# Analysis of the first space radiation data, obtained by Liulin Ten-Koh instrument on Japanize Ten-Koh satellite

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# Outlook

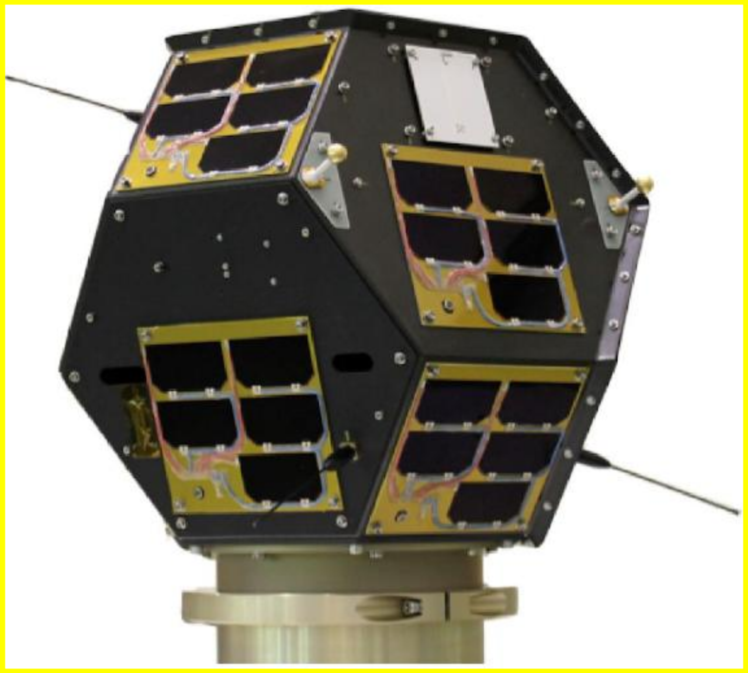
- Liulin Ten-Koh spectrometer;
- Calibrations of Liulin Ten-Koh;
- Liulin Ten-Koh first data analysis;
- Future space experiments with Liulin type instruments;
- Liulin instrument online database;
- Conclusions

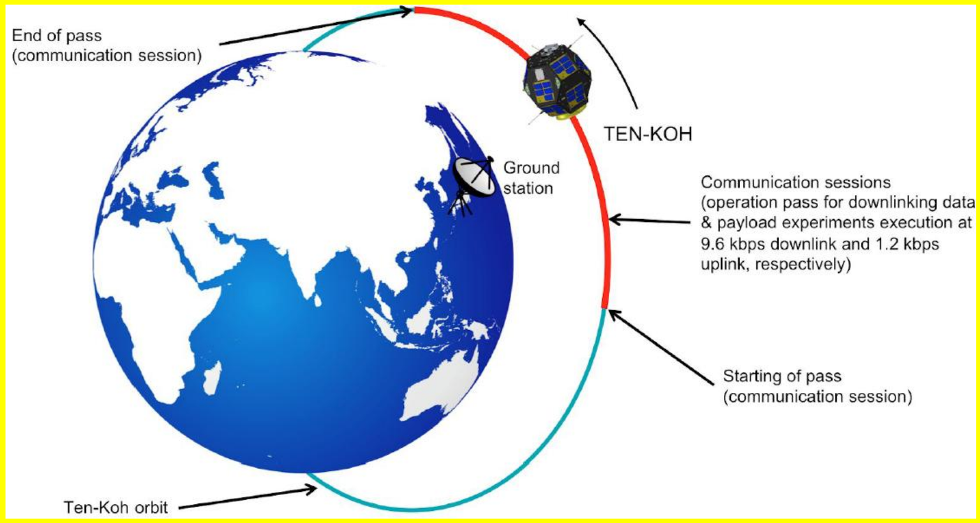
# Bulgarian space radiation experiments on satellite and rocket

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).

# Liulin Ten-Koh (LTK) spectrometer

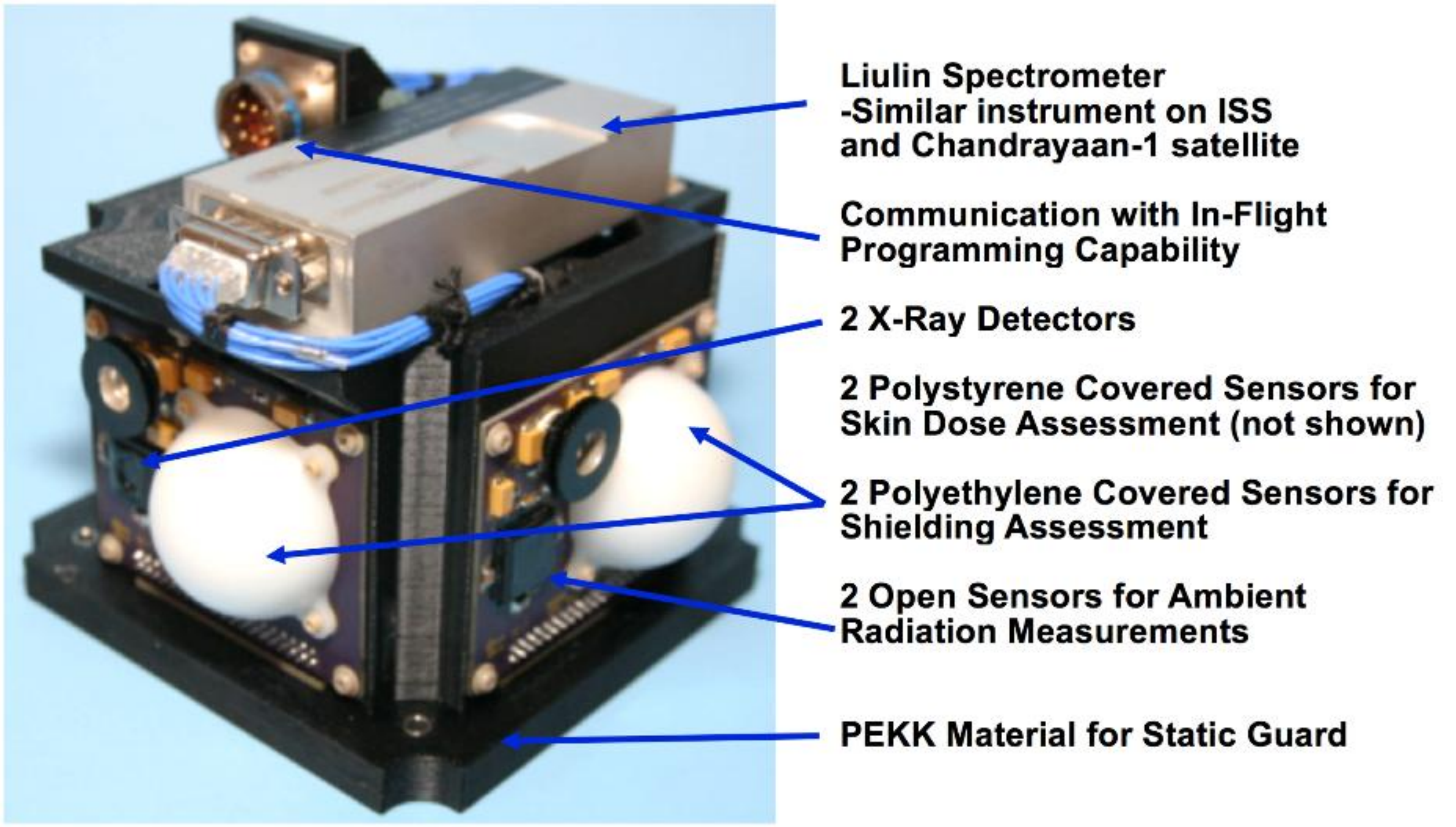
**Ten-Koh satellite is a 23.5 kg small satellite developed under the philosophy of low size and cost while trying to provide high output capabilities for space environment effects research. Developed by Kyushu Institute of Technology in Japan, in partnership with the Radiation Institute for Science and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



