Altitudinal Distribution of the Ionizing Radiation Exposure between the Earth Surface and Moon orbit

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Outlook

- Introduction
- Unique single instrument (R3D-B2) measurements of the space radiation on the ground, on aircraft and in space between 24 May and 3 June 2005
- Groundbased dada
- Aircraft and balloon data
- ISS data
- Chandrayaan-1 data
- The space exposure altitudinal profile from the Earth surface to the free space
- Future space experiments
- Conclusions

Introduction

Since 2000 scientists from the former Solar-Terrestrial Influences Institute at the Bulgarian Academy of Sciences contributed Bulgarian-build instruments to a number of experiments for measurements of the incoming space radiation fluxes and dose rates from the Earth surface up to the free space and 100 km Moon orbit.

The purpose of this paper is to summarize the data obtained by different instruments on the ground and in aircraft, balloon, rocket, and on spacecraft.

Special attendance was given to the altitudinal dependences obtained at the ISS. Dose rate, flux and specific dose (SD) data are analyzed, compared and plotted.

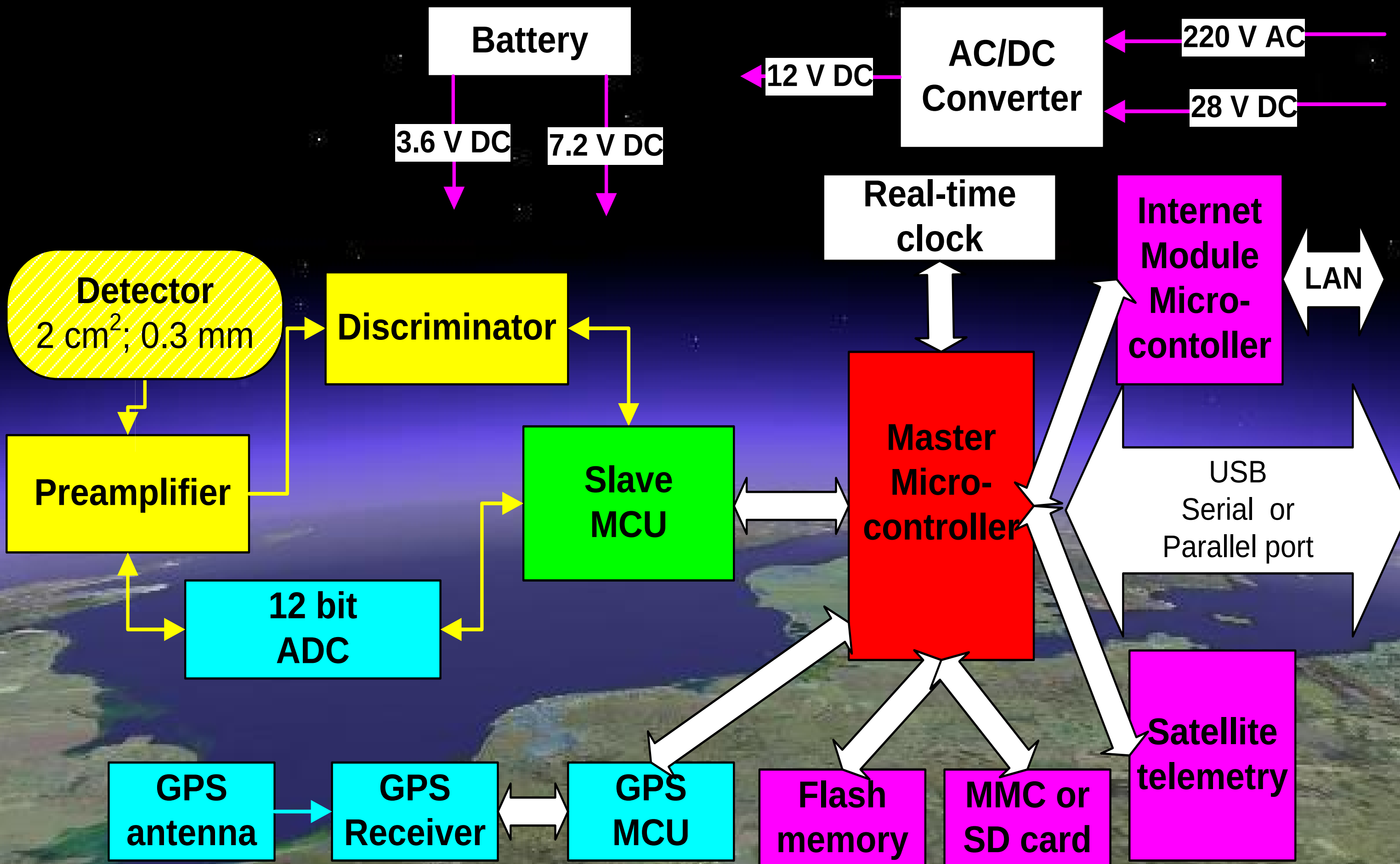
The result is a unified picture how the different ionizing radiation sources contribute and build the space exposure altitudinal profile from the Earth surface to the free space*.

*Dachev, T.P., Profile of the ionizing radiation exposure between the Earth surface and free space, Journal of Atmospheric and Solar-Terrestrial Physics, 102, September 2013, 148–156, http://dx.doi.org/10.1016/j.jastp.2013.05.015, 2013.

SRTI-BAS space radiation measurements experiments since 2000

1. Liulin-MDU1, June 14, 2000, ESA balloon flight up to 33 km over Gap, France;
2. Liulin-MDU5, more than 10000 hours from 2001 till 2009 on Czech airlines aircrafts;
3. Liulin-E094, May-August 2001, ESA-NASA exp. on the International space station (ISS);
4. 2 Liulin-MDU, June 2001, NASA ER-2 flights at 20 km altitude in USA;
5. R3D-B1, October 2002, ESA Foton M1 satellite – unsuccessful launch;
6. R3D-B2, 1-12 юни 2005, ESA Foton M2 satellite;
7. 3 Liulin-MDU, June 11, 2005, NASA balloon flight up to 40 km over New Mexico, USA;
8. Liulin-ISS, ROSCOSMOS, launched to ISS in September 2005 (active now);
9. Liulin-Moussala, since June 2006 working in Internet (active now);
10. Liulin-5, ROSCOSMOS, since June 28, 2007 working at ISS (active now);
11. R3D-B3, September 14-26 2007, ESA Foton M3 satellite;
12. Liulin-6S, since October 2007 working at Jungfrau peak in Internet (active now);
13. Liulin-R, January 31, 2008, ESA rocket experiment up to 380 km from Norway;
14. R3DE, worked at ESA Columbus module at ISS between 17/02/2008 and 01/09/2009;
15. Liulin-6SA, since October 2009 working at Lomnitski stit peak in Internet (active now);
16. RADOM, worked at Chandrayyan-1 satellite around Moon between 22/10/2008 and 29/08/2009;
17. R3DR, worked at ESA EXPOSE-R facility on Russian Zvezda module of ISS between March 2009 and August 2010;
18. Liulin-LS, April 19-May 19 2013, BION-M No1 satellite;
19. РЗД-БЗ, April 19-May 19 2013, BION-M No1 satellite.

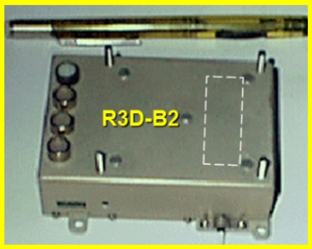
Integrated Block - diagram of the Liulin type devices

