The modelling of nuclear planetology space experiments using NICA complex

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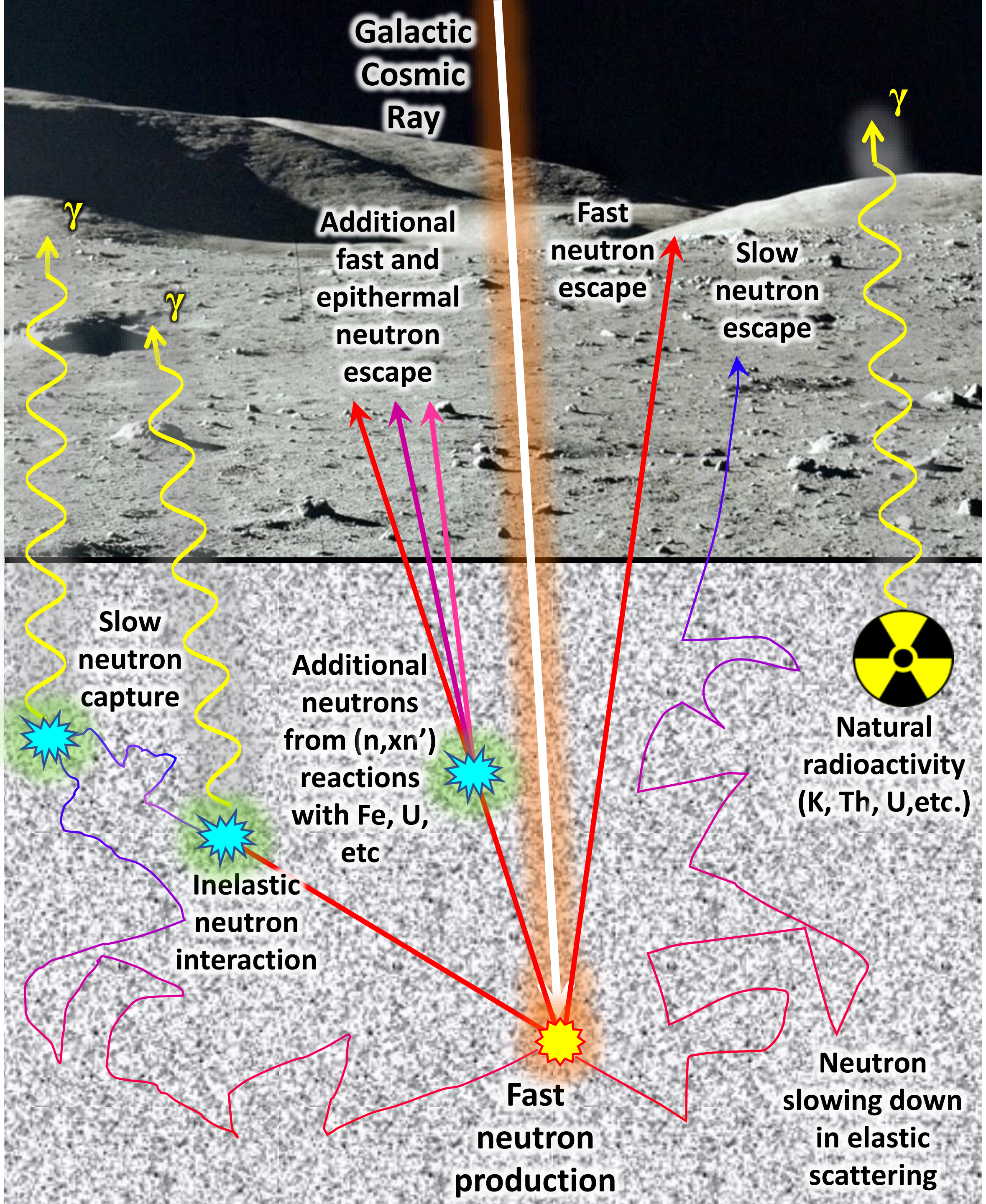
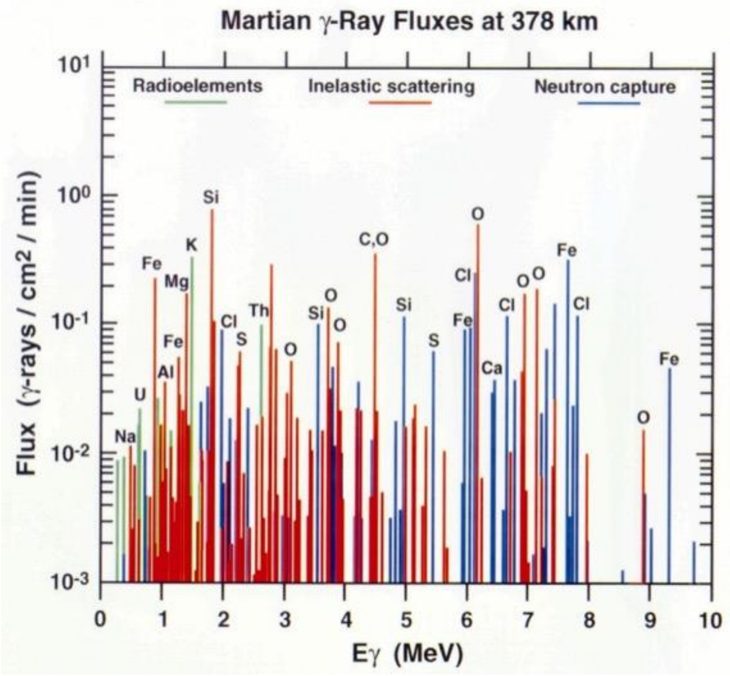
Nuclear Planetology

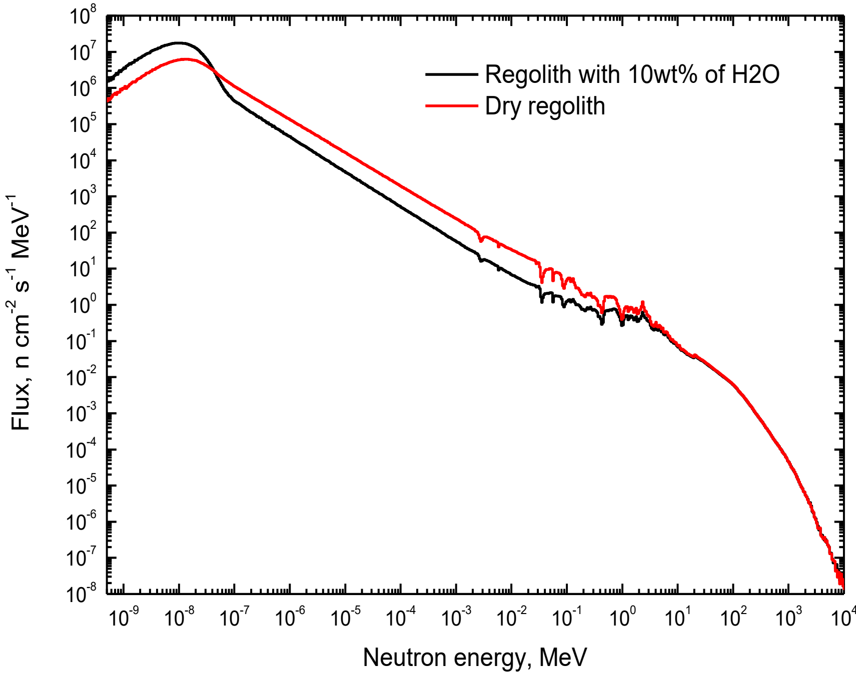
Studies of Solar System planets and bodies with neutron and gamma-ray spectrometers onboard spacecrafts (orbiters and landers)

- ❑ To map planetary neutron albedo and gamma radiation in the different energy ranges
- ❑ To search for bulk (to the depth 1-2 m) water/water ice distribution
- ❑ To determine bulk (to tens of centimeters) elemental composition of the planetary regoliths: major/minor/trace rock forming elements (H, Si, O, Al, Mg, Fe, Na, Cl, Ti, U,Th, K)
- ❑ To monitor neutron component of radiation background (during quite and active Sun)

