Russian – Aserbaijdshan Small Satellite Project for Monitoring of Radiation and Upper Atmosphere

- **V.I. Osedlo*, M.I. Panasyuk,* P. Abdullaev†, G. Agaev,† V.V.Bogomolov,* R. Gasanov,† V.V. Kalegaev,* T. Mamedzade,** V.L. Petrov,* M.V.Podzolko,* A. Proskuryakov,† R. Rustamov,† A.S. ogly Samedov,† H. Seyidov,† S.I. Svertilov***
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- M.V. Lomonosov Moscow State University, 1(2), Leninskie gory, GSP-1, Moscow 119991, Russian Federation

† Azerbaijan National Aviation Academy, Baku, Azerbaijan

** Azercosmos, Baku, Azerbaijan

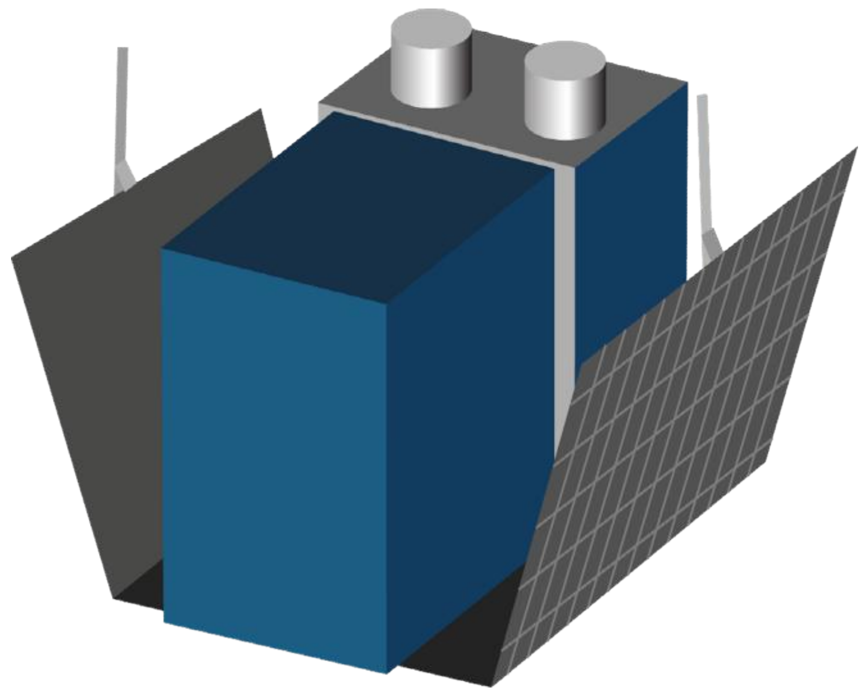
The project of a satellite experiment on the observation of intense flashes (transients) of electromagnetic emission from the Earth's atmosphere in different spectral ranges, as well as the measurement of the medium- and long-term dynamics of the spatial distribution of the energetic charged particles fluxes in near-Earth space is presented. To implement the experiment, it is planned to develop a Russian-Azerbaijani small spacecraft capable of carrying a payload of up to 25-30 kg. The satellite also plans to realize a number of technological experiments, in particular, to study the effect of space flight factors on the matrix of silicon photomultipliers. We also consider the possibility of installing a telescope for photometric observations of binary stars. The requirements from the payload to the orbit and spacecraft orientation modes, as well as to its on-board systems, are considered in accordance with the goals and objectives of the experiment. The measurement data, which are planned to be obtained during this experiment, will subsequently be used for various scientific and applied problems including validation of existing and development of new dynamic models of radiation in near-Earth space, ensuring the safety of the functioning of spacecrafts.

Micro-Satellite:

AzSat main parpameters.

Parameter	Value
Satellite platform mass, kg	up to 100
Payload mass, kg	up to 30
Average daily power consumption of payload, W	20
Rate of data transmitting, Mb/s	32 (X band)
Orientation accuracy, °	<0.2
Stabilization accuracy, %	<0.01
Time of exploitation, year	≥5

Orbit - from 500 to 1000-1500 km



.Payload (for the low-height orbit):

