TUS-Lomonosov/K-EUSO.

Pavel Klimov

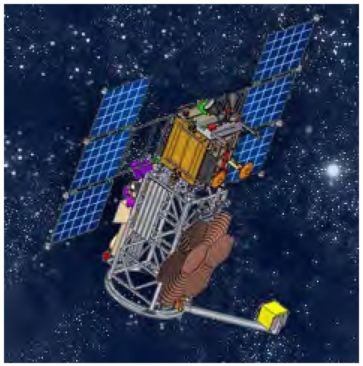
The NextGAPES-2019 Workshop
21.06.2019

Report content

- Scientific objectives of TUS and K-EUSO
- Comparison with other experiments and projects. Advantages of space-based measurements
- The TUS detector onboard Lomonosov satellite results
- K-EUSO status and design
- Technical description
  - Optical scheme
  - Data acquisition (FS, CU, MCDPS)
  - Mechanical structure
  - LIDAR
- Description and justification of the chosen construction
  - Simulations
  - Breadboarding
- Ensuring the reliability, radiation resistance and safety of K-EUSO
- Schedule, plan and cost estimation
- Verification of TR

UV radiation and UHECR projects

TUS



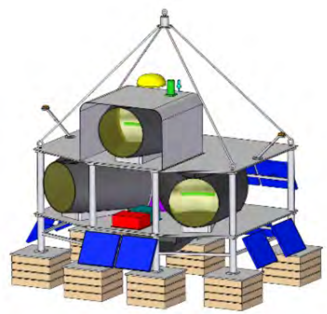
Tatiana-1

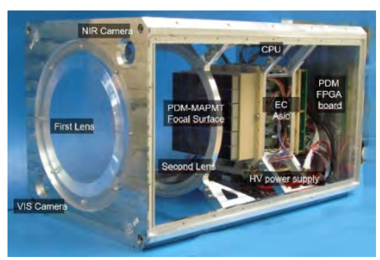
Tatiana-2

Vernov

K-EUSO

EUSO-SPB-2





УФ атмосфера/
Mini-EUSO

EUSO-TA

Space experiment K-EUSO

The design of the detector should provide measurements of UHECR with a threshold neat 50 EeV with statistics of ~100 events per year.

The main task is the energy spectrum and anisotropy measurements with uniform exposure over the celestial sphere

- Scientific objectives:

  UHECR fluorescent radiation measurements from space

- Placement:

  Russian Segment of the ISS

- Main technical parameters

✓K-EUSO – Telescope with an optical Schmidt scheme (a large area of the entrance window and a wide field of view)

  ✓Mirror diameter – 3.6-4 м

  ✓Time resolution 1-2.5 us

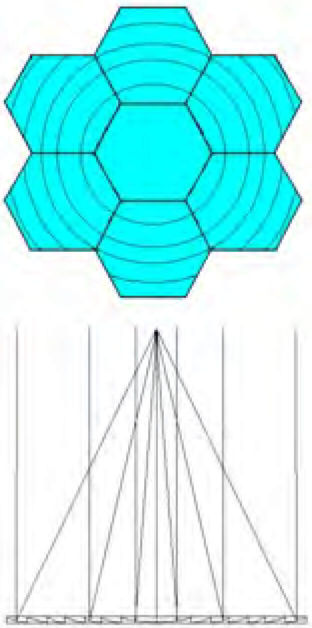
  ✓FOV 40 degrees.

  ✓Angular resolution ~10^{-6} sr

  ✓Mass ~ 500 - 850 kg

TUS detector on board the Lomonosov satellite

Fresnel type mirror–concentrator



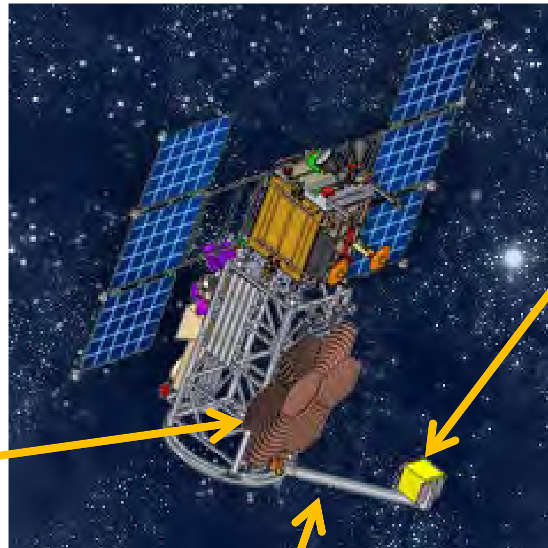
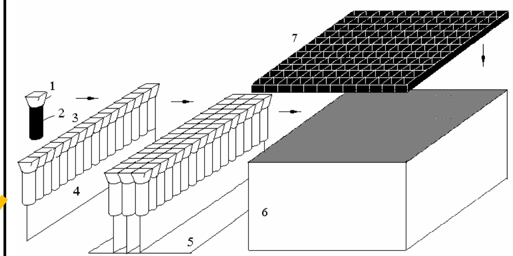


Photo receiver moving system



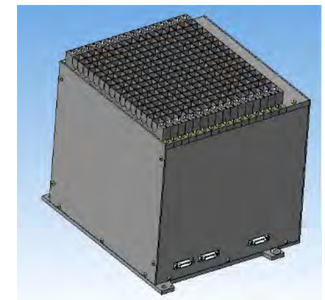
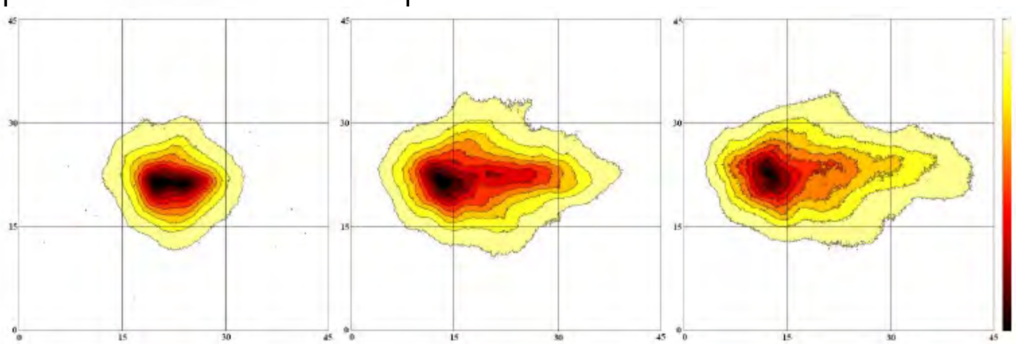
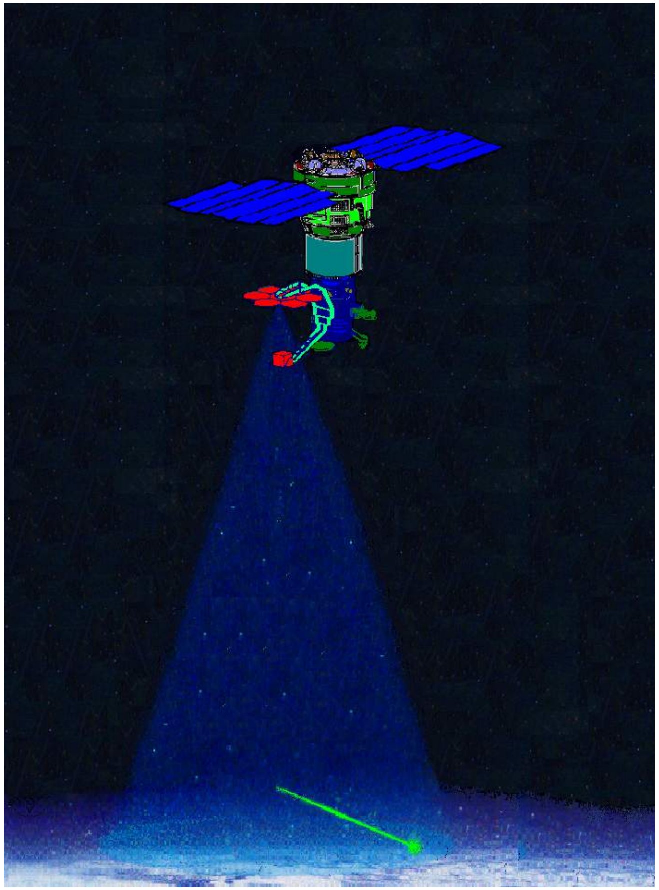


