Radiation measurements with Liulin-MO dosimeter of FREND instrument aboard ExoMars Trace Gas Orbiter during cruise to Mars and on Mars orbit

Victor Benghin[1], Jordanka Semkova[2], Igor Mitrofanov[3], Lev Zelenyi[3], Alexey Malahov[3], Rositza Koleva[2], Vyacheslav Shurshakov[1], Tsvetan Dachev[2], Yuri Matviichuk[2], Borislav Tomov[2], Stephan Maltchev[2], Plamen Dimitrov[2], Krasimir Krastev[2], Dmitry Golovin[3], Maxim Mokrousov[3], Anton Sanin[3], Maxim Litvak[3], Andrey Kozyrev[3], Vladislav Tretyakov[3], Sergey Nikiforov[3], Andrey Vostrukhin[3], Natalia Grebennikova[3], Sergey 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.*

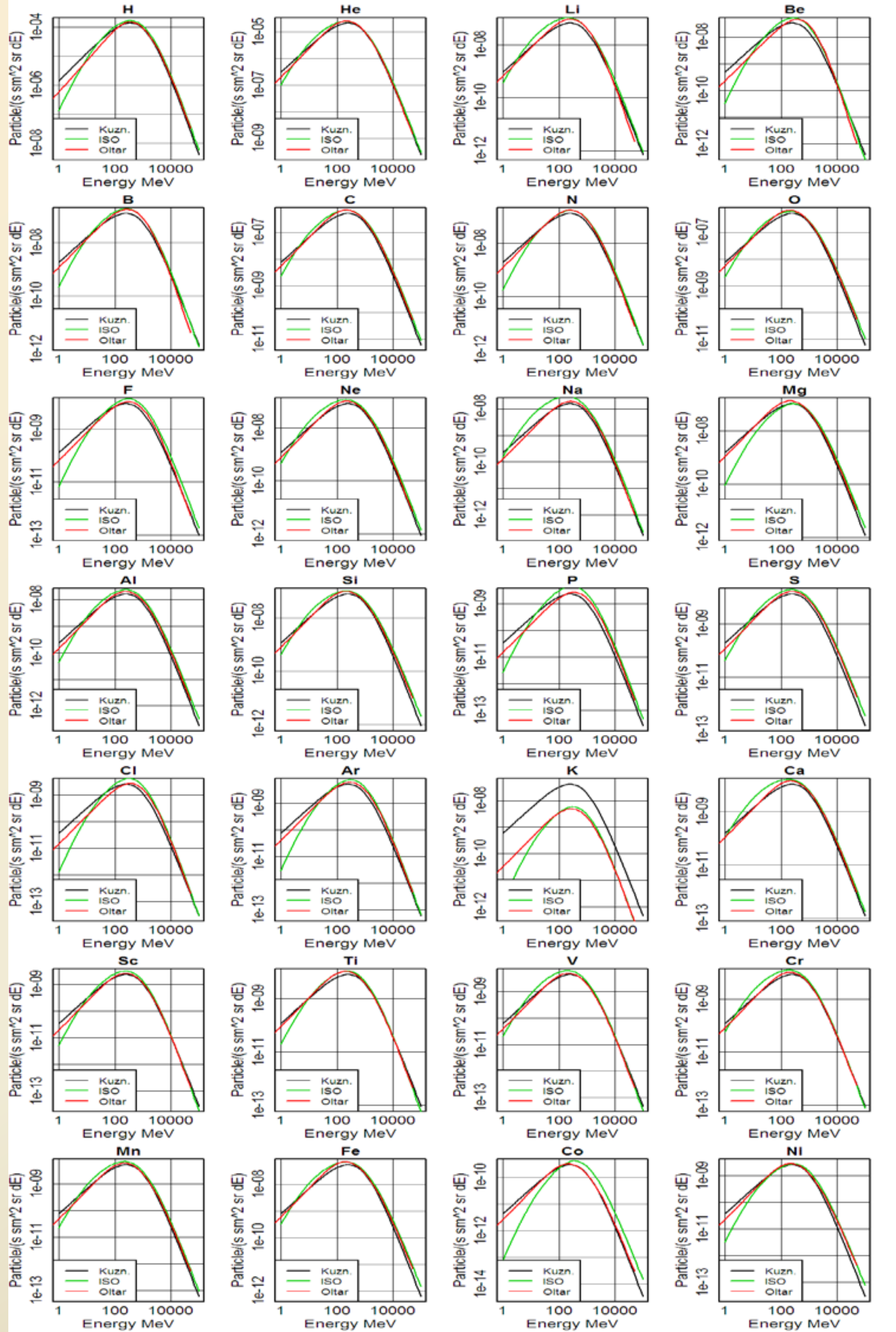
The 23rd annual WRMISS, Tsurugo, Japan, September 6, 2018

Presentation outline

- A few slides from our previous presentation on WRMISS 22
- Martian shadowing influence on flux and dose rate
- Estimation of deep space flux and dose rate based on low orbit Liulin-MO data and comparison with estimations based on GCR models
- Conclusion

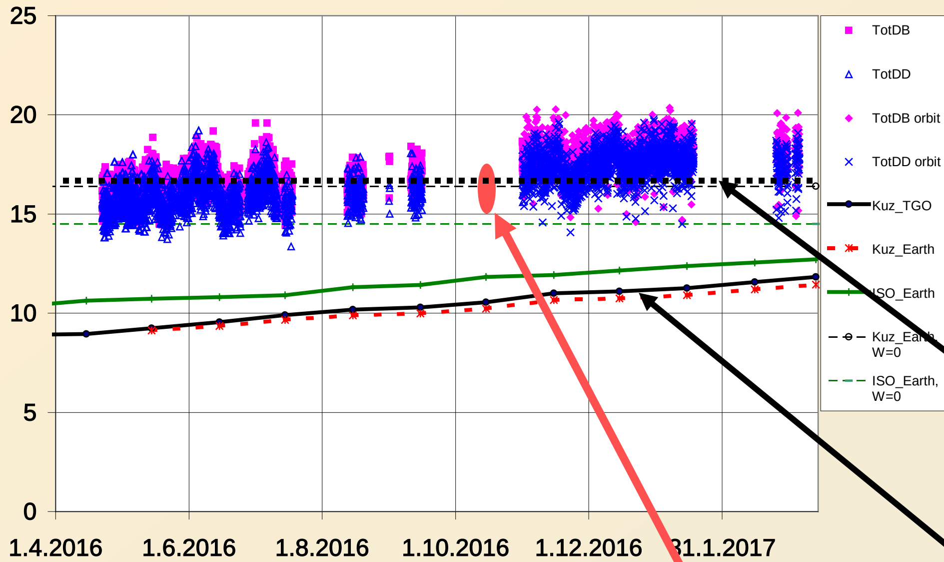
Galactic Cosmic Ray models

- The Badhwar–O’Neill GCR model. O’Neill, P.M. Badhwar–O’Neill 2010 galactic cosmic ray flux model—Revised. IEEE Transactions on Nuclear Science 57 (6), 3148–3153, 2010.
- International standard ISO/DIS 15390
  ISO 15390. Space environment (natural and artificial) – galactic cosmic ray model, 2004.
- SINP-2017 GCR model



Comparison of measured and calculated fluxes and dose rates

Dose rate, mkGy/h

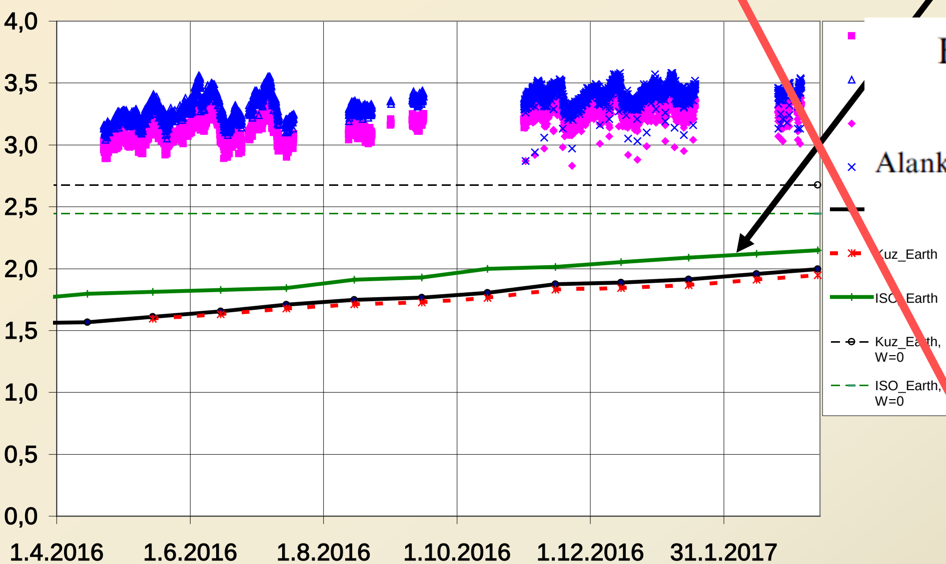


To achieve a satisfactory agreement between estimations and measurements, we set the Solar activity level to zero.

Estimation for zero Solar activity level.

Estimation for real Solar activity level.

Flux, # cm^{-2} s^{-1}



How Galactic Cosmic Ray models affect the estimation of radiation exposure in space

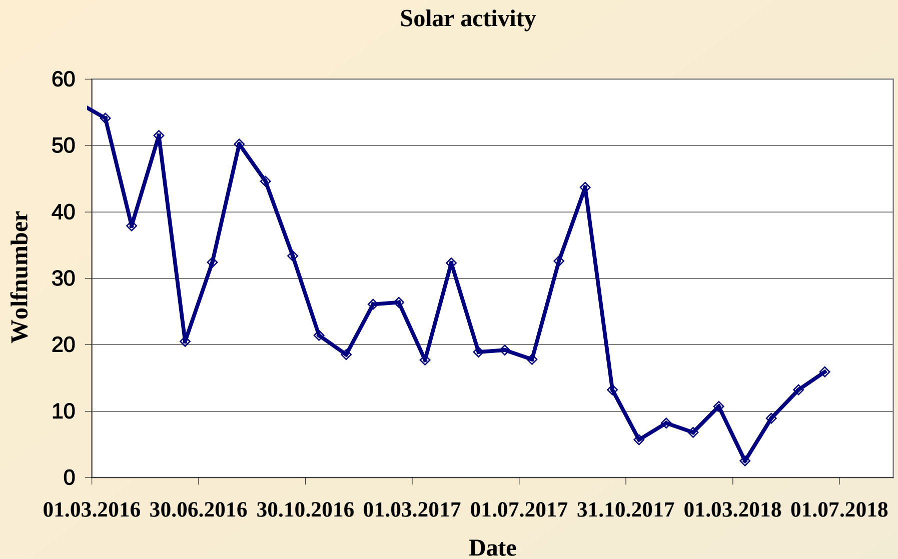
Alankrita Isha Mrigakshi [a,*], Daniel Matthiä [a], Thomas Berger [a], Günther Reitz [a], Robert F. Wimmer-Schweingruber [b]

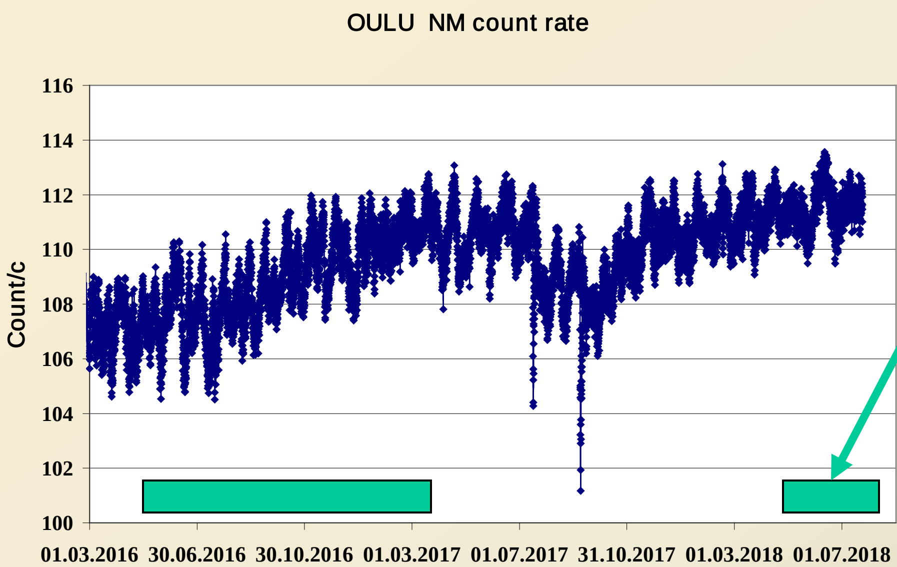
Advances in Space Research 51 (2013) 825–834

"Based on the BON2010 model, the absorbed dose … are estimated to range from 0.14 to 0.38 mGy/d "

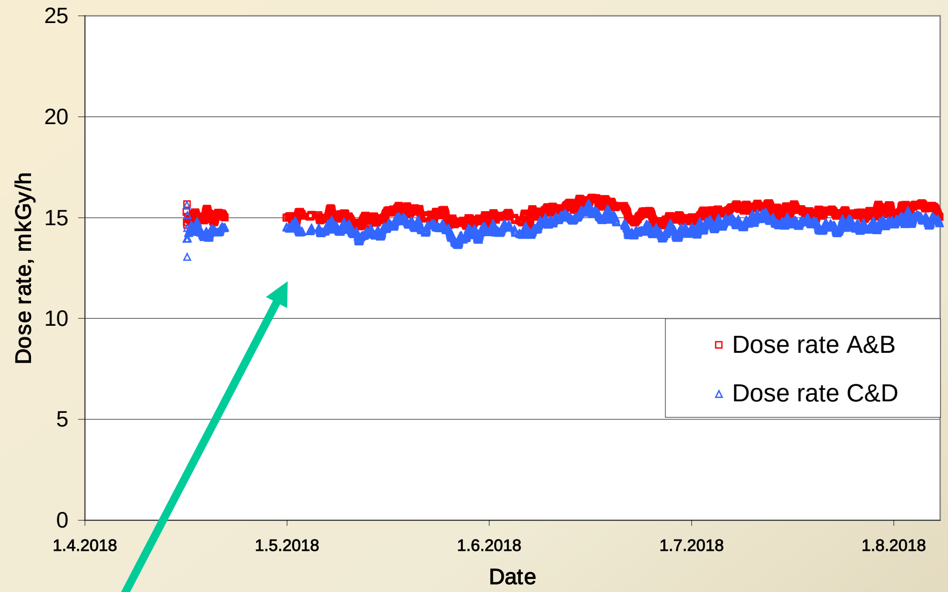
0.38 mGy/d -> 15,8 μGy/h

Solar activity and NM count rate since January 2016



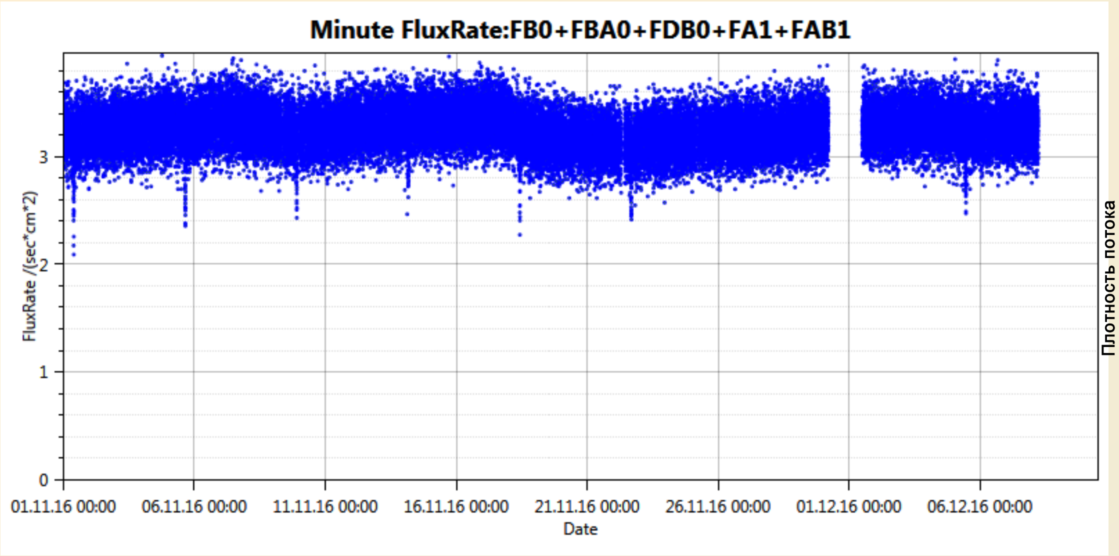


Since April 16, 2018/ TGO Mars Science Orbit

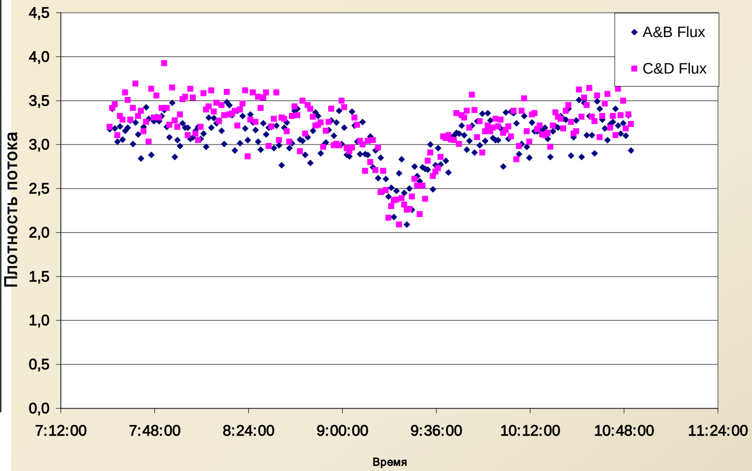


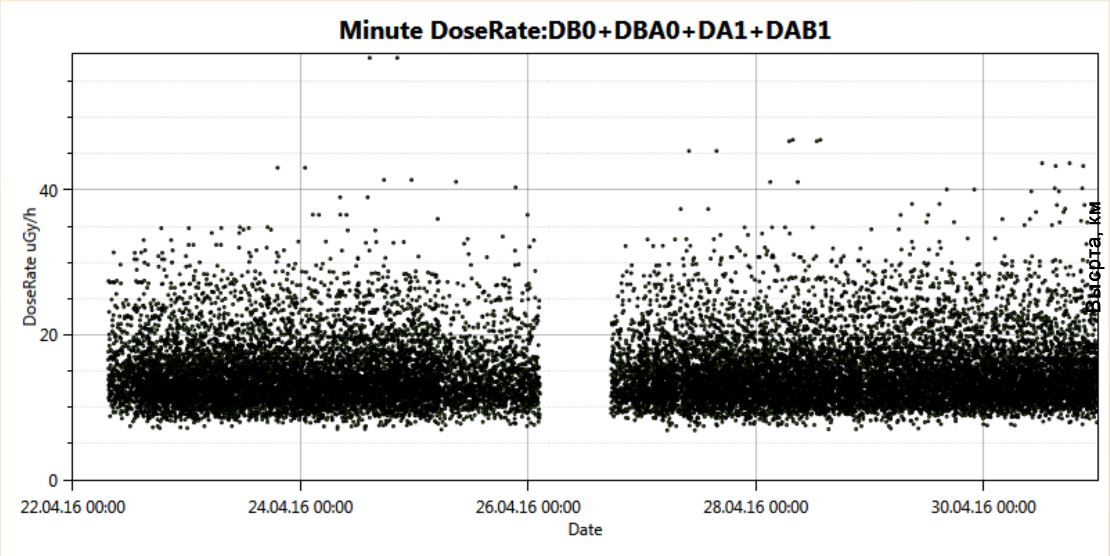
We acknowledge the NMDB database (www.nmdb.eu), founded under the European Union's FP7 programme (contract no. 213007) for providing NM data.