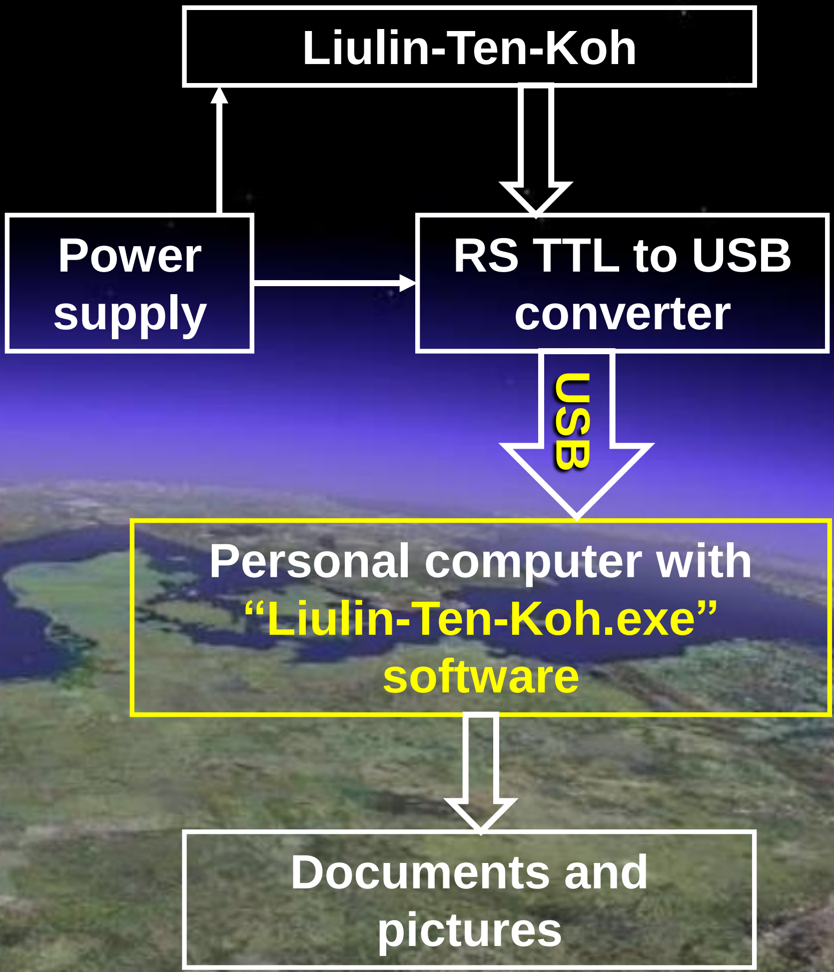



***Fajardo I., et al., Challenges, development and operation of a small satellite mission to explore the space environment and its effects on spaceborne platforms, Acta Astronautica, 2019. (in print)**

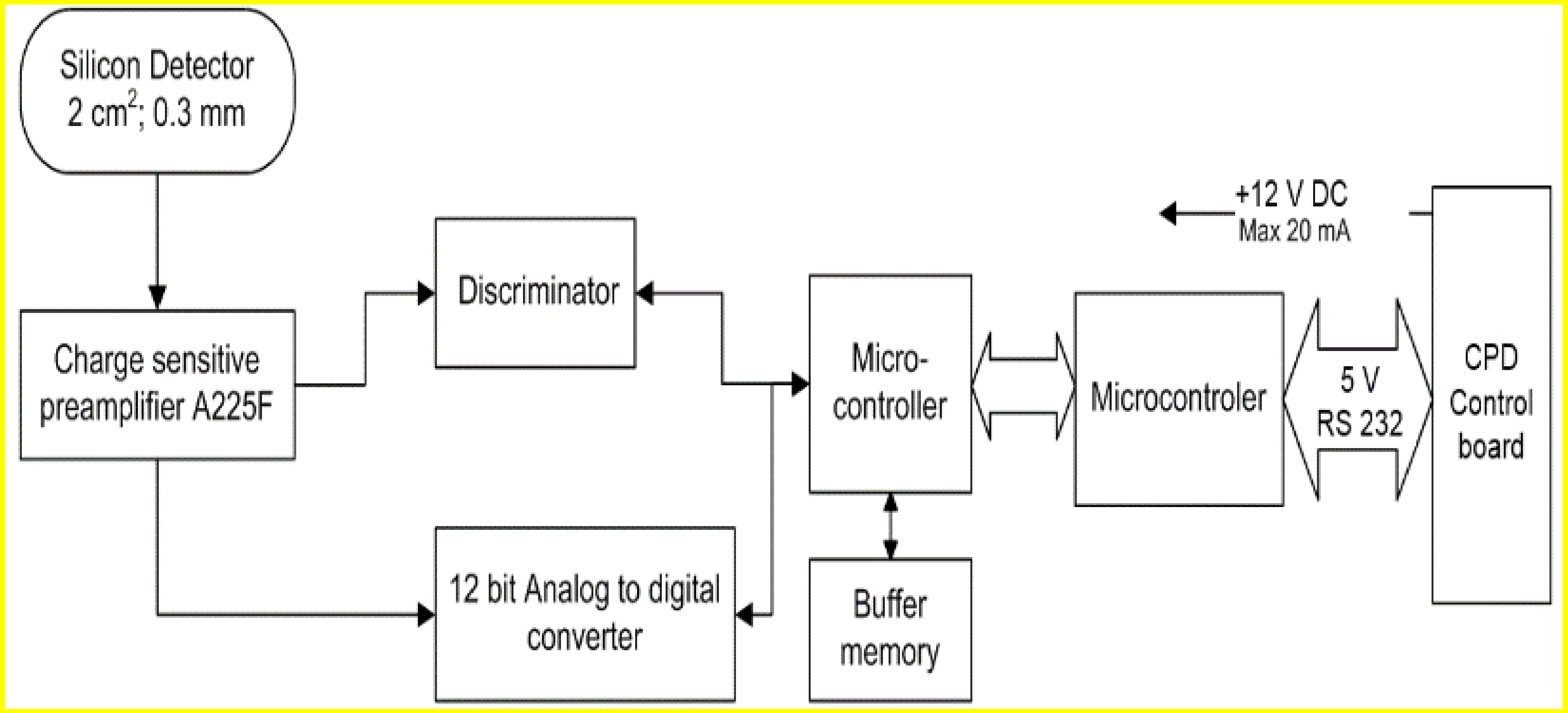
# Liulin Ten-Koh spectrometer in the Charged Particle Detector, developed by the Radiation Institute for Science and Engineering of Prairie View A&M University, USA and Holland-Space LLC, USA



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

# Block diagram of the Liulin Ten-Koh spectrometer



# Liulin Ten-Koh first data analysis
# (Preliminary results)

# Liulin Ten-Koh shielding

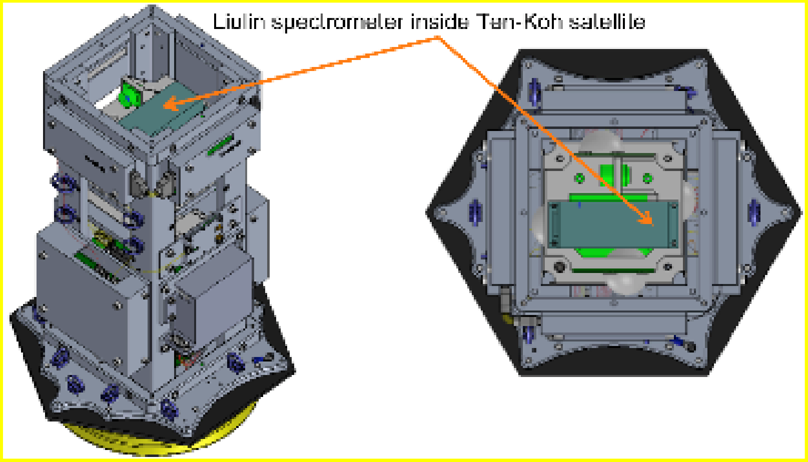
The semiconductor detector of the "Liulin Ten-Koh" instrument is mounted approximately 2 mm below the 0.3 mm thick aluminum cover plate.

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.