Photo receiver

Mass	60 kg
Power	65 W
FOV	±4,5 degree
Channels	16 modules of 16 PMTs
Pixel size	10 mrad (5×5 km)
Mirror area	~2 m^2
Duty cycle	30%

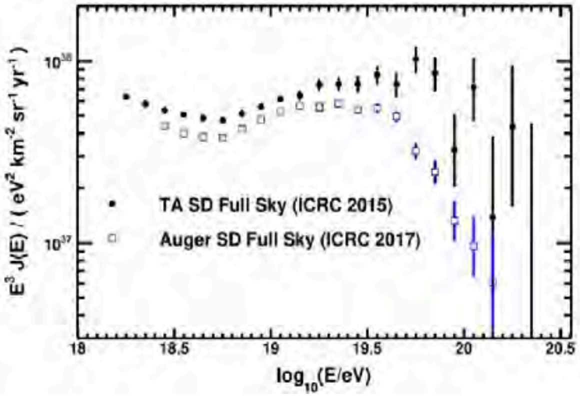


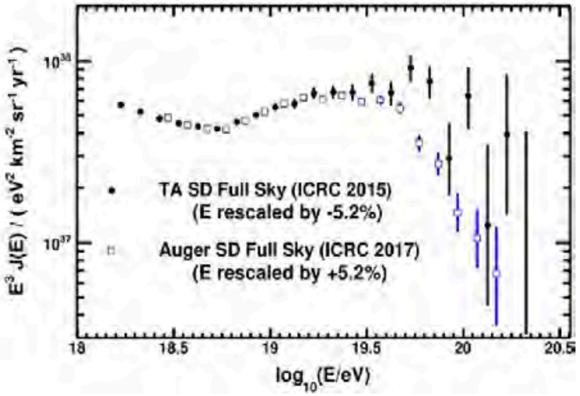
Scientific goals of the experiment



UHECR spectrum.

PAO and TA UHECR spectra. Obvious difference in shape after GZK cut-off energy.



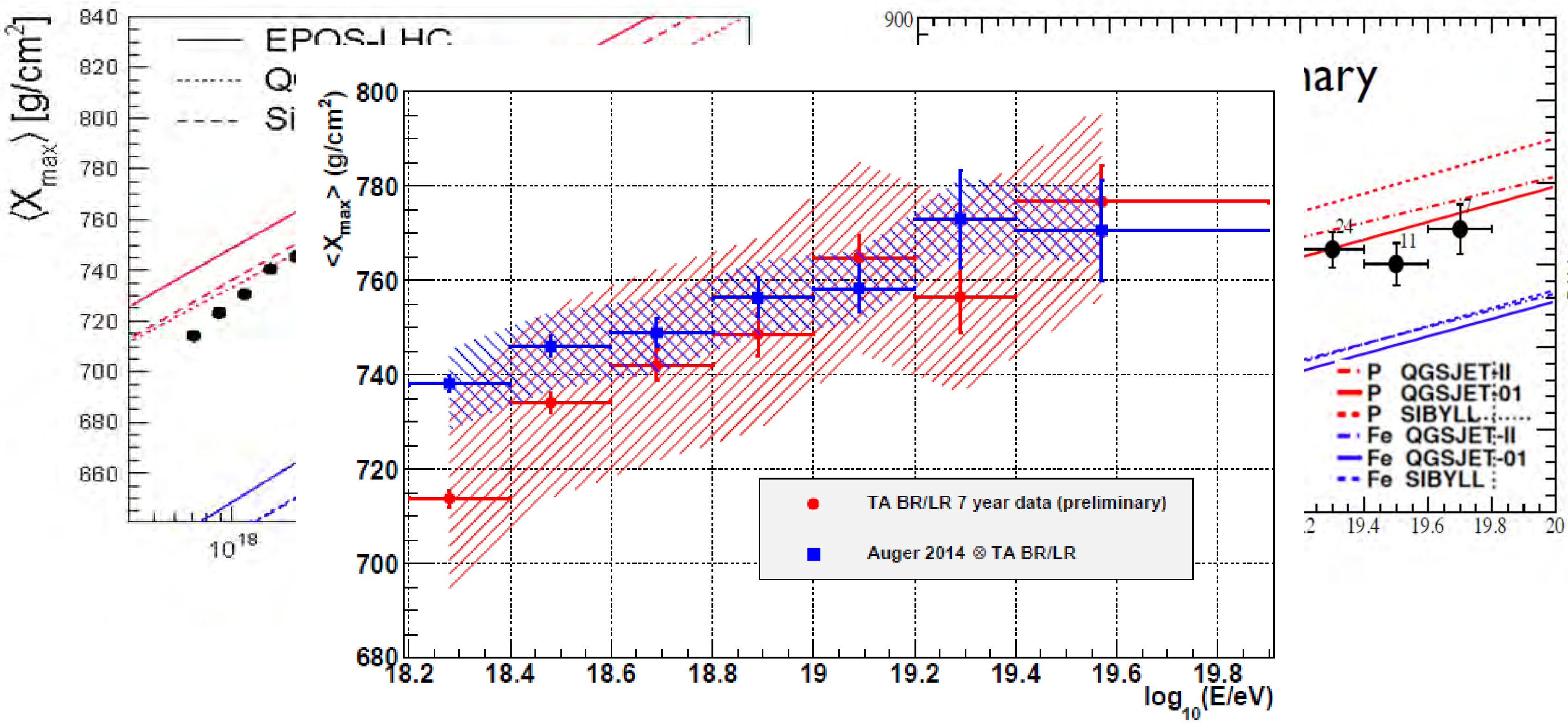


The energy spectrum of UHECR according to the TA and Auger. Left: energy spectra of each experiment. Right: the same, but the energy of UHECR registered by TAs is reduced by 5.2%, and registered by TA are increased by 5.2%.