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

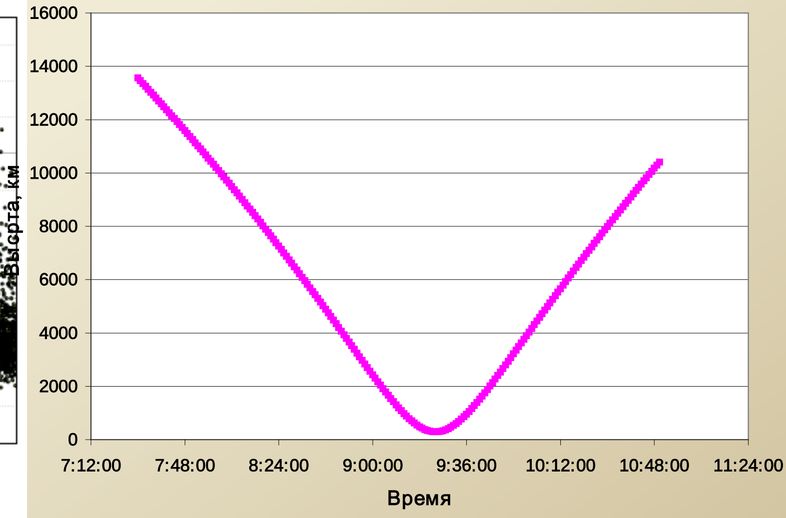


The particle flux near the Martian pericenter

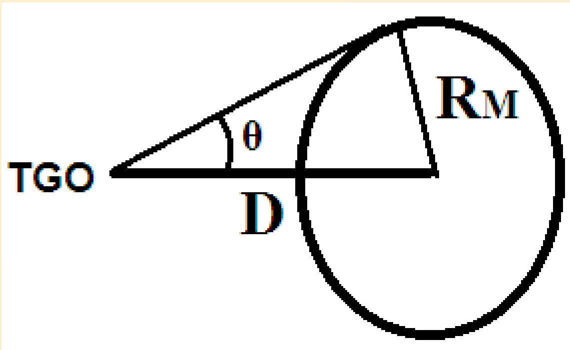




Altitude above Mars



Mars shadow effect estimation



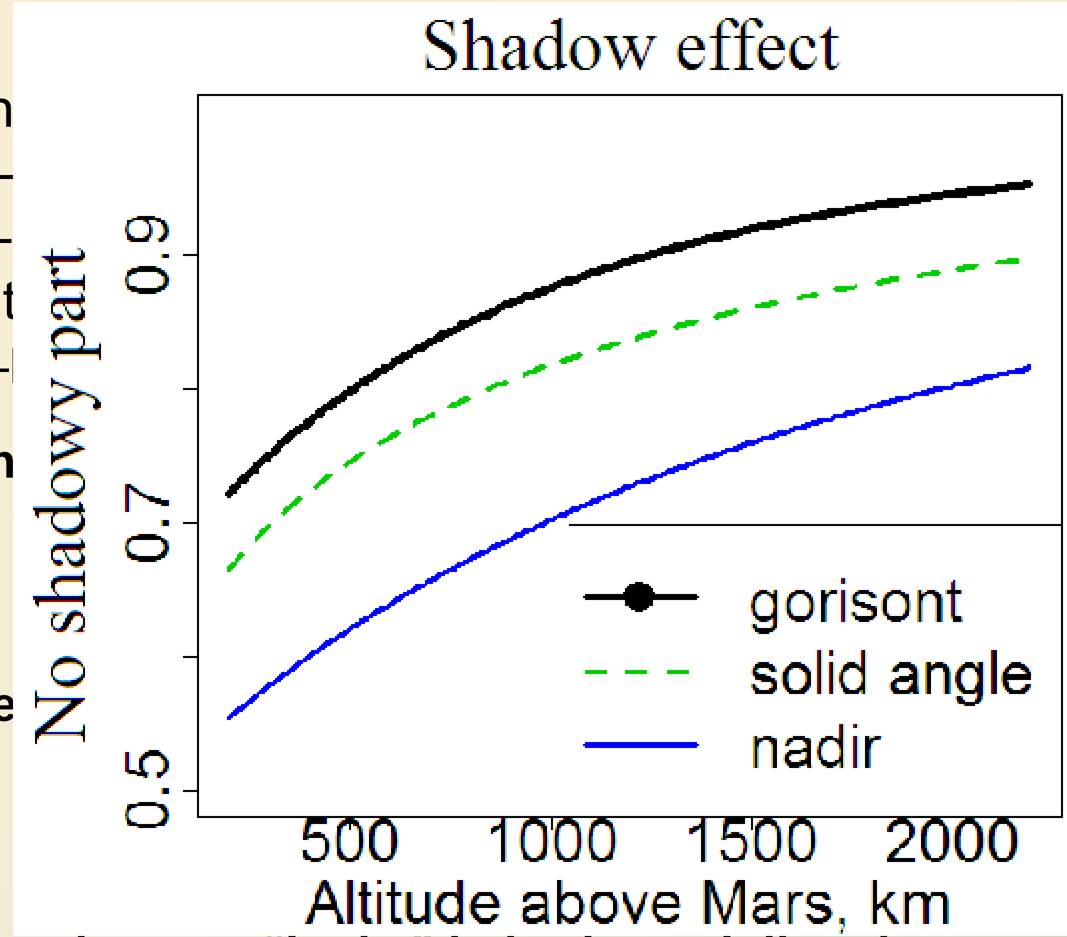
Den

R_M -

D –

cent

Θ –



Part of the TGO solid angle n

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

Part of the flux recorded whe

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

Part of the flux recorded when detector "looks" in horizontal direction:

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

Data for the Martian pericenter November 1 2016

Altitude

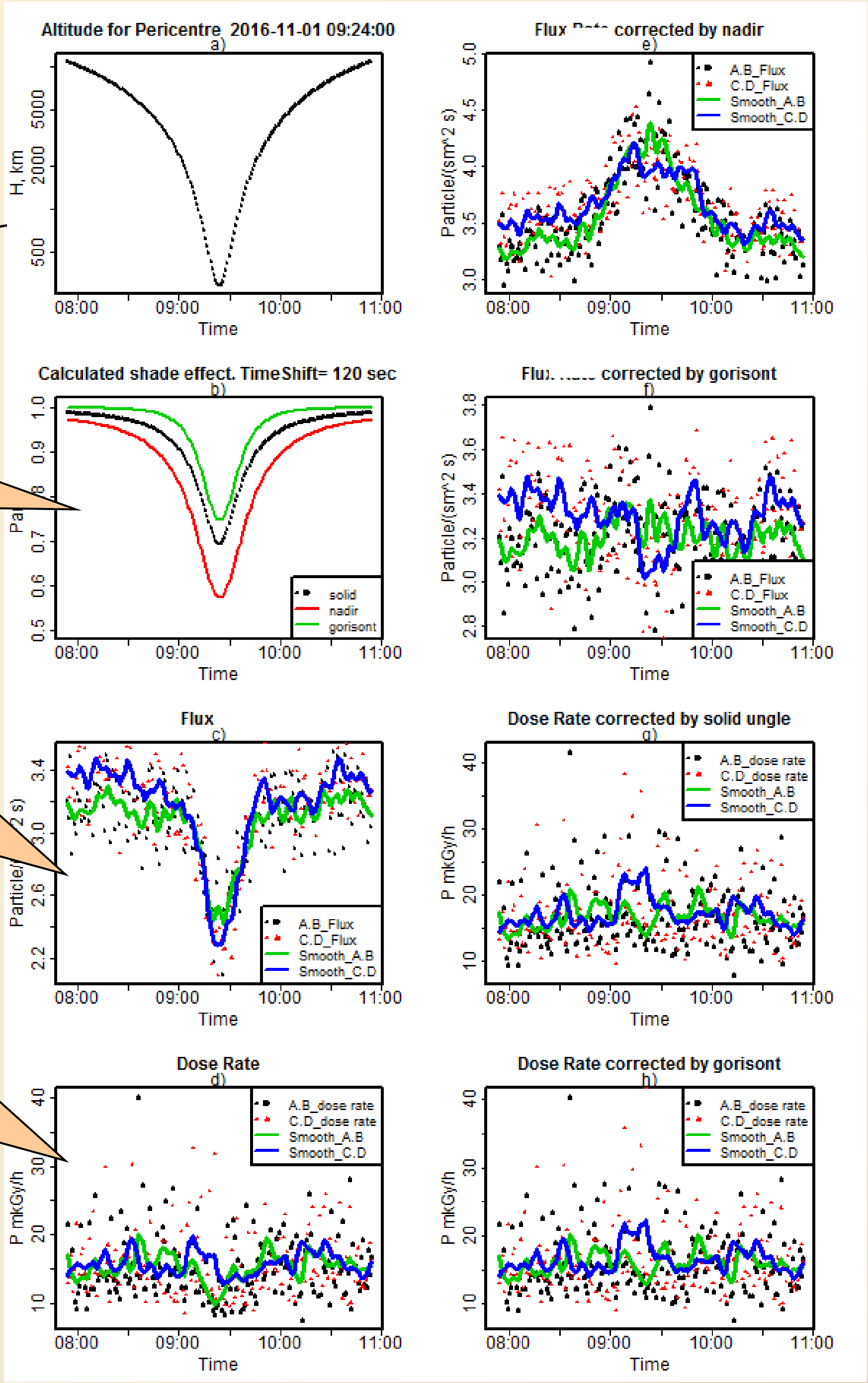
η - Calculated part of recorded parameter

Flux

Points – measured data, Curves – smoothed values

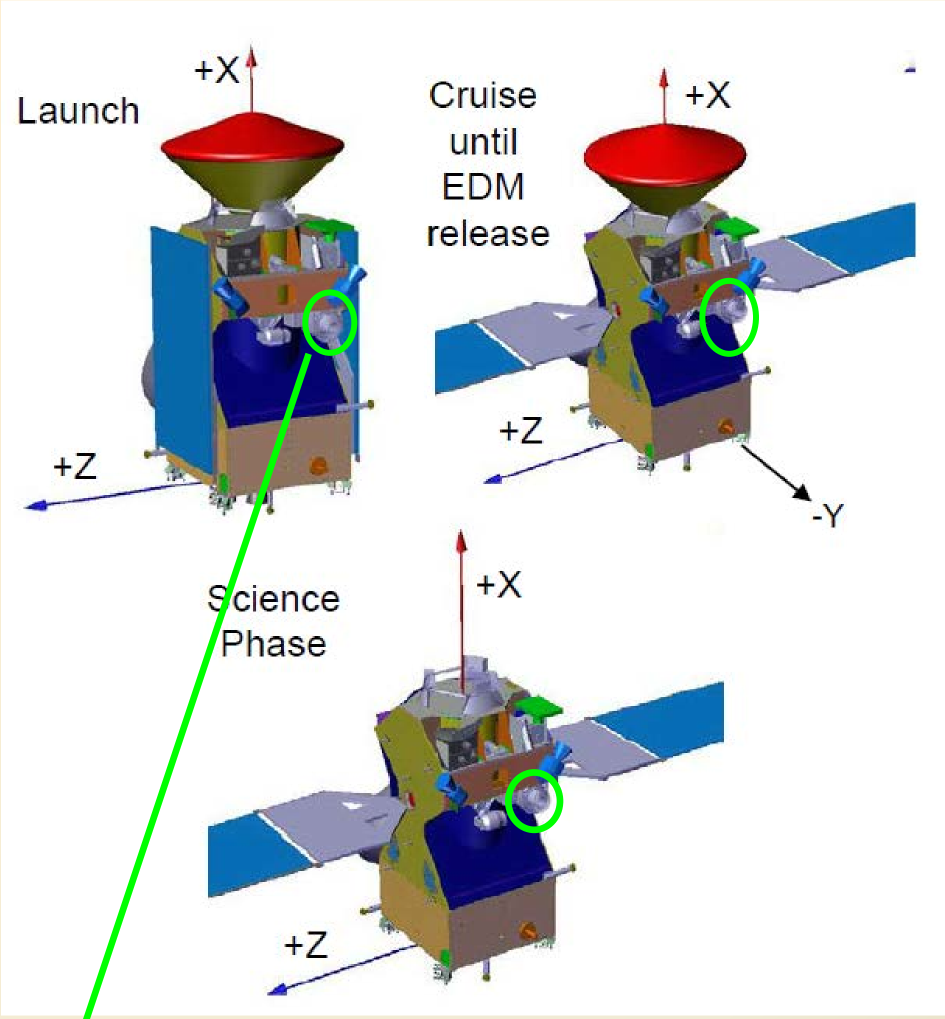
Dose rate

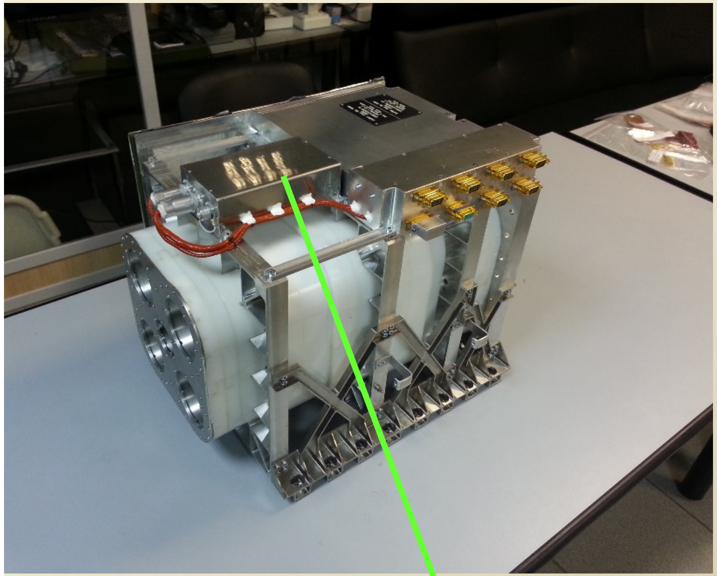
Points – measured data, Curves – smoothed values