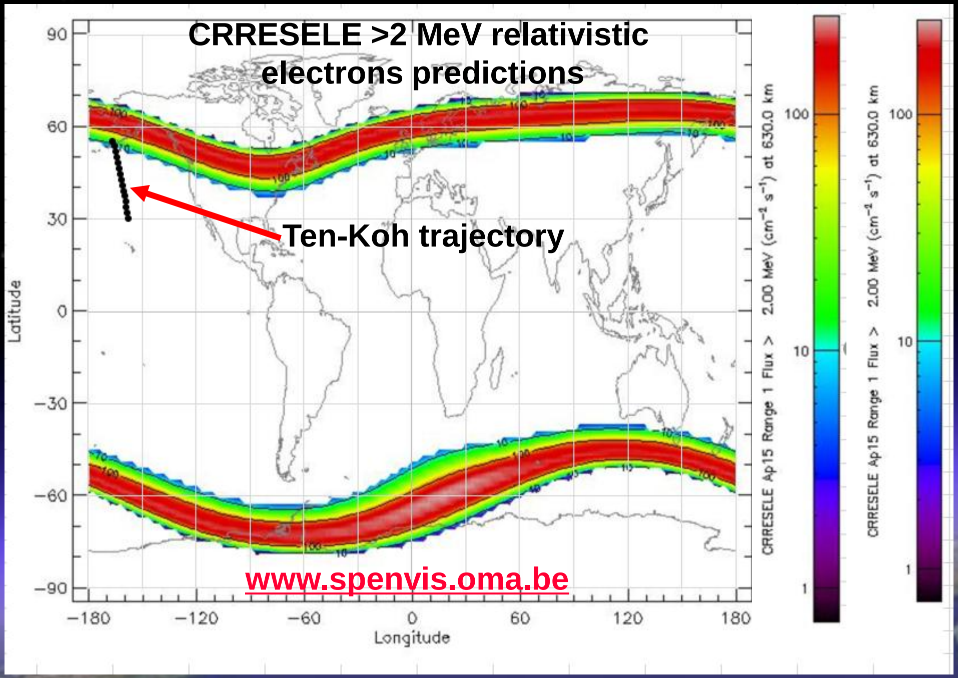
The "Liulin Ten-Koh" instrument is additionally shielded by 2 FR-4 (glass epoxy) plates with total thickness of 3.15 mm and by 5.0 mm carbon fiber reinforced polymer (CFRP).

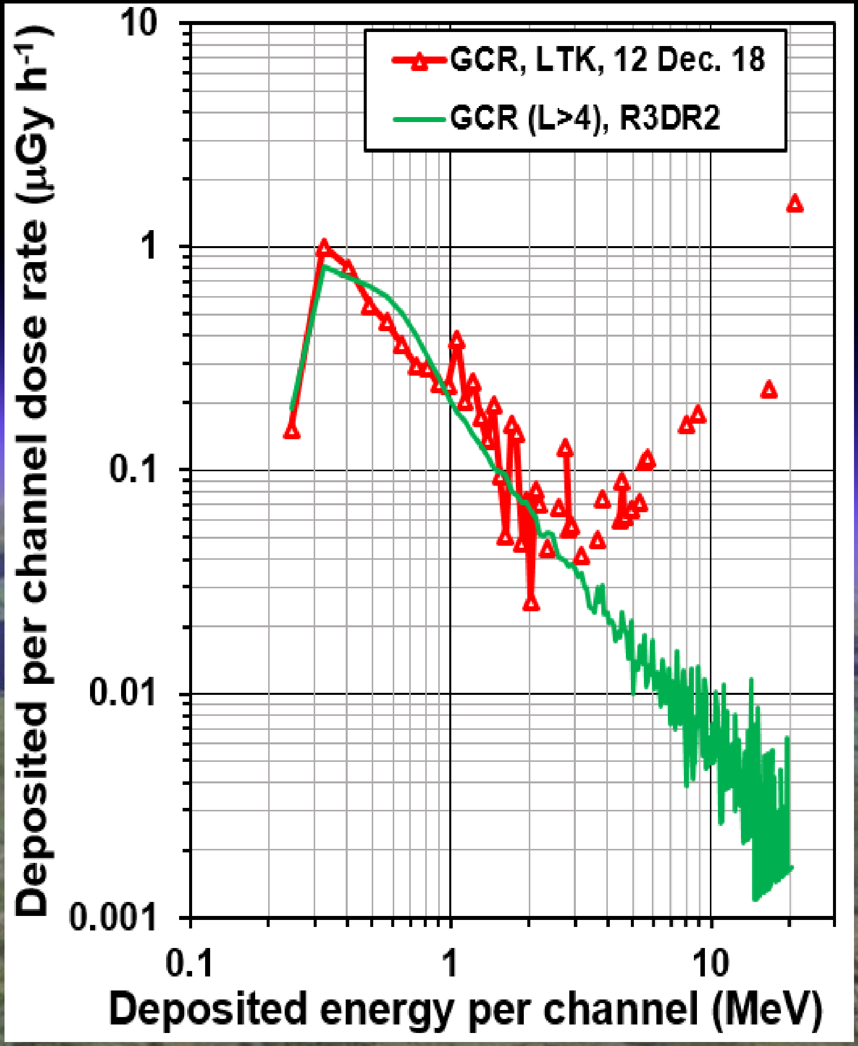
The calculated required kinetic energy of particles penetrating all the shielding's perpendicular to the detector is 2.6 MeV for electrons and 62.5 MeV for protons (https://physics.nist.gov/PhysRefData/Star/Text/PSTAR.html)*.

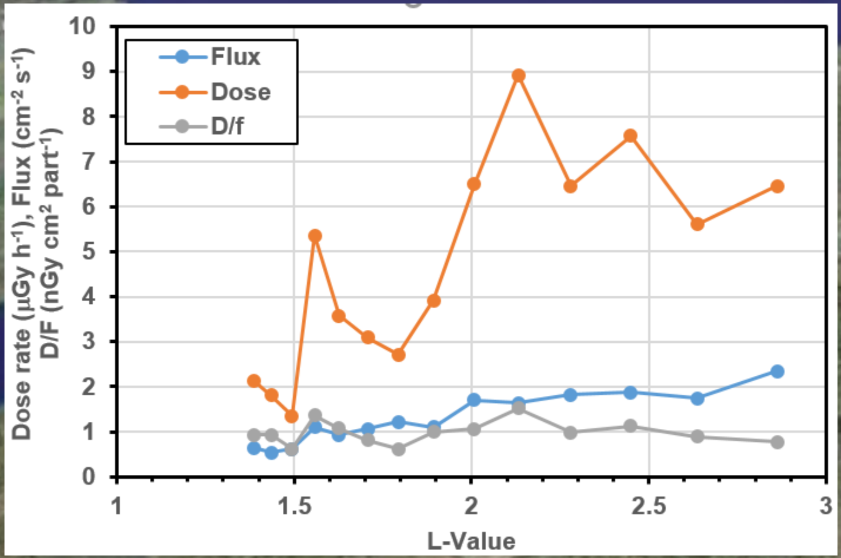
*The obtained kinetic energy values are approximatively because in the cited above tables the FR-4 and CFRP materials are not listed.