Mass composition

PAO

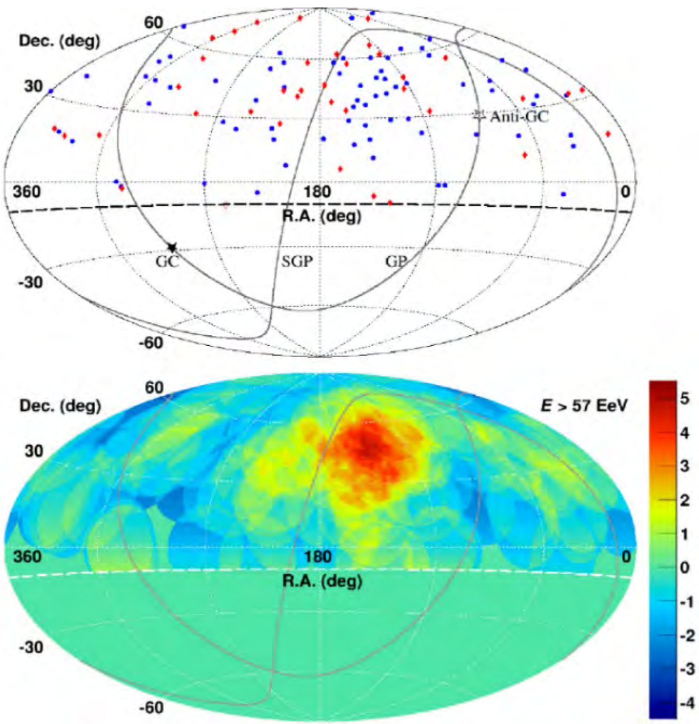
TA



W. Hanlon et al., Report of the working group on the mass composition of ultrahigh energy cosmic rays, JPS Conf. Proc. 19, 011013 (2018). doi:10.7566/JPSCP.19.011013

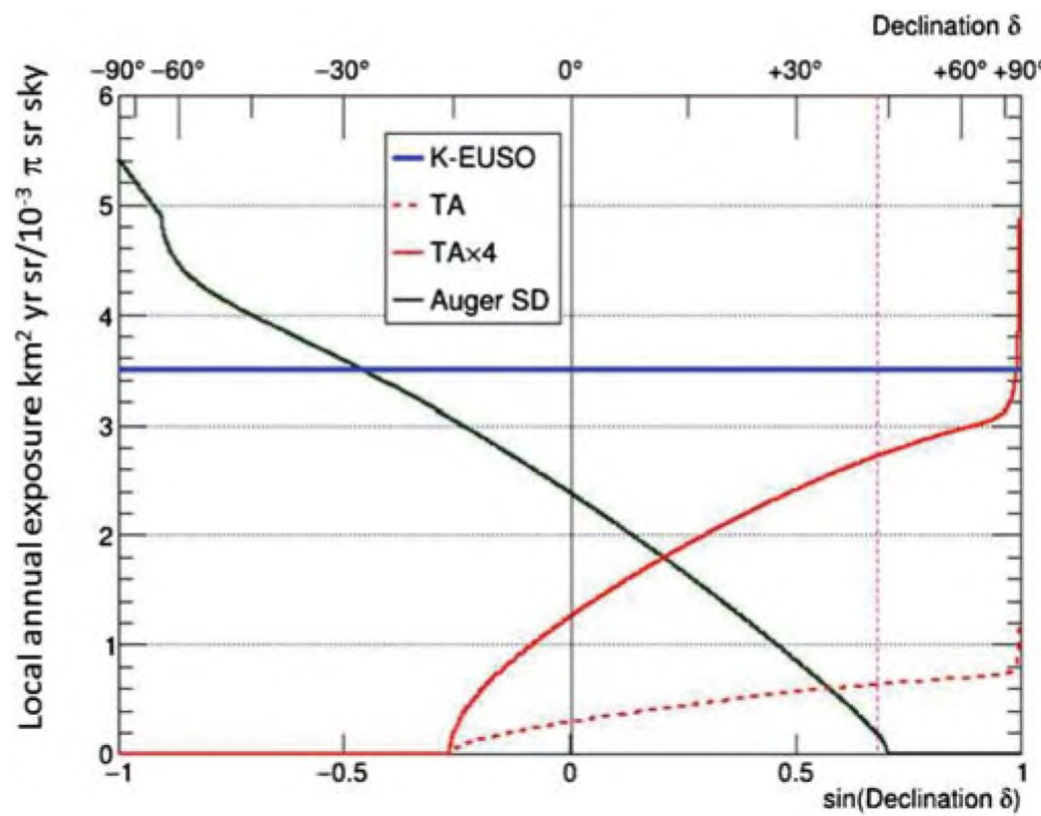
Not enough statistics of ground-based oservatories

