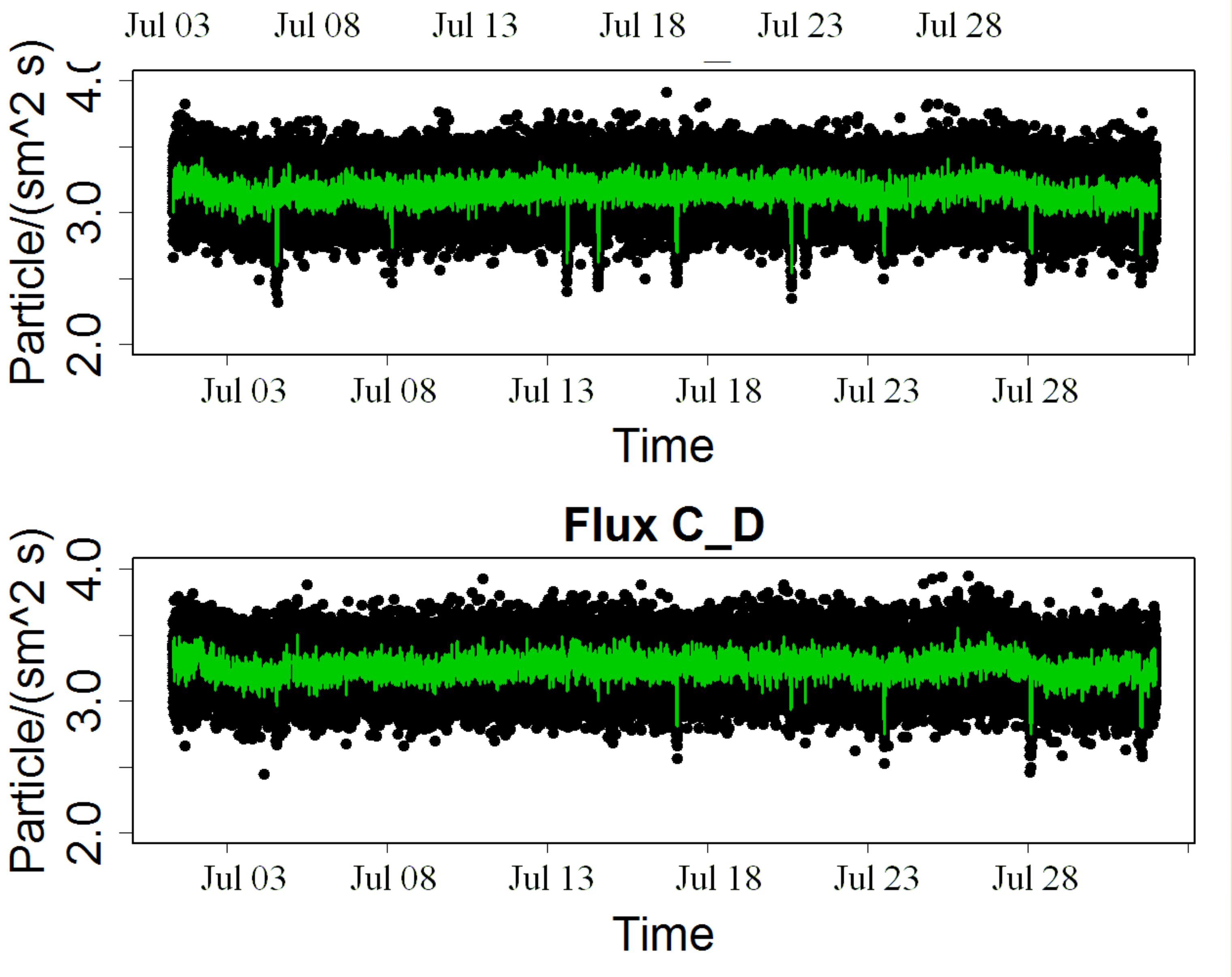
Diagram of steps for comparison



Presentation outline

- The analysis of Liulin-MO data measured on circular orbit
- Recalculation measured flux and dose rate to interplanetary space
- Used GCR models brief description
- Estimations of flux and dose rate in silicon detector behind shielding
- Comparison of measurements and estimations for low orbit stage of flight
- Conclusion

Flux measurements during July 2019



Black points – measurements,

Green curve – smoothed values

Main scientific device of Trace Gas Orbiter.

CaSSIS – Colour and Stereo Surface Imaging System

A high resolution camera (5 metres per pixel) capable of obtaining colour and stereo images over a wide swathe. CaSSIS will provide the geological and dynamical context for sources or sinks of trace gases detected by NOMAD and ACS.

NOMAD – Nadir and Occultation for MArs Discovery

NOMAD combines three spectrometers, two infrared and one ultraviolet, to perform high-sensitivity orbital identification of atmospheric components, including methane and many other species, via both solar occultation and direct reflected-light nadir observations.

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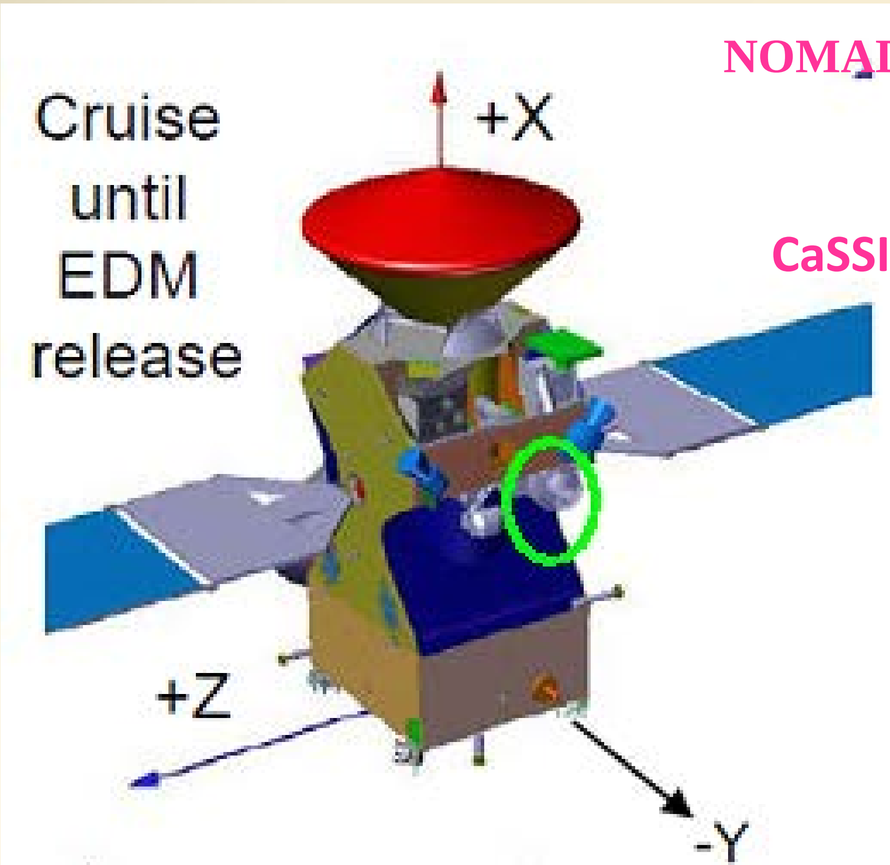
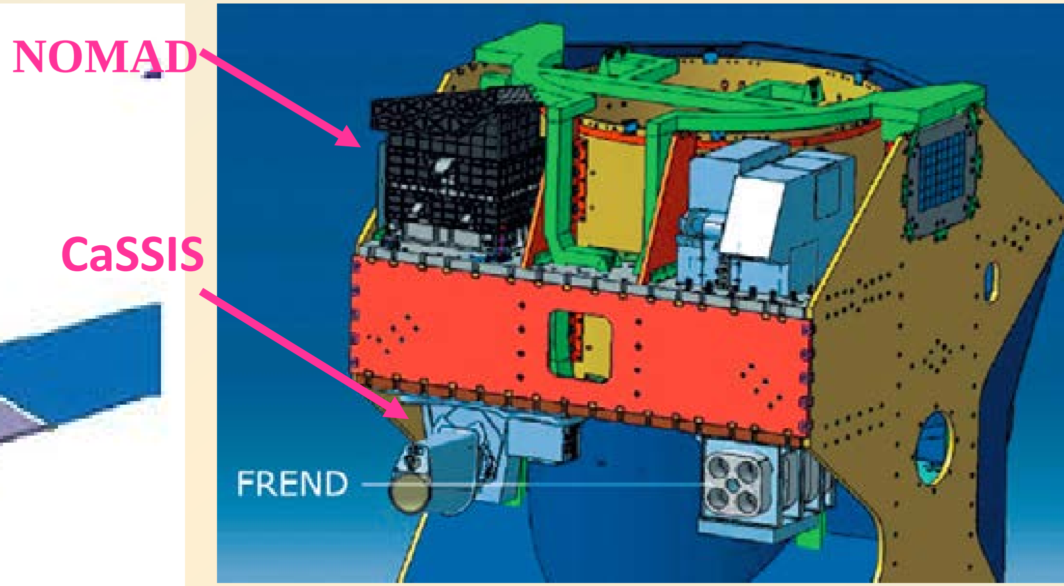
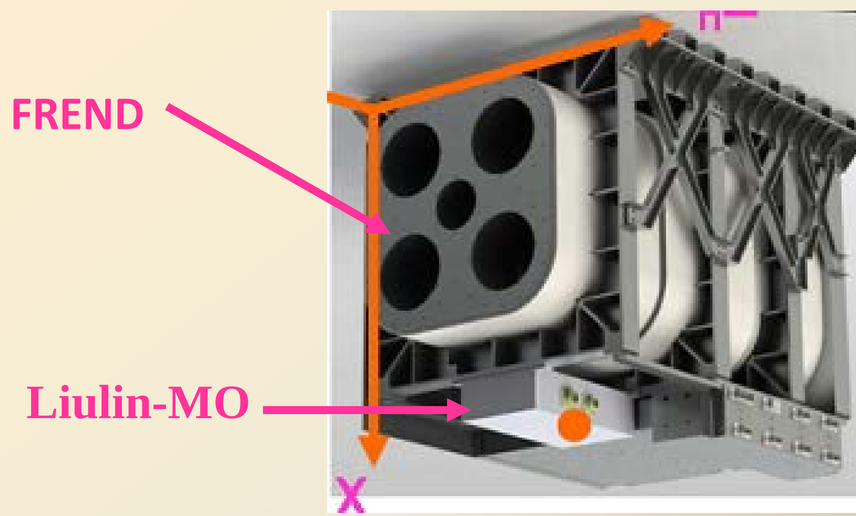
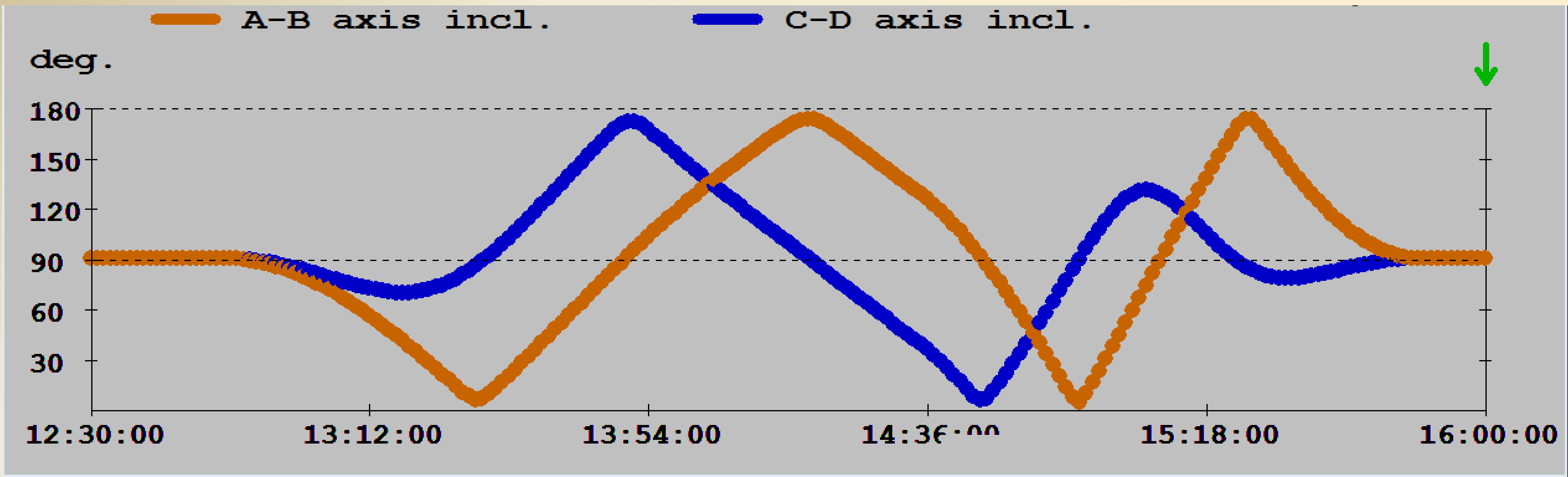
http://exploration.esa.int/mars/48523-trace-gas-orbiter-instruments/

The TGO spacecraft, and arrangement on it the device the FREND with the unit Liulin-MO





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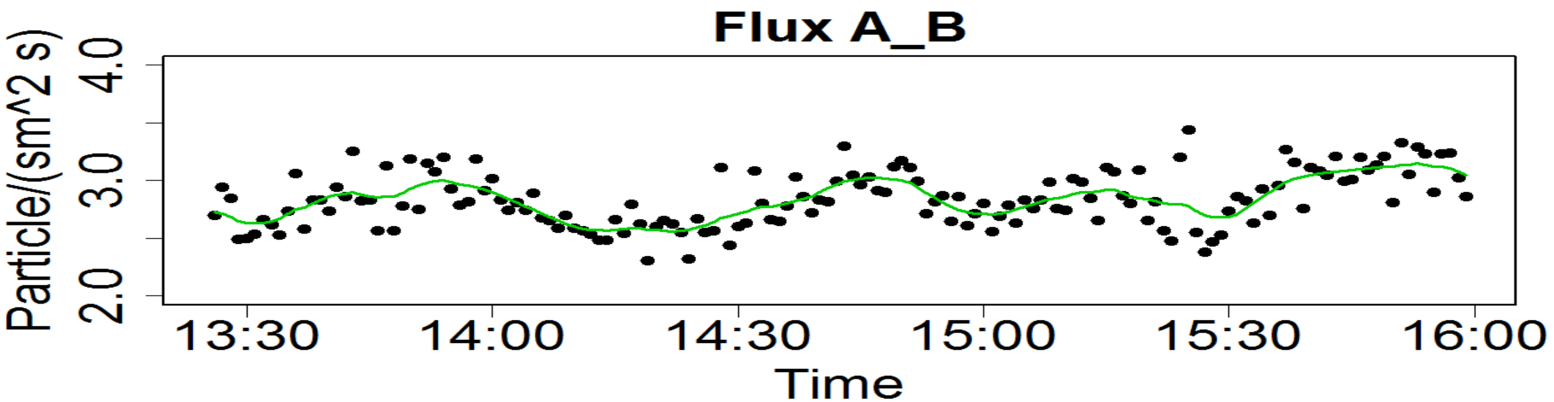
Flux A_B
Particle/(sm^2 s)
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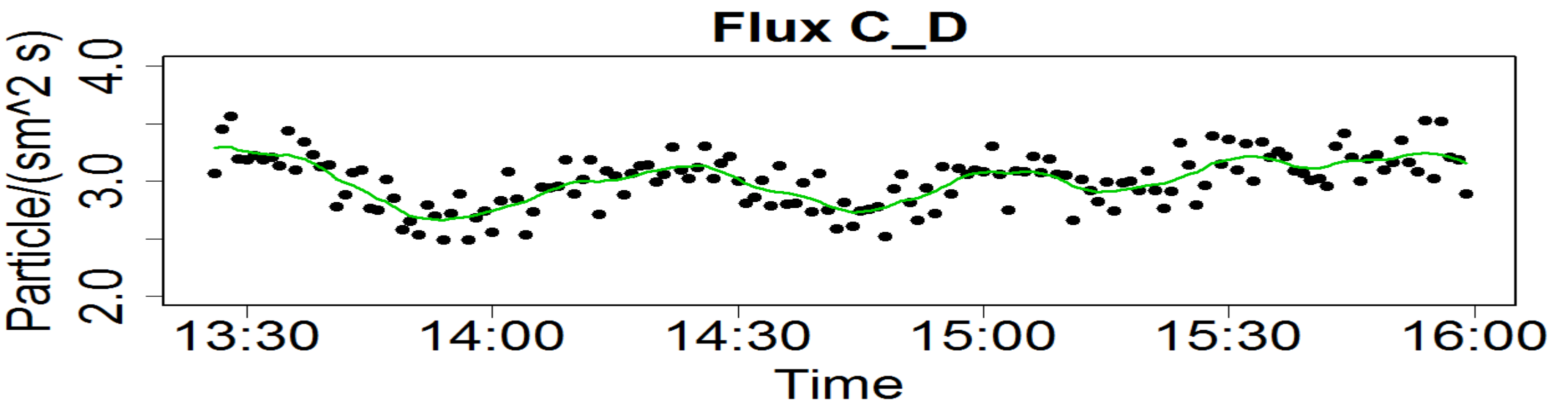
Time


