Bulgarian Academy of Sciences

Institute for Space Research and Technology

(SRTI-BAS)

Bulgarian space dosimetry instruments from the "Lyulin" series and the main scientific results

Prof. Dr.S. Tsvetan Dachev, Ph.D.

on behalf of a team of like-minded people and collaborators consisting of:

Borislav Tomov, Yuri Matviychuk, Plamen Dimitrov, Mityo Mitev,
Malina Jordanova , Yordanka Semkova,
Rositsa Koleva, Nikolay Bankov, Stefan Malchev

59th Virtual UNISEC-Global Meeting

16 August 2025

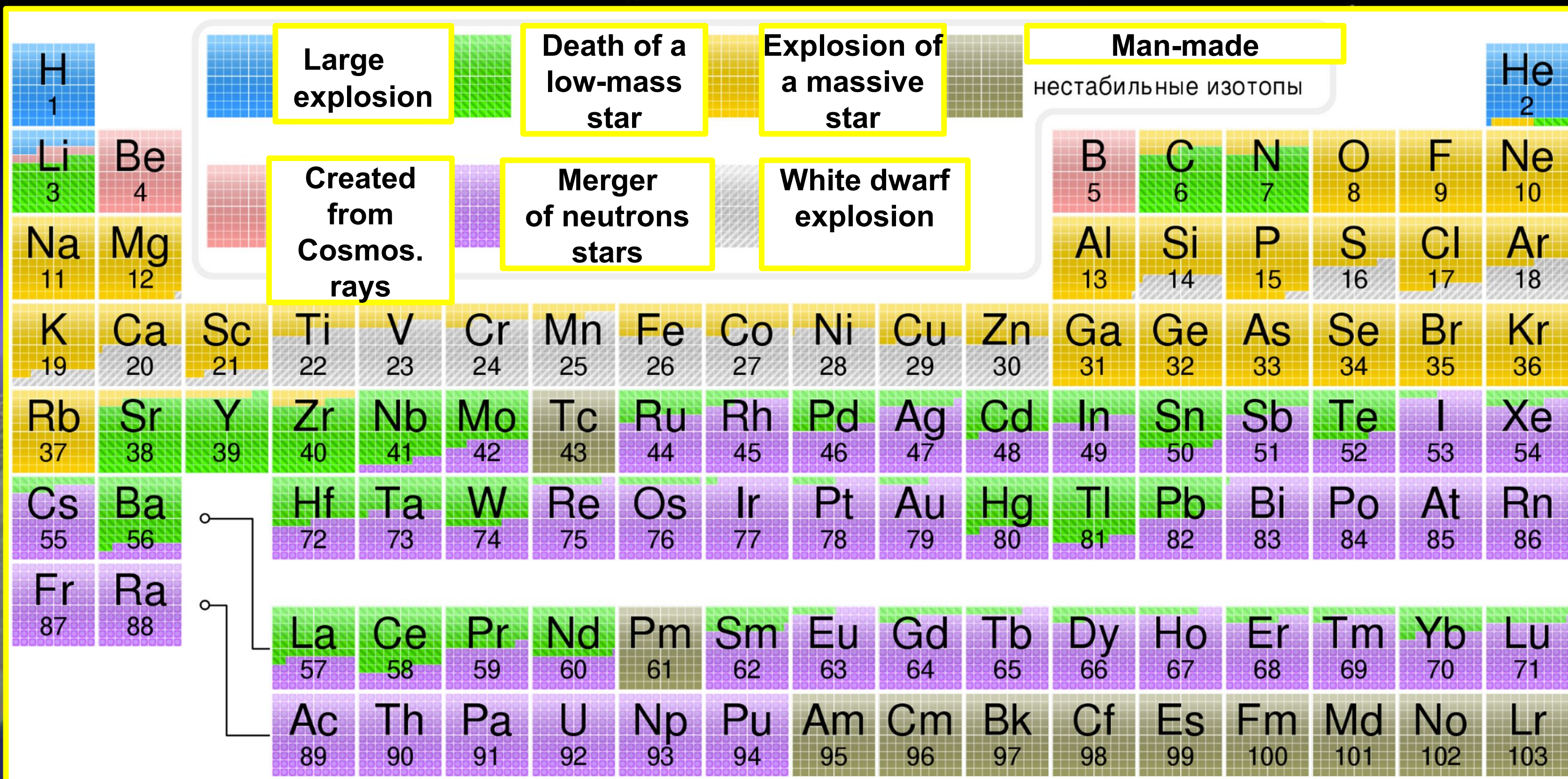
Outline

- ►Introduction: Ionizing radiation from Galactic, Solar cosmic rays (GCR and SCR) and from the Earth's Radiation Belts (ERB)
- ►The impact on the health of personnel in aviation and astronautics
- ►The scientific instruments developed at SRTI-BAS
- ►The main results and contributions
- ►The current and new space experiments
- ►Conclussions

Introduction

We are stardust!

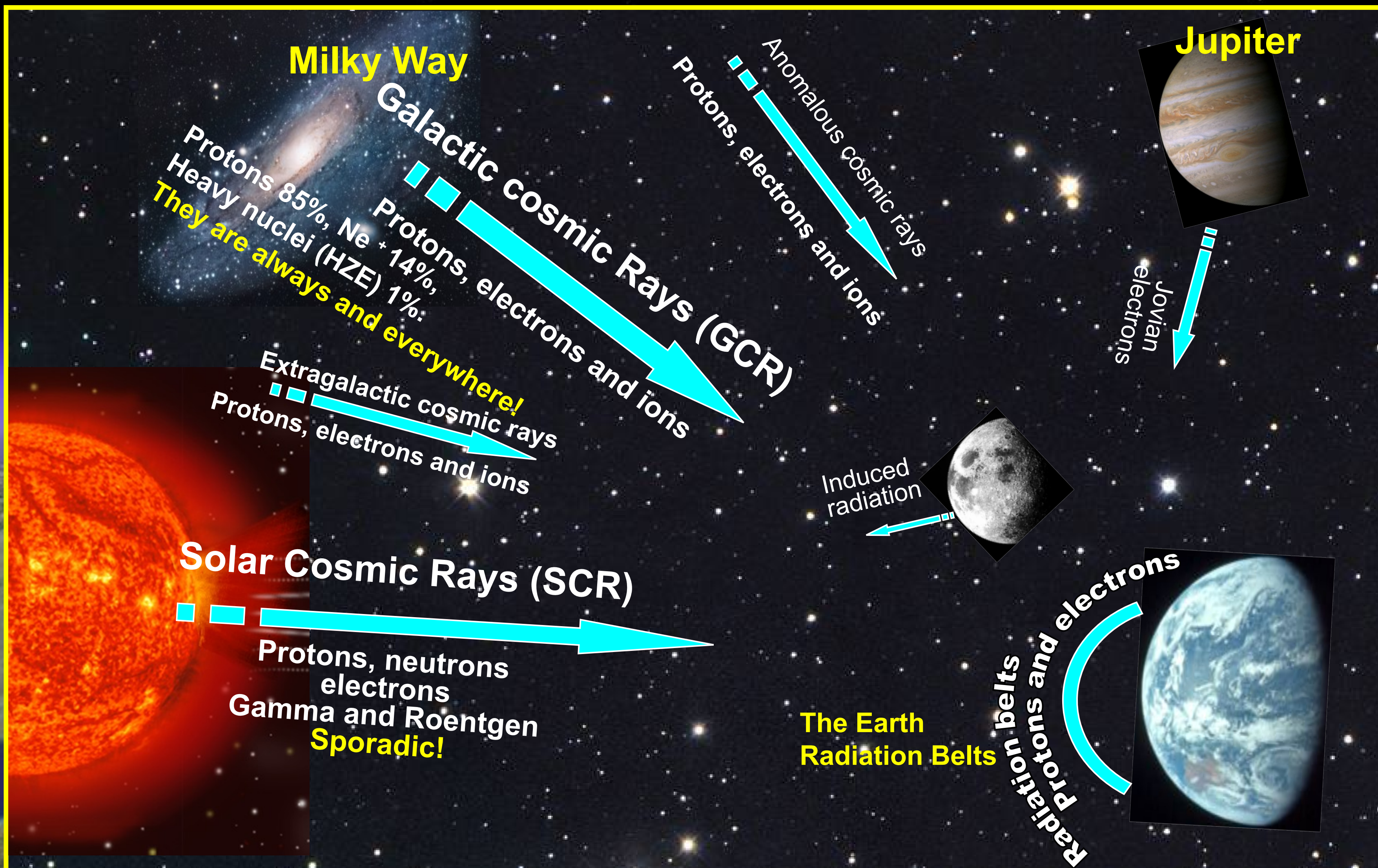
All the elements in Mendeleev's periodic table were created at some point in the life and death of stars. Only hydrogen and helium were created as a result of the explosion of the Big Bang.



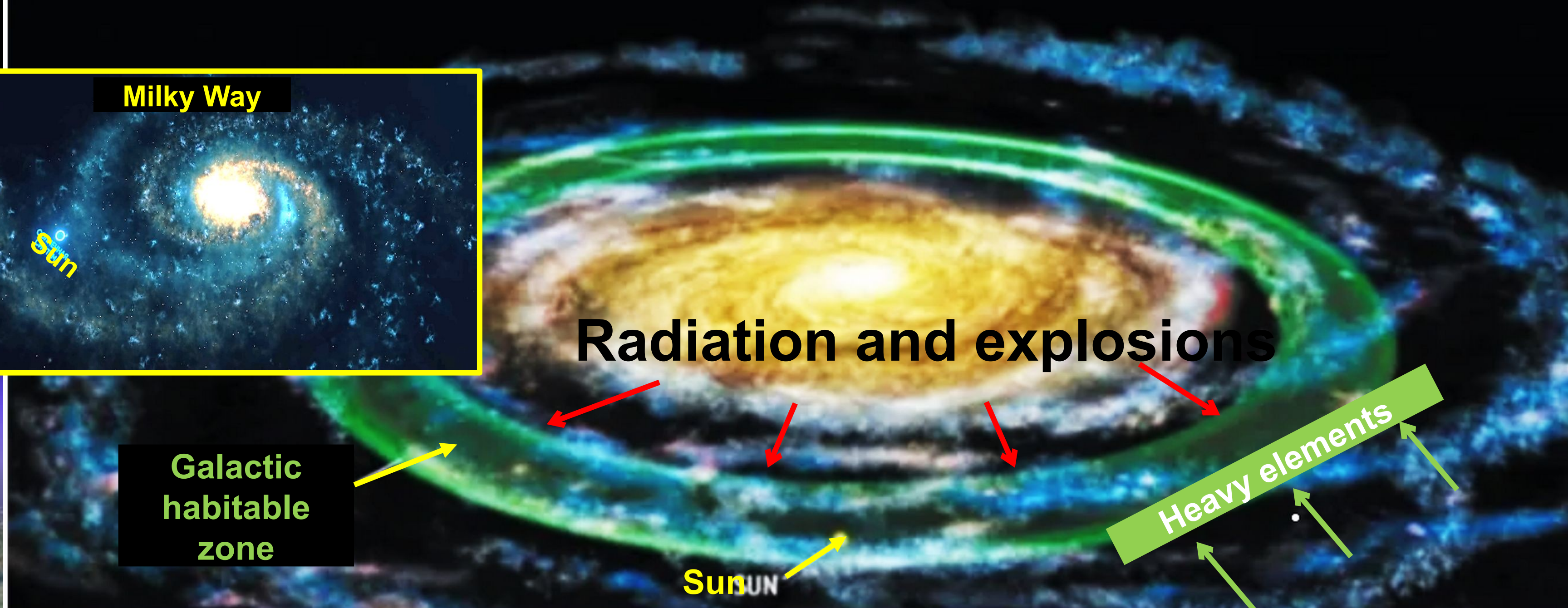
Each of the atoms in our bodies is billions of years old!

https://upload.wikimedia.org/wikipedia/commons/9/91/Nucleosynthesis_periodic_table-ru.svg

Radiation sources in the Earth and Moon space environment



Galactic cosmic rays form the inner boundary of the Galactic Habitable Zone

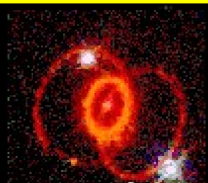


The Sun is outside the spiral arms and far from the galactic center of the Milky Way, which creates good conditions for the formation of life outside the dangerous zones of radiation and explosive gravitational forces. The galactic habitable zone is defined as 23-29 thousand light-years from the center of the galaxy. (The Sun is 27 thousand light-years away .)

Data from the Kepler space telescope suggests that there could be up to 300 million potentially habitable planets in our galaxy.

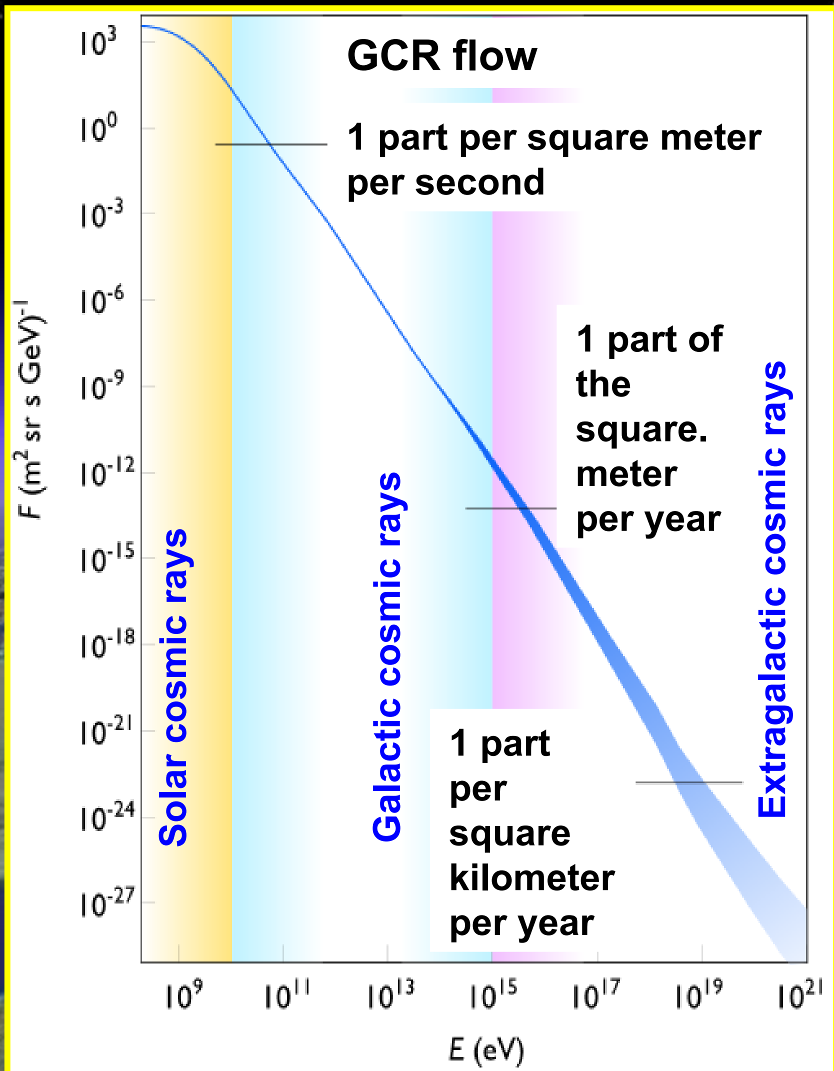
Galactic cosmic rays (GCR)

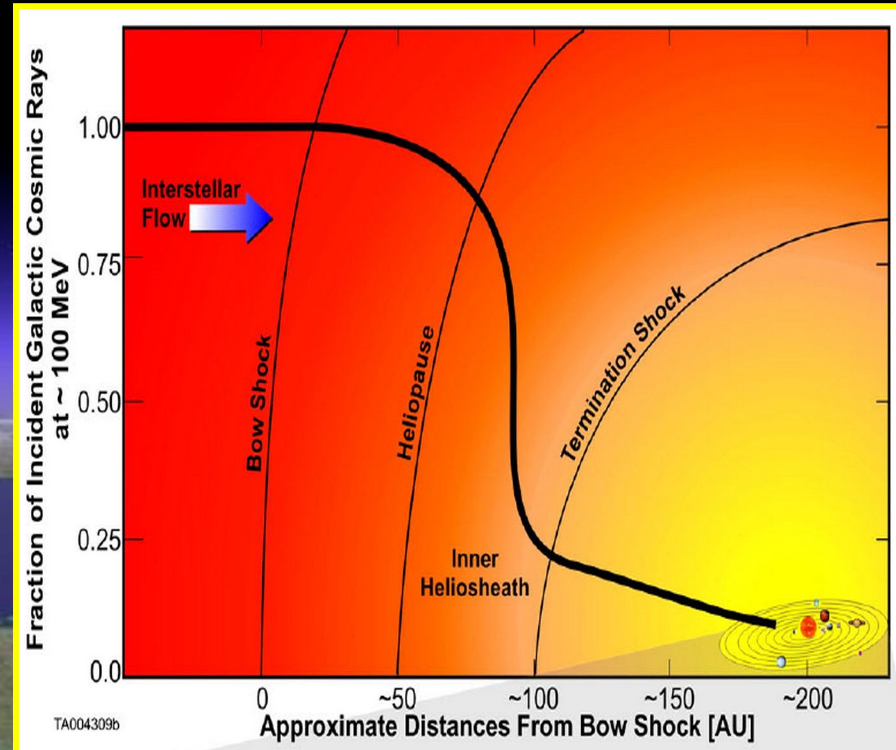
(Supernovae are the most likely source. The highest-energy particles have extragalactic origins.)



Remnants of the 1987 supernova.

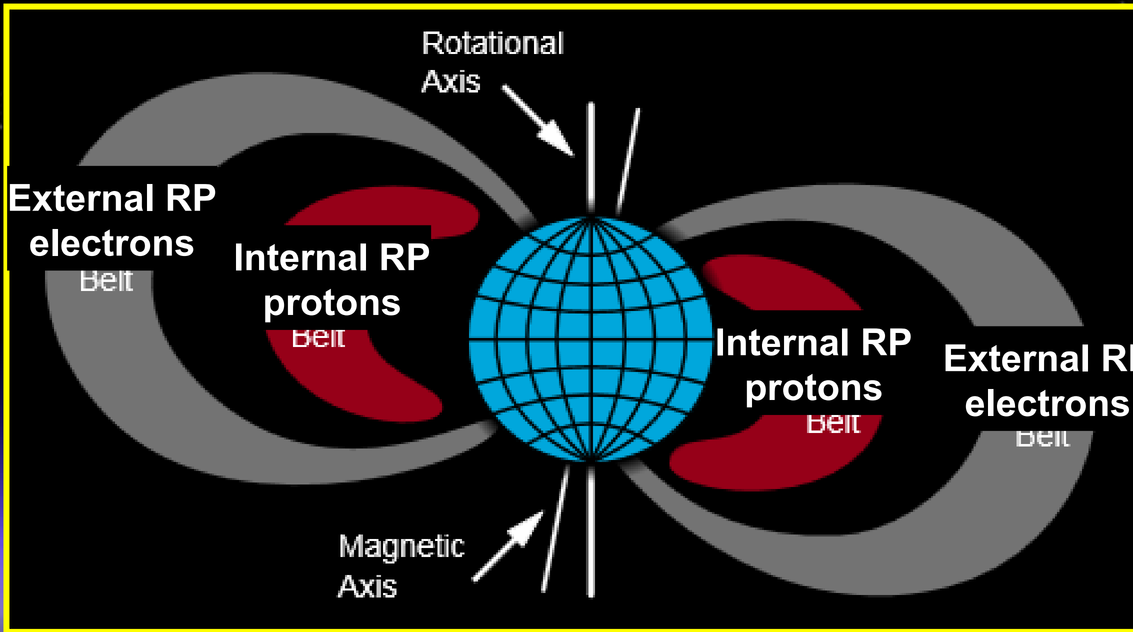
The Crab Nebula



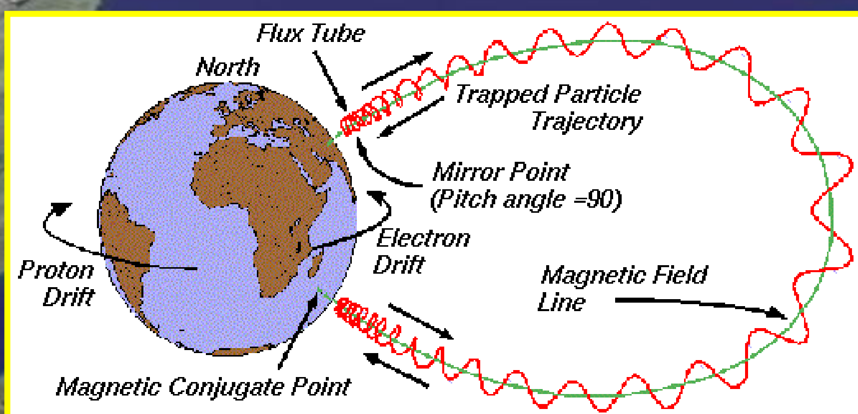


The flux from GCRs with energies of 100 MeV decreases to the boundary of the Solar System, with about 12% of the primary flux remaining at the boundary of the heliosphere, due to the interaction with the magnetic field embedded in the solar wind.

