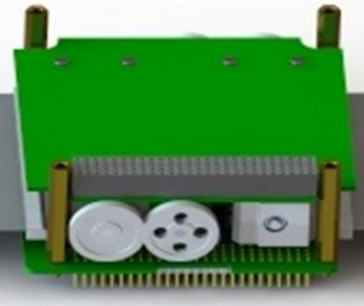
Bauman Moscow State technical University (BMSTU)

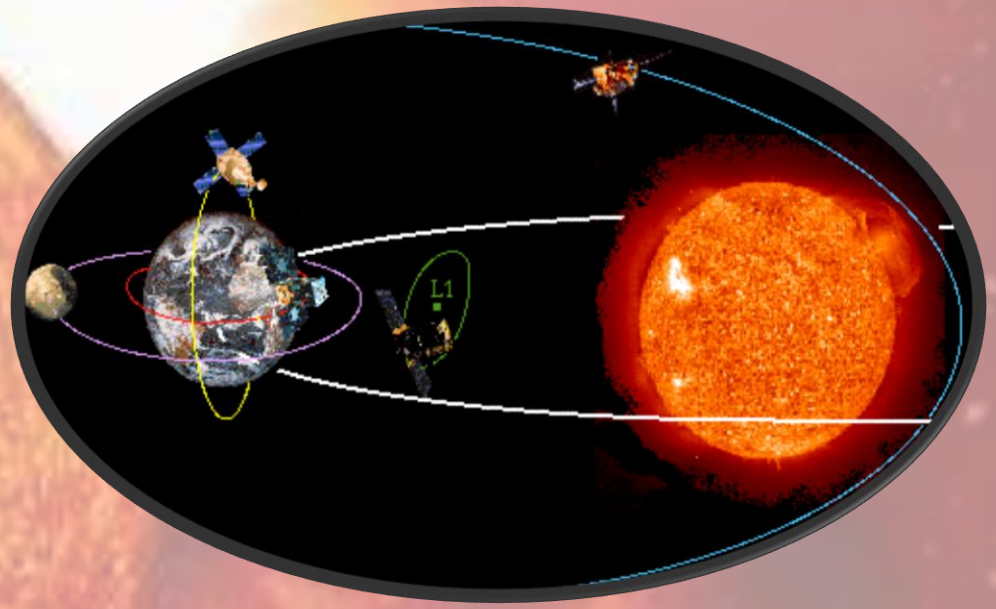


Solar sail-driven nanosatellite constellation for Sun activity monitoring

Author: Ekaterina Timakova, BMSTU graduate

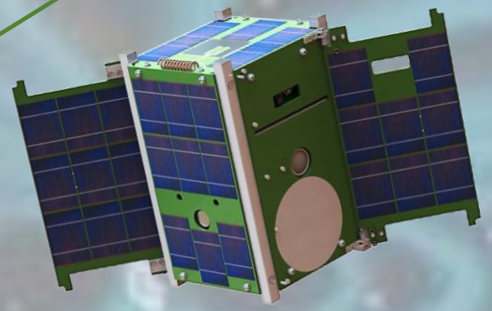
e-mail: timakova.bmstu@mail.ru

Solar research: big satellites vs CubeSats



Advantages :

- precise equipment;
- detailed scientific data;
- multiple operating features.

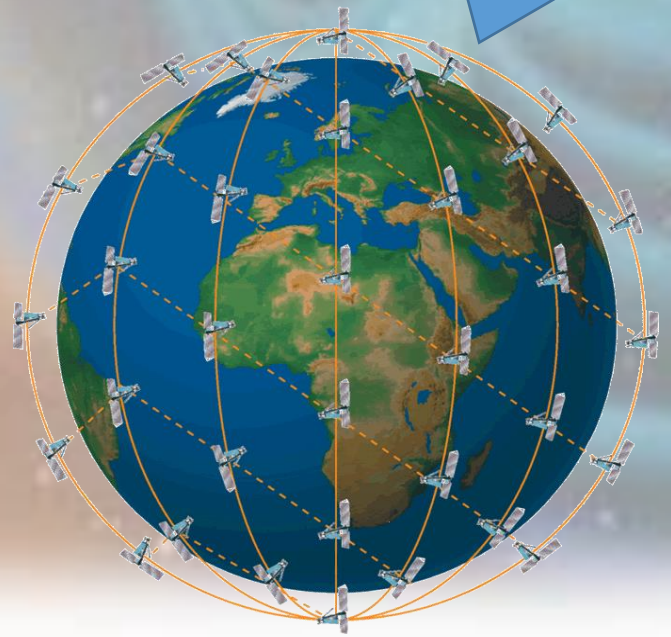


Disadvantages of big satellites:

- high manufacturing complexity and costs;
- long waiting for launch.

Benefits of a constellation:

- high redundancy and replaceability;
- non-stop monitoring;
- fast and easy to launch;
- low cost.



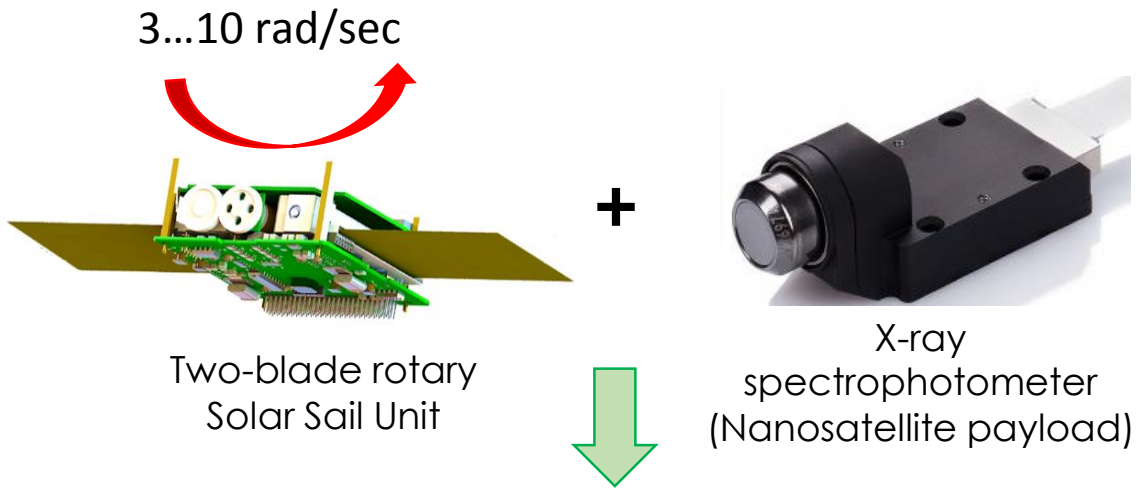
The «Yareelo» experiment

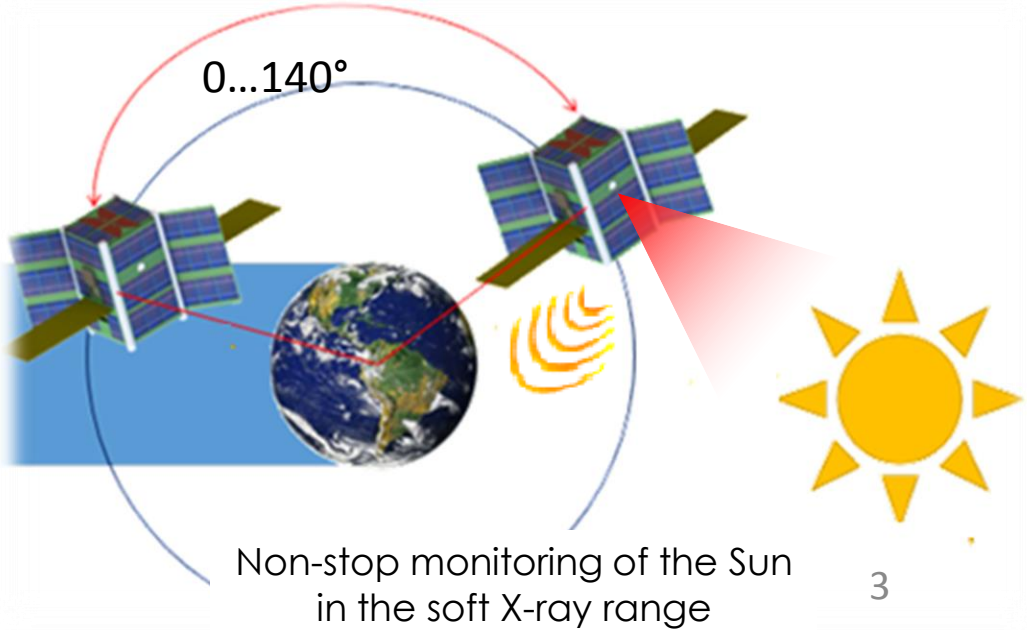
Purposes:

