Analysis of the radiation environment, obtained in 2018-2019 by Liulin Ten-Koh instrument on the Japanize Ten-Koh satellite

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Outlook

- Introduction
- Bulgarian build space dosimetry instruments;
- Liulin Ten-Koh spectrometer;
- Calibrations of Liulin Ten-Koh;
- Liulin Ten-Koh data analysis;
- Future space experiments with Liulin type instruments;
- Liulin instrument online database;
- Conclusions

Introduction

Bulgarian build space dosimetry instruments

Bulgarian space radiation experiments on satellite and rocket

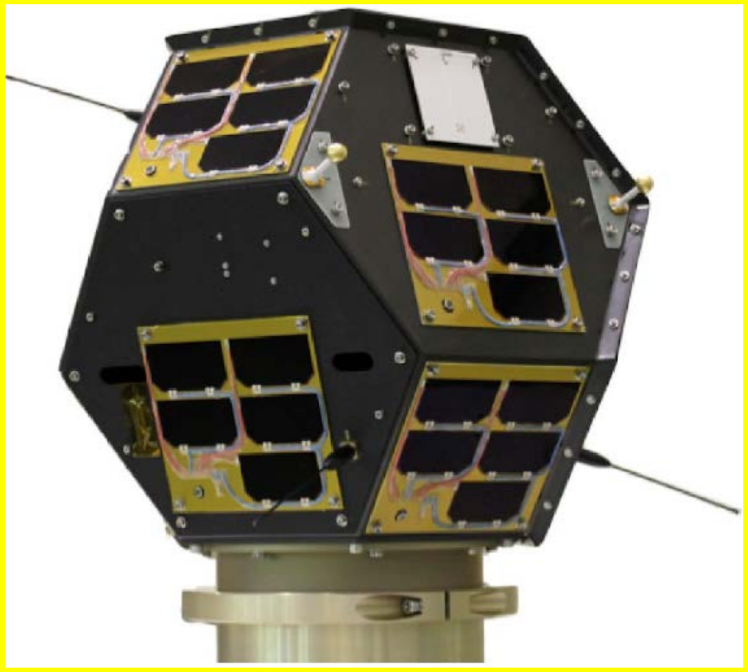
1. LIULIN, 04/1979 - 09/1984, Roscosmos, MIR space station, (Dachev et al., 1989);
2. RADIUS-MD, Mars-96 satellite, 1996, unsuccessful launch, (Semkova et al., 1994);
3. Liulin-E094, 05 - 08/2001, ESA-NASA exp. on the International space station (ISS), (Dachev et al., 2002, Wilson et al., 2007, Nealy et al., 2007, Slaba et al., 2011, Badavi, 2014, 2016);
4. R3D-B1, 2002, ESA-Roscosmos, Foton M1 satellite – unsuccessful launch;
5. R3D-B2, 1 - 12/06/2005, ESA-Roscosmos, Foton M2 satellite, (Häder et al., 2008);
6. Liulin-ISS, 09/2005- , Russian segment of ISS, (Panasyuk et al., 2007) (Currently at ISS);
7. Liulin-6R, 31/01/2008, Rocket flight up to 380 km altitude from Andoya, Norway, (Dachev, 2013);
8. Liulin-5, 06/2007- 05/2016, Russian segment of ISS, Semkova et al., 2012);
9. R3D-B3, 14 - 26/09/2007, ESA-Roscosmos, Foton M3 satellite, (Damasso et al., 2008);
10. Liulin-Photo, 14 - 26/09/2007, ESA-Roscosmos, Foton M3 satellite, (Damasso et al., 2008);
11. R3DE, 02/2008 - 09/2009, ESA Columbus module of ISS (Dachev et al., 2012);
12. RADOM, 10/2008 - 08/2009, Indian Chandrayyan-1 satellite around Moon, (Dachev et al., 2011);
13. R3DR, 03/2008 - 08/2009, ESA-Roscosmos, EXPOSE-R, Zvezda, ISS, (Dachev et al., 2012);
14. Liulin-Phobos, Russian Phobos-Ground, 2011, – unsuccessful launch, (Semkova et al., 2012);
15. RD3-B3, 04 - 05/2013, Roscosmos, BION-M1 satellite , (Dachev et al., 2014);
16. RD3-B3, 07 - 09/2014, Roscosmos Foton-M1 satellite, (Dachev et al., 2017a);
17. R3DR2, 10/2014 - 01/2016, ESA-Roscosmos, EXPOSE-R2, Zvezda, ISS, (Dachev et al., 2017b);
18. Liulin-MO, since 14 March 2016 working at ESA-Roscosmos, ExoMars TGO satellite (Mitrofanov et al., 2017), (Currently at Mars 400 km orbit);
19. Liulin Ten-Koh, since 29 October 2018 working at Japanese Satellite Ten-Koh, (Currently at Earth orbit).

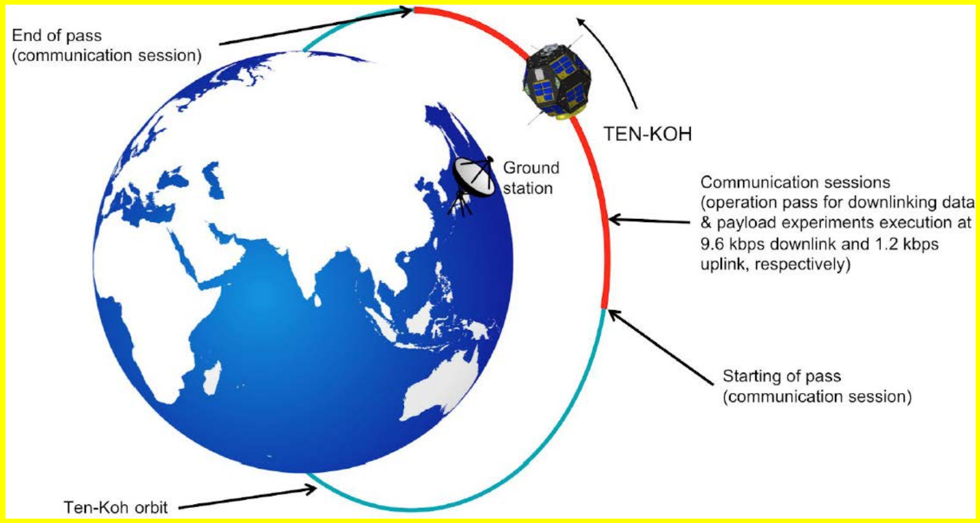
Space radiation experiments with Bulgaria instruments on the ground, aircraft and balloons

1. **Liulin-MDU1**, 14/06/2000, ESA balloon flight up to 33 km over Gap, France, (Spurny 2001);
2. **Liulin-MDU5/6**, more than 10000 hours on Czech airlines aircrafts (Ploc et al., 2014);
3. **2 Liulin-MDU**, 06/2001, NASA ER-2 aircraft flights at 20 km alt. over USA, (Uchihori et al. 2002);
4. **2 Liulin-MDU**, 10/2003-04/2004, 19 flights on board of IBERIA airlines A-340-300 aircraft, (Sa´ez Vergara and Dominguez-Mompell, 2009)
5. **1 Liulin-4N-MDU**, 05/2003 – 09/01/2004, 42 jet-altitude flights in Canada, (Green et al., 2005);
6. **1 Liulin-4N-MDU**, 11/2003-12/2004, 9 flights at Australian Qantas Airways, (Getley at al., 2005);
7. **Liulin-6R**, 10/2005 – 07/2010, Andoya, Norway, working in Internet
8. **3 Liulin-MDU**, 06/2005, NASA balloon flight up to 40 km over NM, USA, (Benton et al. 2007; Adams et al. 2007);
9. **8 Liulin 6Sp-MDU**, 09/2007 - 09/2009, 4500 flights on board of IBERIA airlines A-340-300 aircraft, (Sa´ez Vergara and Dominguez-Mompell, 2009)
10. **Liulin-Moussala**, 06/2006, Moussala peak in Internet (Matviichuk et al. 2007), (active now at: http://beo-db.inrne.bas.bg/moussala/index.php);
11. **Liulin-6S**, October 2007-December 2016, Jungfrau peak in Internet ;
12. **Liulin-4SA**, 09/2008 – 03/2009, 16 flights at Australian Qantas Airways, (Getley at al., 2009);
13. **Liulin-RG**, 06/07, 07/07/2011, 25/07, 26/07 and 01/08/2012, 5 balloon flights, up to 30 km, Lindenberg, Germany, (Wissmann et al., 2013);
14. **Liulin-6SA1**, 25-26/09/2015, NASA RAD-X balloon flight up to 30 km over NM, USA (Mertens et al., 2016);
15. **Liulin-6SA1**, 10/10/2015, JefferSat CRM on NASA Scientific balloon - University of Virginia flight up to 30 km over NM, USA, Goyne, 2015.

Liulin Ten-Koh (LTK) spectrometer

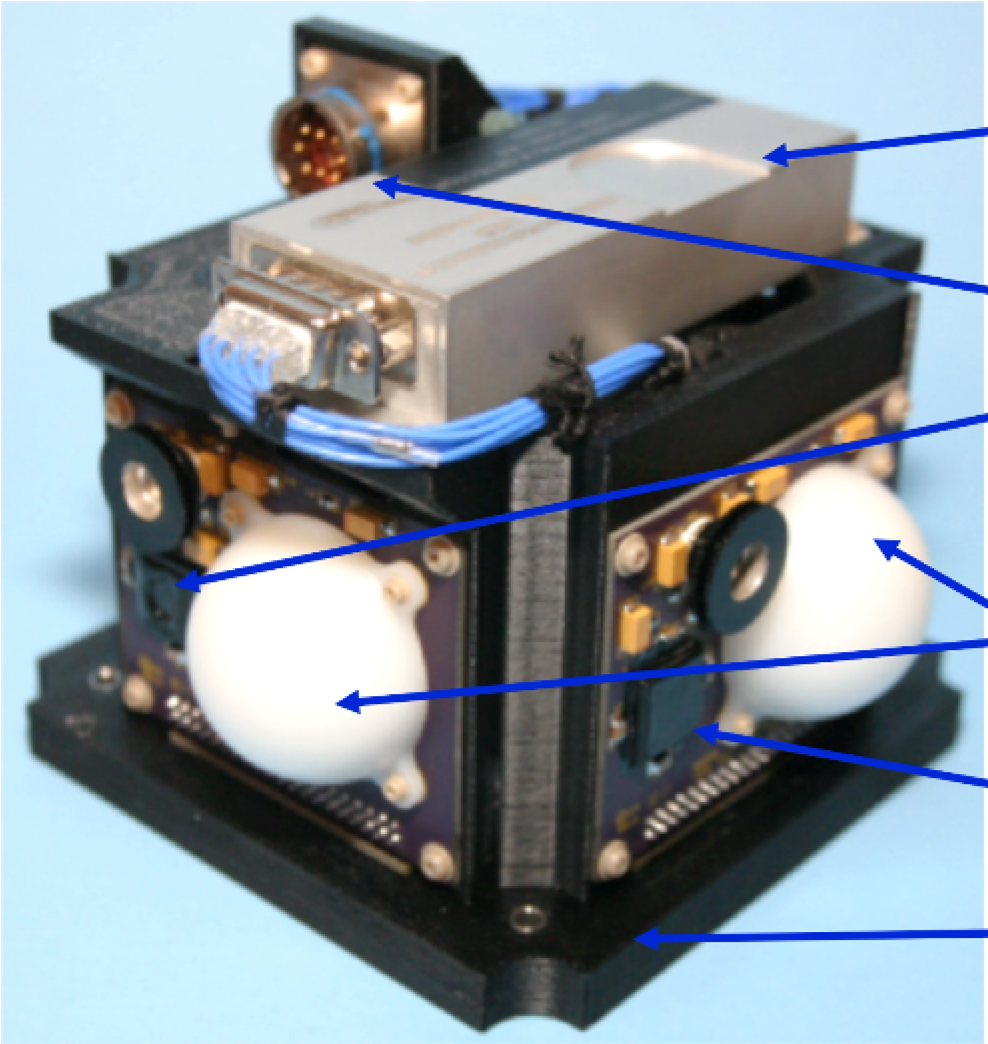
Ten-Koh satellite is a 23.5 kg small satellite developed under the philosophy of low size and cost while trying to provide high output capabilities for space environment effects research. Developed by Kyushu Institute of Technology in Japan, in partnership with the Radiation Institute for Science and Engineering of Prairie View A&M University, Holland-Space LLC and the Space Research and Technology Institute of the Bulgarian Academy of Sciences*