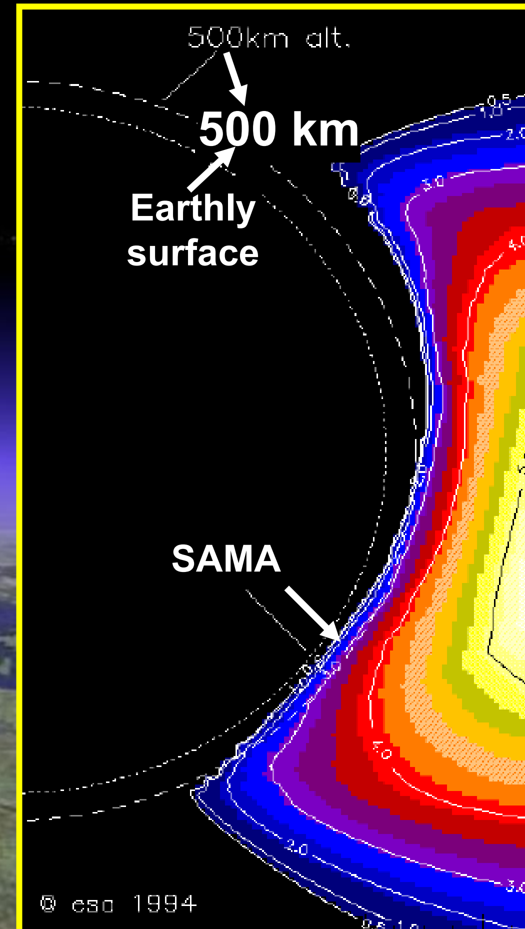
Introduction
Earth Radiation belts



Eaarth radiation belts

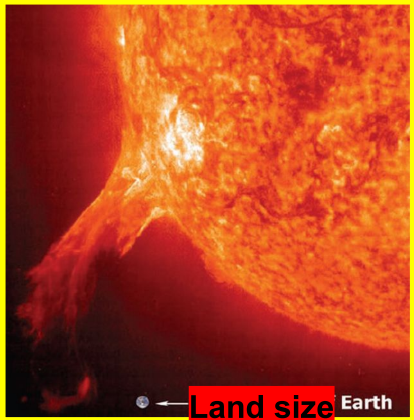


Particle motion in the magnetosphere

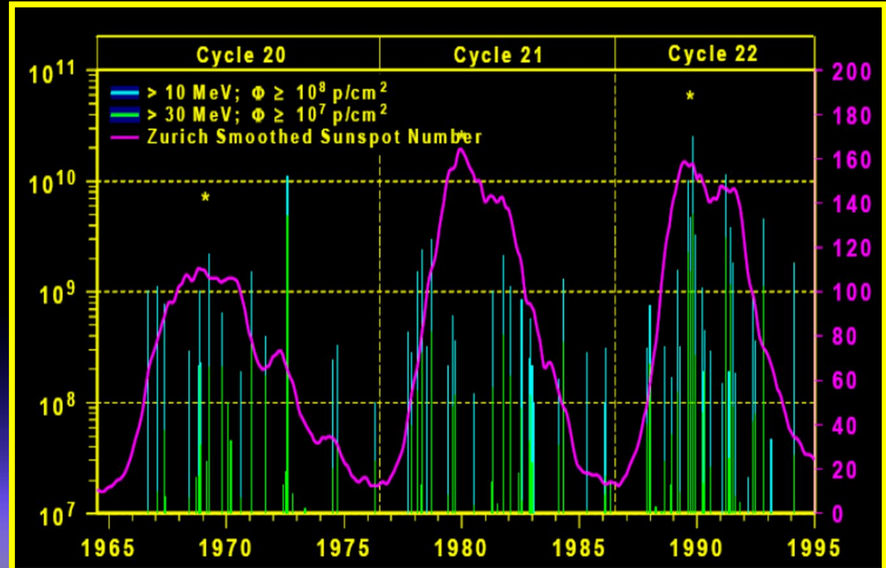


Formation of the flux and dose maximum in the South Atlantic Magnetic Anomaly (SAMA) region [Heyndericks , D. , 2002.]

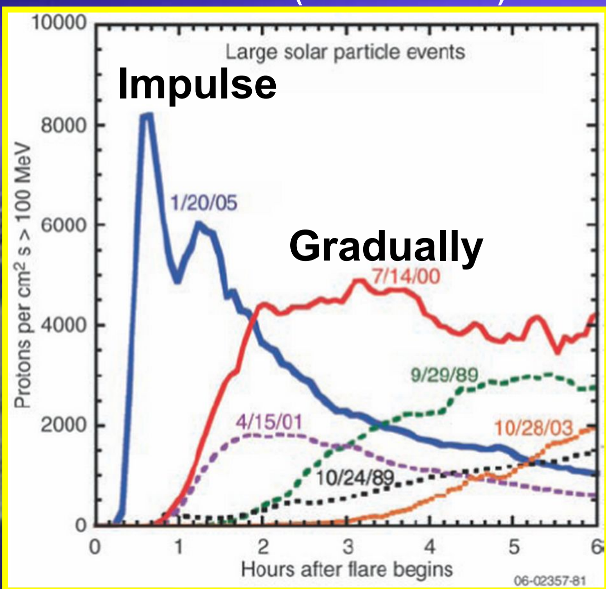
Solar cosmic rays
(They are conditionally divided into two types: impulse and gradual)



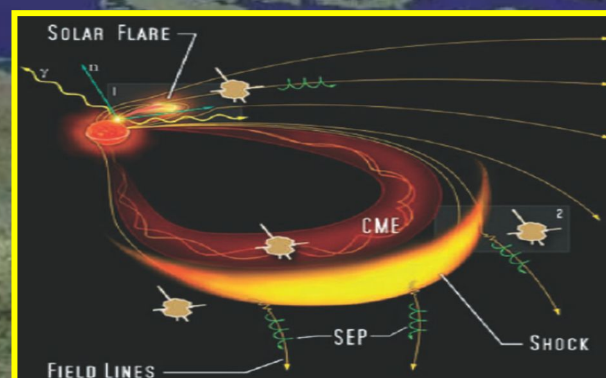
Solar eruption
(Credit: NASA)



SCRs are observed more frequently during the maxima of solar activity.

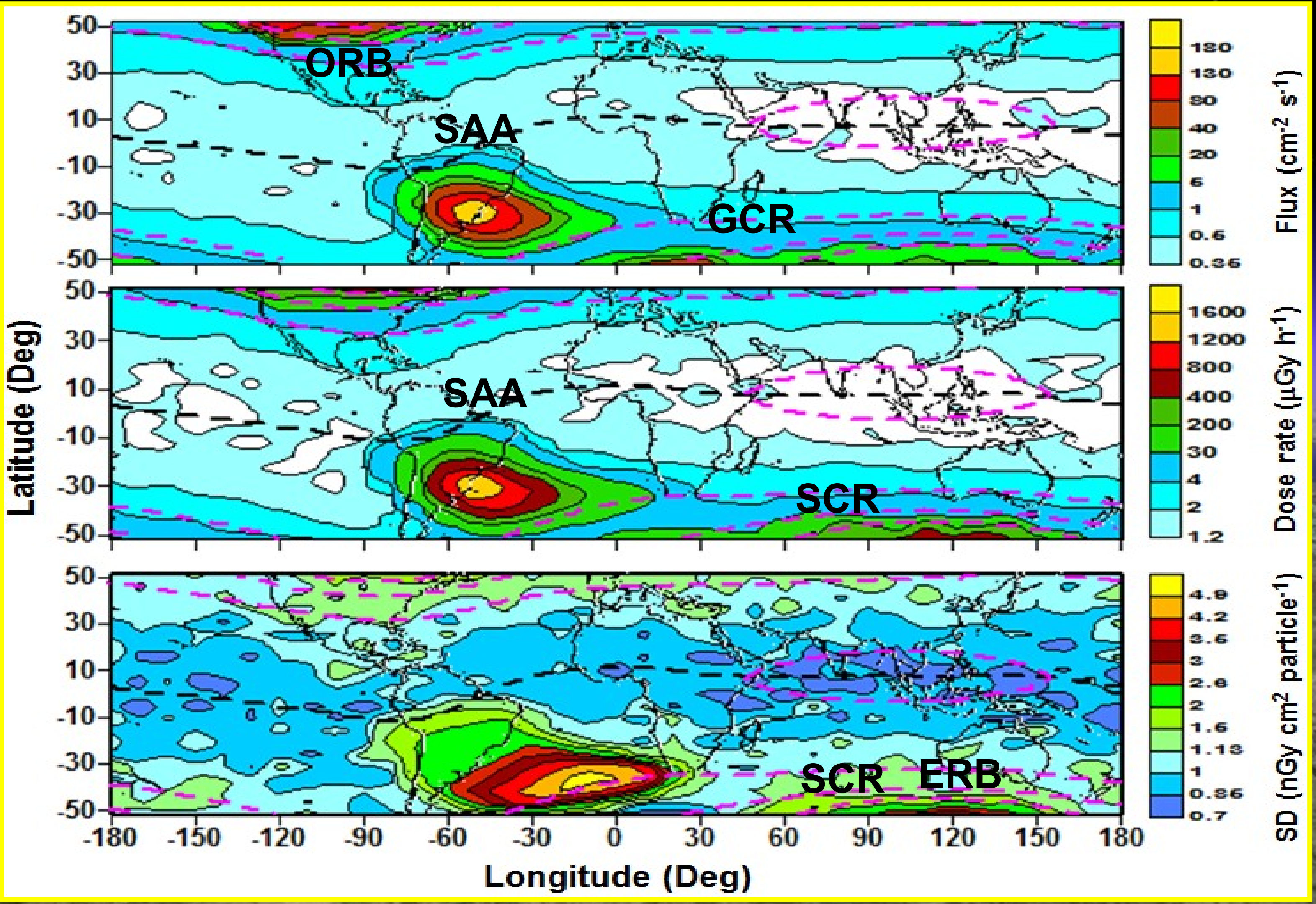


Profiles of change in SCL [Mewaldt, RA et all , 2005.]

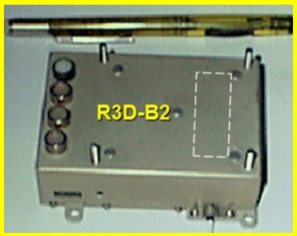


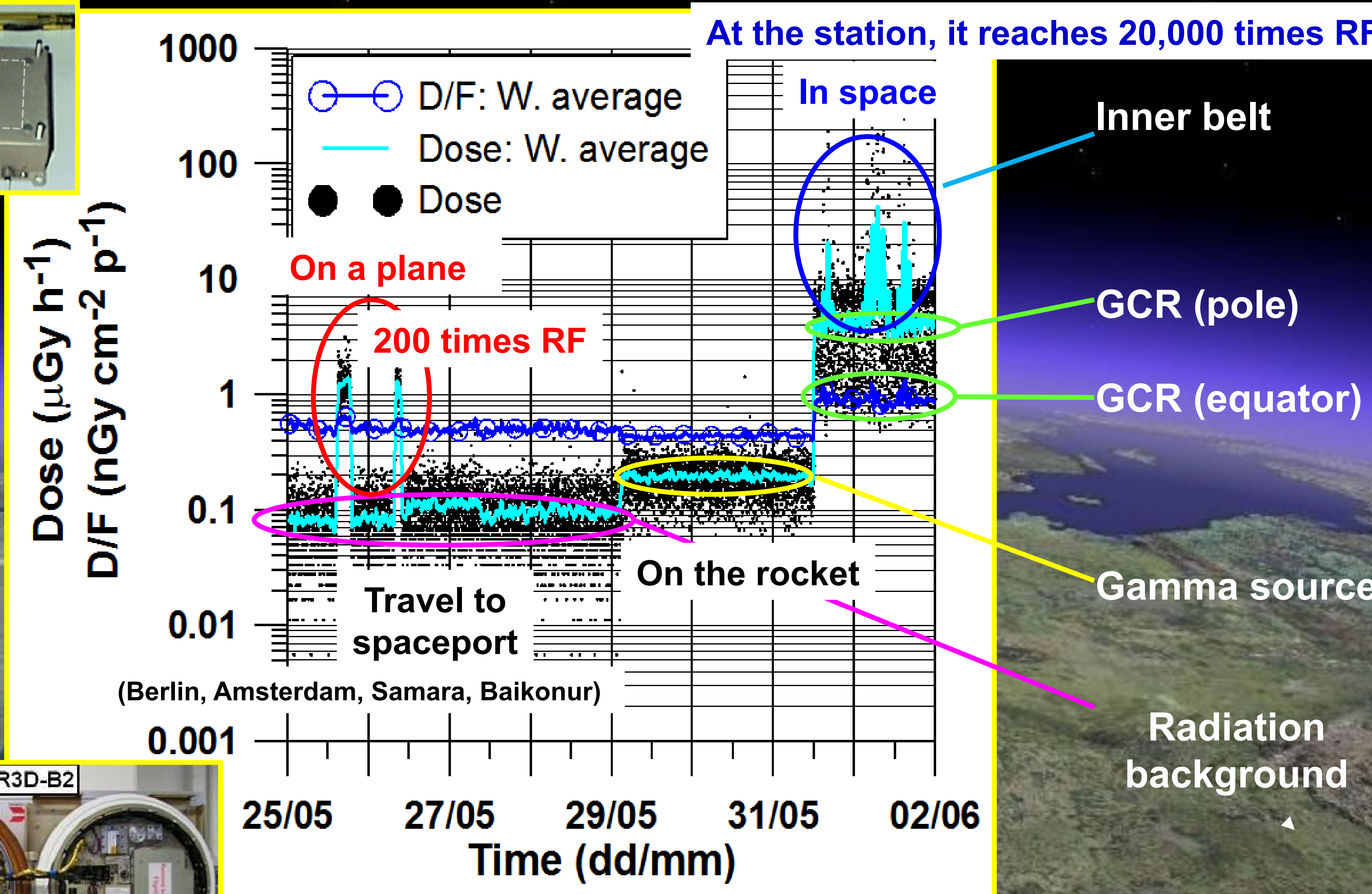
SCRs are accelerated in the shock wave at the boundary with interplanetary space.

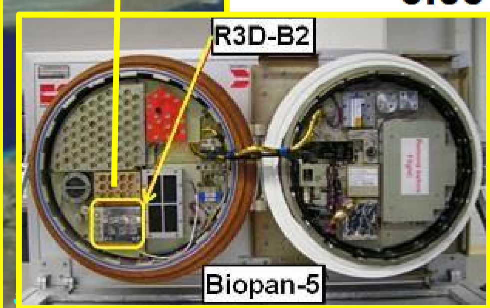
Global distribution of cosmic radiation dose and flux in the period 18-30 June 2015 outside the International Space Station (ISS) (in the ESA EXPOSE-R2 platform based on data from R3DR2, (SRTI & University of Erlangen , Germany)



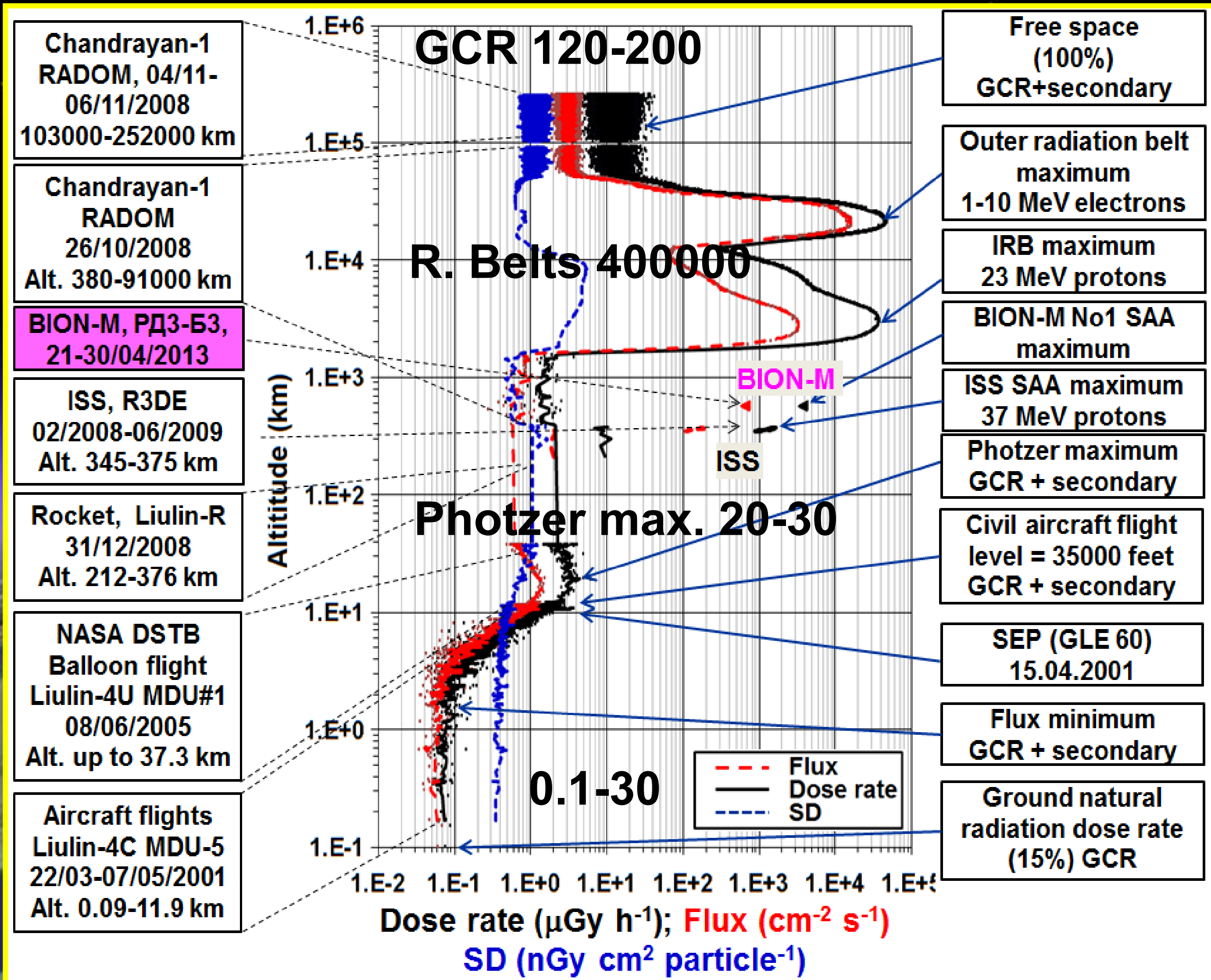
Example of the dose rate distribution in the near-Earth space based on continuous data from the R3D-B2 instrument on the Foton M2 satellite measured in June 2005







Profile of dose rate, flux and specific dose based on data from "Lyulin" type instruments from the Earth's surface to free space



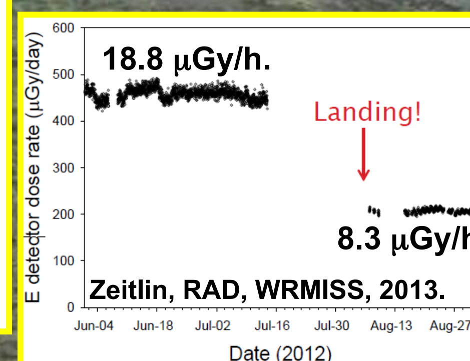
Earth 0.1 µGy/h, Gamma background.

Earth, Ramsar town, Iran: ~30 µGy/h, 300 times more than the average Gamma background.

Interplanetary space: ~15-20 µGy/h, 150 times, GGR.

Moon: ~8 µGy/h, 60-100 times, GCR.

Mars: 8.3 µGy/h, 83 times, GCR.

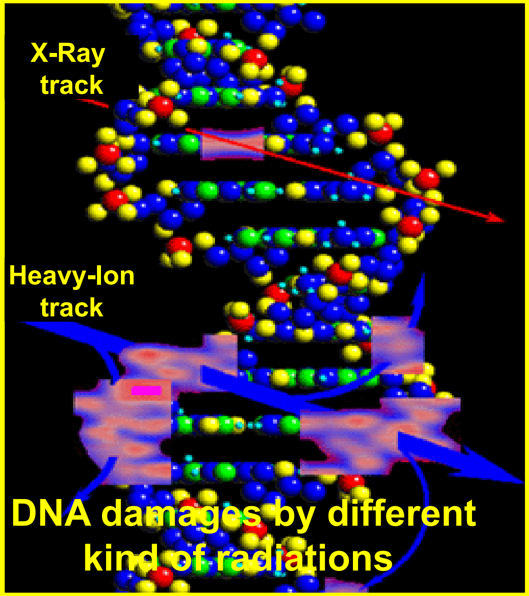


Dachev, T.P., Profile of the ionizing radiation exposure between the Earth surface and free space, Journal of Atmospheric and Solar-Terrestrial Physics, 102, September 2013, 148–156, 2013.