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

FREND with Liulin-MO

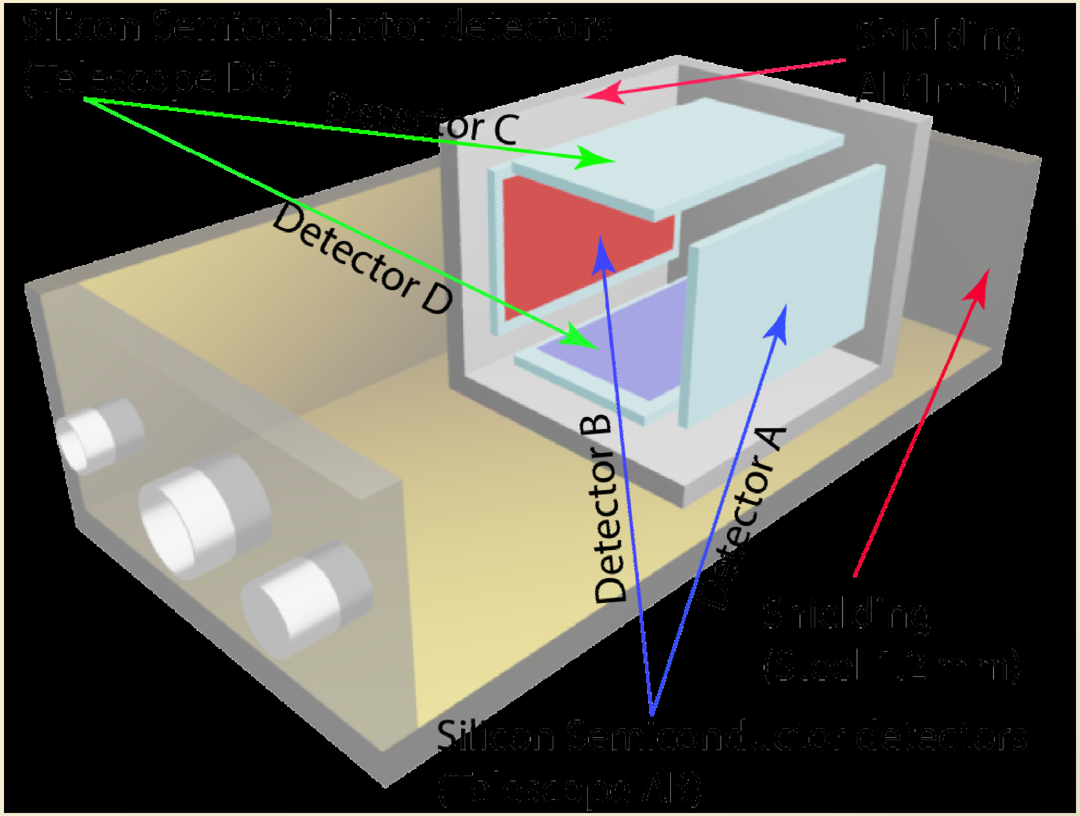




FREND on TGO

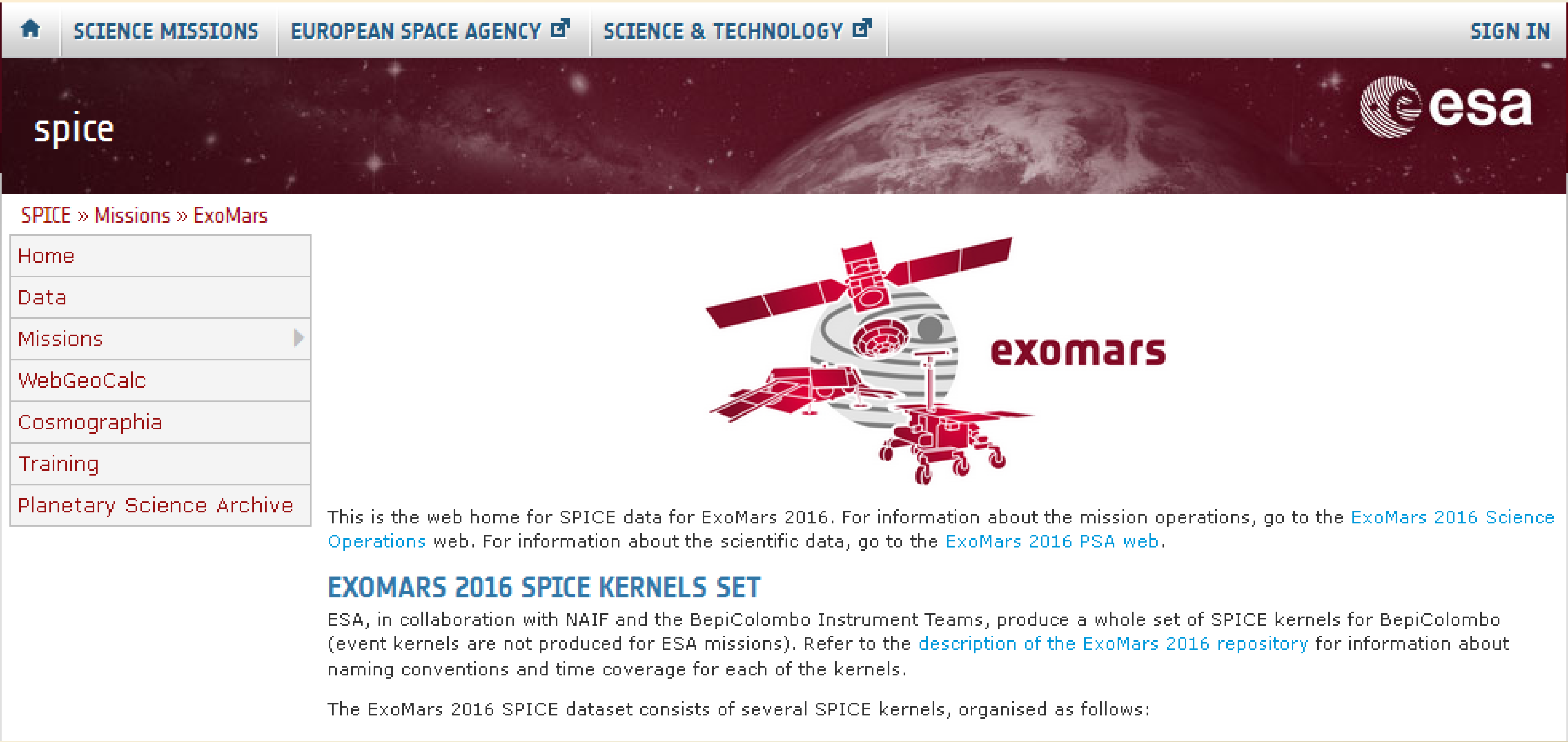
FREND instrument with Liulin-MO *Credit: ESA/Roscosmos/FREND/IKI* .

Liulin –MO description



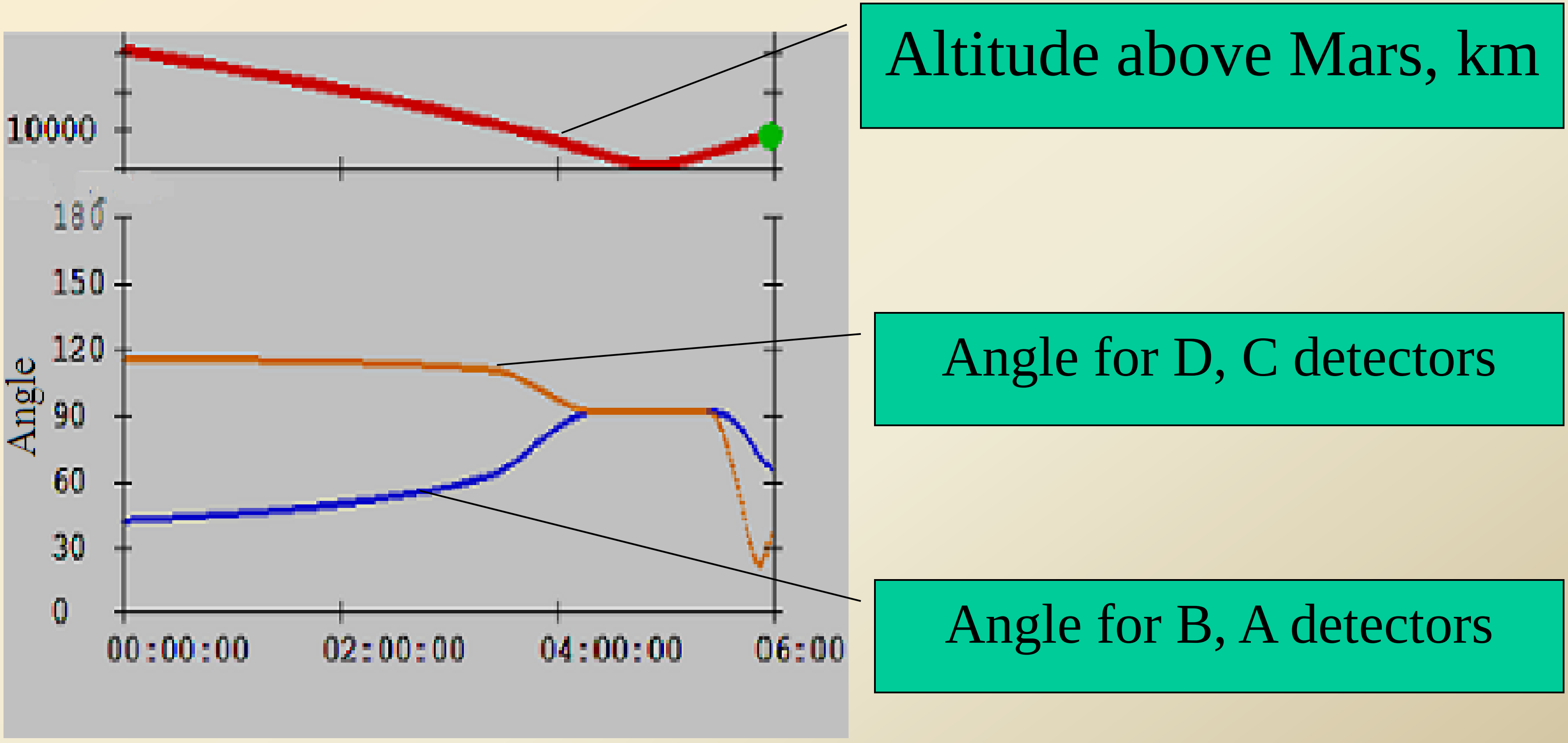
Each pair of the dosimetric telescopes consists of two Si PIN photodiodes. The distance between the parallel Si PIN photodiodes is 20.8 mm. Liulin-MO provides data for the dose rates D, particle fluxes F, LET spectra, radiation quality factor Q, and dose equivalent rates H in 2 perpendicular directions.

The SPICE system was used to estimate detectors shadowing by Mars



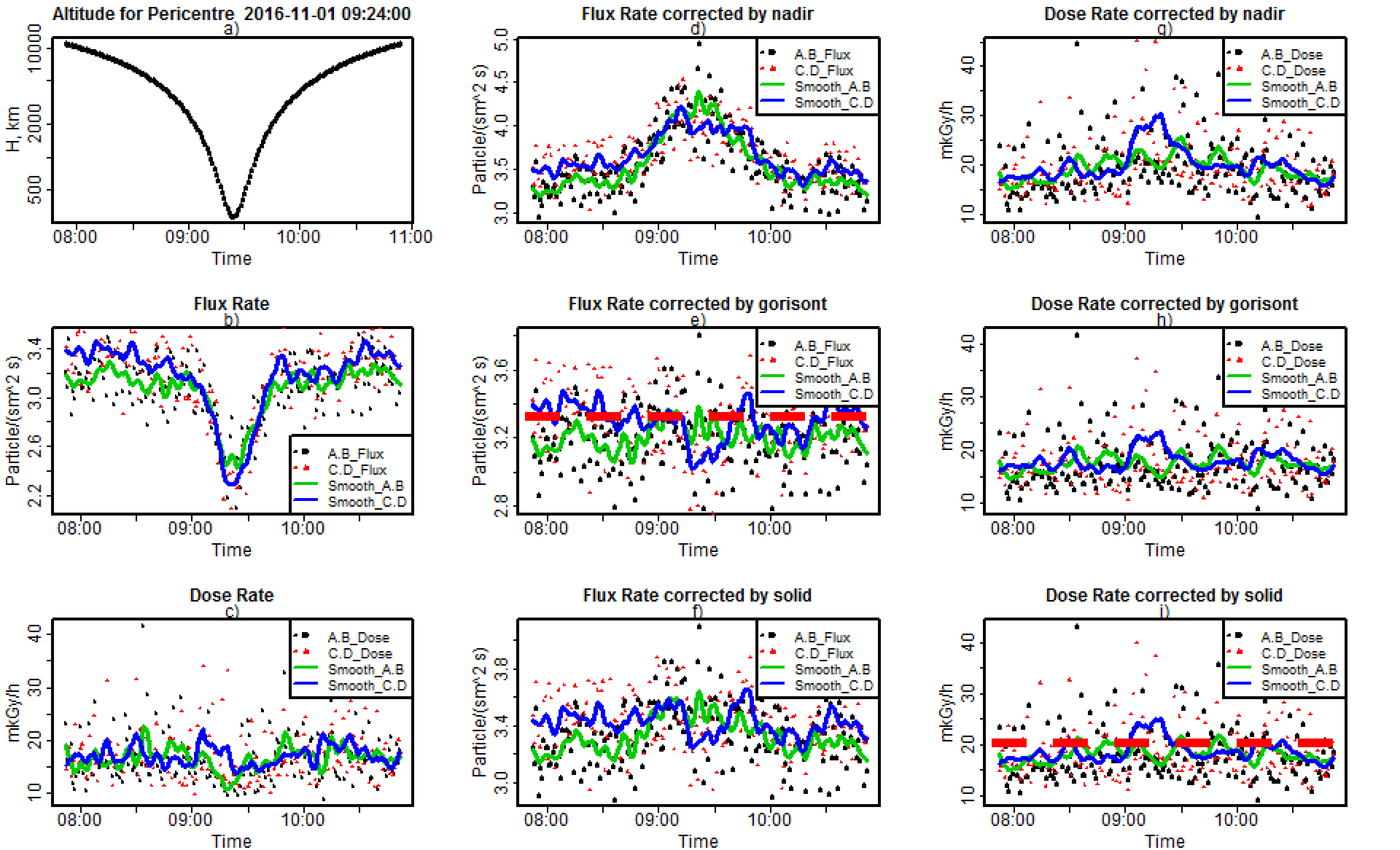
https://www.cosmos.esa.int/web/spice/spice-for-exomars-2016

The angles between the detector's axis and the direction to Mars during pericenter crossing on November 1, 2016.



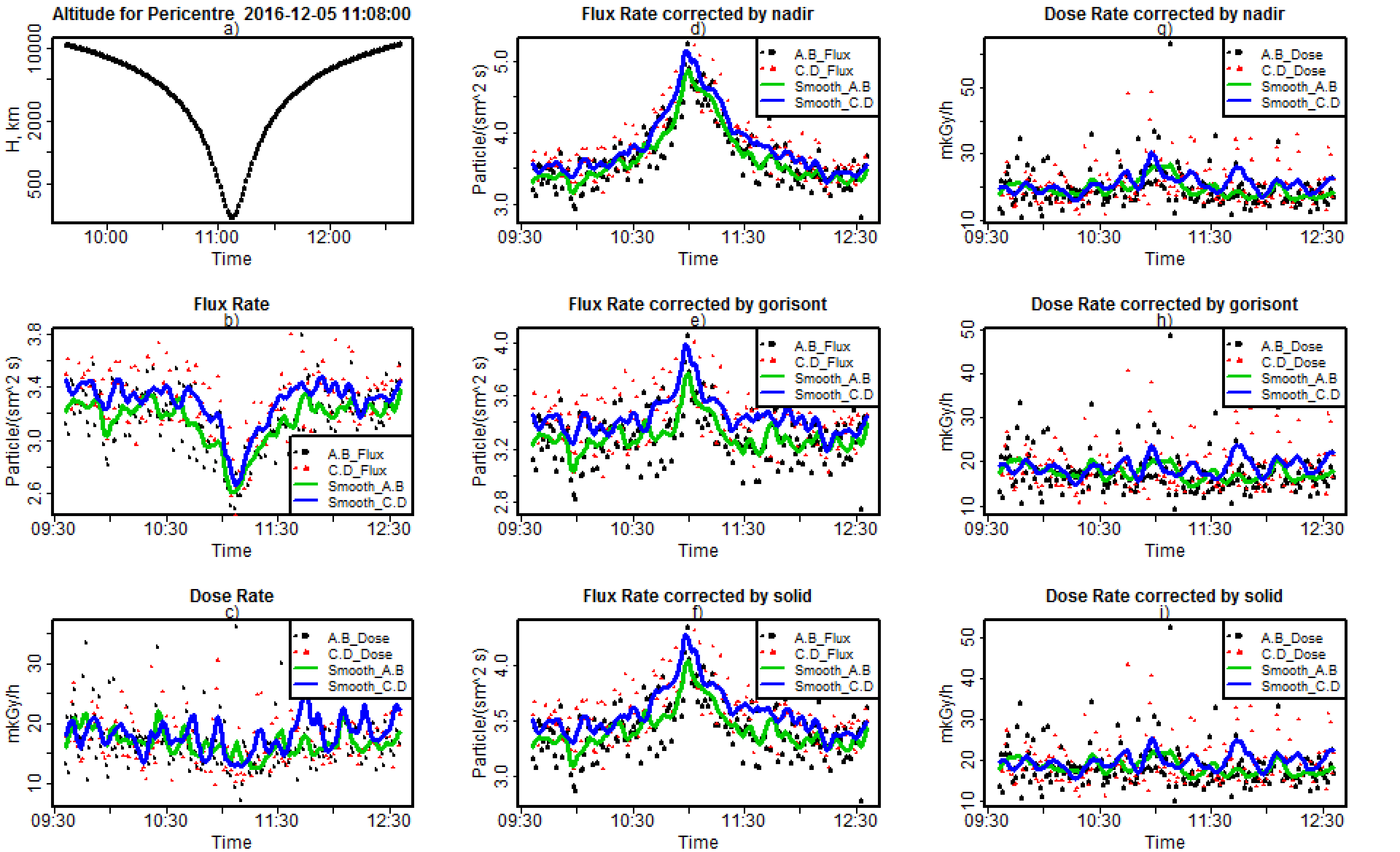
Correction of flux and dose rate during the pericenter crossing