Anisotropy search

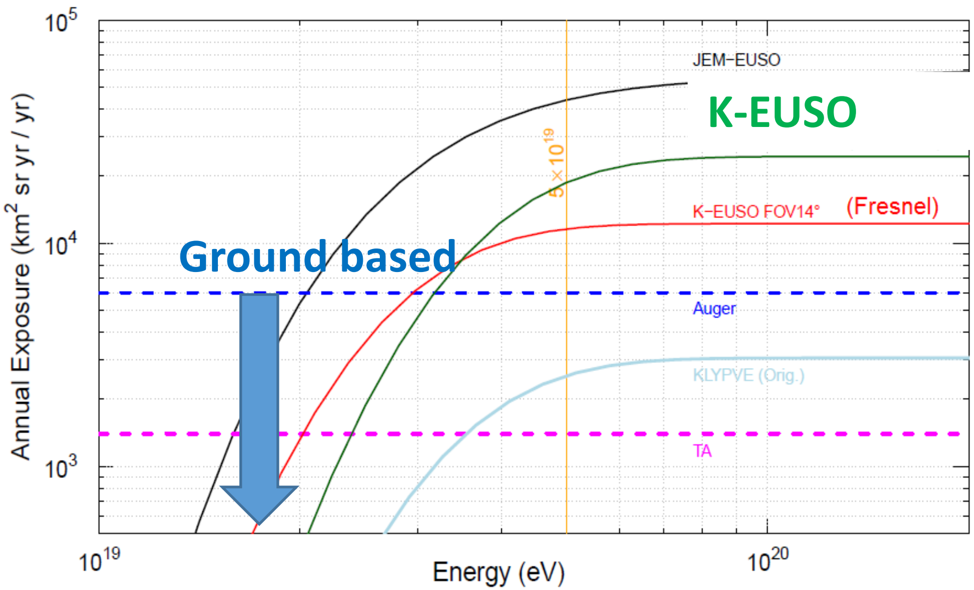


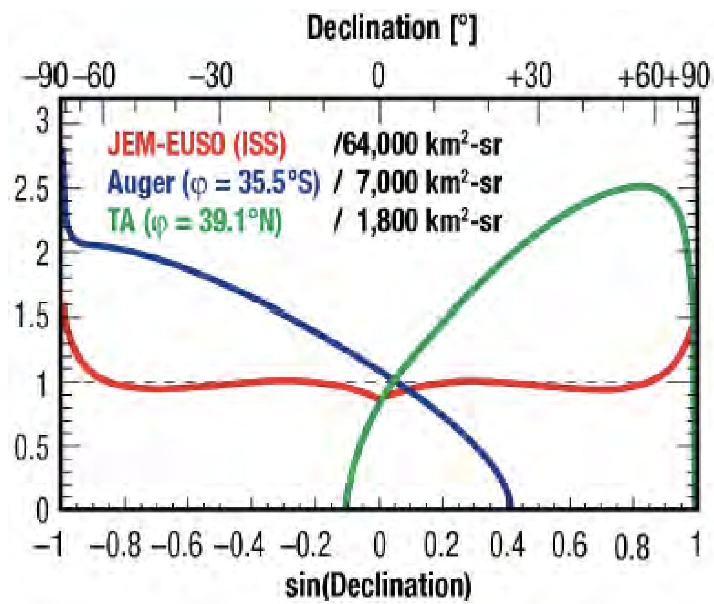
Directions of arrival of cosmic rays with an energy of more than 57 EeV, registered by the TA experiment (in equatorial coordinates).

The key factor: the uniformity of exposure throughout the celestial sphere - unattainable by ground means!