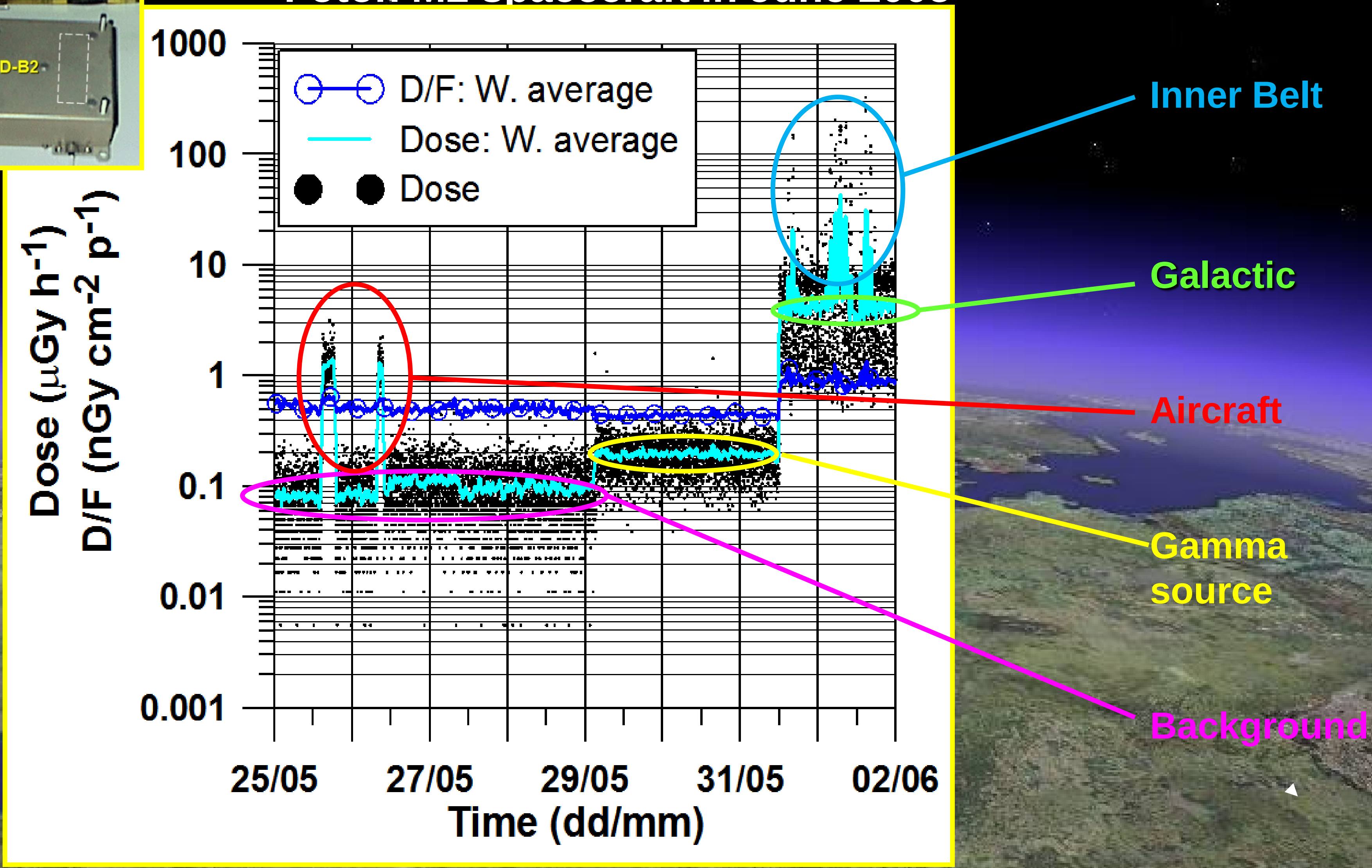


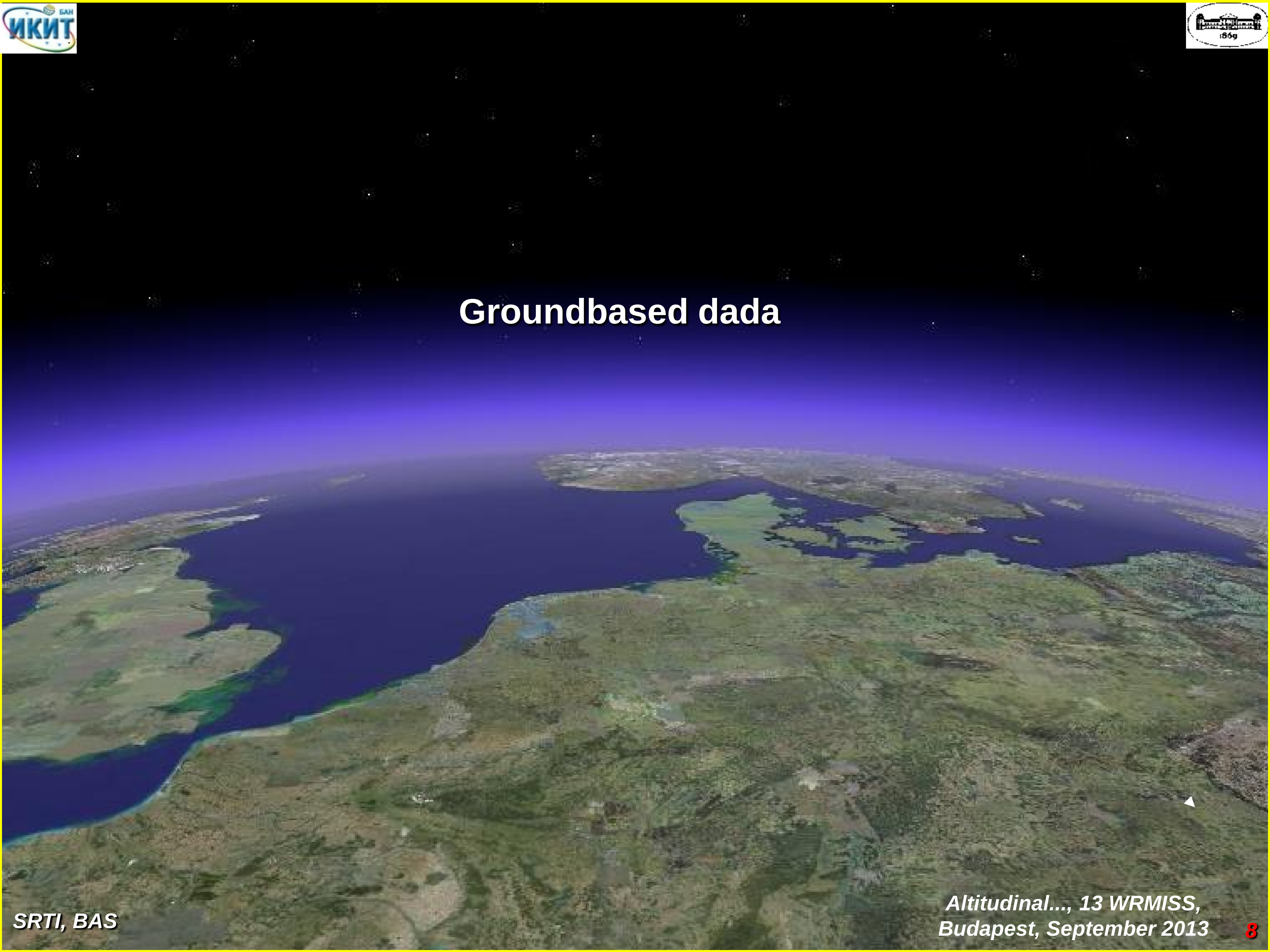
The usage of fast 12 bit ADC allows Liulin devices to analyze each event in the detector and to build and store the energy deposition spectrum for each measurement cycle. The form of the spectrum and specific deposited energy per each event characterize the predominant radiation source as Inner Radiation Belt (IRB (SAA)) protons, Outer Rad. Belt (ORB) electrons and Galactic Cosmic Rays (GCR)

Unique single instrument (R3D-B2) measurements of the space radiation on the ground, on aircraft and in space between 24 May and 3 June 2005

Example of the dose distribution in near Earth radiation environment on the base of R3D-B2 measurements on Foton M2 spacecraft in June 2005

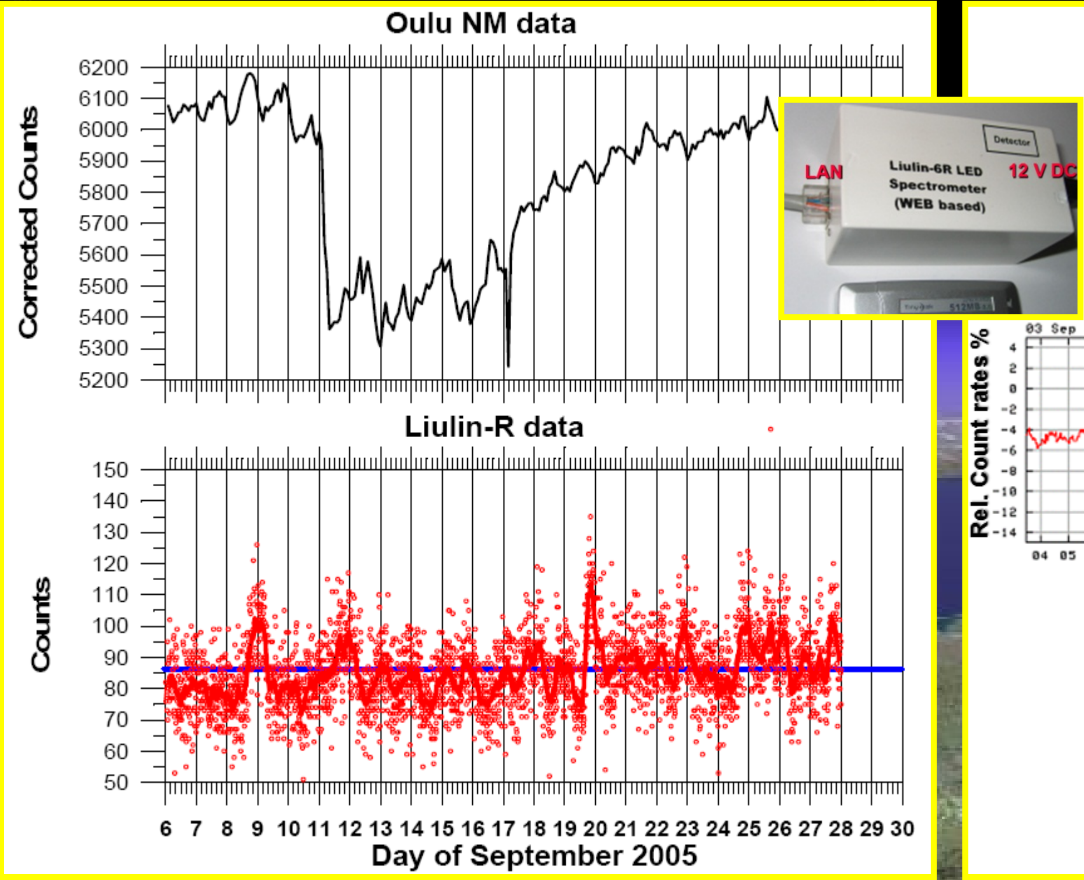


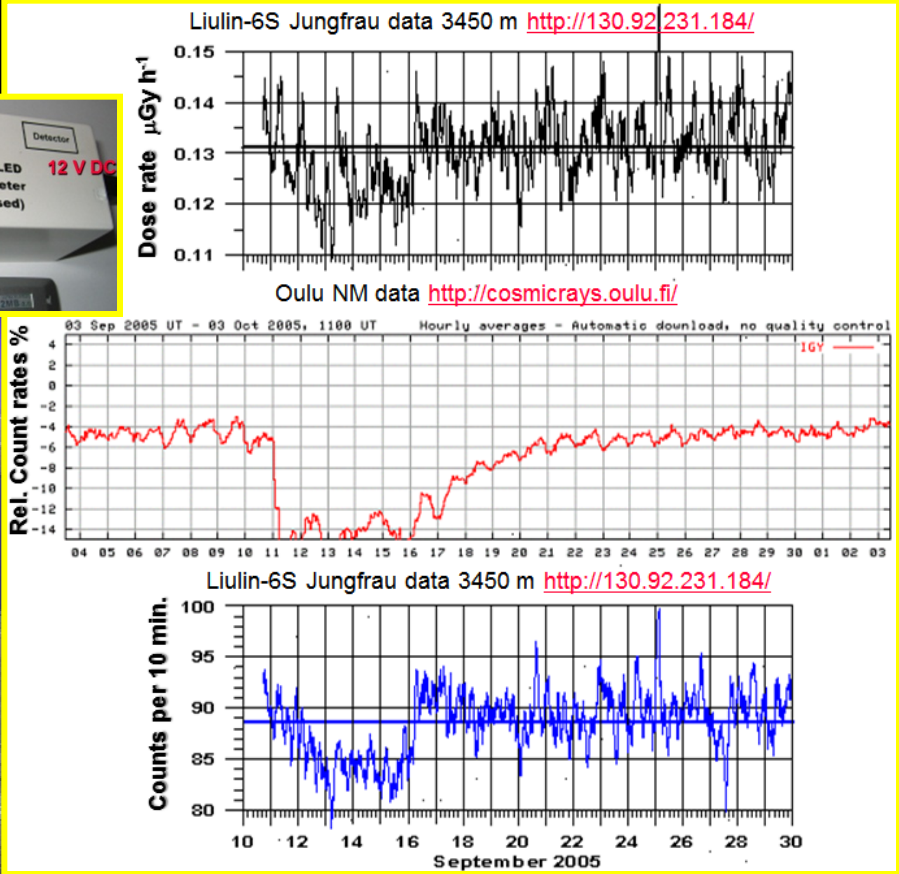




Groundbased dada

Comparison of the variations of the groundbased Jungfrau and ALOMAR dose and count rate with the Oulu NM relative count rate data around the Forbush decrease in September 2005