Flux C_D
Particle/(sm^2 s)
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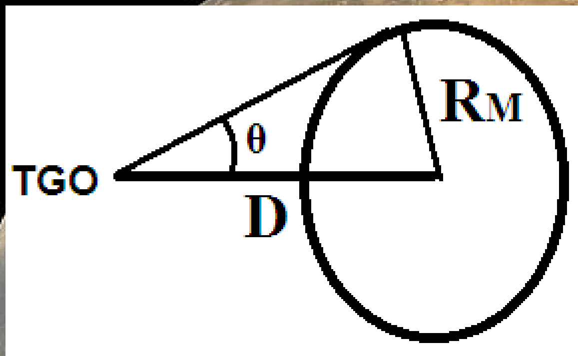
Time

Mars shadow effect estimation



Denotations:

R_M – Martian radius;

D – Distance between TGO and Martian centrum;

Θ –Half of the s

Part of the TGO solid angle not shadowe

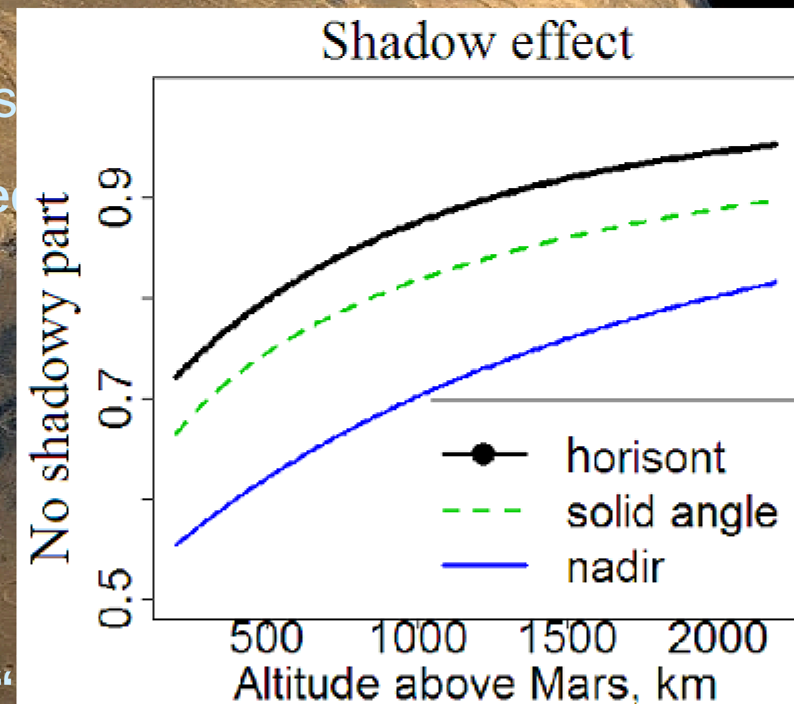
$$\eta = [1 + \cos(\Theta)]/2$$

Part of the flux recorded when detector

$$H = [1 + \cos^2(\Theta)]/2$$

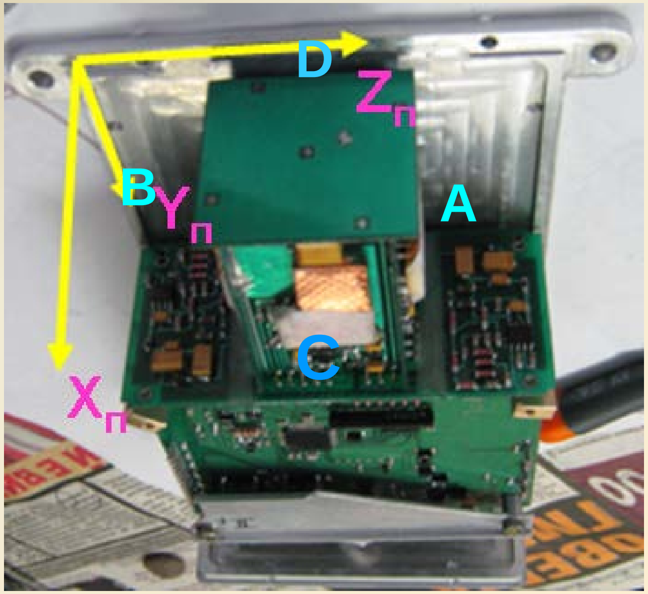
Part of the flux recorded when detector "

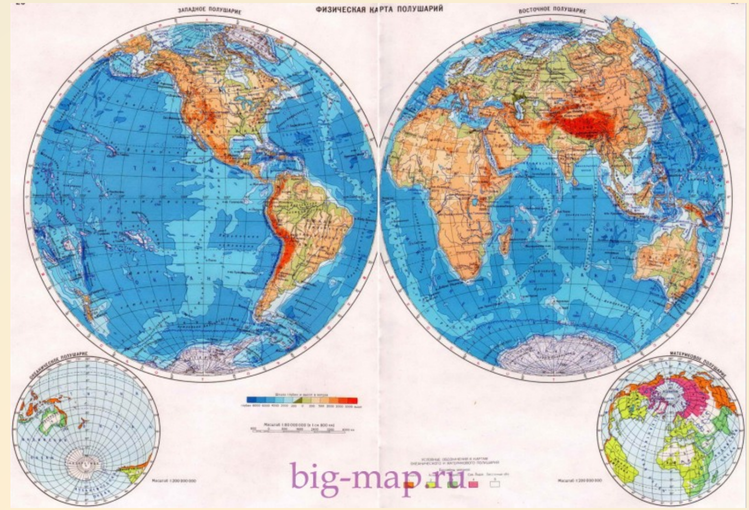
$$\eta = 1 - \frac{1}{\pi} \bullet \int_0^{\left(Rm/D\right)^2} \arcsin\left(\sqrt{\frac{\left(Rm/D\right)^2 - \nu}{1-\nu}}\right) d\nu \qquad (3)$$

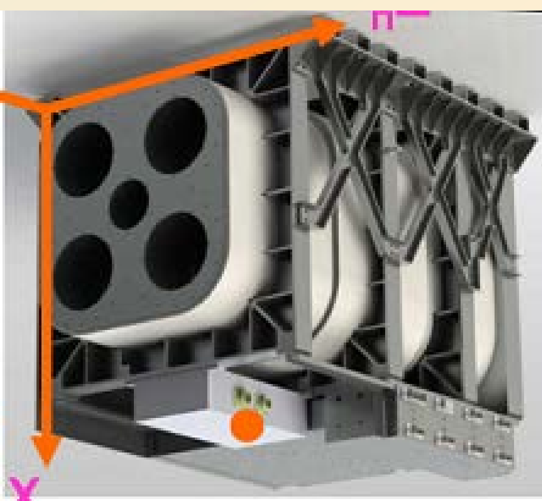


Picture credit: https://ru.wikipedia.org/wiki/%D0%9C%D0%B0%D1%80%D1%81#/media/File:Mars_23_aug_2003_hubble.jpg