Impact of ionizing radiation on the health of personnel in aviation and astronautics

Ionizing radiation of cosmic origin is dangerous to the health of astronauts and aircraft crews . The object of SRTI-BAS is its measurement and study.

Human body damages



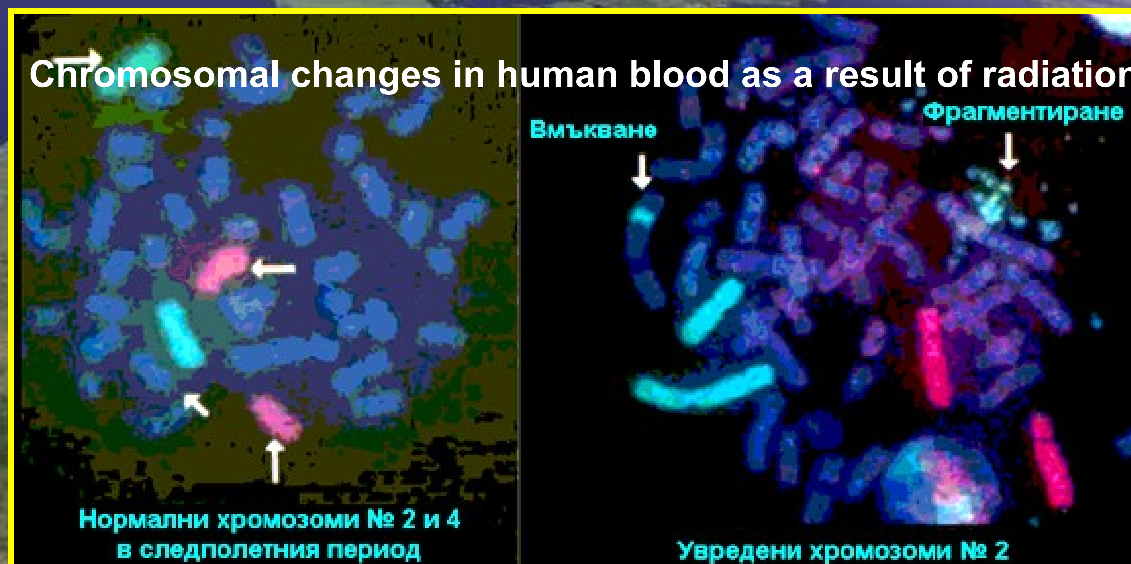
DNA damages by different kind of radiations

The increased radiation background for astronauts, crews and passengers of civil aircraft leads to events dangerous to their health in the short and long term.

In the short term, if the permissible dose is exceeded, they may develop radiation sickness, which can be fatal, and in the long term, they may develop so-called late-stage cancer , which can also lead to death.

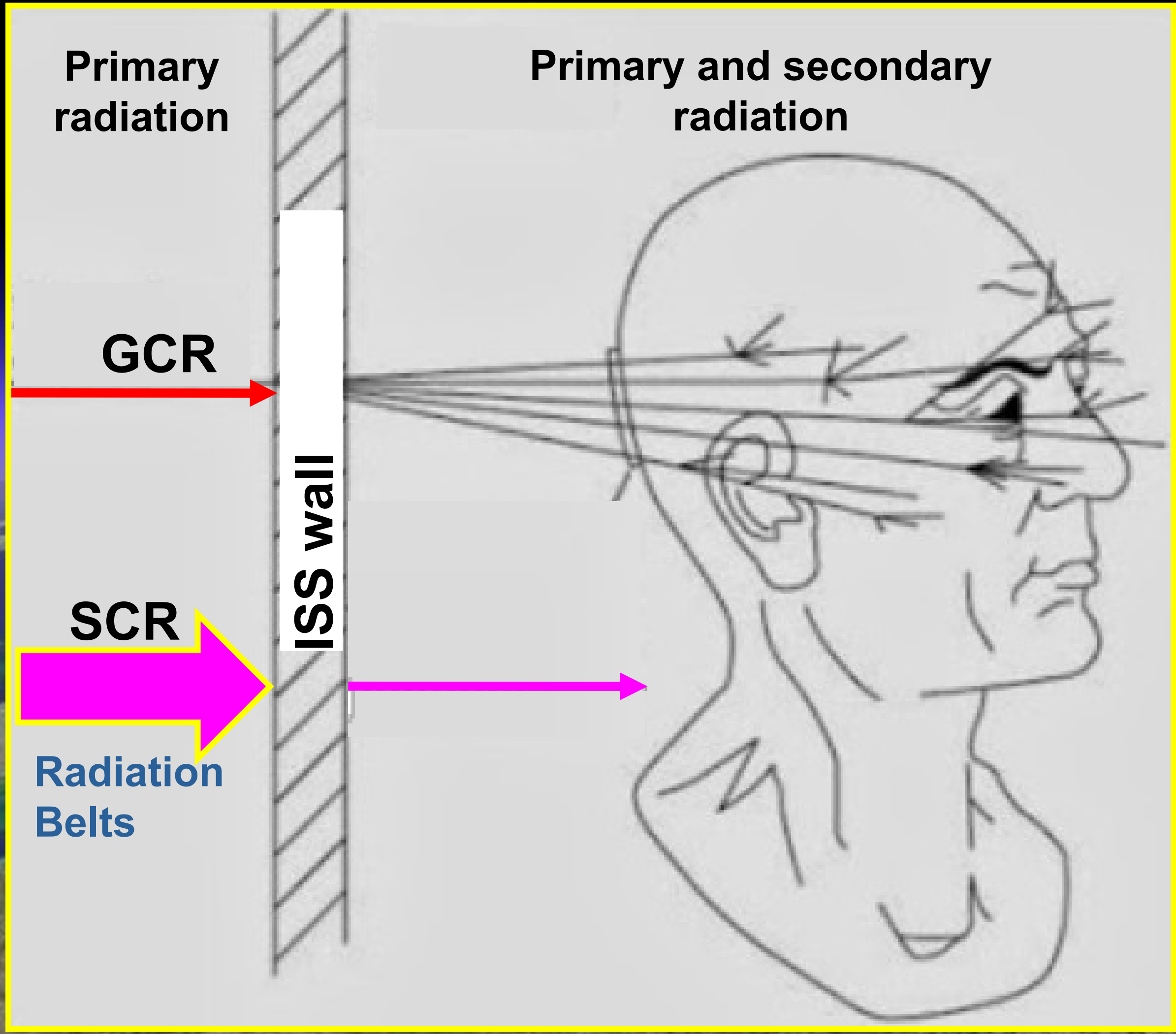
Radiation risk is one of the limiting factors for future space flights to planets in the solar system, beyond it, and to stars.


Bone marrow cells are damaged by radiation and stop to produce erythrocytes

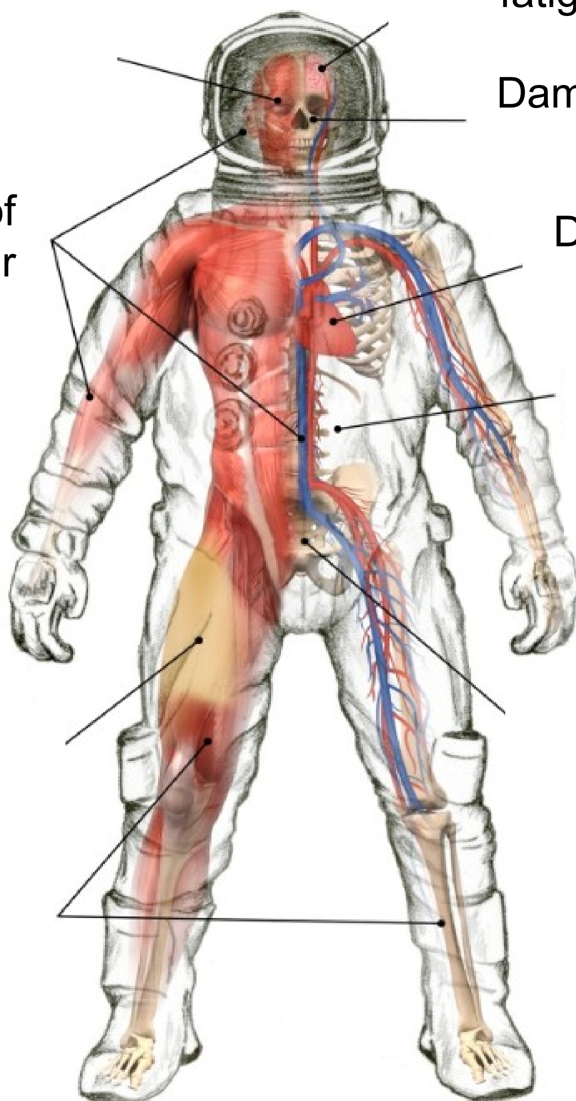


Chromosomal changes in human blood as a result of radiation

Peculiarities of the passage of various sources of cosmic radiation through the wall of the International Space Station (ISS). GCR produce secondary radiation in the ISS walls



Cosmic radiation affects multiple organs and physiological systems*



*https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4206856/

Cosmic radiation is **a limiting factor** for the development of astronautics due to **its irreversible effects** on the central nervous system (CNS).

Research results so far show that the acute effects are:

1. Cognitive deficits in behavior, learning ability and operator functions, even at doses below 0.5 Sv ;

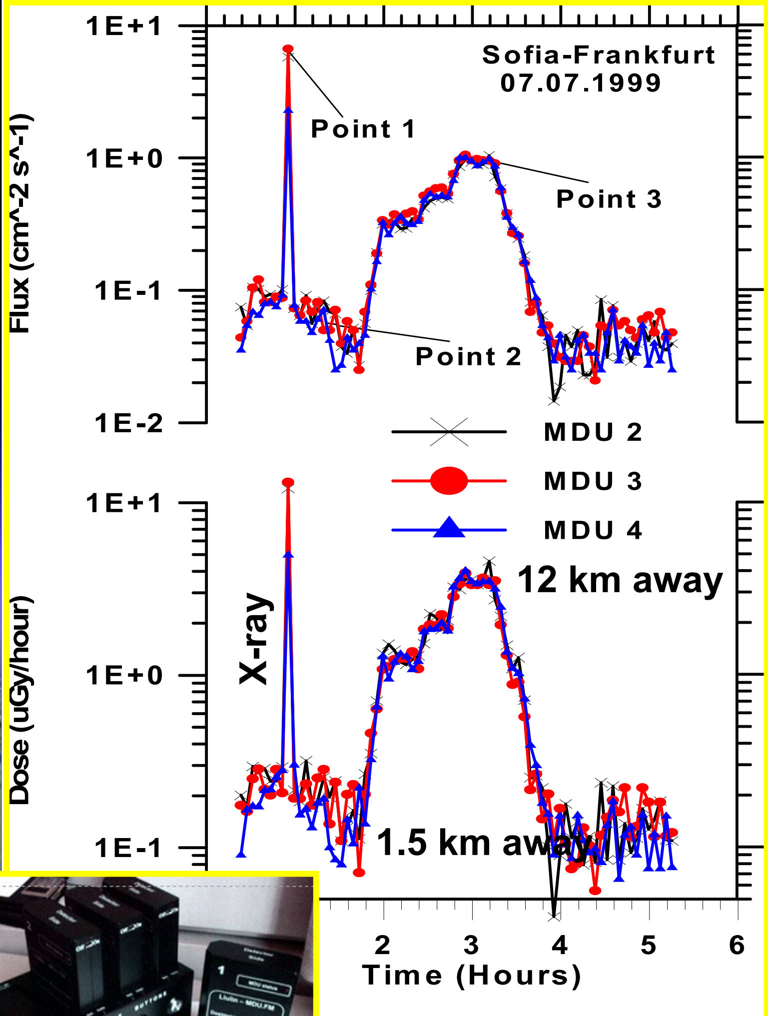
2. Stops the process of neuron regeneration;

3. Unique CNS changes are observed, reminiscent of those associated with aging;

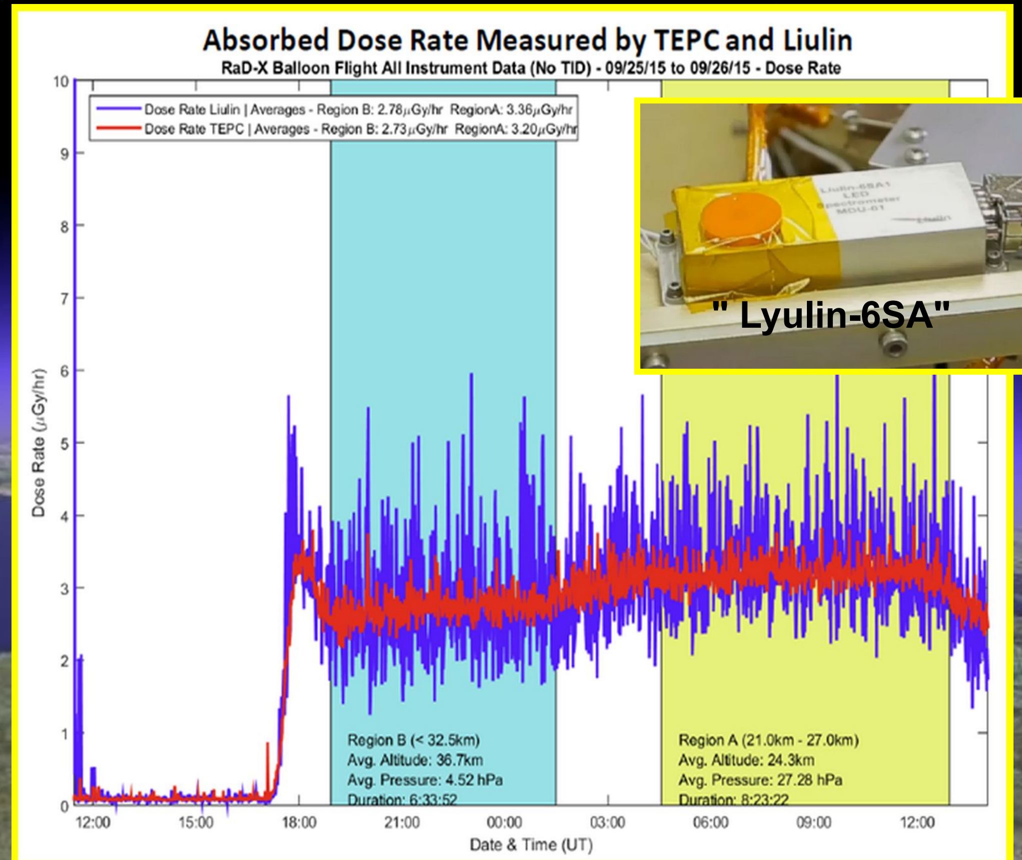
Chronic effects are associated with **increased risk of Alzheimer's disease, dementia and premature aging.**

Impact of GCR and SCR on the health of aviation personnel

Dose and flux dynamics during airplane and stratospheric balloon flight

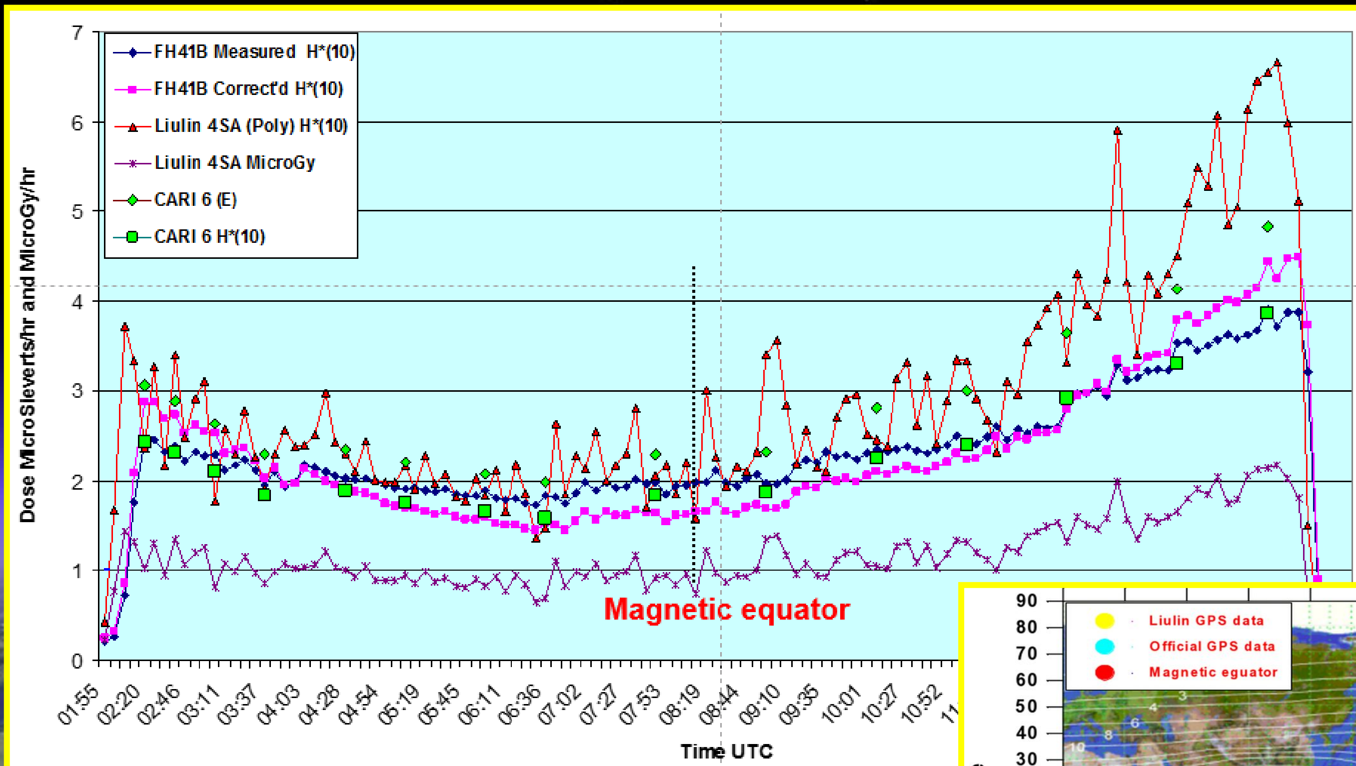


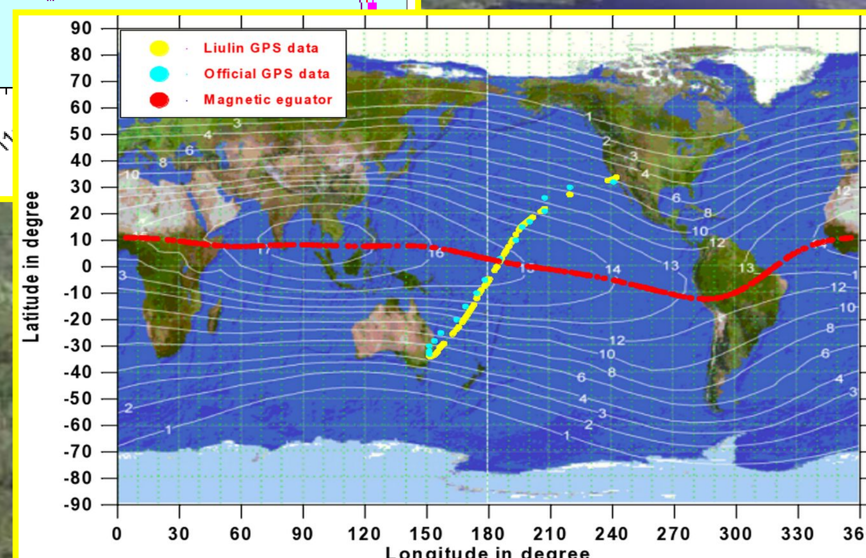
Dynamics of the dose and flux of cosmic radiation during an airplane flight, measured with 3 of the dosimeters of "Lyulin-E094"



Comparison of data from a NASA balloon flight, obtained on 25.09.2015 from the instruments "Lyulin-6SA" and TEPC.

Comparison of data from the "Lyulin-4SA" instrument with the FH41B instrument and the CARI model for a flight of an aircraft of the Australian airline " Qantas" airlines from Sydney to Los Angeles on February 8, 2006.





Some basic concepts in radiology

Unit of radiation dose associated with health risk = Sievert (Sv)

- chest x-ray = 0.1 mSv;
- Instant death > 3 S v.

ICRP recommended limits:

- Annual limit for a citizen <1 mSv;
- Prenatal limit <1 mSv total; <0.5 mSv each month;
- Annual limit for a radiation worker <20 mSv;

(Aircraft crews are classified as radiation workers.)

Typical exposure for airplane passengers:

- one international trip = 0.2 mSv (2 chest X-rays);
- 160,000 kilometers = 2 mSv (20 chest X-rays).

Doses from solar storms at high latitudes

- January 2005 = 1 mSv;
- February 1956 = 5 mSv;
- Carrington 1859 = 20 mSv.