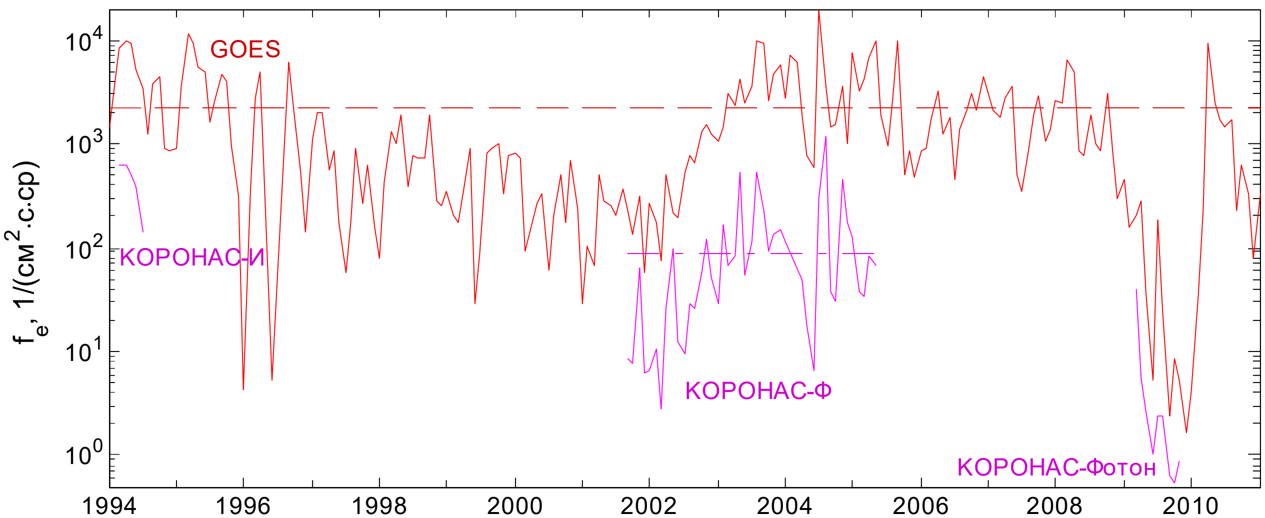
From Lomonosov MSU^

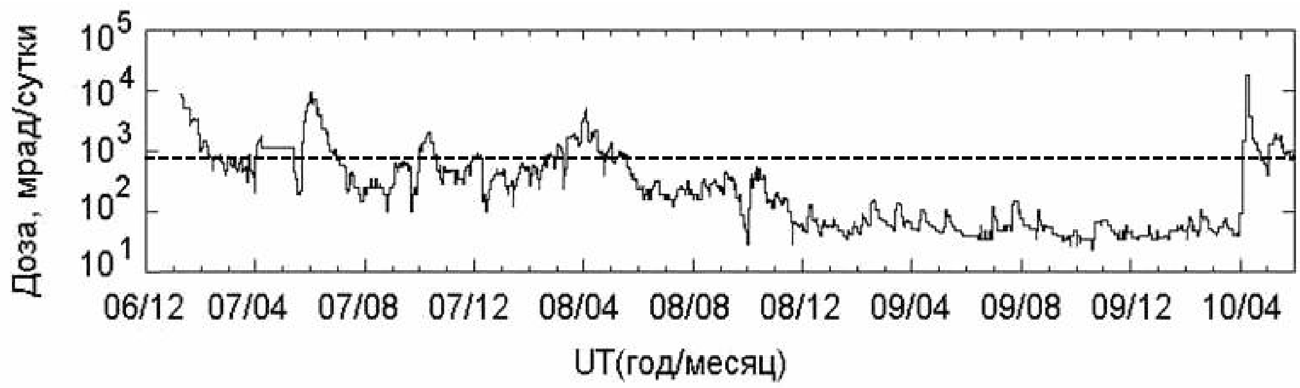
- charge particle detector
- gamma-ray burst monitor
- UV photometer

From National Academy of Aviation of Azerbaijan:

- SiPM matrix (together with JINR)
- telescope for astronomical observations by Shemaha observatory

Medium- and long-term variations of the Earth radiation belts





Upper plot — the time dependence of the average monthly fluxes of relativistic electrons detected by the spacecraft GOES series and CORONAS from 1994 to 2011..

Bottom plot — the time dependence of the average monthly dose rate values from measurements on the GLONASS spacecraft from 2006 to 2010.

The dotted line shows the differences of model values from the experimental ones up to> 1 order.

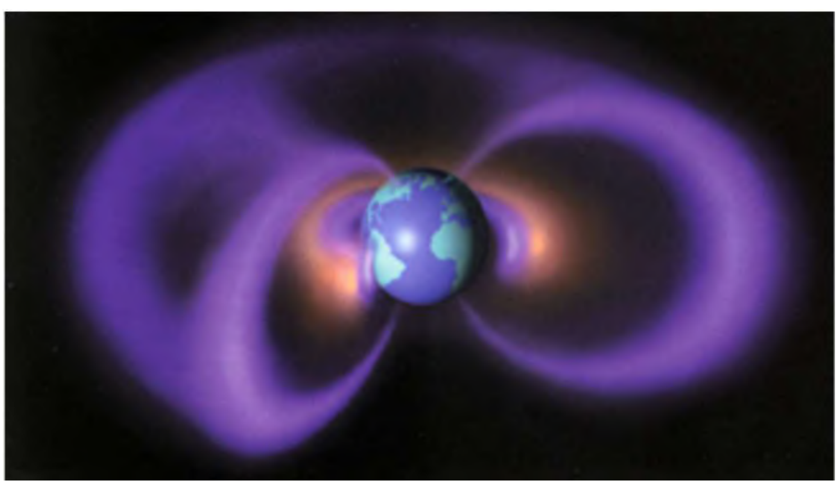
Conception of small multi-satellite experiment for radiation monitoring

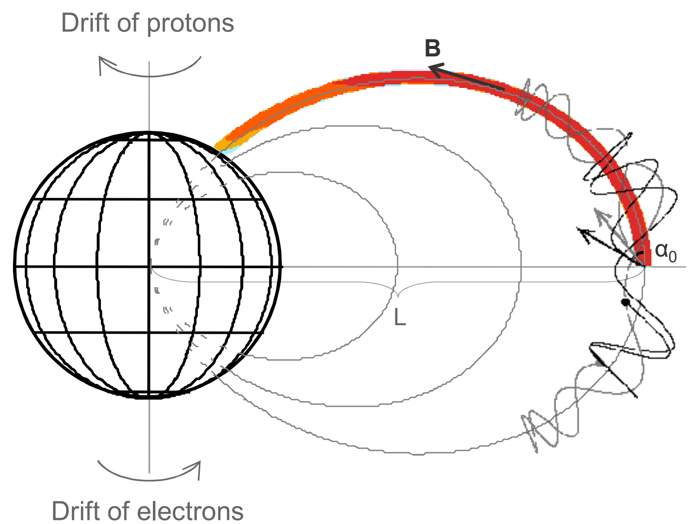
Goal: To carry out measurements that will allow reconstructing the current distribution of energetic particle fluxes in a large areas of Earth's radiation belts.