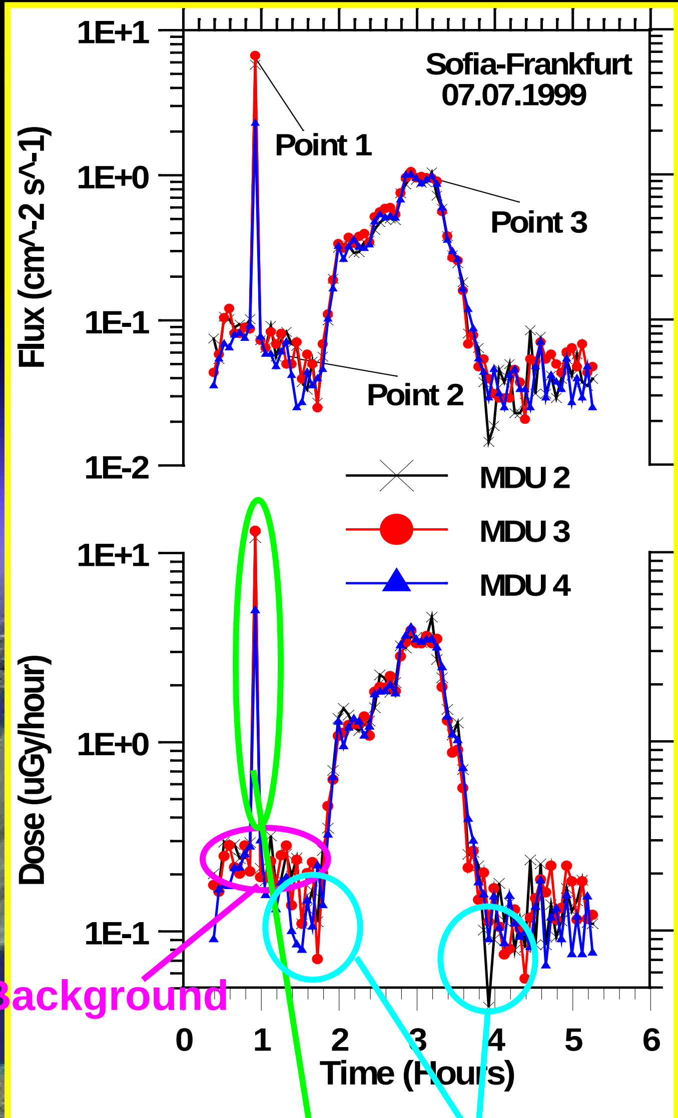
The count rate, which is proportional to the absorbed dose rate at ALOMAR observatory (300 m a s l) do not show decrease during the Forbush event

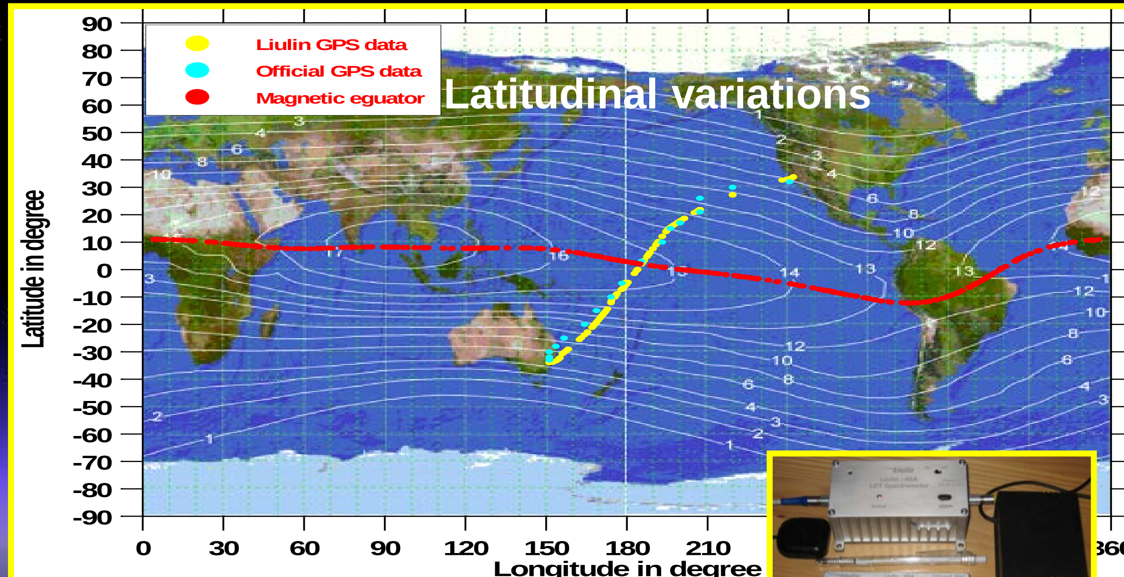
The count rate and the absorbed dose rate at Jungfrau peak (3450 m a s l) do show decrease during the Forbush event

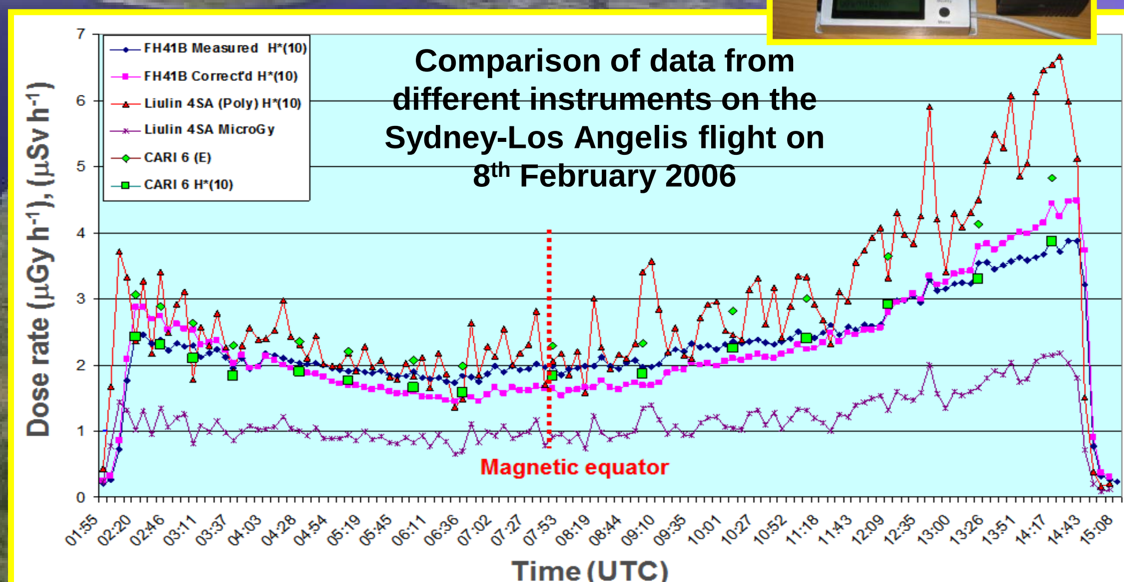
Aircraft and balloon data

Altitudinal and latitudinal variations of the GCR radiation during aircraft flights

Altitudinal variations







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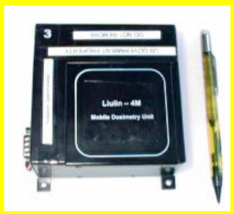
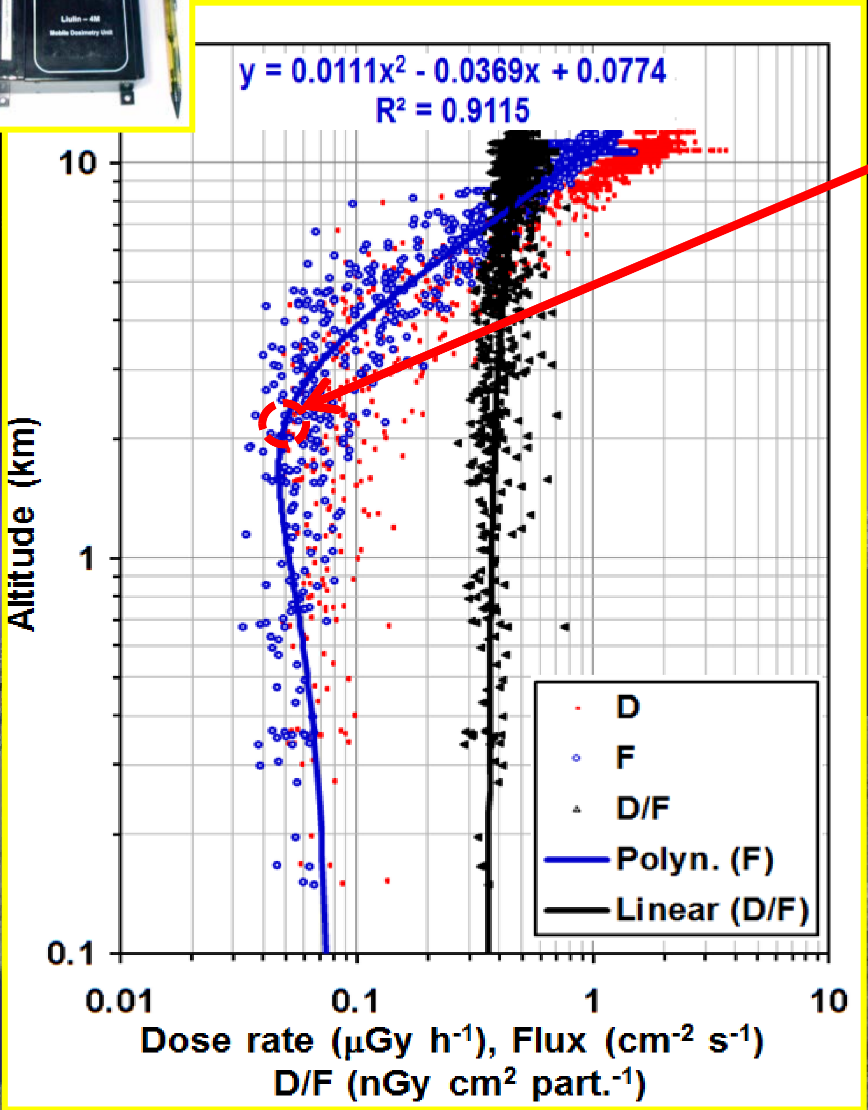
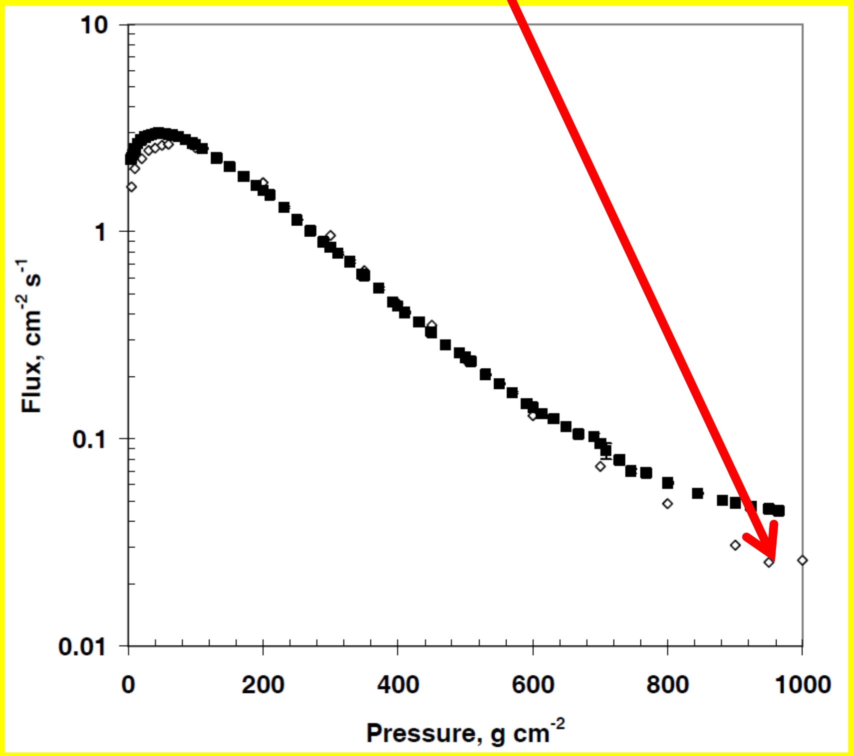
Altitudinal profile obtained by MDU#5 during aircraft flights in period March-May 2001