2016-11-01

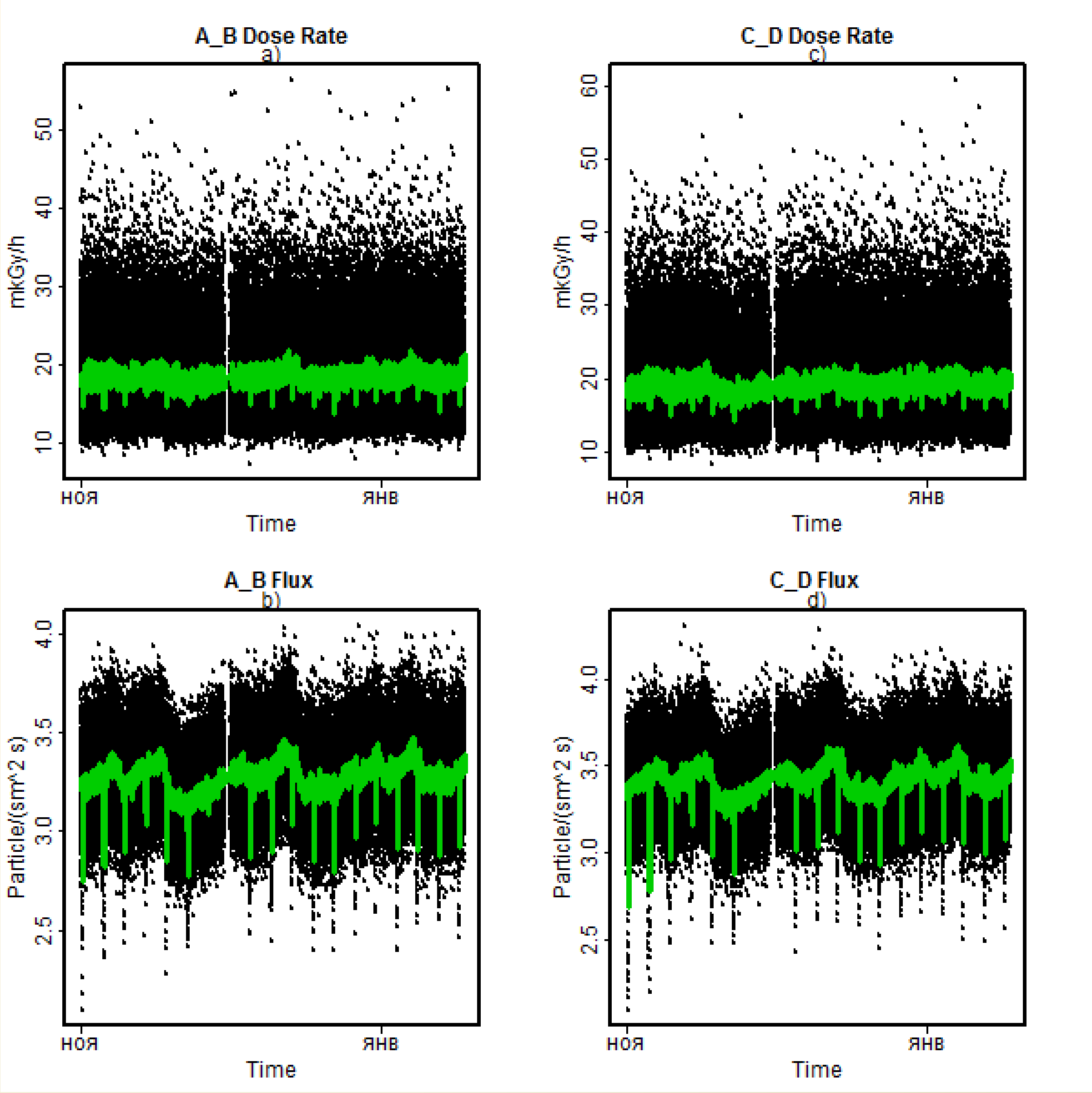


Correction of flux and dose rate during the pericenter crossing

2016-12-05



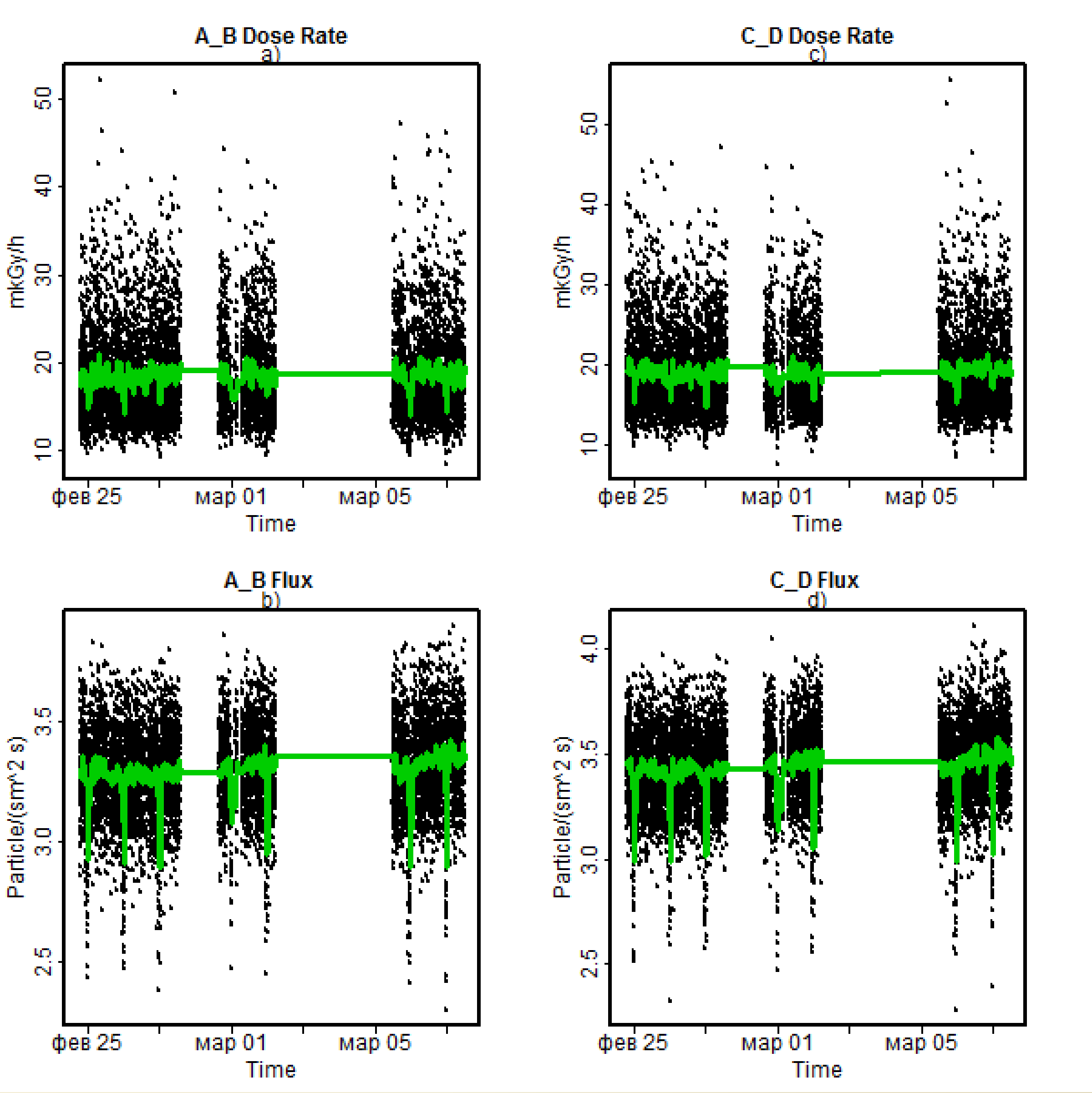
Flux and dose rate during MCO1 (November 01, 2016 - January 17, 2017)



The black points – results of measurements. Green curve – smoothed data

Available data for 18 pericenter crossings.

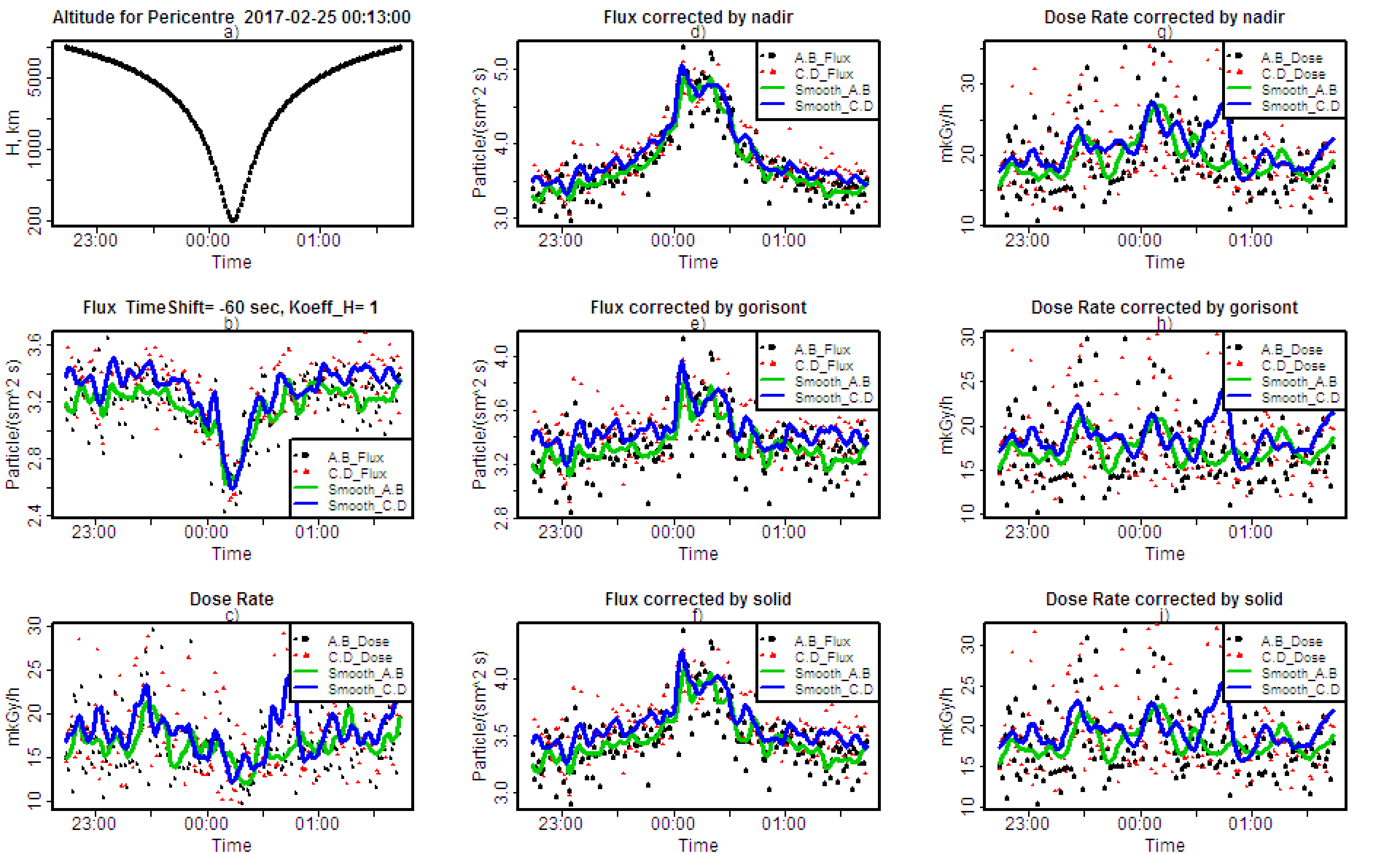
Flux and dose rate during MCO2 (February 24, 2017 - March 07, 2017)



Available data for 6 pericenter crossings.

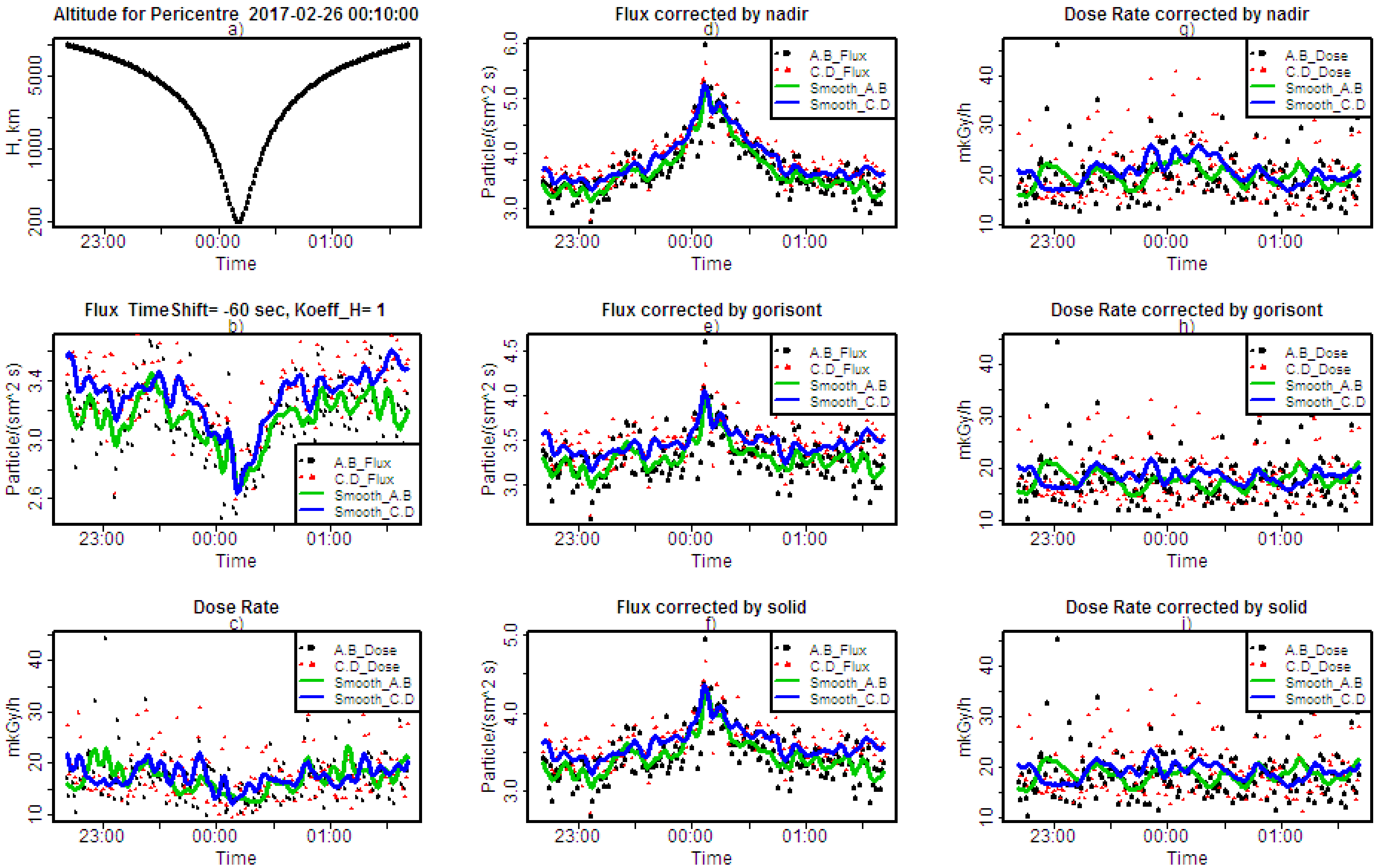
Correction of flux and dose rate during the pericenter crossing

2017-02-25



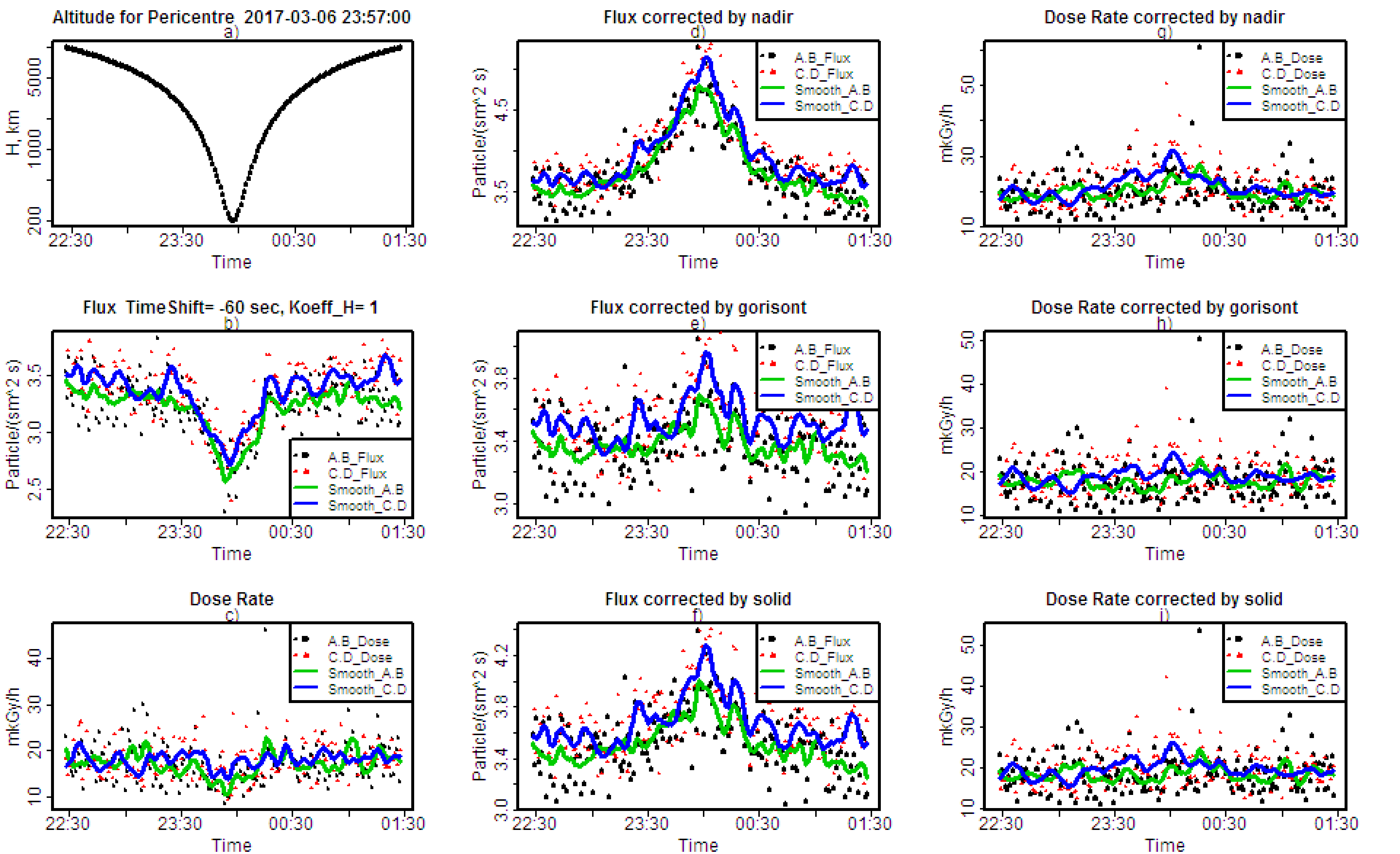
Correction of flux and dose rate during the pericenter crossing