*Fajardo I., et al., Challenges, development and operation of a small satellite mission to explore the space environment and its effects on spaceborne platforms, Acta Astronautica, 2019. (in print)

Liulin Ten-Koh spectrometer in the Charged Particle Detector, developed by the Radiation Institute for Science and Engineering of Prairie View A&M University, USA and Holland-Space LLC, USA



Liulin Spectrometer
-Similar instrument on ISS and Chandrayaan-1 satellite

Communication with In-Flight Programming Capability

2 X-Ray Detectors

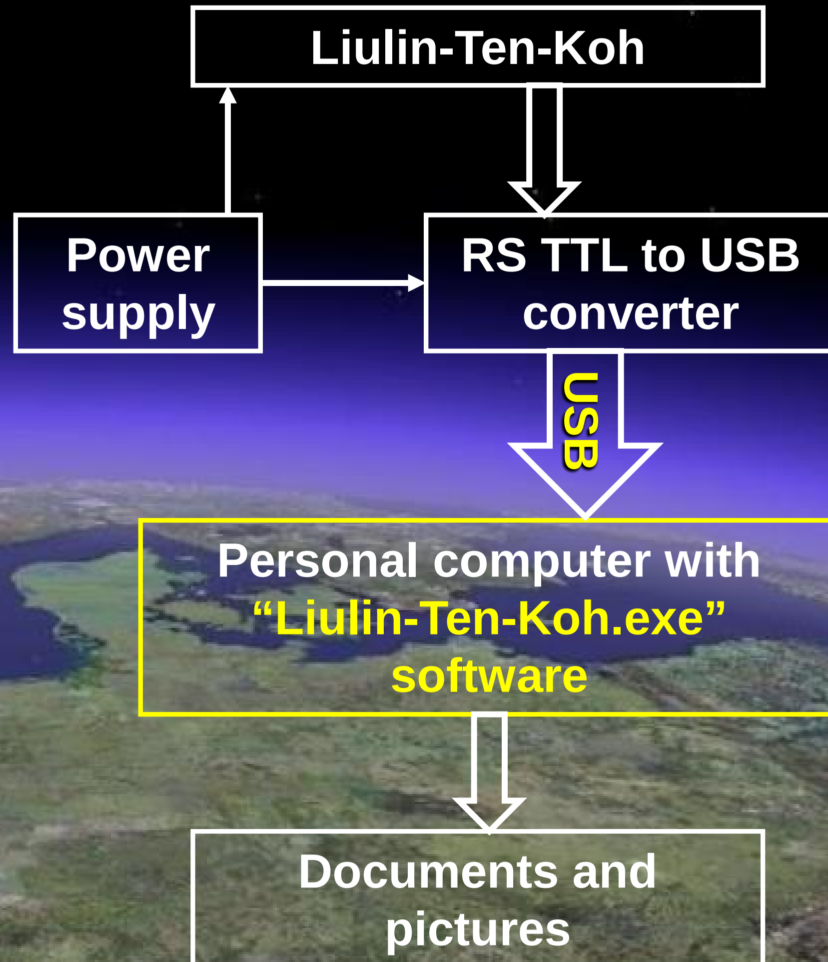
2 Polystyrene Covered Sensors for Skin Dose Assessment (not shown)

2 Polyethylene Covered Sensors for Shielding Assessment

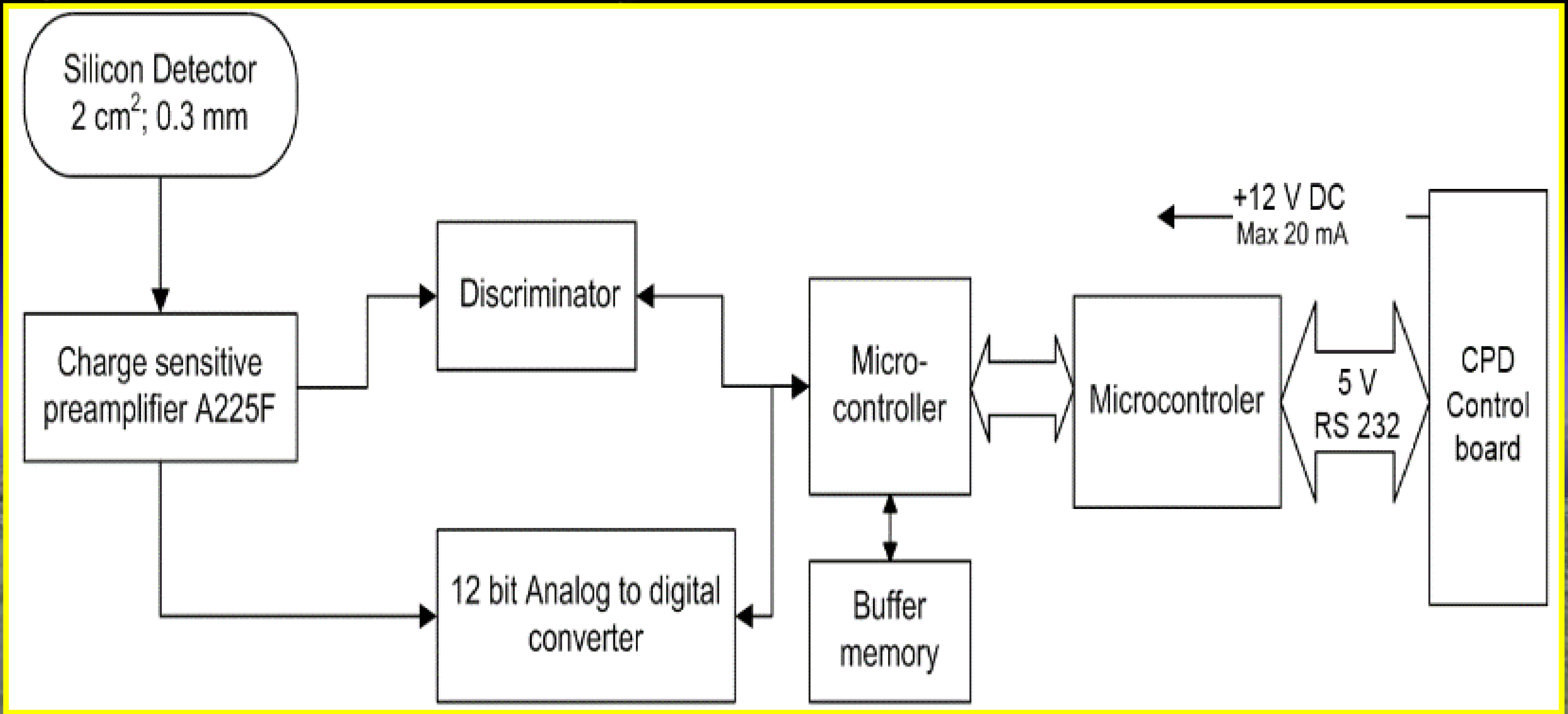
2 Open Sensors for Ambient Radiation Measurements

PEKK Material for Static Guard

Completion, appearance and method of use of the Liulin Ten-Koc (LTK) spectrometer in laboratory tests



Block diagram of the Liulin Ten-Koh spectrometer



LTK dose determination procedure

By definition the dose in the silicon detector D_{Si} [Gy] is one joule deposited in 1 kg of matter. The LTK absorbed dose is calculated by dividing the summarized energy deposition in the spectrum in joules by the mass of the detector in kilograms:

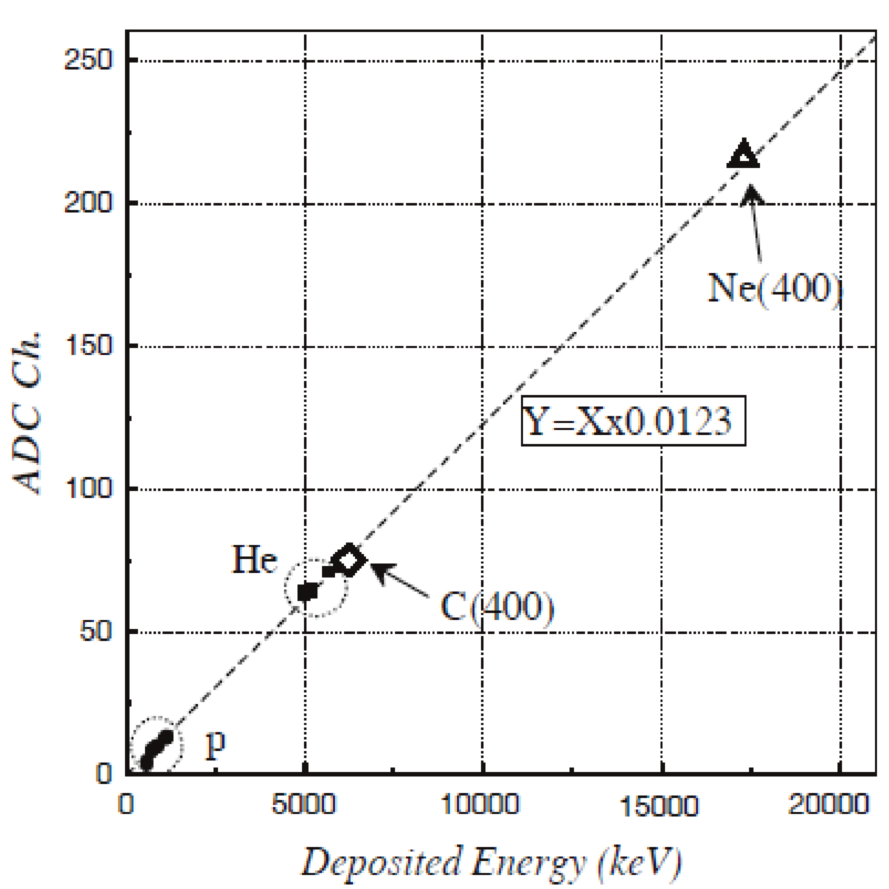
$$D_{Si}[Gy] = K\sum_{i=1}^{255}(EL_i i)[J]/MD[kg]$$

where *K* is a coefficient. *MD* is the mass of the detector, and EL_i is the energy loss in Joules in channel *i*. The energy in MeV is proportional to the amplitude *A* of the pulse: $EL_i[MeV]=A[V]/0.24[V/MeV]$, where *0.24[V/MeV]* is a coefficient dependent on the preamplifier used and its sensitivity.