Galactic cosmic rays as a source of planetary neutron and gamma-radiation

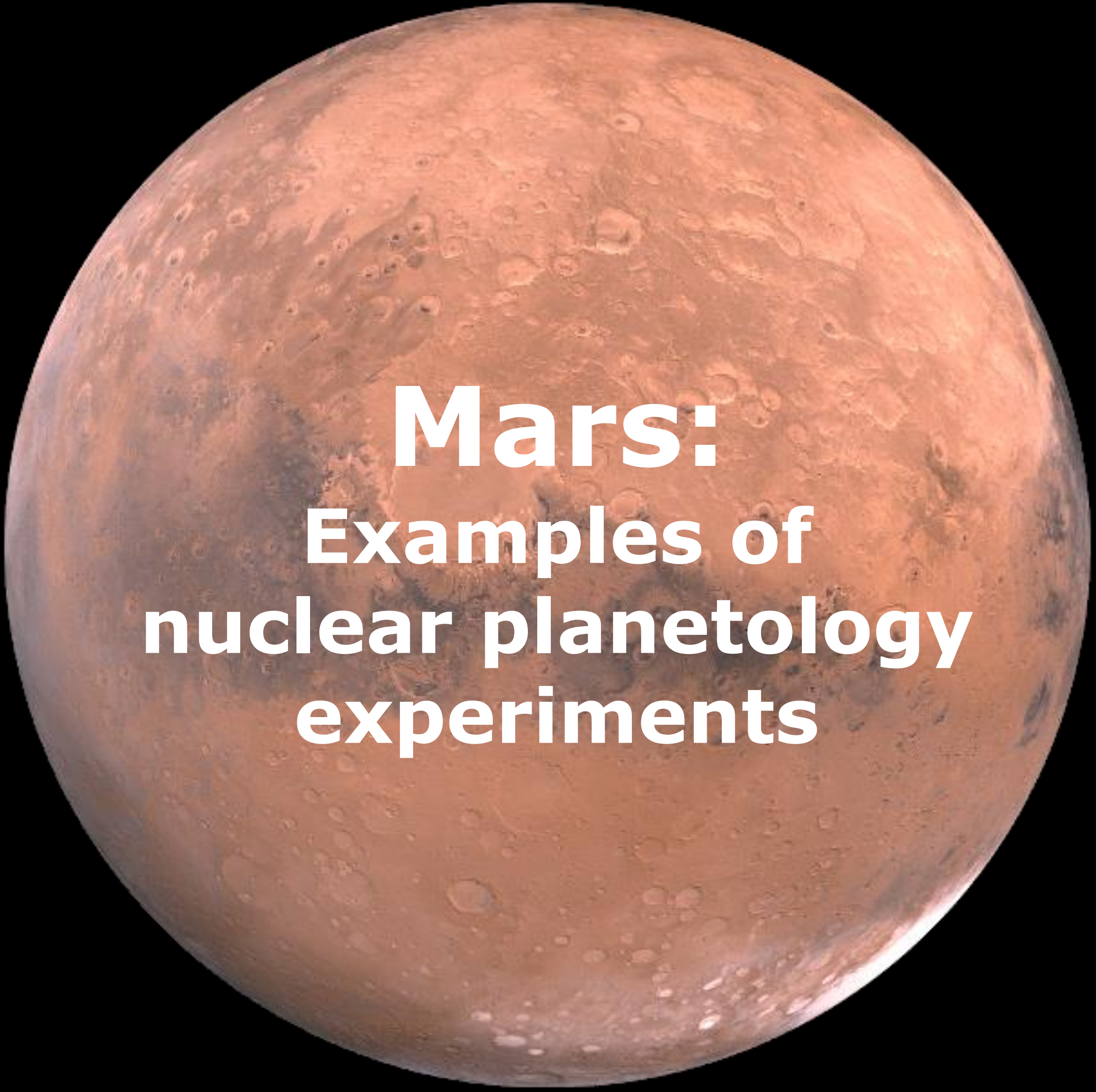






Successful Nuclear Planetology Space Missions

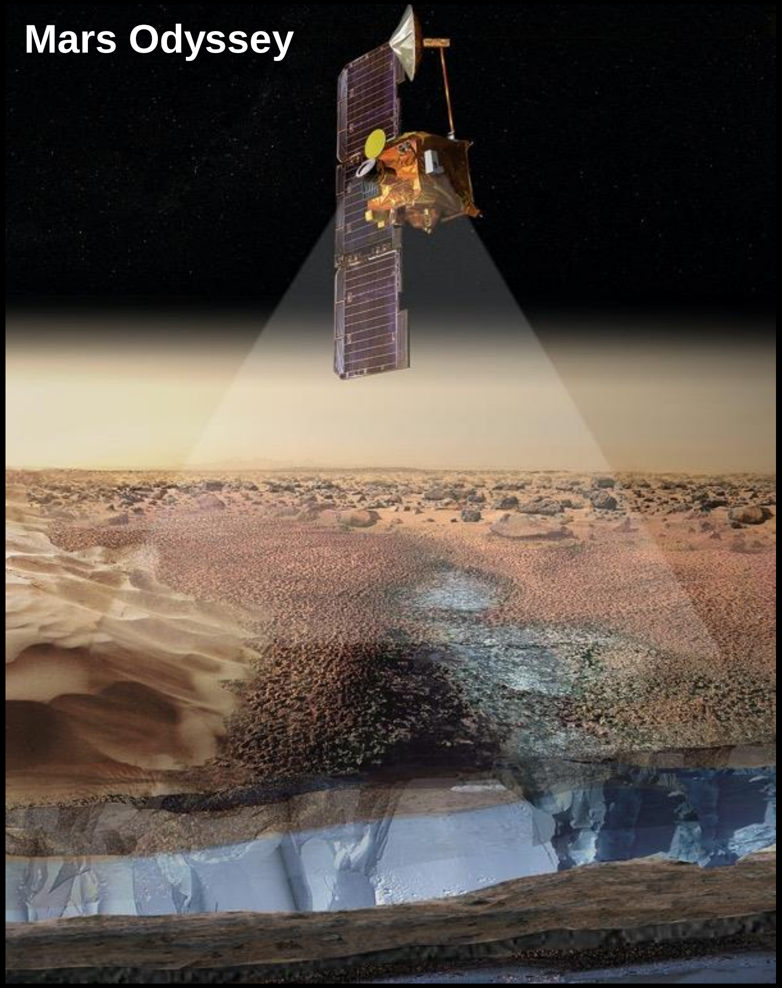
Launch date	Country / Agency	Spacecraft	Planet	Results
31 March 1966	USSR	Luna 10	Moon	Measurements of K, Th, U abundances by γ-ray spectroscopy on the orbiter
22 October 1966	USSR	Luna 12	Moon	Measurements of K, Th, U abundances by γ-ray spectroscopy on the orbiter
4 May 1967	USA	Lunar Orbiter 4	Moon	Radiation environment studding at route to and near the moon by on-board dosimeter
1 August 1967	USA	Lunar Orbiter 5	Moon	Radiation environment studding at route to and near the moon by on-board dosimeter
8 September 1967	USA	Surveyor 5	Moon	Surface composition analysis by detection of the energy spectra of the α-particle spectrometer
7 November 1967	USA	Surveyor 6	Moon	Surface composition analysis by detection of the energy spectra of the α-particle spectrometer
7 January 1968	USA	Surveyor 7	Moon	Surface composition analysis by detection of the energy spectra of the α-particle spectrometer
14 September 1970	USSR	Luna 17 / Lunokhod 1	Moon	Lunar soil composition tests (> 500) with on-board X-ray spectrometer
28 September 1971	USSA	Luna 19	Moon	Soil composition analysis by γ-ray spectrometer
27 March 1972	USSR	Venera 8	Venus	Measurements of K, Th, U abundances by γ-ray spectroscopy on the lander
16 April 1972	USA	Apollo 16	Moon	Measurements of the lunar surface composition by X-ray, α-particle and γ-ray spectrometers
7 December 1972	USA	Apollo 17	Moon	Measurements of the rates of low-energy neutron capture as a function of depth in the lunar regolith
25 July 1973	USSR	Mars 5	Mars	Soil composition analysis by γ-ray spectrometer on the orbiter
29 May 1974	USSR	Luna 22	Moon	Soil composition analysis by γ-ray spectrometer on the orbiter
8 June 1975	USSR	Venera 9	Venus	Measurements of K, Th, U abundances and soil density by γ-ray spectroscopy on the lander
14 June 1975	USSR	Venera 10	Venus	Measurements of K, Th, U abundances and soil density by γ-ray spectroscopy on the lander
20 August 1975	USA	Viking 1	Mars	Soil samples composition analysis inside the lander by X-Ray Fluorescence Spectrometer
9 September 1975	USA	Viking 2	Mars	Soil samples composition analysis inside the lander by X-Ray Fluorescence Spectrometer
9 September 1978	USSR	Venera 11	Venus	Analysis of the chemical composition of aerosols in the atmosphere via X-ray fluorescence during descent
14 September 1978	USSR	Venera 12	Venus	Analysis of the chemical composition of aerosols in the atmosphere via X-ray fluorescence during descent
30 October 1981	USSR	Venera 13	Venus	Measurements of the major element composition (SiO_2, TiO_2, Al_2O_3, FeO, MnO, MgO, CaO, K_2O, SO_3, Cl) by X-ray fluorescence analysis on the lander
4 November 1981	USSR	Venera 14	Venus	Measurements of the major element composition (SiO_2, TiO_2, Al_2O_3, FeO, MnO, MgO, CaO, K_2O, SO_3, Cl) by X-ray fluorescence analysis on the lander
15 December 1984	USSR	Vega 1	Venus	Measurements of K, Th, U abundances by γ-ray spectroscopy on the lander
21 December 1984	USSR	Vega 2	Venus	Measurements of SiO_2, TiO_2, Al_2O_3, FeO, MnO, MgO, CaO, K_2O, SO_3, Cl by X-ray fluorescence analysis and K, Th, U by γ-ray spectroscopy on the lander
17 February 1996	USA	NEAR	433 Eros	Determination of the surface distribution of Mg, Al, Si, S, Ca, Fe, O, K by X-ray and γ-ray spectrometer on-board the orbiter
4 December 1996	USA	Mars Pathfinder / Sojourner	Mars	Determination elemental composition of Mars rocks and dust, except for hydrogen, by the Alpha Proton X-ray Spectrometer (APXS)
7 January 1998	USA	Lunar Prospector	Moon	Detection of the Si, Al, O, Mg, Ca, Fe, Ti, K, U, Th by γ-ray spectrometer and water ice in the polar regions by neutron spectrometer on-board the orbiter
7 April 2001	USA	2001 Mars Odyssey	Mars	Mapping of the H, Si, Fe, Cl, K, Th by the neutron and γ-ray spectrometers on-board the orbiter
10 June 2003	USA	Spirit (MER-A)	Mars	Analysis of the soil samples composition by the Alpha particle X-ray spectrometer (APXS)
7 July 2003	USA	Opportunity (MER-B)	Mars	Analysis of the soil samples composition by the Alpha particle X-ray spectrometer (APXS)
2 March 2004	ESA	Philae	67P / Churyumov–Gerasimenko	Gathering information on the elemental composition of the comet's surface by the Alpha particle X-ray spectrometer (APXS) on-board the lander
3 August 2004	USA	MESSENGER	Mercury	Detection of the Si, O, S, Fe, K, U, Th by γ-ray spectrometer and hydrogen by neutron spectrometer on-board the orbiter
14 September 2007	JAXA	SELENE	Moon	Soil composition analysis using γ-ray spectrometer on-board the orbiter
27 September 2007	USA	Dawn	Vesta, Ceres	Analysis of the surface composition by the γ-ray and neutron spectrometer on-board the orbiter
24 October 2007	China	Chang'e 1	Moon	Mapping the distribution of various chemical elements on the lunar surface by the γ-ray spectrometer on-board the orbiter
22 October 2008	India	Chandrayaan-1	Moon	Detection of some natural radioactive elements on the surface by γ-ray spectrometer and radiation environment around the Moon by dosimeter on-board the orbiter
18 June 2009	USA	Lunar Reconnaissance Orbiter	Moon	High resolution mapping of hydrogen distribution by collimated neutron detector on-board the orbiter
1 October 2010	China	Chang'e 2	Moon	Mapping the distribution of various chemical elements on the lunar surface by the γ-ray spectrometer on-board the orbiter
26 November 2011	USA	Mars Science Laboratory	Mars	Measuring the hydrogen at the soil by a pulsed neutron generator and detector and characterizing the radiation by a dosimeter on-board the rover
31 December 2013	China	Chang'e 3	Moon	Analysis of the soil samples composition by the Alpha particle X-ray spectrometer (APXS)
14 March 2016	ESA	ExoMars Trace Gas Orbiter	Mars	High resolution mapping of hydrogen distribution by collimated neutron detector on-board the orbiter
8 September 2016	USA	OSIRIS-REx	101955 Bennu	Regolith composition analysis by X-ray Imaging Spectrometer on-board the orbiter