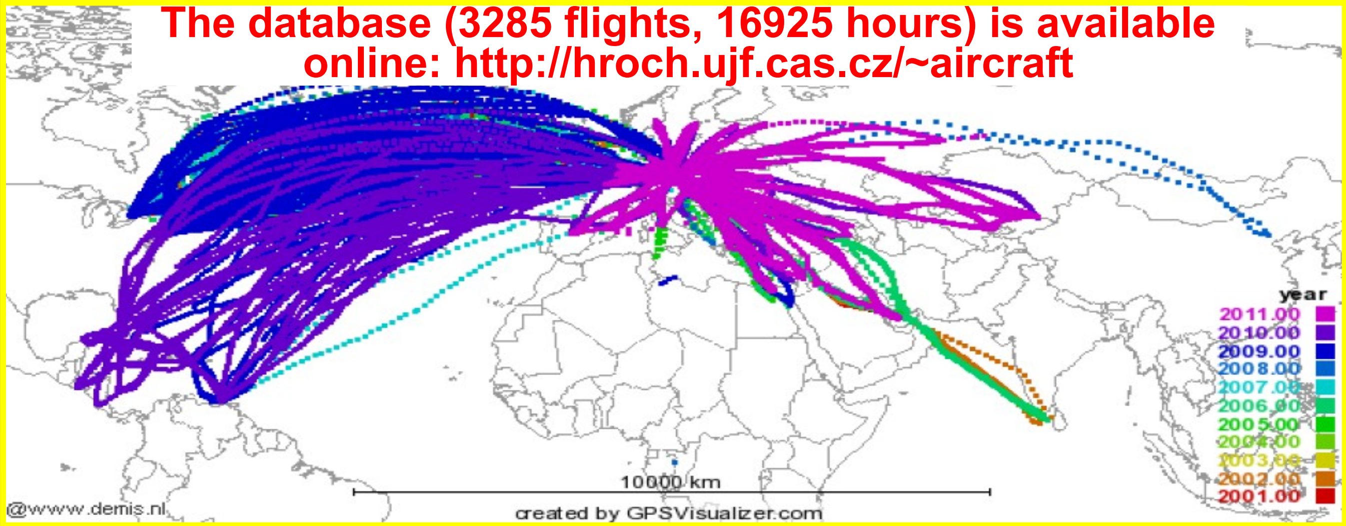
Lethal doses of radiation [Gy]

Lethal radiation doses [Gy]

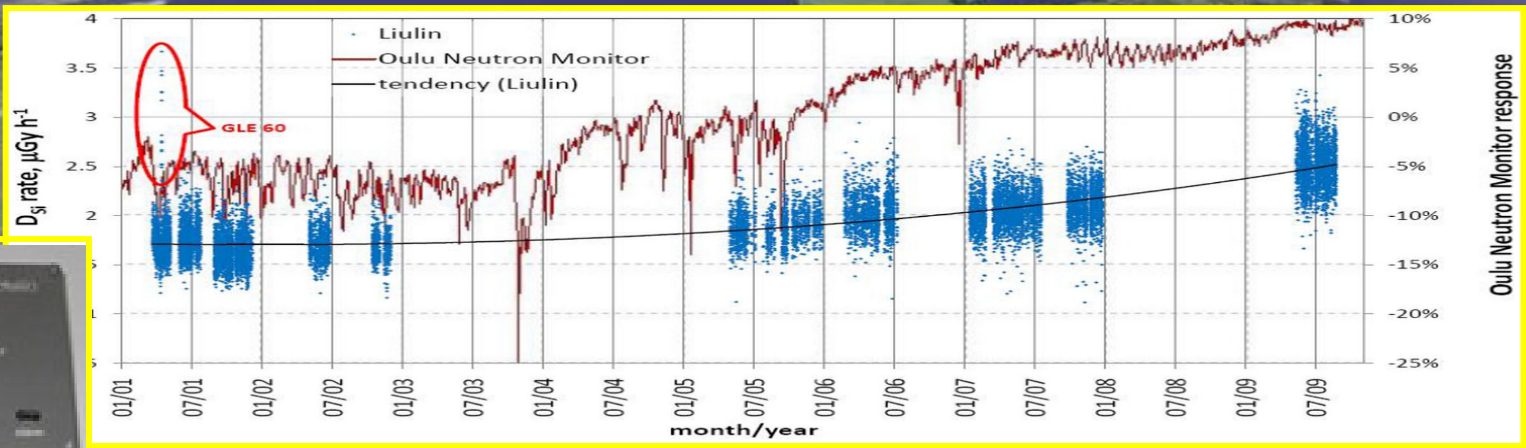
	Lethal dose	LD_{50}	LD_{100}
Dog		3.5 ($LD_{50/30\ \text{дни}}$)[4]	
Human	4 – 10[5]	4.5[6]	10[7]
Rat		7.5	
Mouse	4.5 – 12	8.6 – 9	
Rabbit		8 ($LD_{50/30\ \text{дни}}$)[4]	
Turtle		15 ($LD_{50/30\ \text{дни}}$)[4]	
Goldfish		20 ($LD_{50/30\ \text{дни}}$)[4]	
Escherichia Coli			60
Cockroach		64[5]	
Mollusks		200 ($LD_{50/30\ \text{дни}}$)[4]	
Fruit fly	640[5]		
Ameba		1000 ($LD_{50/30\ \text{дни}}$)[4]	
Braconidae	1800[5]		
Milnesium tardigradum	5000[8]		
Deinococcus radiodurans	15000[5]		
Thermococcus gammatolerans	30000[5]		

Long-term dose monitoring during flights of aircraft (A310 and A320) of the Czech airline CSA , conducted by collaborators of the Institute of Nuclear Physics-CHAN, Prague

Prof. Dr. of Science
F. Spurney



Flights of CSA aircraft (A310 and A330) from 2001 to 2011.



Comparison of measured doses on aircraft
with data from the neutron monitor in Oulu, Finland.

Most significant results and contributions

of SRTI-BAS in space experiments for measuring cosmic radiation

Main scientific goals of the 16 past experiments with Lyulin?

1. Monitoring of variations in the flux and dose rate from GCR, SCR, radio belts in near-Earth and interplanetary space.
2. Using data in models;

Around the Earth

On a rocket

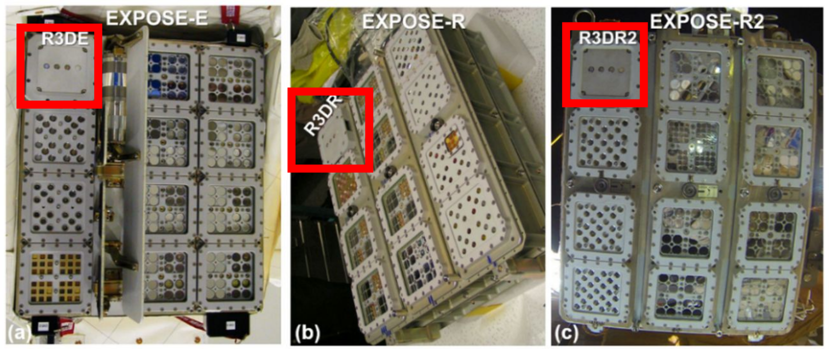
In the interstitial space

7 experiments out of 16

3. Support biological and chemical experiments with up-to-date information on the history of dose accumulation. Monitoring of dose variations.

Foton-M2/3, BION-M1, Foton-M4

ISS, Liulin-5



ISS, Expose-E/R/R2

9 experiments out of 16

The topic was created in 1986 in connection with **the scientific program of the second Bulgarian cosmonaut - Alexander Alexandrov** . "Lyulin" worked at the Mir station from 1988 to 1994

Detector unit
104x40x20 mm
Weight 0.095 kg

Control unit :
300x220x170mm
Weight : 10.5 kg

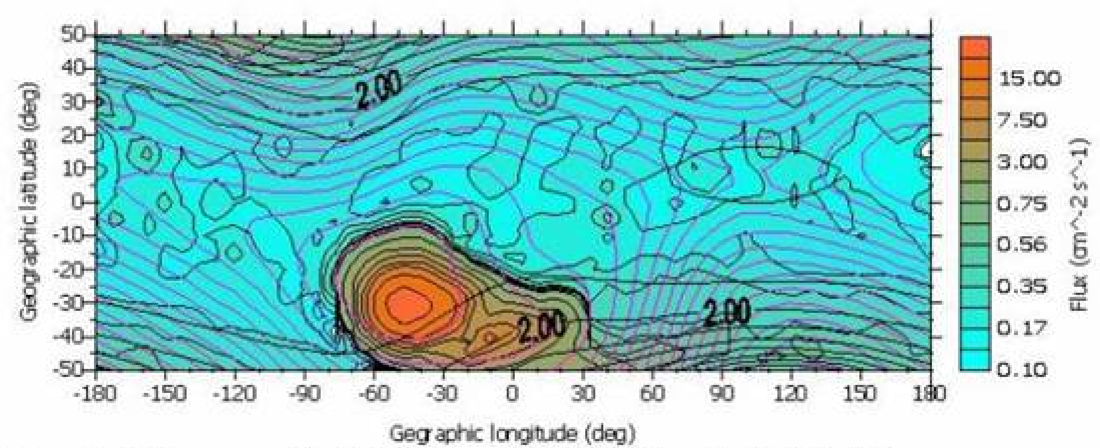


Figure 3. Global geographical distribution of the LIULIN flux data for July 1991.

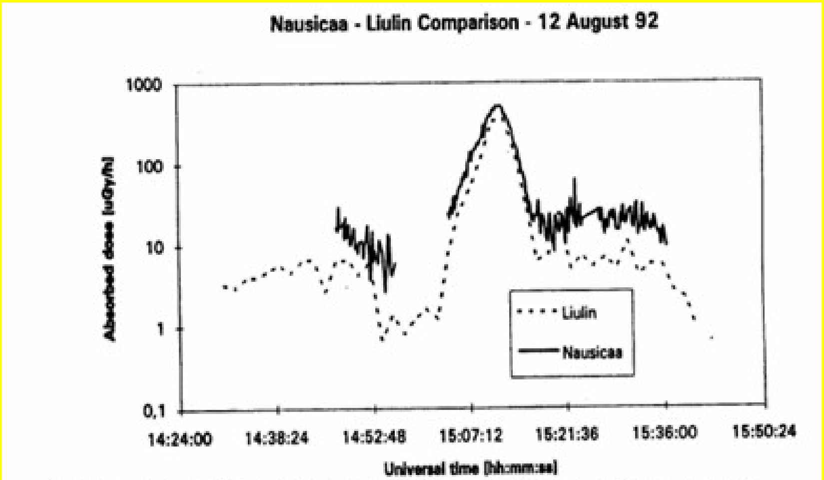
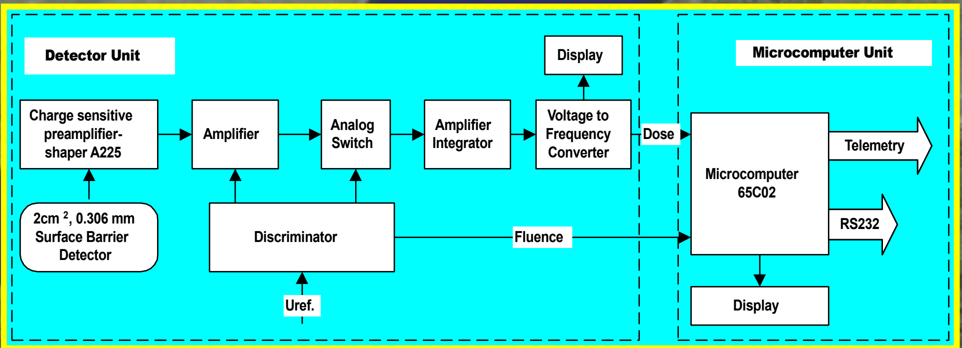


Figure2. Intercomparison of Liulin and NAUSICAA data obtained on MIR on August 12, 1992.

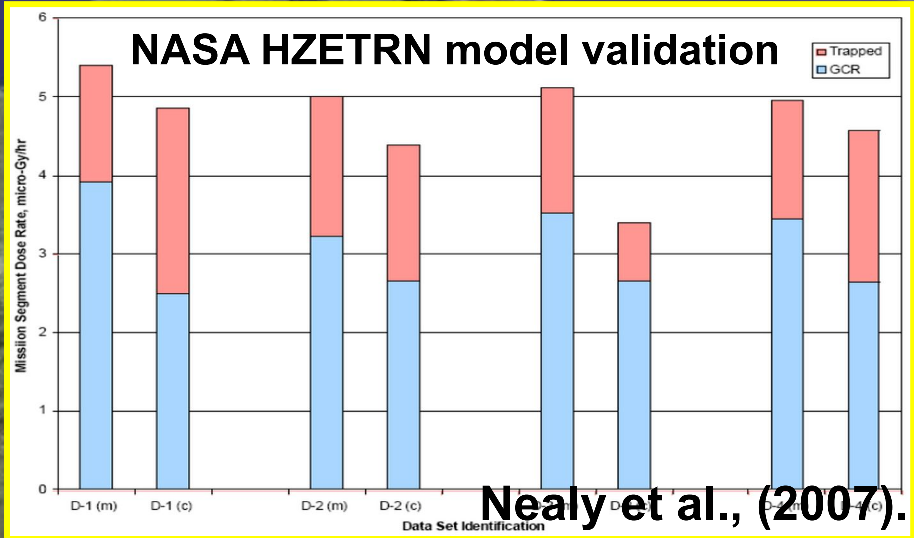


The first "Lyulin" - 1988

The device "Liulin-E094" was created under the ESA program. It was successfully used in the American laboratory module of the ISS from May to July 2001 as part of the German experiment "Dosimetric mapping"


Liulin -E094 system

American astronaut James Voss works with " Dosimetric mapping " on 26.06.2001

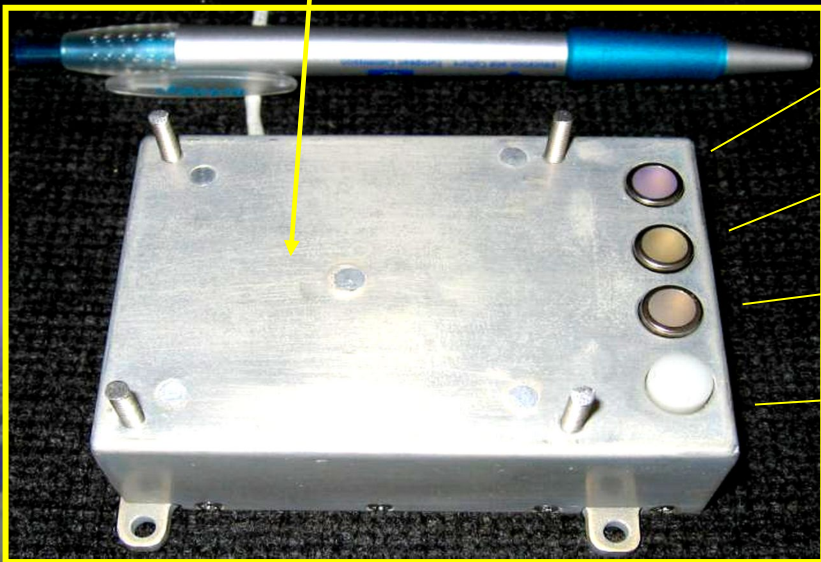


Nealy et al., (2007).

The R3D-B2/B3 instruments for ESA's Biopan 5/6 platforms operated outside the Foton M2/M3 satellites in 2005 and 2007. The spectrometers were developed in collaboration with the University of Erlangen, Germany.

Detector of 256 Channels

4 Channels UV spectrometer

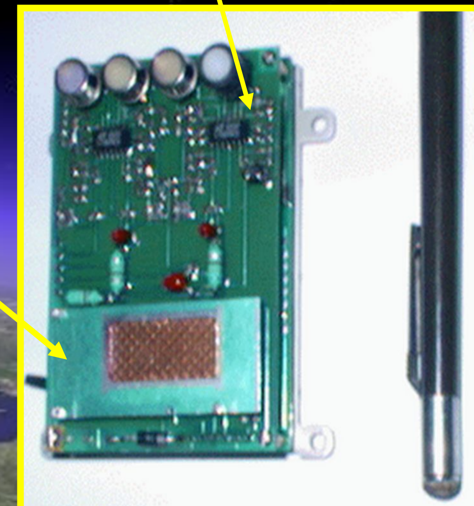


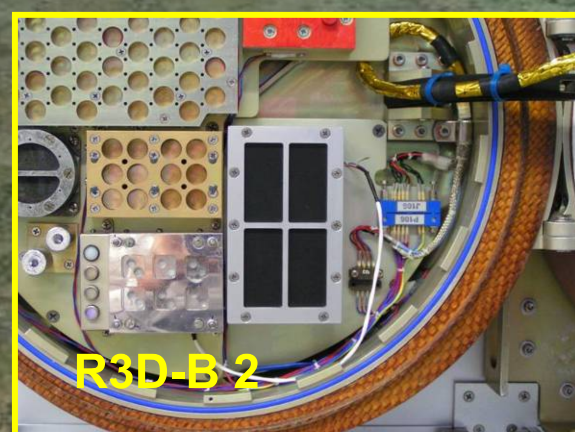
UV-C channel

UV-B channel

UV-A channel

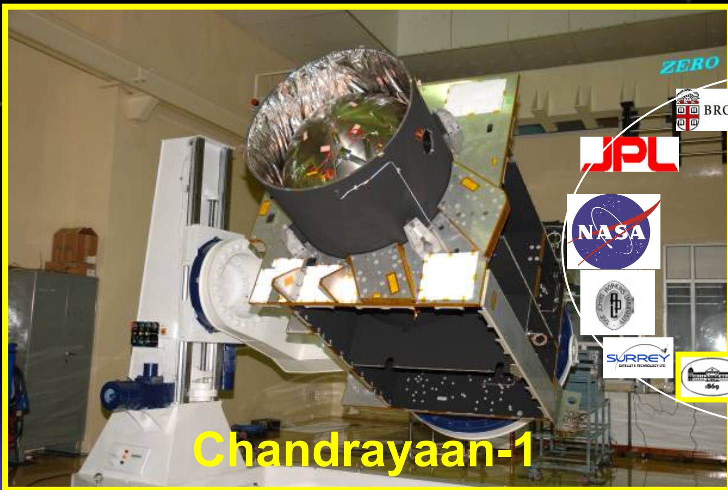
PAR channel

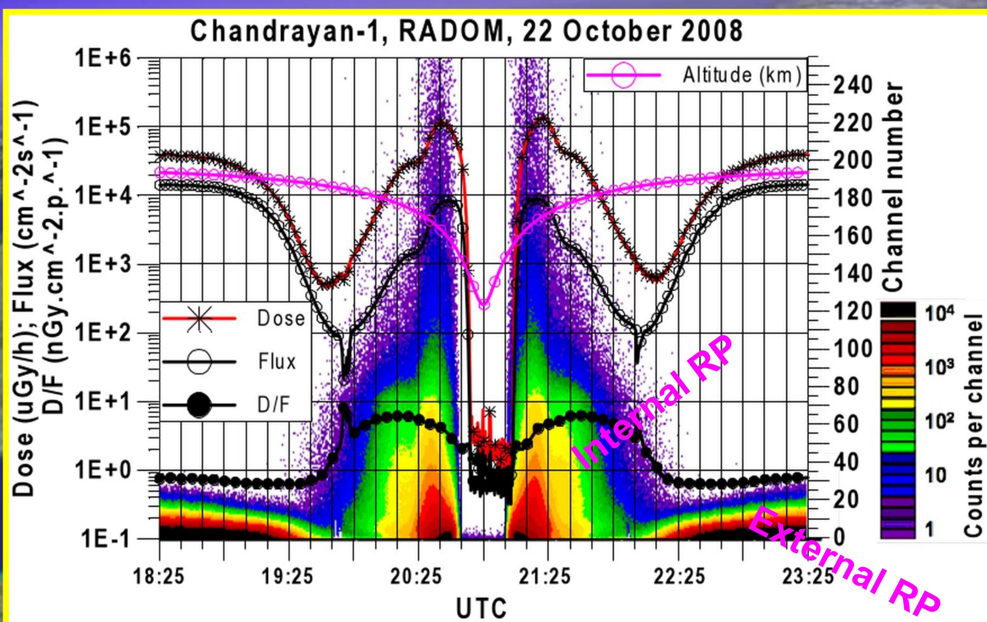


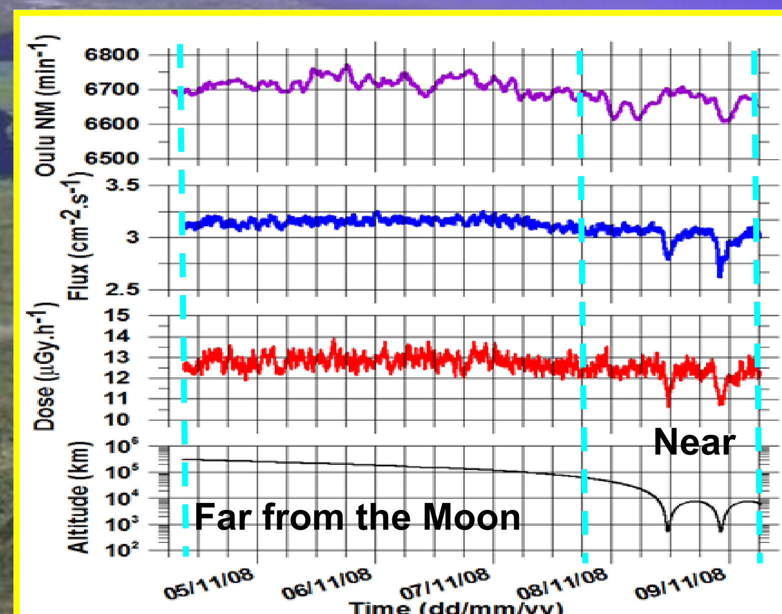


Size : 82x57x25 mm
Weight : 1 2 9 g
Consumption : 84 mW

The RADOM spectrometric instrument operated on India's first lunar satellite, Chandrayaan-1, in 2008-2009.