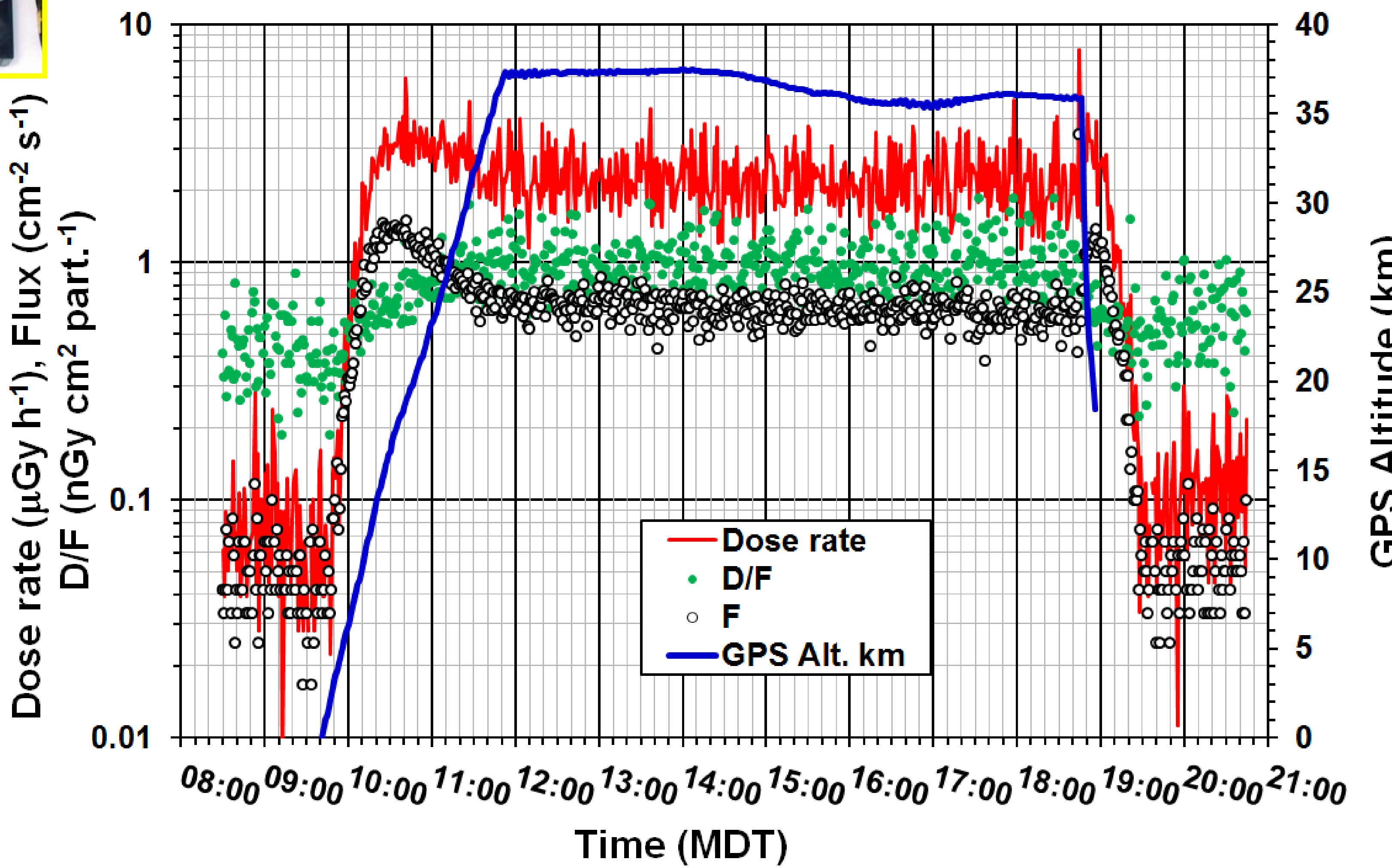


The observed by us flux minimum is 0.046749 cm^{-2} s^{-1} at 1.6 km, while the the predicted by the GEANT-4 model is 0.025 cm^{-2} s^{-1}. From other hand the measured average value for 1976 by (Bazilevskaya et al., 2009) is 0.052 cm^{-2} s^{-1}.



Bazilevskaya, G.A., et al., http://icrc2009.uni.lodz.pl/proc/pdf/icrc0228.pdf

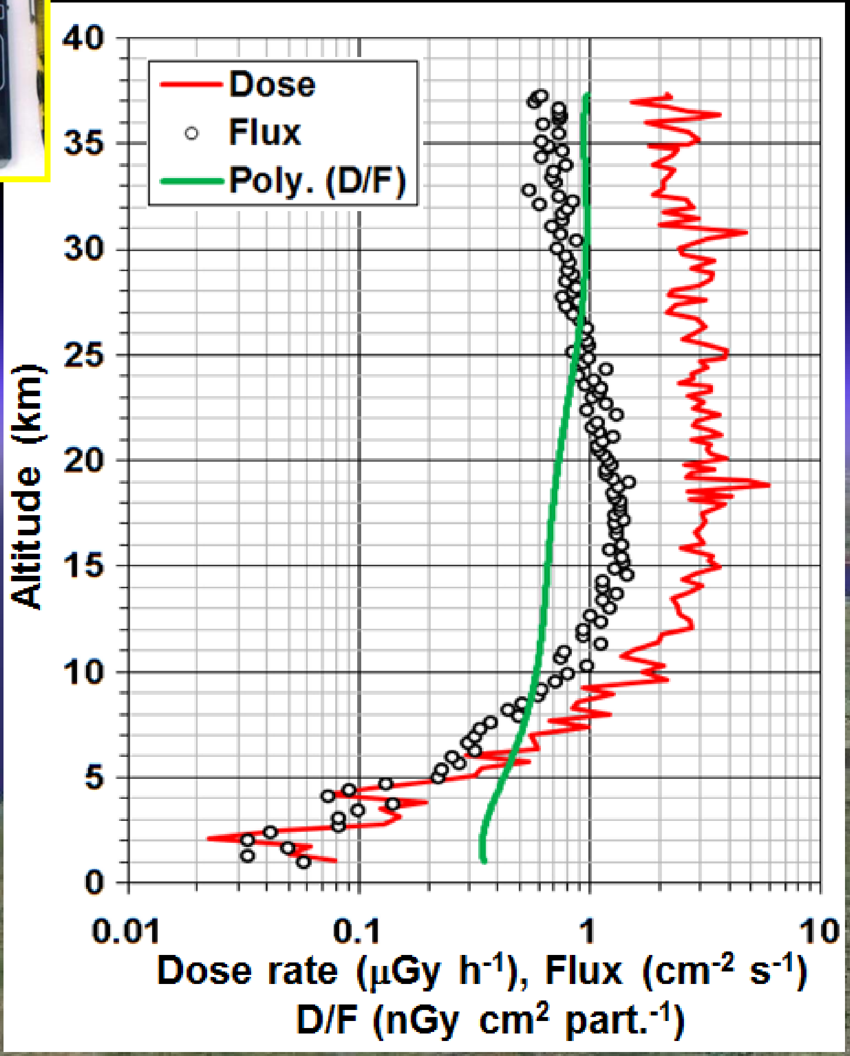
Dose rate, flux and dose to flux ratio (D/F) profiles measured by Liulin-4U MDU#2 during the NASA DSTB Certification Flight 8 June 2005