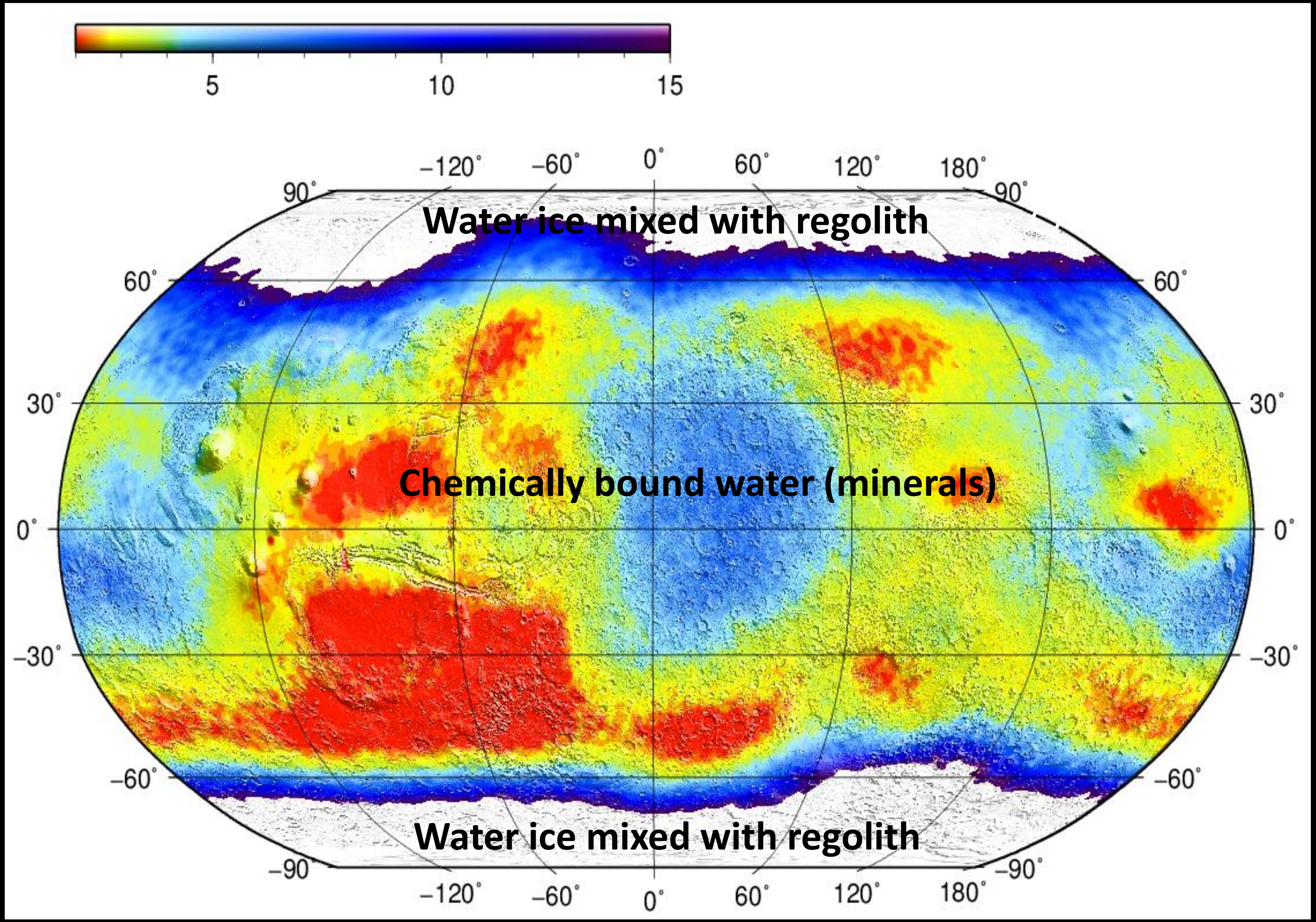
Mars:

Examples of nuclear planetology experiments

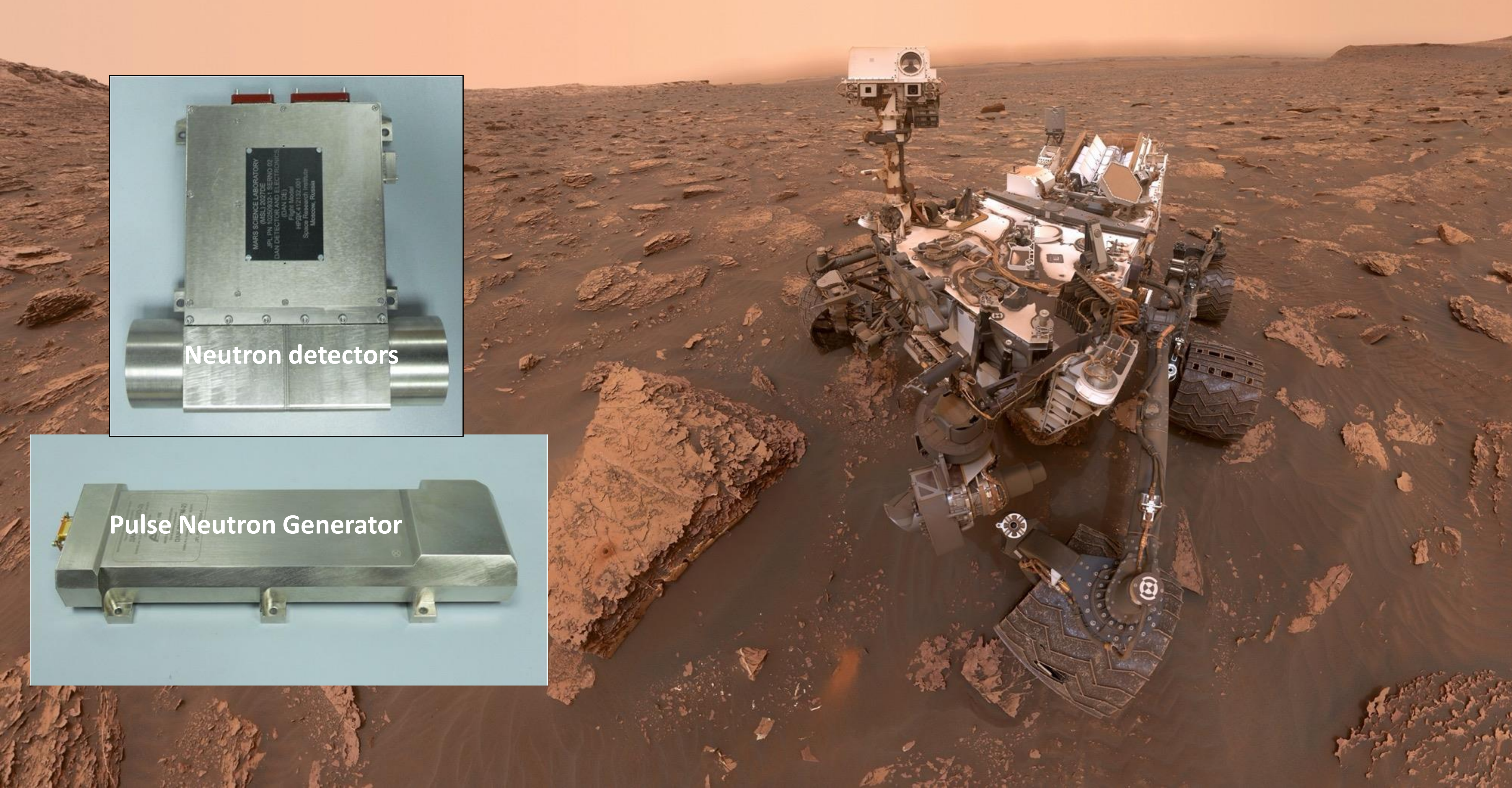
Subsurface water ice and bound water (at depth of 1 – 2 м)

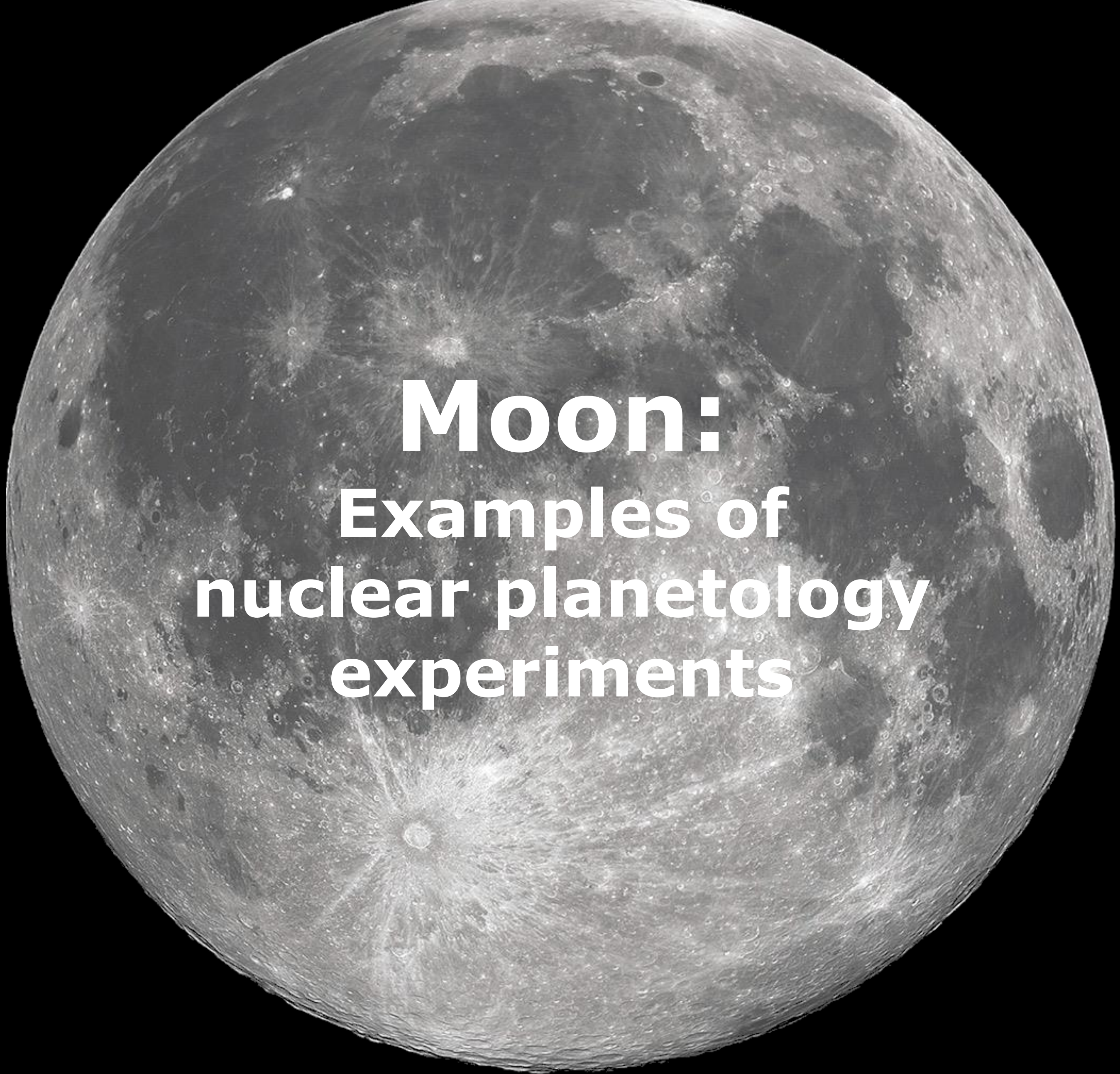


Water content in martian regolith, %



Active neutron spectrometer DAN instrument onboard Curiosity rover



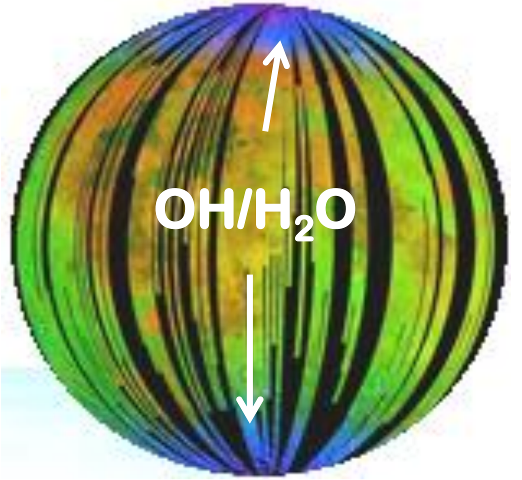


Moon:

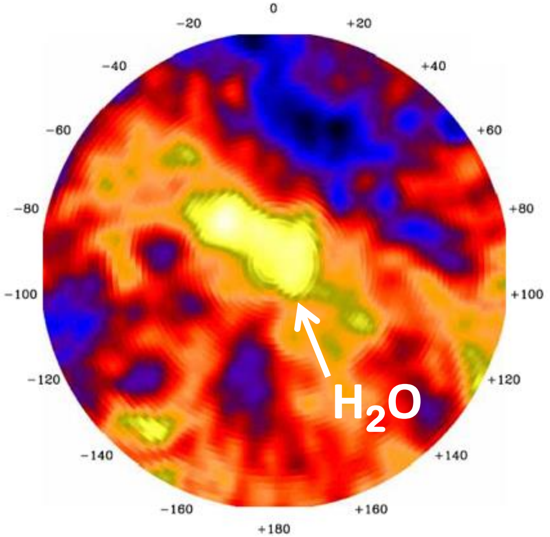
Examples of nuclear planetology experiments