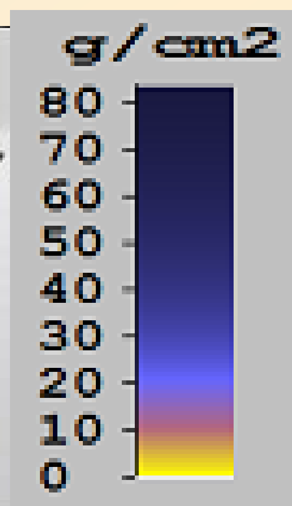
Shielding angular distribution

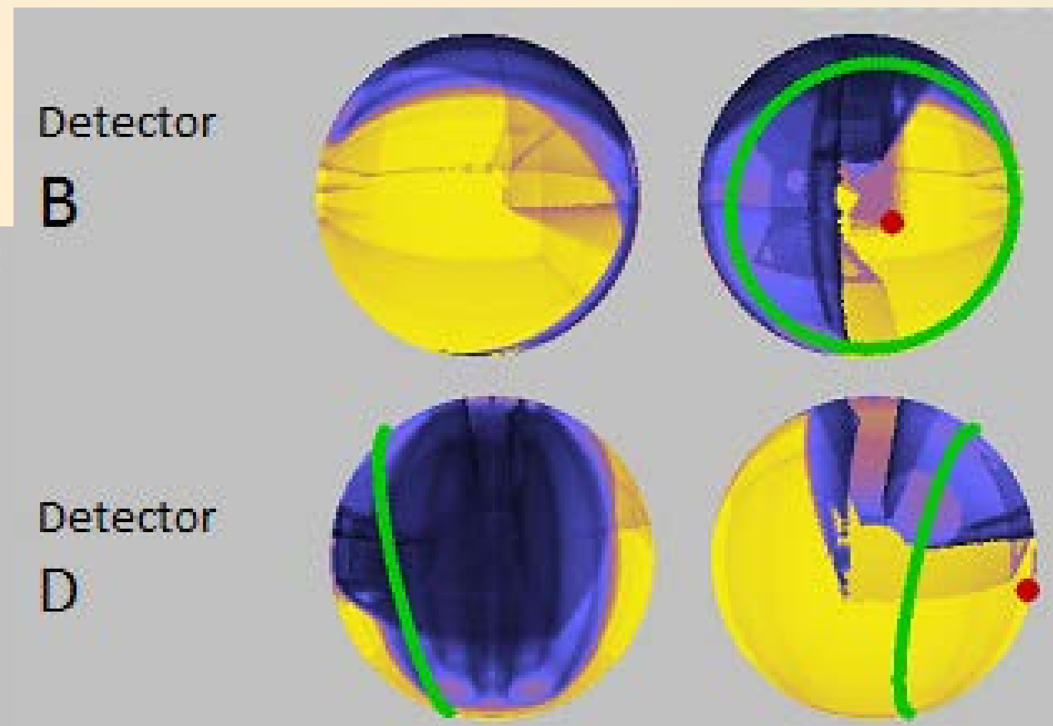


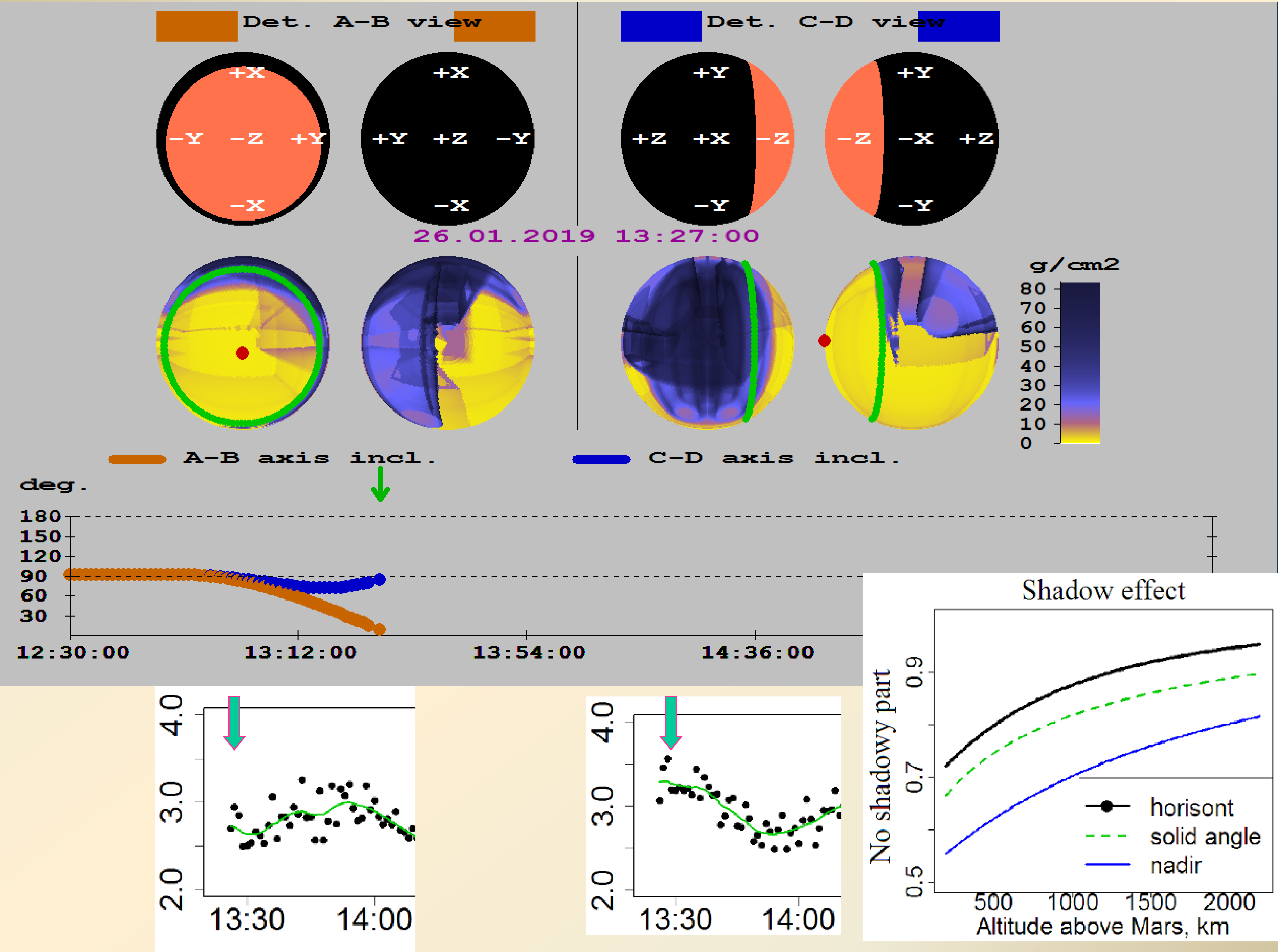




Shielding thickens scale, g/cm^2







Det. A-B view
Det. C-D view
+X
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26.01.2019 13:27:00
g/cm2
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A-B axis incl.
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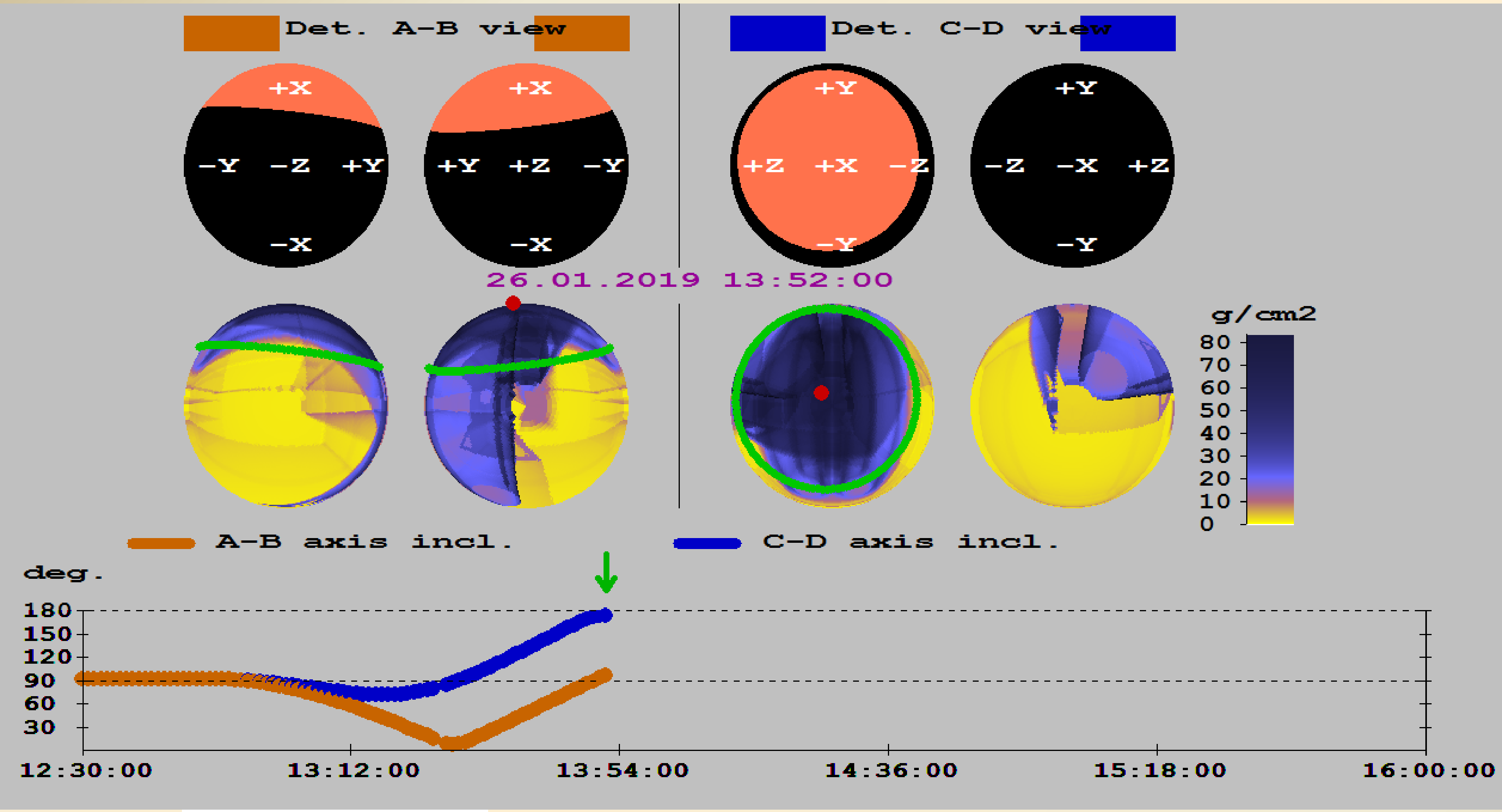
Shadow effect
No shadowy part
0.5
0.7
0.9
500
1000
1500
2000
Altitude above Mars, km
horisont
solid angle
nadir



Det. A-B view
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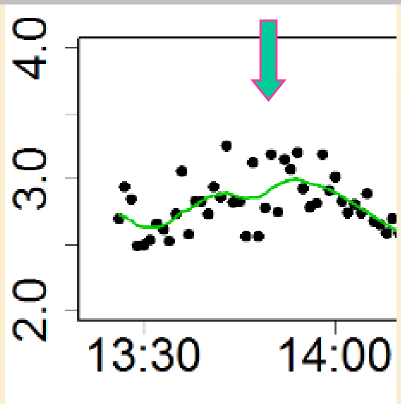

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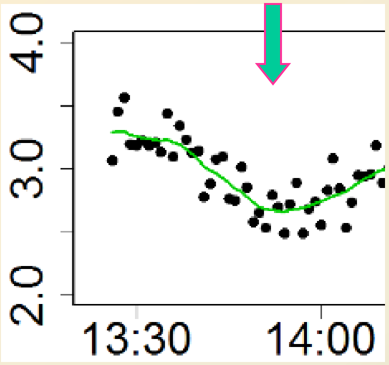

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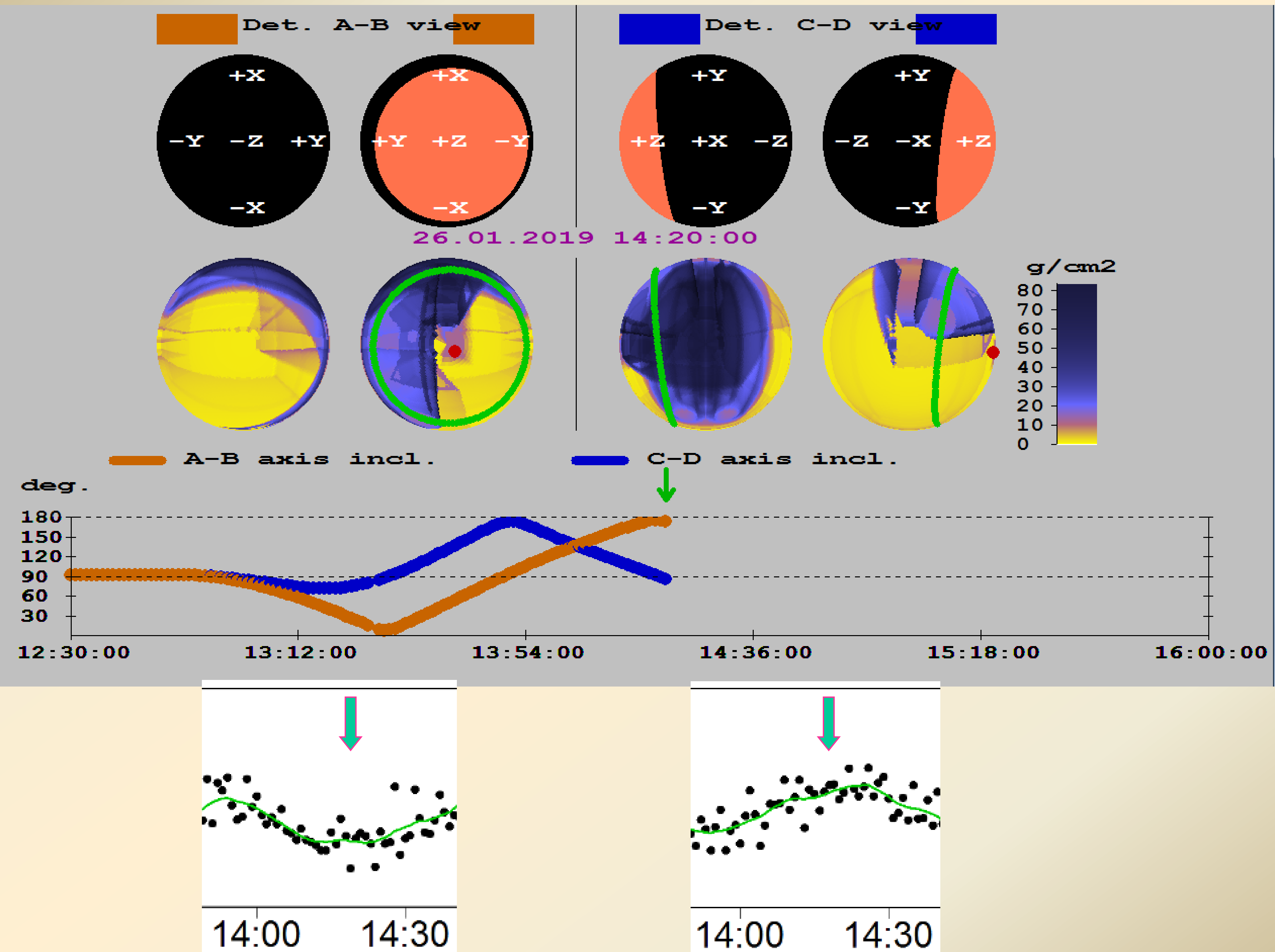
Det. A-B view
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+Y +Z -Y
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Det. C-D view
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-Y
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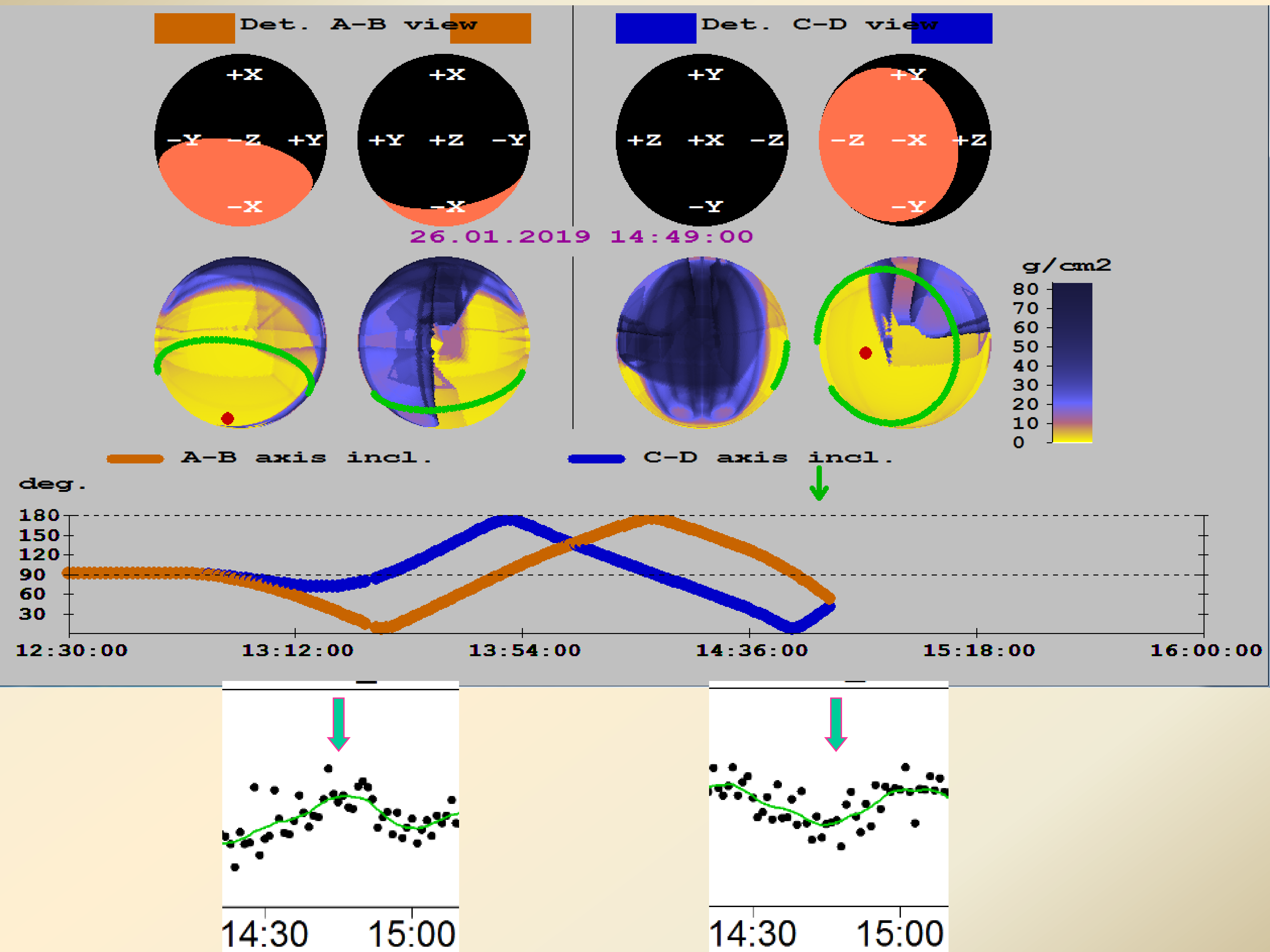
Det. A–B view
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+X
–Y –Z +Y
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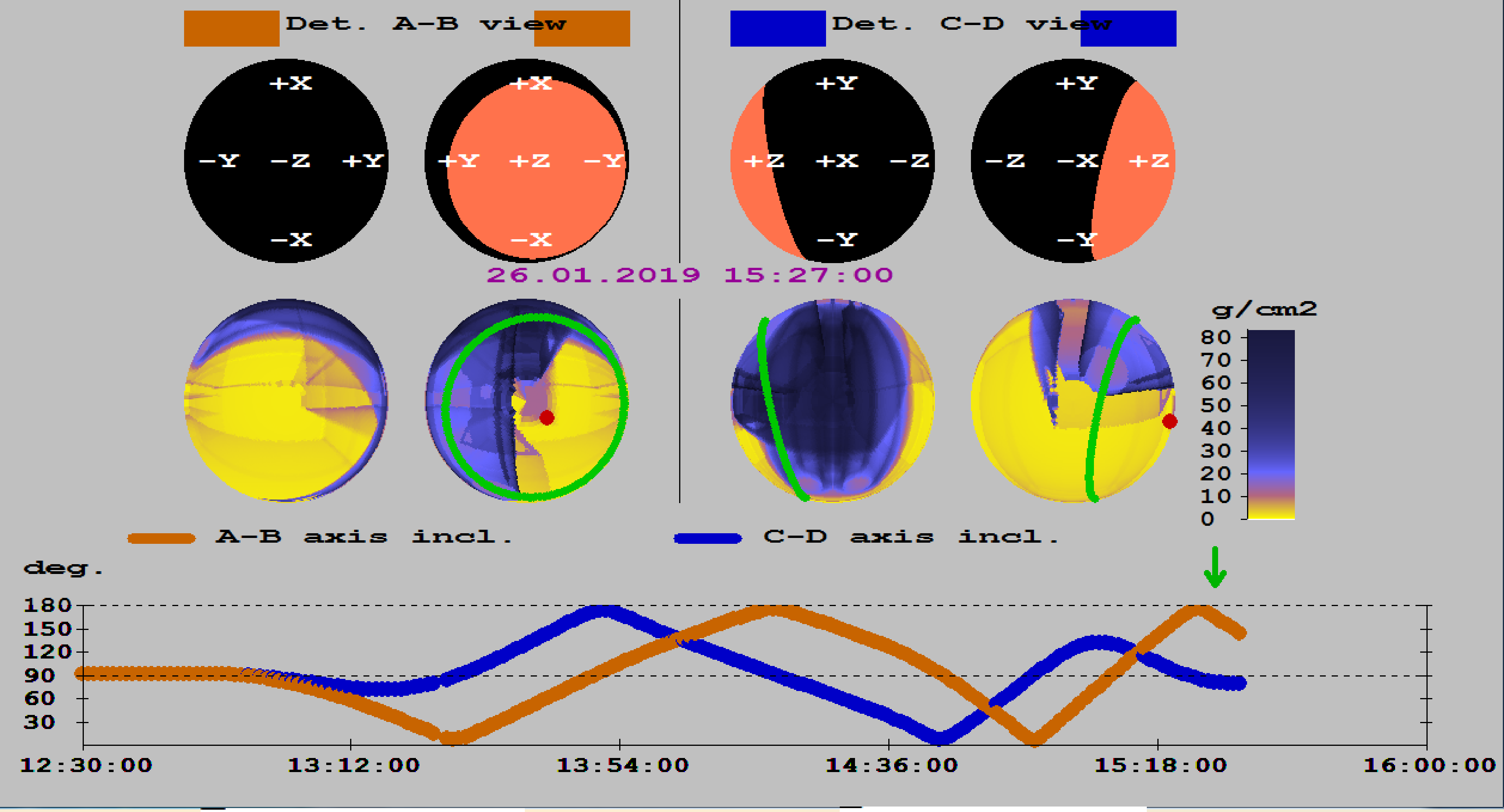