- Scientific research of the Sun;
- Demonstration of a nanosatellite constellation formation by means of the solar sail.

Tasks:

- to launch two 1,5 U CubeSats in one P-POD;
- to distance the nanosatellites to enable non-stop monitoring the Sun (required angular distance: 140…180°);
- to register the solar activity;
- to prove the possibility of a long-term nanosatellite group flight;
- to deorbit the nanosatellites at the end of their service life in a passive mode (by deploying the solar sail).



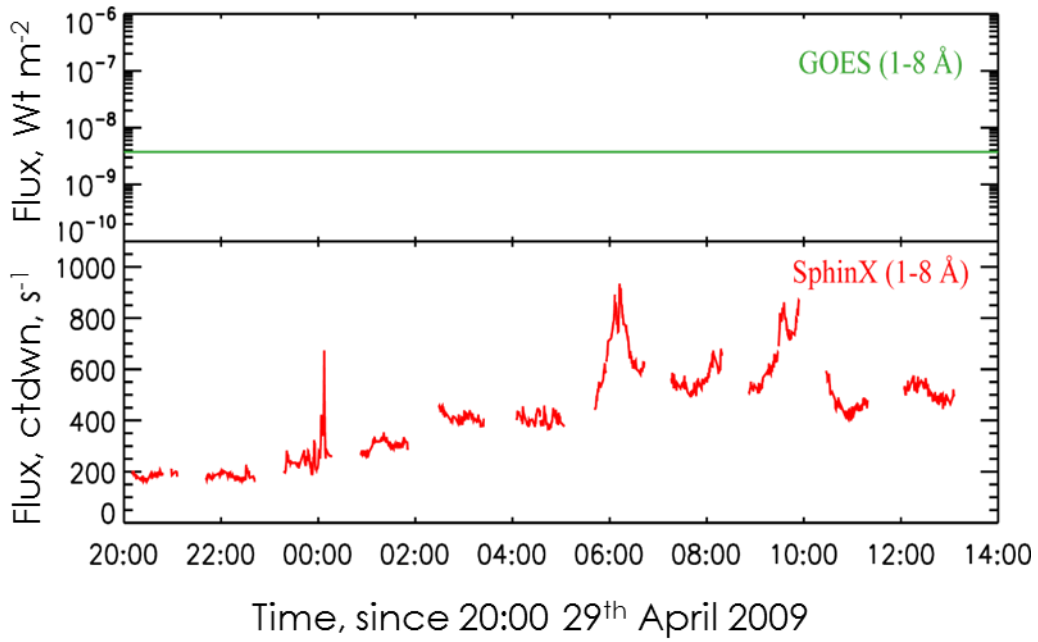


Non-stop monitoring of the Sun
in the soft X-ray range

X-ray Spectrophotometer

Functional area:

- Receiving non-stop and quick information about solar activity;
- Space weather forecasting;
- Registering of the solar flares (0.5-15 KeV).



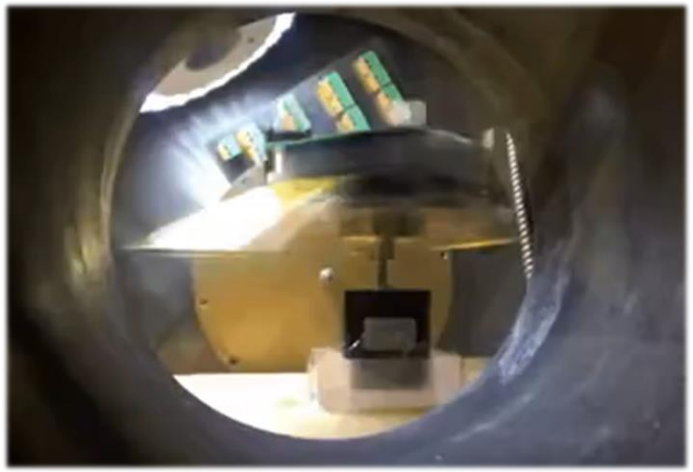
Spectrophotometer developed by physical institute of Russian Academy of Science (on base of the Ketek Technology)

Device technical features:

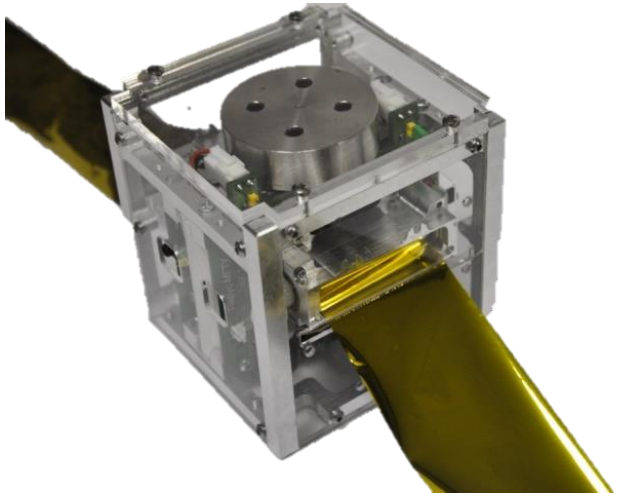
- Power consumption: 0,35 W;
- the accuracy of orientation in the Sun: 1-2°.

Sensitivity of the developed detectors is expected to be equal to SphinX device.