Motivation: Orbital observations of water ice at Polar areas of the Moon

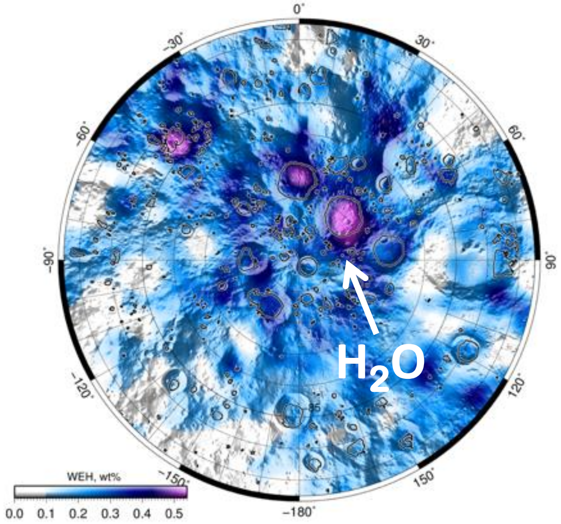
Water distribution in regolith according to M³ (USA) data from Chandrayan-1 (India)



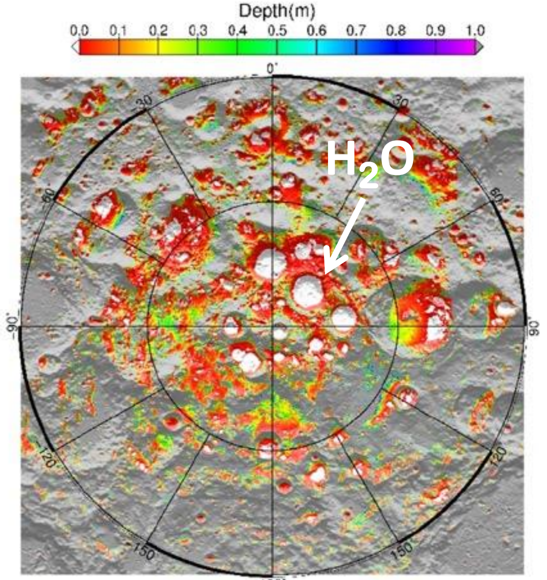
Water distribution in regolith according to LPNS data from Lunar Prospector (NASA)



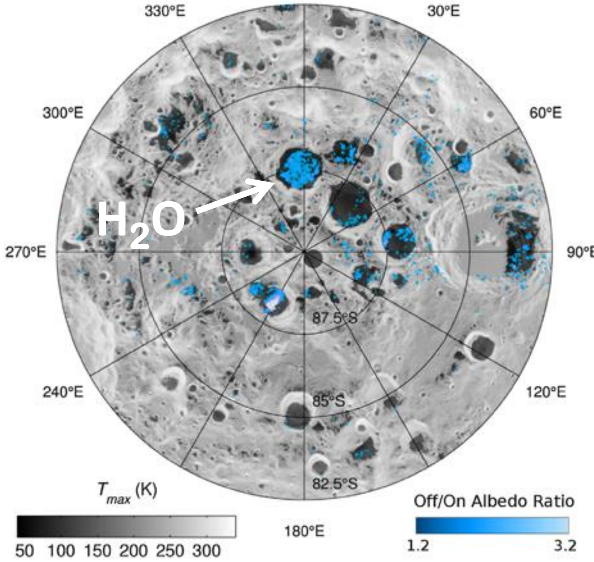
Water distribution in regolith according to data from LEND (Russia) onboard Lunar Reconnaissance Orbiter (NASA)



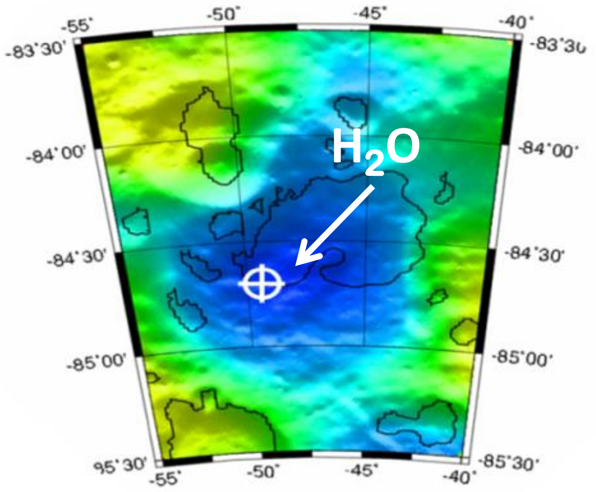
Possible ice depths according to data from Diviner onboard Lunar Reconnaissance Orbiter (NASA)



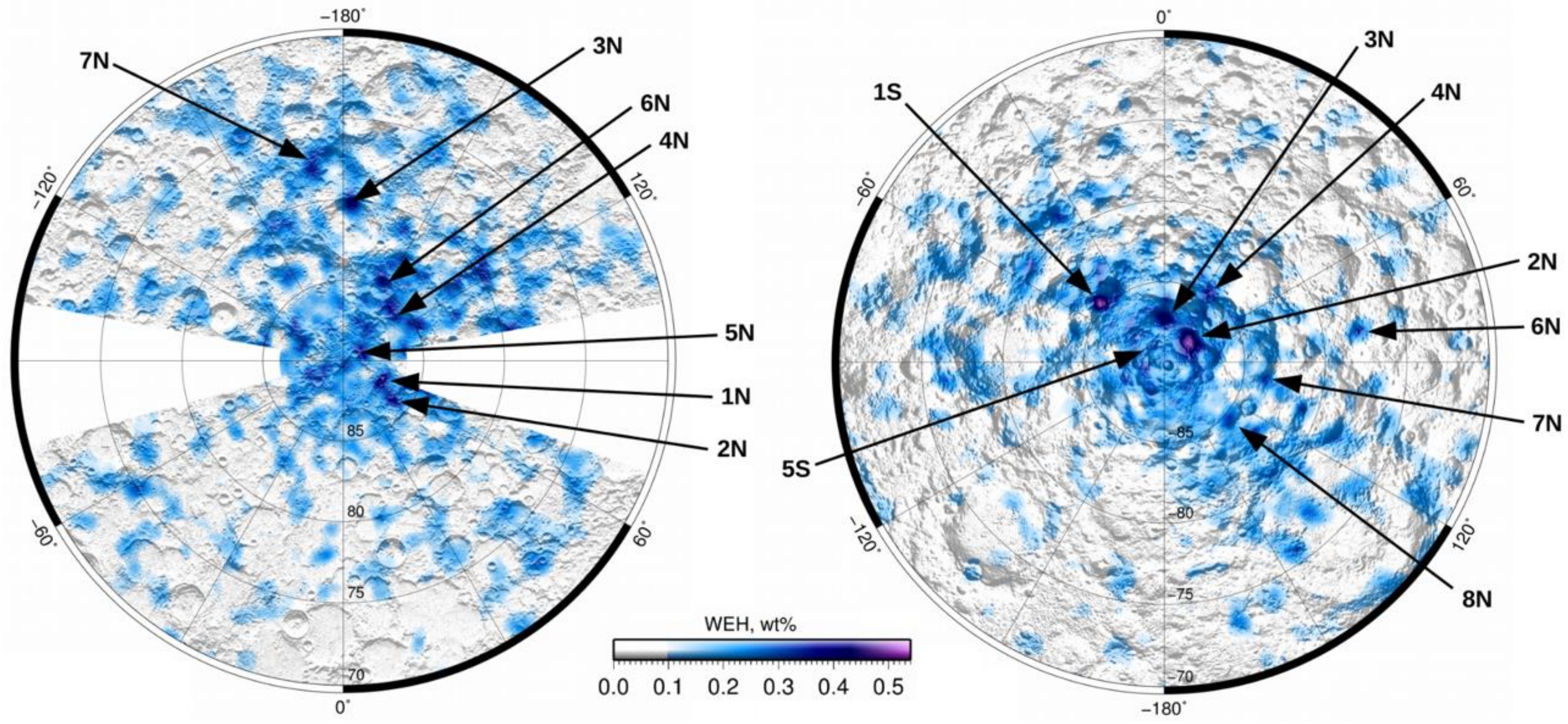
Observation of surface ice frost according to data from LAMP onboard Lunar Reconnaissance Orbiter (NASA)

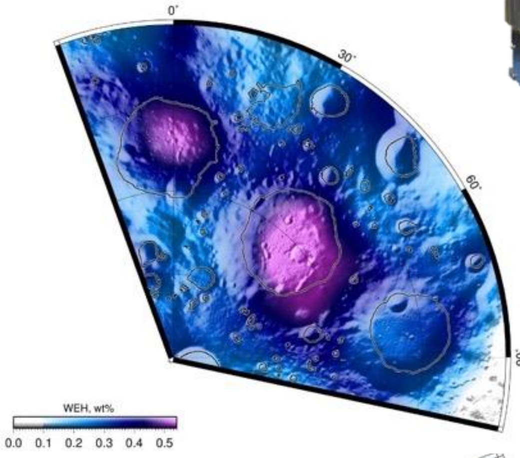


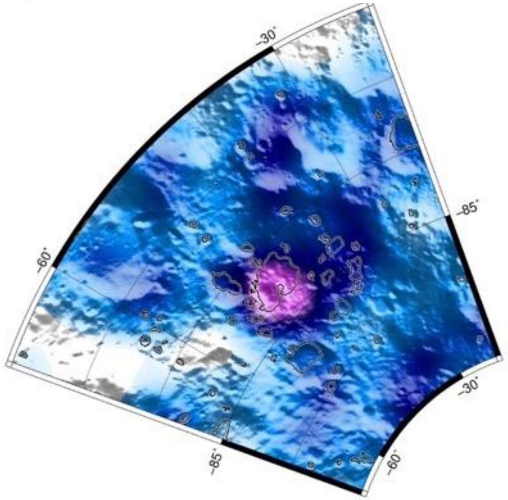
Detection of water vapor in Cabeus during impact experiment «LCROSS» (NASA)



LEND – collimated neutron telescope for the Moon mapping







There are three types of lunar water by its origin:

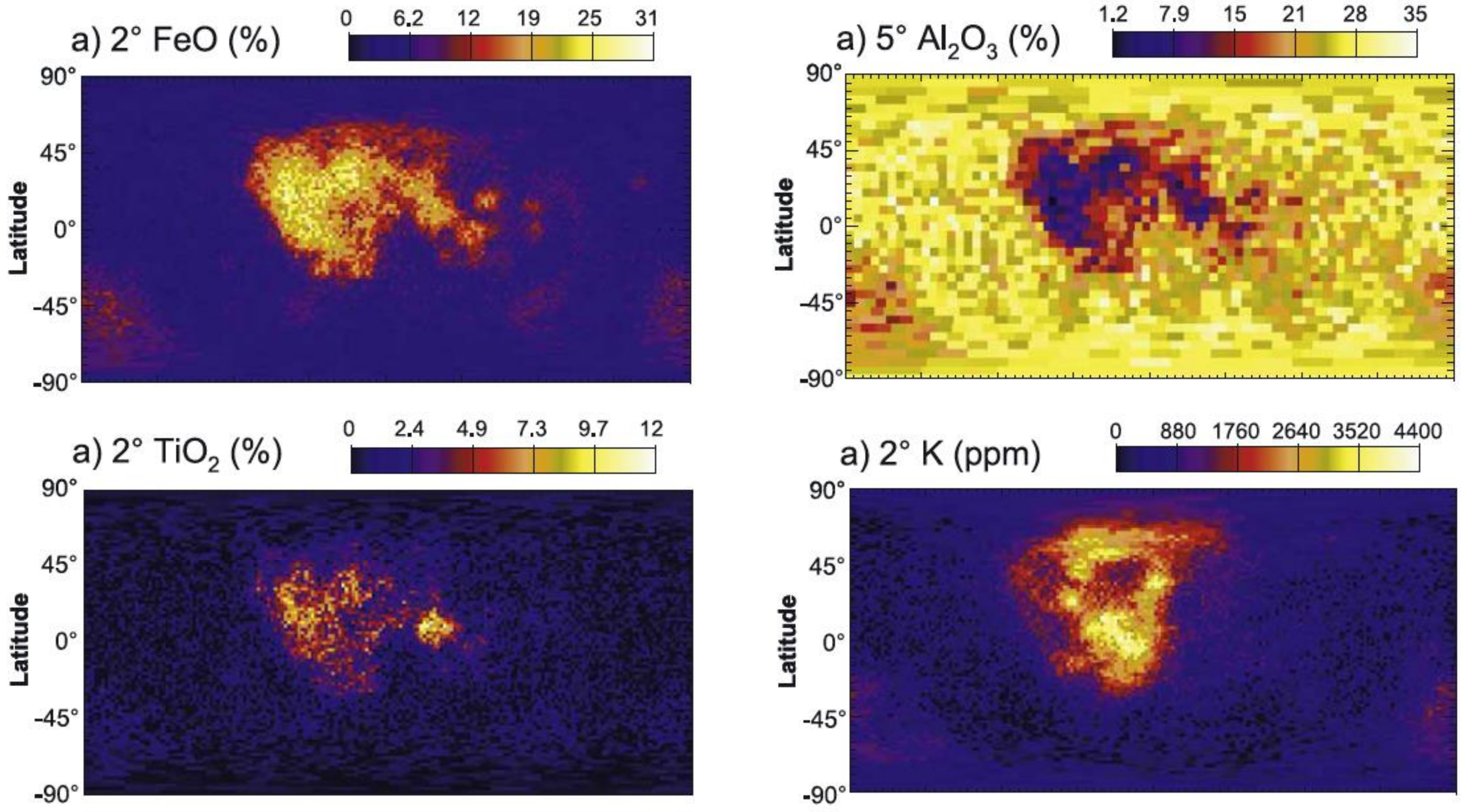
1. **External water brought to the the Moon by comets and asteroids.**

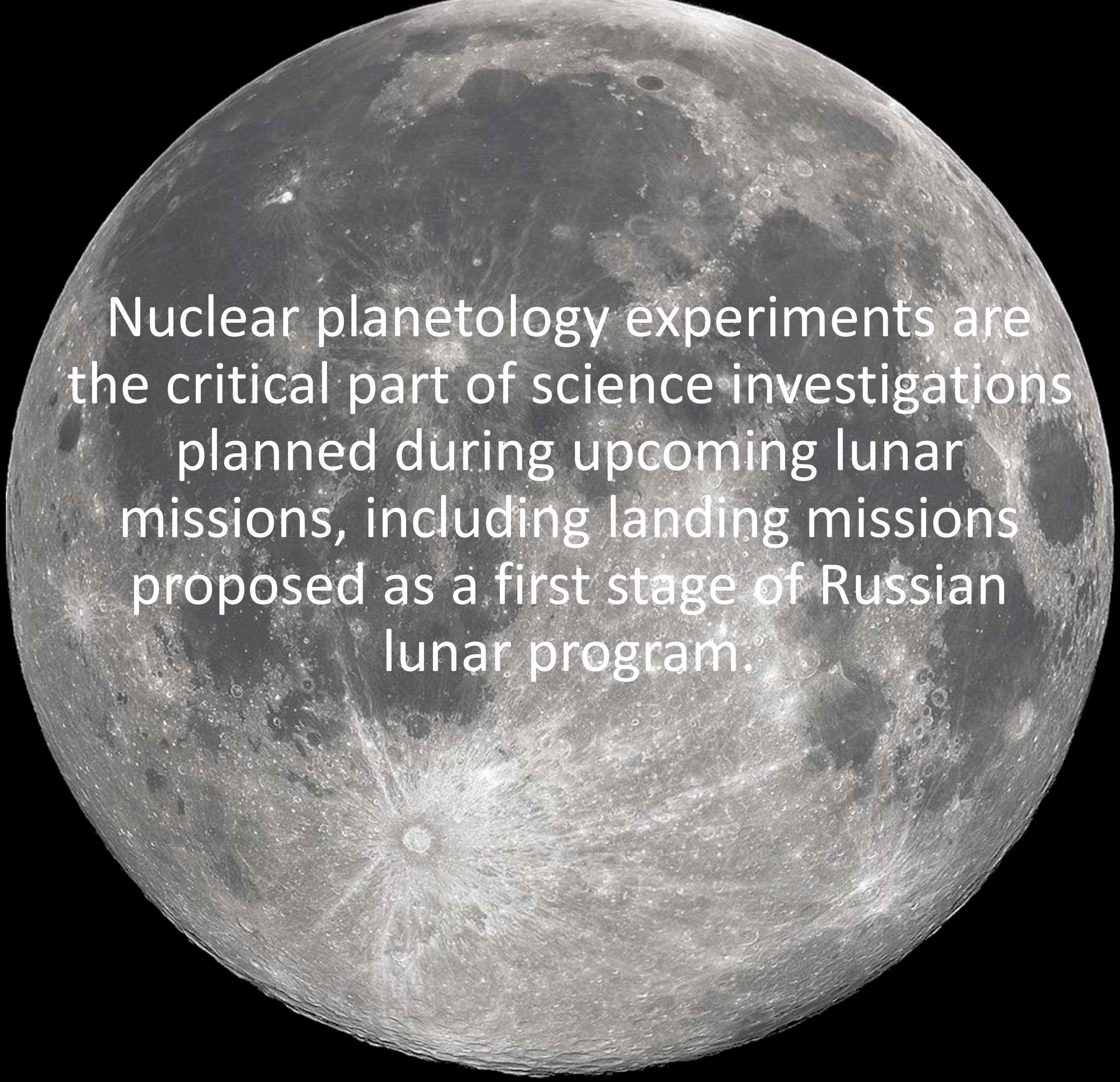
2. **Solar water produced by interaction of solar wind with lunar regolith.**

3. **Endogenic water originated together with Moon formation.**

Most probable locations of subsurface water ice are the permanently shadowed regions (PSR) and their partially sunlit surrounding areas.

Elemental composition (Gamma-Ray spectrometer onboard NASA Lunar Prospector mission)





Nuclear planetology experiments are the critical part of science investigations planned during upcoming lunar missions, including landing missions proposed as a first stage of Russian lunar program.

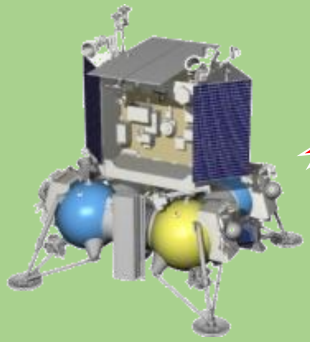
Federal Space Program
2016 - 2025

Science goals
Study of mineralogical, chemical, elemental and isotopic content of regolith and search for a volatiles in regolith of polar area of Moon.
Study dynamic of daily processes at lunar poles, including thermal property variations of subsurface layers of regolith
Study of plasma, neutral and dust exosphere of Moon and interaction of space environment with Moon surface.
Study of inner structure of Moon
Global mapping of lunar surface and reconnaissance and of lunar resources