Det. A-B view
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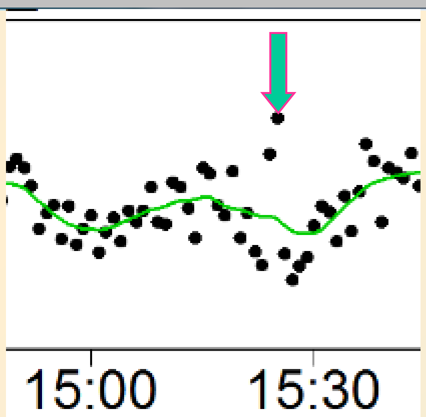

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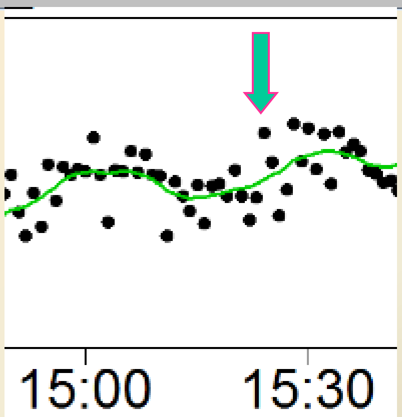

15:00
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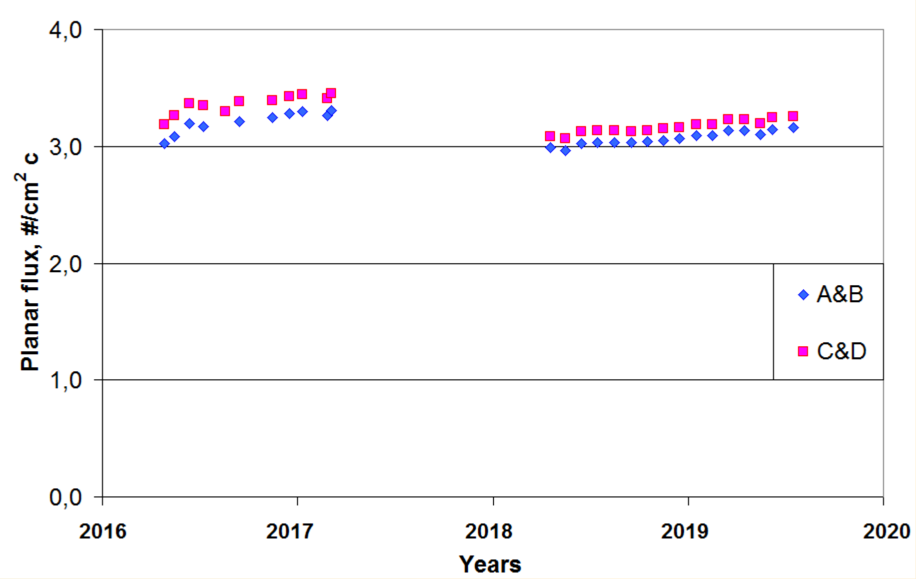
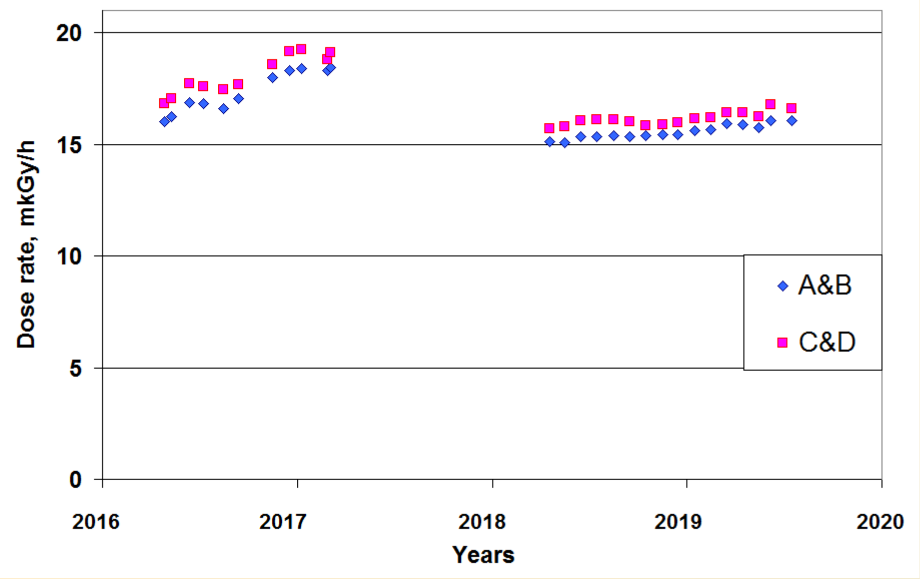
Recalculation of flux and dose rate from a circular orbit around Mars to interplanetary space

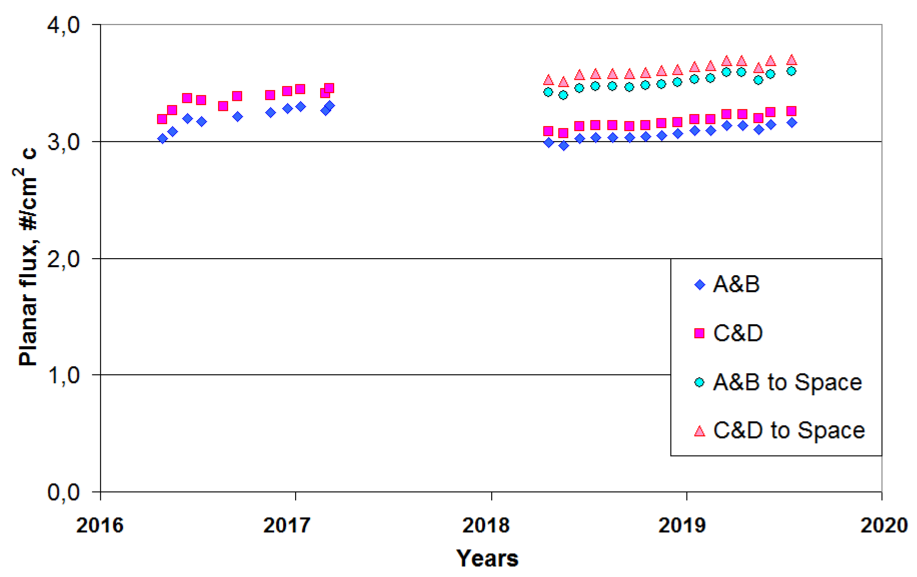
- We had calculated monthly average values of fluxes and dose rates for each pair of detectors to subsequent comparison with estimations based on GCR models. Estimates were carried out both for a full sample of data for the month, and with the removal of variations due to changes in the orientation of the spacecraft. The difference in results did not exceed 0.2%.
- It was shown at a previous Workshop that the flux in a circular orbit is approximately 82% of the value in free space, and for a dose rate of 88%. Based on these factors, a recount was made.

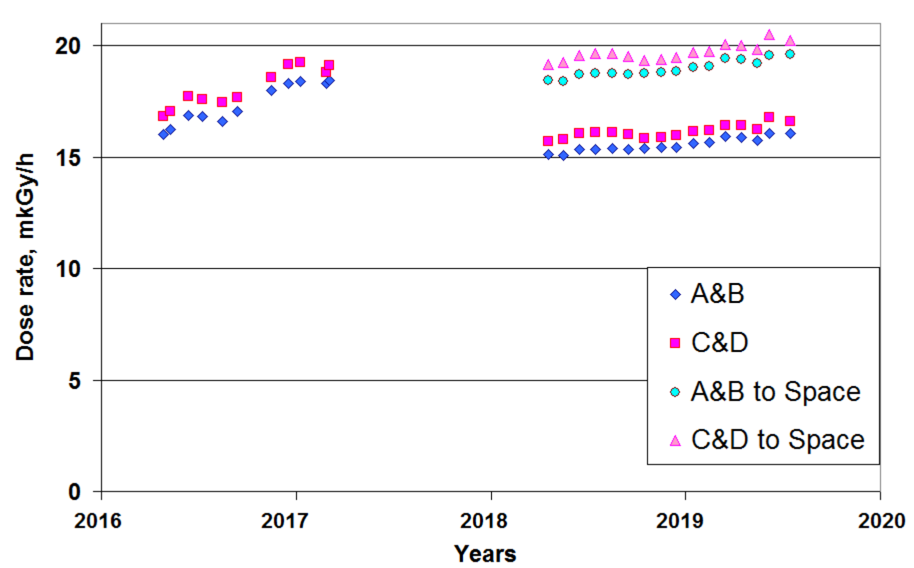
Flux and dose rate without recalculation





Flux and dose rate. Recalculated values were added.





Galactic cosmic ray models will be considered

- International standard ISO/DIS 15390
  ISO 15390. Space environment (natural and artificial) – galactic cosmic ray model, 2004.
- SINP-2017 GCR model
  N.V. Kuznetsov, H. Popova, M.I. Panasyuk. Galactic Cosmic Ray Flux Prediction for Furure Space Missions. – Bulletin of the Russian Academy of Sciences: Physics, **2017,** v.81, No 2, pp.199-202. (in Russian)
- DLR model
  A ready-to-use galactic cosmic ray model. Daniel Matthia, Thomas Berger, Alankrita I. Mrigakshi, Gunther Reitz. Advances in Space Research 51 (2013) 329–338

ISO 15390 galactic cosmic ray model brief description

GCR particle rigidity spectra $\Phi_i(R,t)$ (s.m2.sr.GV)$^{-1}$ for particles of rigidity R at moment t are calculated as

$$\Phi_i(R,t) = \frac{C_i \times \beta^{\alpha_i}}{R^{\gamma_i}} \times \left[\frac{R}{R + R_o(R,t)}\right]^{\Delta_i(R,t)}$$

$$R_0\{\overline{W}[t - \Delta t(n,R,t)]\} = 0.37 + 3\times 10^{-4} \times W^{1.45}[t - \Delta t(n,R,t)]$$

where $\Delta_i(R,t)$ is a dimensionless parameter calculated as

$$\Delta_i(R,t) = 5.5 + 1.13\frac{Z_i}{|Z_i|} M(W,n) \times \frac{\beta R}{R_o(R,t)} \exp\left(-\frac{\beta R}{R_o(R,t)}\right)$$

The lag, $\Delta T(n,R,t)$, of GCR flux variations relative to solar activity variations

$$\Delta T(R,n,t) = 0.5[T_+ + T_-(R)] + 0.5[T_+ - T_-(R)] \times \tau(\overline{W})$$

SINP-2017 galactic cosmic ray model brief description

The formula for calculating the particle flux F(z)(E,t) for any time t and over the entire range of energy E can be represented as

$$F^{(z)}(E,t) = A^{(z)} * E^{-\gamma} * \Psi^{(z)}(E,t)$$

where $\Psi^{(z)}(E,t)$ is a function depending on energy E as well as time t. We will call $\Psi^{(z)}(E,t)$ the "deceleration function".

$$\Psi^{(z)}(E,t) = \left(\frac{E}{E+\varepsilon^{(z)}(t)}\right)^{3.7}$$

where $\varepsilon^{(z)}(t)$ is a deceleration potential (in MeV/nucleon) depending on time t.

$$\varepsilon^{(z)}(t,r) = \varepsilon_0^{(z)}(r) + k^{(z)}(r)\cdot W(t-\Delta t) = \varepsilon_0^{(z)} r^{-\alpha} + k^{(z)}(1-r/120)\cdot W(t-\Delta t)$$

N.V. Kuznetsov, H. Popova, M.I. Panasyuk. Galactic Cosmic Ray Flux Prediction for Furure Space Missions. – Bulletin of the Russian Academy of Sciences: Physics, **2017,** v.81, No 2, pp.199-202. (in Russian)

The brief description of DLR galactic cosmic ray model

The galactic cosmic ray model presented by Daniel Matthia was derived from the GCR-ISO model. The description the modulation of the GCR in the heliosphere used the OULU neutron monitor count rates.

$$\Phi_i(R,t) \equiv \frac{dN}{dA\,dt'\,d\Omega\,dR}(R,t) = \frac{C_i\beta^{\alpha_i}}{R^{\gamma_i}}\left[\frac{R}{R+R_0(R,t)}\right]^{\Delta_i(R,t)}$$

Modulation parameter Ro calculated as:

$$R_0(R,t) = 0.37 + 3\cdot 10^{-4}\cdot\left(W(t,\Delta t(R,t))\right)^{1.45}$$

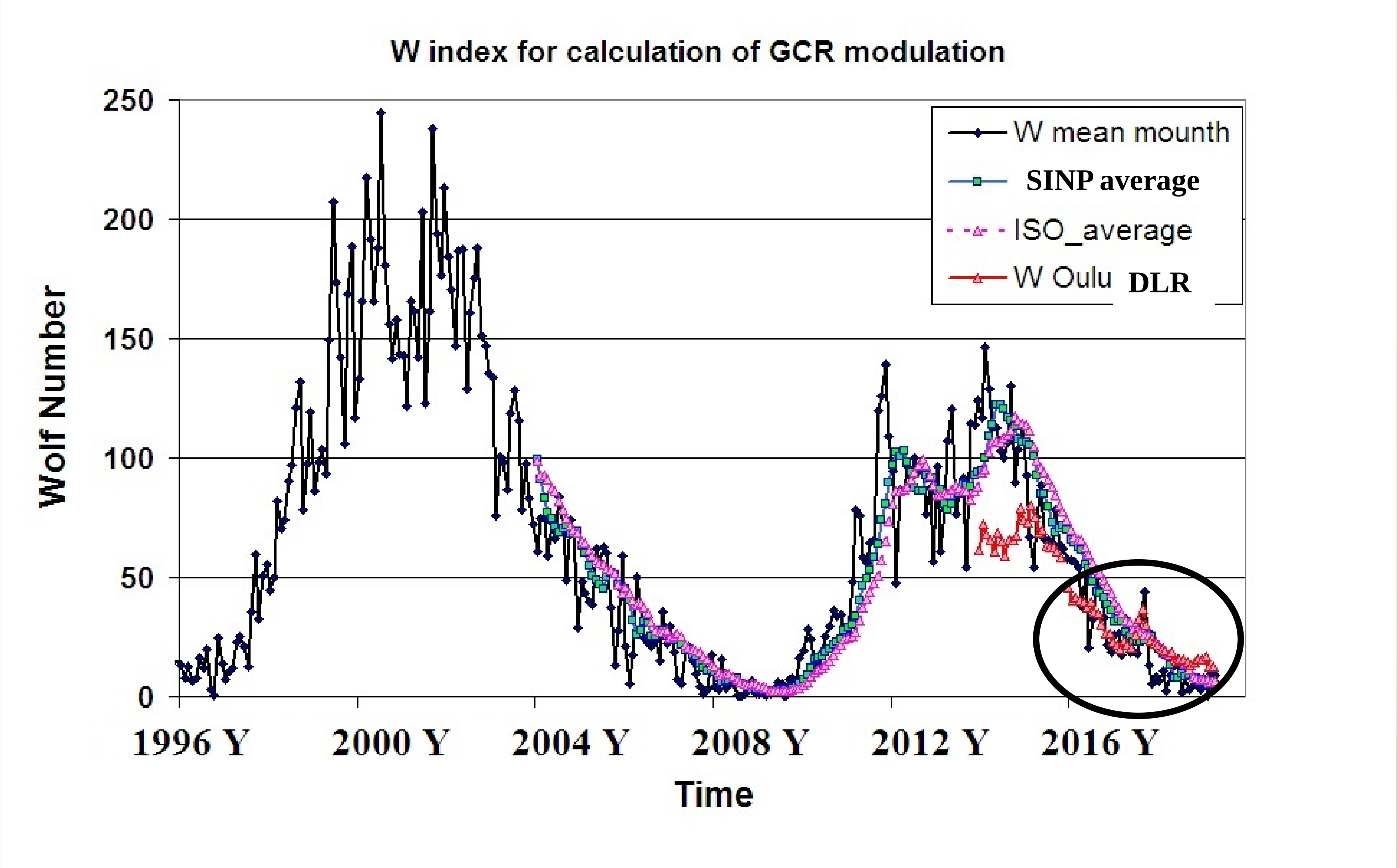
The exponent calculated as: $\Delta = b\cdot W + c$