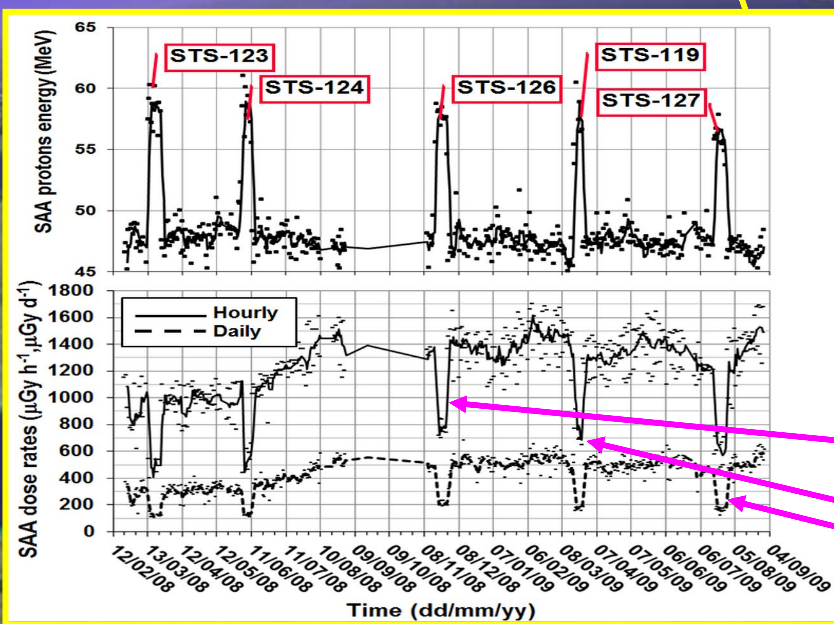


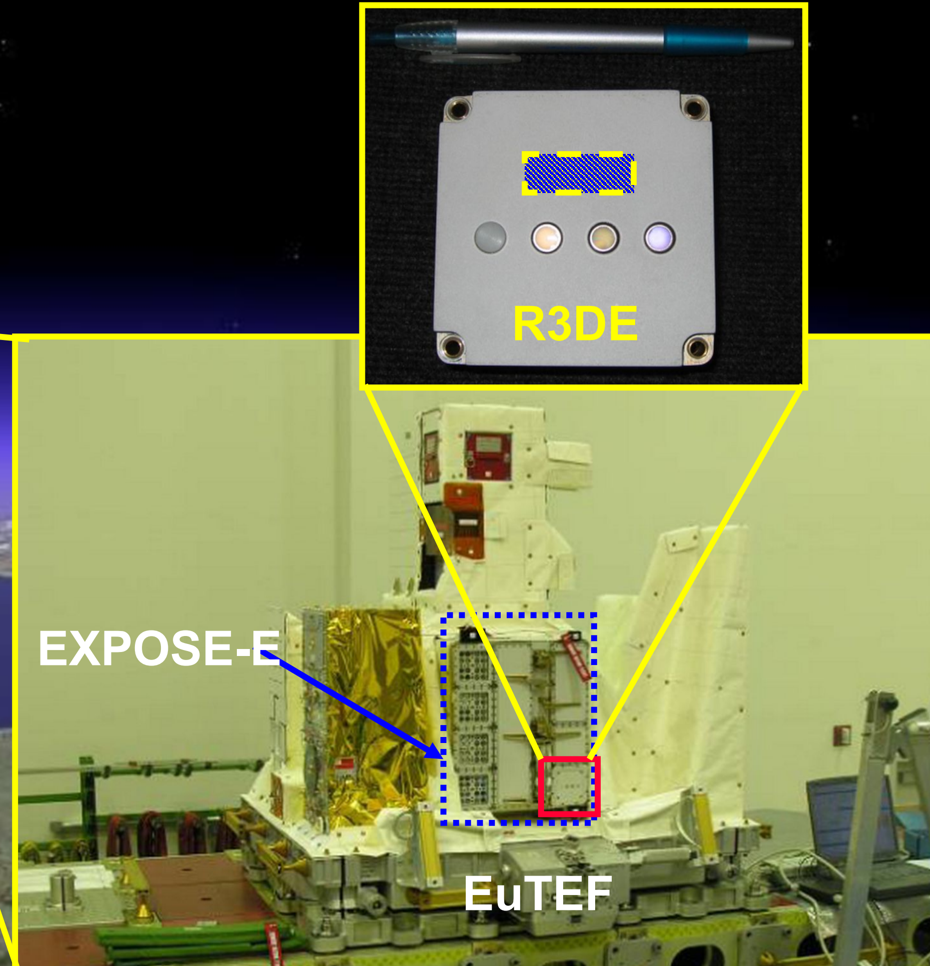




R3DE instrument on ESA's EXPOSE-E platform is operating on the Columbus module of the ISS from 2008 to 2009.

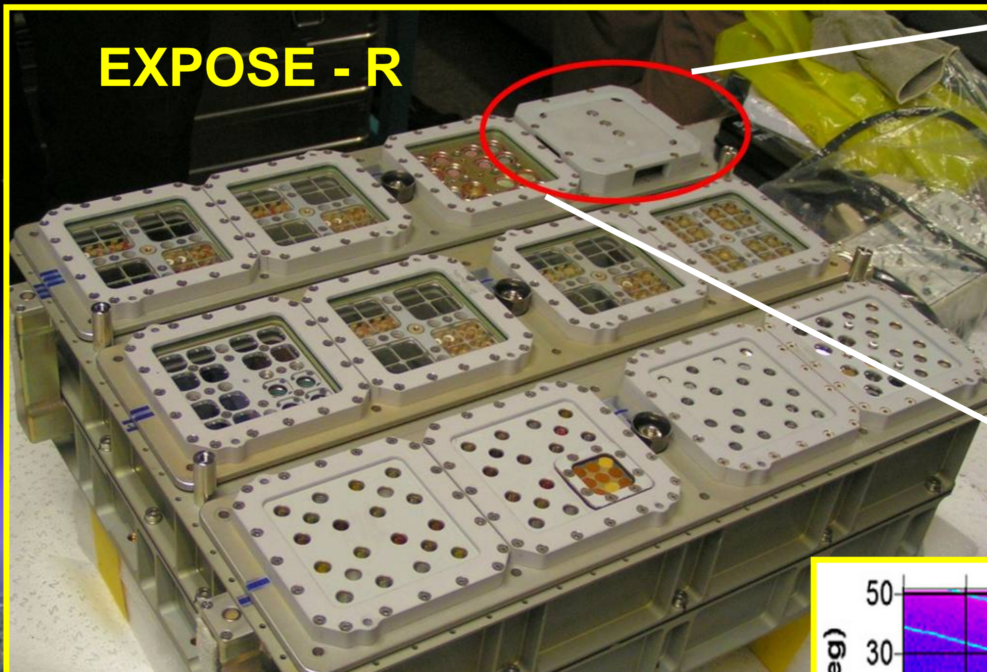
ESA Columbus laboratory on ISS
Credits: ESA/NASA

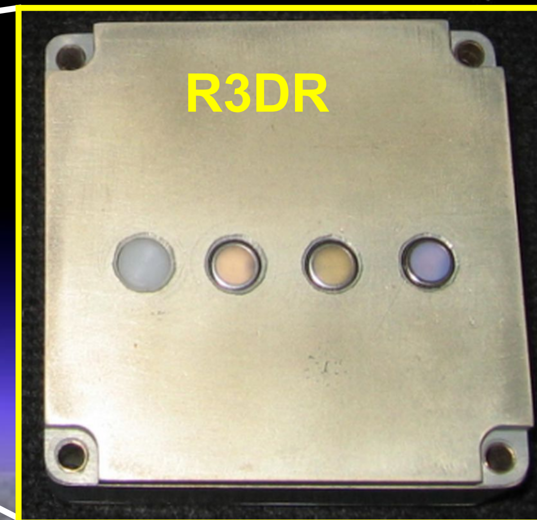


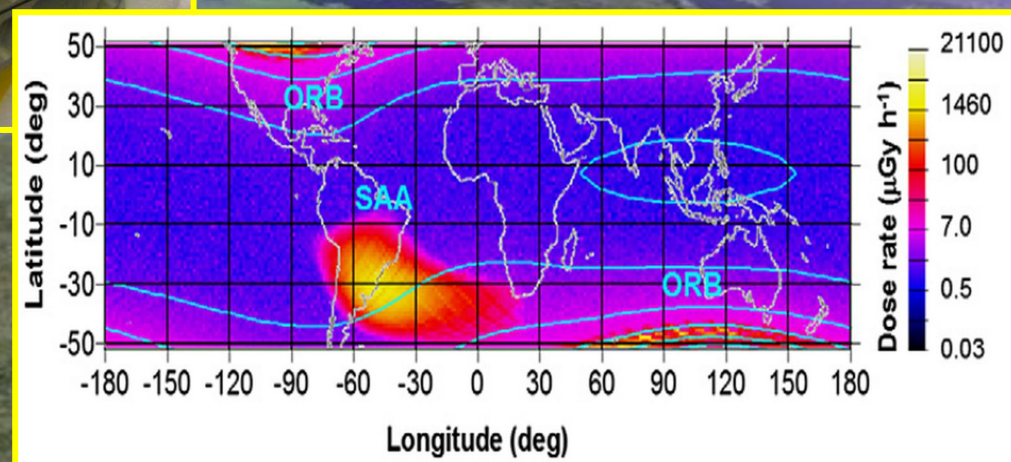


Dachev et al., (2011) found dose reductions during the docking of the US space shuttle with the ISS.

The R3DR instrument operated on ESA's EXPOSE-R platform from 2009 to 2010.

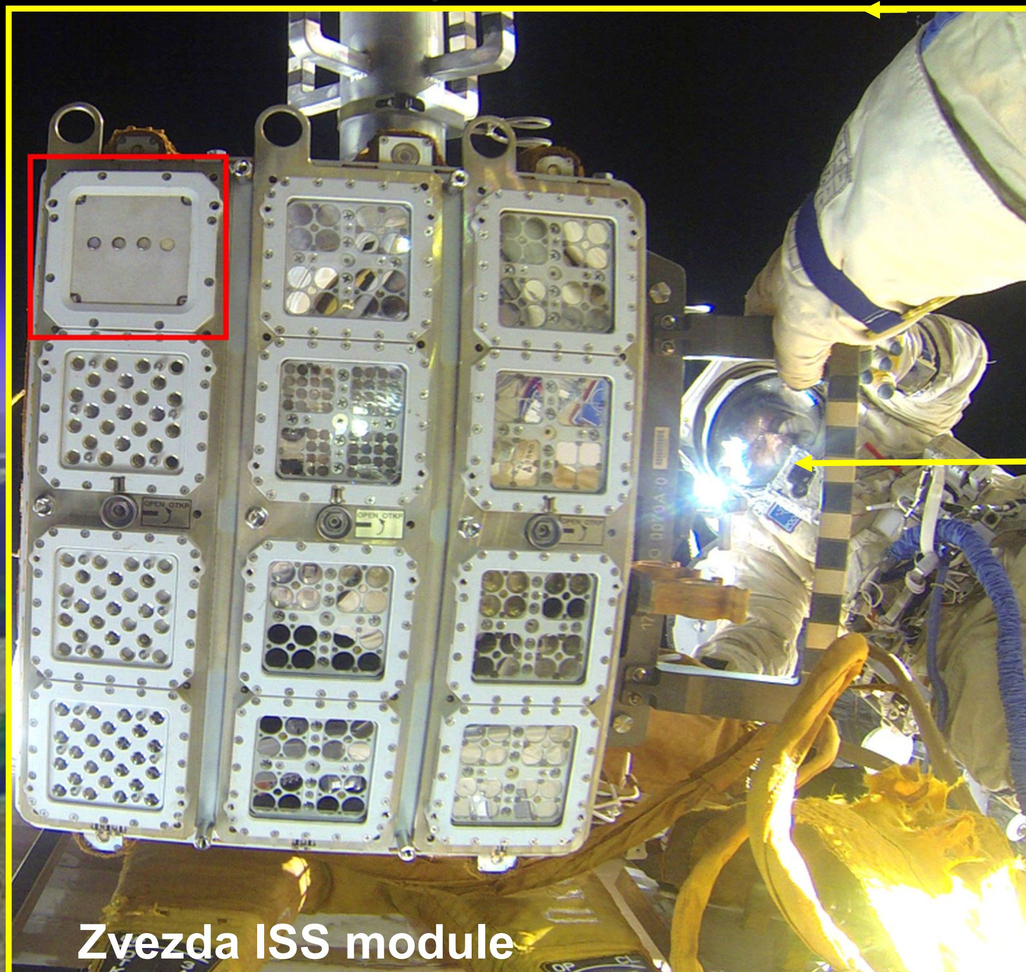






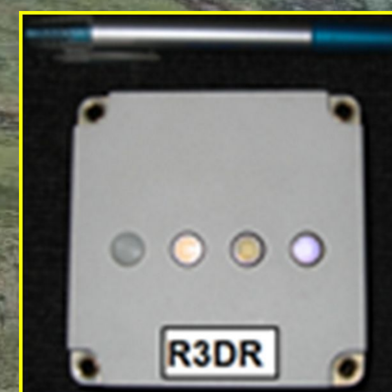
The R3DR2 instrument (in the red square) operated on the ISS from 2014 to 2016.

(The photo was taken by the Russian Cosmonaut G. Padalka on August 15, 2015 during a walk outside the ISS to inspect the EXPOSE-R2 platform outside the ISS Zvezda module (Picture credit of ESA/RKA)



Hand of Padalka

The astronaut M. Kornienko

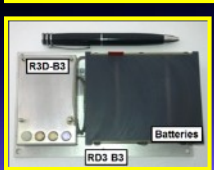


Interesting facts about Lyulin utensils

1. **Three instruments were lost in failed launches:** RADIUS-MD on Mars-96 (1996 d.) , R3D-B 1 on Foton-M 1 (2002) and Liulin-F on Phobos-Grunt (2011);

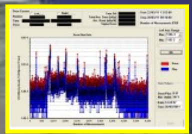
2. **The longest-operating devices** are the Musala device **from 2005 to date** and the Jungfrau peak, Switzerland, from 2005 to 2016 ;

3. **The longest-running spacecraft in space without interruption is "Lyulin-5" –** from 2007 to 2015;



4. **This device has flown 3 times in** space - on satellites: Foton-M 3 (2007), BION-M #1 (2013) and Foton-M1 (2014);

4. **This device has flown 2 times** on the ISS (2009-2010 and from October 2014 to January 16, 2016;



5. **The most intriguing data are from the flights** of the American "spy" plane U2 . (2001) and dose monitoring at the damaged Japanese nuclear power plant "Fukushima" (2011);

6. **Most significantly, the data** from Liulin- E094 were used for verification of the AP-9 model (Badavi, 2014);

7. **The first instrument in orbit around the Moon -** RADOM, 2008 ;

8. **The furthest one is "Lyulin-MO" - in orbit around Mars.**

Most significant technological result:

With the new measurement methodology and modern technologies, a significant reduction in the weight and size of the instruments has been achieved. Higher measurement accuracy has been achieved.

1987

Detector unit :
Size : 40x100x160mm
Weight : 0.49 kg
Control unit :
Size : 300x220x170 mm
Weight : 10.5 kg
Consumption: 15 W

2007

Detector block + Control block :
Size : 104x40x20 mm
Weight reduced 116 times to : 0.095 kg
Consumption reduced 1000 times to : 0.015 W

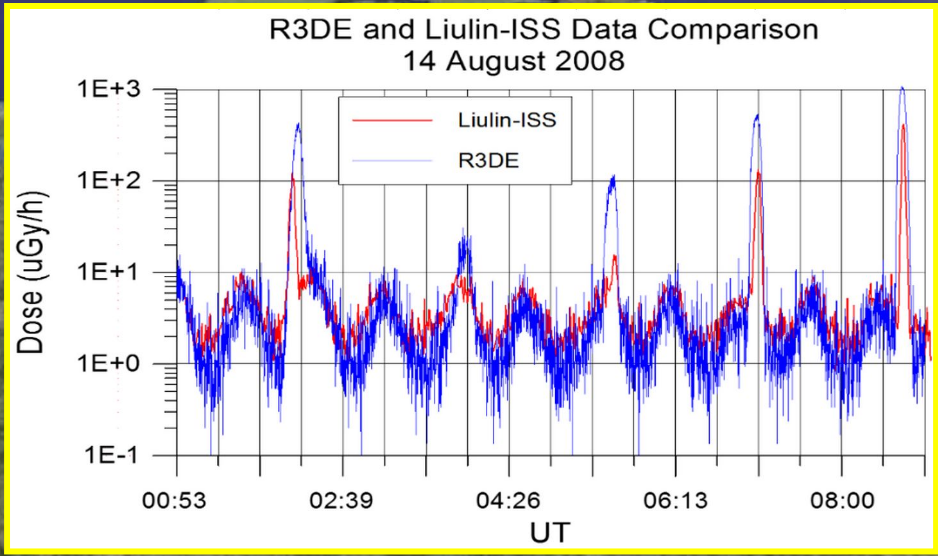
Most significant contribution:

For 30 years, the unknown device **"Lyulin"**
has become a **"trademark" of the Bulgarian Academy of Sciences** ,
which is used by scientific teams in:

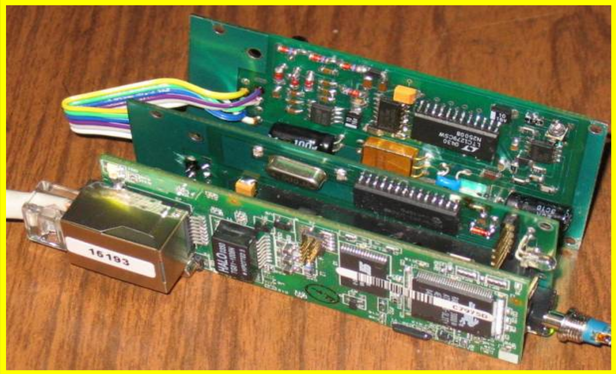
Japan, USA, Russia, Germany, France, Canada, Spain, Italy, Austria, Australia, Poland, South Korea, Czech Republic, Brazil, etc.