1976

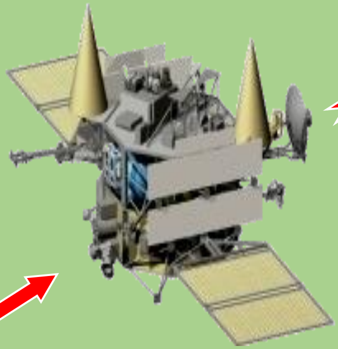
Луна-24

2021/22



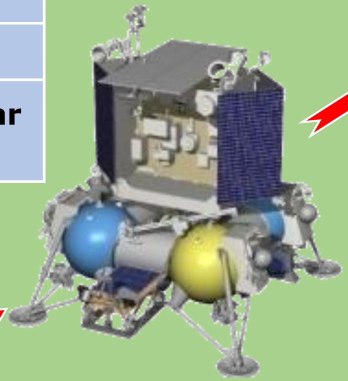
LUNA-25

2024



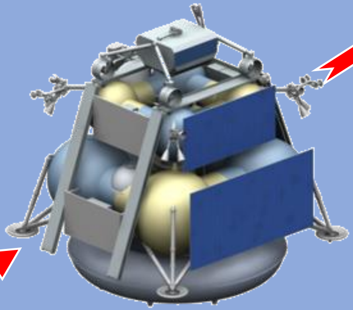
LUNA-26

2025

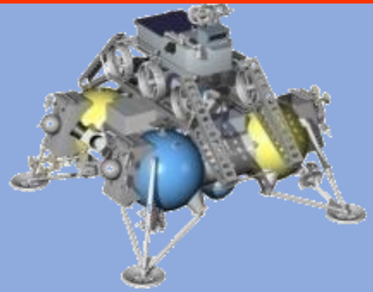


LUNA-27

Federal Space Program
2025+

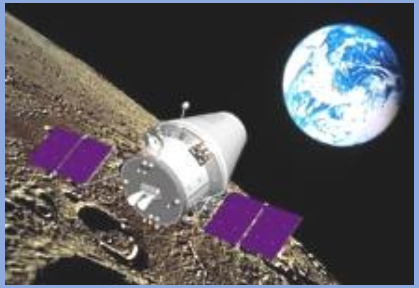


LUNA -28



LUNA-29

2025 – 2040: Robotic and manned missions on lunar orbit



https://np.cosmos.ru/en-us/instruments

Nuclear planetology

Department №63

ИКИ

www.iki.rssi.ru

Please see for more details on nuclear planetology instruments on IKI website

- Home
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  - DAN
  - MGNS
  - NS-HEND
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  - ADRON-LR
  - ADRON-RM
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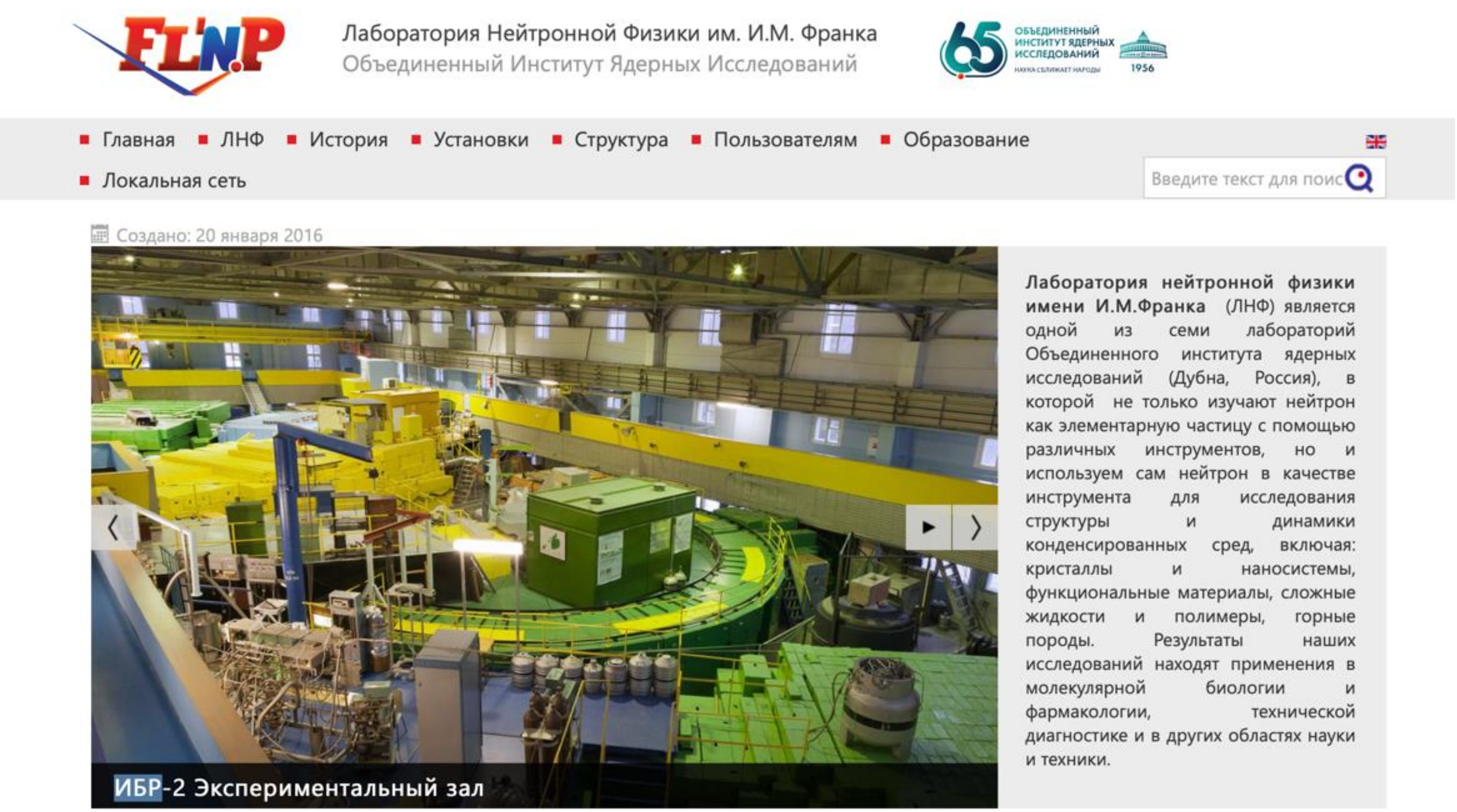
Cooperation with JINR

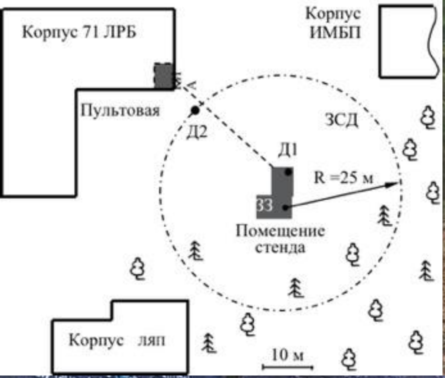
- More than 20 years of close and effective cooperation with Laboratory of Neutron Physics (Dr. V.N. Shetsov) and Laboratory of Radiation Biology (Dr. G.N. Timoshenko).

- All IKI (Space Research Institute) neutron and gamma-ray spectrometers were calibrated on neutron and gamma ray sources at different JINR facilities.

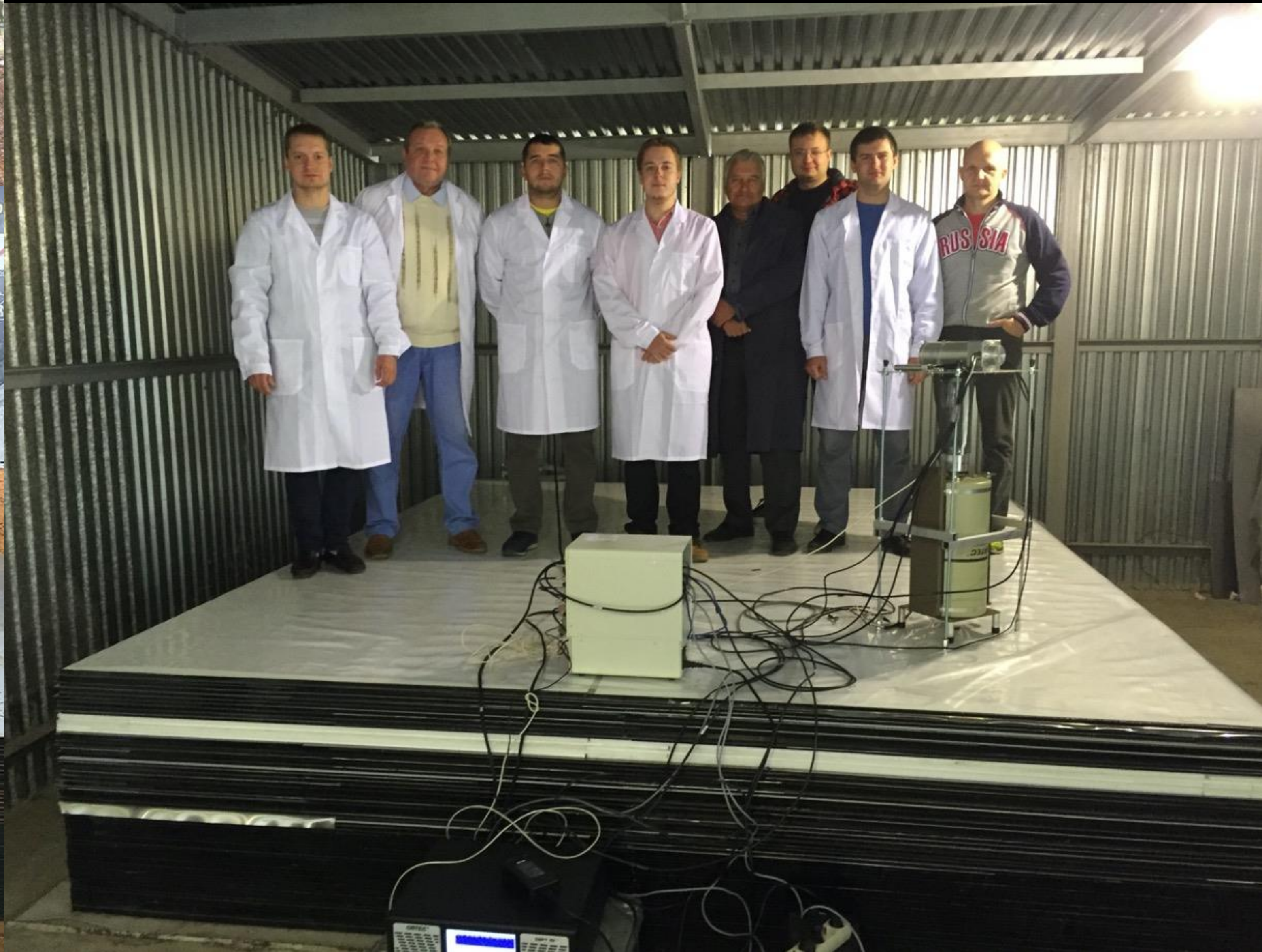
- The special facilities were even created to test neutron and gamma-ray instruments on simulants of planetary regolith.



Cooperation with JINR



JINR Facility to calibrate active (with pulse neutron generator) neutron and gamma-ray spectrometers