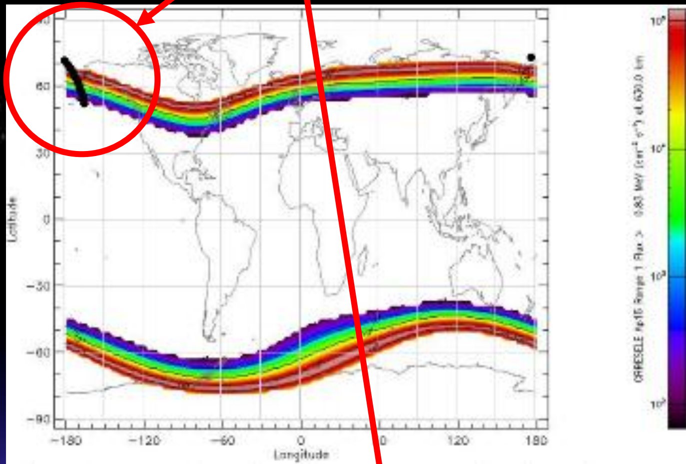
# 12 December GCR data

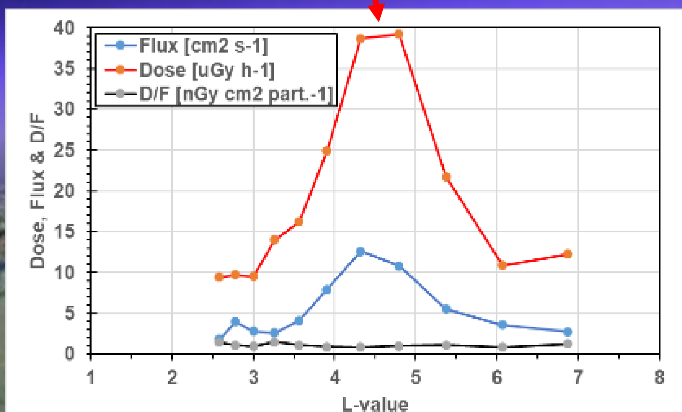


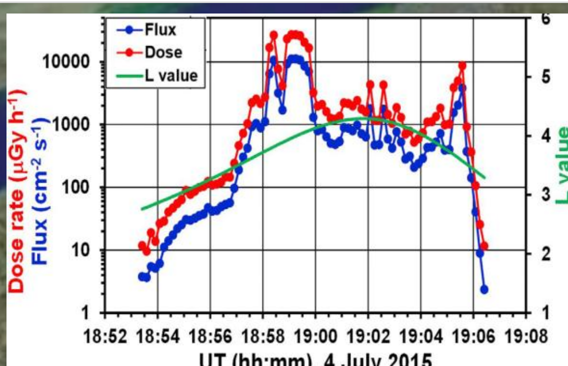



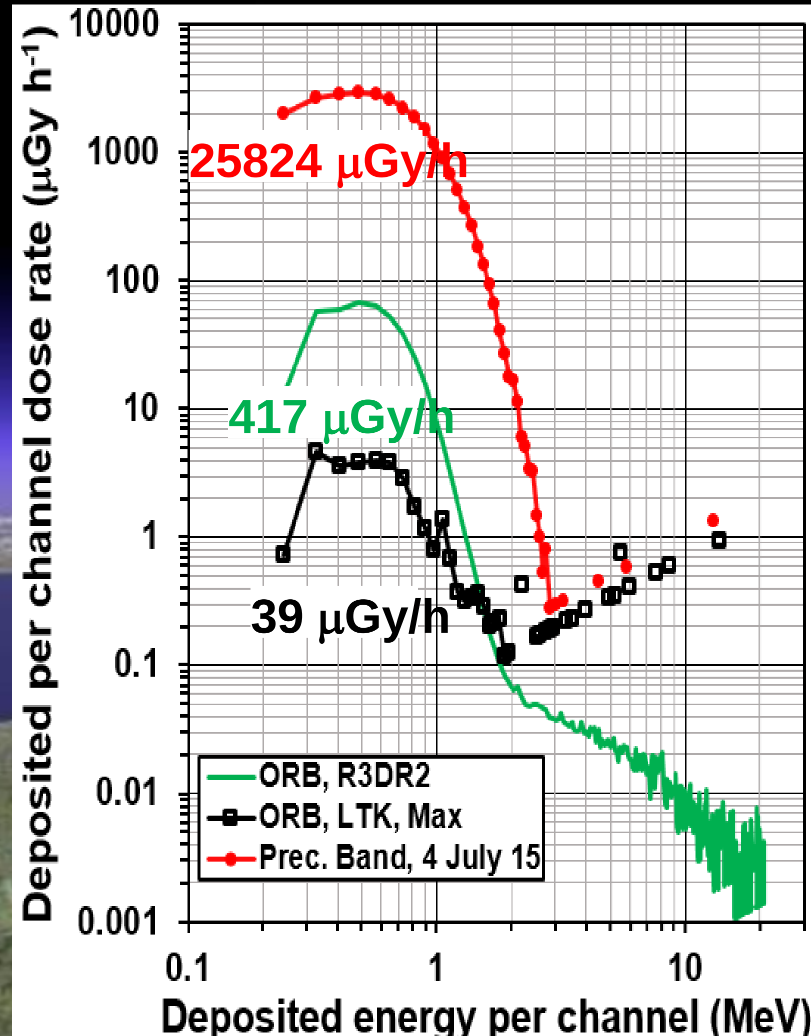



# Ten-Koh crossing of the Outer radiation belt (ORB) region on 20 December 2018 data. Comparison with R3DR2 data



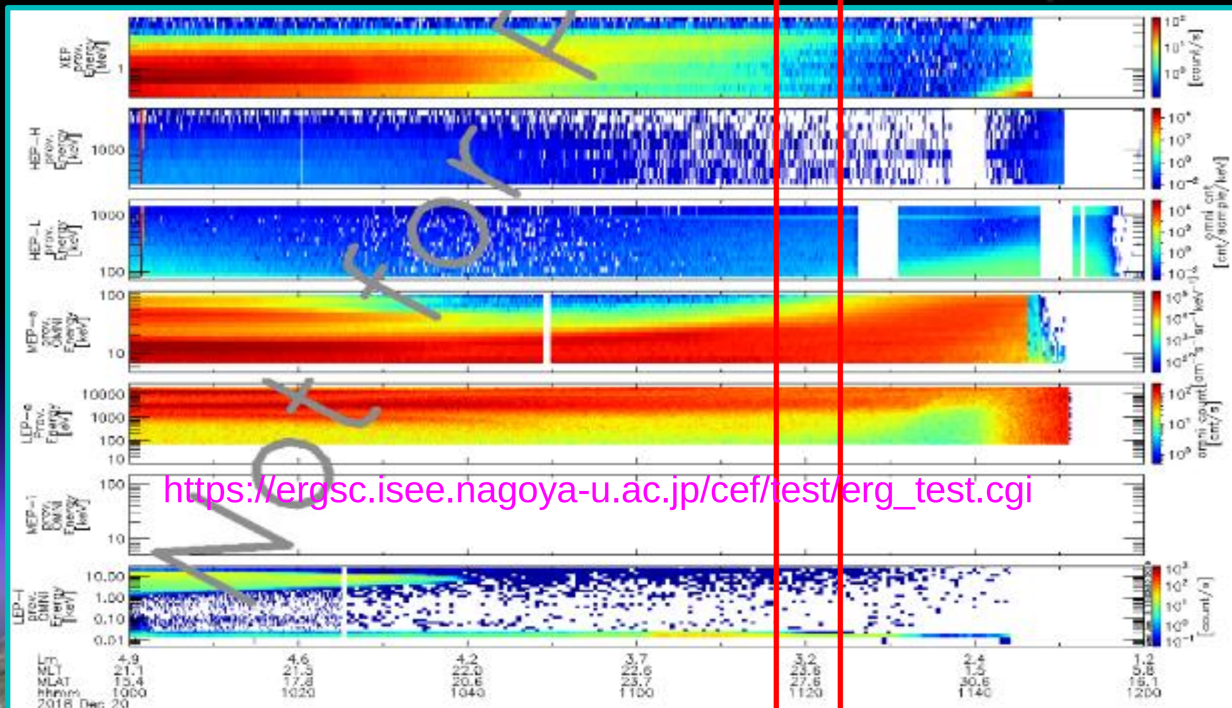



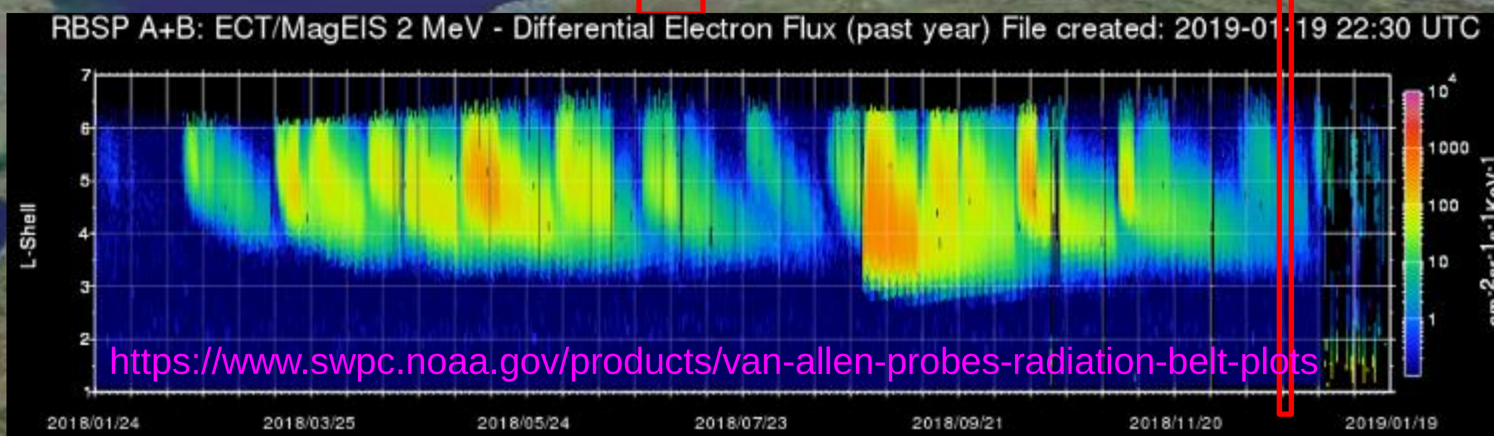




Dachev, T. P., Relativistic Electron Precipitation Bands
https://doi.org/10.1016/j.jastp.2017.11.008