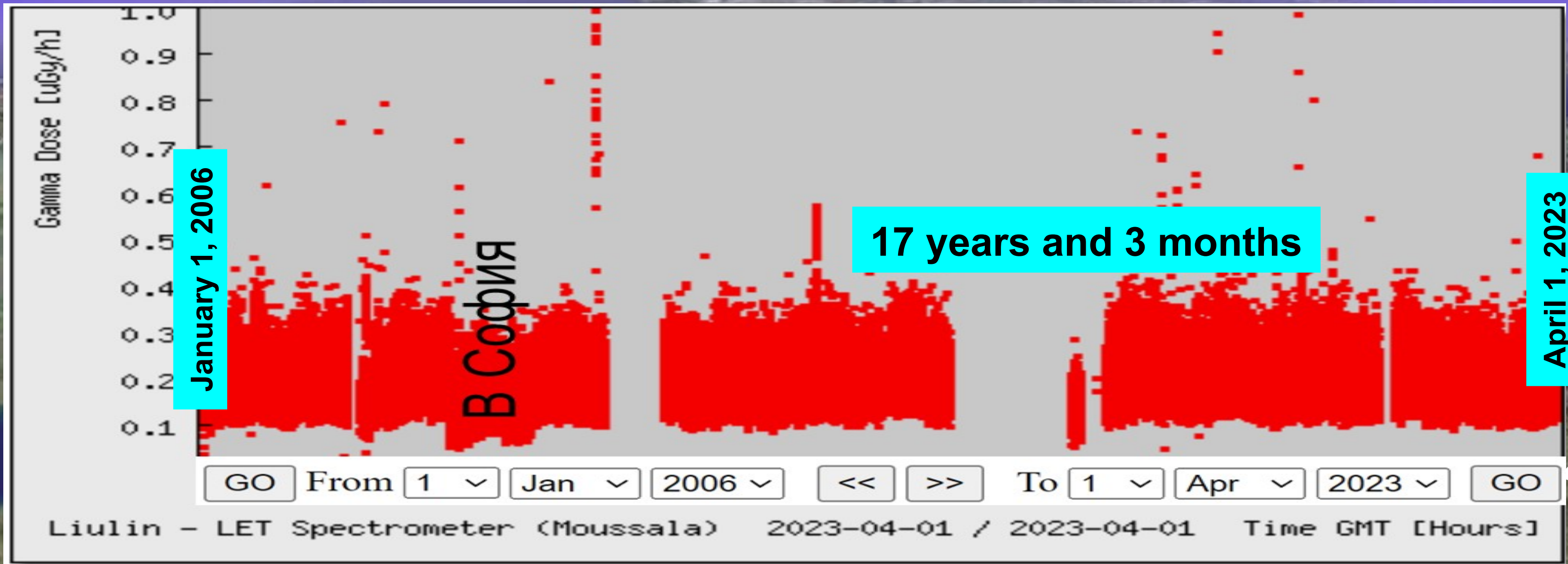
Ongoing experiments with "Lyulin" type utensils

The Lyulin-ISS instrument has been operating intermittently in the Russian segment of the International Space Station **since 2005.**



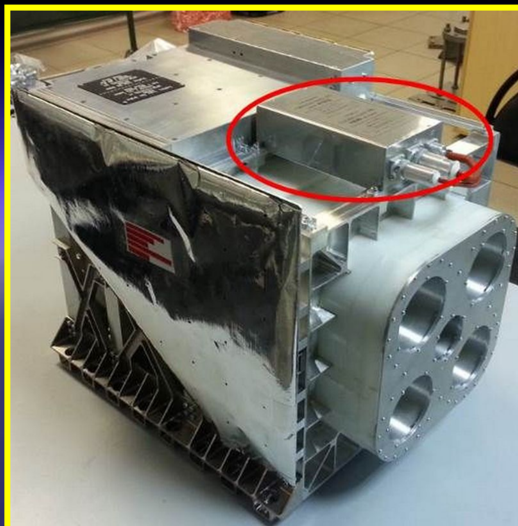
The Internet device "Lyulin-6MV" has been operating at the "Musala" Base Station of the Institute of Electrical and Electronic Engineering-BAS since 2006.



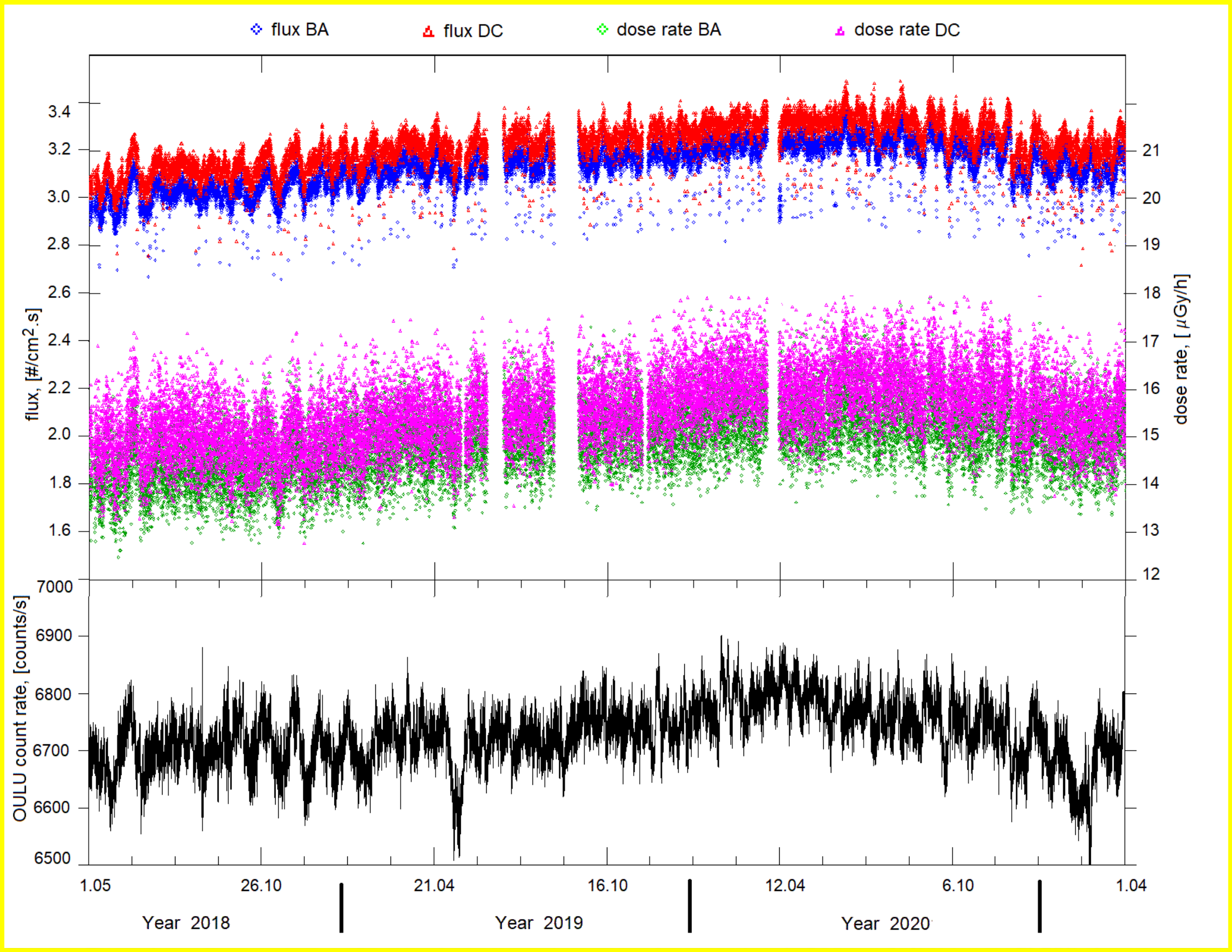


http://beo-db.inrne.bas.bg/moussala/index.php

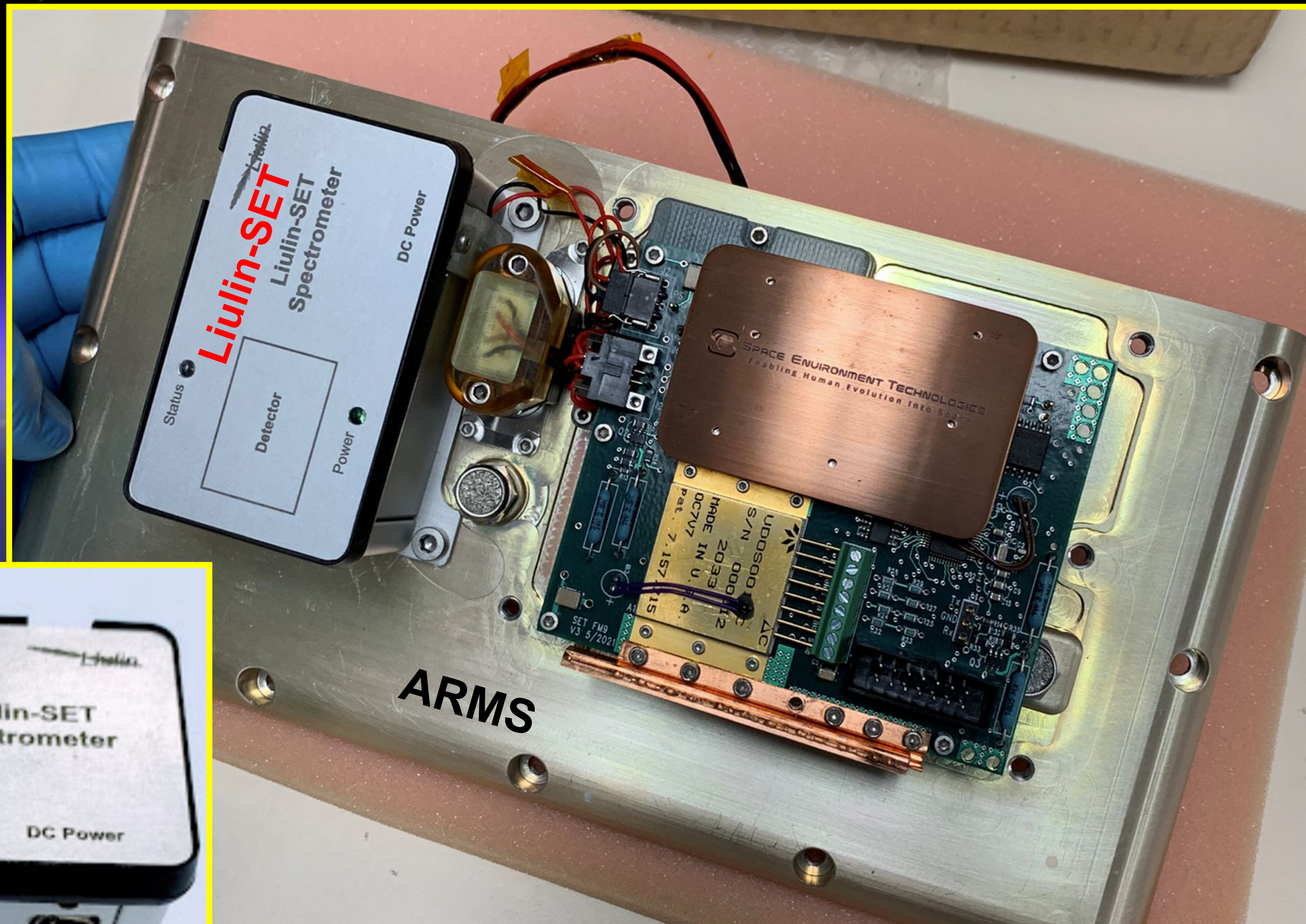
On the ExoMars-TGO orbital station, since March 14, 2016, the Russian neutron detector "Friend" has been operating the Lyulin-MO instrument . It is currently active in a circular orbit at an altitude of 400 km above the surface of Mars

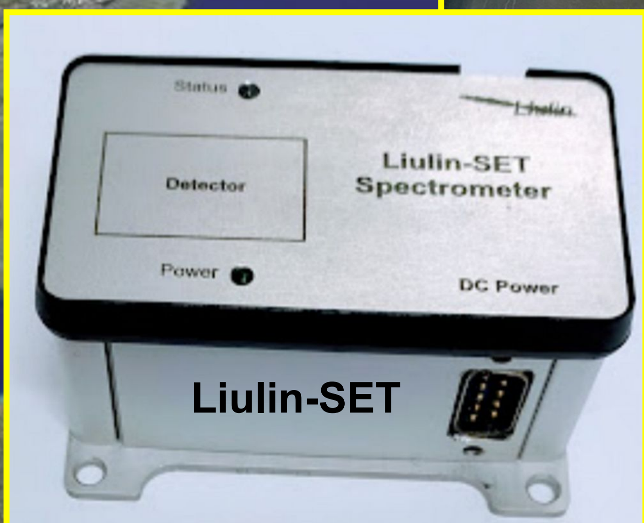


Results of the comparison of the measured flux and dose of galactic cosmic rays with the Lyulin-MO instrument and the neutron monitor in Oulu for the period May 1, 2018-March 31, 2021

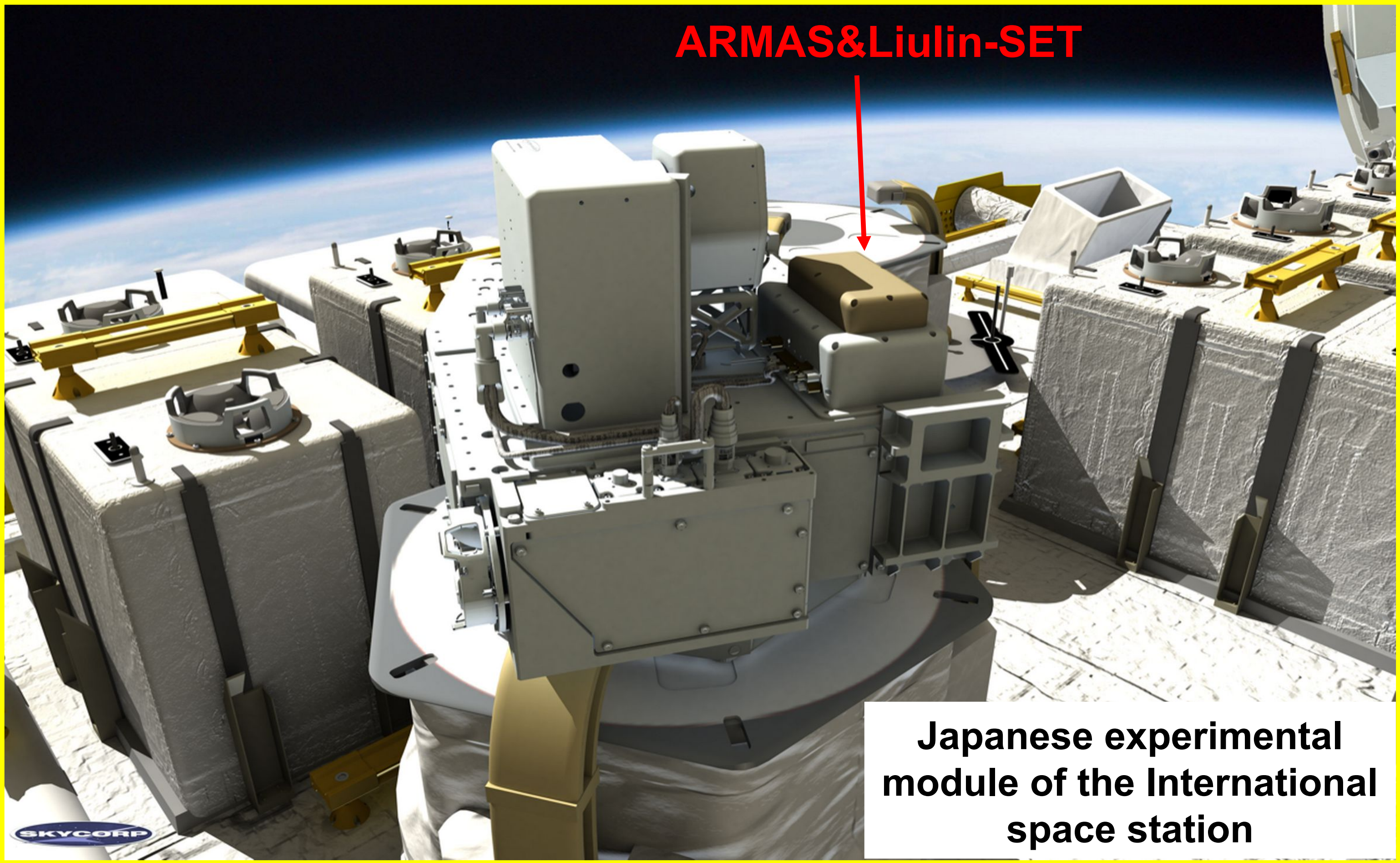


The Liulin-SET instrument was created by order of the American company "Space Technologies" and is part of the ARMAS module. After successful tests, it will operate on the International Space Station (ISS) from March to December 2022.

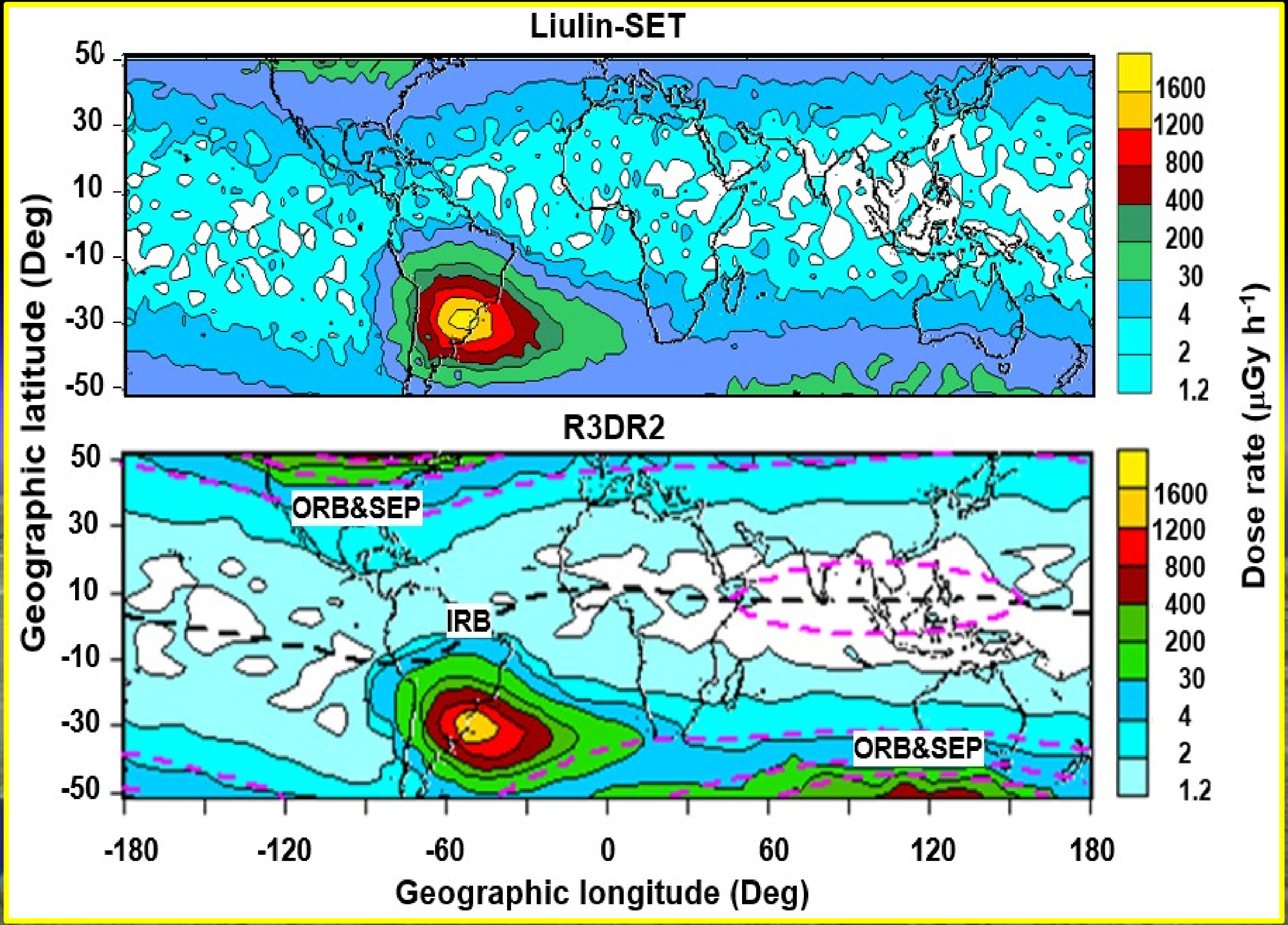




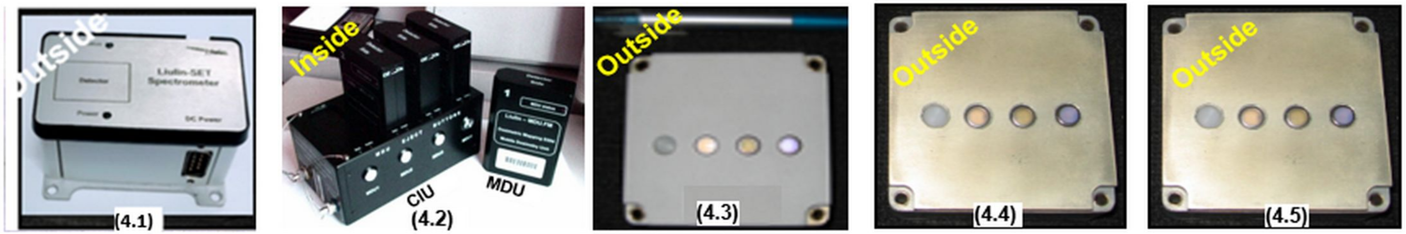
The ARMAS module and its included Liulin-SET simultaneously measure the cosmic radiation dose on the Japanese Experimental Module between March 3 and November 9, 2022 . It was returned to Earth and some results are shown on the next slide