2017-02-26



Correction of flux and dose rate during the pericenter crossing

2017-03-06

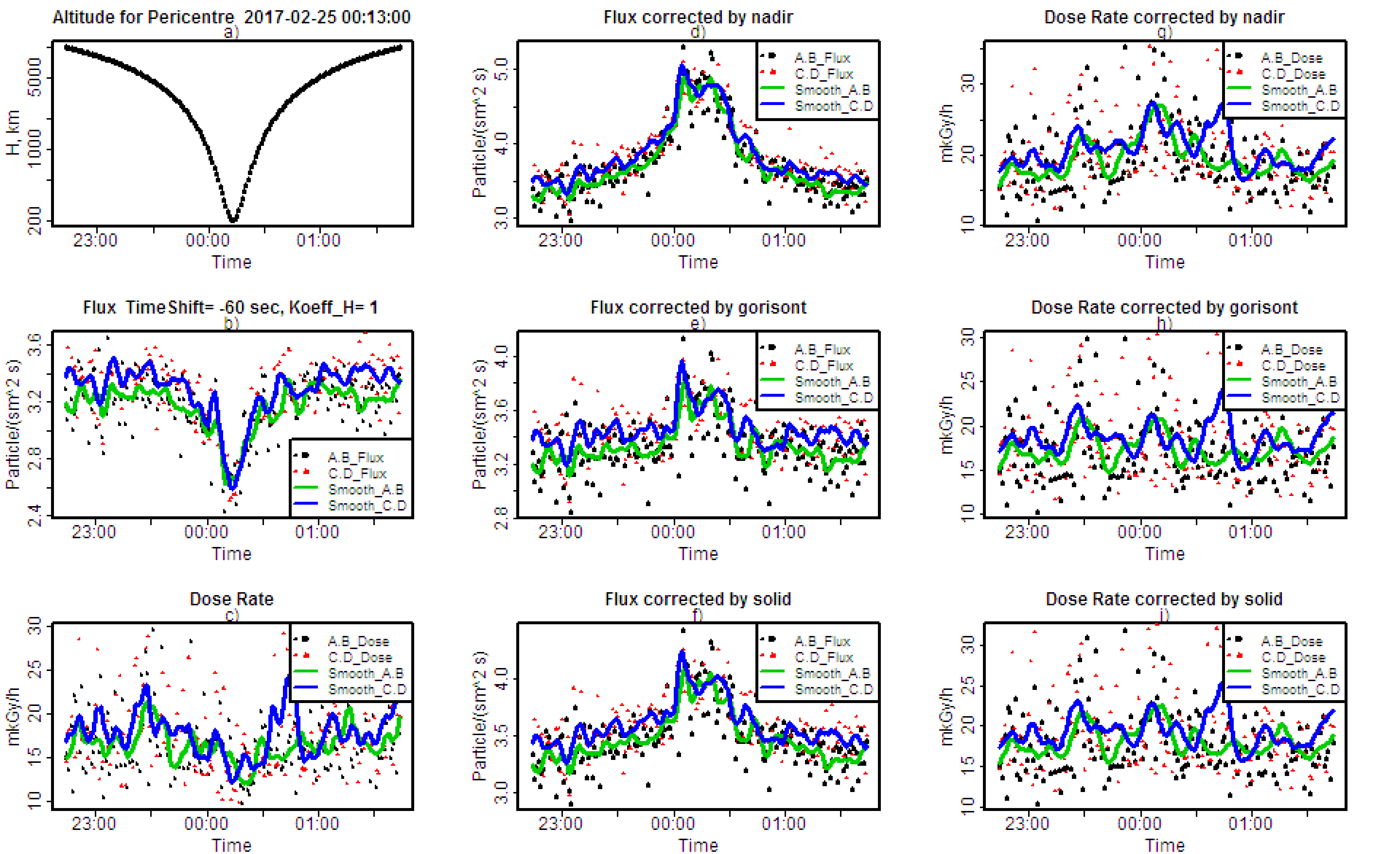


Corrected flux values are overestimated systematically.

Why? - Our opinion is that this surplus is caused by albedo flux from Mars

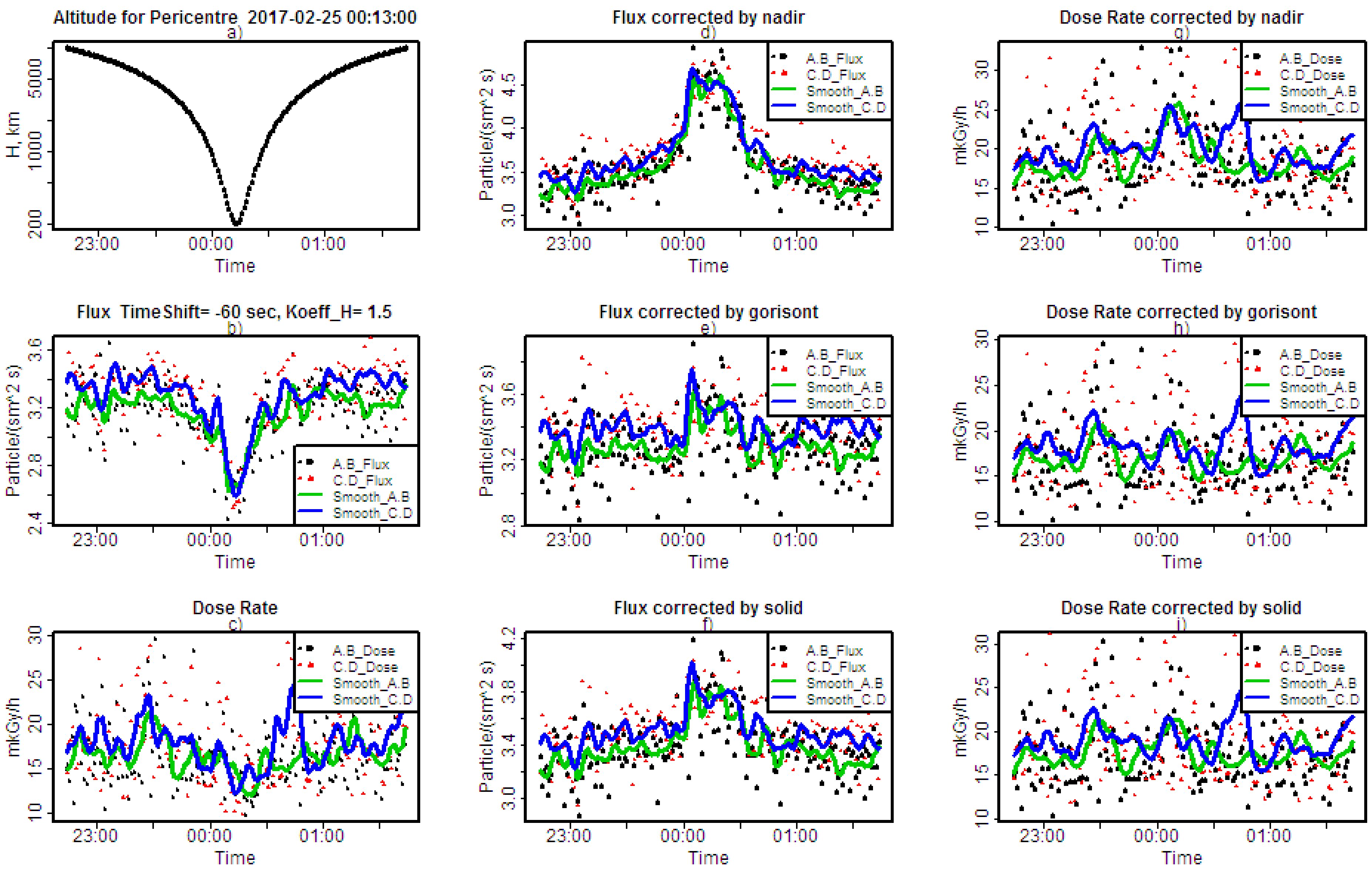
- How to account for the albedo contribution when we estimate the deep space flux using orbital data? – Our suggestions is to fit curves replacing altitude with altitude multiplied by the allowance factor when **η** value is calculated

Correction of flux and dose rate for altitude multiplication by 1.0 2017-02-25

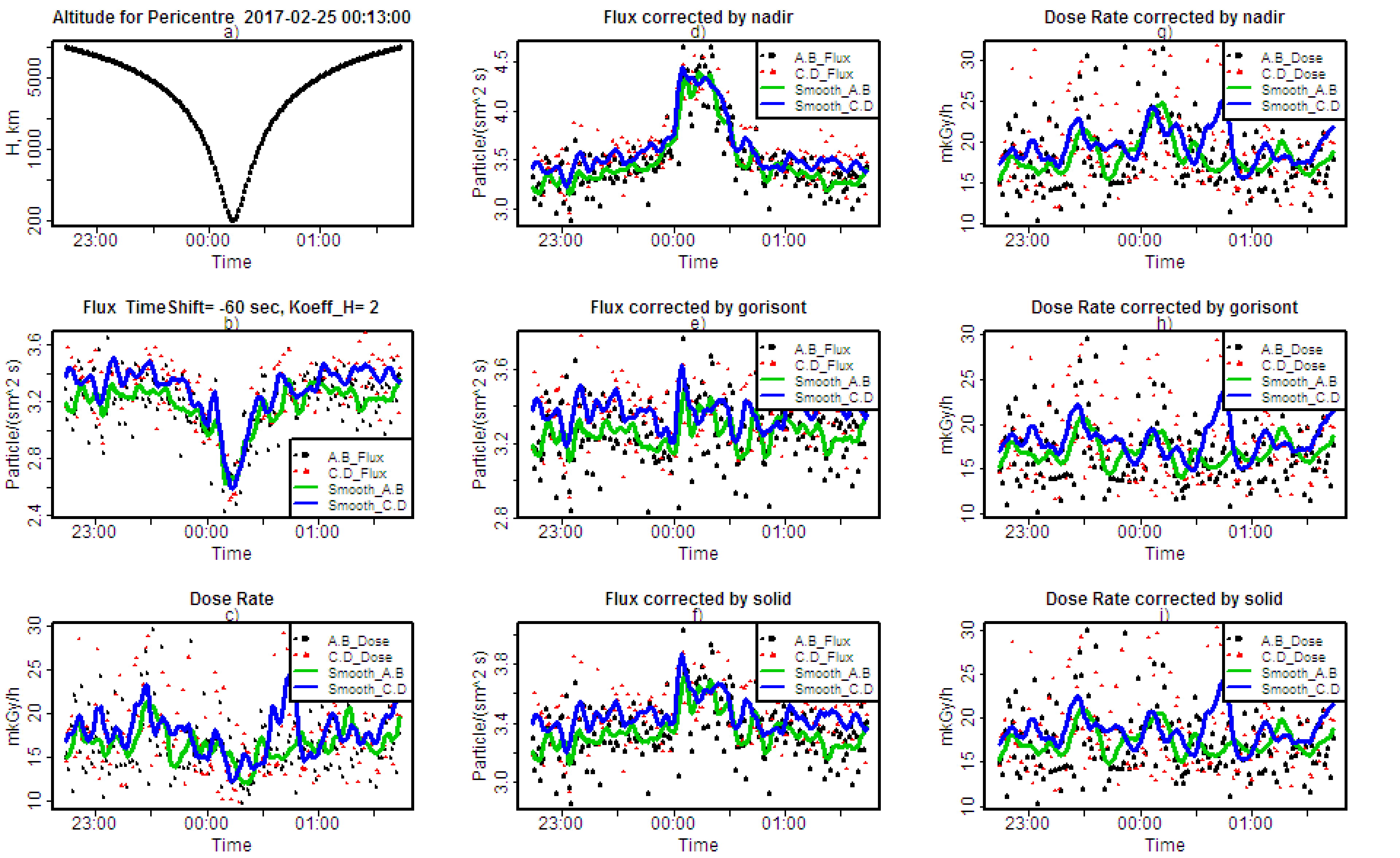


Correction of flux and dose rate for altitude multiplication by 1.5

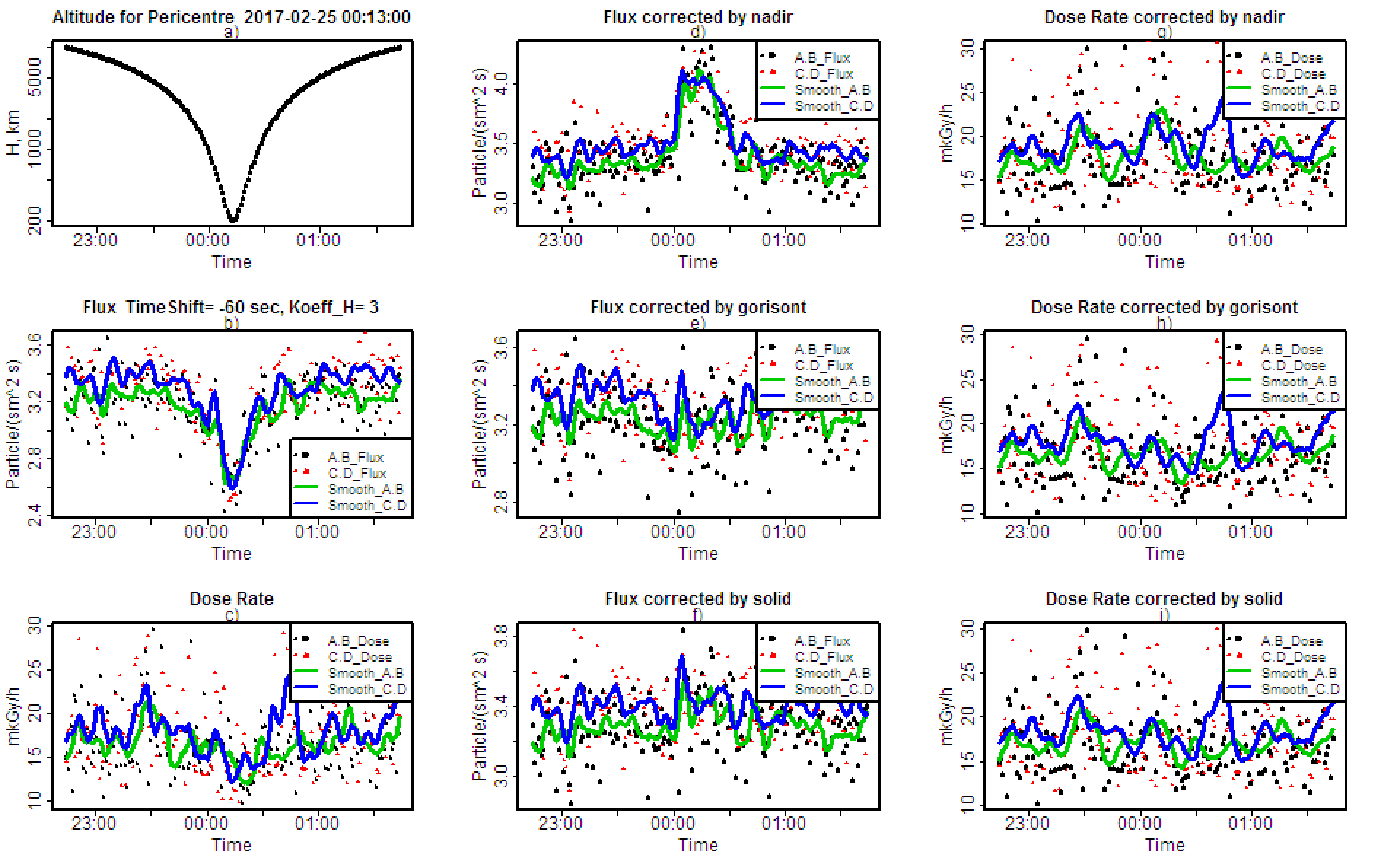
2017-02-25



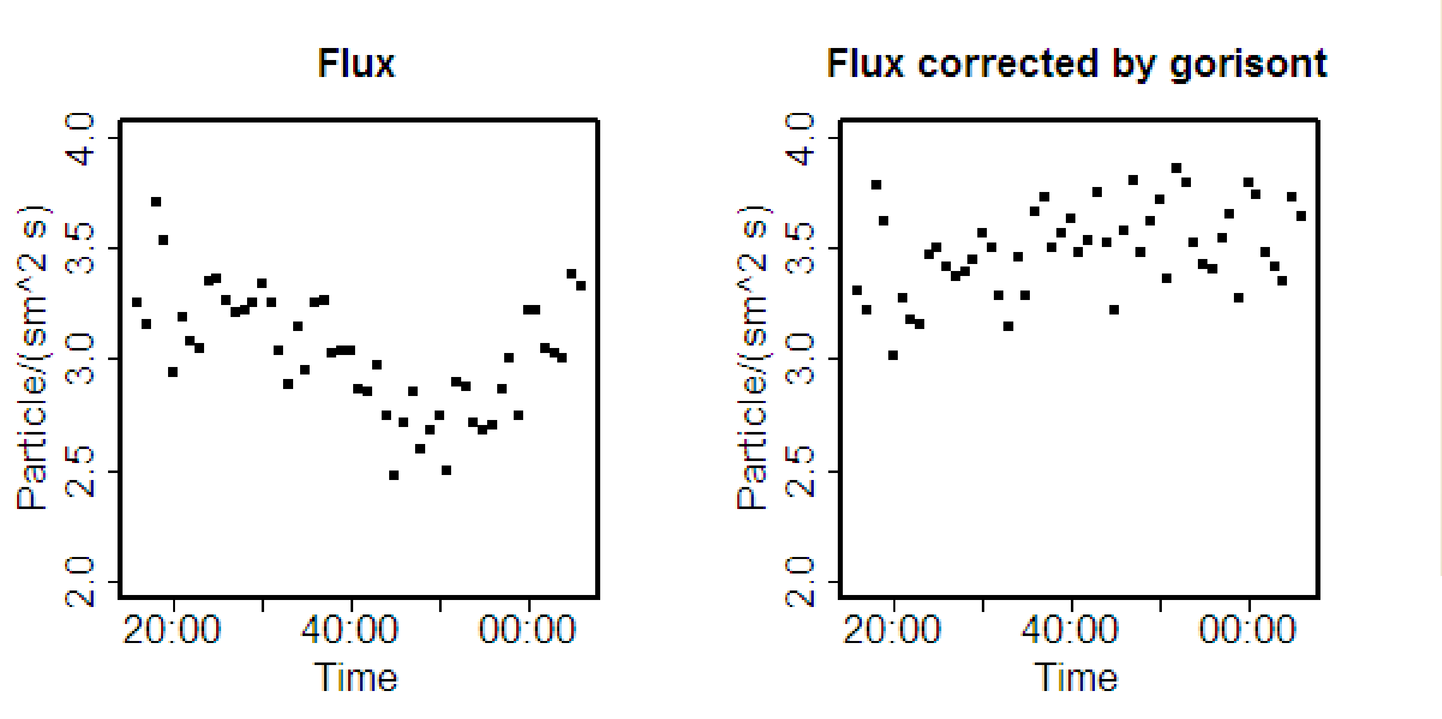
Correction of flux and dose rate for altitude multiplication by 2.0 2017-02-25



Correction of flux and dose rate for altitude multiplication by 3.0
2017-02-25

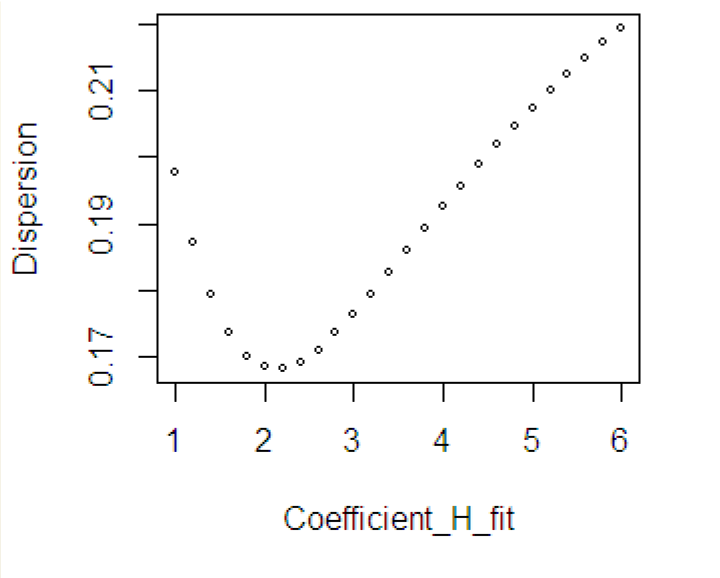


How to choose the multiplication factor?