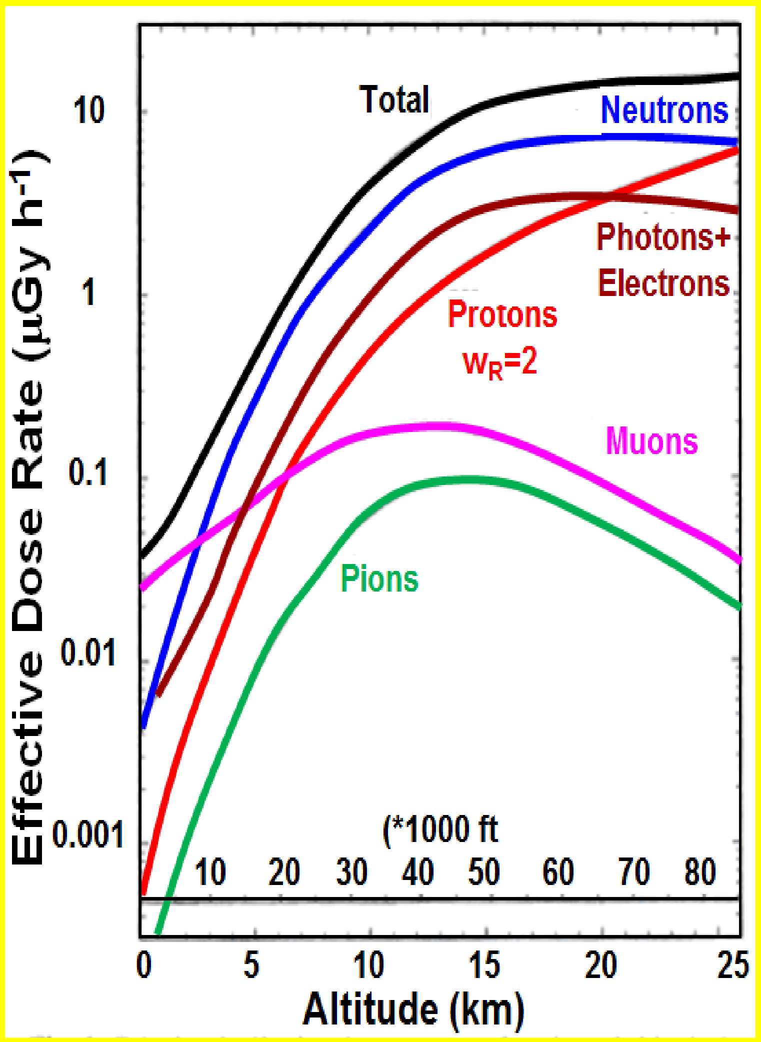
SRTI, BAS

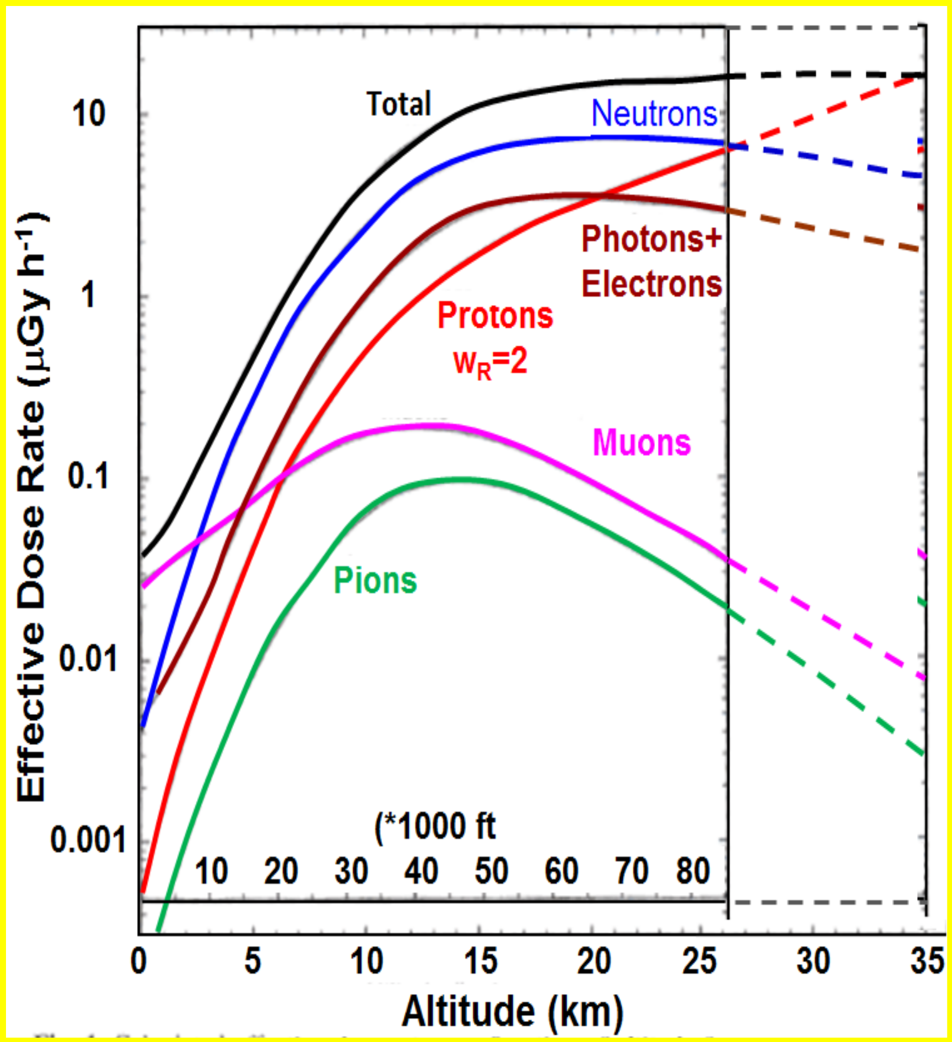
Altitudinal..., 13 WRMISS, Budapest, September 2013

Altitudinal profiles od the dose rate, flux and dose to flux ratio (D/F) measured by Liulin-4U MDU#2 during the NASA DSTB Certification Flight 8 June 2005



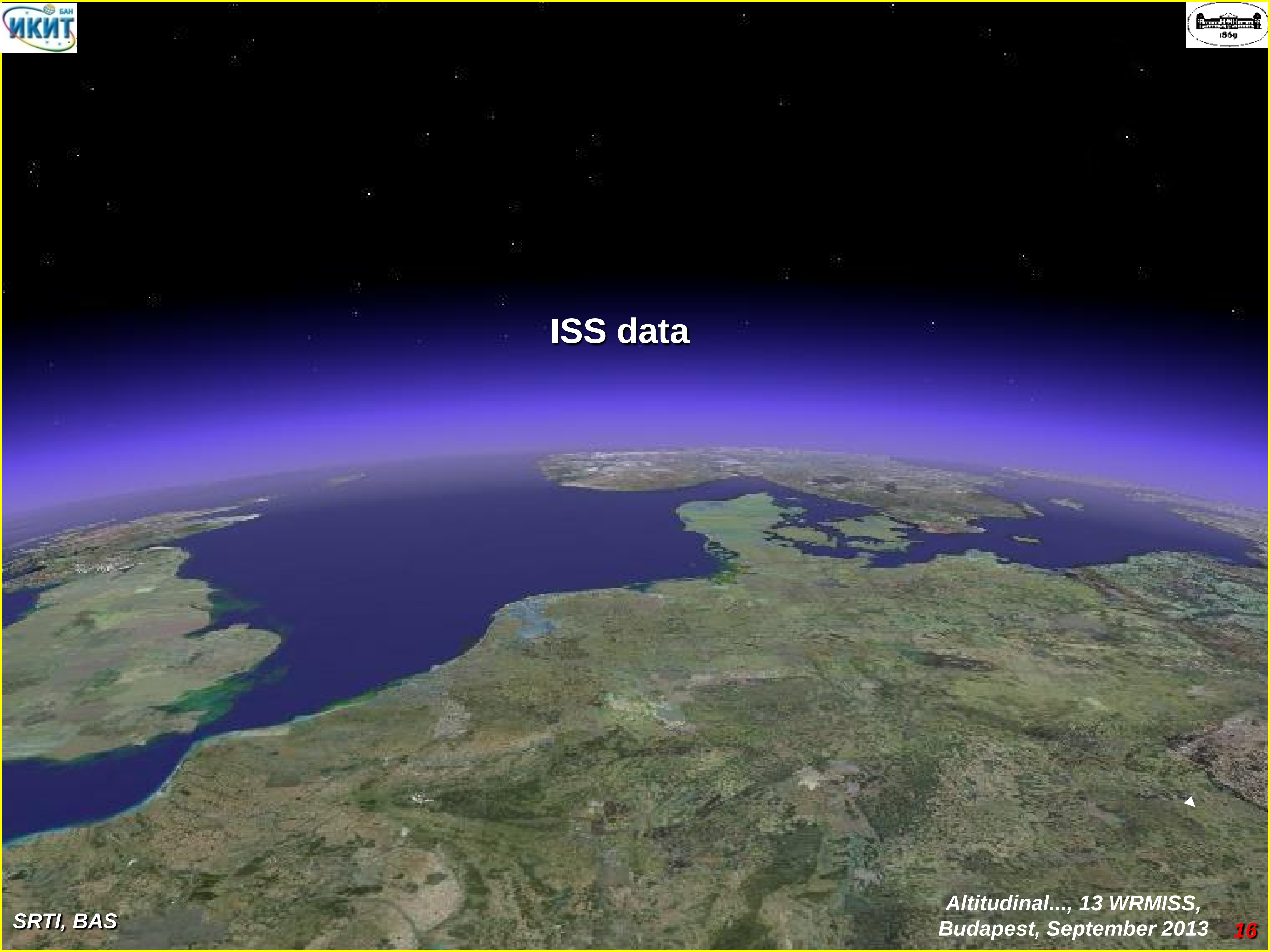
Calculated effective dose rate as a function of altitude for various particles of GCR in the atmosphere near the polar plateau (cutoff – 0.8 GV) at solar minimum (June 1997)*