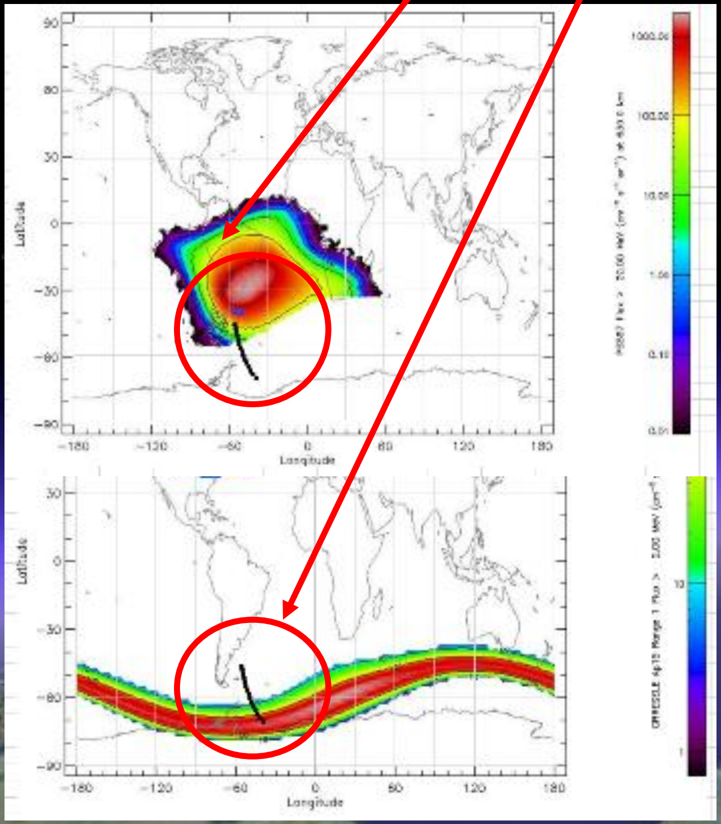
# 20 December 2018 data comparison with ARASE/ERG and Van-Allen Probes data

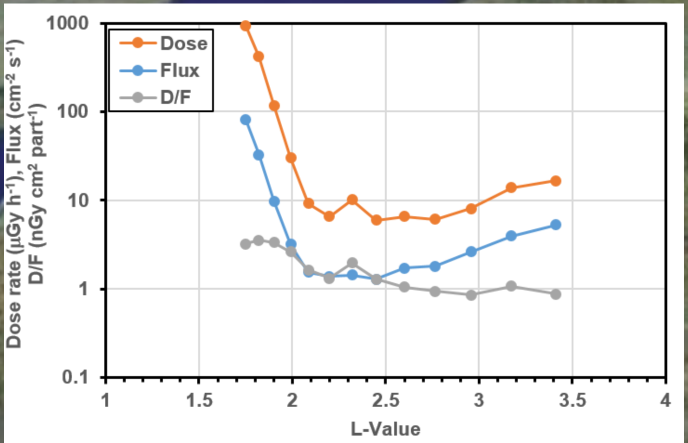



Ten-Koh satellite time interval

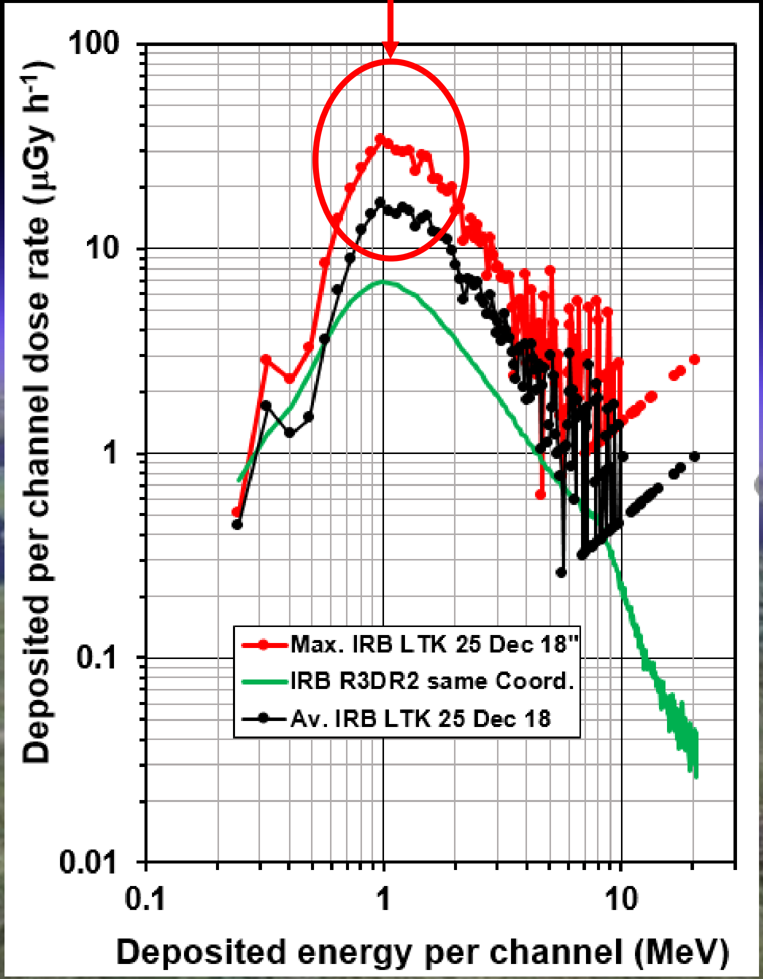


# Crossing of the Inner radiation belt (IRB) in the region of the South-Atlantic anomaly SAA and ORB are observed in the 25 December 2018 data