All 255 deposited dose values, depending on the deposited energy for one exposure period, form the deposited energy spectrum. Channel 256 accumulates all pulses with amplitudes higher than the upper energy of 20.83 MeV measured by the spectrometer.

Calibrations of Liulin Ten-Koh

Dependence of the ADC channel number on the deposited energy in the Liulin type detector at 0° angle for H^+, Ne^+, C^+ and Ne^+ ions



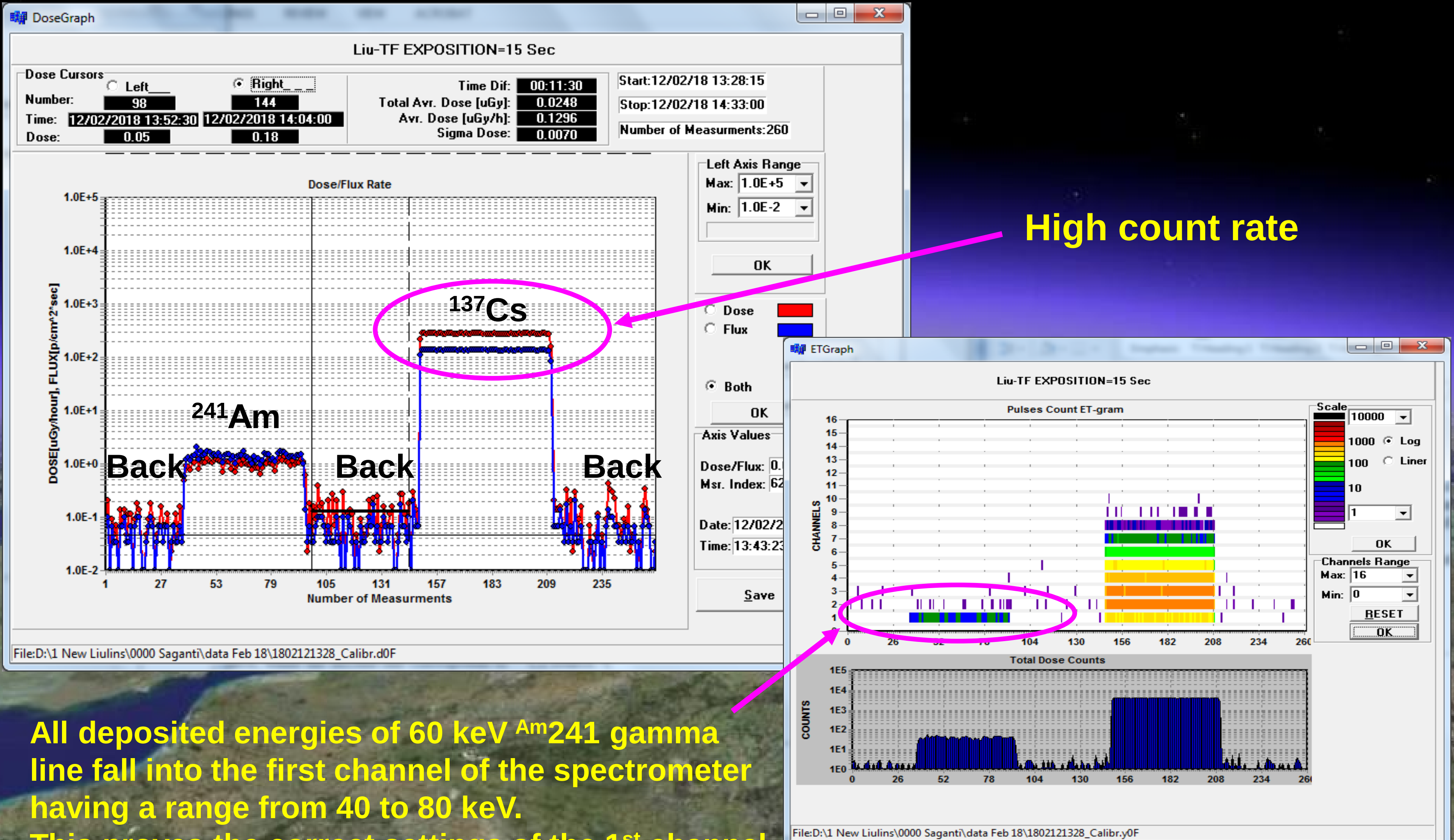
1. Channel number depends linearly from the deposited energy.

2. The experimental result coefficient of 0.0123 good matches predictions from 0.0124.

3. Because of the use of the same schematics and components, in LTK we suppose that the linearity obtained by Uchihori, Y. et al. during calibrations with protons and ions at NIRS cyclotron and HIMAC heavy ion synchrotron facilities, Chiba, Japan , is preserved.
We perform only linearity test on the methodology of AMPTEK INC

Uchihori, Y. et al., Analysis of the calibration results obtained with Liulin-4J spectrometer-dosimeter on protons and heavy ions, Radiation Measurements, 35, 127-134, 2002.
http://dx.doi.org/10.1016/S1350-4487(01)00286-4

Determination of the position of the first channel of the spectrometer by the 60 keV line of $^{Am}241$ source. Observation of high counting rates from $^{Cs}137$ source

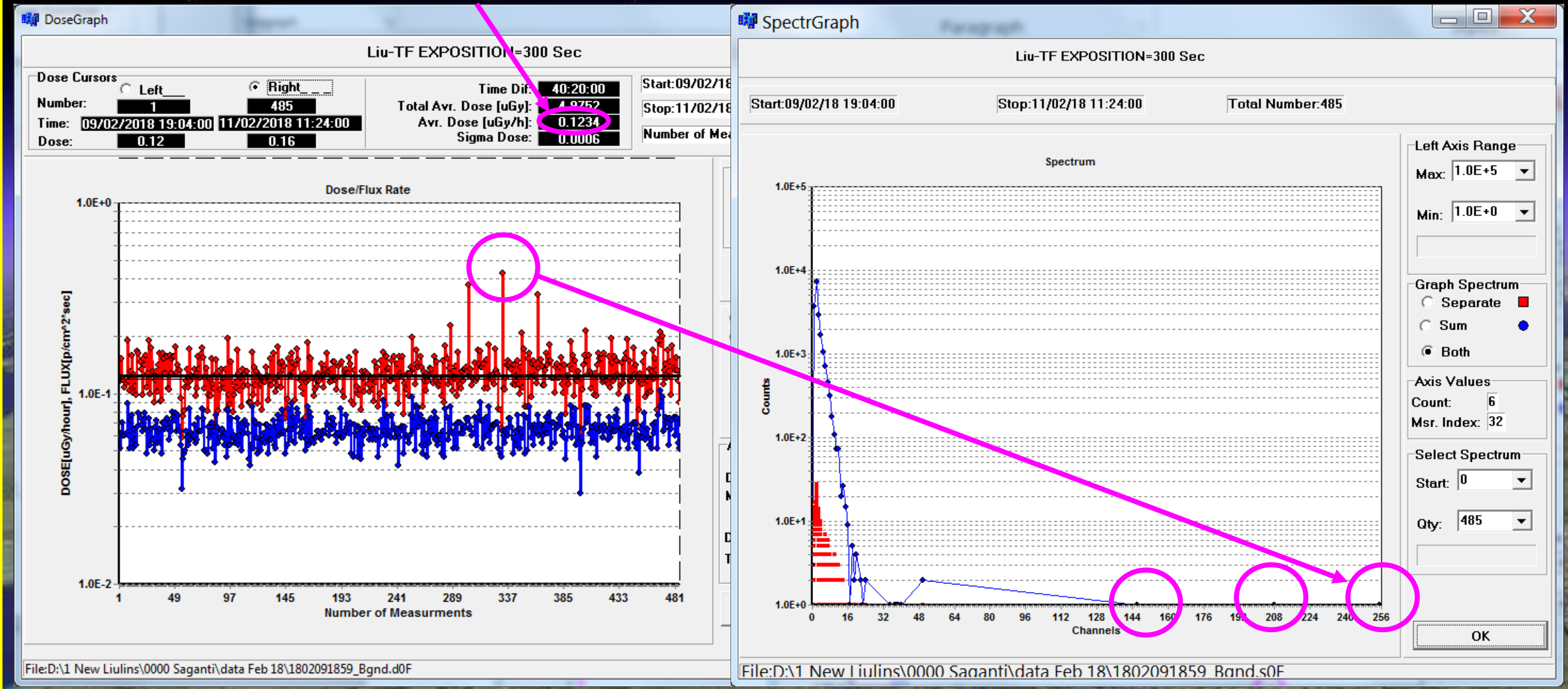


All deposited energies of 60 keV $^{Am}241$ gamma line fall into the first channel of the spectrometer having a range from 40 to 80 keV.
This proves the correct settings of the 1st channel.