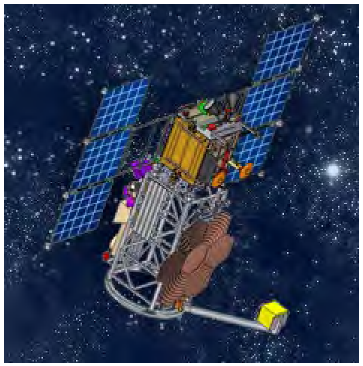
Comparison with ground-based projects





UV radiation and UHECR projects

TUS



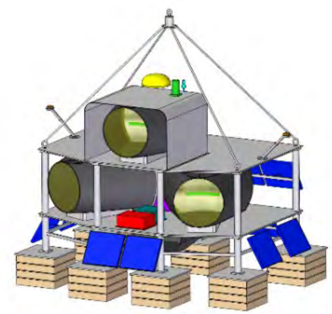
Tatiana-1

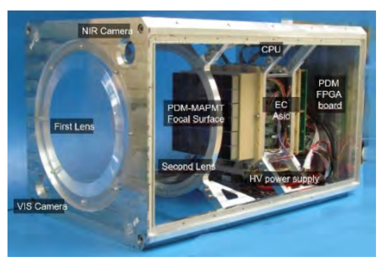
Tatiana-2

Vernov

K-EUSO

EUSO-SPB-2

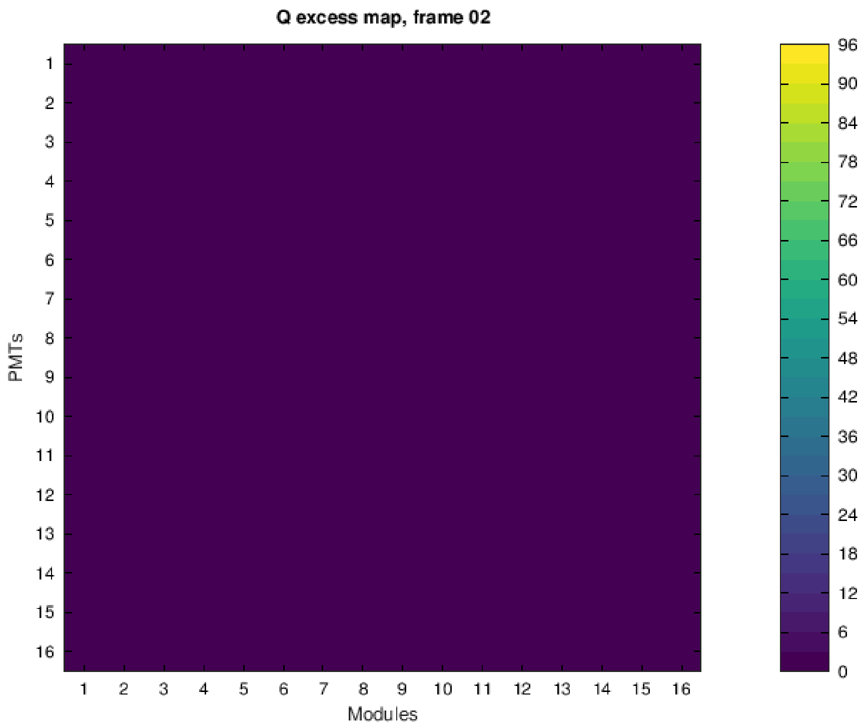


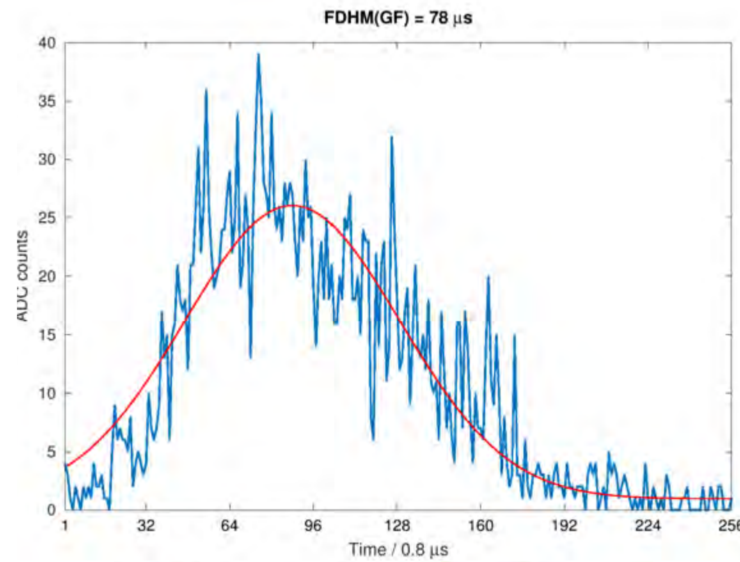


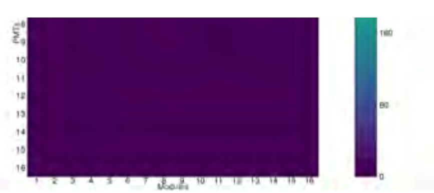
УФ атмосфера/
Mini-EUSO

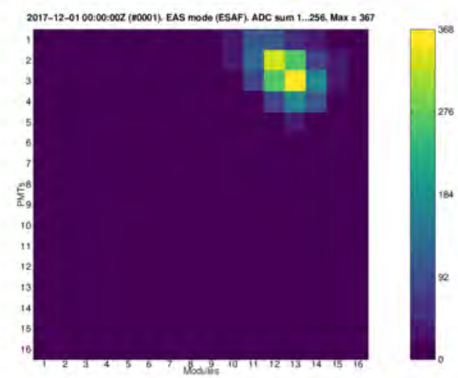
EUSO-TA

EAS simulations for the TUS detector









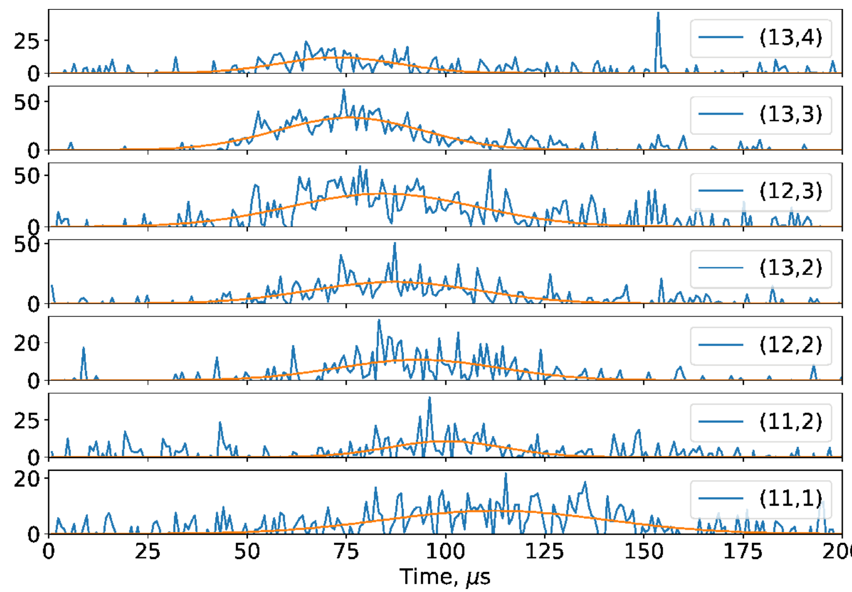
θ = 60°

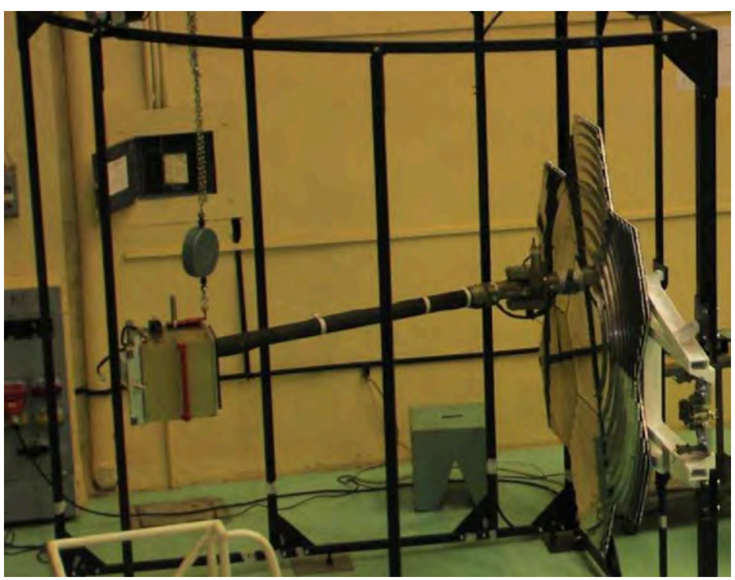
E=200 EeV

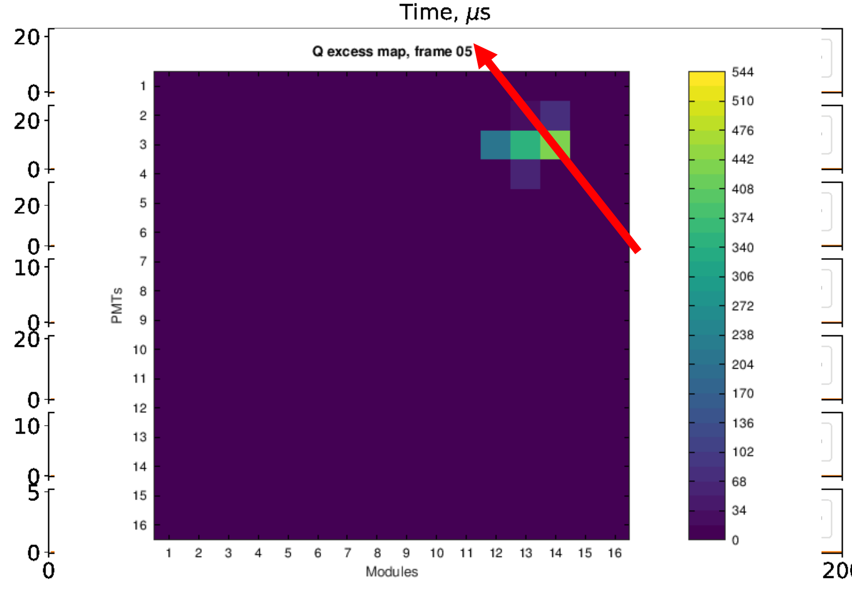
For the TUS detector simulation we use the ESAF – JEM-EUSO simulation code with implemented TUS design.

C. Berat, S. Bottai, D. De Marco et al., *Full simulation of space-based extensive air showers detectors with ESAF*, *Astroparticle Physics* **33** (May, 2010) 221–247

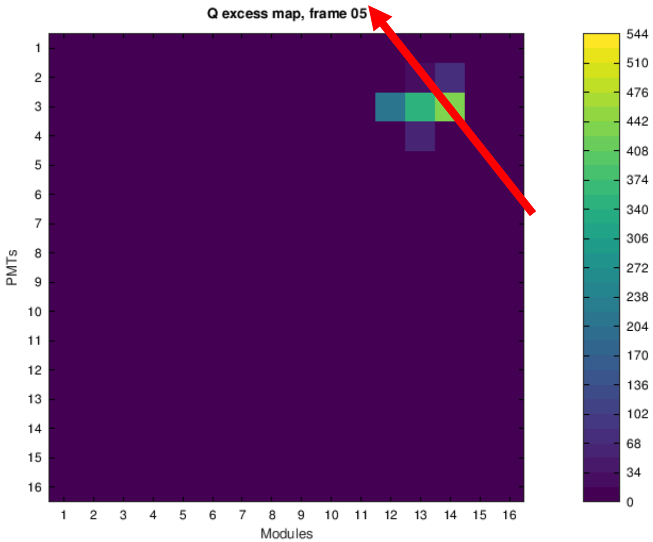
Detector TUS. Example of the EAS-like event (TUS20171003.)