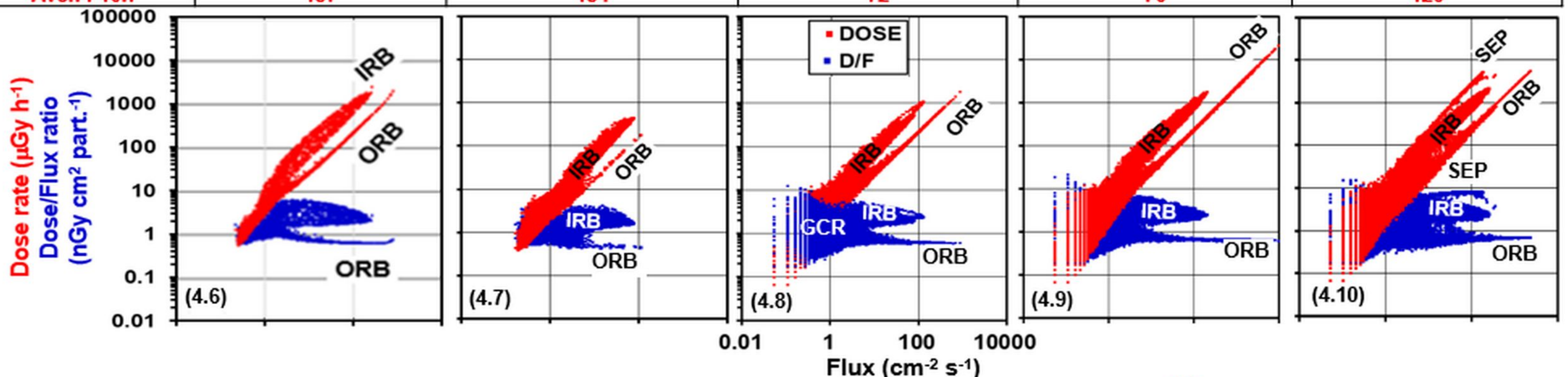
Global distribution of the IRB and ORB doses measured with Liulin-SET and R3DR2 Instruments in 2022 and 2015

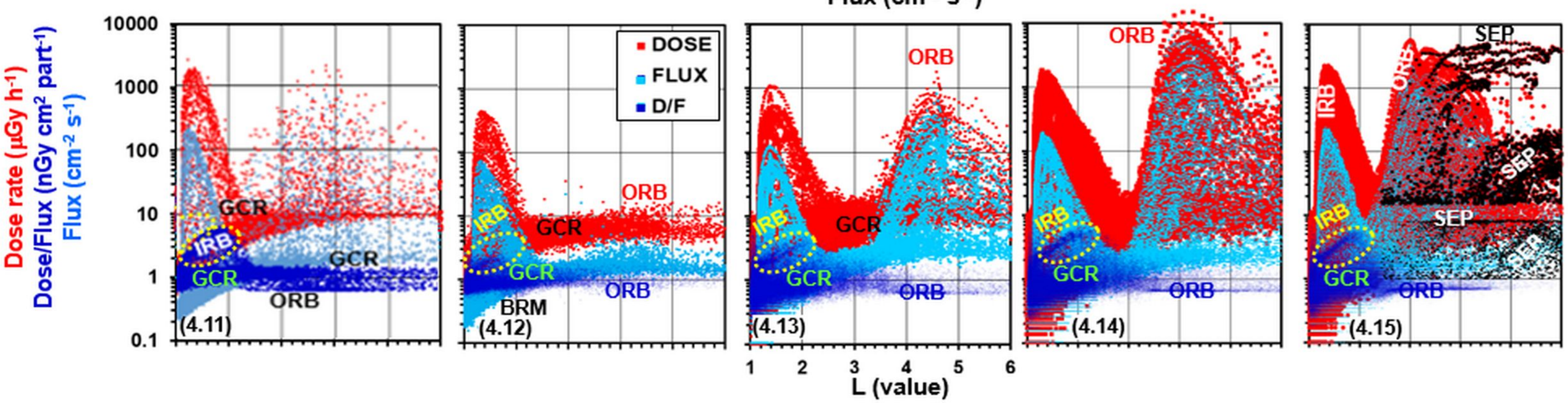


Comparison of Liulin-SET data with data from other instruments at the station

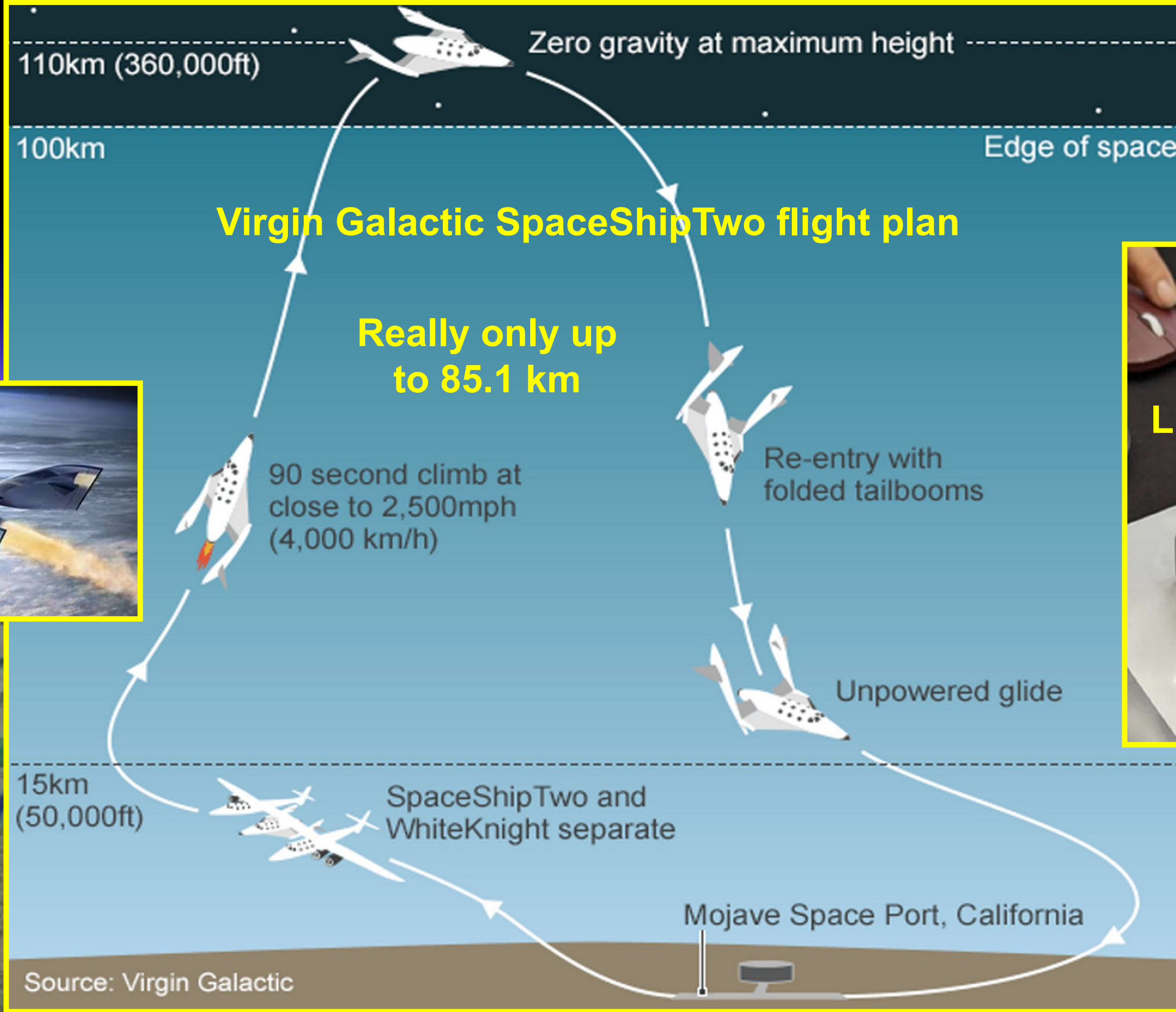


Name, Resol. [sec]	Liulin-SET, 300	Liulin-E094, MDU-2, 30	R3DE, 10	R3DR, 10	R3DR2, 10
Position	Outside Jap. Exp. Module of ISS	Inside Amer. Lab. Module and NODE-1 of ISS	In ESA EXPOSE-E facility outside Russian Seg. of ISS	In ESA EXPOSE-R facility outside Rus. Seg. of ISS	In ESA EXPOSE-R2 facility outside Rus. Seg. of ISS
Time, Aver alt. Aver. F10.7	2 Sept.-17 Oct. 400 km 137	11 May - 25 July 2001, 400 km 154	12 -20 March 2008, 347 km 72	1-10 April 2010, 352 km 76	21-30 June 2015, 407 km 120

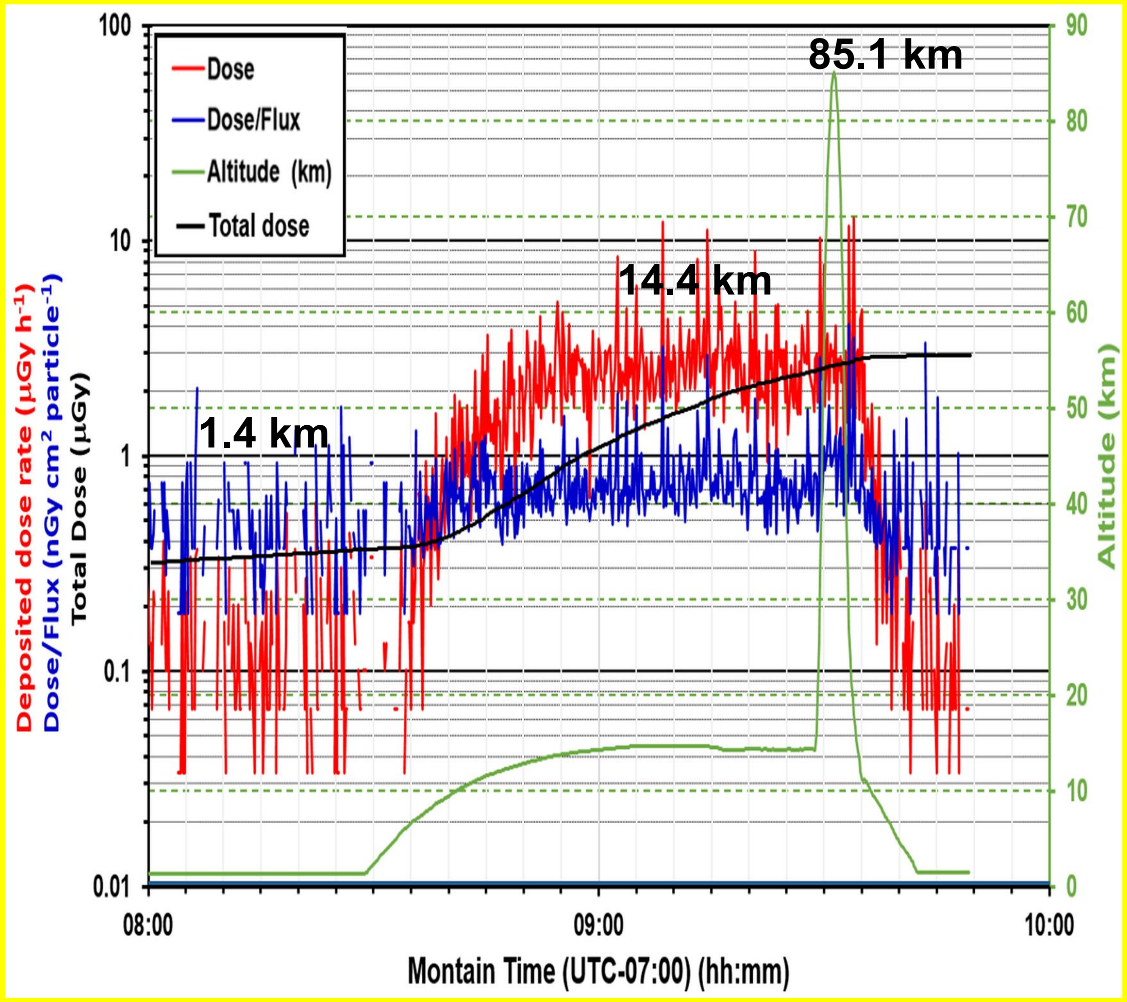


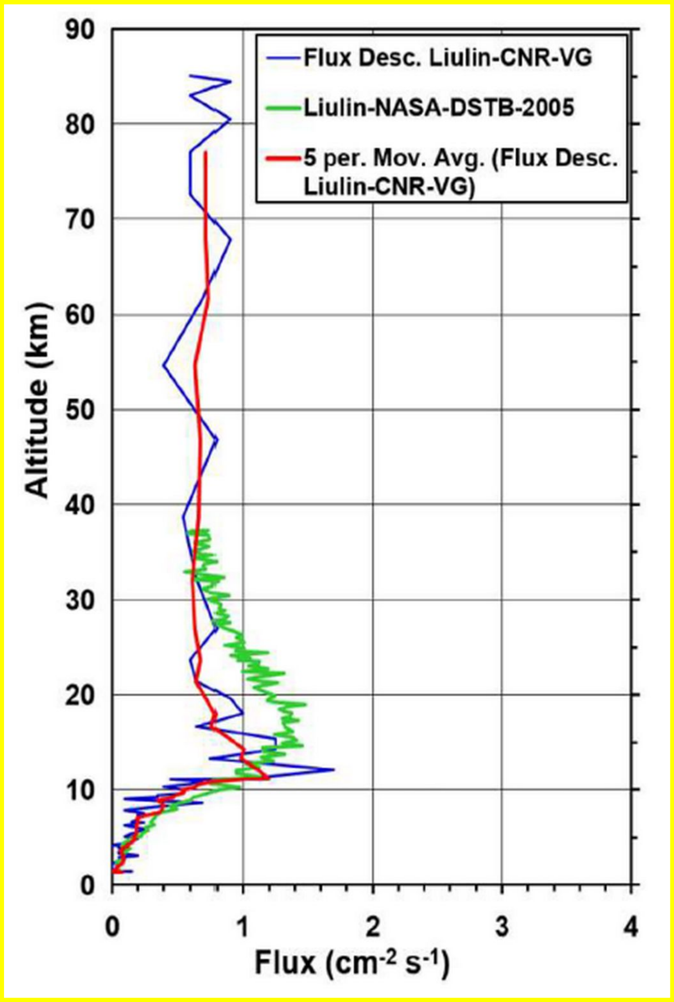


The Liulin-CNR-VG instrument was developed under a cooperation agreement between the Institute of Space Research (ICSR) and the Italian National Research Council (CNR). The instrument was used to measure the cosmic radiation dose during a Virgin Galactic flight at altitudes of up to 86 km on April 29, 2023.



Space radiation measured during first-ever commercial suborbital mission on Virgin Galactic SpaceShipTwo Unity on 29 June 2023



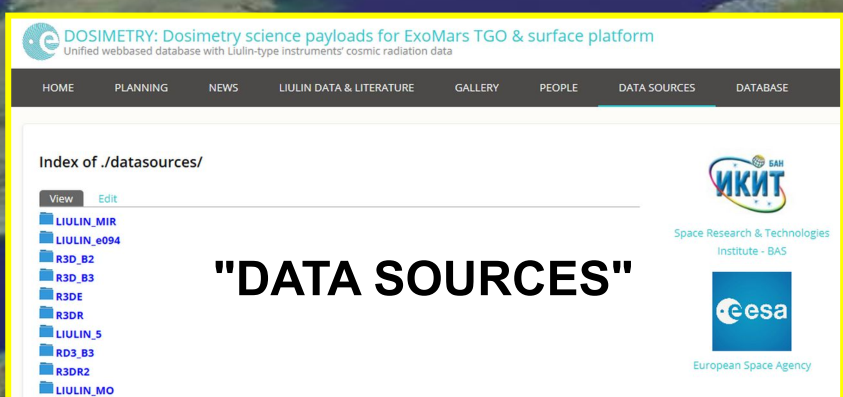


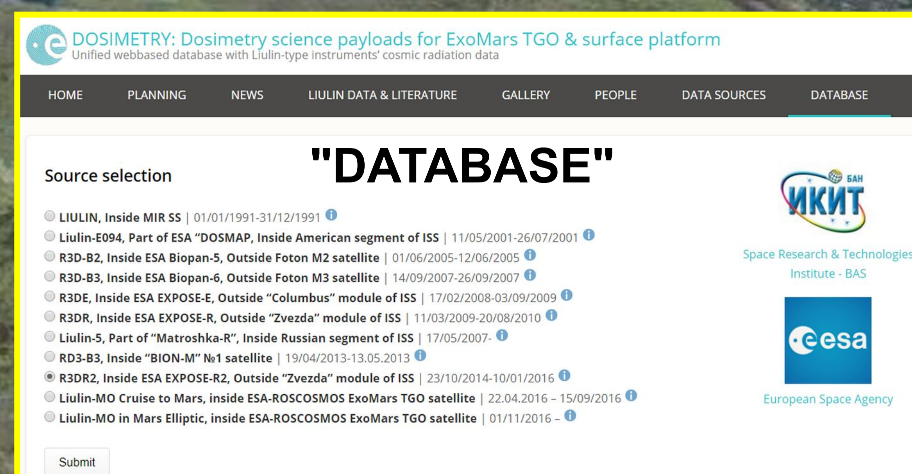
Data from **10 Lyulin-type instruments** are available online in a database with **free access for all interested parties.**

During the implementation of a contract with ESA (http://esa-pro.space.bas.bg/) in 2016-2018, a unified database was developed for cosmic radiation measured with the "Lyulin" type instrument in the period 1991-2018. The database provides for two separate options:

The first, called "DATA SOURCES" (http://esa-pro.space.bas.bg/datasources), downloads data files in CSV format to the user's computer.

The second, called "DATABASE" (http://esa-pro.space.bas.bg/database) allows selection and visualization of data in vector, JPEG and PDF format.





Future space experiments with "Lyulin" type utensils

Bulgarian scientists have a long lasting fruitful collaboration with Japanese scientists.

For example:

The calibration results obtained with Liulin-4J spectrometer–dosimeter on protons and heavy ions in at the National Institute of Radiological Sciences cyclotron and HIMAC heavy ion synchrotron facilities by Dr. Yukio Uchihori in 2002 (Uchihori et al. 2002) and his team was used in all Liulin type instruments developed in Space Research and Technology Institute at the Bulgarian Academy of Sciences;

Japanese colleagues use 16 Liulin type spectrometers–dosimeters in their scientific research.

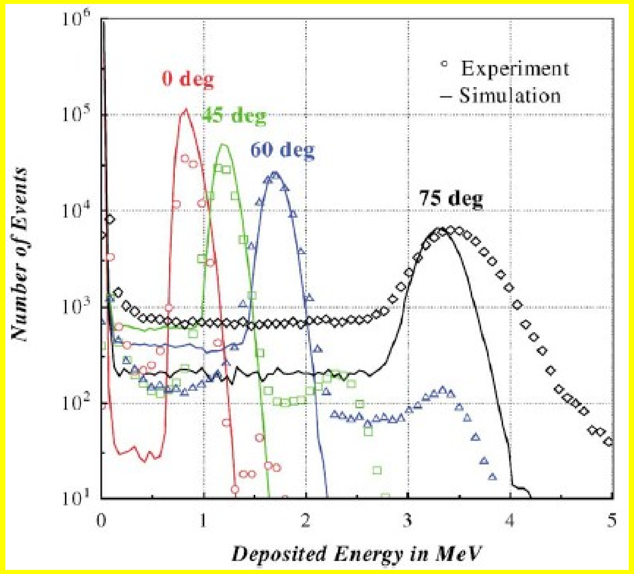
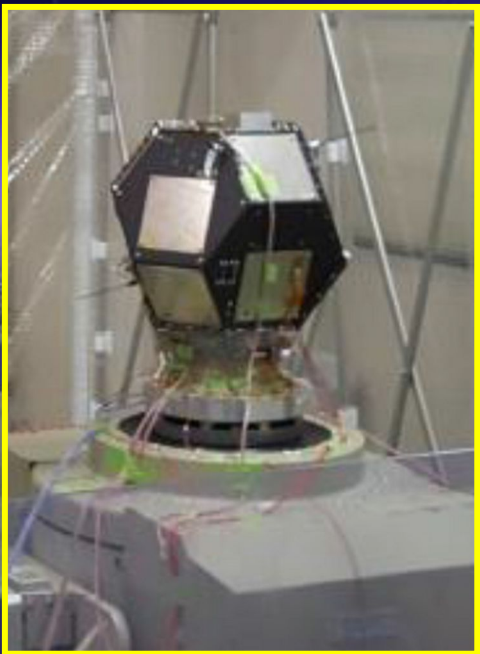
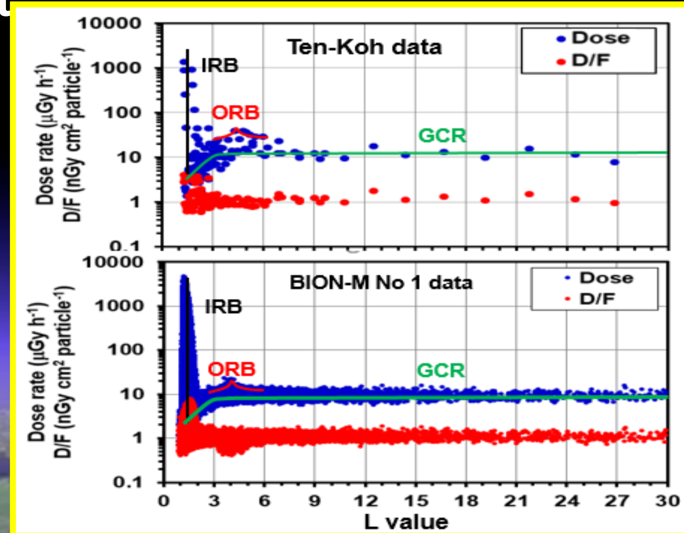


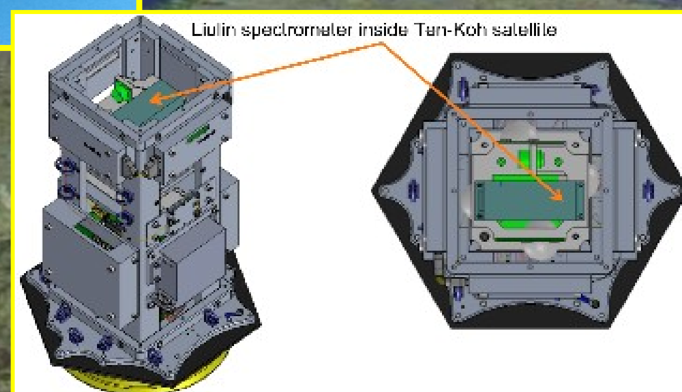
Fig. 7. (Uchihori et al. 2002) Comparison of distributions obtained from the cyclotron experiments and the GEANT4 simulation. Four distributions corresponding to deposited energy for 0◦, 45◦, 60◦ and 75◦ are shown. The symbols show experiment data and the connecting lines show simulation results for irradiations at these incident angles. The discrepancy of the peak value for 75◦ between the simulation and experiment data corresponds to a discrepancy of1 ◦ in the 75◦ irradiation angle.