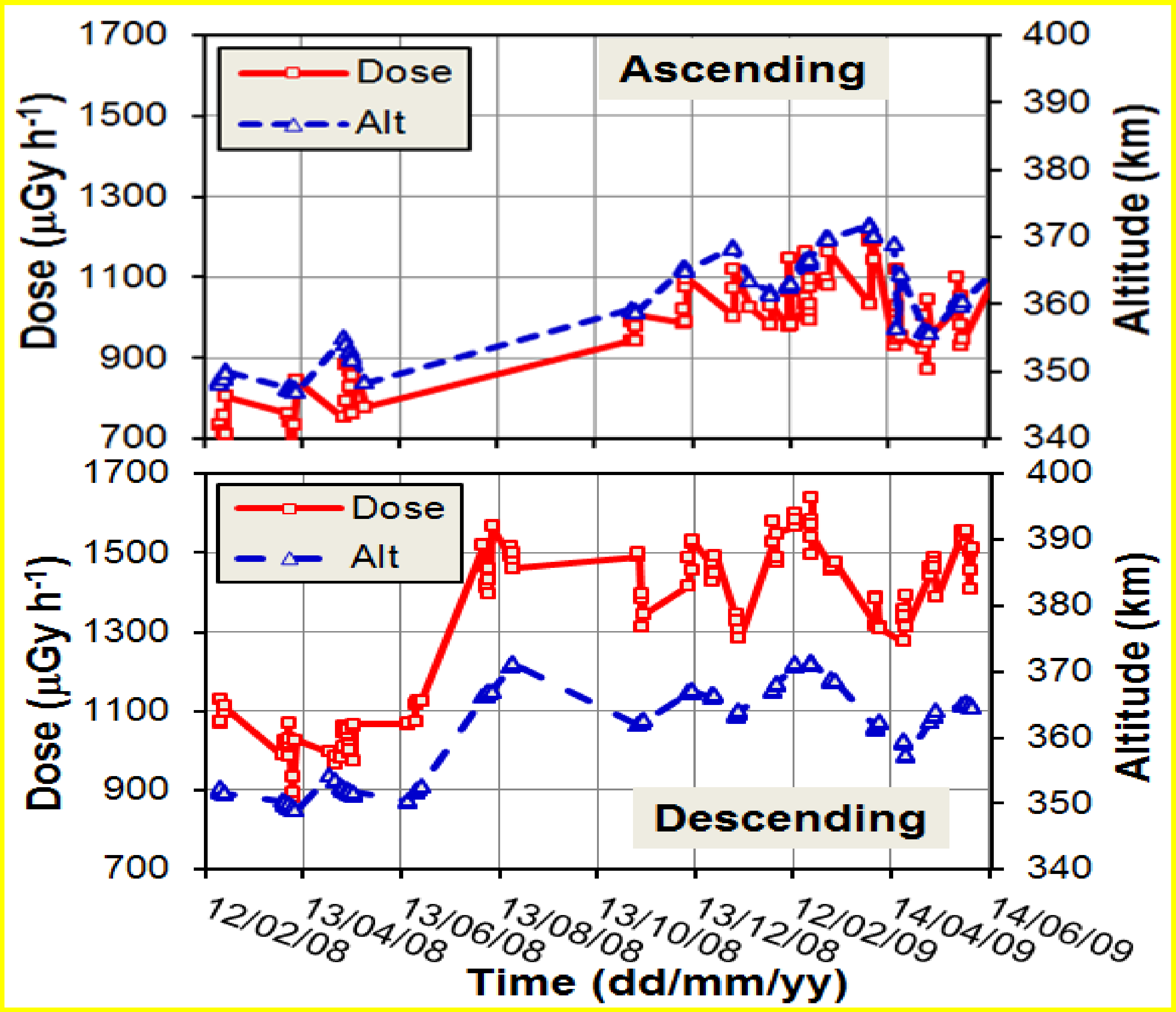


*Data are courtesy of K.O. Brian calculated using his LUIN-98F radiation transport code, but with wR for protons equal to 2 (NCRP 1993) rather than 5.

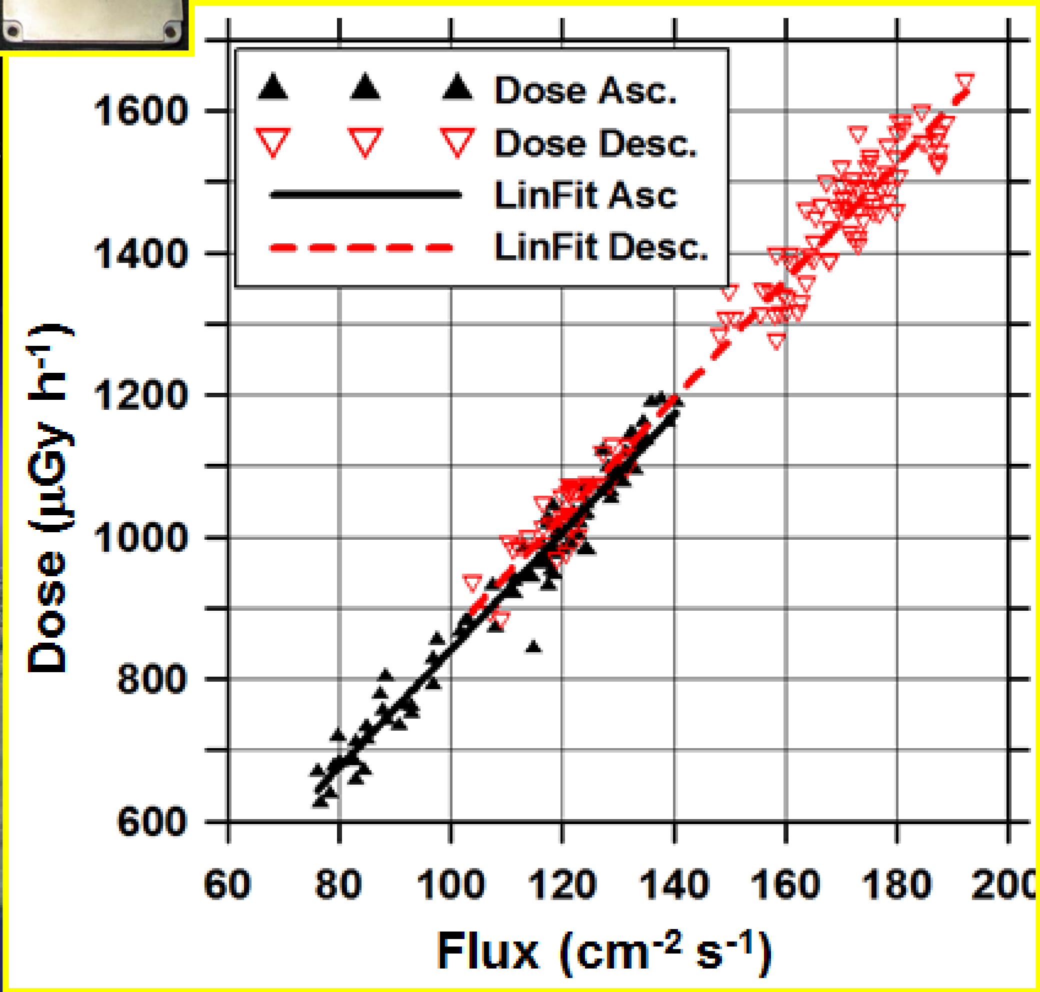
ISS data



Altitudinal dependence of the SAA maximum (Long=-50°W; Lat=-32°S) observed by R3DE instrument at ISS



SAA maximum R3DE dose rate depend linearly by the flux of particles



Ascending

$D_{Asc} = 8.27*Flux + 14.09$

Average Flux = 108 $cm^{-2}\ s^{-1}$

Average Dose = 904 $\mu Gy\ h^{-1}$

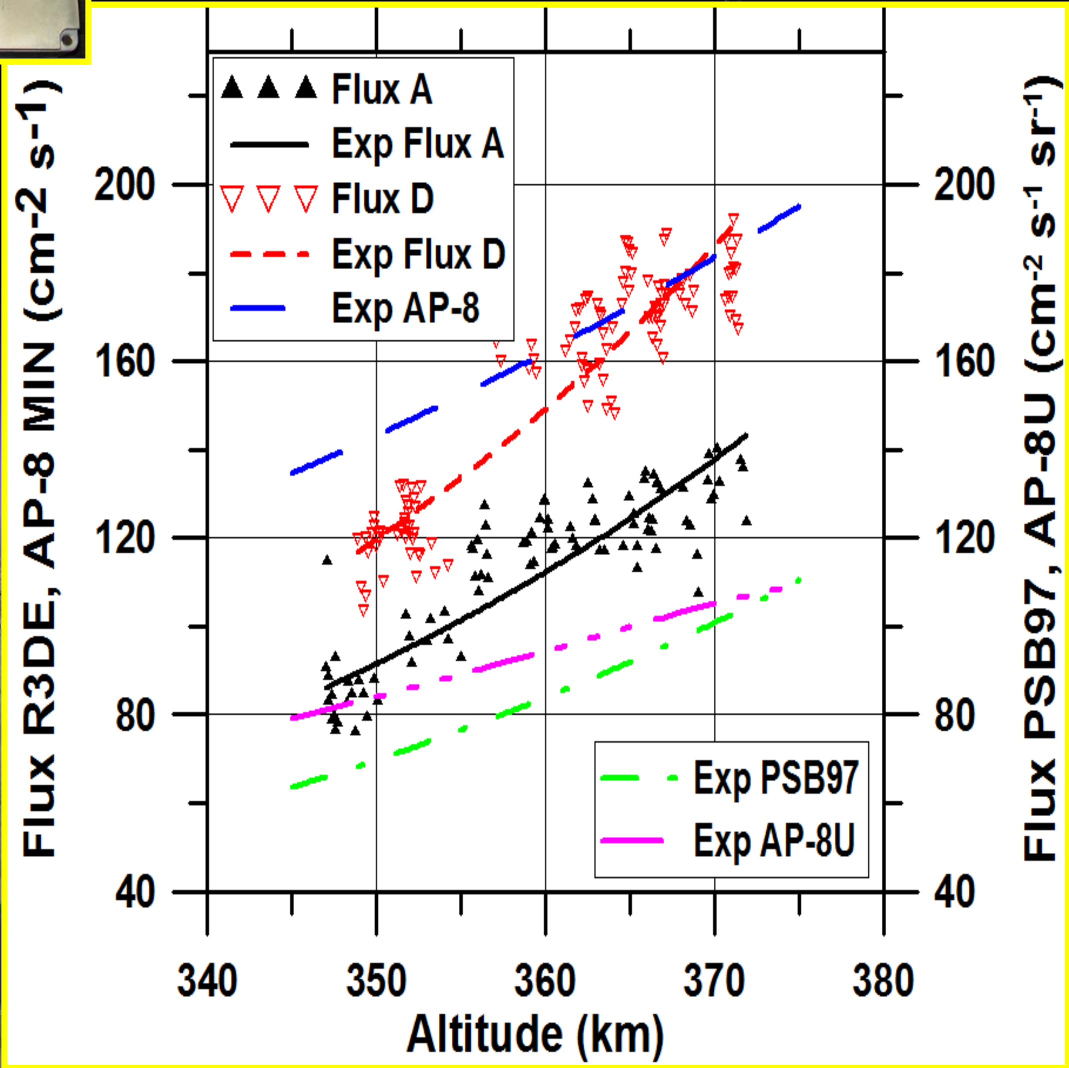
Descending

$D_{Desc} = 8.27*Flux + 36.22$

Average Flux = 154 $cm^{-2}\ s^{-1}$

Average Dose = 1310 $\mu Gy\ h^{-1}$

Comparison of the R3DE SAA$_{max}$ flux data profiles with the AP-MIN, AP-8U and PSB97 models (http://www.spenvis.oma.be/)