Event kinematics



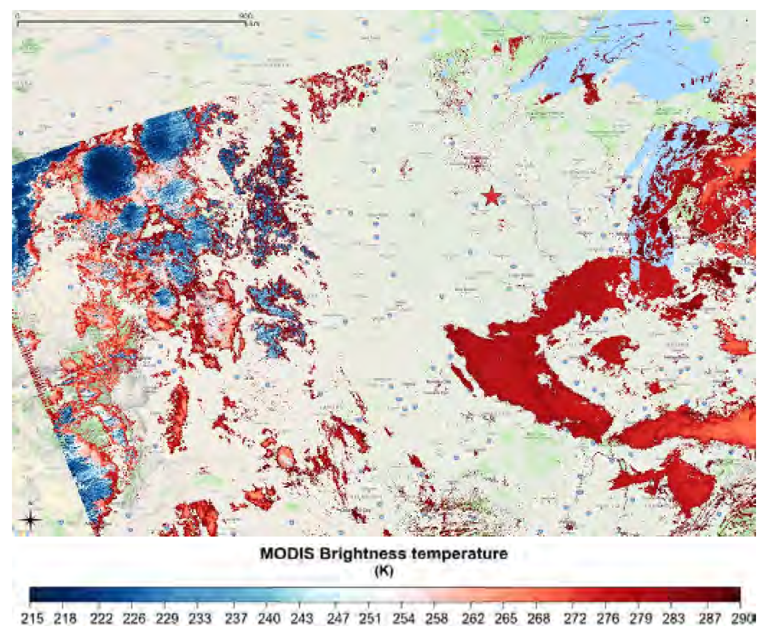
Linear Track Algorithm (LTA)

$$x(t) = x_0 + u_x(t - t_0), \quad y(t) = y_0 + u_y(t - t_0)$$

$$\phi = \arctan(u_x/u_y), \quad \theta = 2\arctan(fRu/c)$$

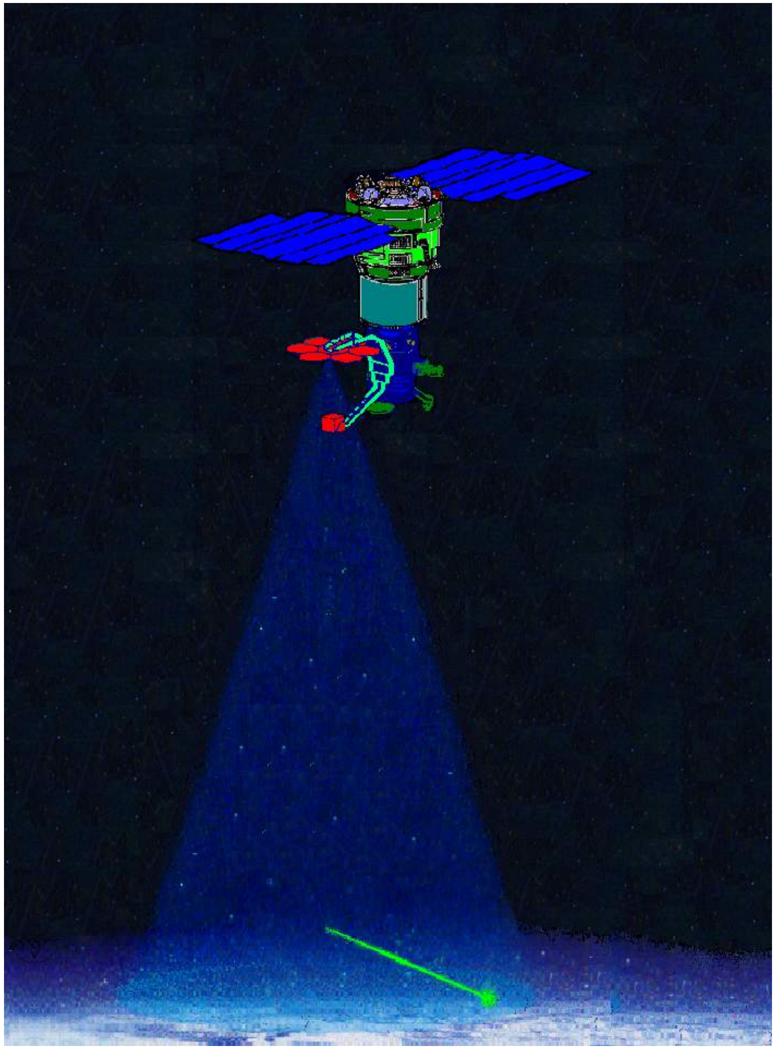
$(\theta, \varphi) \sim (40°, 50°)$

Event observation conditions



Multifunctional orbital detector

1)Measurements of fluorescent EAS radiation UHECR)
2)Measurements of the Cherenkov radiation of EAS (direct, diffuse and reflected)
3)Registration of large-scale fluorescent emission of the atmosphere from gamma radiation fluxes (GRB)
4)UV tracks of meteors, space debris, relativistic dust particles, etc.
5)Measurements of atmospheric transient phenomena
6)Anthropogenic Glow Monitoring
7)etc…