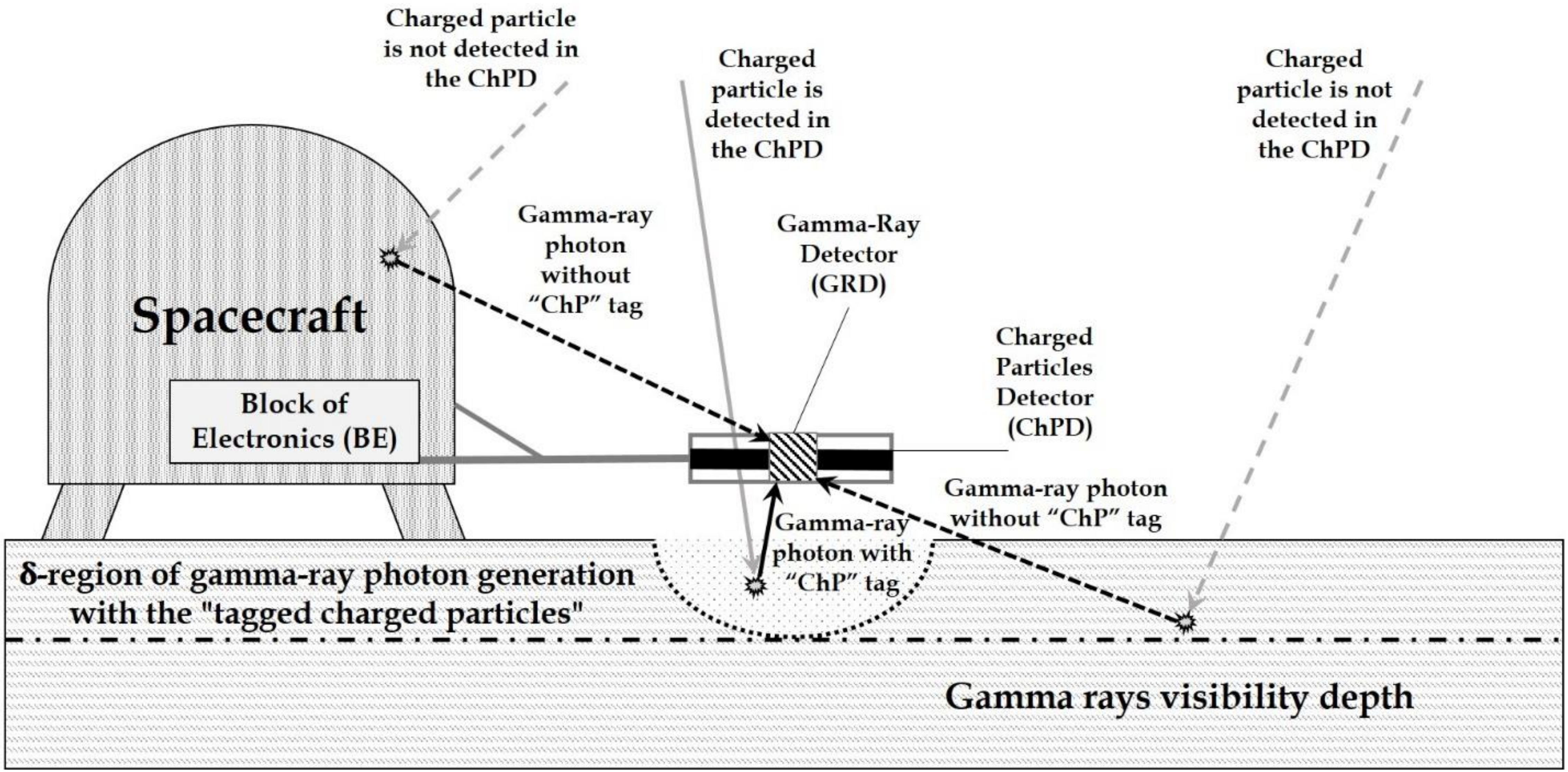


Cooperation with JINR

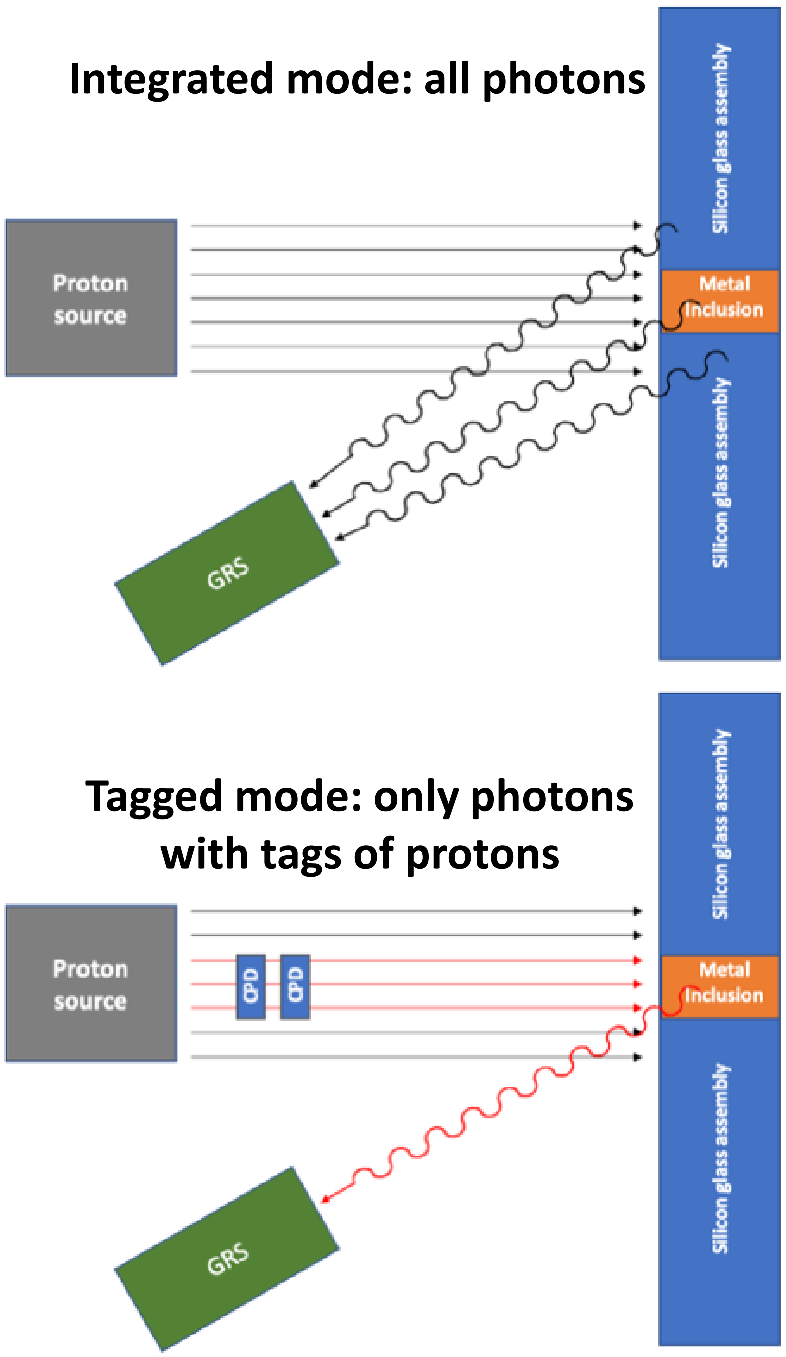
Current joint project with JINR on a development of future nuclear planetology experiment proposing perspective gamma-ray spectroscopy measurements with tags of GCR particles

Laboratory demonstration of space experiment for spectrometry of planetary gamma-rays with tags of Galactic Cosmic Rays

I.G. Mitrofanov, et al., Nucl. Inst. and Methods in Physics Research. A 953 (2020)
I.G. Mitrofanov et al., Nucl. Inst. and Methods in Physics Research, A, 1003 (2021)

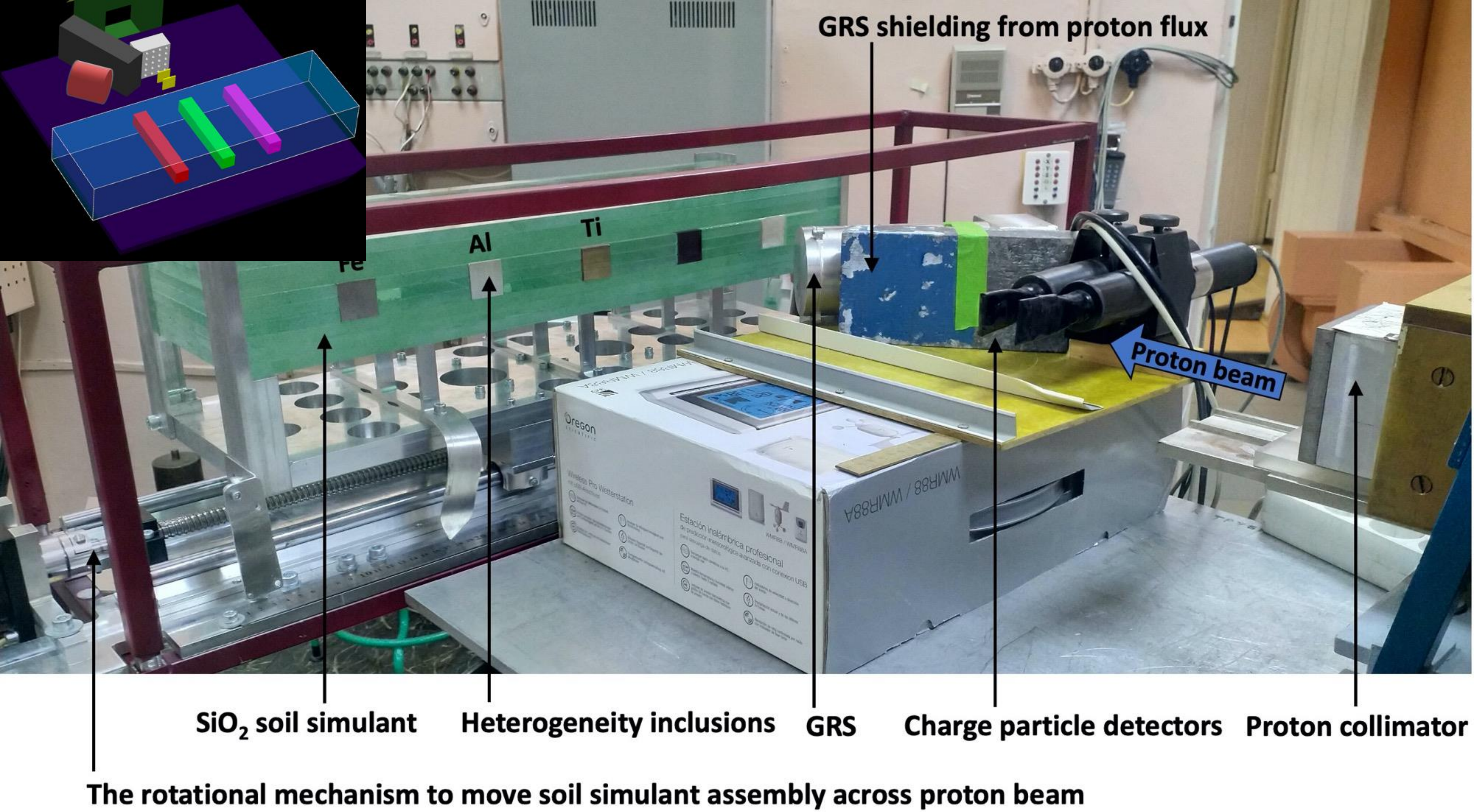


Current laboratory experiments at JINR



GRS = Gamma-ray spectrometer; CPD = Charge particle detector

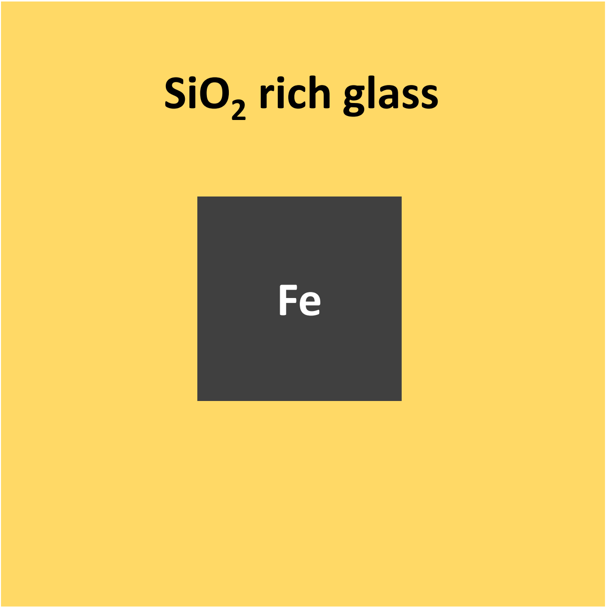
- The ground tests with a laboratory prototype of tagged GRS were held at JINR, Dubna, Russia in 2019 - 2021.
- Project is supported by Russian Science Foundation until 2023.
- To simulate GCR flux we used proton beam with an energy of 171.5±8.6 MeV generated by the charge particle accelerator - JINR phasotron.
- In our experiment protons irradiate heterogeneous target (silicon glass + metal inclusions) and produce secondary gamma-ray emission recorded by GRS.
- The proton beam was profiled by a system of collimators, providing an irradiation area for targets as much to 8 x 8 cm. The charge particle accelerator is operating in a pulsed mode with characteristic time 70 nanoseconds between successive proton bunches.
- The resulted density of incident proton flux was about ~0.5 x 10^4 protons/s/cm^2.