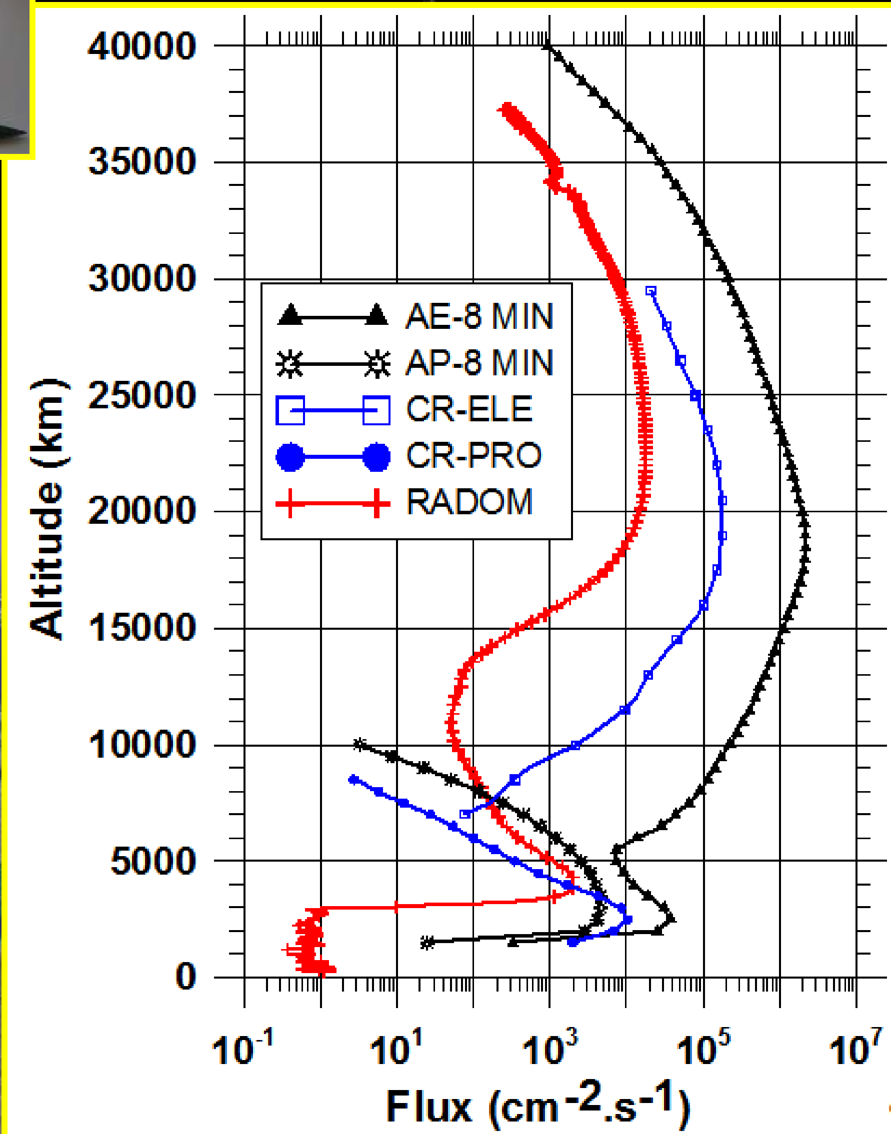


Ascending
The observed ascending flux values are about 2 times smaller than the AP-8 MIN predicted but follow well the shape.

Descending
The observed descending flux values are close to the predicted by the AP-8 MIN model but did have more steeper shape

Chandrayaan-1 data

Comparison of the RADOM inner and outer radiation belt altitudinal profiles with AP/AE MIN and CRESS models*

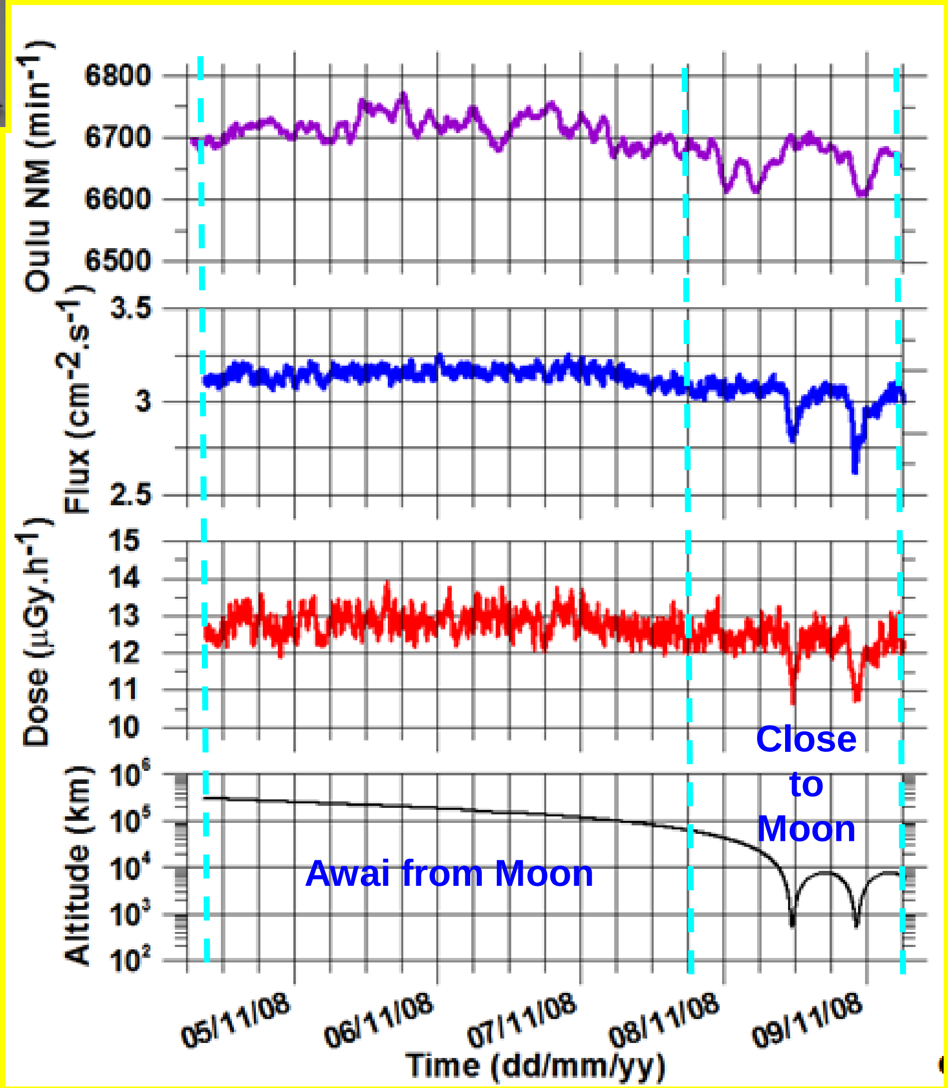


Both models predict the location of the inner radiation belt maximum at about 2500 and 3000 km altitude, whereas it is observed at about 4000 km by RADOM;

The observed slot region form is much wider than the predicted by both models;

***Dachev, Ts. P., B. T. Tomov, Yu.N. Matviichuk, Pl .G. Dimitrov, Vadawale, S. V., J. N. Goswami, V. Girish, G. de Angelis, An overview of RADOM results for Earth and Moon Radiation Environment on Chandrayyan-1 Satellite, Adv. Space Res., 48, 5, 779-791, 2011. http://dx.doi.org/10.1016/j.asr.2011.05.009**

RADOM observations during lunar transfer trajectory and lunar orbit capture. The distance is from the Moon. The trends in particle flux coincide with the Oulu neutron monitor data trends

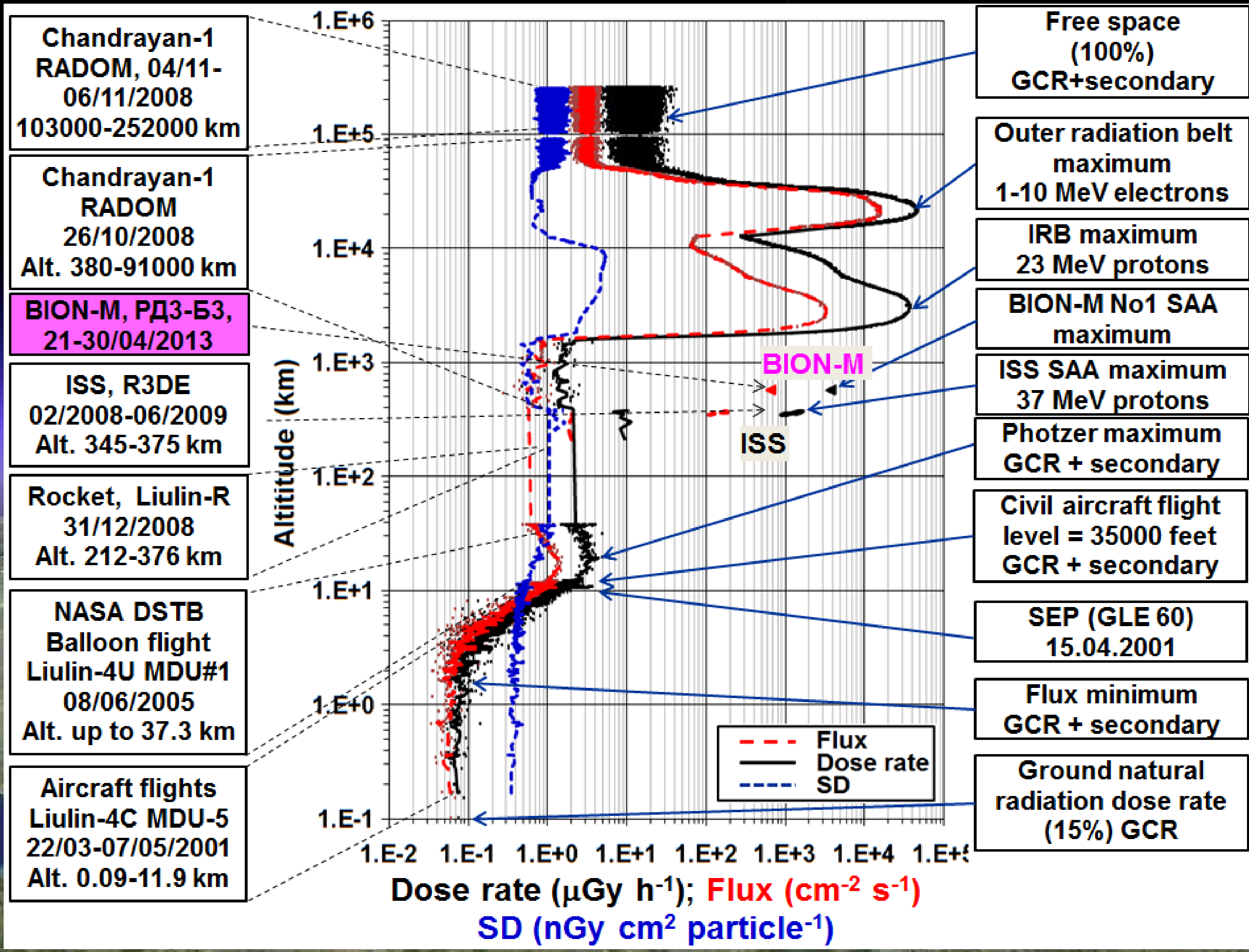


When the Chandrayaan-1 satellite is far from the Moon the flux and dose rate are generated mainly by GCR that is why they correlate with the Oulu NM count rate.