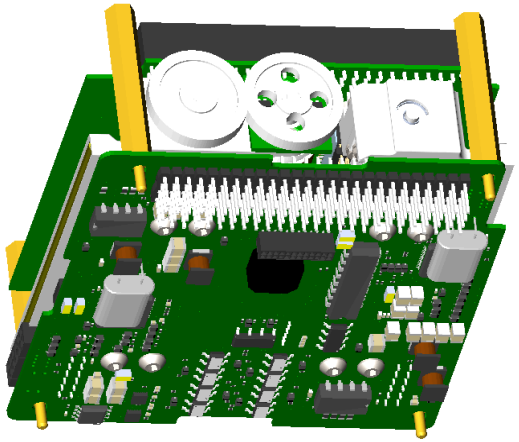
Two-blade rotary solar sail



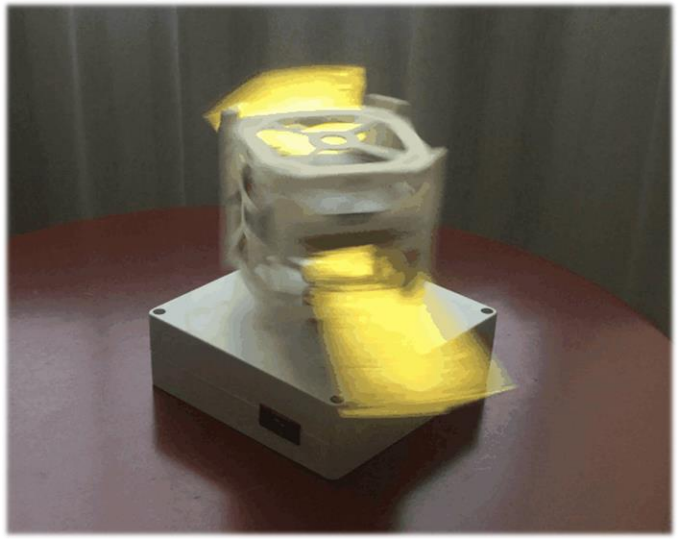
Solar Sail Unit in vacuum



BMSTU Sail



Solar Sail Unit

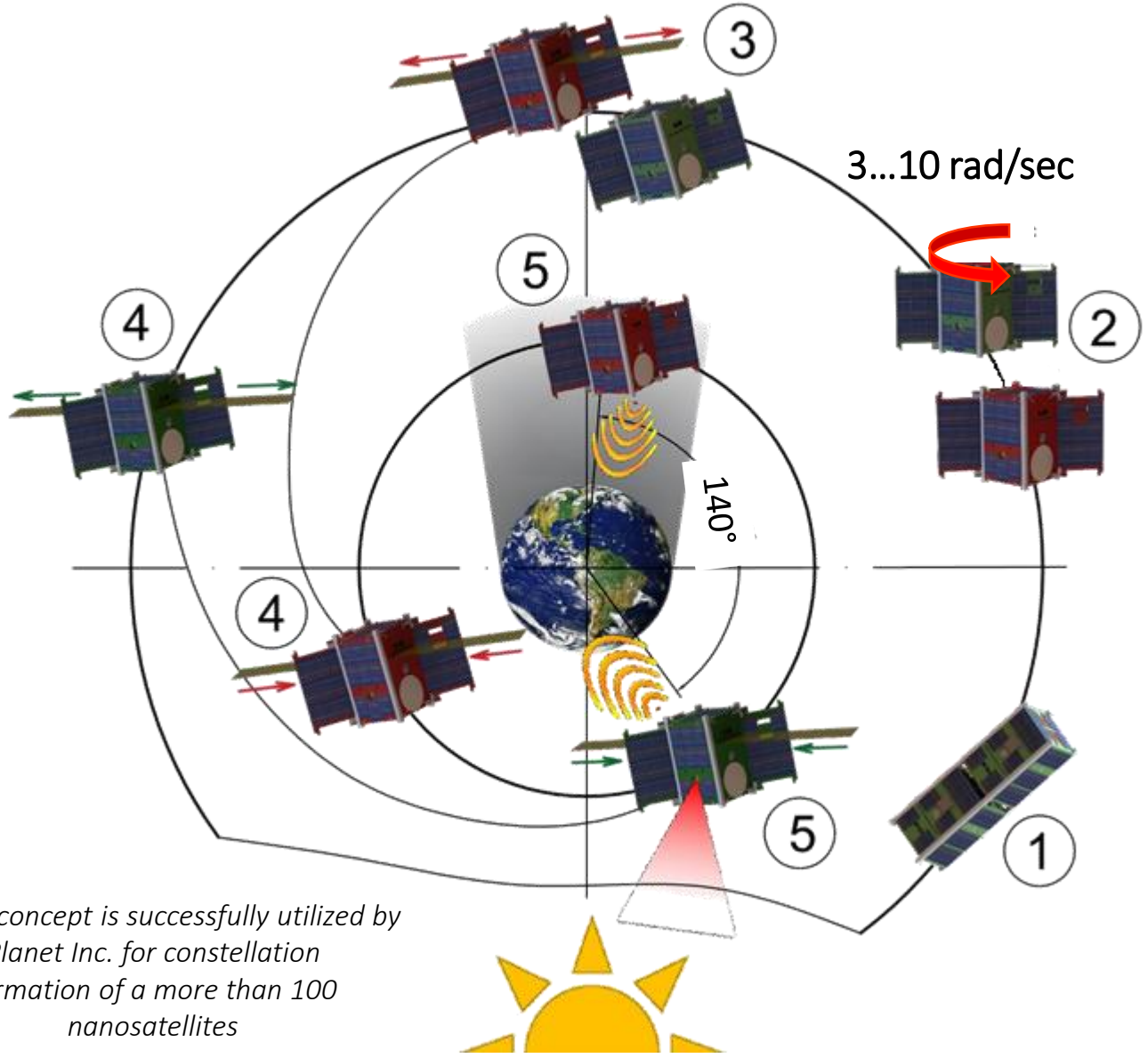


1U CubeSat mock-up with the Solar Sail Unit onboard

Mass, kg	1
Dimensions, mm (sail is folded)	100x100x100
Sail max length, m (two blades, total)	10
Sail material characteristics	NIIKAM aluminized polyimide 12μm thick
Sail max width, mm	50
Initial orbit	400 km LEO
Launch year	2019

Mass, kg	0,30
Dimensions, mm (sail is folded)	90 x 96 x 38
Sail max length, m (two blades, total)	20
Sail max width, mm	70
Average energy consumption, W	0
Energy consumption during sail deploying/folding, W	1,2 (up to 15 min)

Constellation formation process



Similar concept is successfully utilized by Planet Inc. for constellation formation of a more than 100 nanosatellites

1
- Launching from the P-pod

2
- Initial orientation
- Solar panels deploying
- Spinning with magnetic coils

3
- Solar sail deploying from the first nanosatellite

4
- Aerobraking maneuvering

5
- Operational flight with the constant angular distance between CubeSats
- Sun activity monitoring
- Communication sessions with the ground control station

Ballistic calculation

$$\ddot{\vec{X}}(t) = \frac{\vec{F}}{m}$$

$\ddot{\vec{X}}(t)$ – coordinate vector;

m – satellite mass;

$\vec{F} = \overrightarrow{F_g} + \overrightarrow{F_a} + \overrightarrow{F_s}$ – force vector of:

$\overrightarrow{F_g}$ – force of gravity
(ellipsoid WGS-84, 20 zonal harmonics);

$\overrightarrow{F_a}$ – atmospheric drag force
(atmospheric model NRLMSIS-00);

$\overrightarrow{F_s}$ – solar pressure power.

Integration by Runge-Kutta method (4^{th} order)

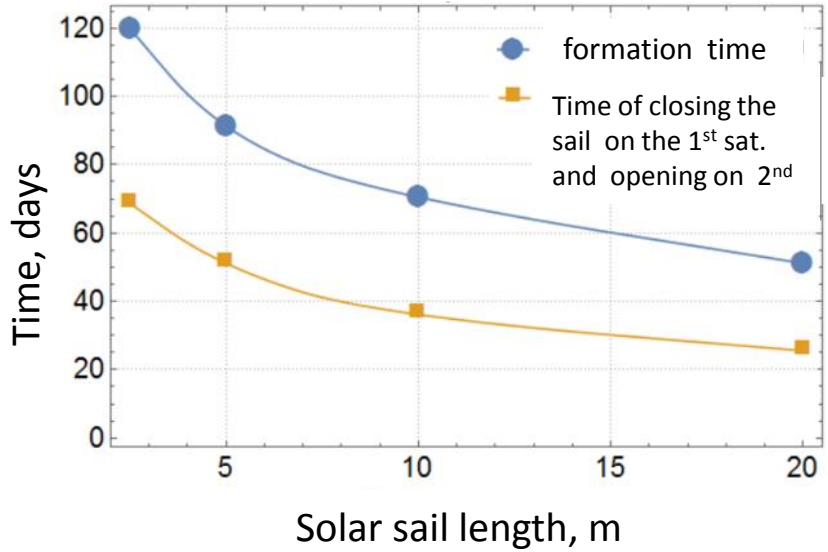
Assumptions:

- *Satellite orientation is constant in inertial space;*
- *The gravity of the Sun and other planets are not taken into account;*
- *-sail stays undeformed during the mission.*

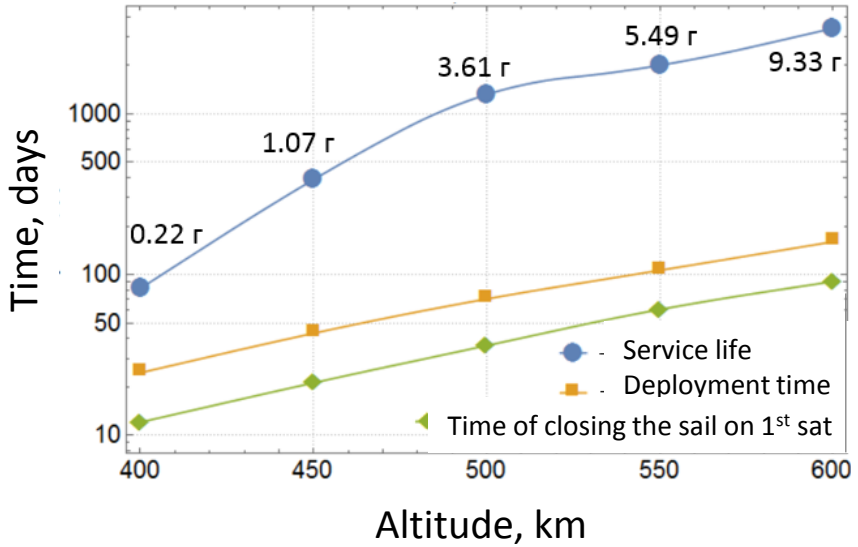
Optimized parameters (max service life and constellation formation life)

Altitude:	500 km
Sail length:	10 m
Constellation formation :	71 days
Satellite's service life:	> 3,5 years

Dependence of the main time parameters of the sail length (initial altitude 500 km)



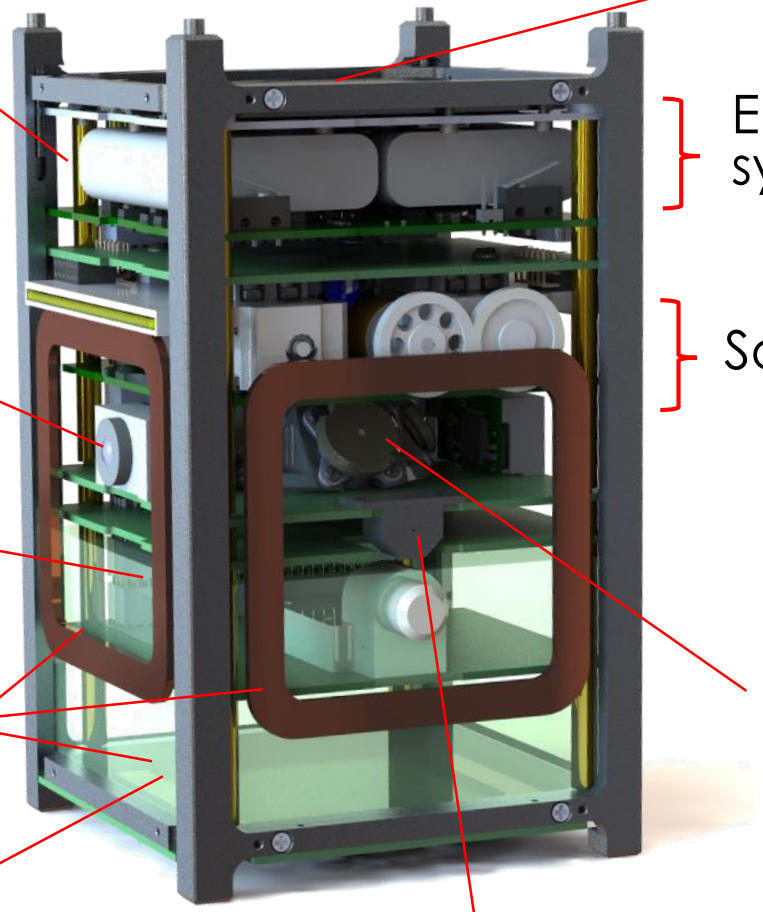
Dependence of the main time parameters of the initial altitude (sail length10 m)