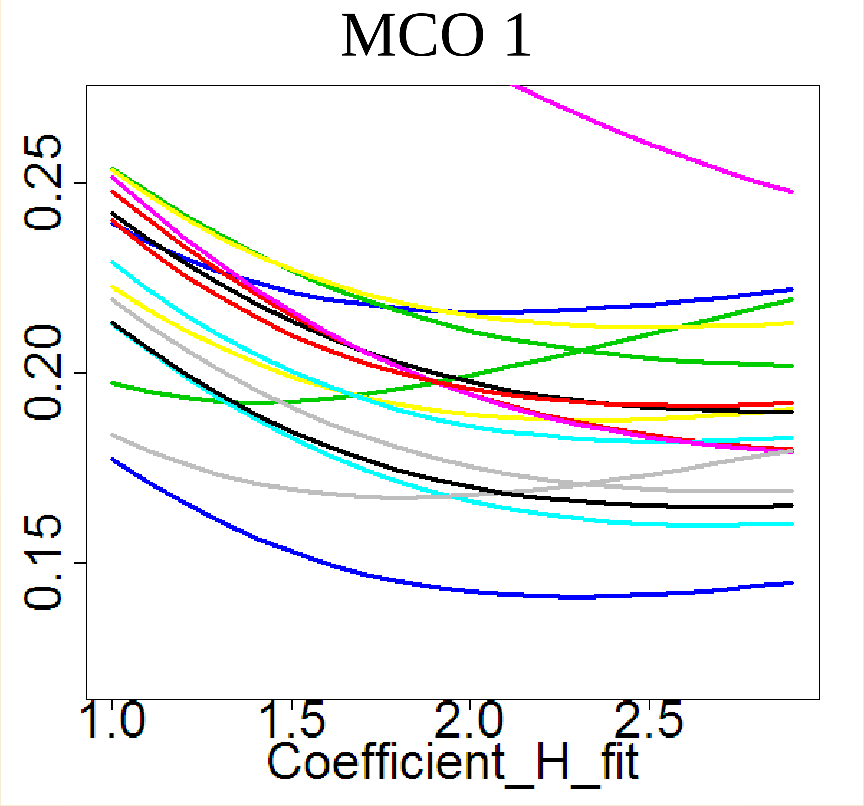


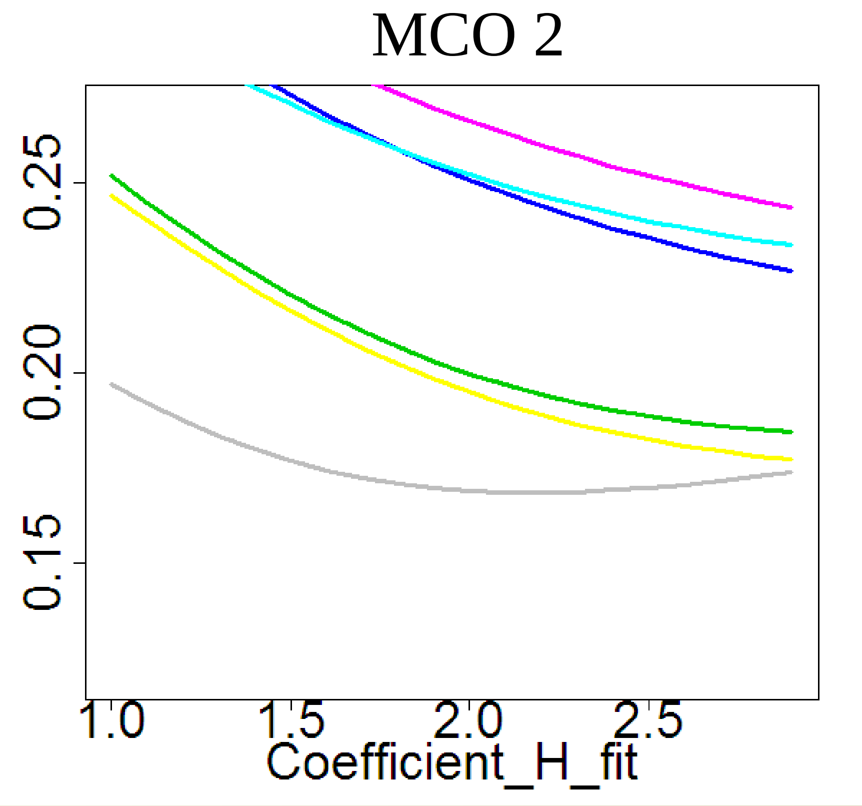
We need some formal metewand to fit the multiplication factor.
We had used as such metewand a scatter of points around the mean value described by dispersion.

For the first cause the dispersion value is 0.27, for the second one - 0.20. (Pericenter crossing Nov. 9 2016)



Dependence of the dispersion value on the fitting coefficient of the altitude correction for the flux points

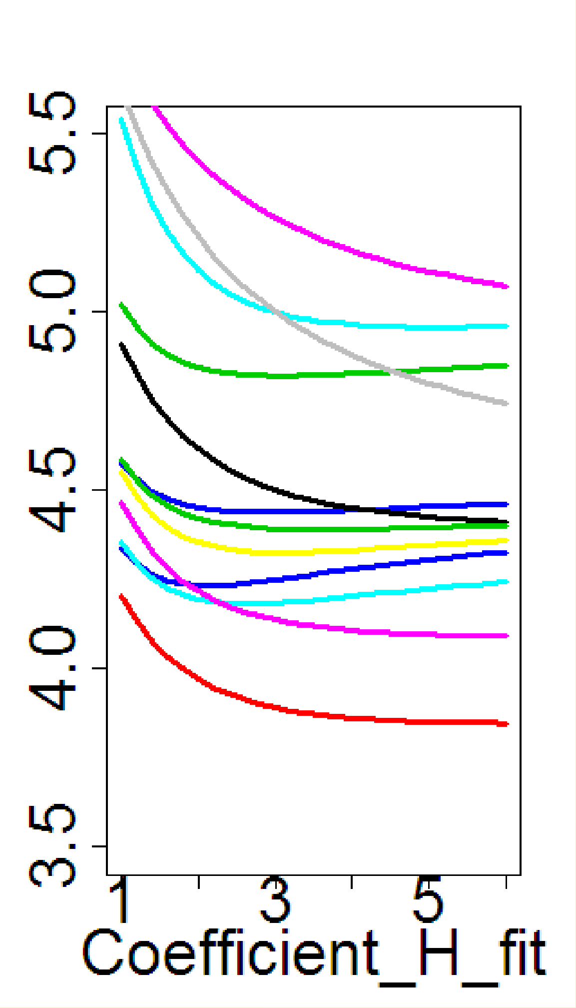




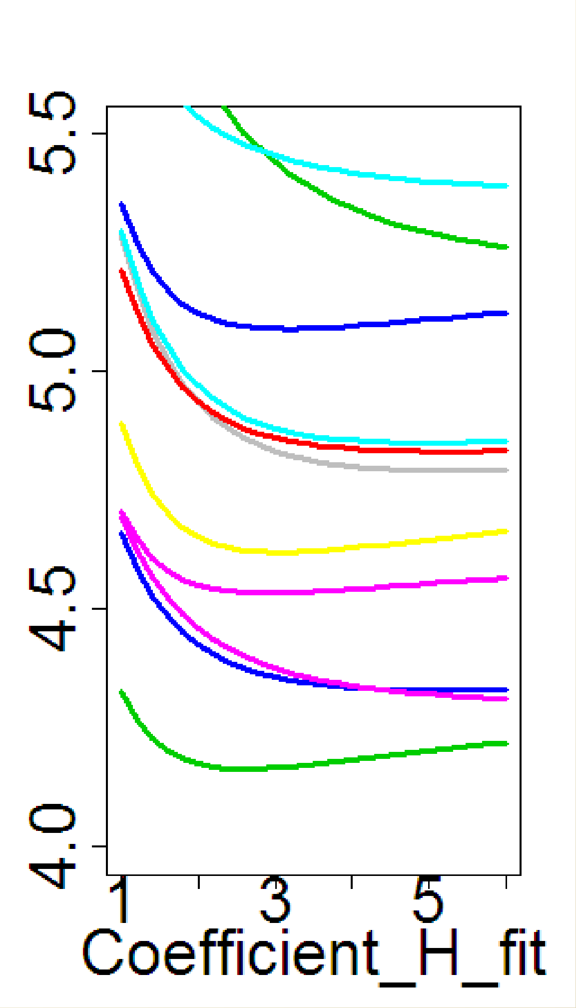
It seems that 2 - 2.5 value for coefficient of altitude correction does not contradict to these curves.

Dependence of the dispersion value on the fitting coefficient of the altitude correction for dose rate points

For A&B detectors

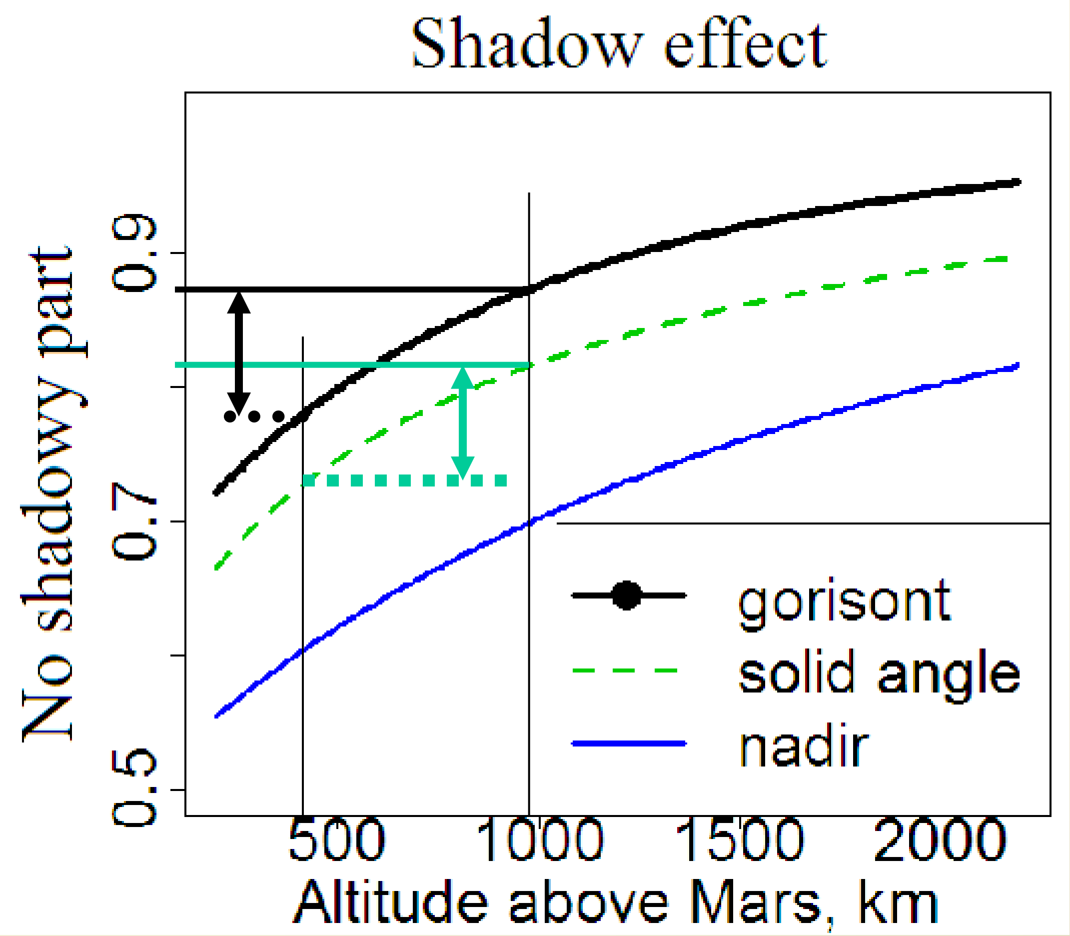


For C&D detectors



We choose 2.5 as the value for coefficient of altitude correction.

Estimation of the effective shadow coefficient for low circular Mars orbit.

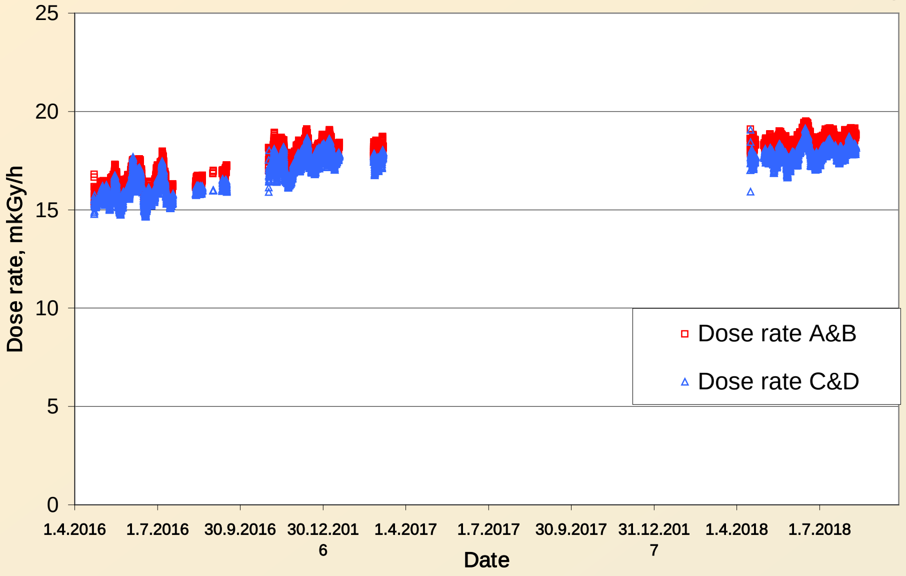


For a circular orbit at an altitude of 390 – 430 km taking into account the selected correction factor, the effective height is about 1000 km.

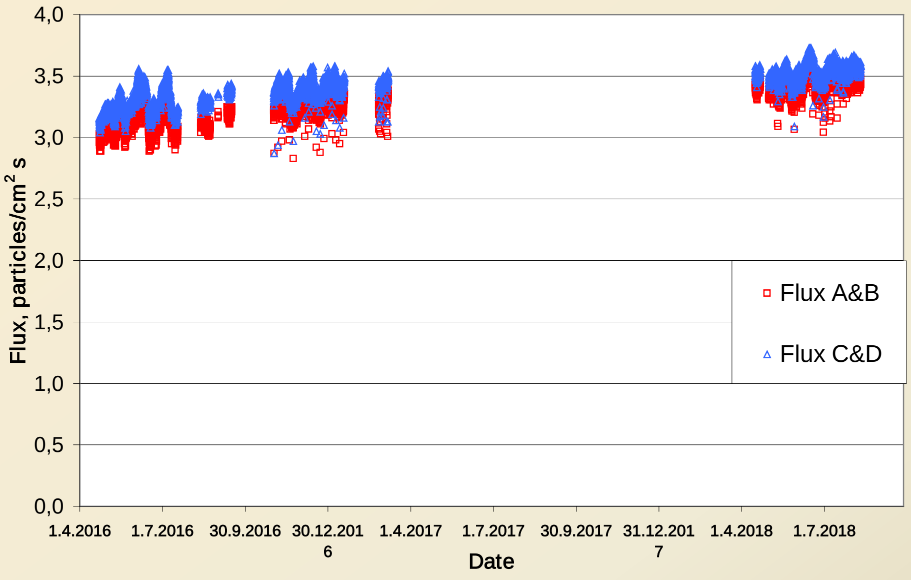
We obtained the parameter η estimations of 0.88 and 0.82 for flux and dose rate respectively.

The difference in the fraction of unshaded flux for the actual and effective height gives estimates of the albedo radiation.