Trapped particles in a quasi-dipole field move along a spiral along magnetic lines and drift across the magnetic meridian, forming drift shells that are described by the McLivin's parameter L (the distance from the center of the dipole to the magnetic field line in the plane of the magnetic equator).

The distribution of particle fluxes F (B) along the L-shell is the altitude dependence. It is also connected with the pitch-angle (the angle between the particle velocity vectors and the magnetic field induction B) distribution of particle fluxes at the magnetic equator F0 by the Liouville theorem.

Therefore, our measurements should encompass a large range of drift shells, and for each of them, let us calculate the altitude dependence of the fluxes.





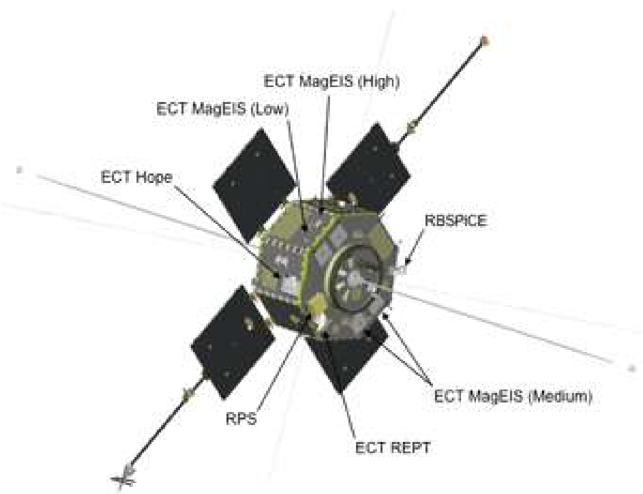
Conception of small multi-satellite experiment for radiation monitoring

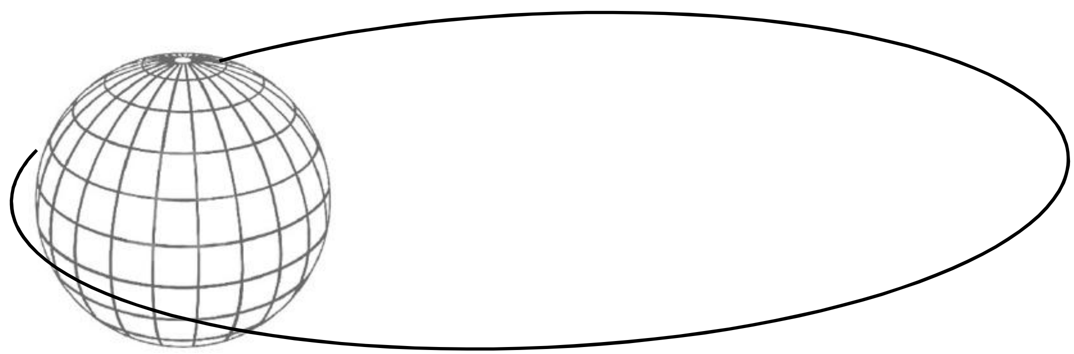
Conception №1: NASA Explorer-45, RBSP/Van Allen Probes

- high-altitude elliptical equatorial orbit, crossing a large range of L-shells;
- measurements of pitch-angle distribution of fluxes near Equator
- calculation of altitude dependences of fluxes at every L-shell according Liouville theorem.

Disadventages:

- high cost of launching;
- high orbital period;
- **necessity of very precise pitch-angle measurements.**





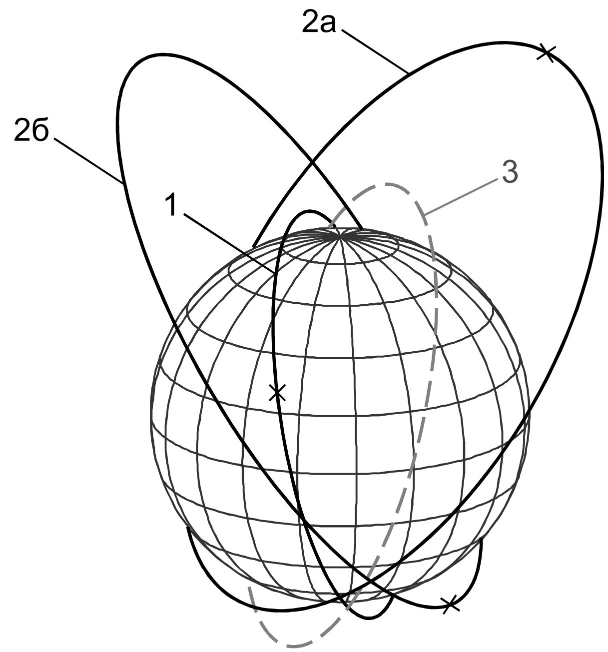
Van Allen Probes (detector arrangement and orbit)