Transient luminous events measurements

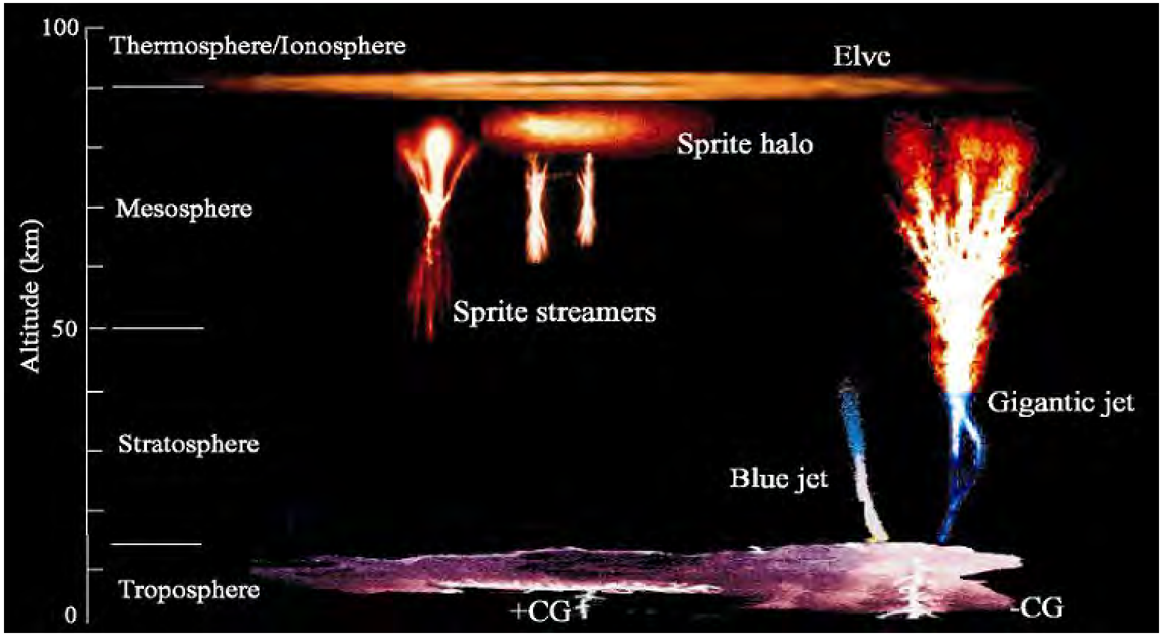


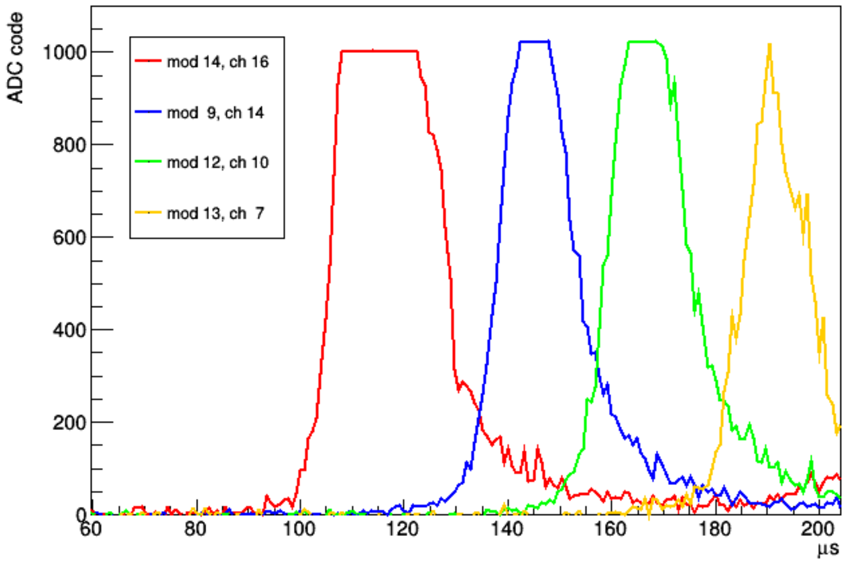
Image via Martin Popek

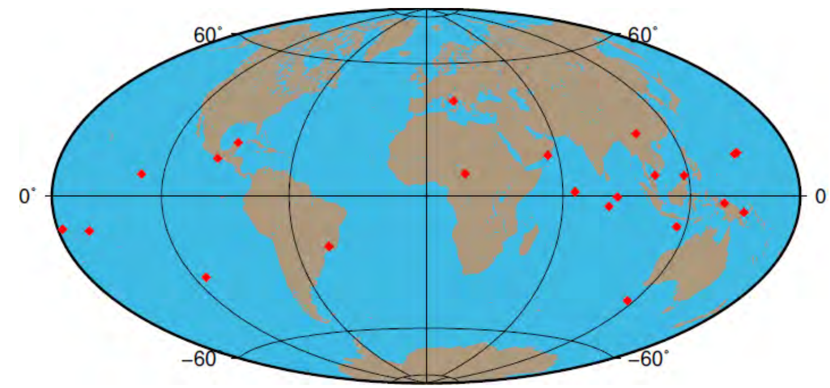
ELVEs

<u>E</u>mission of <u>L</u>ight and <u>V</u>ery Low Frequency perturbations due to <u>E</u>lectromagnetic Pulse

Altitude: 90-100 km
Duration: < 1 ms

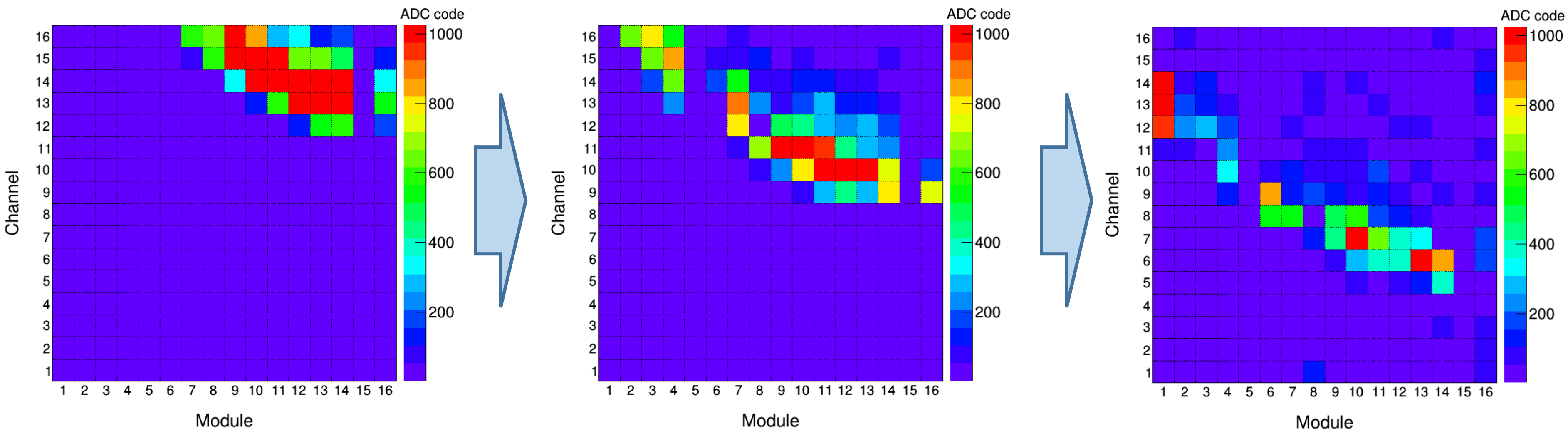
ELVEs measurements by TUS detector





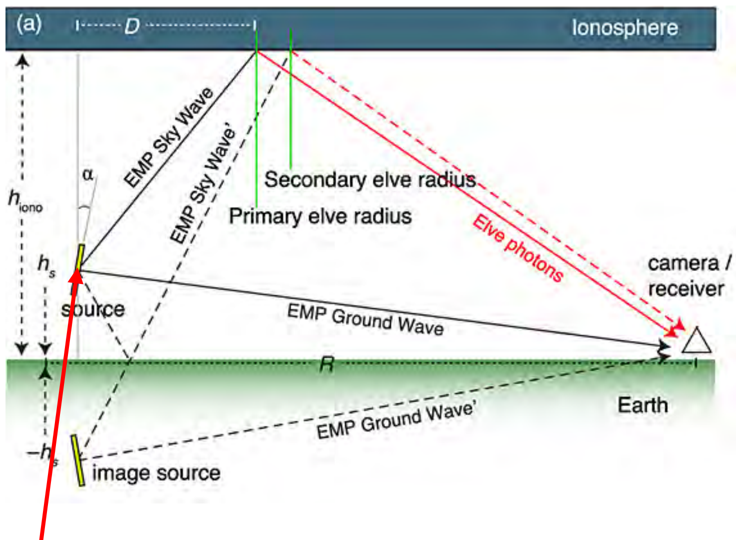
Geographical distribution of ELVES detected by TUS