The fluxes and dose rates for deep space estimated by Liulin-MO date

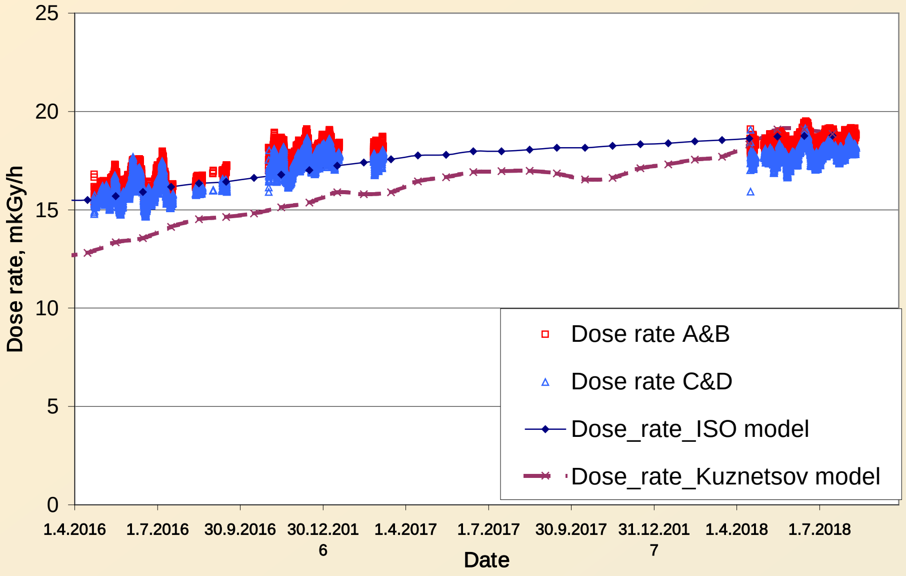


The dose rate for deep space. Values for 2018 divided by a factor of 0.82

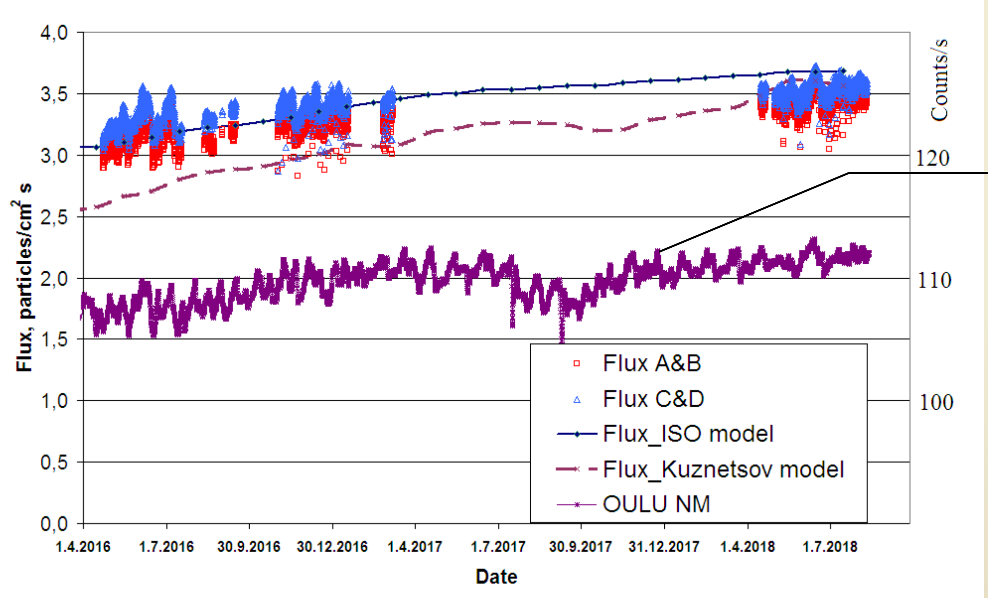


The flux for deep space. Values for 2018 divided by a factor of 0.88

Comparison of measured and calculated fluxes and dose rates

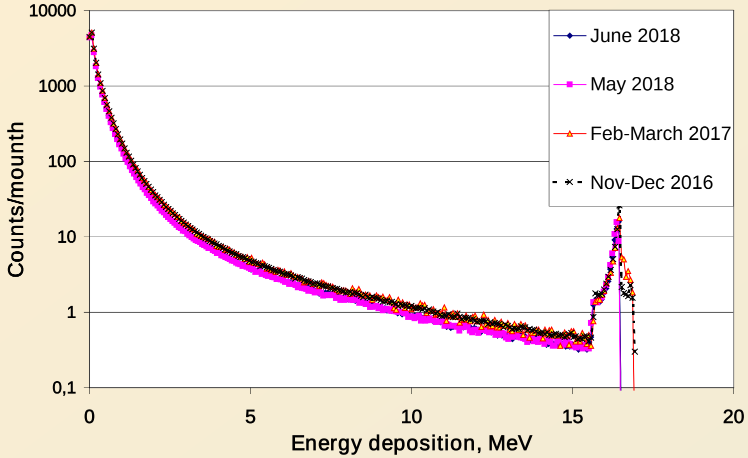
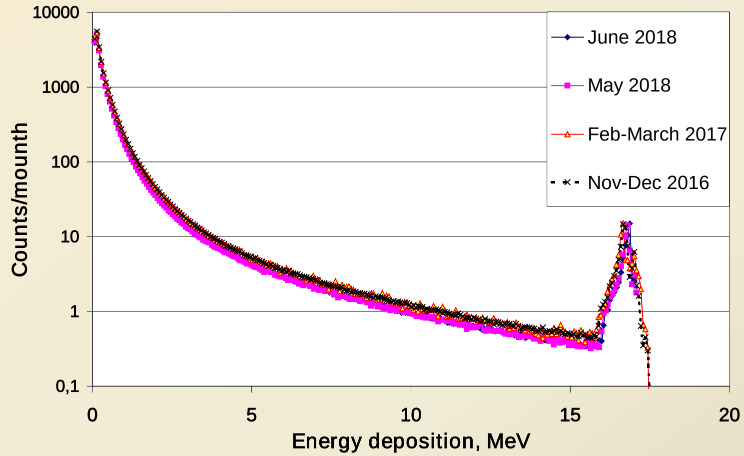
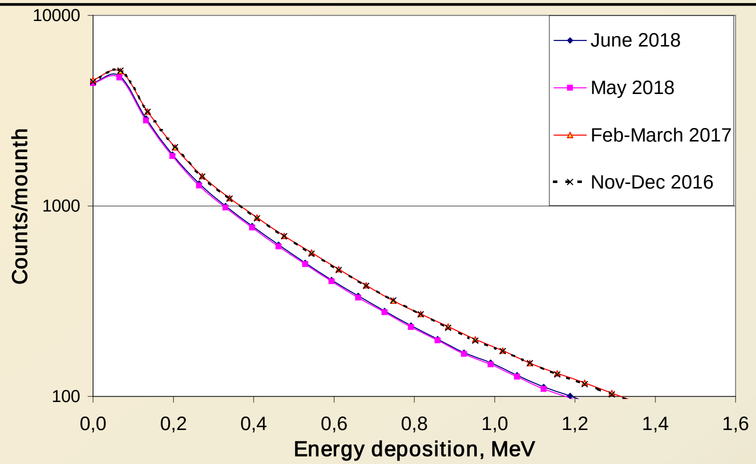
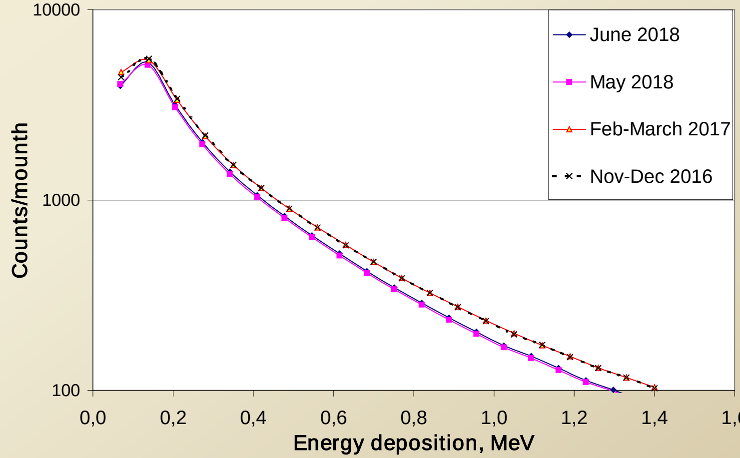


The corrected data were compared with the calculated estimates of the flux and dose rate based on the ISO and SINP-2017 (Kuznetsov) models (Calculations were made for an aluminum shielding 10 g/cm^2).

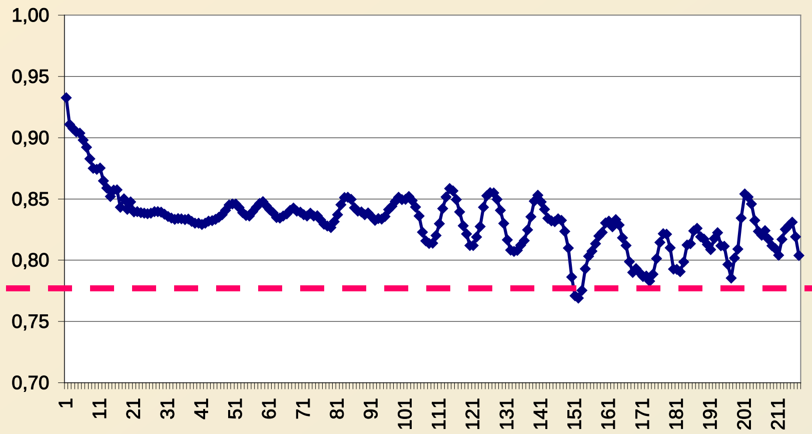
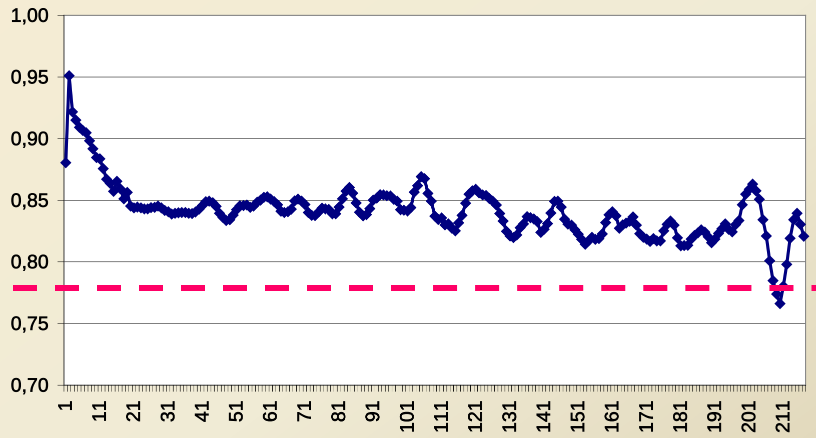


The OULU neutron monitor count rate

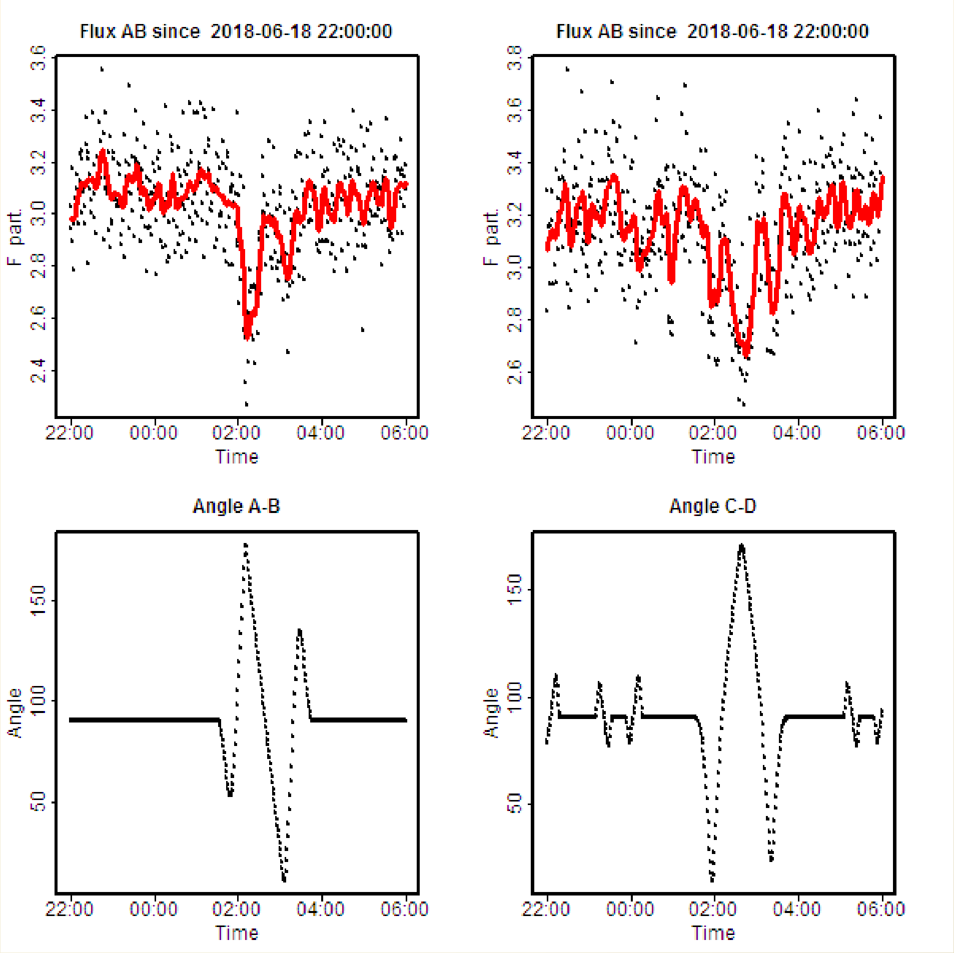
Spectra comparison for November-December 2016 and May 2018.

Detector B	Detector D
	
	

Ratio of counts in energy deposition spectra channels between November-December 2016 and May 2018

Detector B	Detector D
	

Short decreasing of fluxes on Mars' circular orbit

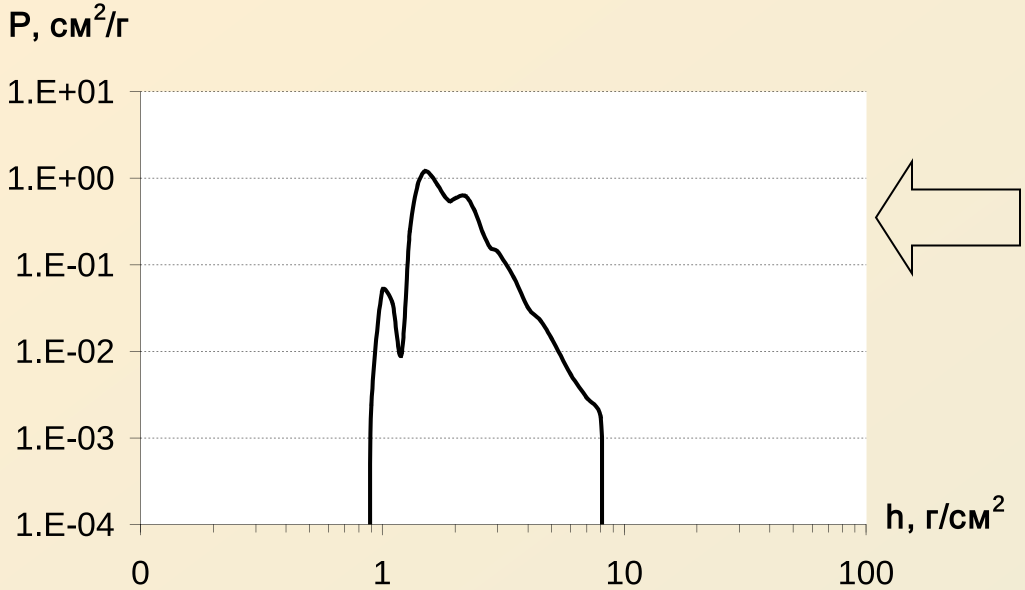


Conclusion

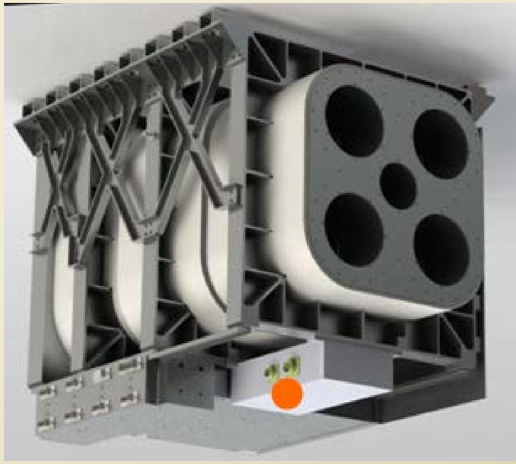
- Method of flux and dose rate data conversion from a low circular orbit around Mars to values in unshadowed Mars space is developed.
- The comparison between the data obtained by this method and the results of calculations based on the ISO and SINP-2017 (Kuznetsov) GCR models gives a satisfactory agreement of the calculated estimates with the measurements.
- The presence of an additional flux of particles at low altitudes near Mars, which is interpreted as albedo radiation, is noted. The preliminary assessment of albedo particles flux is about 10%.

Thank you for your attention!