Conception of small multi-satellite experiment for radiation monitoring

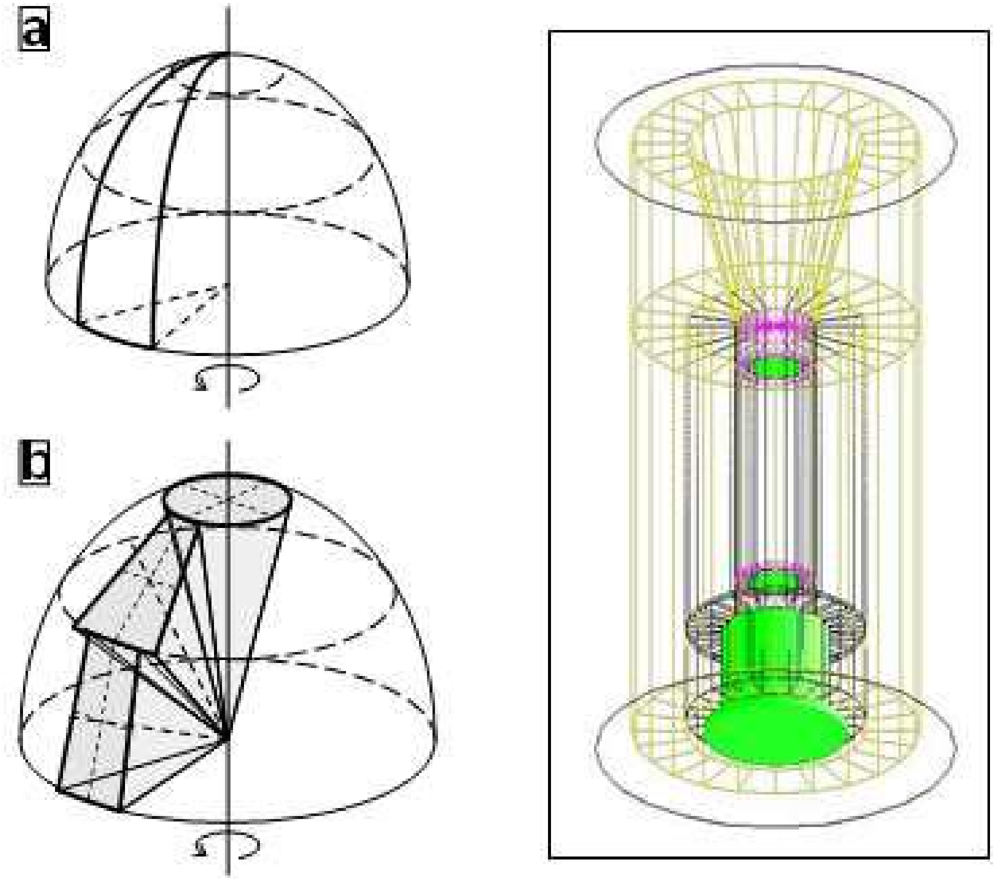
Conception №2: SINP MSU project:

- more low-altitude orbits with high inclination crossing the large range of L-shells at different altitudes
- measurements of omni-directional fluxes in different points of every L-shell,
- calculation of the altitude dependence of fluxes at other points of the L-shell by interpolation and extrapolation using known physical and empirical relations of high-altitude dependence.

Conception of small multi-satellite experiment for radiation monitoring



1. More large satellite at solar-synchronous orbit with altitude ≈600 km:
   – operative monitoring of space debris and asteroids;
   – observations of electromagnetic transients
   – measurements of energetic charge particle fluxes.
2. Two small satellites for operative radiation monitoring in large areas of radiation belts at elliptical orbit (in opposite phases)
3. Alternative — one of satellites on the circular orbit with altitude ≈1500 km, or elliptical with altitude 800–2000 km and inclination ≈80°.



Left panel: a) field of view in the form of a rotating hemispherical sector; b) a configuration of three detectors, which provides this method of measurement practically. Right panel: the general view of telescope.

Ranges of registered energies of particles :

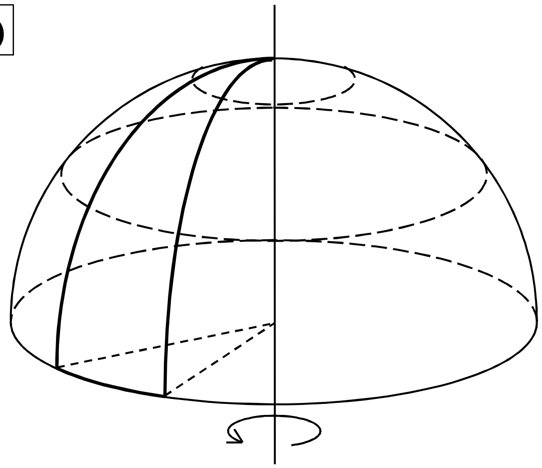
electrons 0.15–0.35, 0.35–0.6, 0.6–1, 1–2, 2–4, 4–10 MeV;