When the Chandrayaan-1 satellite is close to the Moon the flux and dose rate decrease because they are shadowed by the Moon body.

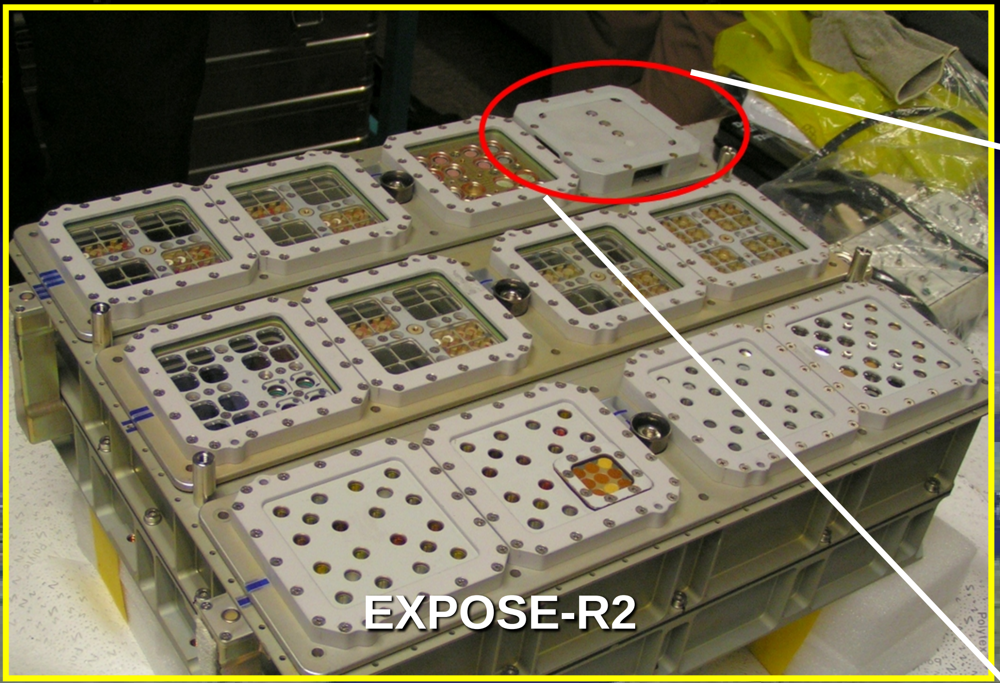
The space exposure altitudinal profile from the Earth surface to the free space

Space radiation profile from ground to free space



Future space experiments

In the frame of the ESA project EXPOSE-R2 it is planned to be performed a new long duration experiment at the Russian segment of ISS with the R3DR instrument after April 2014



During 2016 at the Russian Moon satellite and lander „Луна-Глоб“ will be flown the instrument Liulin-L, which will be very similar to the RADOM instrument flown in 2008-2009 at the Indian Moon satellite Chandrayaan -1

Luna-Glob Orbiter

Luna-Glob Rover?

Luna-Glob Lander?

http://ria.ru/science/20120409/621613448.html

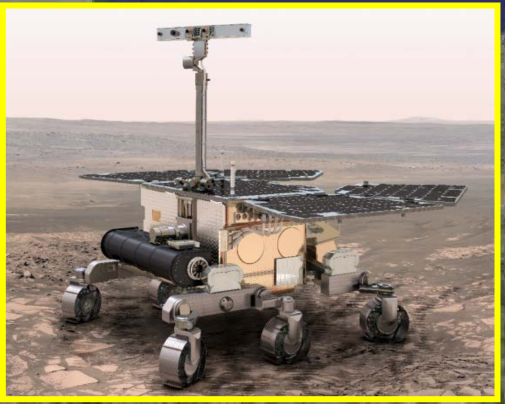
2015

System of 2
Liulin-L instruments
at 2 different locations
And angle of view

1 new Liulin-F type instrument will be used at ESA ExoMars TGO spacecraft (2016) and another on the lander in 2018. They are part of FREND instrument and will be build in cooperation with IKI-RAS and IMBP-RAS, Moscow, Russia

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

MarsTrace Gas Mission-Orbiter



ESA's ExoMars Rover

Liulin-MO and ML will be similar to Liulin-F instrument

FREND instrument will be similar to the LEND instrument flown on the NASA Lunar Reconnaissance Orbiter

http://l503.iki.rssi.ru/LEND.html

CONCLUSIONS

- It is understand that the obtained profile of exposure does not have a global coverage because of limited distribution of the IRB, which maximum extent up to L=1.6;
- The limitation of the paper is that the aircraft and the balloon data in the low altitudes were collected mainly at mid latitudes at relatively high solar activity, while the high altitude data of the Chandrayaan-1 satellite was obtained at low latitudes and low solar activity;
-
- The strong point of this paper is that original experimental data are compared and plotted to reveal a unified picture how the different ionizing radiation sources contribute and build the space radiation exposure altitudinal profile from the earth surface up to the free space;
- The dose rate and flux data cover 7 orders of magnitude and can be used for educational purposes and also as reference values for new models;
- The presentation of data in kilometers above the Earth surface instead in L values allows space agencies medical staff and that not specialized in the geophysics support to use them for a first approach for the expected human exposure at different altitudes and also the general public and students to have a simple knowledge about the position of the most common maxima of exposure around the Earth and up to free space.

Acknowledgements

➢The author would like to thank:

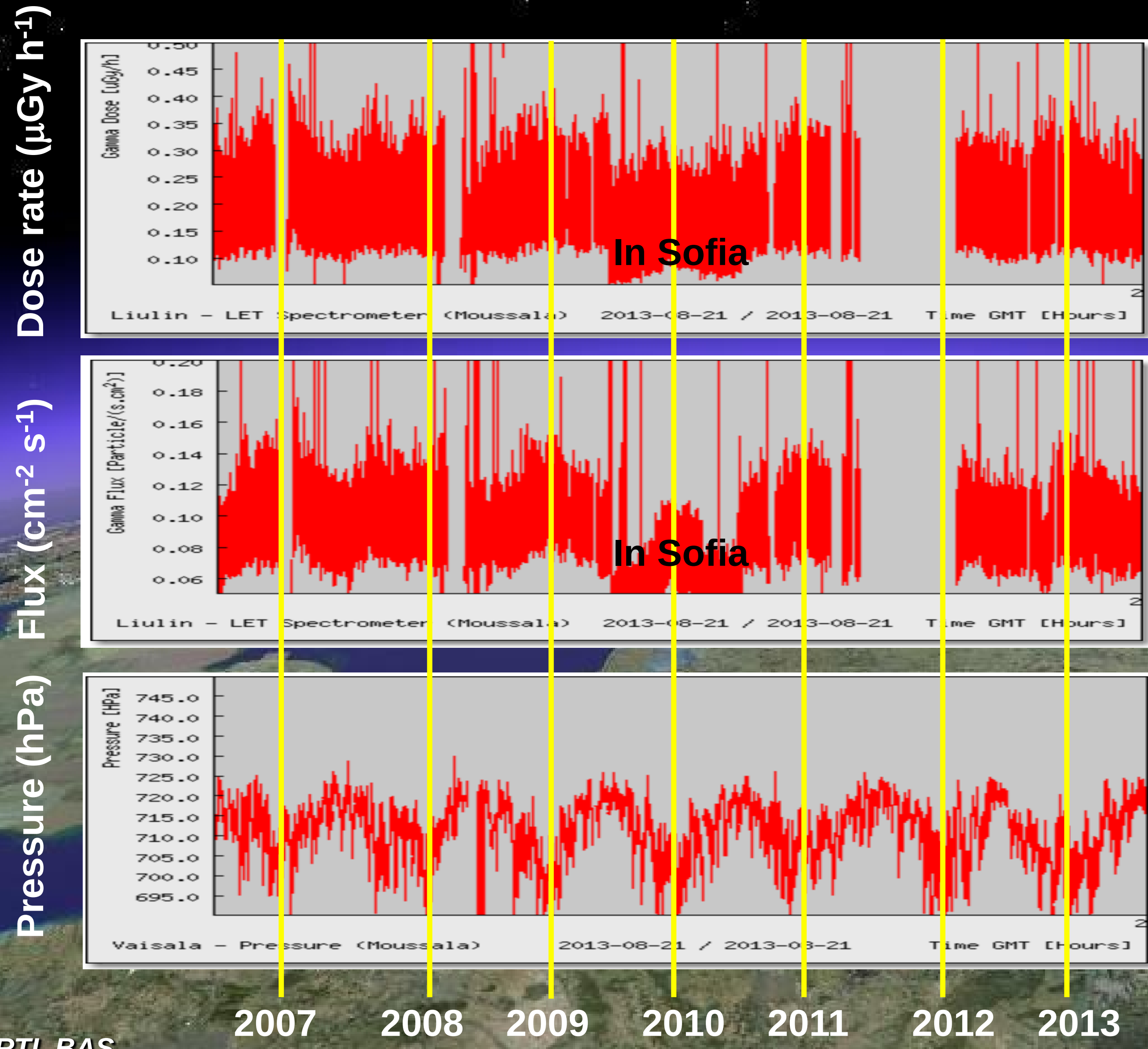
B. Tomov, P. Dimitrov and Y. Matviichuk from the Space Research & Technology Institute at the Bulgarian Academy of Sciences for their cooperation in the development of the Liulin type spectrometers and for the assistance with data analysis; F. Spurny, and O. Ploc from Nuclear Physics Institute, Czech Republic for the aircraft data and work on the interpretation procedure; G. Horneck and G. Reitz from DLR, Institute of Aerospace Medicine, Germany, D.-P. Häder, M. Lebert and M. Schuster from Department für Biology der Friedrich-Alexander-Universität, Germany for the leadership and cooperation in the experiments on Foton-M2 spacecraft and ISS; E. Benton from Department of Physics, Oklahoma State University, USA for the balloon data from MDU#1 of Liulin-4U instrument; ISRO staff and more specially to: Mr. M. Annadurai, Project Director and J. N. Goswami, Project scientist of Chandrayaan-1 satellite, P. Sreekumar and V. Sharan, Space Astronomy & Instrument Div., and Dr. J D Rao, ISTRAC/ISRO Bangalore for the RADOM instrument support.

➢ grant DID-02/8 from the Bulgarian Science Fund;

Thank you for your attention

Variations of the flux and dose rate at Moussala peak (2925 m asl) in Rila mountain, Bulgaria

http://beo-db.inrne.bas.bg/moussala/



The background radiation at Moussala peak show the following features:

- Is higher at Moussala peak than in Sofia;

- The non corrected dose rate and flux show maximums when the atmospheric pressure have minimums and in reverse.