Inner design

Transceivers

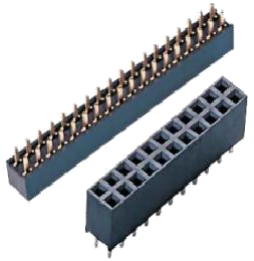
Framing



Electrical power system

Solar sail unit

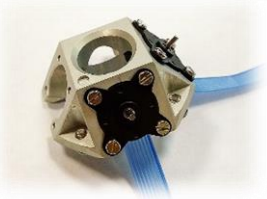
Camera

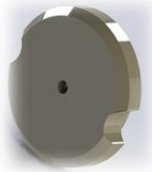


Board-to-board connectors

Magnetic coils

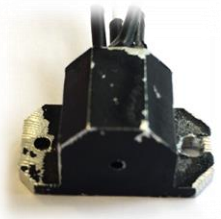
Reaction wheels



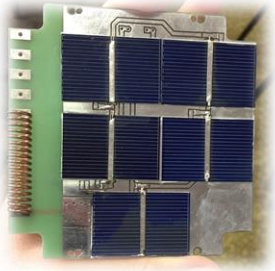


Available for the payload

Solar sensor



Outer design



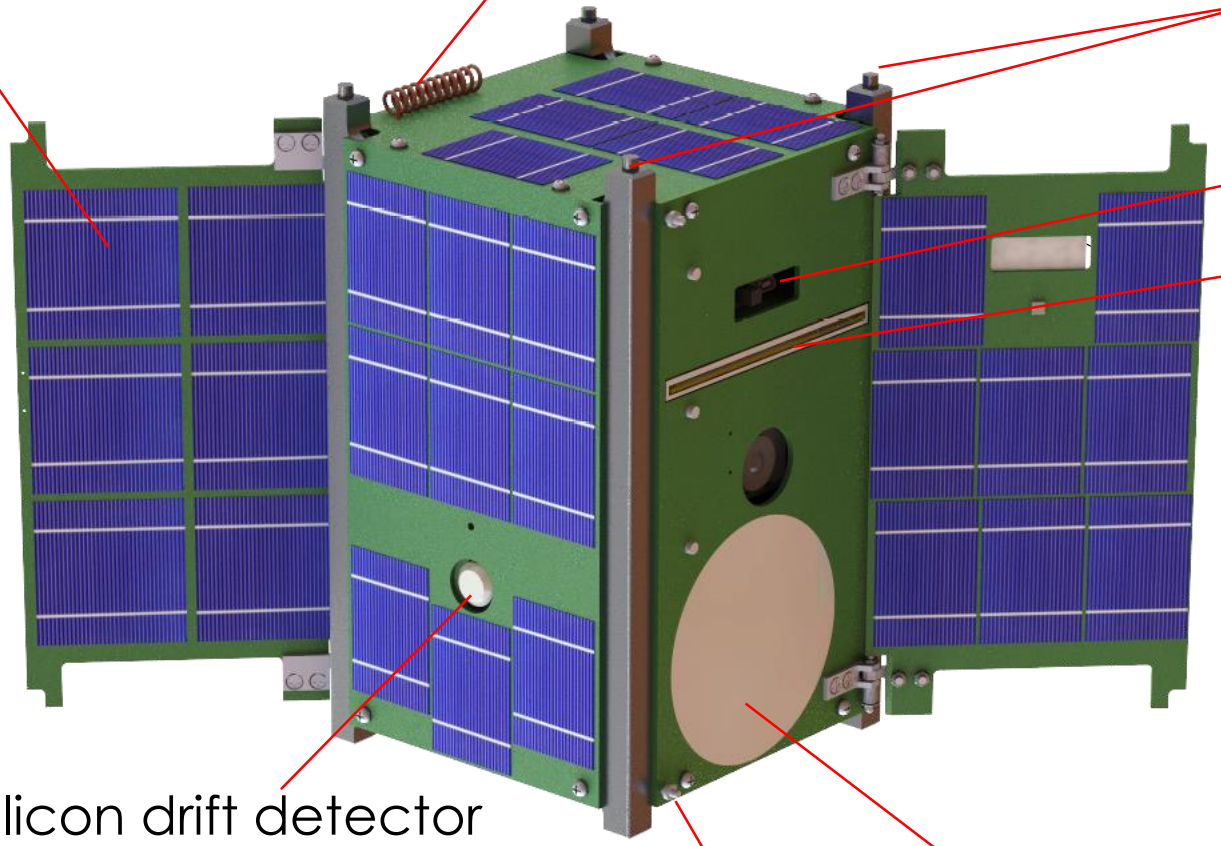
435 MHz antenna

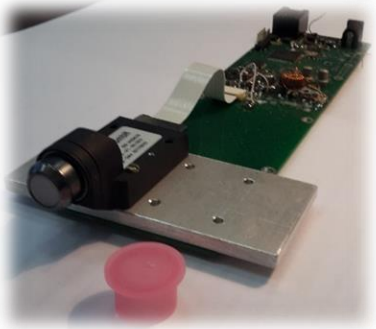
Deployable solar panels

Spring-loaded actuators

Usb socket

Solar sail



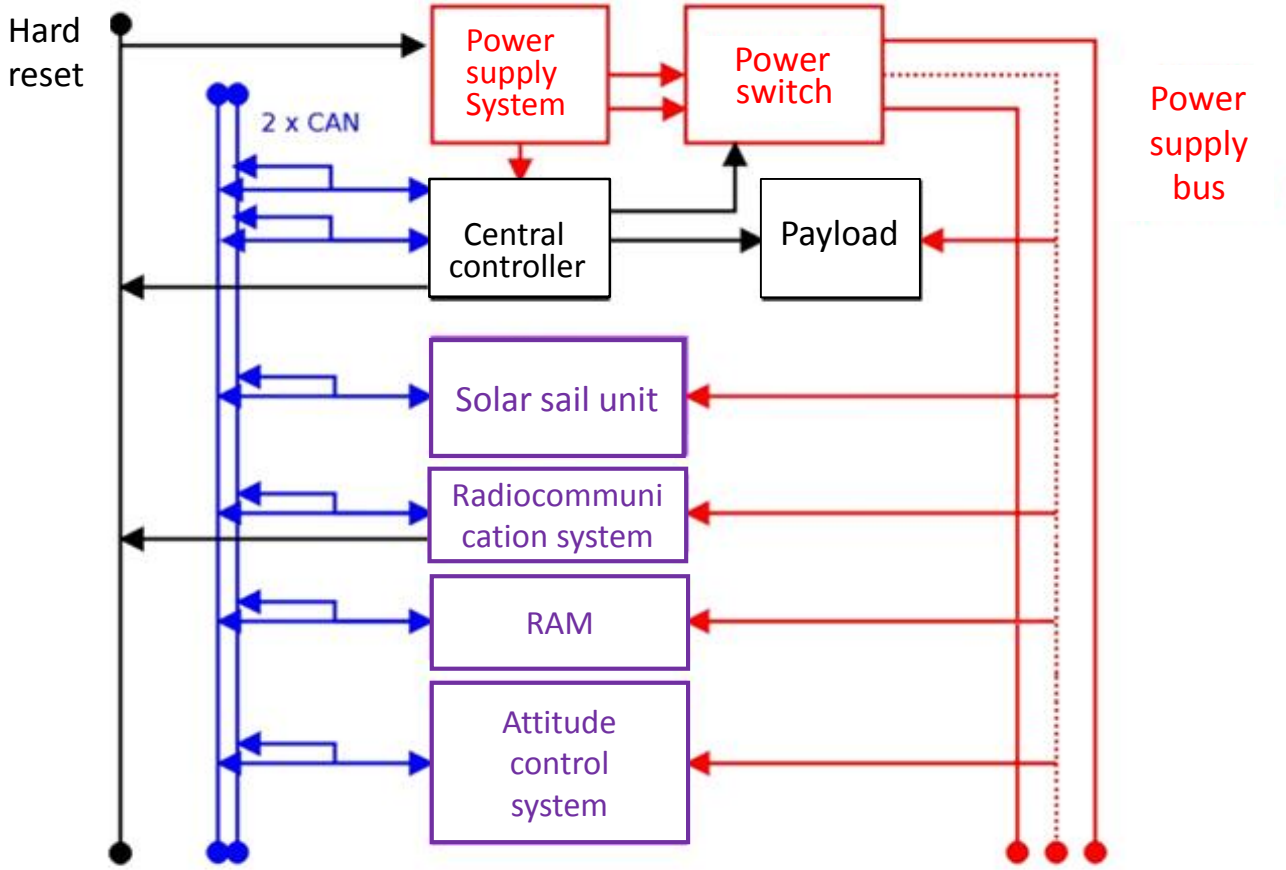


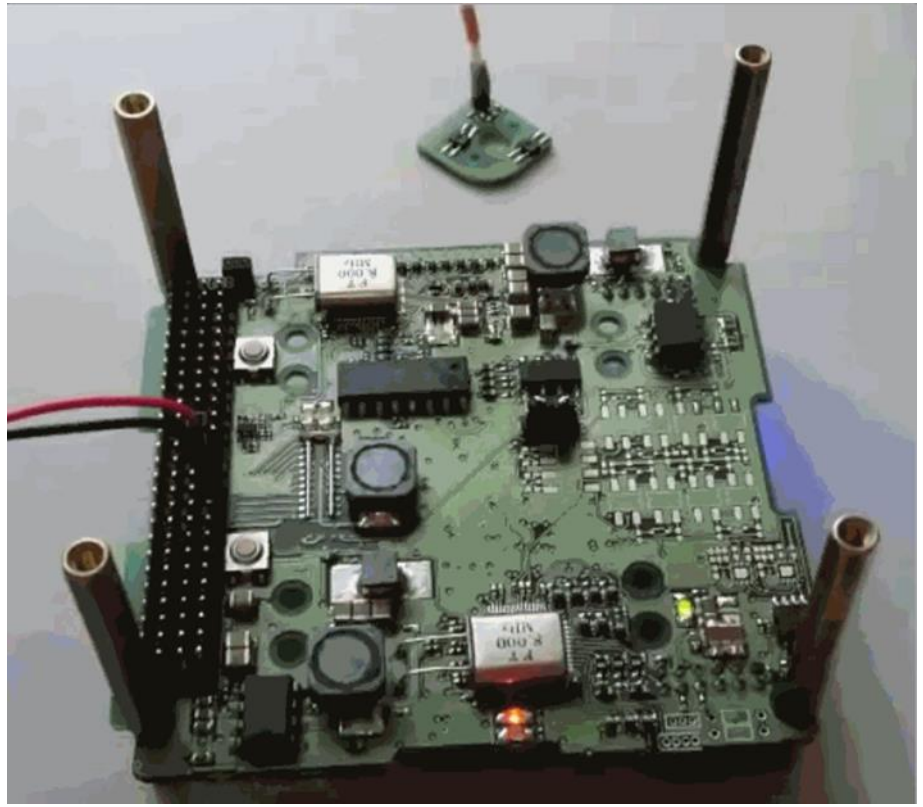
Silicon drift detector (spectrophotometer)