SRTI-BAS in collaboration with Prairie View A&M University, USA, NASA/Johnson Space Center, USA, and School of Engineering, Kyushu Institute of Technology, Japan will participate in the experiment on the Japanese satellite Ten-Koh with the Liulin-Ten-Koh-2 instrument

2026



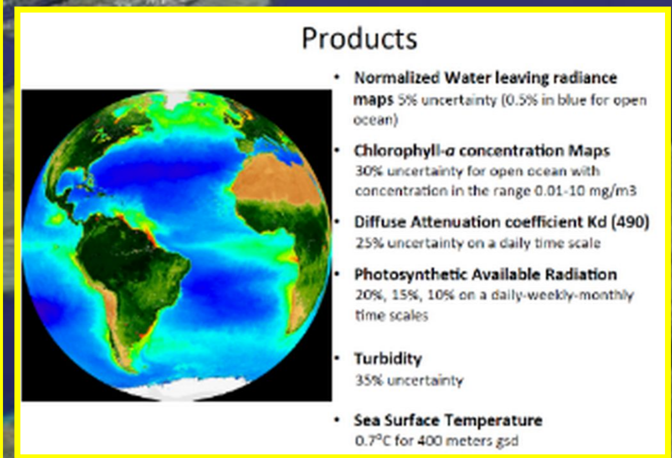


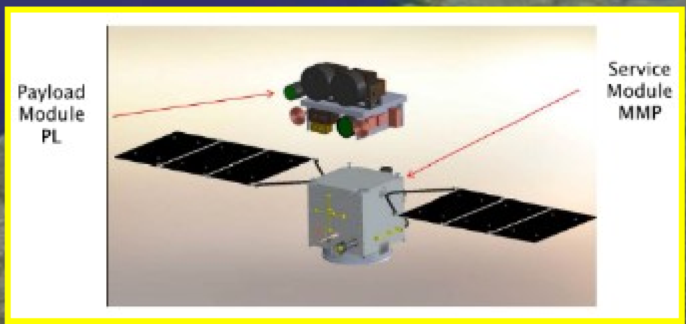


The Liulin-AR spectrometer will study the radiation environment of the Argentine-Brazilian satellite SABIA-MAR 1

20 2 6

SABIA-MAR 1 satellite is a joint Argentine-Brazilian Earth observation mission, whose objective is to study the ocean biosphere, its changes over time and how it is affected by human activities. The satellite is planned to be launched into a 702 km sun-synchronous circular orbit in 202 3. The platform and instruments for observing ocean color and determining sea surface temperature were developed in Argentina. The Liulin-AR instrument will record the global distribution of the 4 possible primary sources of cosmic radiation outside the satellite. The dimensions of the Liulin-AR are 100x40x20 mm and weight 0.092 kg.



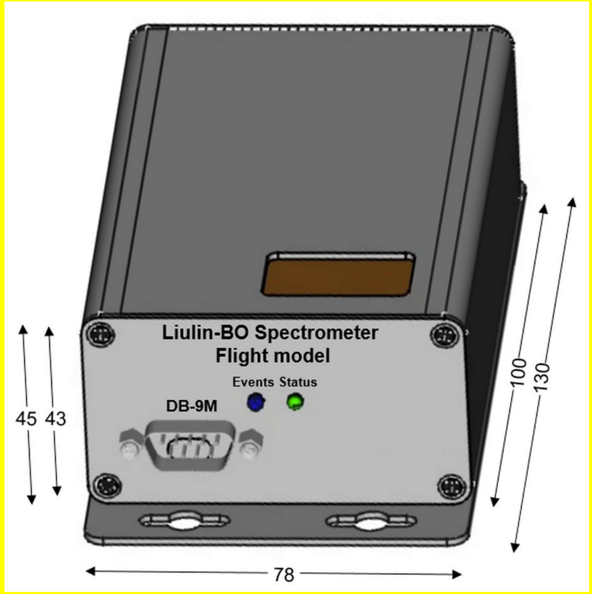


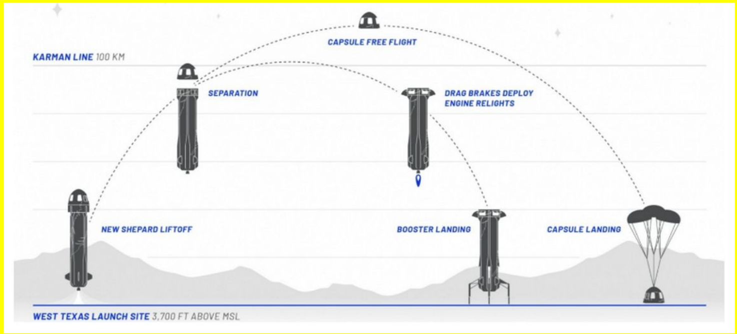
SABIA-Mar satellite

Liulin-AR device

By the end of 2025, a Lyulin-type device is expected to fly to an altitude of 107 km on **Blue Origin 's New Shepard rockets** . The experiment is in collaboration with the Department of Physics. Oklahoma State University p USA.

2026





Contributions

- A new scientific direction and methodology for measuring cosmic radiation in the near-Earth space and atmosphere has been created. The methodology has been successfully implemented in practice. Instruments of the "Lyulin" type have been used in scientific and applied scientific projects by the Center for Space Research and the Institute of Space Research-BAS and by colleagues abroad;
- The high quality of the new measurement methodology has been proven in the calibrations of "Lulin" type instruments of various radioactive sources and accelerators in the USA, Belgium, Japan and CERN;
- Together with colleagues from NASA, a new model for the radiation field in the inner radiation belt has been created;
- The radiation in the atmosphere during changes in solar activity and during proton penetration to the Earth's surface (GLE) on April 15, 2001 was studied. These studies serve to assess and improve the radiation protection of crews and passengers of civil aircraft, according to the requirements of Directive 96/29 of the European Union;
- The long-term variations of the "new" radiation belt, created after the solar proton event and magnetic storm in March 1991, have been discovered and studied;
- Dose reductions from the inner belt during Space Shuttle docking with the ISS have been discovered;
- Experimental data has proven the distribution profile of cosmic radiation from the Earth's surface to outer space.
- With experimental data from 1991 to 2019, the modulation of dose in the Earth's orbit by solar activity was studied;
- Variations in the outer radiation belt and precipitation bands of the ISS have been discovered.

Conclusions

- Various sources of cosmic radiation create conditions dangerous to human health in near-Earth, near-lunar, interplanetary and interstellar space;
- "Lyulin" type instruments are relatively inexpensive, but highly informative , which makes them sought after and applied by scientists working in the field of radiation safety of aviation and space personnel;
- Cosmic radiation limits the time and place for direct human participation in future space missions beyond the orbit of Mars ;
- "Colonization" of Mars would be practically impossible due to radiation and harsh climatic conditions;
- A manned flight beyond the Solar System must for now be considered science fiction , due to the still unknown effects of long-term exposure to galactic cosmic rays and the unclear scientific contributions of the mission;
- **New scientific research and experiments are needed.**

How is the work of scientists evaluated?

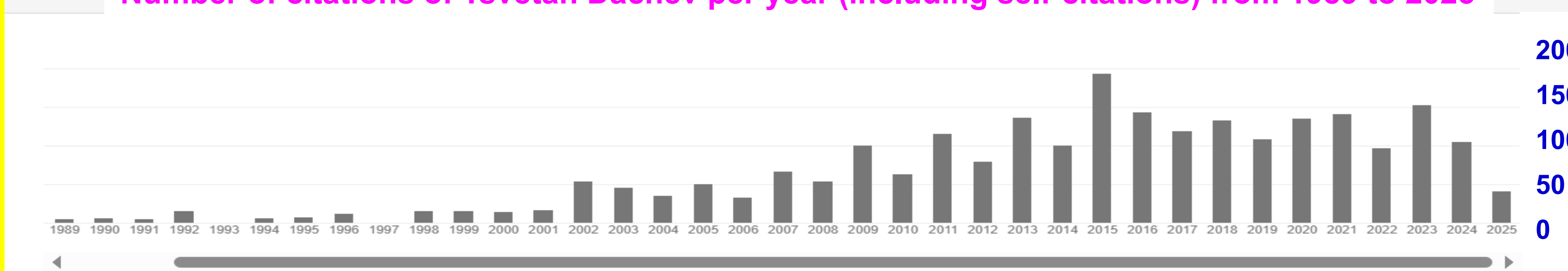
By the number of citations of their publications by other scientists.

Tsvetan Dachev's quotes mainly reflect the quotes from the articles about "Lyulin" utensils

In 2022, Prof. Dachev was included in the Stanford University rating of the top 2% most cited scientists In the world

https://scholar.google.com/citations?user=uzmW_mwAAAAJ

Number of citations of Tsvetan Dachev per year (including self-citations) from 1989 to 2025



Acknowledgements

The authors thank:

- To all Bulgarian and foreign specialists and organizations who participated in the development of the "Lyulin" series of devices, in the conduct of the experiments and the interpretation of the data;
- To the Bulgarian Academy of Sciences, the Bulgarian National Science Foundation , Bulgaria-ESA PECS program and our international partners for funding the projects related to the creation of the "Lyulin" equipment;
- To the cosmonauts and astronauts aboard the manned space stations "Mir" and the ISS for conducting experiments with the "Lyulin" equipment.

Prof. Dachev is thankful for the help from following colleagues:

B. Tomov[1], Yu. Matviichuk[1], P. Dimitrov[1], M. Mitev[1], M. Jordanova[1]J. Semkova[1], R. Koleva[1], St. Malchev[1], N. Bankov[1], K. Krastev[1]

I. Mitrofanov[2], A. Malahov[2], M. Mokrousov[2], A. Sanin[2], M. Litvak[2], A. Kozyrev[2], V. Tretyakov[2], D. Golovin[2], S. Nikiforov[2], A. Vostrukhin[2], F. Fedosov[2], N. Grebennikova[2],

V. Petrov[3], I. Chernykh[3], V.A. Shurshakov[3], V.V. Benghin[3], E.N. Yarmanova[3], O.A. Ivanova[3],

F. Spurny[4], O. Ploc[4], J. Kubancak[4],

D.-P. Häder[5], M. Lebert[6], M.T. Schuster[6],

G. Reitz[7], G. Horneck[7],

Y. Uchihori[8], H. Kitamura[8],

[1]Space Research and Technology Institute, Bulgarian Acad., of Sciences, Sofia, Bulgaria te, Russian Acad. of Sciences, Moscow, Russia

[3]State Research Center Institute of Biomedical problems, Russian Acad. of Science, Moscow, Russia; [4]Nuclear Physics Institute, Czech AS, Prague, Czech Republic

[5]Neue Str. 9, 91096 Möhrendorf, Germany

[6]Friedrich-Alexander-Universität, Department for Biology, Erlangen, Germany;

[7]DLR, Institute of Aerospace Medicine, Köln, Germany

[8]National Institute of Radiological Sciences-STA, Chiba, Japan;

Table 1. Liulin Type Instruments Used In Space Missions (1/3)

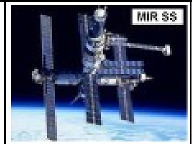
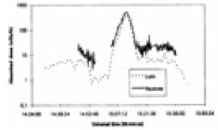
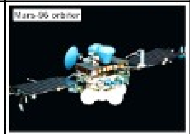
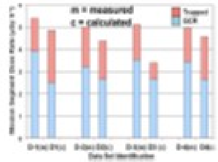
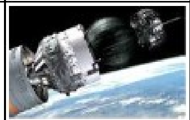
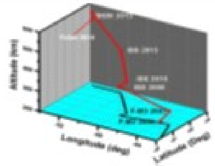
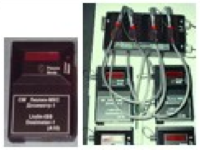
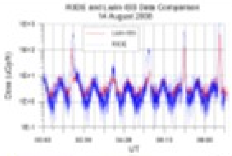
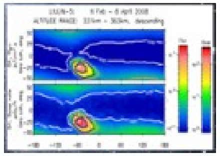
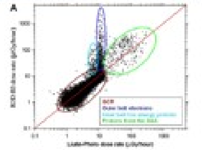
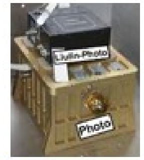
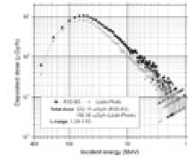
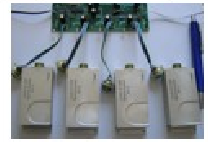
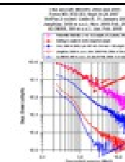
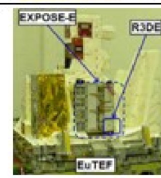
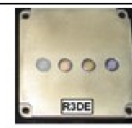
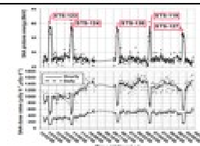
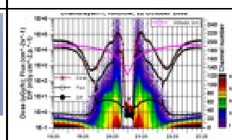
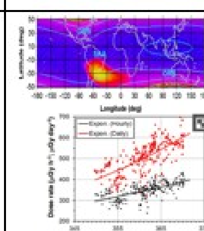
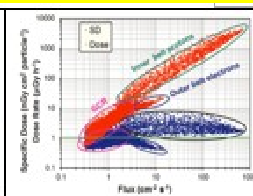
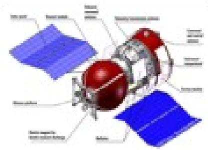
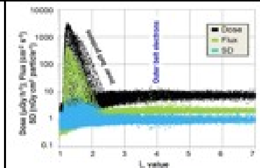
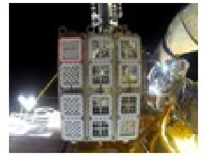
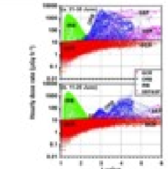
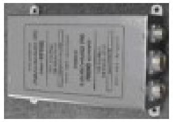
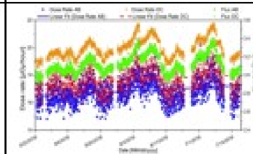
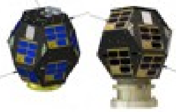
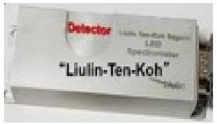
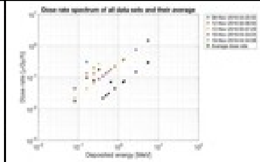
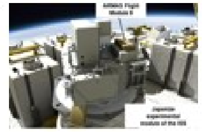
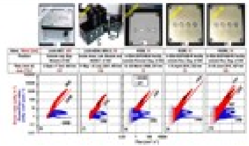
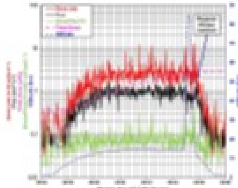
No	Carrier name, Name of Liulin device, Scientific cooperation, (Main Reference)	Data time cover		External view of the carrier (satellite)	External view of Liulin instrument	Example of the scientific results
		Begin (dd/mm/yy),	End (dd/mm/yy)			
1	**LIULIN** Inside "MIR" Space Station, Bulgaria, Russia (Dachev et al., 1989)	16/04/1989	30/12/1994			
2	**RADIUS MD** Outside/inside Mars 96 station, Bulgaria, France, Russia (Semkova et al., 1994)	Unsuccessful launch on 16.11.1996				
3	**Liulin-E094 with 4 Mobile Dosimetry Units (MDUs)** Inside of the American laboratory module of the International Space Station (ISS) Bulgaria, Germany (Reitz et al. 2005) (Dachev et al., 2005, 2006, 2009a)	11/05/2001 (Wilson et al., 2007, Nealy et al, 2007, Slaba et al., 2011)	25/07/2001			
4	**R3D-B2** Outside of the Foton-M2 satellite, Bulgaria, Germany (Header et al., 2009)	01/06/2005	11/06/2005			
5	**Liulin-ISS 4 MDU** Inside of the Russian segment of the ISS, 4 MDU with displays, Bulgaria, Russia (Dachev et al., 2009ab)	01/09/2005	Still operable at the ISS			
6	**Liulun-5**-Dosimetry Telescope, Russian segment of the ISS, Bulgaria, Russia. (Semkova et al. 2007, 2014)	17/05/2007	09/2015			
7	**R3D-B3** Outside of the Foton-M3 satellite, Bulgaria, Germany, Italy, (Header et al. 2009)	14/09/2007	26/09/2007			

Table 1. Liulin Type Instruments Used In Space Missions (2/3)

8	**Liulin-Photo** Inside of the Foton-M3 satellite, Bulgaria, Italy, (Damasso et al., 2009)	14/09/2007	26/09/2007			
9	**Liulin-S** With 4 MDUs, Inside of the ROSCOSMOS, Project Space Suit (Скафандр) at the ISS. (Kartashov et al., 2010)					No information for the performance of the experiment on the ISS.
10	**Liulin-R** Outside of the HotPay2 rocket, Bulgaria, Norway (Tomov et al., 2008) (Dachev et al., 2012a)	31/01/2008 370 km Apogee at 14.04°E, 70.67°N,				
11	**R3DE** Outside of the ISS, on ESA Columbus Module and inside of ESA EXPOSE-E facility, Bulgaria, Germany (Dachev et al., 2012b)	22/02/2008	22/06/2009			
12	**RADOM** Outside of the Chandrayaan-1 satellite, Moon circular orbit at 100/200 km. Bulgaria, India (Dachev et al., 2011)	29/10/2008	07/11/2008			
13	**Liulin-Phobos** Outside of the Phobos-Grunt interplanetary station, Bulgaria, Russia, (Semkova et al., 1994)	Unsuccessful entry in interplanetary orbit on 8/11/2011				
14	**R3DR** Outside of the ISS "Zvezda" Module and inside the ESA EXPOSE-R facility, Bulgaria, Germany, (Dachev et al. 2015a)	20/02/2010	20/08/2010	 		

15	**RD3-B3** Inside of the BION-M No 1 satellite, Bulgaria, Germany, Russia, (Dachev et al. 2015b)	19/04/2013	13/05/2013			
16	**RD3-B3** Inside of the Foton-M No 4 satellite, Bulgaria, Germany, Russia, (Damasso et al. 2016)	18/07/2014	31/08/2014		 The R3D-B3 instrument was used for second flight on Foton-M No 4 satellite	
17	**R3DR2** Outside of the ISS “Zvezda” Module and inside of ESA EXPOSE-R2 facility, Bulgaria, Germany, (Dachev et al. 2017)	25/10/2014 In the Liulin database, this is the most advanced set.	10/01/2016		 The R3DR instrument was used for second flight on ISS	
18	**Liulin-MO** Outside of the ExoMars Trace Gas Orbiter (TGO), Bulgaria, Russia, (Semkova et al., 2018, 2024)	22/04/2016, (Semkova et al., 2018)	(Still operable in Mars 400 km orbit)			
19	**Liulin Ten-Koh** Inside of the Ten-Koh satellite, Bulgaria, USA, Japan (Fajardo et al., 2019)	29/10/2018	16/01/2019			
20	**Liulin-SET** Outside of the Japanize experimental platform of the ISS Bulgaria, USA. (Tobiska et al. 2024)	17/03/2022	09/12/2022			
21	**Liulin-CNR-VG** Inside of VG Spaceship Two Unity, Bulgaria, Italy (Dachev et al., 2024)	Operated for about 8 hours on 29 June 2023				

The TEAM who started this exciting adventure ...

Dimitrov Tomov Matviichuk Dachev

Thank you for your attention and interest in our work !