Shielding function for point located between the detectors "Liulin-MO"



Shielding with elements of the "Liulin-MO“ dosimeter



Shielding with "Liulin-MO" and "FREND" elements

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:

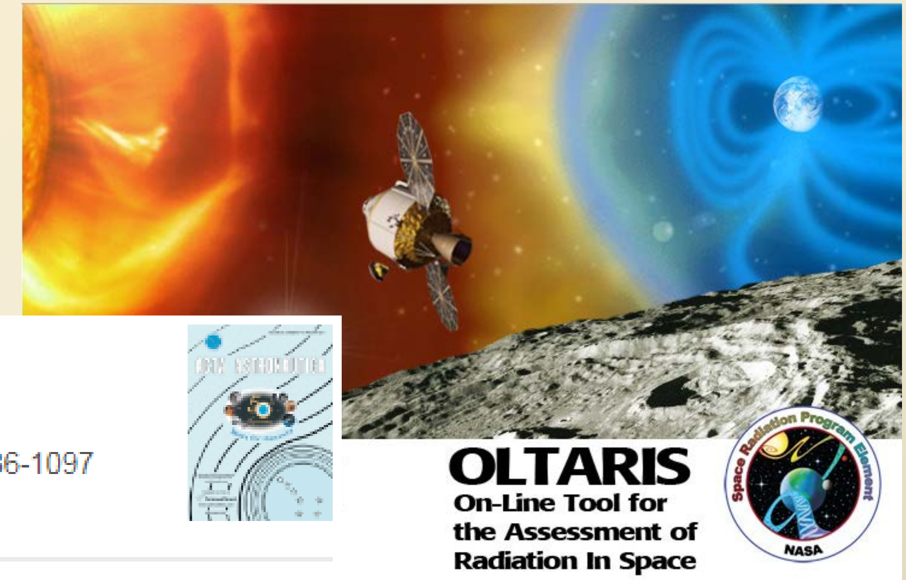
$$R(E) = \int_0^E \frac{dE'}{S(E')}$$

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/gsubs/23483

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




ELSEVIER
Acta Astronautica
Volume 68, Issues 7–8, April–May 2011, Pages 1086-1097

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]

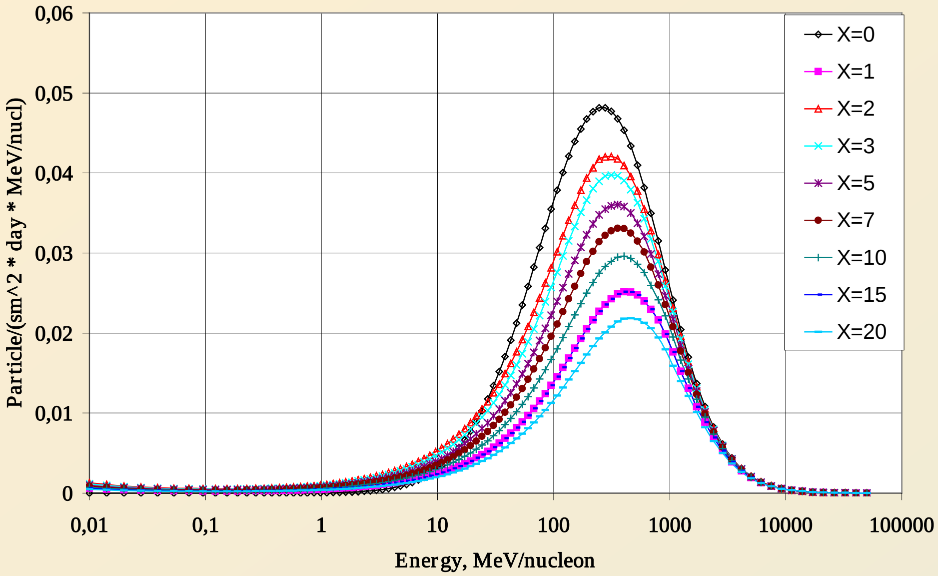
⊞ Show more

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

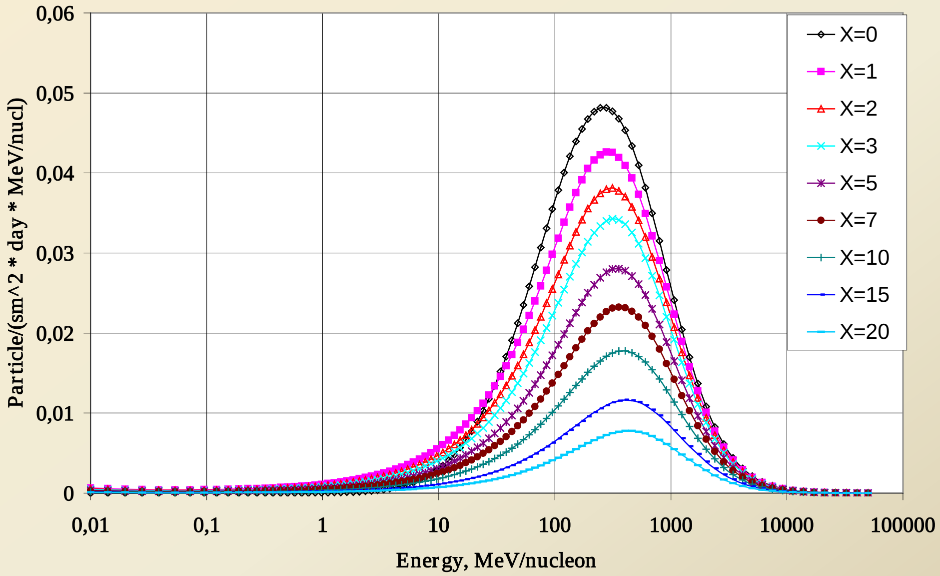
The OLTARIS tool was used also for flux and dose calculation with NASA HZETRN particle transport code

Calculation Fe-56 spectra beyond shielding

Calculation Fe-56 spectra with R(E) relation



Calculation Fe-56 spectra with NASA Oltaris site



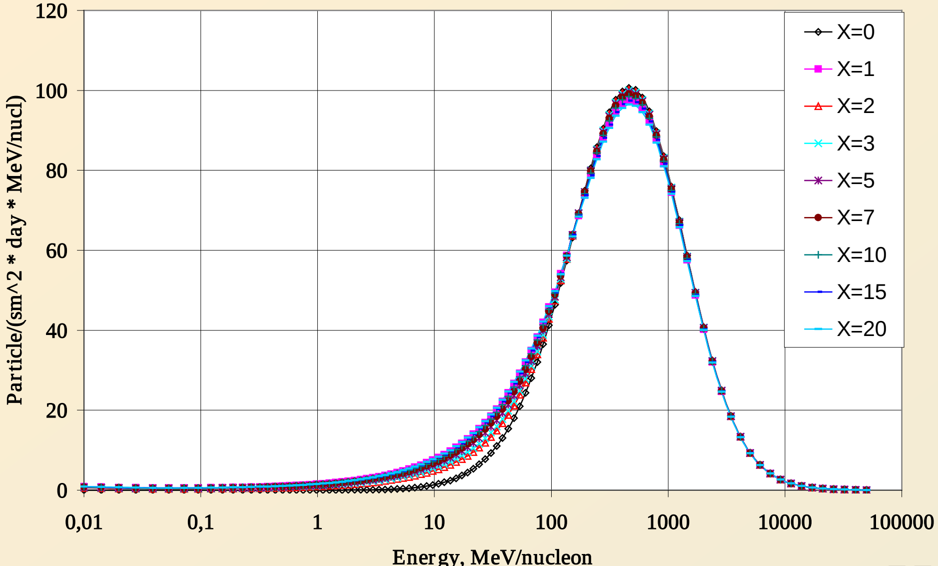
The both case were used the same ISO 15390 spectra for March 2013 year.

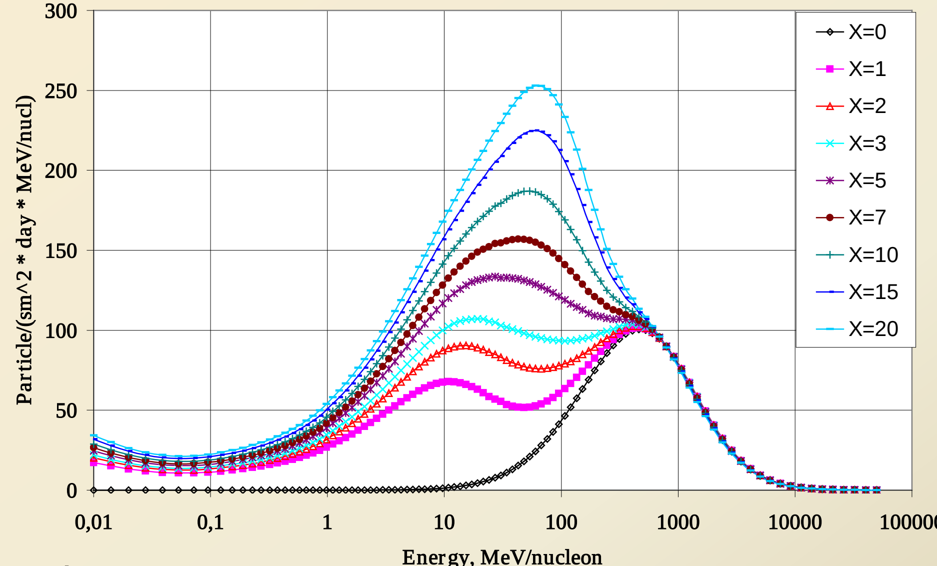
Calculation proton and He-4 spectra beyond shielding

Calculation with R(E) relation

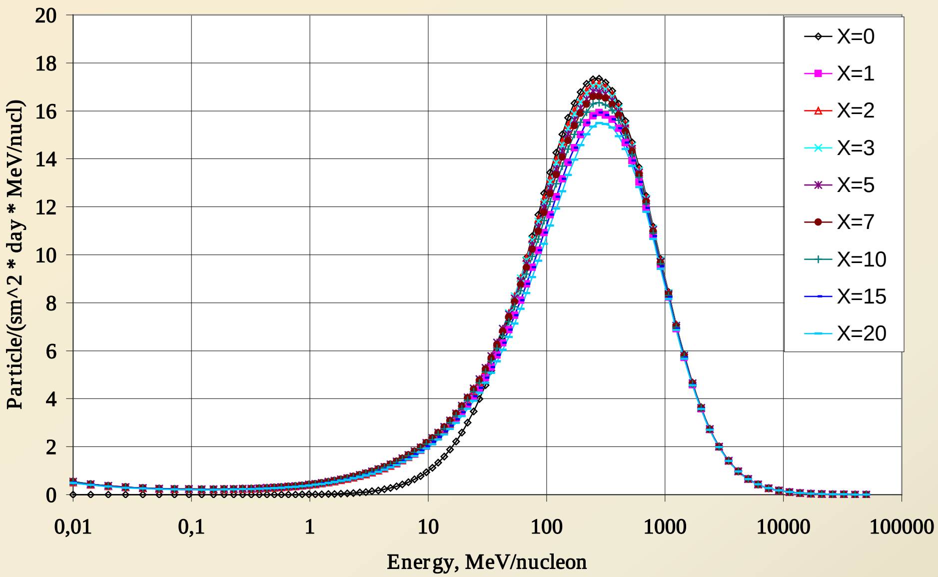
Calculation with NASA Oltaris site

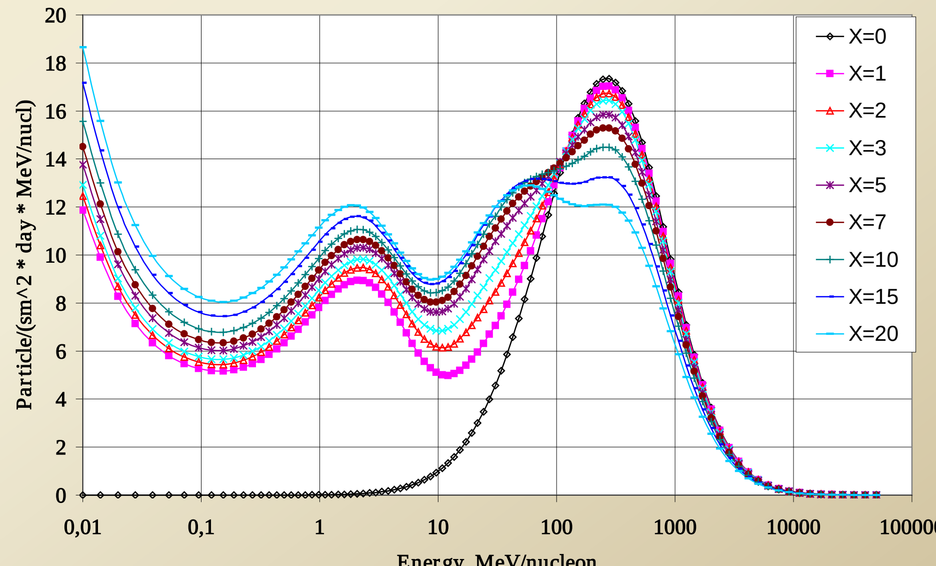
Protons



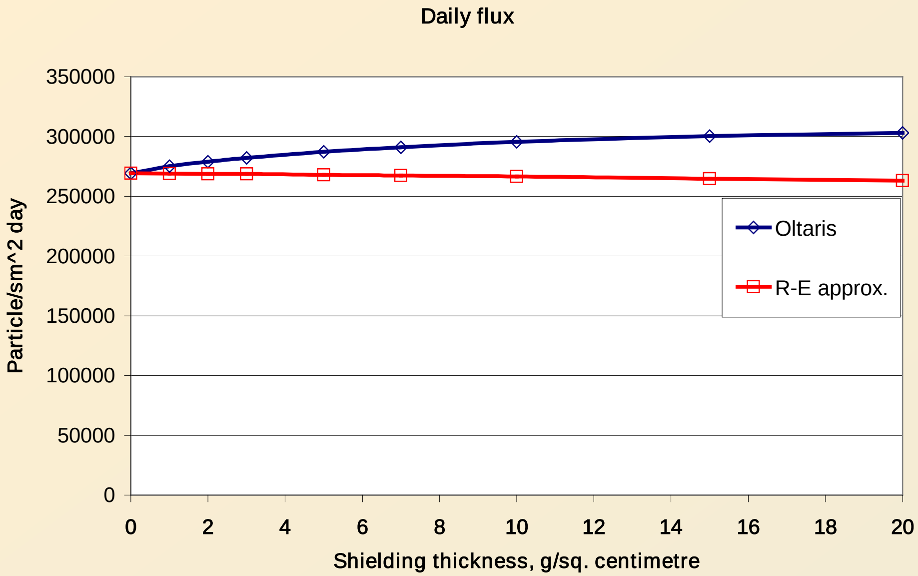


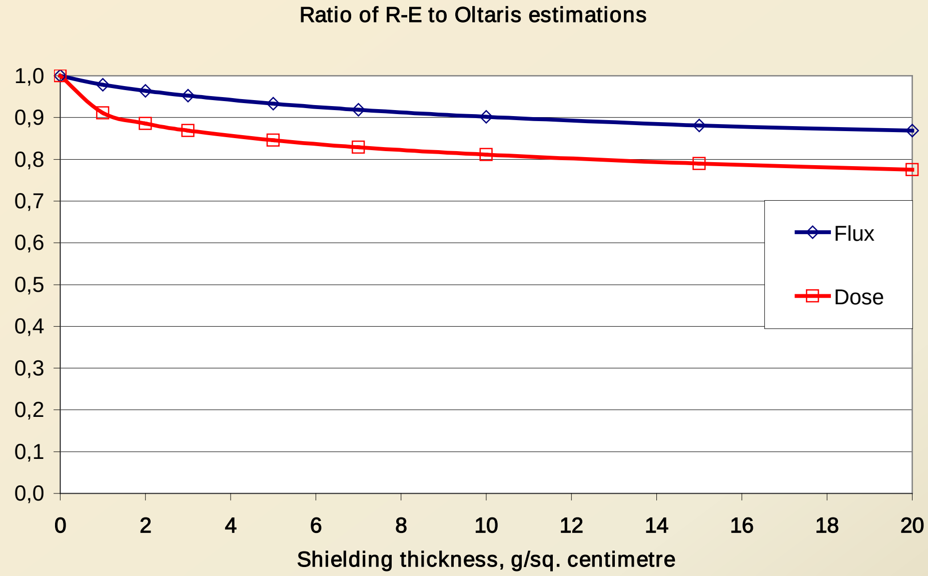
He-4

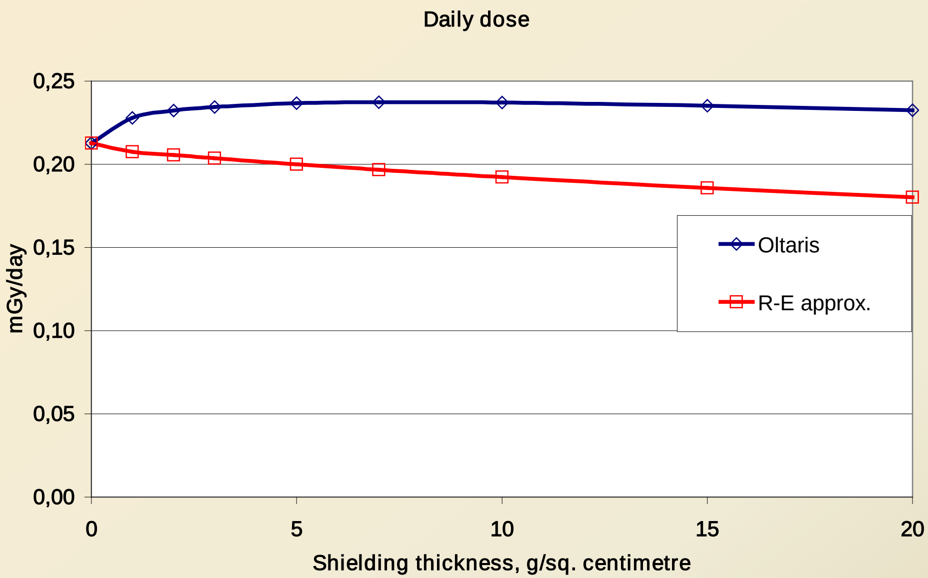


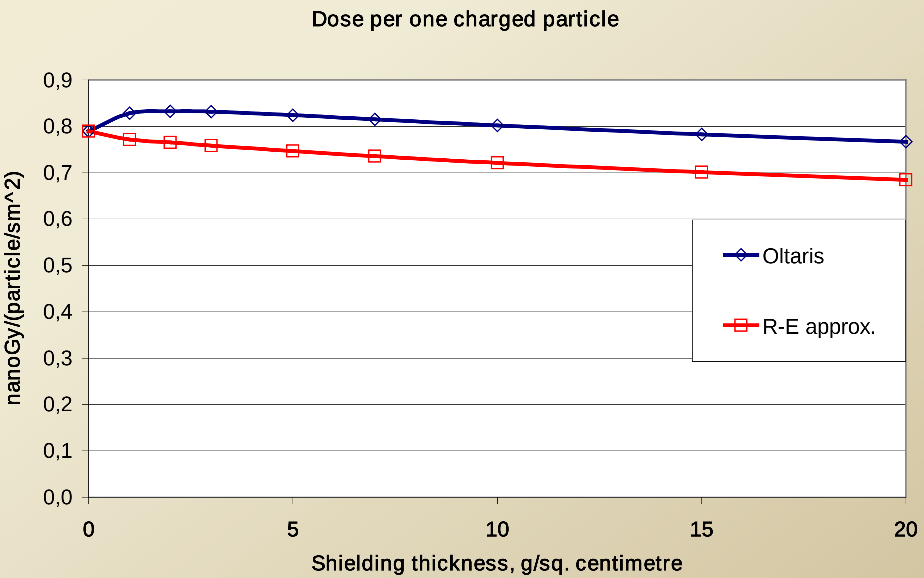


Comparison of R-E approximation and Oltaris results









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.

ISO 15390 galactic cosmic ray model brief description

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

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

$$R_0\left\{\overline{W}\left[t-\Delta t(n,R,t)\right]\right\}=0.37+3\times10^{-4}\times W^{1.45}\left[t-\Delta t(n,R,t)\right]$$

where $\Delta_i\left(R,t\right)$ 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, $\Delta T\left(n,R,t\right)$, of GCR flux variations relative to solar activity variations

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

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)