GPS antenna

2,4 GHz antenna

Functional chart



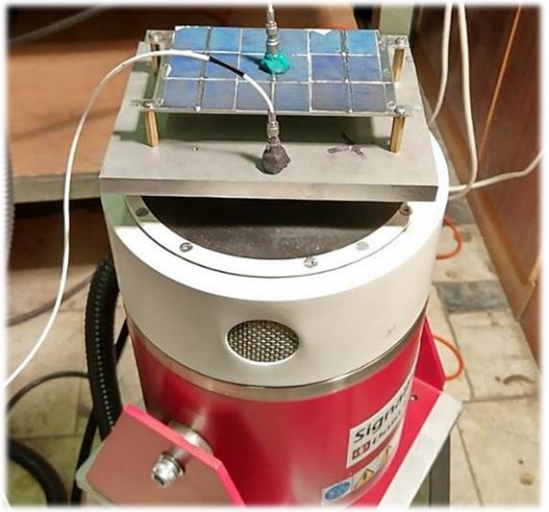


Unified microcontroller

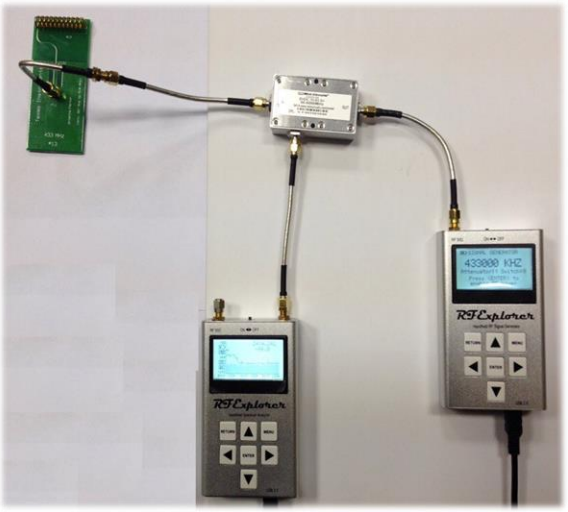
- Regulated power(3,3; 5,0 V) for internal circuits
- Control of all operating modes of a sail
- Full-redundancy
- One failure in any component tolerance