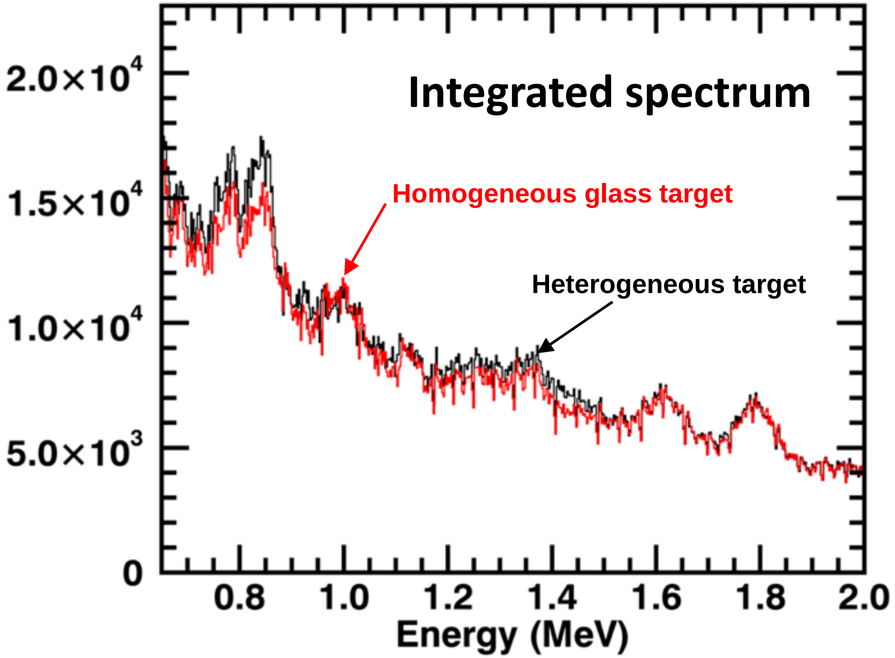
GRS shielding from proton flux
Fe
Al
Ti
Proton beam
SiO_2 soil simulant
Heterogeneity inclusions
GRS
Charge particle detectors
Proton collimator
The rotational mechanism to move soil simulant assembly across proton beam

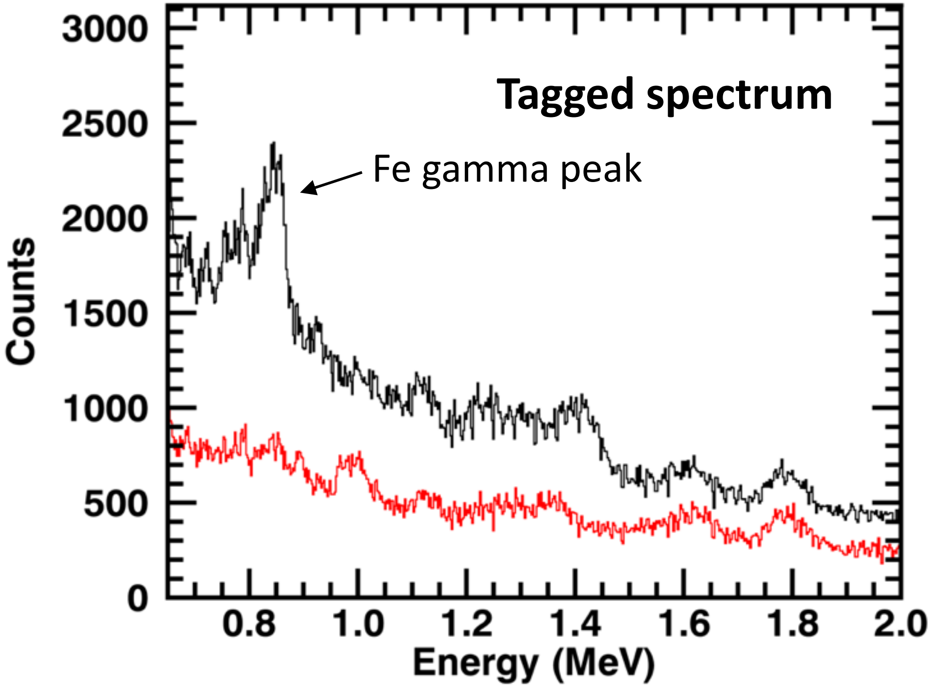
Homogeneous target

Heterogeneous target



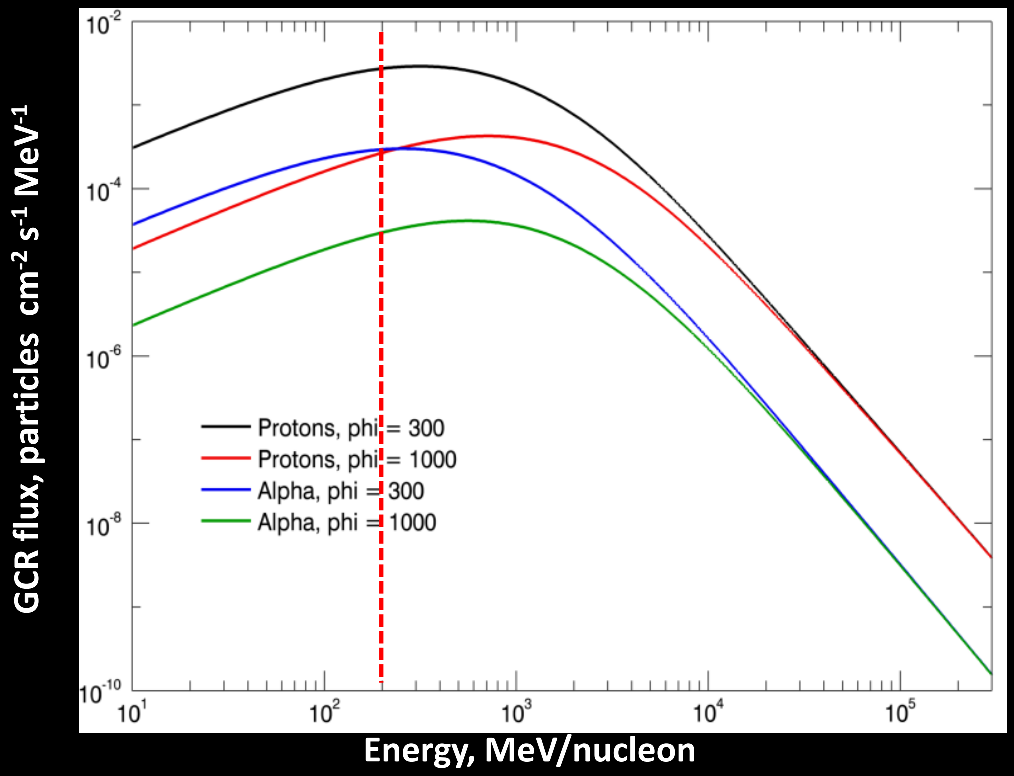
The results of laboratory experiment. The measurements with Fe inclusion is shown as an example. Please look for details Mitrofanov et al., Nucl. Inst. and Methods in Physics Research, A, 1003 (2021)



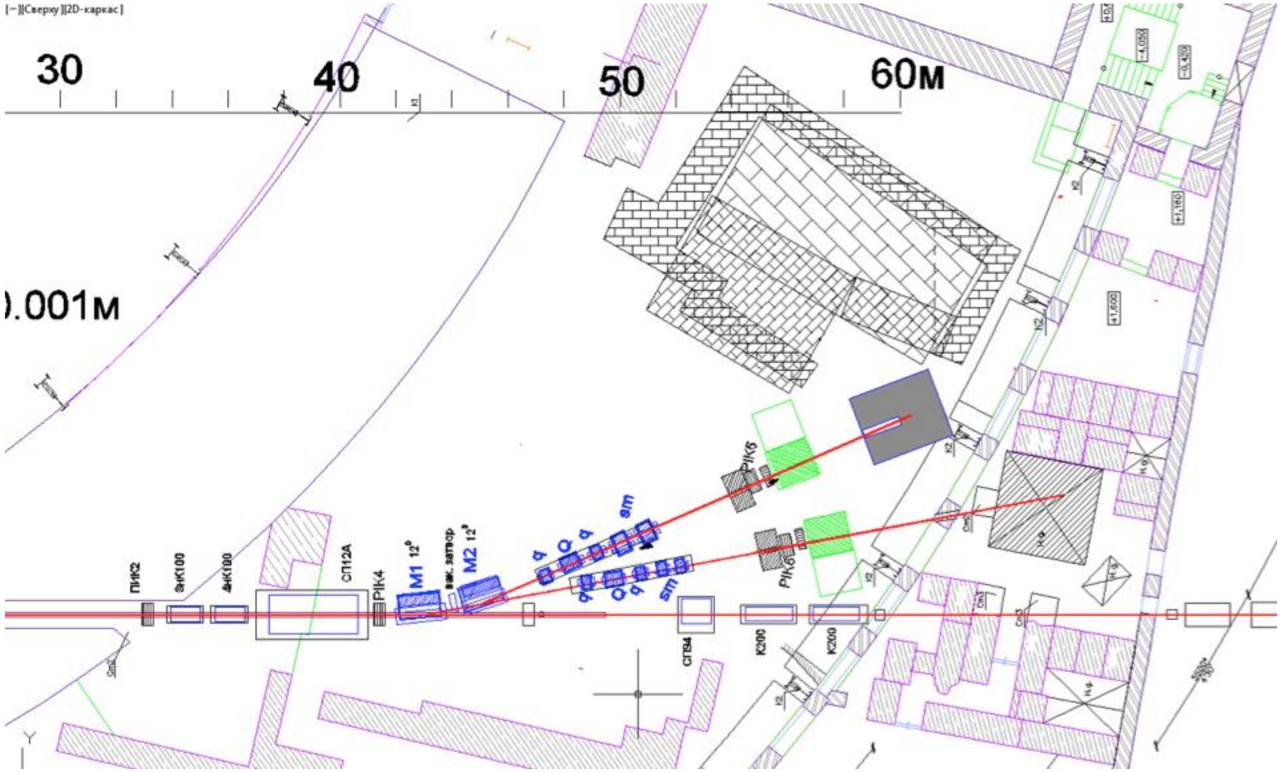


The current experimental setup constraints

- ❑ Single and low energy (<200 MeV) in comparison with GCR peak flux energies 300 – 1000 MeV per nucleon.
- ❑ Only protons. No heavy ions.
- ❑ Narrow proton beam: maximal irradiated area is 8 x 8 cm.
- ❑ High proton fluxes (dead time effects in detectors).
- ❑ Organization issues.



Possible continuation of the experiment on NICA complex



Параметры ионных пучков и требования к оборудованию СОДИТ

Параметры	Величина
Типы ионов	p, $^{12}C^{6+}$, $^{40}Ar^{18+}$, $^{56}Fe^{26+}$, $^{84}Kr^{36+}$, $^{131}Xe^{54+}$, $^{197}Au^{79+}$
Энергия ионов, выведенных из Нуклотрона, МэВ/н	250-800
Длина торможения в кремнии, мм	10
Энергия ионов после торможения в дегрейдере, МэВ/н	10-200
Энергия ионов в чувствительной области микросхемы МэВ/н	10-50
Поток ионов, ион/(см^2×с)	$10^2 - 3\cdot10^5$
Длительность импульса выведенного пучка, с	2 - 20
Максимальный флюенс за сеанс ион/(см^2)	10^7
Продолжительность сеанса, мин	30 - 40
Эмиттанс пучка на входе в стенд, (2σ) $\varepsilon_x/\varepsilon_y$ π·мм·мрад	3/8
Диаметр пучка на мишени, мм (ширина на полувысоте	10 - 40
Однородность потока при облучении размера 30×30 мм	±10%
Максимальная область облучения мишени, мм	200×200
Однородность потока при максимальной области облучения	±15%
Частота сканирования пучка при максимальной области облучения, Гц	1 - 2
ЛПЭ в Si, МэВ×см^2/мг (на поверхности чувствительной области микросхемы)	1 - 65
Давление в камере,	$10^{-2} - 10^{-3}$Торр, 760 мм ртст
Температура мишени при облучении, ^{0}С (размер кристалла микросхемы 20×20 мм)	-65^{0}С-1+125^{0}С

NICA provides several channels for the ground-based experiments

One of them is implemented for testing space/aviation electronics in harsh radiation environment (СОДИТ)

Another one is implemented for the radiobiology studies (СОДИБ) related with understanding how radiation environment could impact astronauts' health during interplanetary flights

Each of these options could enhance our experiment by availability of

- ✓ **wide energy range 250 – 800 MeV/n;**
- ✓ **irradiation not only by protons;**
- ✓ **wide irradiated surface area (10 cm x 10 cm / 20 cm x 20 cm);**
- ✓ **low intensity ion fluxes (to exclude dead time effects).**