The description of W as a function of the OULU neutron monitor count rate cr (cr in counts/min):

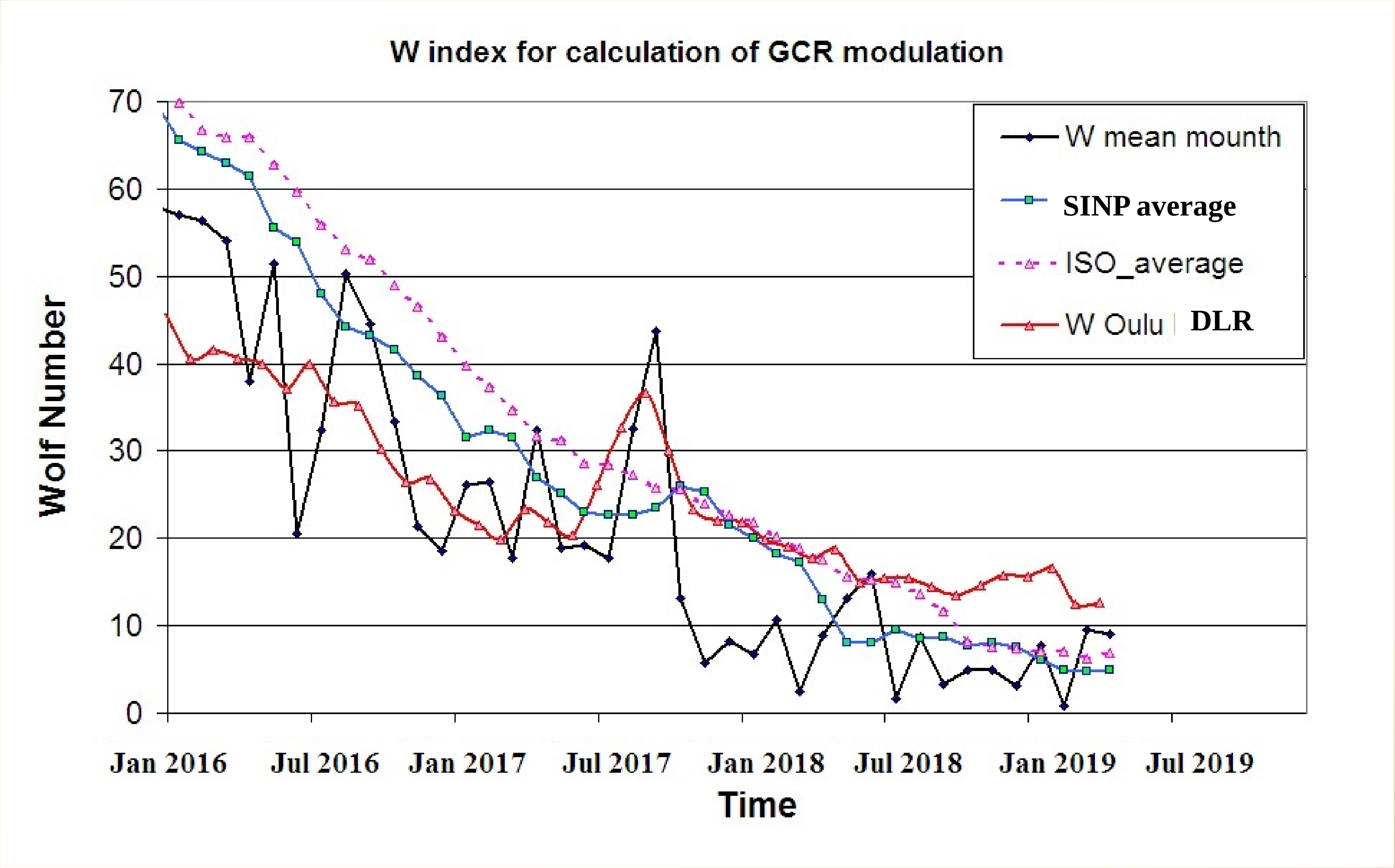
$$W_{\mathrm{Oulu}} = -0.093\cdot cr + 638.7$$

A ready-to-use galactic cosmic ray model. Daniel Matthia, Thomas Berger, Alankrita I. Mrigakshi, Gunther Reitz. Advances in Space Research 51 (2013) 329–338

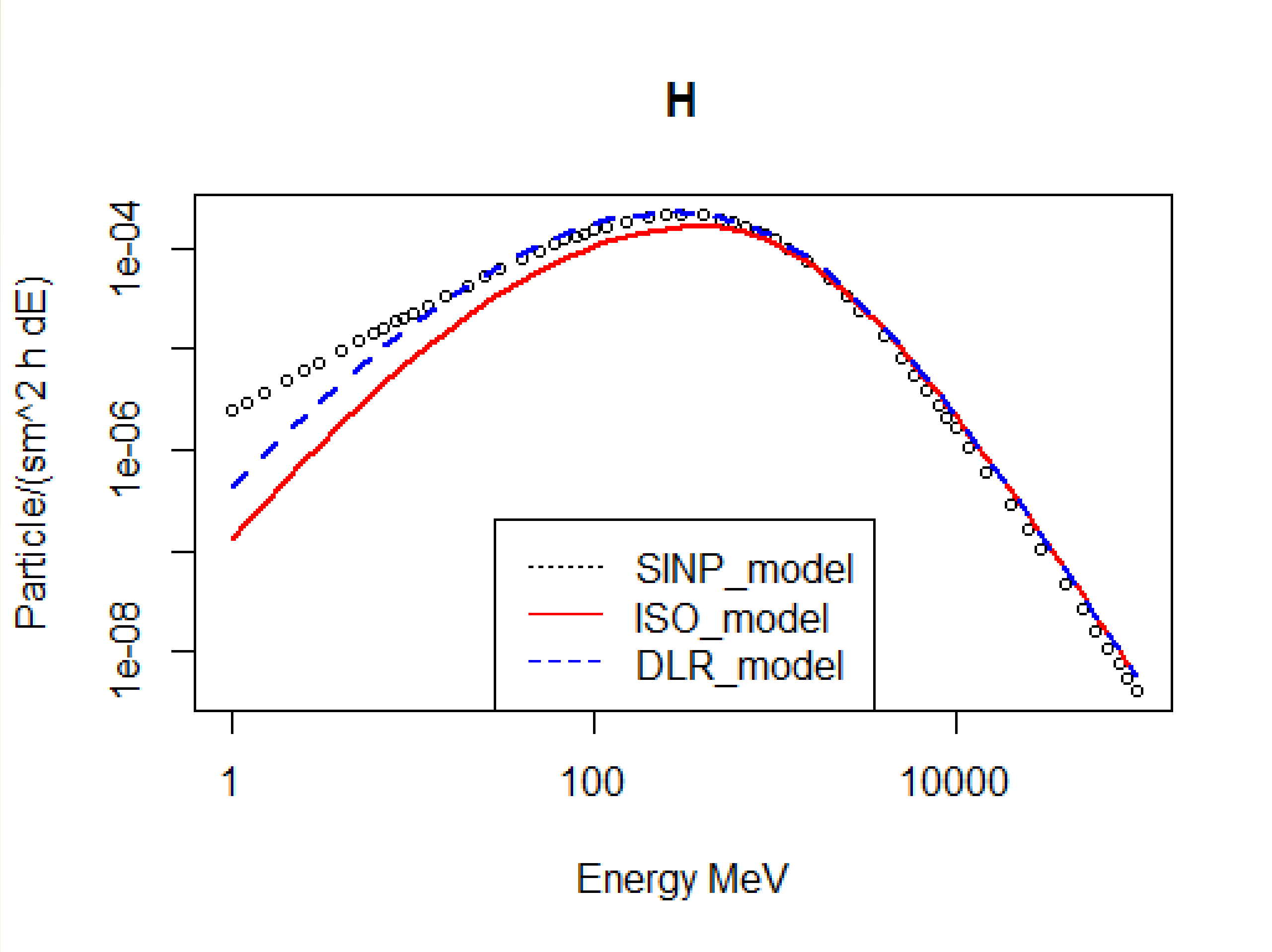
Wolf number as indicator of GCR modulation

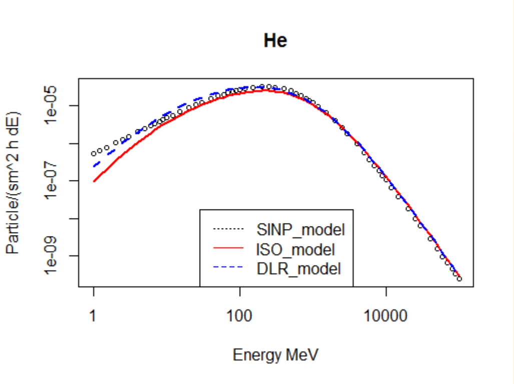


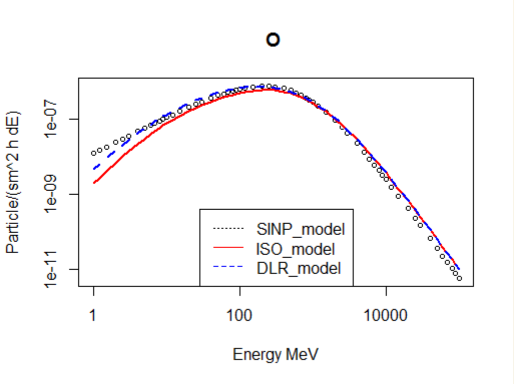
Wolf number as indicator of GCR modulation

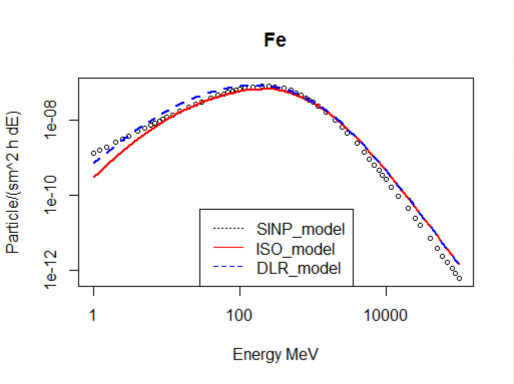


Calculated GCR spectra for January 2019









Dose and particle spectra beyond shielding

$$D = \int_E \varphi(E) \frac{dE}{dx}(E) dE$$

Where: $\varphi(E)$ - particles spectra in the point of interest;

$\frac{dE}{dx}(E)$ - particle energy losses (the stopping power S)

The stopping power S is adequately described by the Bethe-Bloch formula. The range of the ion is evaluated from the stopping power as:

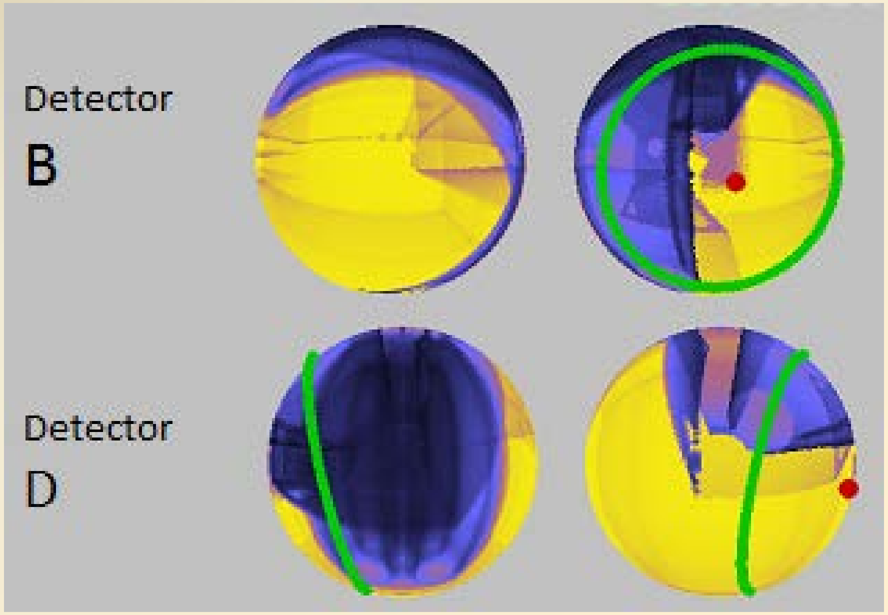
$$R(E) = \int_0^E \frac{dE'}{S(E')}$$

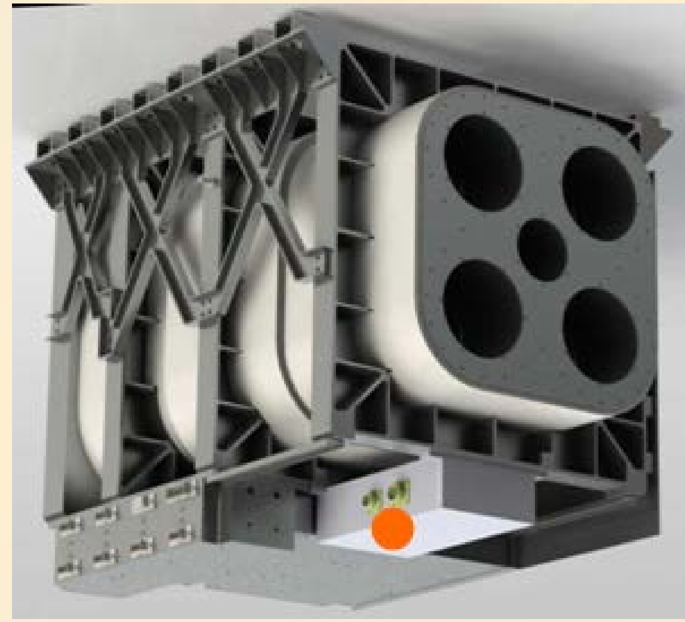
The simplest way to evaluate particles spectra beyond shielding – to calculate them with R(E) relation.
But it isn't take into account nuclear collisions.