Technical experiments

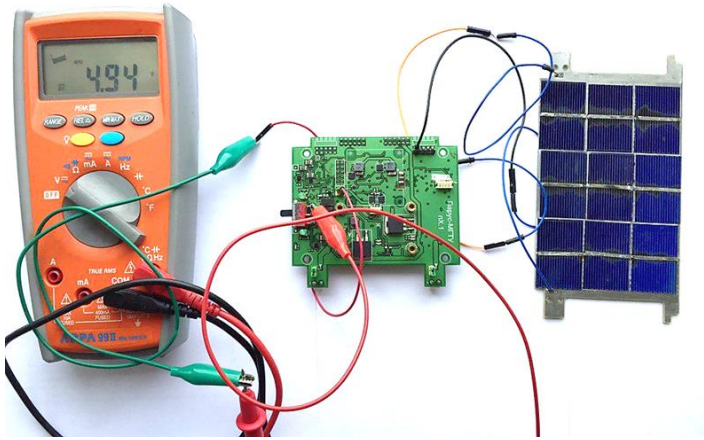
Testing in vacuum



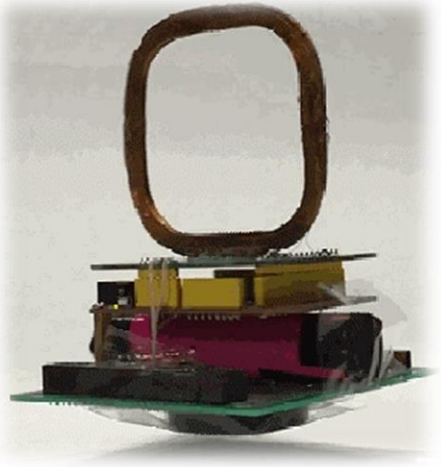
Solar panels vibrations



Communication system testing

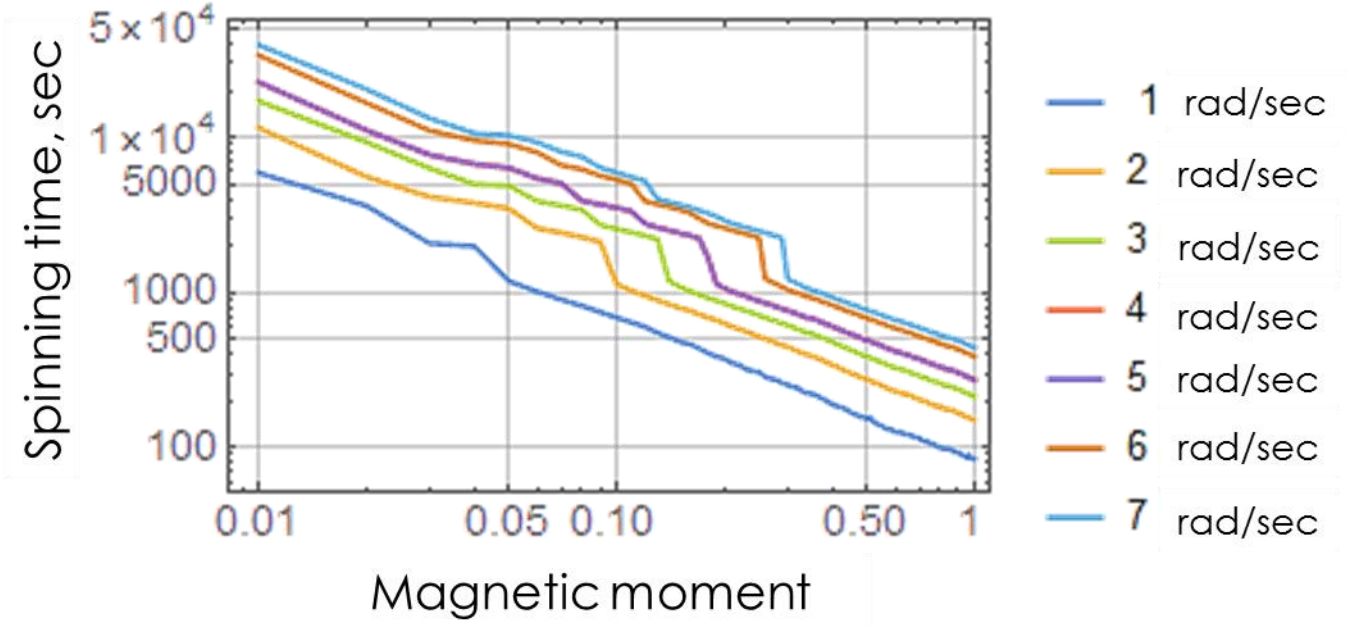


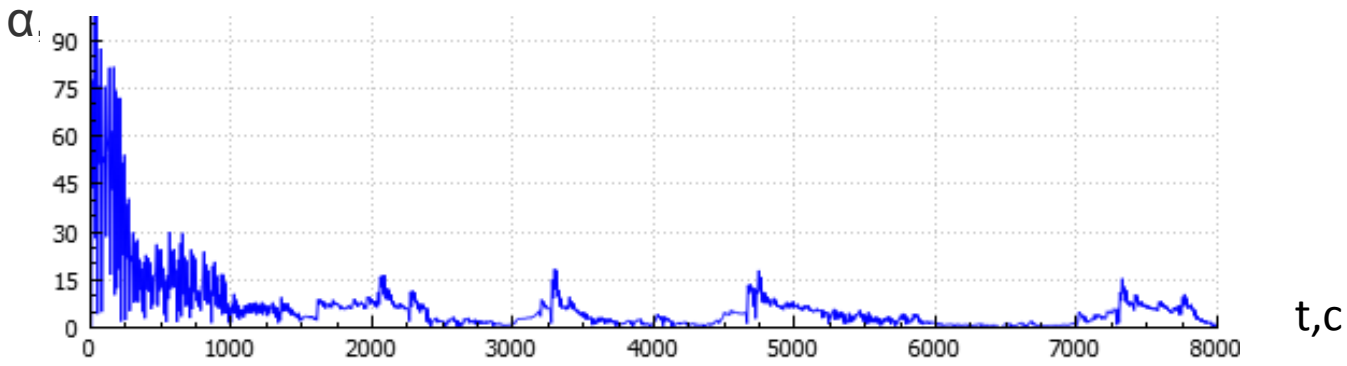
Power supply system testing



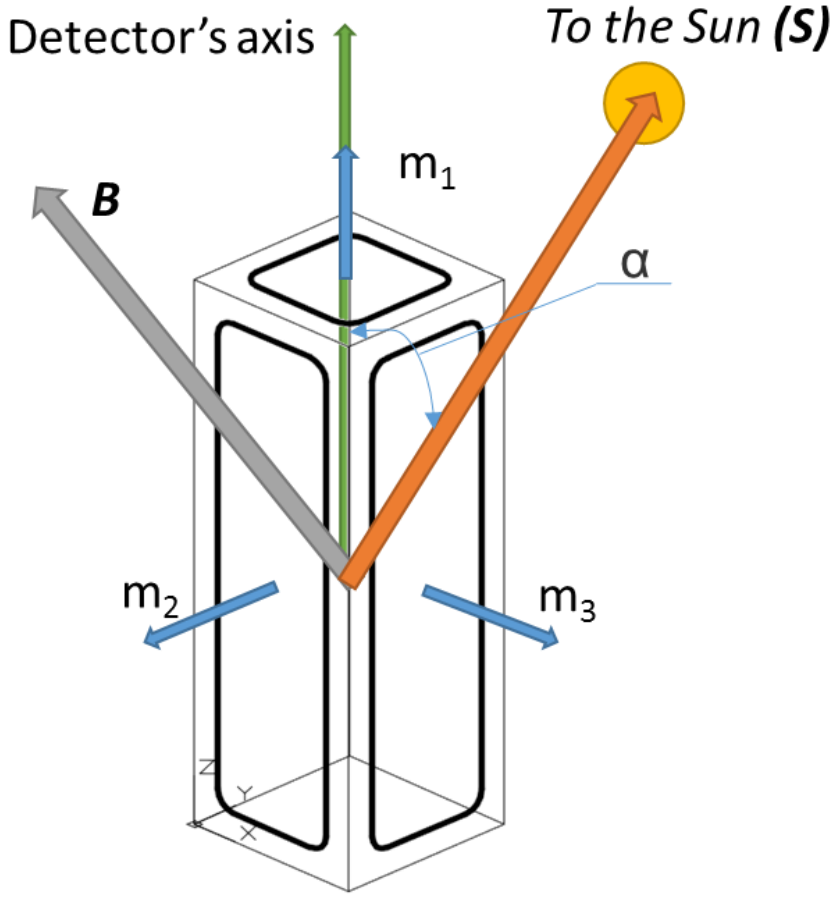
Attitude control system testing

Attitude control simulations





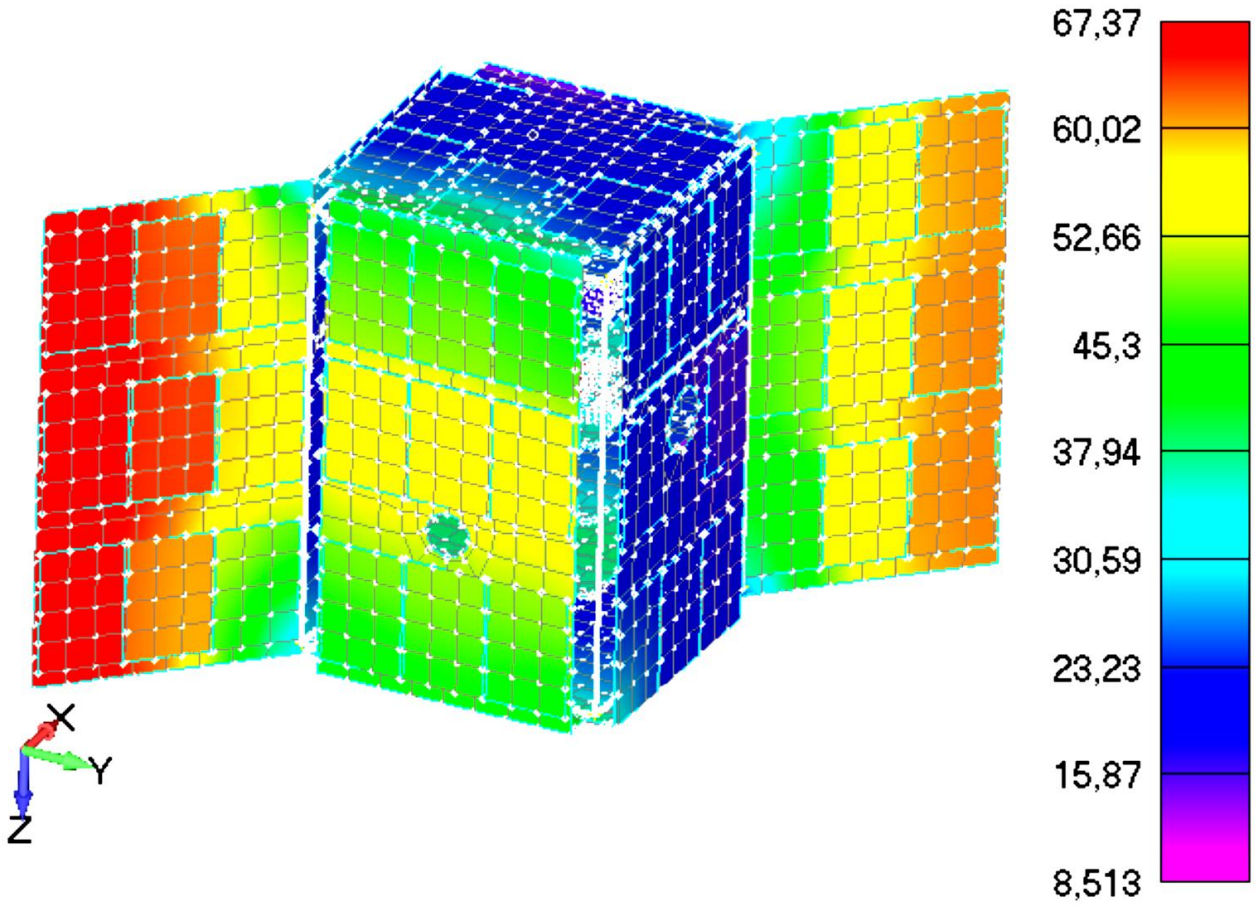
Newly developed stabilization algorithm



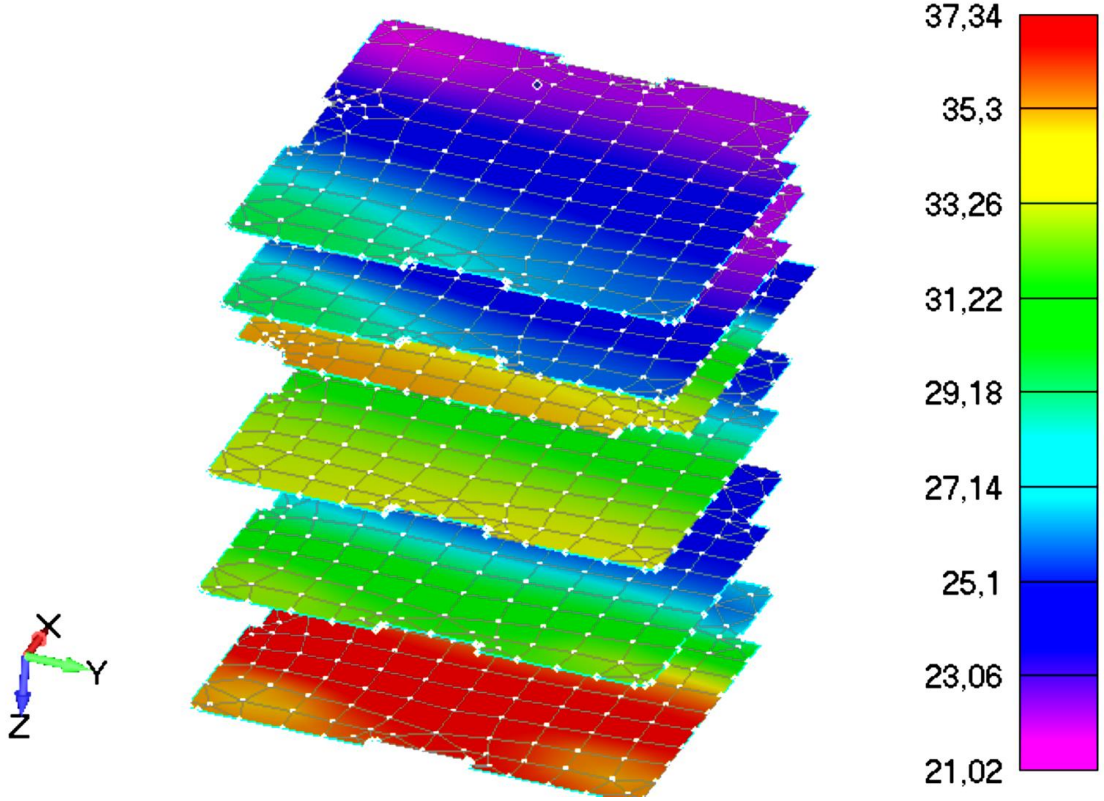
Uniaxial orientation to the Sun by means of magnetic coils