Long-term measurements of the background radiation level. Absolute dose rate calibration

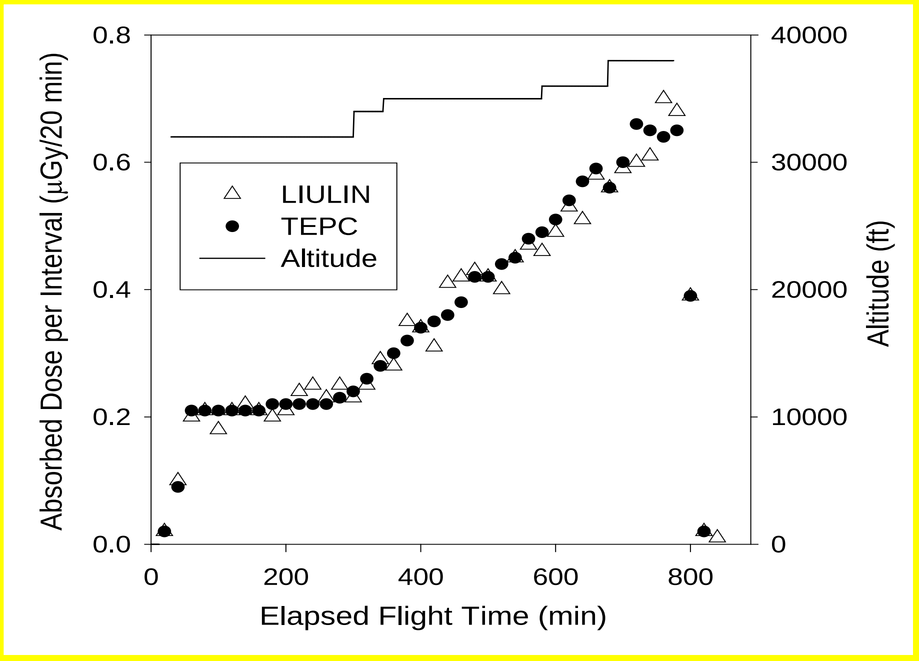
The average background dose rate for 40 h and 20 m is 0.123 μGy h^{-1}. The average for
for this lab background is 0.12 μGy h^{-1}.
The accuracy of the measurement is 10% or 0.012 μGy h^{-1}.
All values between 0.108 and 0.132 are accepted.

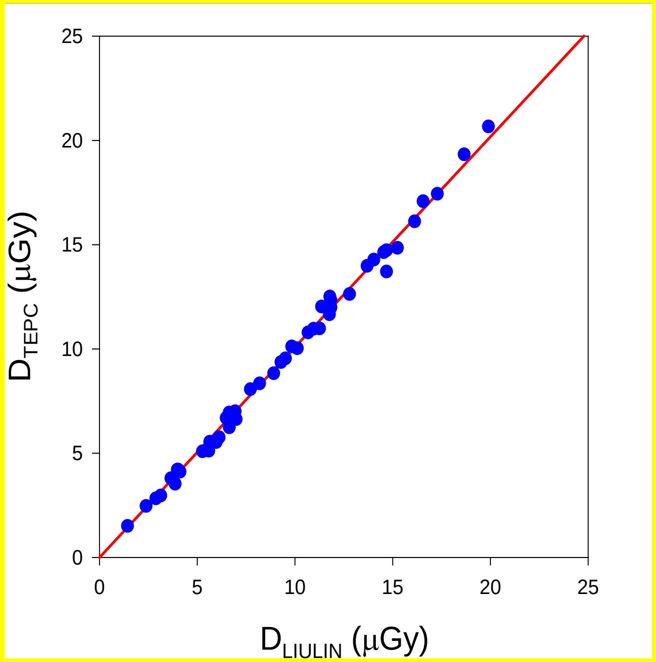
0.108<0.123<0.132



There are events in high channel number!

Comparison of Liulin-4SN data with TEPC data during airplane flight conducted by Royal College, Canada*





Liulin and TEPC data are in good coincidence!

*Green, A. R.; Bennett, L. G. I. Lewis, B. J.; Kitching, F. McCall, M. J.; Desormeaux, M. Butler, A., An empirical approach to the measurement of the cosmic radiation field at jet aircraft altitudes, Advances in Space Research, 36, 9, p. 1618-1626, 2005.

Kitching, F, "Use of a Liulin Detector for the Determination of Aircrew Radiation Exposure", Doctoral thesis, Royal College, Canada 2005.

Getley, I., "Cosmic and Solar Radiation Exposure to Australian Commercial Flight Crew at High Southern Latitudes as Measured and Compared to Predictive Computer Modeling", Doctoral thesis, University of New South Wally, Australia, 2007.

Liulin Ten-Koh data analysis
(Preliminary results)

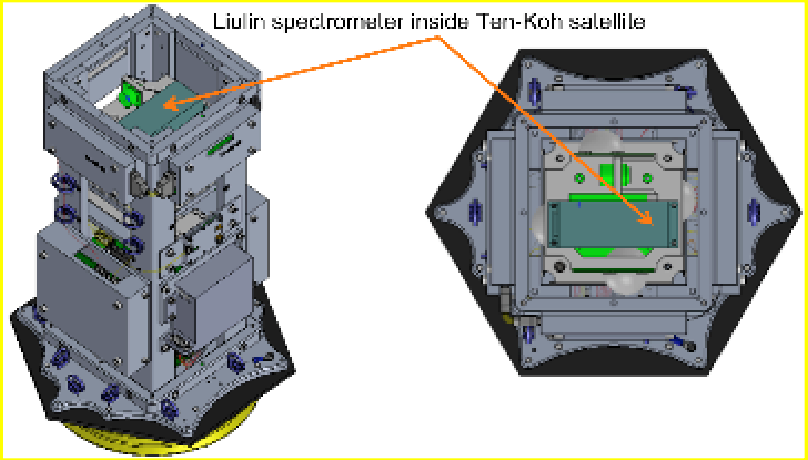
Liulin Ten-Koh shielding

The semiconductor detector of the "Liulin Ten-Koh" instrument is mounted approximately 2 mm below the 0.3 mm thick aluminum cover plate.

Furthermore, there is shielding from 0.07 mm copper and 0.2 mm plastic, which provided 0.3 g cm^{-2} of total shielding from the front side.

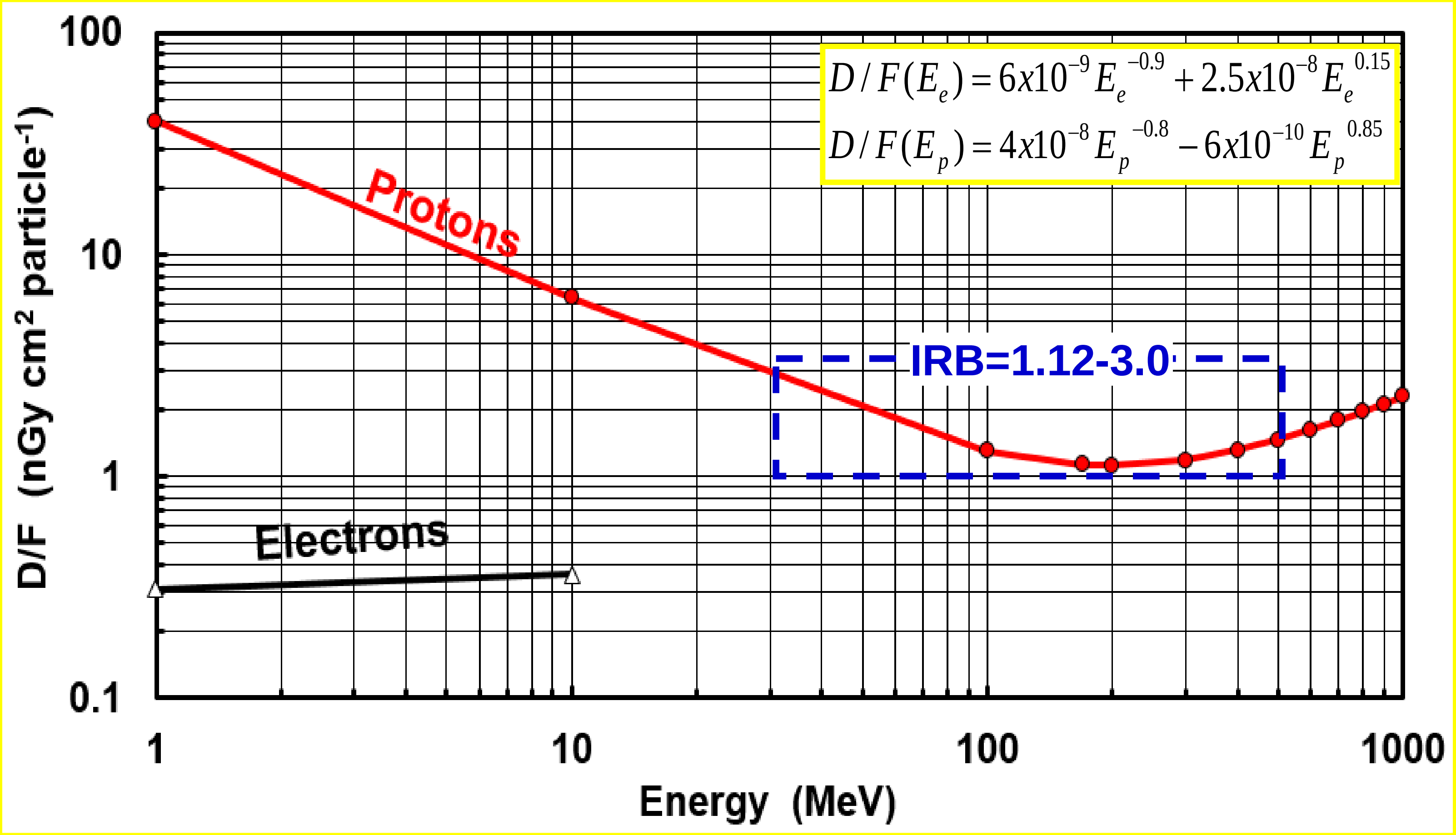
The "Liulin Ten-Koh" instrument is additionally shielded by 2 FR-4 (glass epoxy) plates with total thickness of 3.15 mm and by 5.0 mm carbon fiber reinforced polymer (CFRP).

The calculated required kinetic energy of particles penetrating all the shielding's perpendicular to the detector is 2.6 MeV for electrons and 62.5 MeV for protons (https://physics.nist.gov/PhysRefData/Star/Text/PSTAR.html)*.



*The obtained kinetic energy values are approximatively because in the cited above tables the FR-4 and CFRP materials are not listed.