protons: 2–4, 4–9, 9–15, 15–30, 30–53, 53–100, 100–160, >160 MeV

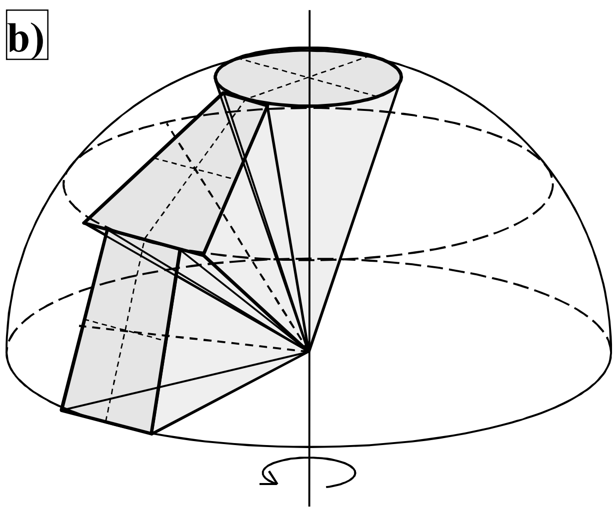
Electrons and protons spectrometer

Method #2: Direct measurement of omnidirectional streams of particles – using of SC rotation. The required rotation period — 6 seconds, the measurement frame — 300 ms.

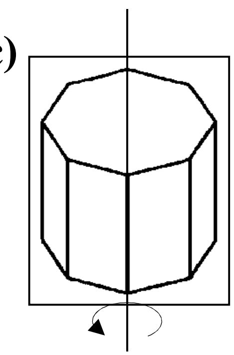
a)



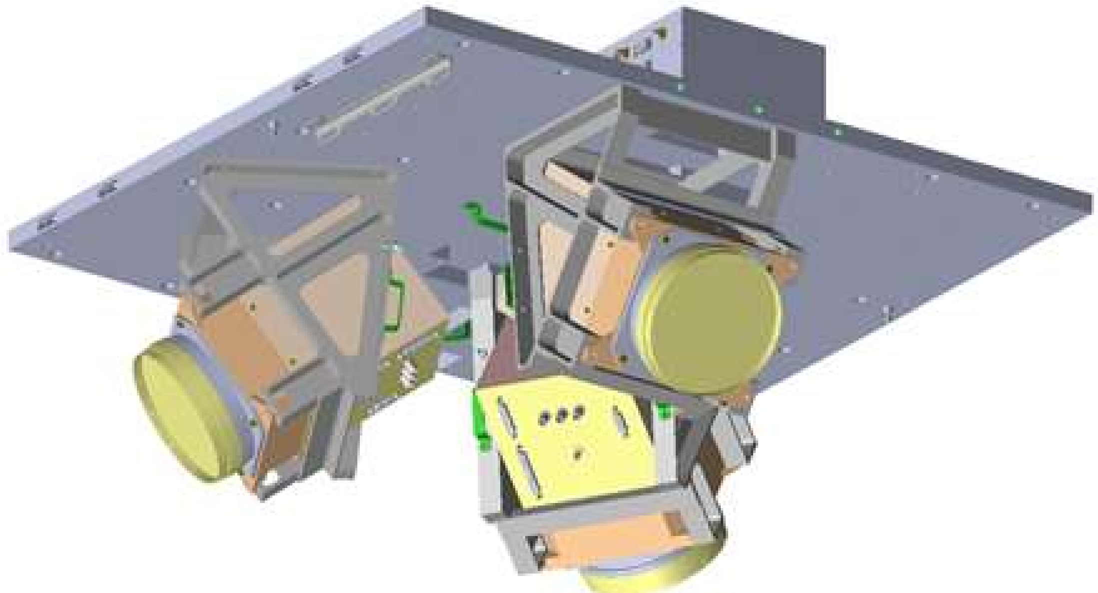
b)



c)

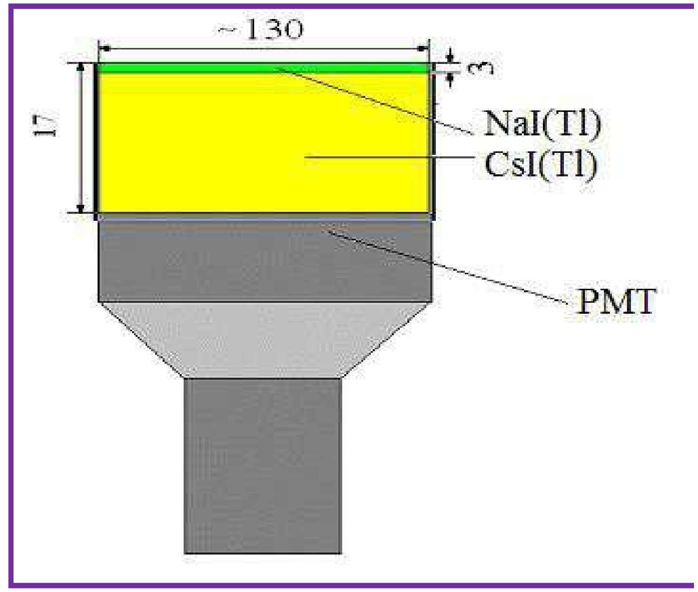


a) field of view in the form of a rotating hemispherical sector;
b) a configuration of three detectors, which provides this method of measurement practically;
c) a schematic view of the satellite: solar panels on the side faces; the axis of rotation is perpendicular to the plane of the equator;
The period of rotation of the spacecraft is 6 s; optional detection period of detectors 300 ms.
An active orientation system is not required. Orientation and rotation are set at separation from the upper stage