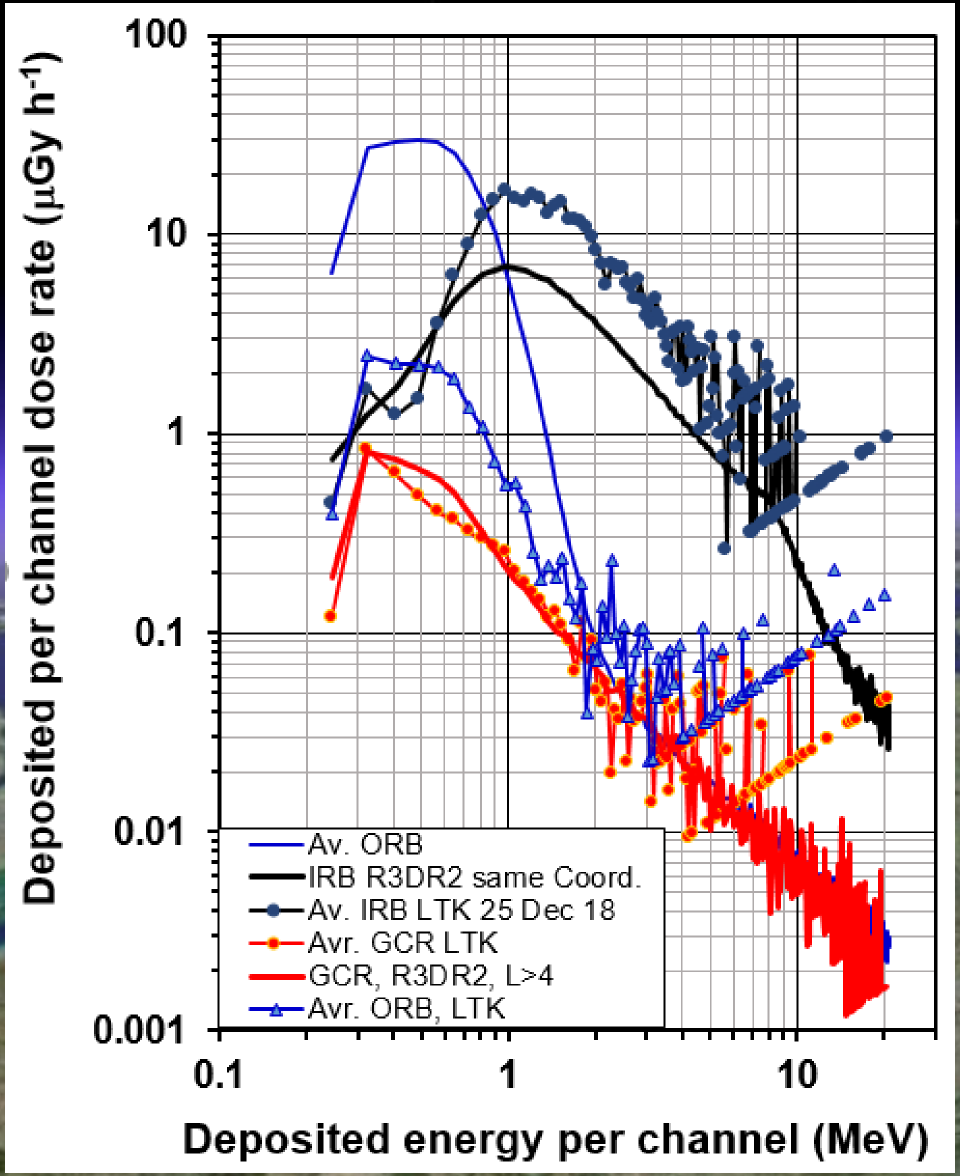



**The spectra maxima of LTK are moved to the left similarly to the R3DR2 IRB data.**



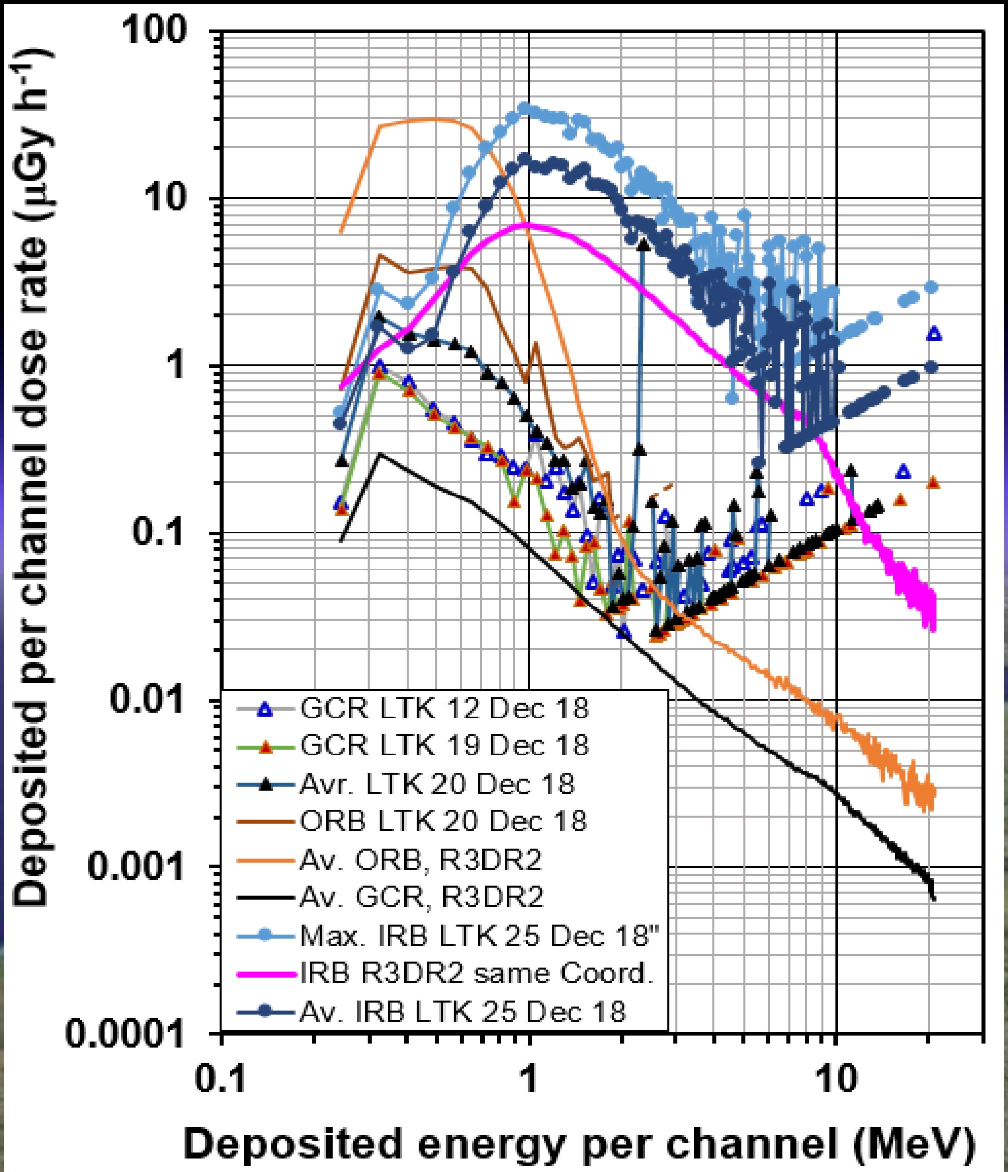
# Comparison of the spectra shapes, obtained by LTK on Ten-Koh and R3DR2 on ISS



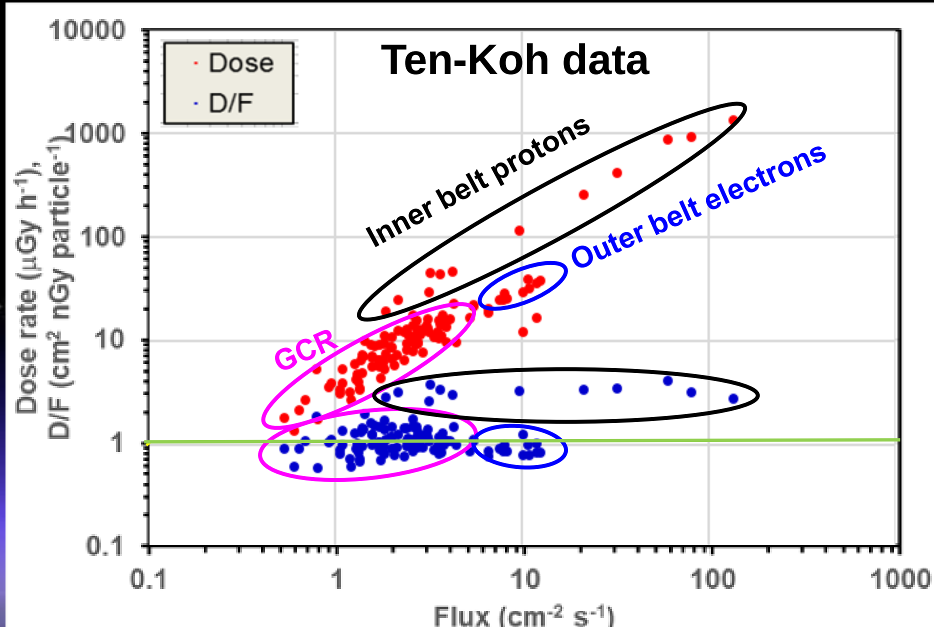

The spectra shapes of equal color lines are very similar.

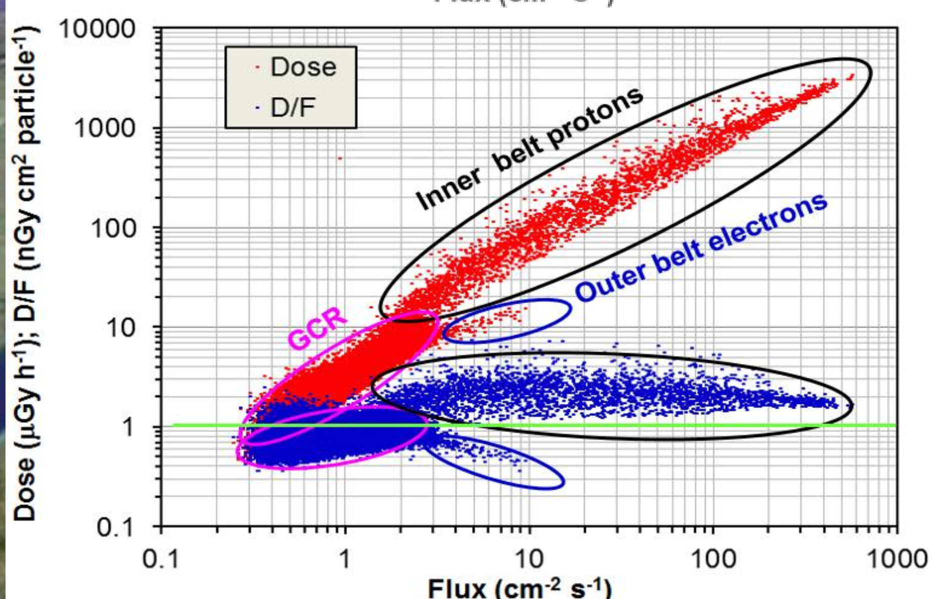
This verify the right Interpretation of the LTK data.