Dose to Flux (D/F) calculations*



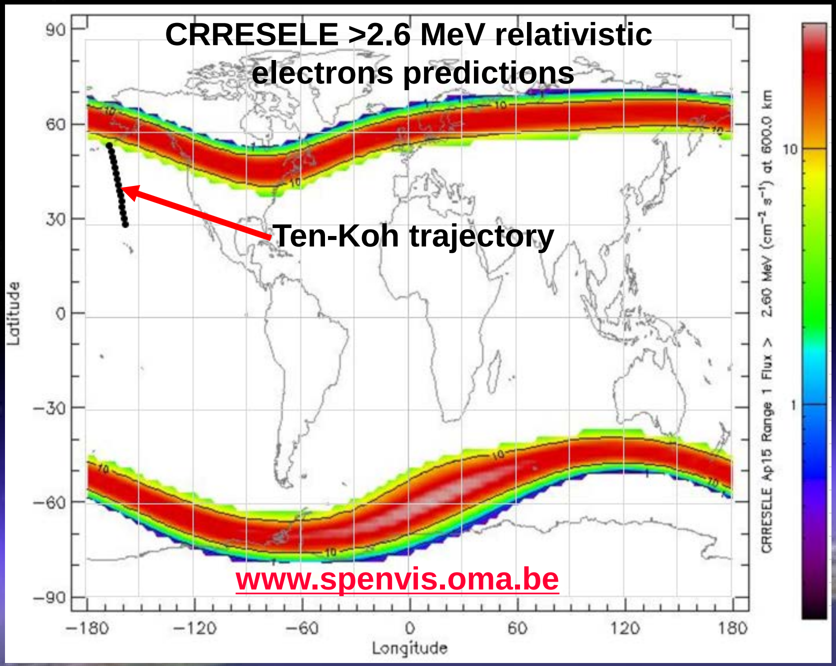
$$D/F(E_e) = 6x10^{-9} E_e^{-0.9} + 2.5x10^{-8} E_e^{0.15}$$

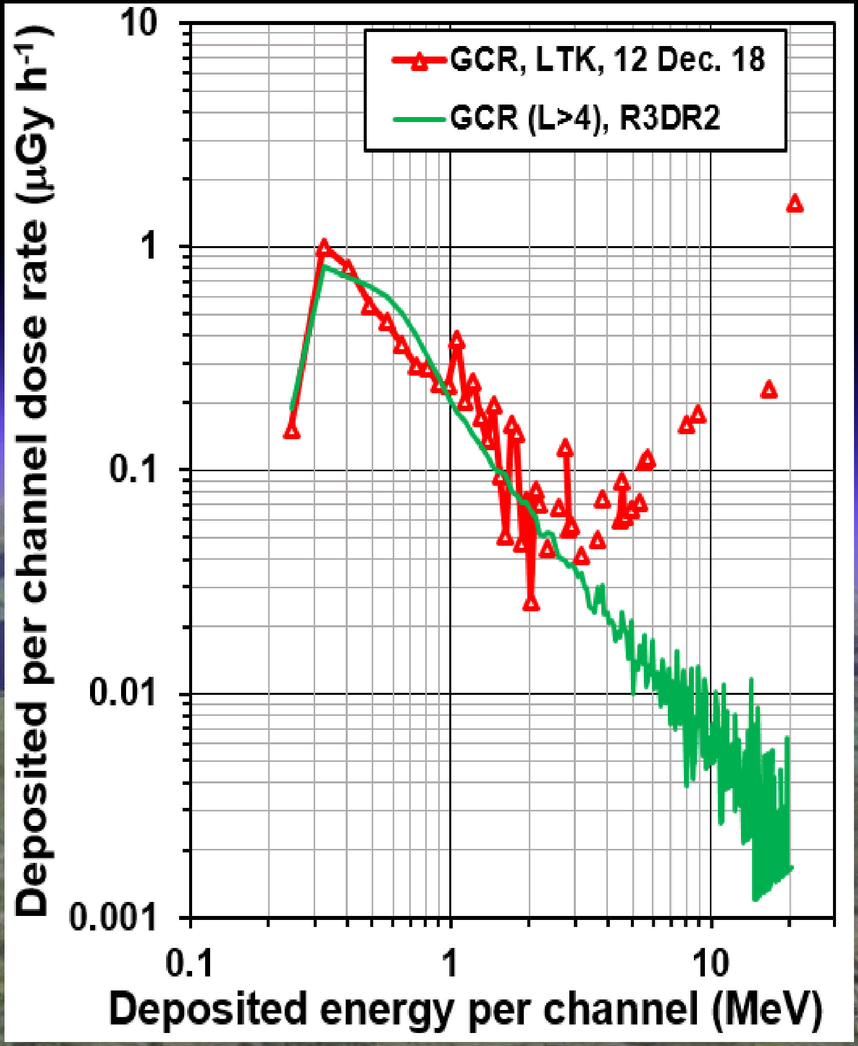
$$D/F(E_p) = 4x10^{-8} E_p^{-0.8} - 6x10^{-10} E_p^{0.85}$$

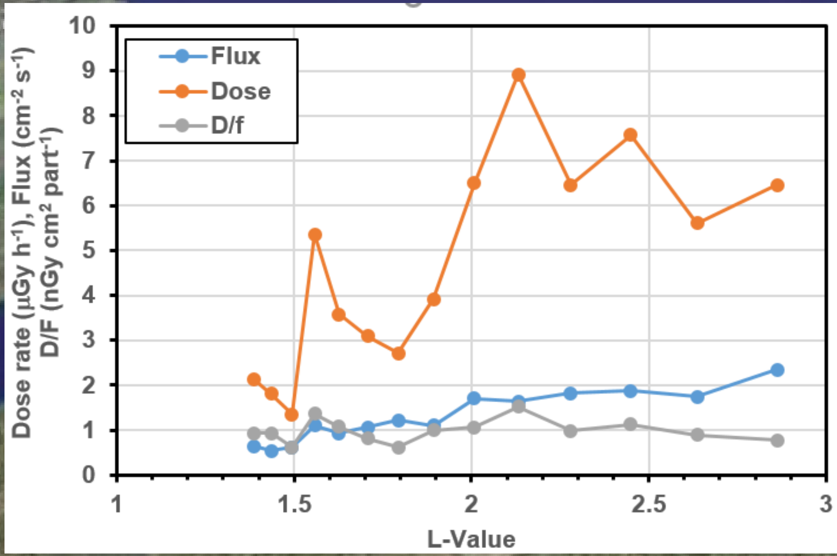
The valid ranges for D/F(Ee) and D/F(Ep) are 1-10 MeV, and 1-1000 MeV, respectively

Haffner, J.W., Yadernoe izluchenie i zashchita v kosmose (Nuclear Radiation and Protection in Space), pp 115, Atomizdat, Moscow, 1971. (book in Russian).

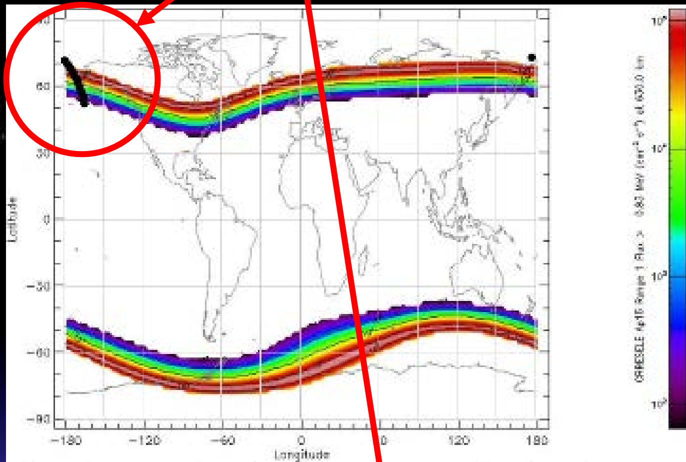
12 December GCR data

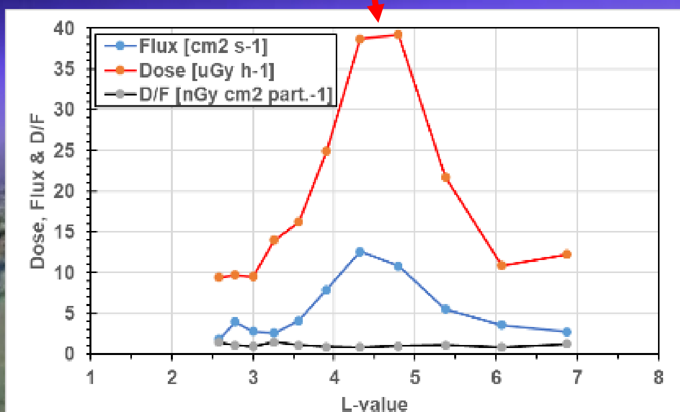


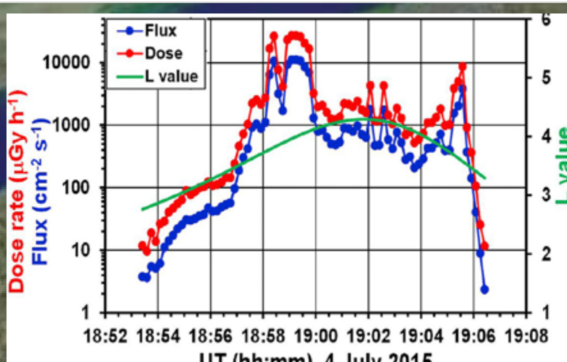


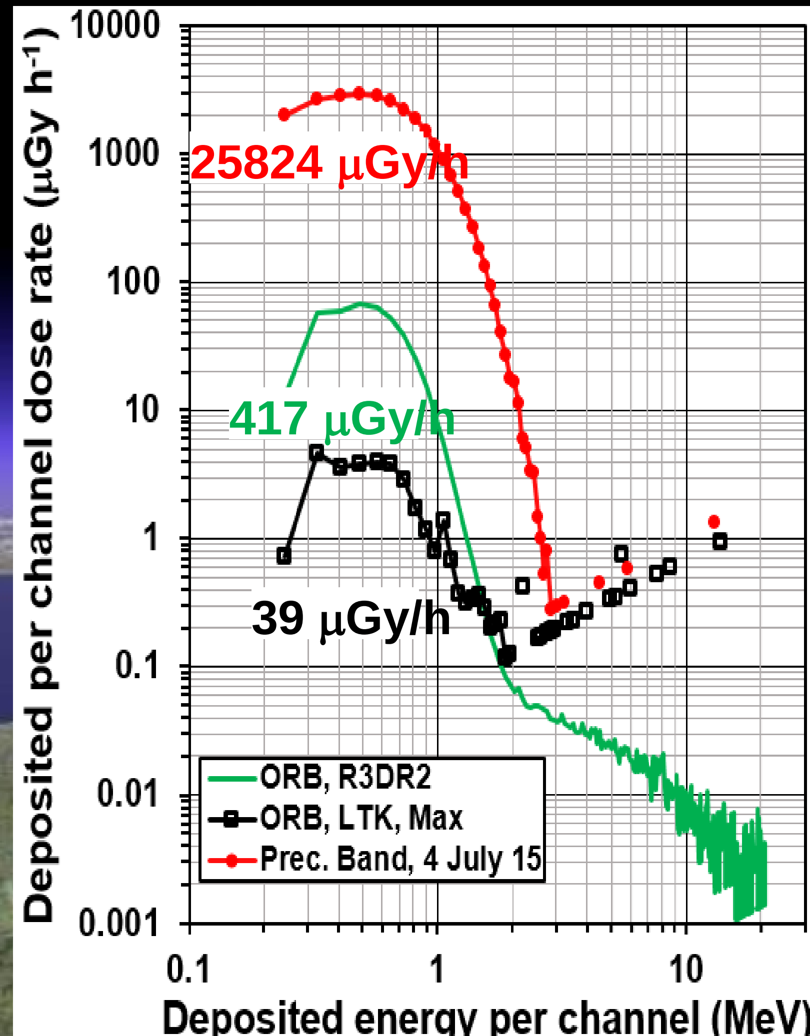


Ten-Koh crossing of the Outer radiation belt (ORB) region on 20 December 2018 data. Comparison with R3DR2 data