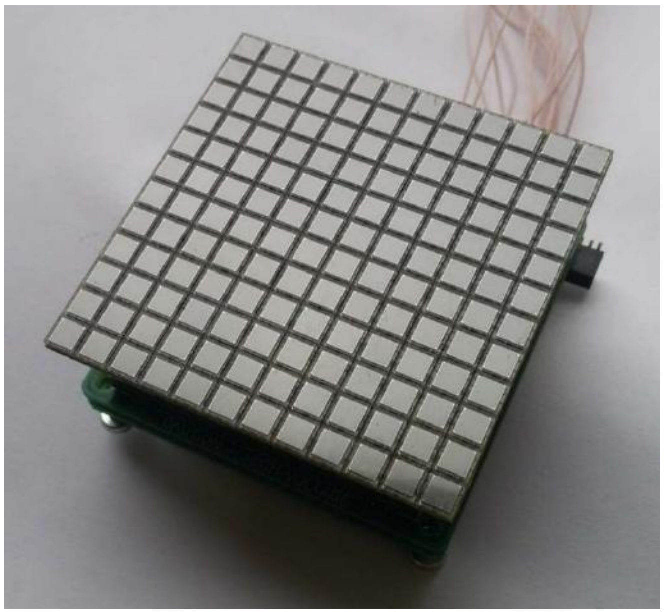


Detector: 3mm NaI(Tl) /17 mm CsI(Tl)
Sensitive area: ∅130mm
Energy range: 0.01 – 3 MeV

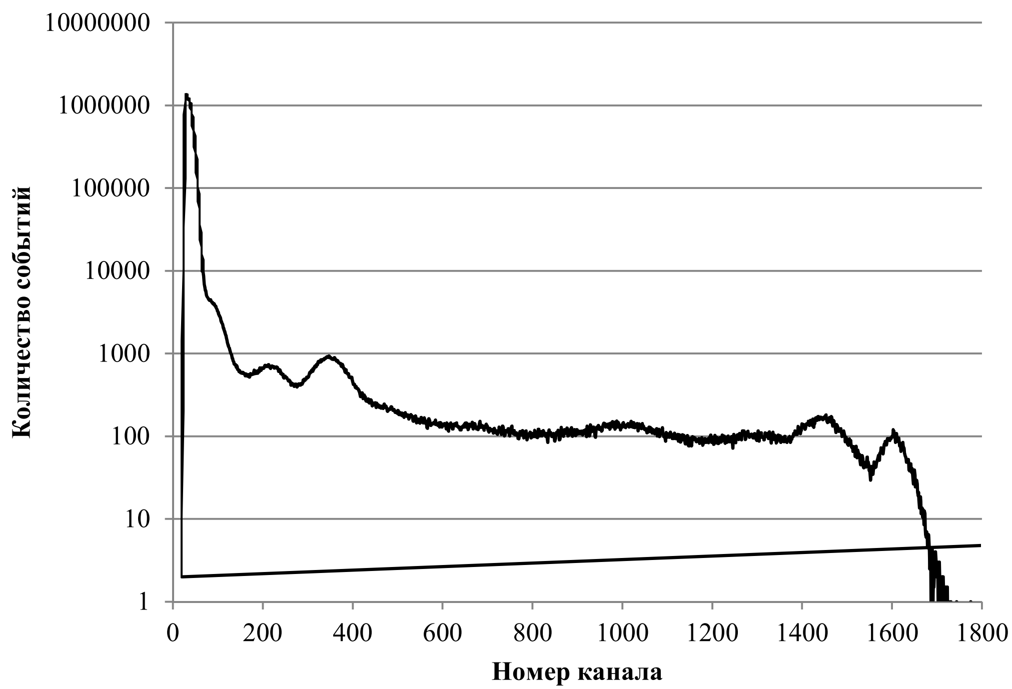
Sensitivity for GRBs ~10^{-7} erg/sm^2
GRB localization- ~2^o for bright GRBs



Measurements with SiPM matrix AIT 12x12.



Matrix AIT SiPM 12x12.



Spectrum of Eu-152 obtain with CeiGAGG crystal at bias voltage 28,5V.

Analysis of stability of the argument of perigee

Initial orbital parameters:

inclination – 63.394º

Eccentricity– 0.3405

The semi-major axis – 10721 км

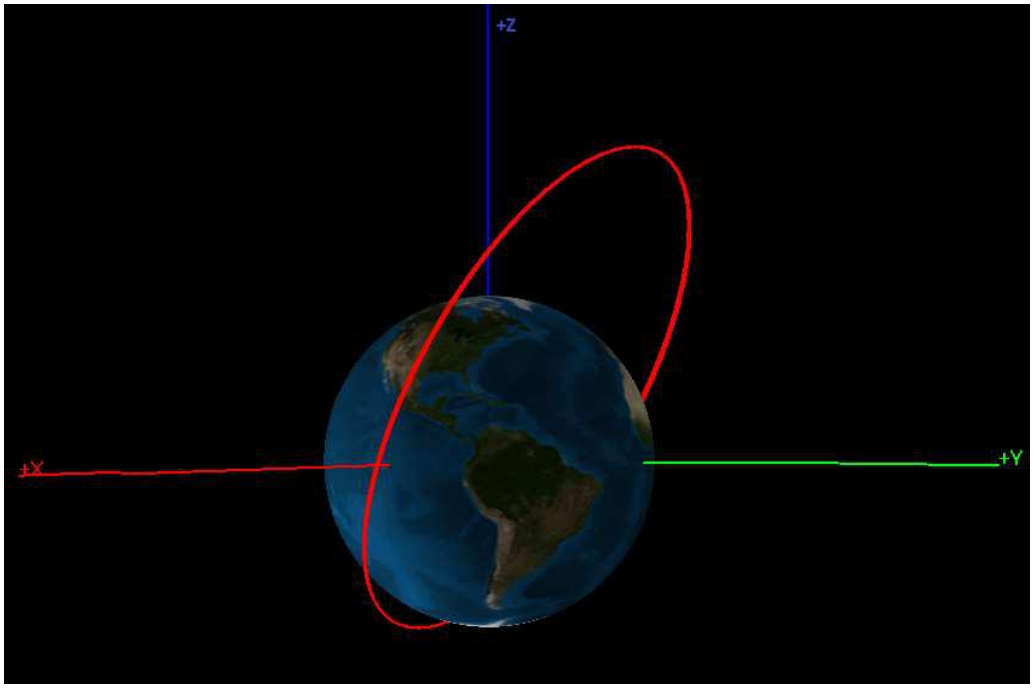
The argument of perigee – 310º

Longitude of ascending node – 0º

Mean anomaly – 0ºof

The basic option for the AzSat orbit is a sun-synchronous orbit with an inclination 98° and altitude 650-700 km

The second option considers the AzSat as one of the vehicles of the group of small satellites of Moscow State University, launched to the elliptical orbit with initial orbital parameters



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Longitude of ascending node – 0º

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The stability analysis was performed for this orbit. The program on Julia language was implemented for the satellite trajectory propagation. The satellite acceleration a_{total} was calculated using the following equation:

$$a_{total} = a_{gr} + a_{har} + a_{dr} + a_{rad} + a_{rel}.$$

In this equation a_{gr}, a_{har}, a_{dr}, a_{rad}, a_{rel} are the acceleration components taking into account different perturbations.

The gravity of the Earth, Sun and Moon:

$$a_{gr} = G\sum_{k=1}^{n} m_k \left(\frac{r_k - r}{\|r_k - r\|^3} - \frac{r_k}{\|r_k\|^3}\right),$$

where G is gravitational constant.

The gravitational effect due to the non-spherical Earth

$$a_{har} = \nabla U$$

$$U = \frac{\mu}{r\left[1 + \sum_{n=1}^{10}\left(\frac{R_e}{r}\right)^n \sum_{m=0}^{n} A_{nm}(u)[C_{nm}\cos(m\lambda)\cos^m\varphi + S_{nm}\sin(m\lambda)\cos^m\varphi]\right]},$$

where:

C_{nm}, S_{nm} are gravitational coefficients (model JGM-3);

$s = \frac{x}{r}, t = \frac{y}{r}, u = \frac{z}{r} = \cos\varphi$;

A_{nm} is reduced Legendre function;

λ, φ are latitude and longitude;

R_e is the Earth radius;

μ is the Earth gravitational parameter.

Atmospheric drag

$$a_{dr} = -0.5\rho|v|^2\frac{C_d A}{m}v\ ,$$

where:
v is satellite velocity relatively Earth atmosphere;
ρ is atmosphere density (model NRLMSISE00).

– Solar radiation pressure

$$a_{rad} = -P_{sr}\frac{C_r A}{m}s\ ,$$

where:
s is normalized vector from satellite to Sun;
P_{sr} is pressure force of solar radiation on square unit.

– Relativistic correction

$$a_{rel} = \frac{\mu}{c^2|r|^3}\left(\frac{4\mu}{|r|} - |v|^2\right)r + 4(r|v)v\ ,$$

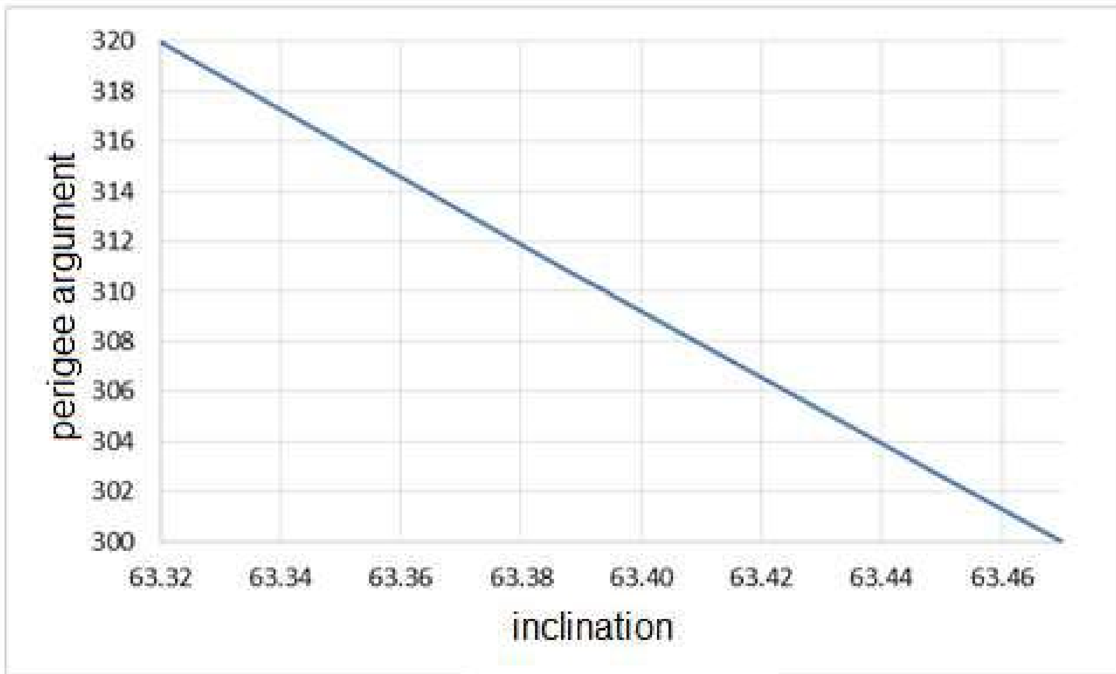
where c is light velocity.