NASA has developed a Boltzmann equation approach for HZE nuclei transport that treat the atomic and nuclear collisions denoted as the HZETRN code

https://oltaris.larc.nasa.gov/projects/5219/gcubs/23483

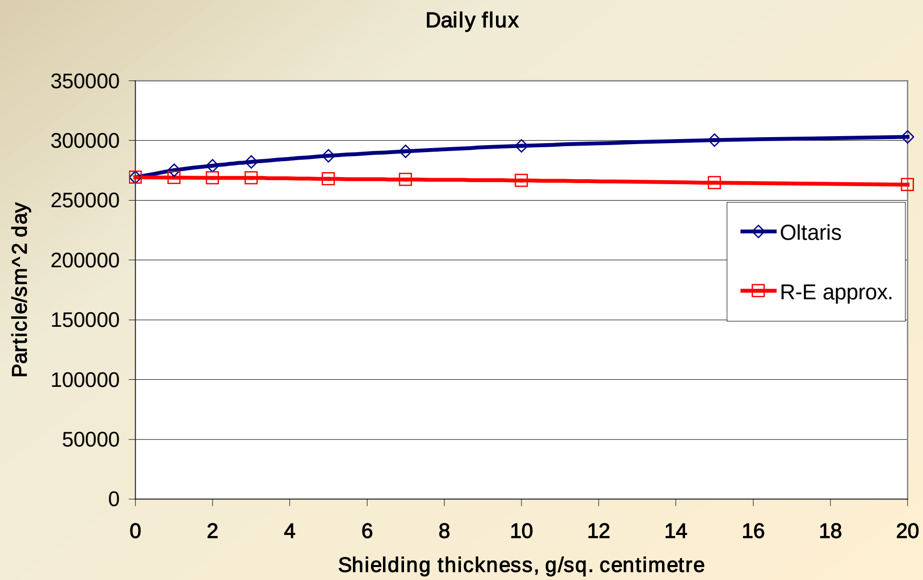
From shielding angular distribution to shielding function for point located between the detectors "Liulin-MO"

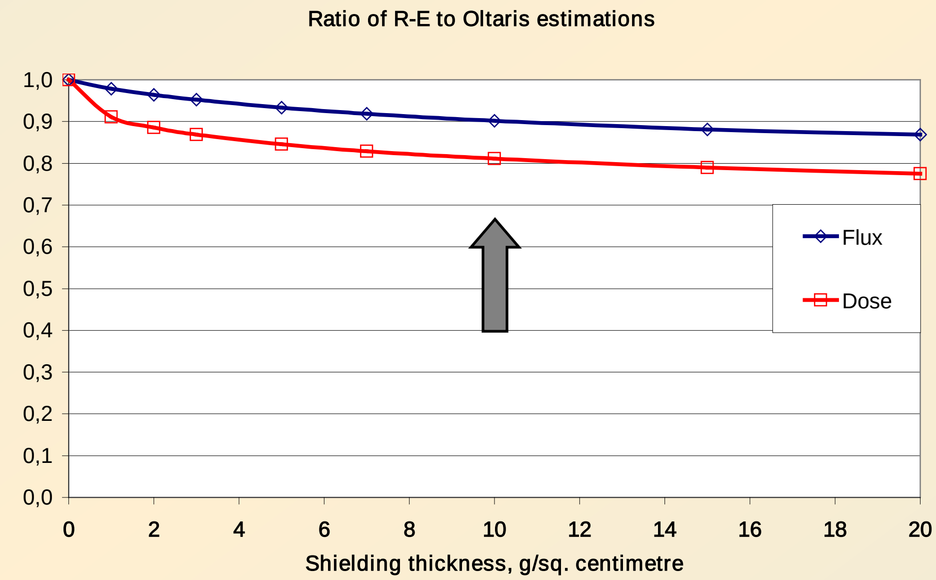


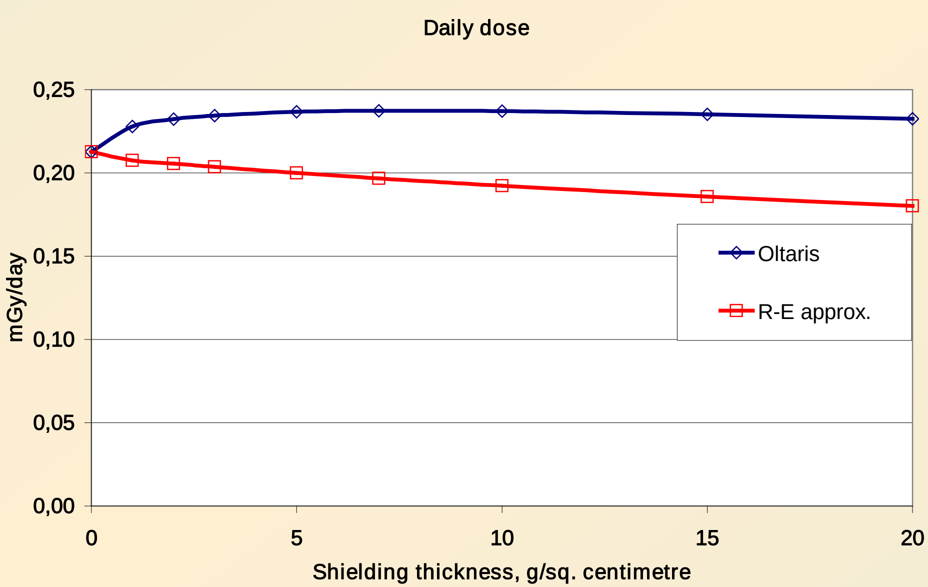


Shielding with "Liulin-MO" and "FREND" elements function for point located between the detectors "Liulin-MO"

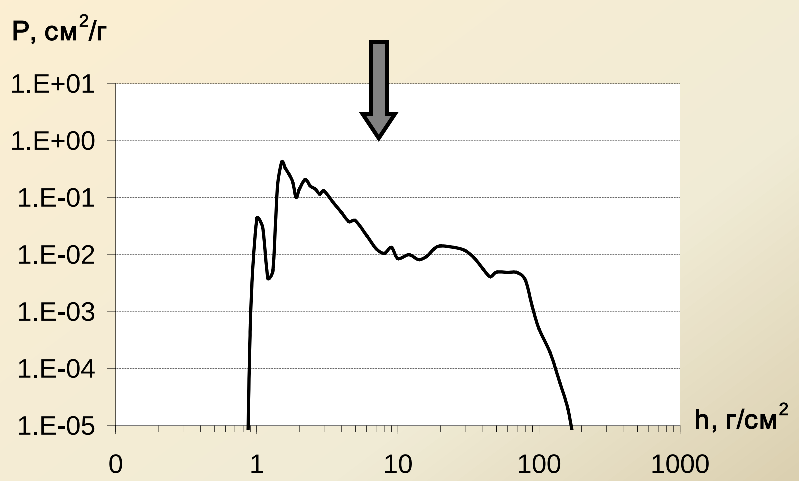
Comparison of R-E approximation and Oltaris results



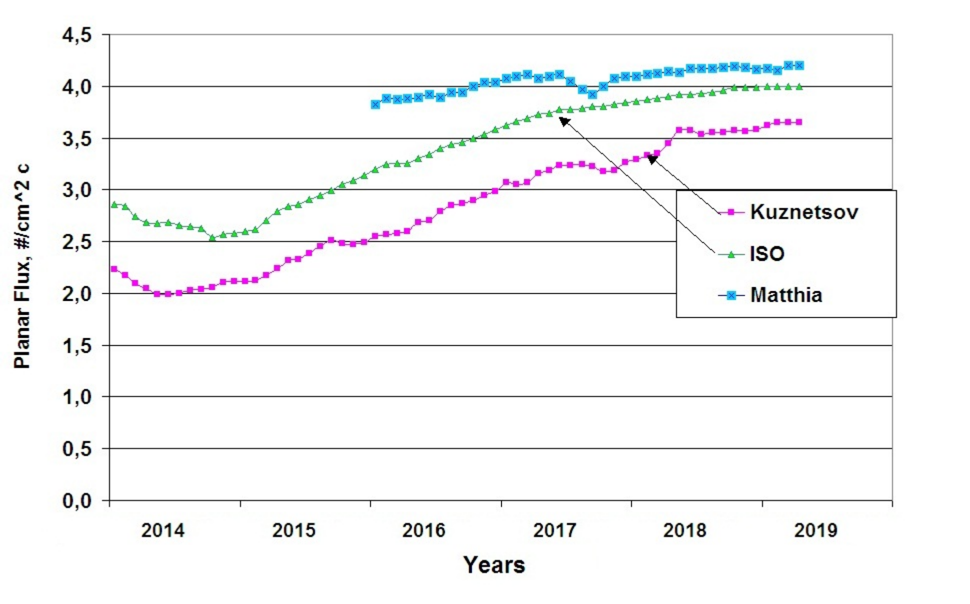


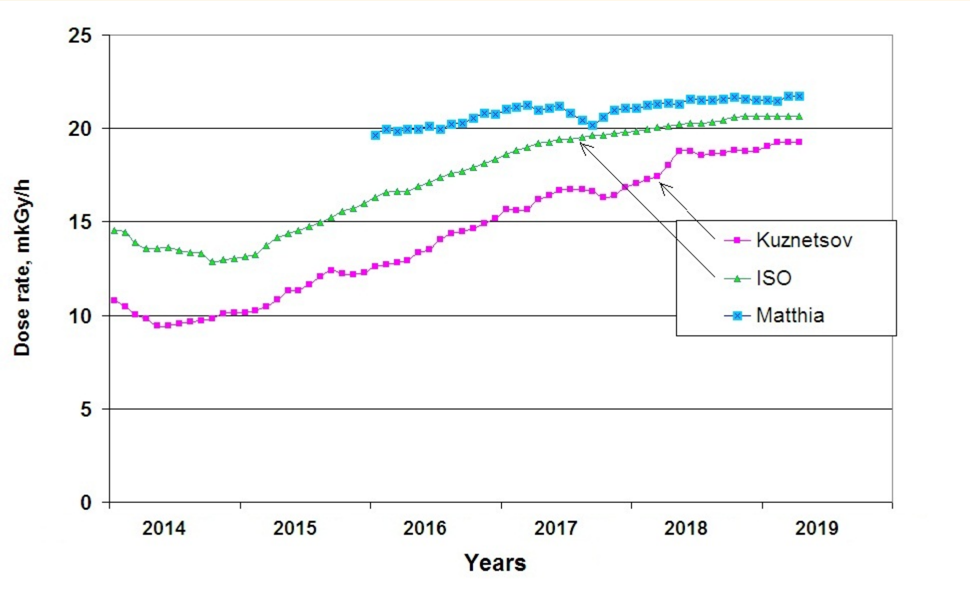


Shielding function (with "Liulin-MO", "FREND" and TGO construction)

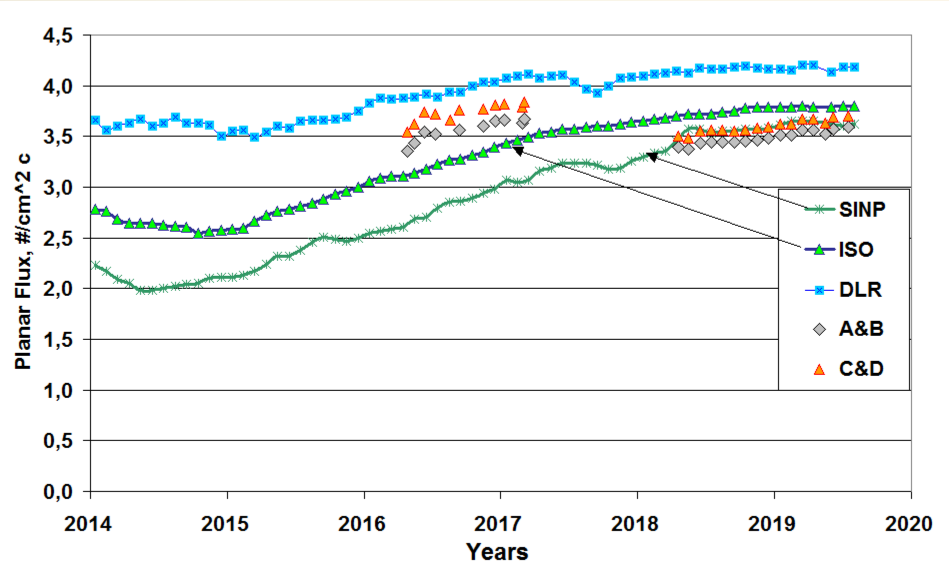


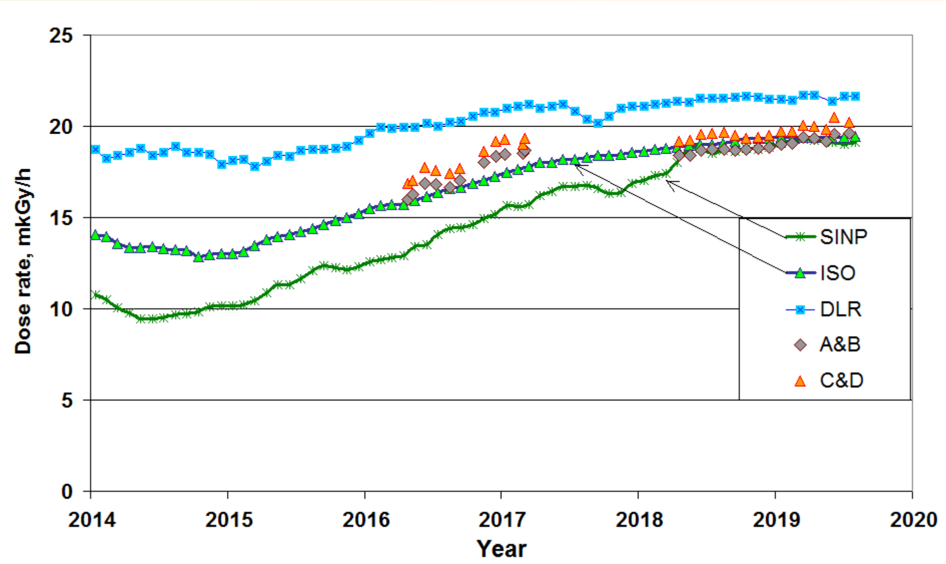
Flux and dose rate calculations based on GCR models



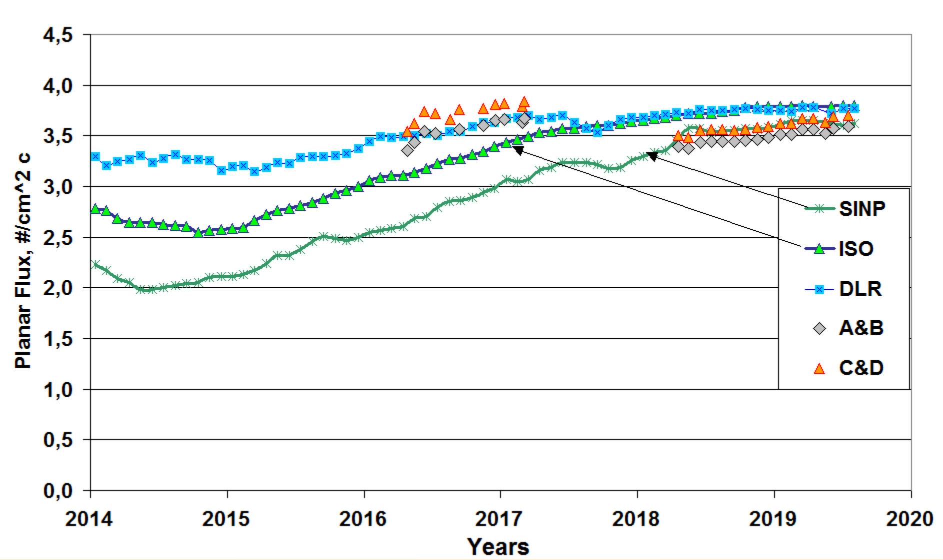


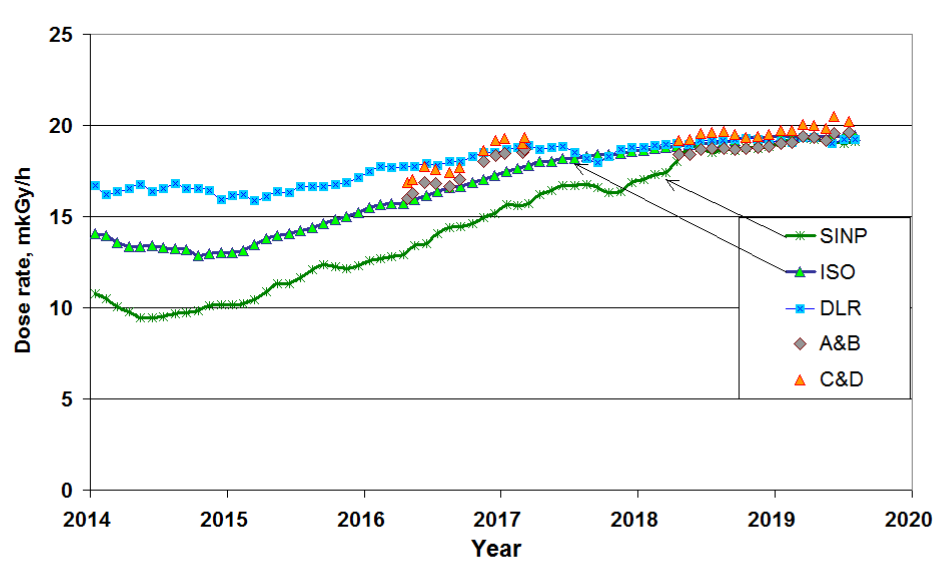
Comparison of flux and dose rate calculations and measurements