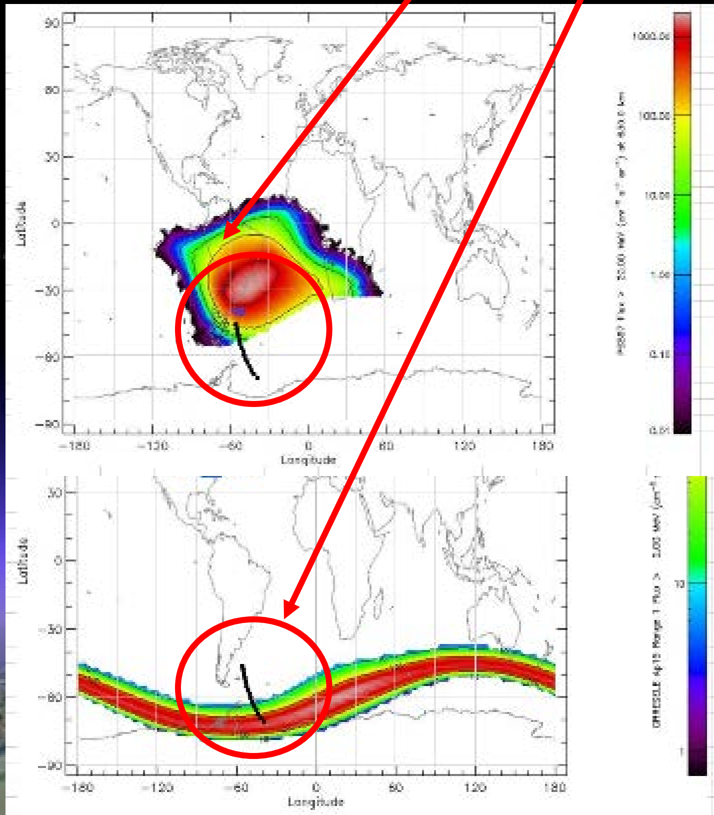




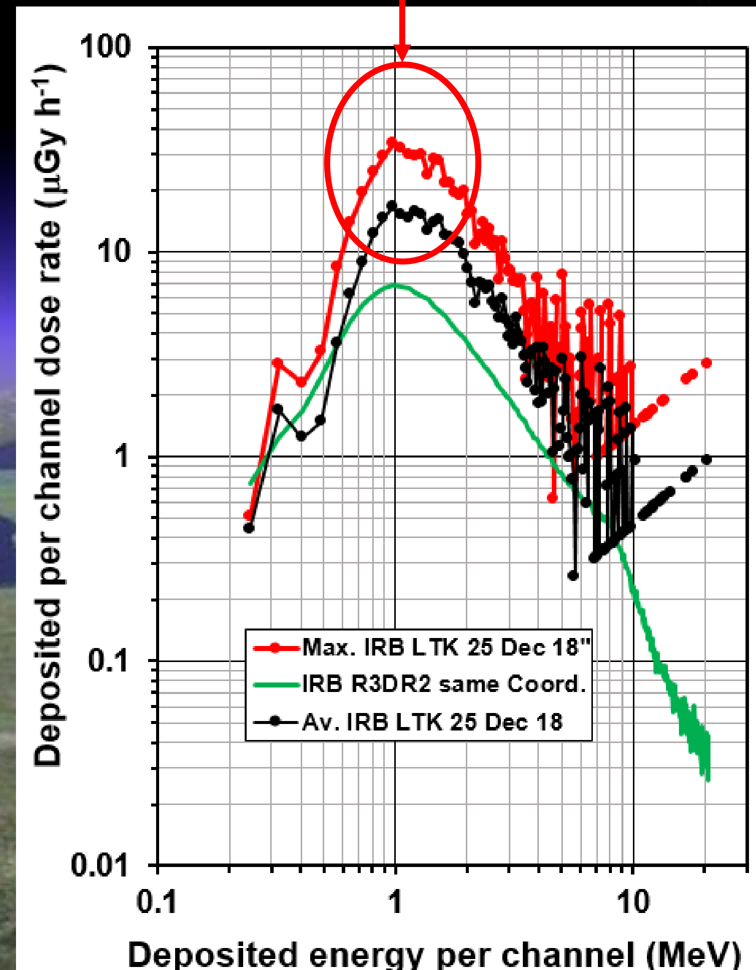


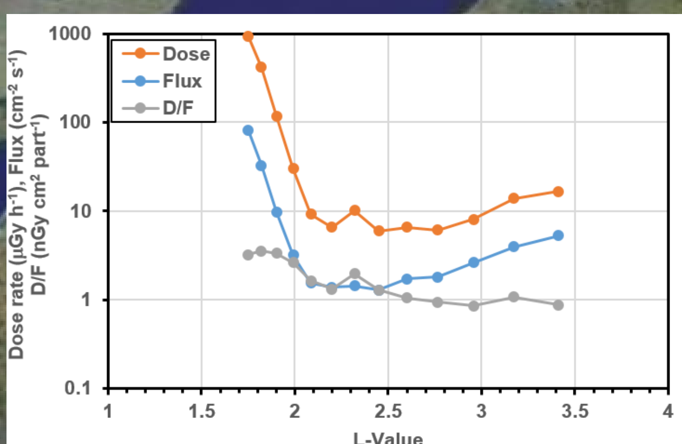
Dachev, T. P., Relativistic Electron Precipitation Bands https://doi.org/10.1016/j.jastp.2017.11.008

Crossing of the Inner radiation belt (IRB) in the region of the South-Atlantic anomaly SAA and ORB are observed in the 25 December 2018 data

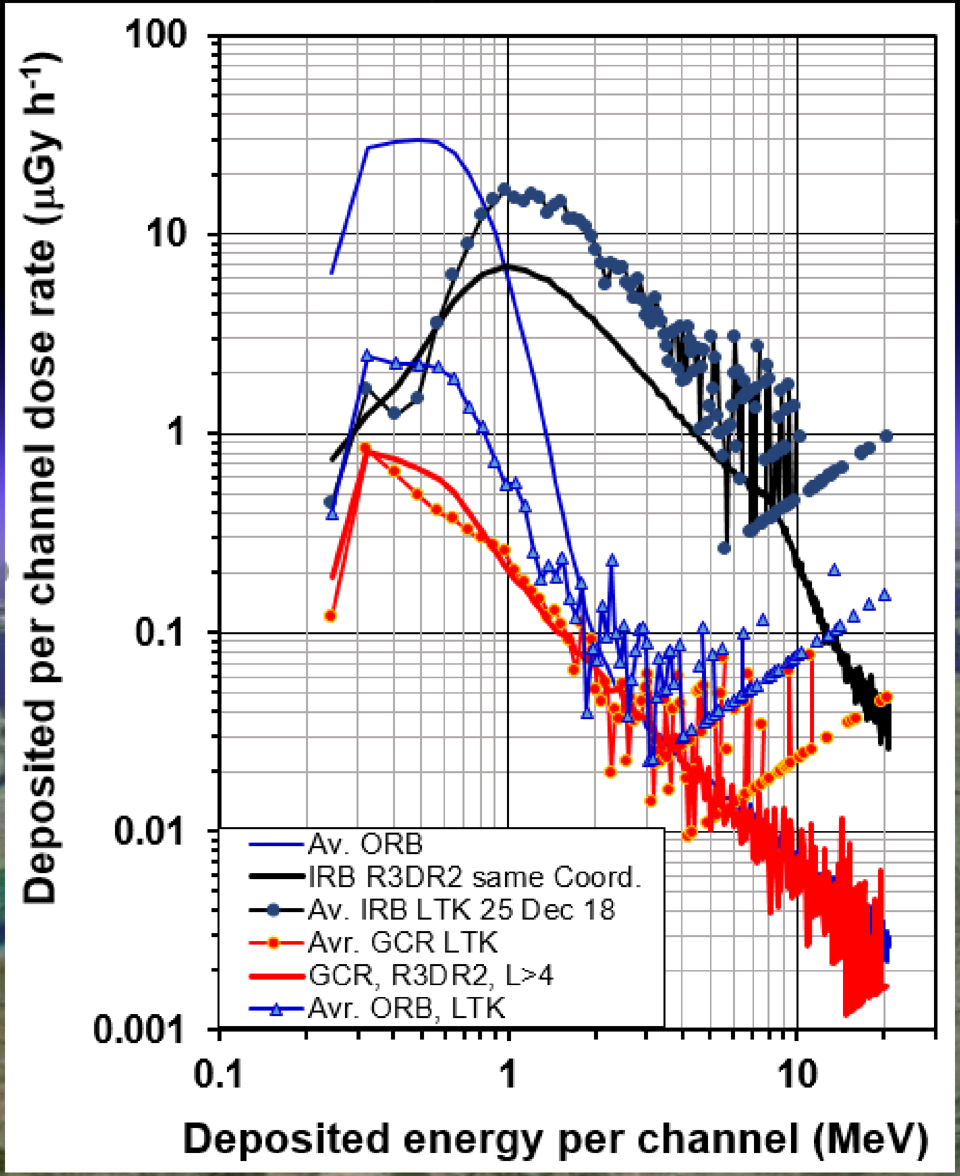


The spectra maxima of LTK are moved to the left similarly to the R3DR2 IRB data.