Integration was made by 9th order Runge-Kutta method with the accuracy 10^{-12}.

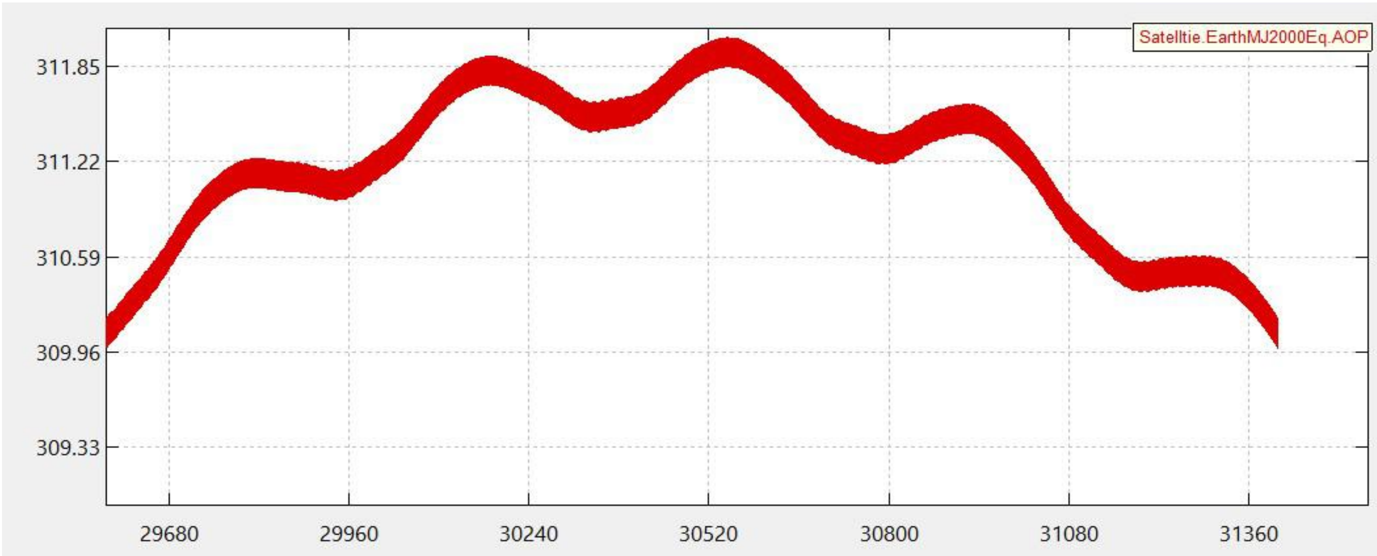
Analysis of stability of the argument of perigee was made with the use of GMAT (General Mission Analysis Tool) for:
Initial time – 2022.01.01 00:00:00
Earth Model – JGM-3 (degree 21, order 21)
Taking into account influence of the Sun and Moon
Model of Atmosphere Jacchia-Roberts

As a result of orbit simulation for 128 days were obtained following values:
– inclination – 63.365°;
– eccentricity – 0.3398;
– the semi-major axis – 10723.36 km;
– the argument of perigee – 310.003°;
– longitude of ascending node – 241.7°;
– mean anomaly – 76.75°.

The change of the final value of the perigee argument from the initial value of the inclination of the orbit



To calculate the optimal orbital inclination, the program went through values in the interval [60°, 70°] with a variable step [0.01, 0.001]. As the result, it was determined that with an inclination 63.475° the argument of perigee remains its value during the simulation (difference between initial and final values is equal to zero), the change in inclination by more than 1° would change the argument of perigee by more than 10°, which is not appropriate by the mission requirements.



Time evolution of perigee argument value

Perigee argument value at inclination 63.475° after 1000 orbits became equal to its initial value. The amplitude of the variation, i.e. difference between maximum and minimum, is 0.2°.

CONCLUSION

During the AzSat project the following will be obtained:

1) Originality, novelty, scientific and practical expediency of the proposed satellite experiment to measure the dynamics of the spatial distribution of energetically charged particles at the radiation belts of the Earth.

2) A general scientific concept of the satellite experiment and the general appearance of the space constellation and the requirements for the ground segment.

3) The optimal orbits of the satellites and the orientation of the satellites and their detectors of energetic particles.

4) Physical and mathematical principles and algorithms, mathematical modelling for calculating the spatial distribution of energetic particles in a significant region of the radiation belts, based on the measurement data, obtained during the experiment.

5) Structural and functional electrical circuits of the main measuring instrument (spectrometer of energetic protons and electrons) will be developed, simulation of the detector assemblies and prototyping of individual electronics assemblies will be carried out, the programs and methods will be tested.

6) The requirements for the design of the satellite and its subsystems, the optimal orbits and the orientation will be determined, accordingly to the purpose of the satellite.

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Thank you