Comparison of flux and dose rate calculations and measurements (after 10% reduction values of DLR model)





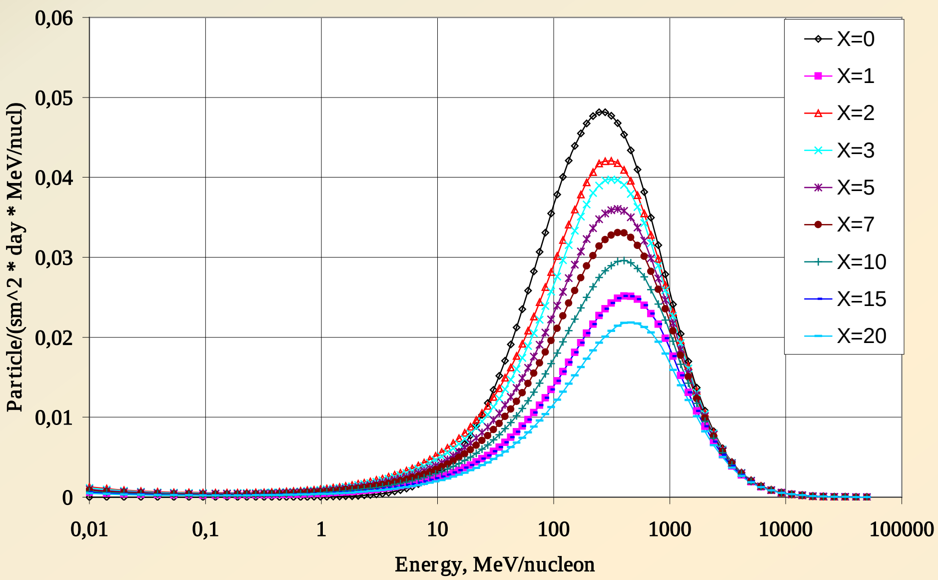
Conclusion

- Recalculation of dose rate and the particle flux values measured on circular orbit to interplanetary space is carried out. The absorbed dose rate in 2019 increased up to 20 mkGy/hour in silicon detectors.
- Calculation of galactic cosmic rays dose rate and particle flux according to ISO 15390, SINP-2017 and DLR models were carried out.
- It is shown that the results of Liulin-MO measurements don’t contradict to calculated values for all considered GCR models.

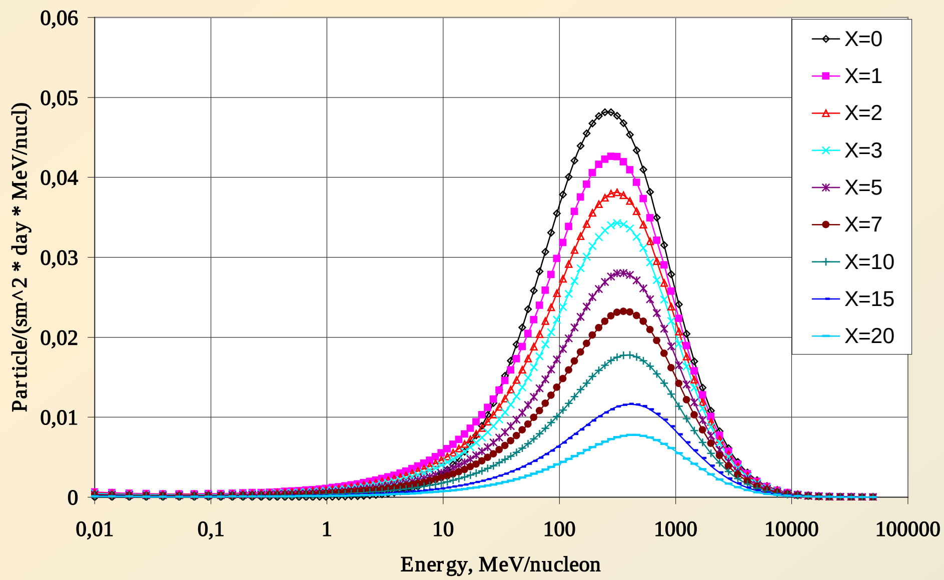
Thank you for your attention!

Calculation Fe-56 spectra beyond shielding

Calculation Fe-56 spectra with R(E) relation



Calculation Fe-56 spectra with NASA Oltaris site



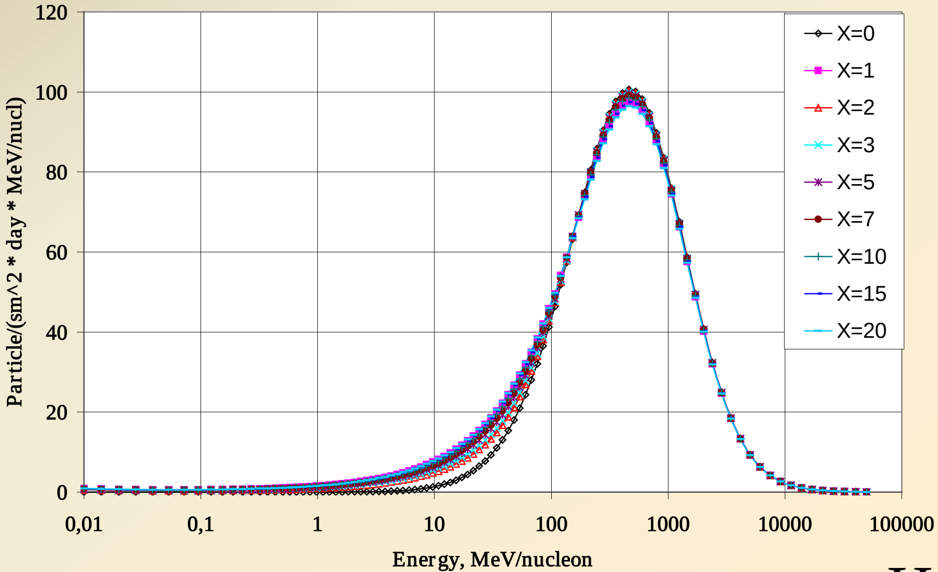
The both case were used the same ISO 15390 spectra for March 2013 year.

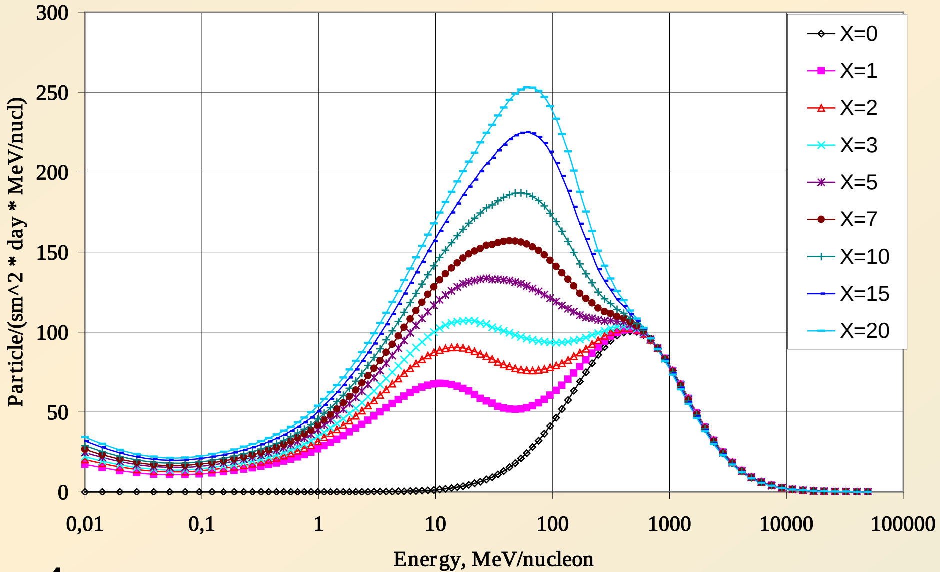
Calculation proton and He-4 spectra beyond shielding

Calculation with R(E) relation

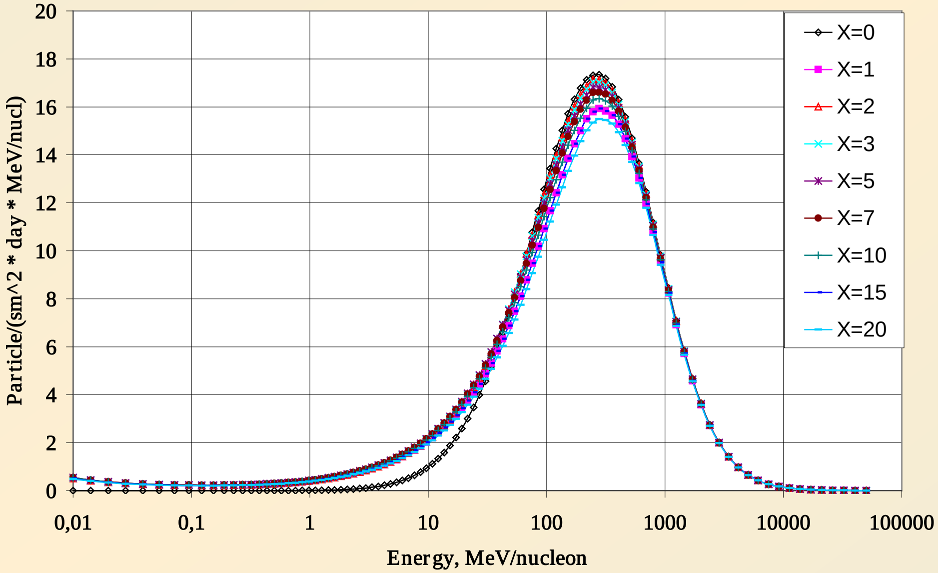
Calculation with NASA Oltaris site

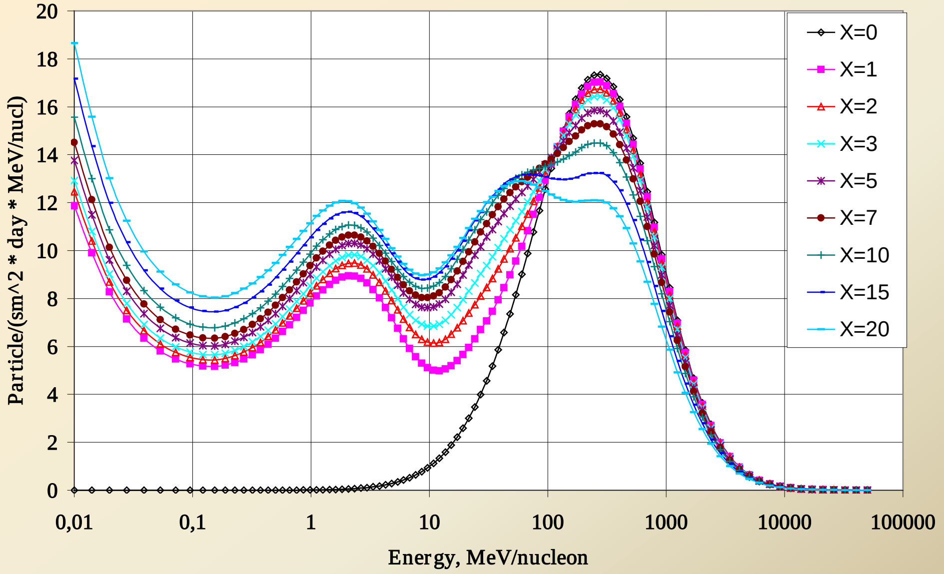
Protons





He-4





The Badhwar–O'Neill Galactic cosmic ray model brief description

$$\frac{j(r,E)}{E^2 - m^2} = \frac{j_0(r_B, E + Ze\phi)}{(E + Ze\phi)^2 - m^2}$$

Where: j_0 is the local interstellar spectrum
φ - the deceleration potential

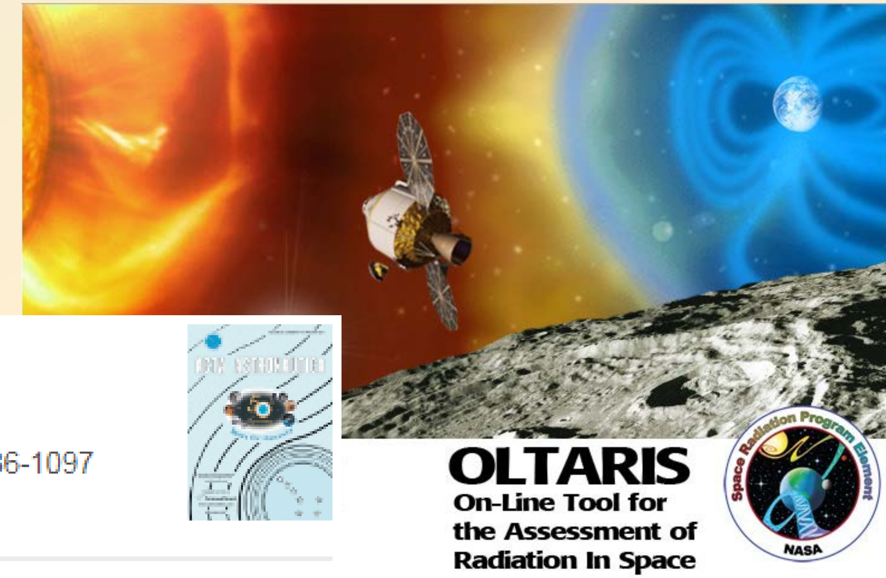
$$j_l = j_0 \beta^{\delta} (E + E_0)^{-\gamma},$$

where E and E_0 are, respectively, the particle kinetic and rest energy and/or nucleon, and δ; γ, and j_0 are the fitting parameters for each charge group

$$\phi(r,t) = \frac{1}{3} \int_r^{r_B} \frac{\vec{V}_w(r',t)}{\kappa(r',t)} dr'$$

where r_B is the radial extent of the heliosphere, *k* is the diffusion coefficient, and V_w is the solar wind velocity.

Calculations with Badhwar–O’Neill Galactic cosmic ray model were made by Nikolay Kuznetsov from Moscow state university using OLTARIS tool.



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OLTARIS: On-line tool for the assessment of radiation in space

Robert C. Singleterry Jr. [a], Steve R. Blattnig [a], Martha S. Clowdsley [a], Garry D. Qualls [a], Chris A. Sandridge [a], Lisa C. Simonsen [a], Tony C. Slaba [a], Steven A. Walker [b], Francis F. Badavi [c], Jan L. Spangler [d], Aric R. Aumann [e], E. Neal Zapp [f], Robert D. Rutledge [f], Kerry T. Lee [f], Ryan B. Norman [a], John W. Norbury [a]

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https://doi.org/10.1016/j.actaastro.2010.09.022

The OLTARIS tool was used also for flux and dose calculation with NASA HZETRN particle transport code

Flux definition

When we estimated measured value of flux we used formula: F = N/(S T)

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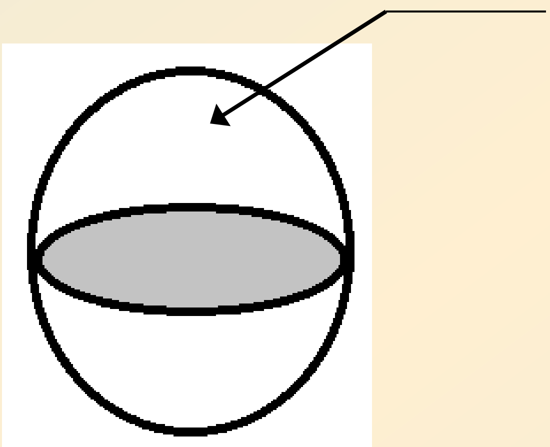
Fluence, Φ

The quotient of dN by da, where dN is the number of particles incident on a sphere of cross-sectional area da, thus:

$$\Phi = \frac{dN}{da}$$

The SI unit of fluence is m^{-2}.