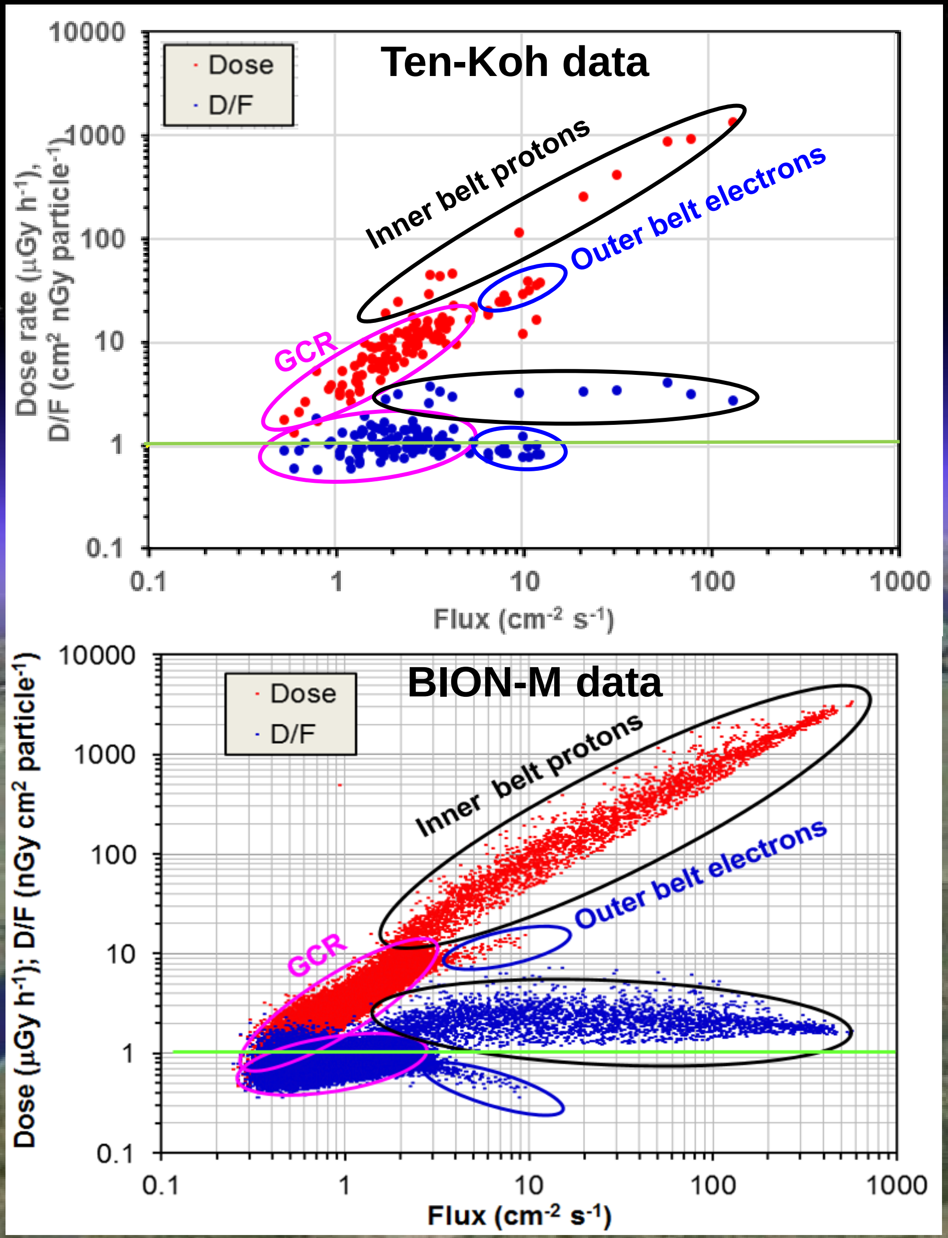
Comparison of the spectra shapes, obtained by LTK on Ten-Koh and R3DR2 on ISS



The spectra shapes of equal color lines are very similar.

This verify the right Interpretation of the LTK data.

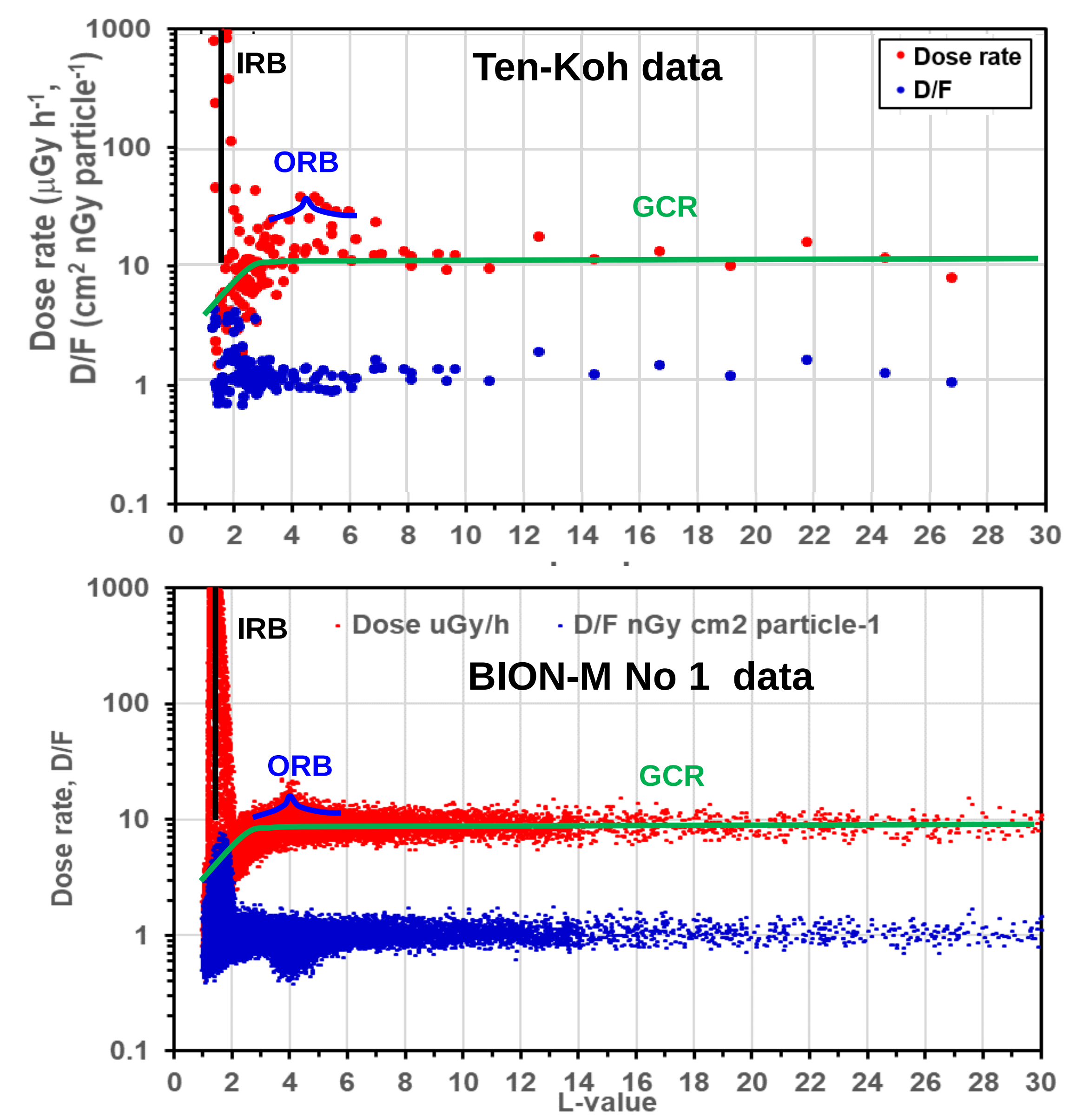
Comparison of the dependence of the dose rate and D/F from flux at Ten-Koh and BION-M No 1 satellite



Never the less, the smaller statistics on Ten Koh satellite, the features are very similar.

It is seen that the maximal LTK relativistic electron flux with energy above 2.6 MeV is 12.57 cm^{-2} s^{-1}.

Comparison of the L profiles of the dose rate and D/F values at Ten-Koh and BION-M No 1 satellite



Av. Dose L>8 = 11.7 µGy h^{-1}

Av. D/F= 1.188 cm^2 nGy $part.^{-1}$

Never the less, the smaller statistics on Ten-Koh satellite, the L-value profile features are very similar.

The Ten-Koh GCR dose rate Value is larger because the smaller solar activity.

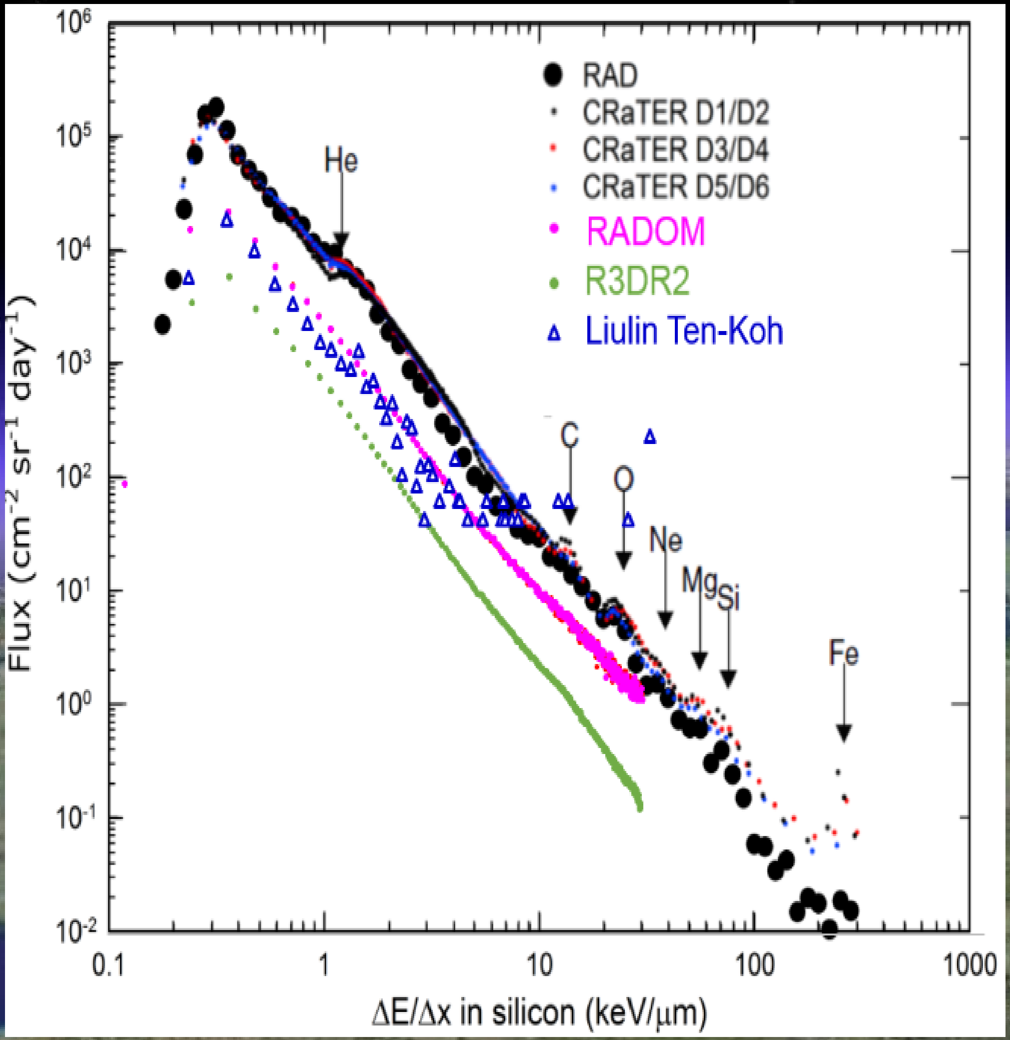
Av. Dose L>8 =9.05 µGy h^{-1}

Av. D/F= 1.061 cm^2 nGy $part.^{-1}$

The analysis of the comparison between Ten-Koh and BION data can be summarized as follows:

- Both data sets are obtained at similar relative large shielding's inside the structure of the satellites, that is why the maximal ORB dose rate data are relative small;
- The GCR dose rate data for L>8 at Ten-Koh satellite

Comparison of LET spectra, obtained by different instruments at different carriers inside and outside the Earth magnetosphere



The figure shows relatively good agreement between the shapes of the different spectra. The RADOM, R3DR2 and LTK spectra are shorter than the RAD and CRaTER spectra because they were obtained with single silicon detector, which covers only the LET range between 0.233 and 29.8 keV mm^{-1}.