# All LTK and R3DR2 spectra



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

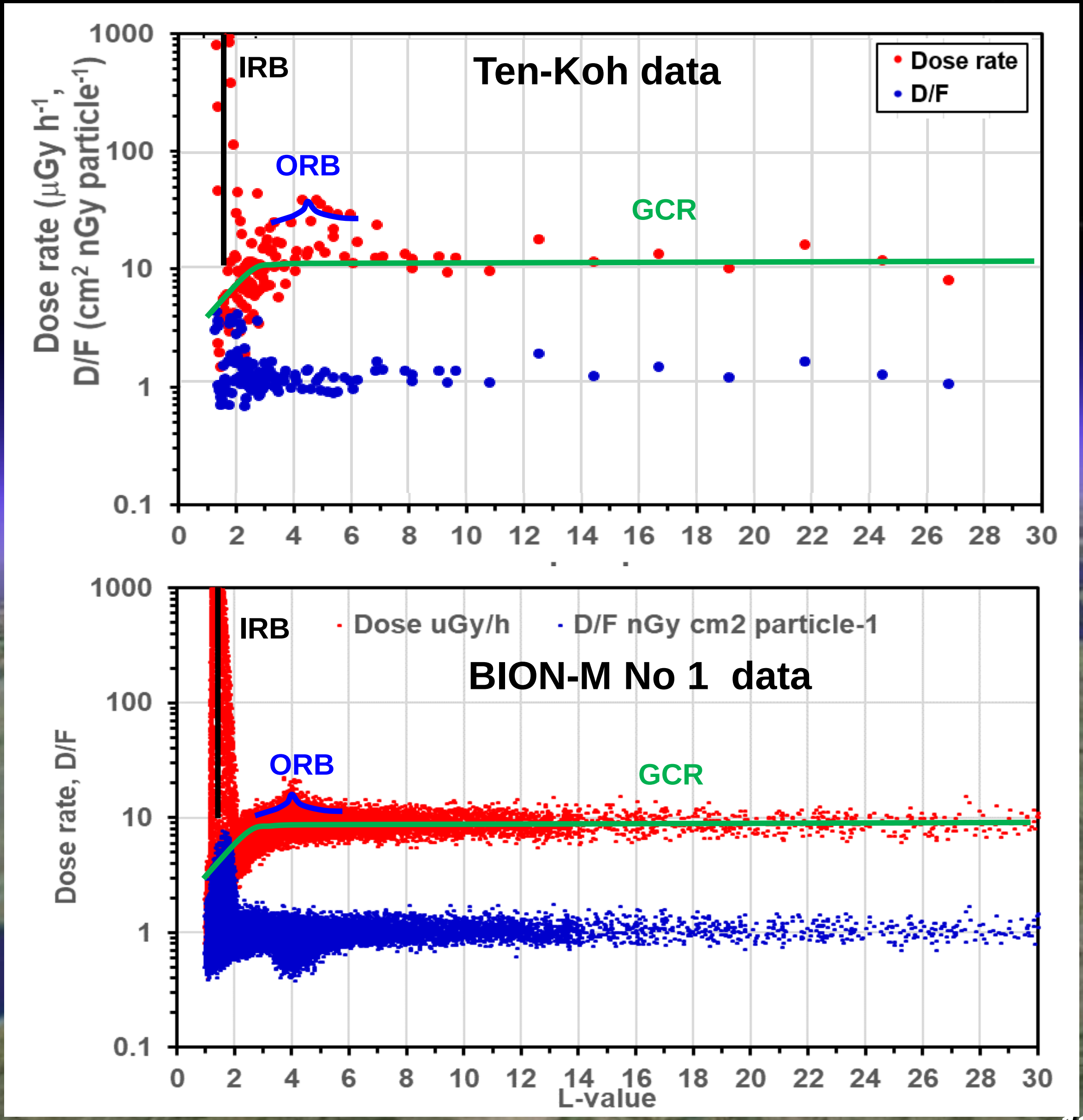



Never the less, the smaller statistics on Ten Koh satellite, the features are very similar.

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 $\mu$Gy $h^{-1}$

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

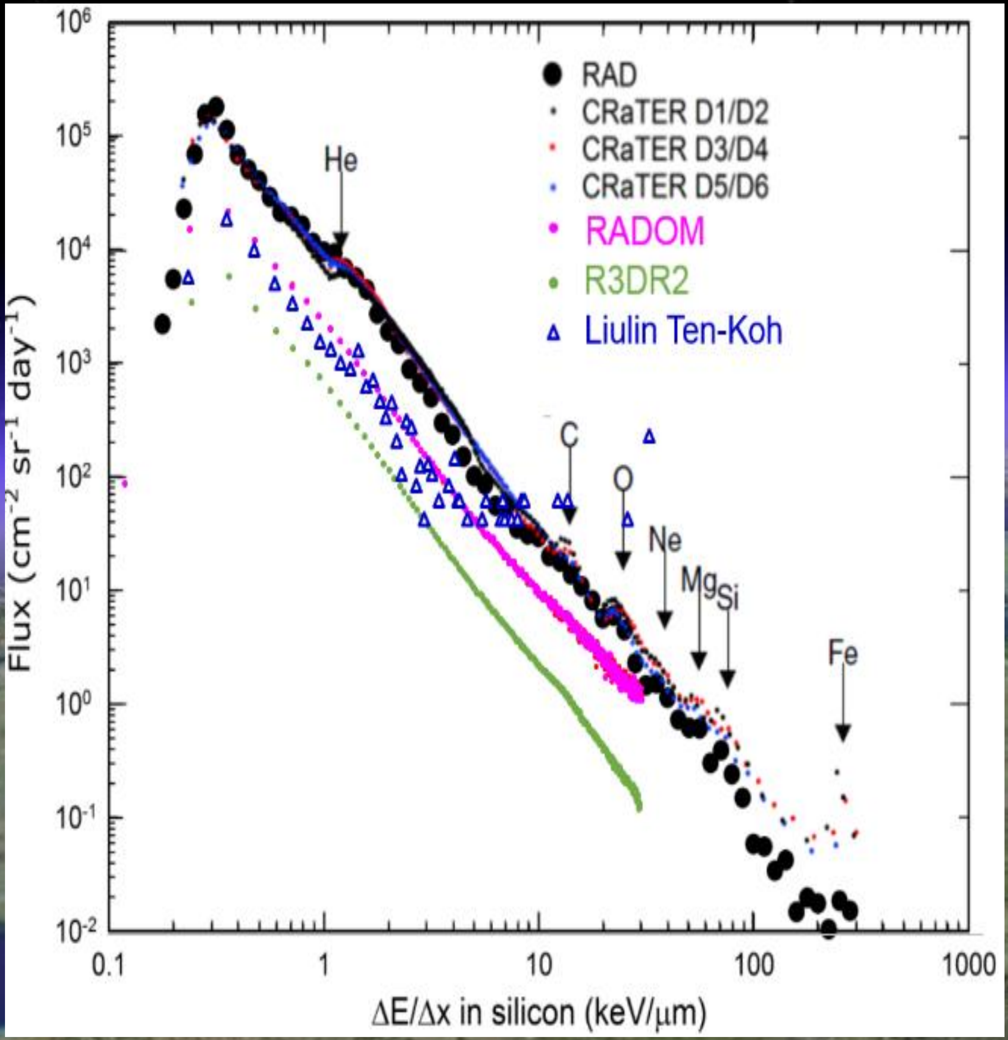
Never the less, the smaller statistics on Ten-Koh satellite, the L-value profile features are very similar.