S=1

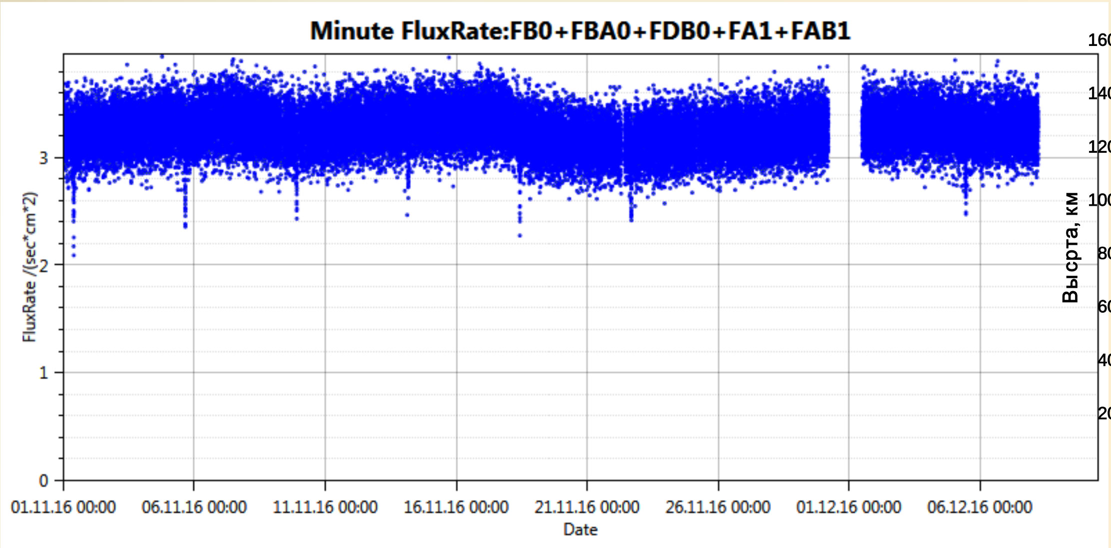


We supposed flux as fluence rate, when it is the number of the particles crossing sphere with unit cross section for 1 second. (We will be mentioned it as spherical flux.)

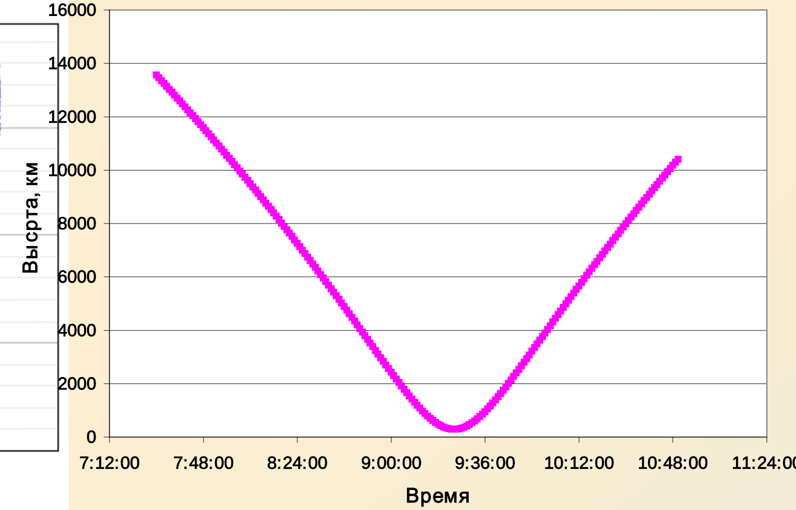
If we define experimental value as the number of particles crossing planar detector with unit squire for 1 second we will find another parameter. Term it planar flux.

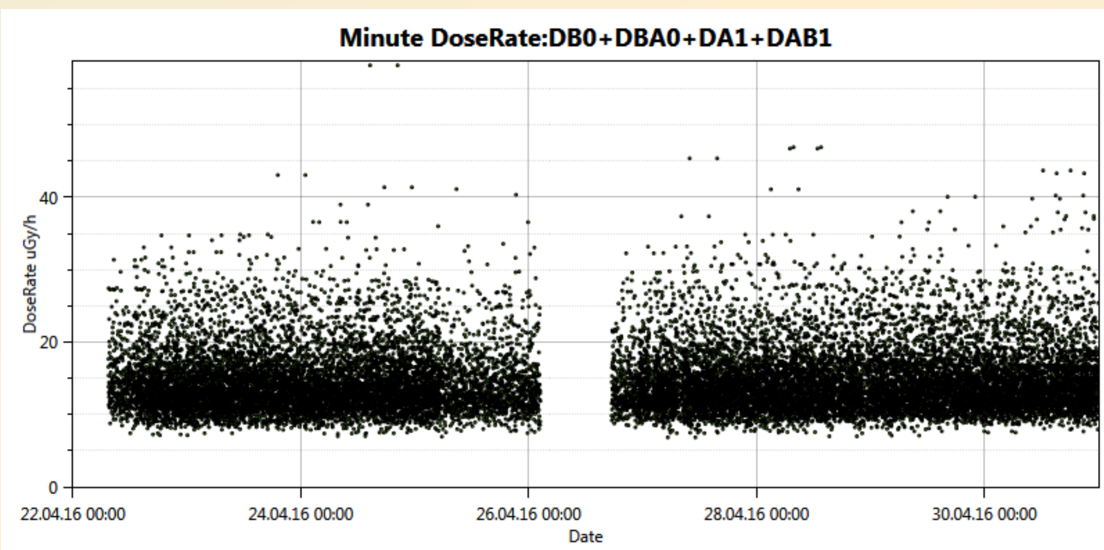
$$F_{Planar} = \int_{4\pi} \frac{F_{Spheric} \bullet |\cos(\theta)|}{4\pi} d\Omega = \frac{1}{2} F_{Spheric}$$

Liulin-MO data in Mars high elliptic orbit (MCO1)

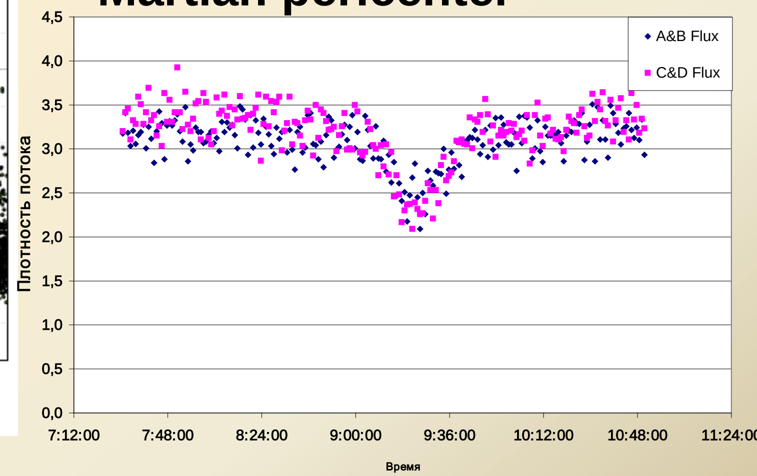


Altitude on the Mars





The particle flux near the Martian pericenter



Data for the Martian pericenter November 1 2016

Altitude

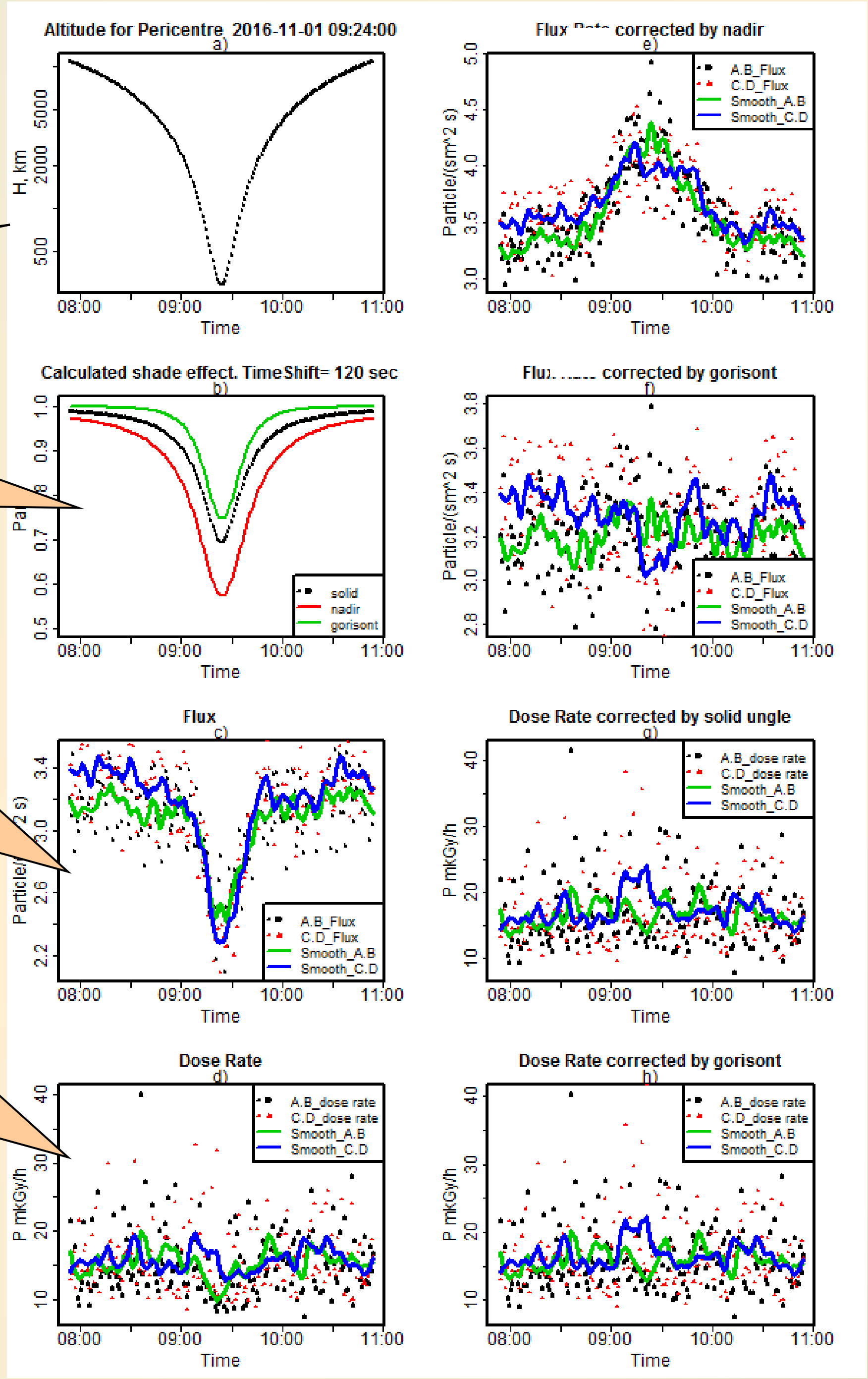
η - Calculated part of recorded flux

Flux

Points – measured data, Curves – smoothed values

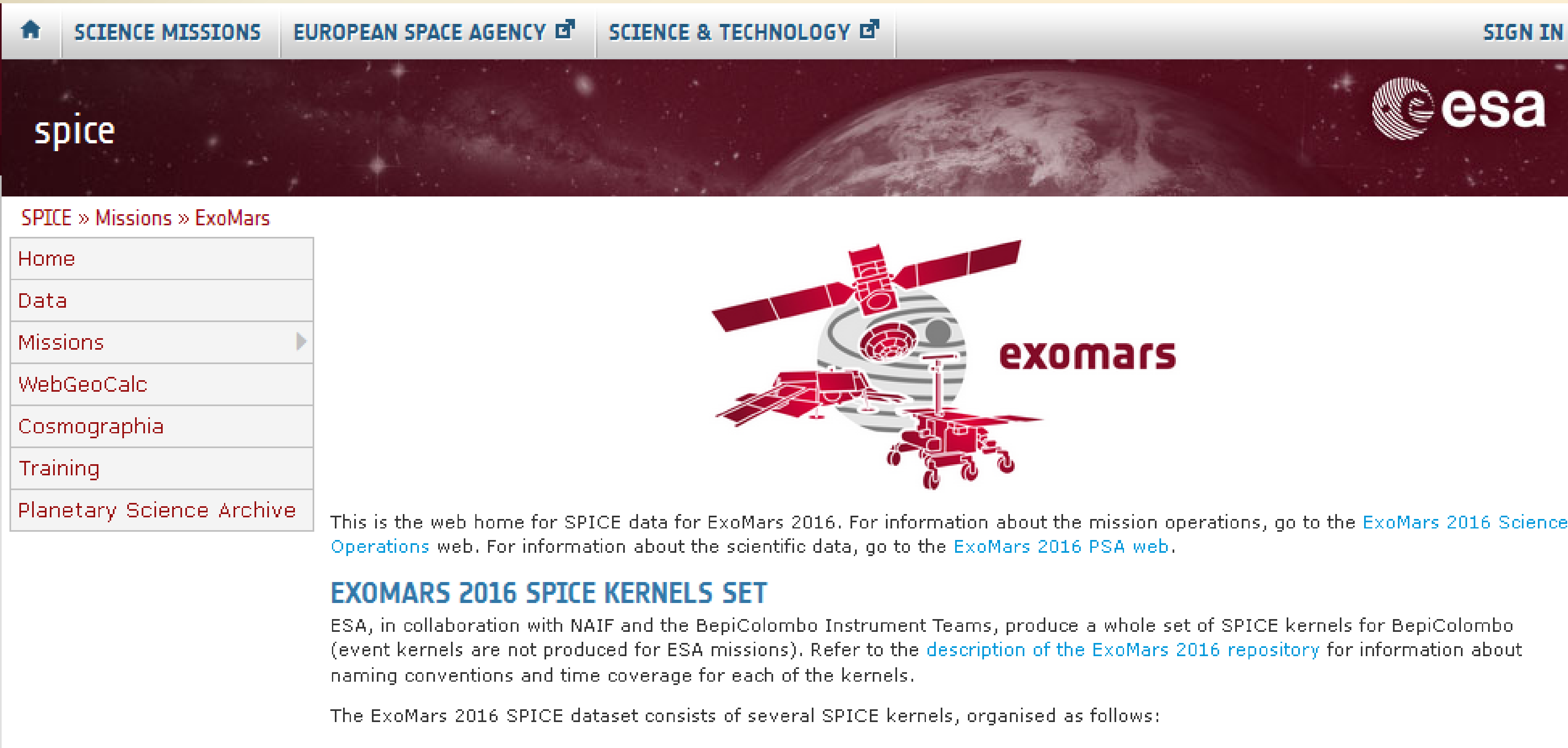
Dose rate

Points – measured data, Curves – smoothed values



Results of correction: flux or dose rate divided on **η**

To estimate detectors shadowing by Mars was used SPICE system



https://www.cosmos.esa.int/web/spice/spice-for-exomars-2016