The RADOM spectrum is below the RAD and CRaTER spectra because smaller shielding.

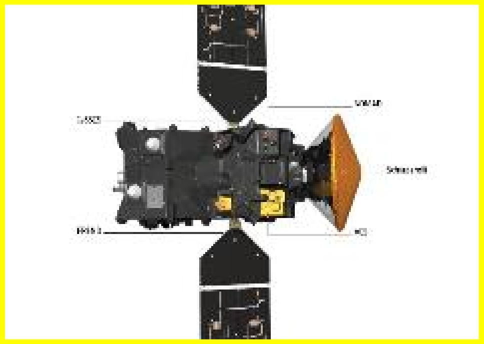
The LTK spectrum is below the RADOM spectrum because these data are obtained inside the magnetosphere in relatively small geographic region.

Future experiments with Liulin type instruments

The Liulin-ML dosimetry telescope is under development for the ESA-Roscosmos lander on MARS in 2020

http://esa-pro.space.bas.bg/

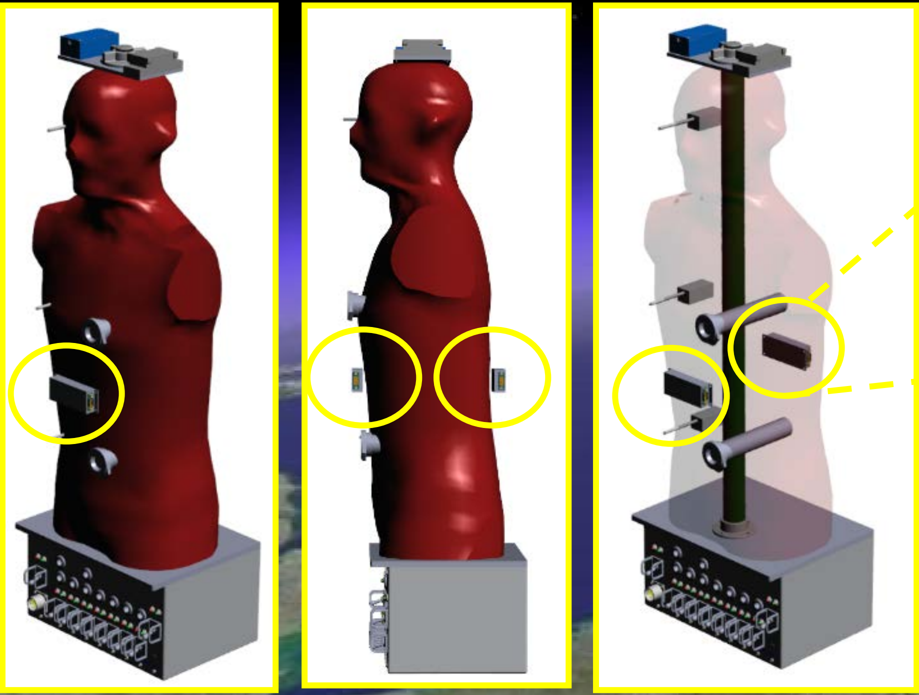
2016 г.



2020 г.

2 Liulin-AF instruments are part of the Matroshka III research project with participants from Germany, Japan, Poland, Hungary, Russia and Bulgaria to study the dynamics of cosmic radiation accumulation in tissue-equivalent phantom in the Russian segment of ISS

2022



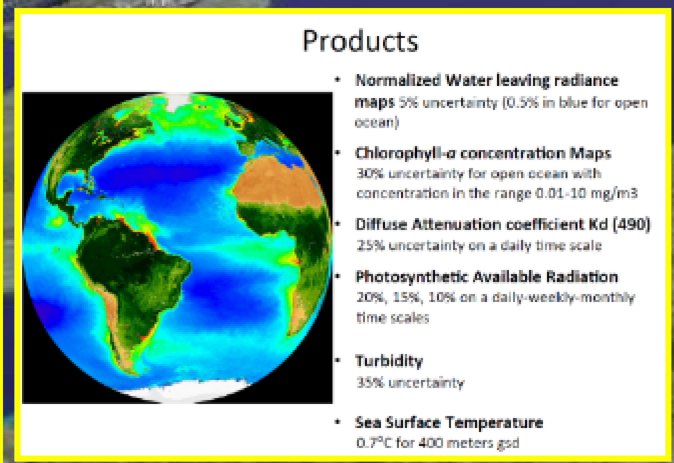
"Liulin-AF“ spectrometers location in the Matroshka-III Phantom

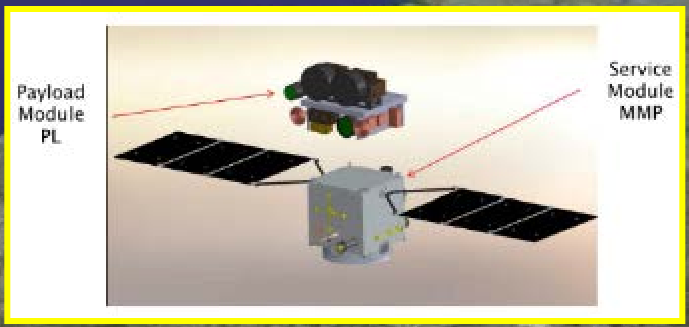
Expected appearance of "Liulin-AF" spectrometers

2021

Liulin-AR spectrometer for radiation environment observation on Argentinian-Brazilian SABIA-MAR 1 satellite

The SABIA-Mar (Satélite Argentino Brasileño para Información del Mar) is a dual satellite joint Argentine-Brazilian Earth observation mission, which objective is to study the oceanic biosphere, its changes along time and how it is affected and reacts to human activity. The Argentinian SABIA-Mar 1 satellite is planned to be launched at 702 km sun-synchronous circular orbit in 2021. The platform and the instruments for ocean color observation and sea surface temperature determination are: 1. developed and built in Argentina. A Liulin instrument for determination and quantification of the global distribution of the 4 possible primary sources of space radiation outside the satellite: The Liulin-AR dimensions are 100x40x20 mm and weight of 0.092 kg.





The SABIA-Mar satellite

The Liulin-AR instrument

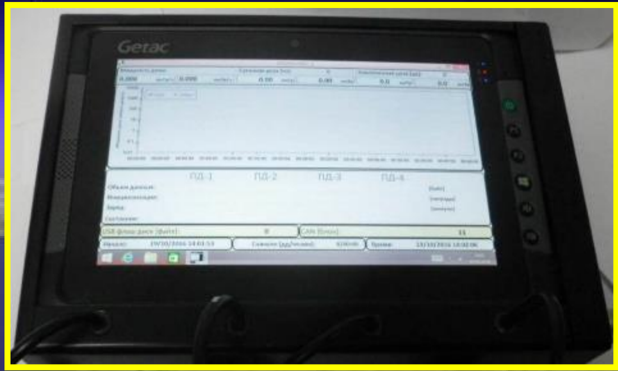
IKIT-BAS in cooperation with the University of Erlangen, Germany and IMBP-RAS, Russia will participate in the experiment BION-M-2 satellite with the P3D-B3 instrument in 2021 at an altitude of 800-1000 km and orbit inclination 62°

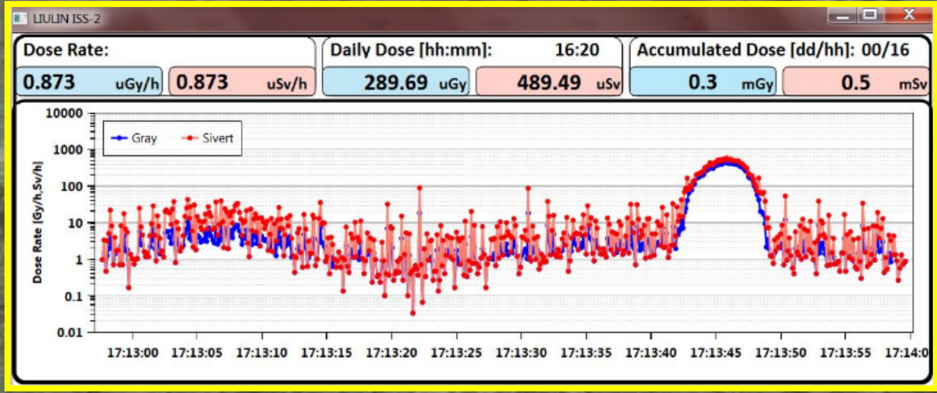
2021

"Фотон-М" №4

The Lyulin-MKS-2 is being developed from 2014 to 2018. The aim is to create an service dosimetric system for monitoring the personal dose of crew members in the Russian segment and outside the ISS

The instrument's priority is to measure the dynamics of dose accumulation during exit into open space. Similar measurements of “MIR" and ISS have not been done so far!





Liulin instrument online database

Conclusions

- Different sources of cosmic radiation form dangerous human health conditions in the Earth's, Moon and Martian space environment;

- The analysis of the preliminary LTK data shows that they are reliable and can be used further for the comprehensive studies of the Ten-Koh satellite radiation environment;

- The very preliminary comparison of the relativistic electron fluxes with energies above 2.5 MeV, measured on ARASE/ERG and Ten-Koh satellite shows that that they are with similar values. Further work is necessary for more detailed comparison;

- Space radiation limits the time and place of direct participation of people in future space missions;

The Liulin instrument database contains space-born data from 10 Liulin type instruments flown in space between 1991 and 2018. More than 11 million dose and flux measurements are available together with their time and space coordinates. The user manual is at: http://esa-pro.space.bas.bg/sites/default/files/Liulin_database_user_manual_August_2018.pdf

The database is situated in two pages:

Page 1: http://esa-pro.space.bas.bg/datasources:

Downloads to the user's computer original, zipped "DATA SOURCES", which contain lists of the measured parameters together with the time and space coordinates in comma separated values (CSV) format.

Page 2: http://esa-pro.space.bas.bg/database:

Allows source (experiment) selection, visualization, synchronized zoom, tooltip and hairline; export of the charts to vector, JPEG and PDF format; data export in CSV and TXT format.

All LTK and R3DR2 spectra