(α < 5°)

Thermal simulations



External structure's temperature field

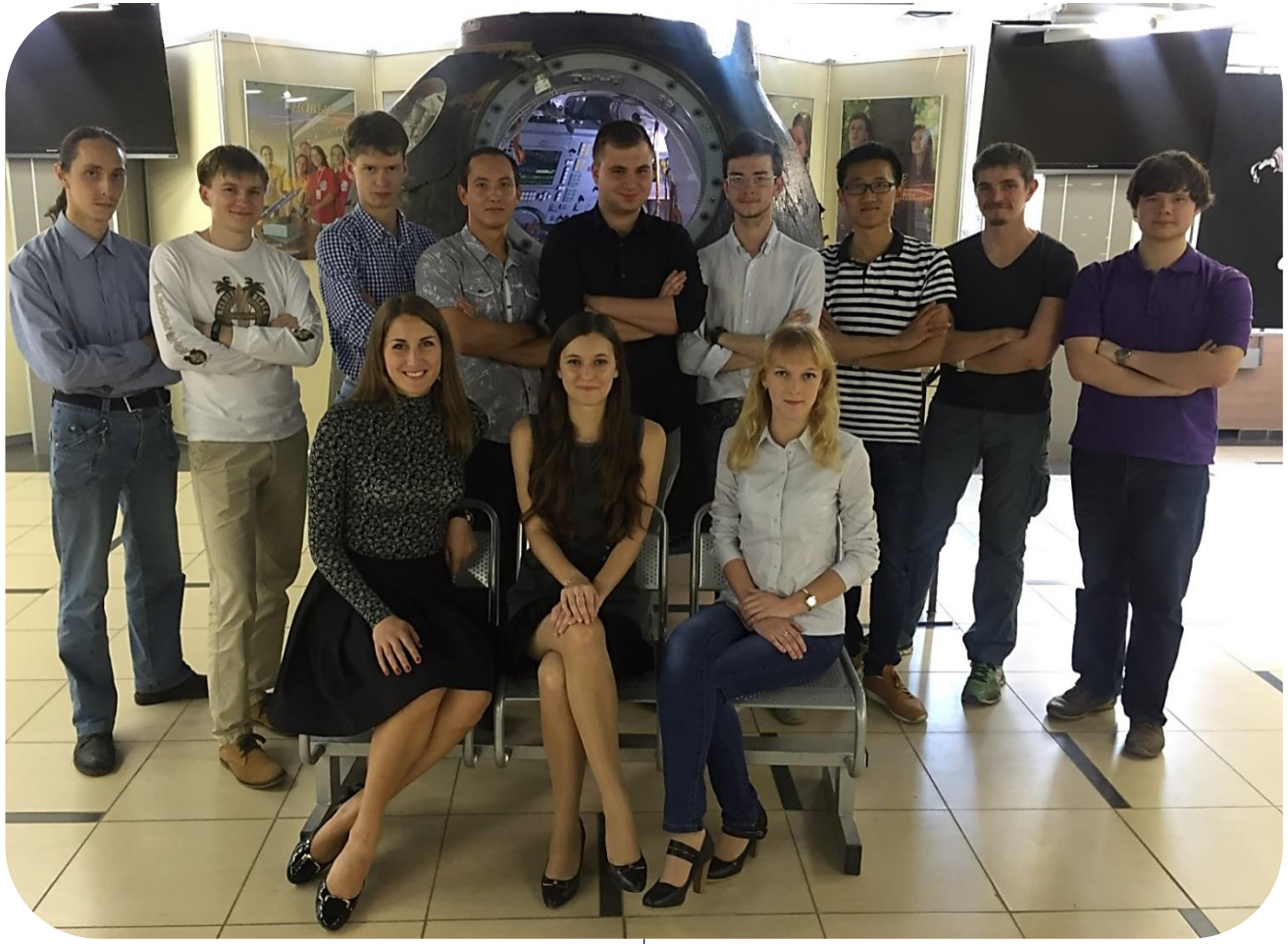


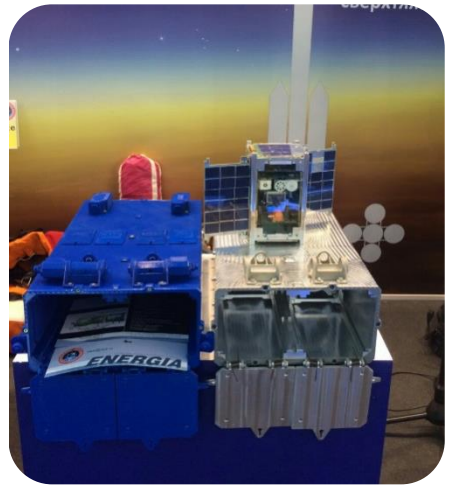
Internal structure's temperature field

Conclusions

- Newly developed concept of constellation formation by means of solar sail
- Newly developed algorithms of orientation
- Newly designed structure and avionics
- Newly written software for ballistic calculation
- Newly developed X-ray detector for monitoring of solar activity

Thank you for your attention





Website: bsail.ru

Instagram: baumansail