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

Av. Dose L>8 =9.05 $\mu$Gy $h^{-1}$

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

# 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.

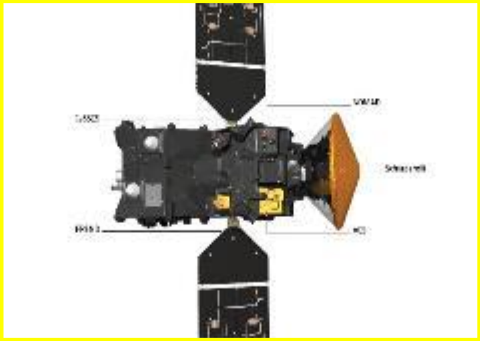
The LTK spectrum is below the RADOM spectrum because these data are obtained inside the magnetosphere in relatively small geographic region.

# Future experiments with Liulin type instruments

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

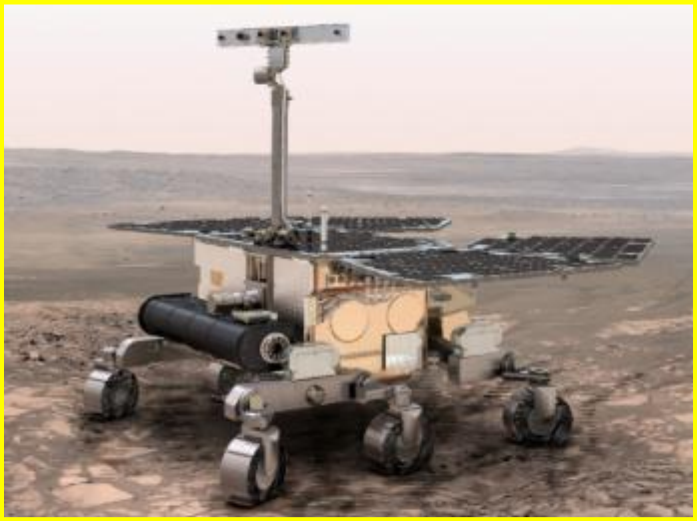
http://esa-pro.space.bas.bg/

**2016 г.**





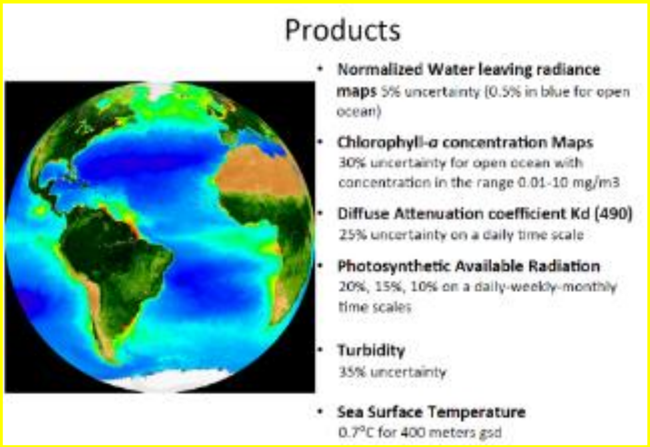

**2020 г.**

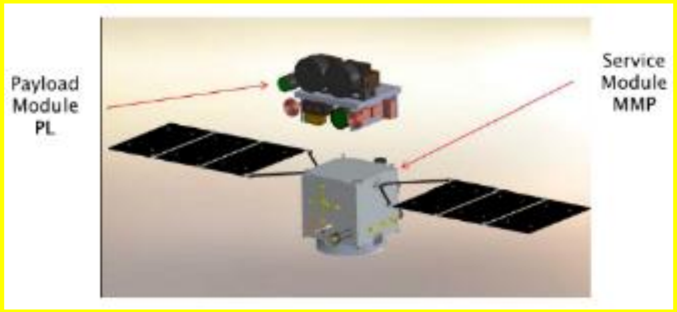


2021

# 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.**



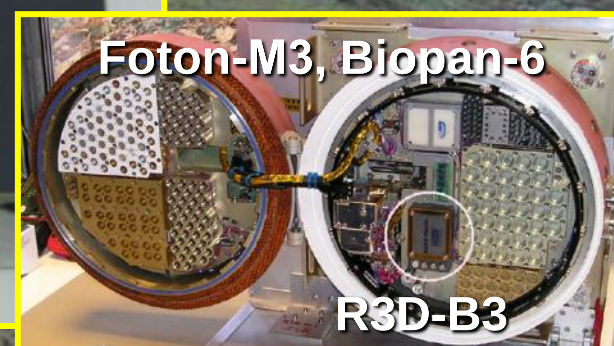

The SABIA-Mar satellite


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°

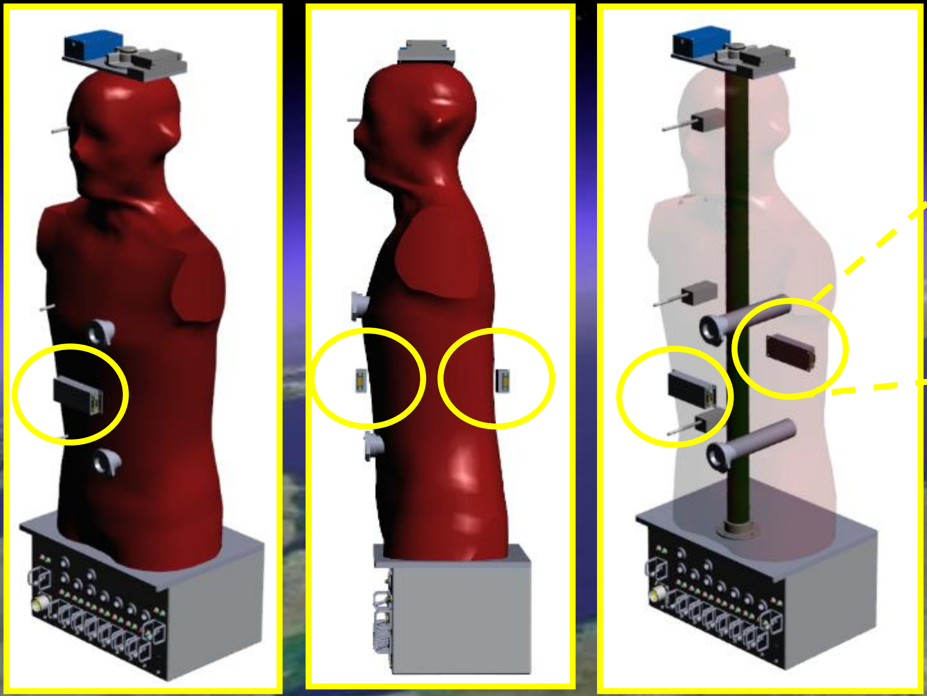
**2021**



# 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**

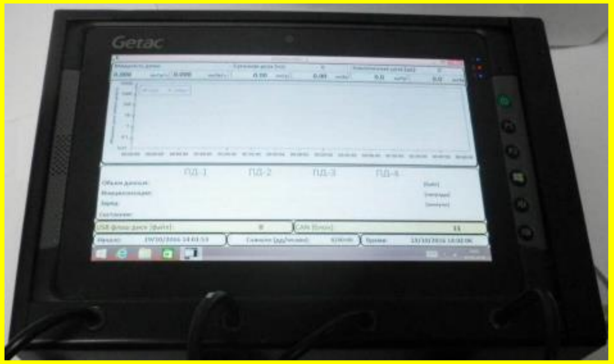


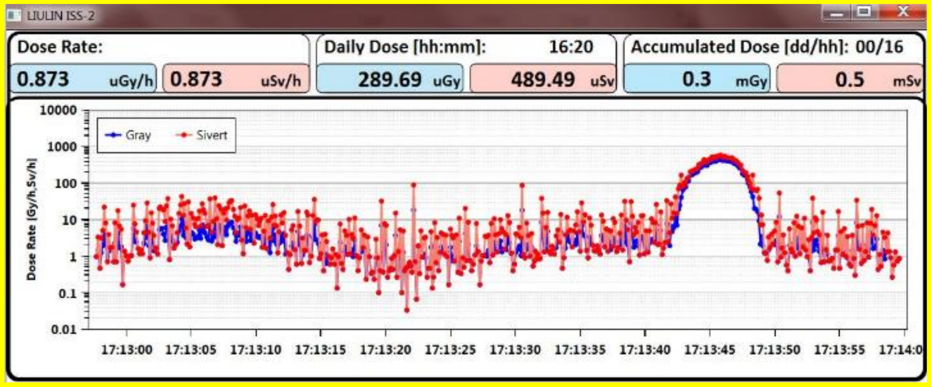
"Liulin-AF" spectrometers location in the Matroshka-III Phantom


Expected appearance of "Liulin-AF" spectrometers

## 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

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 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.

# 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;