An example of ELVE measurement 23.08.2017 07:47:47 UTC



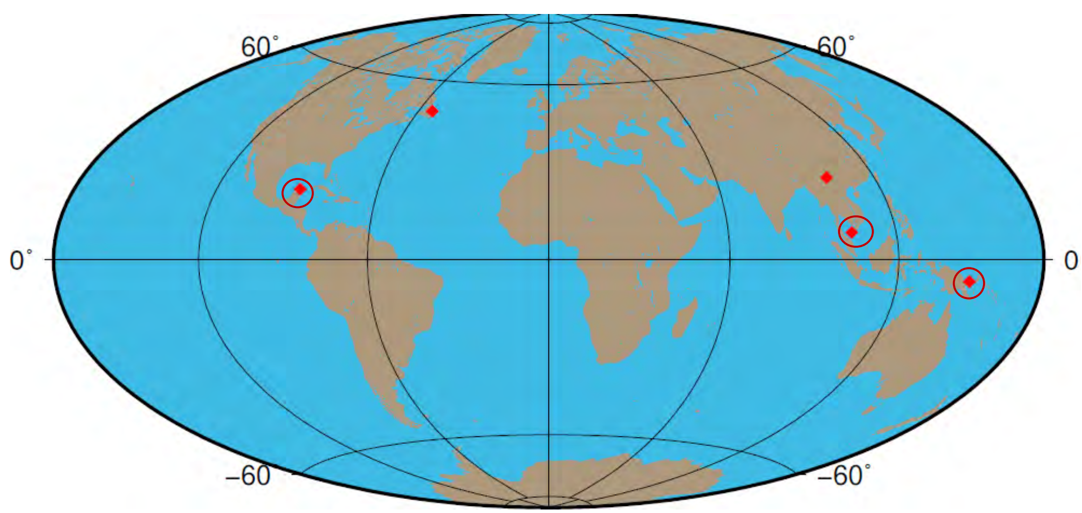
136 μs 168 μs 200 μs

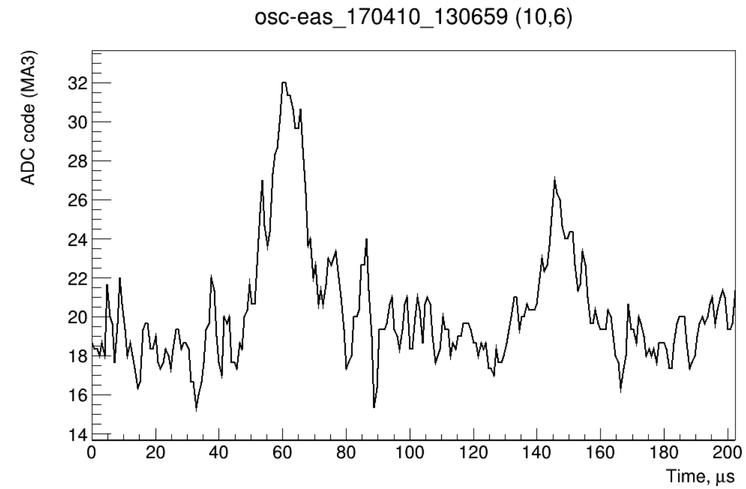
ELVE doublets

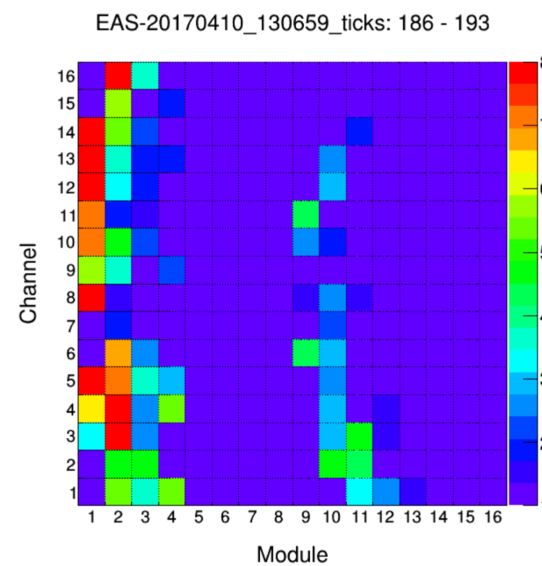


Compact Intracloud Discharge (CID)

[Marshall, Silva, Pasko, GRL, 2015]

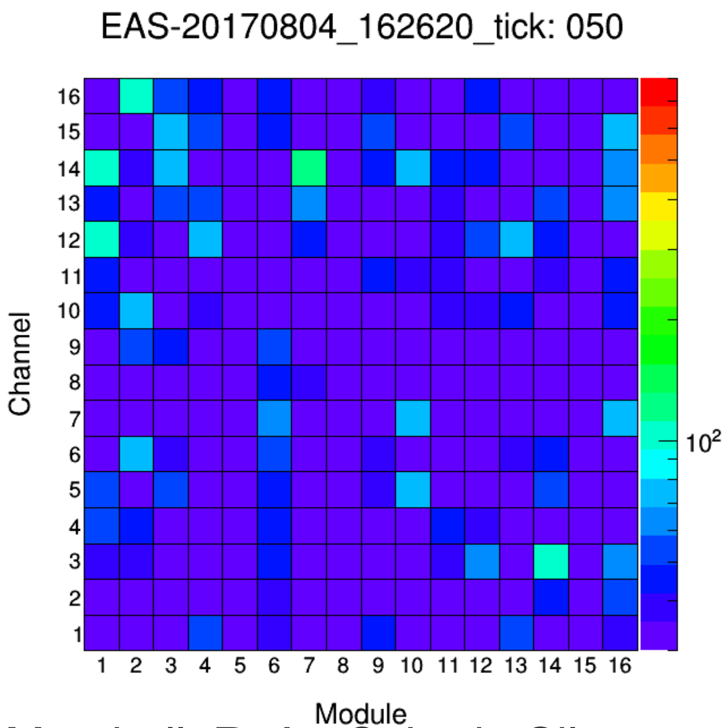


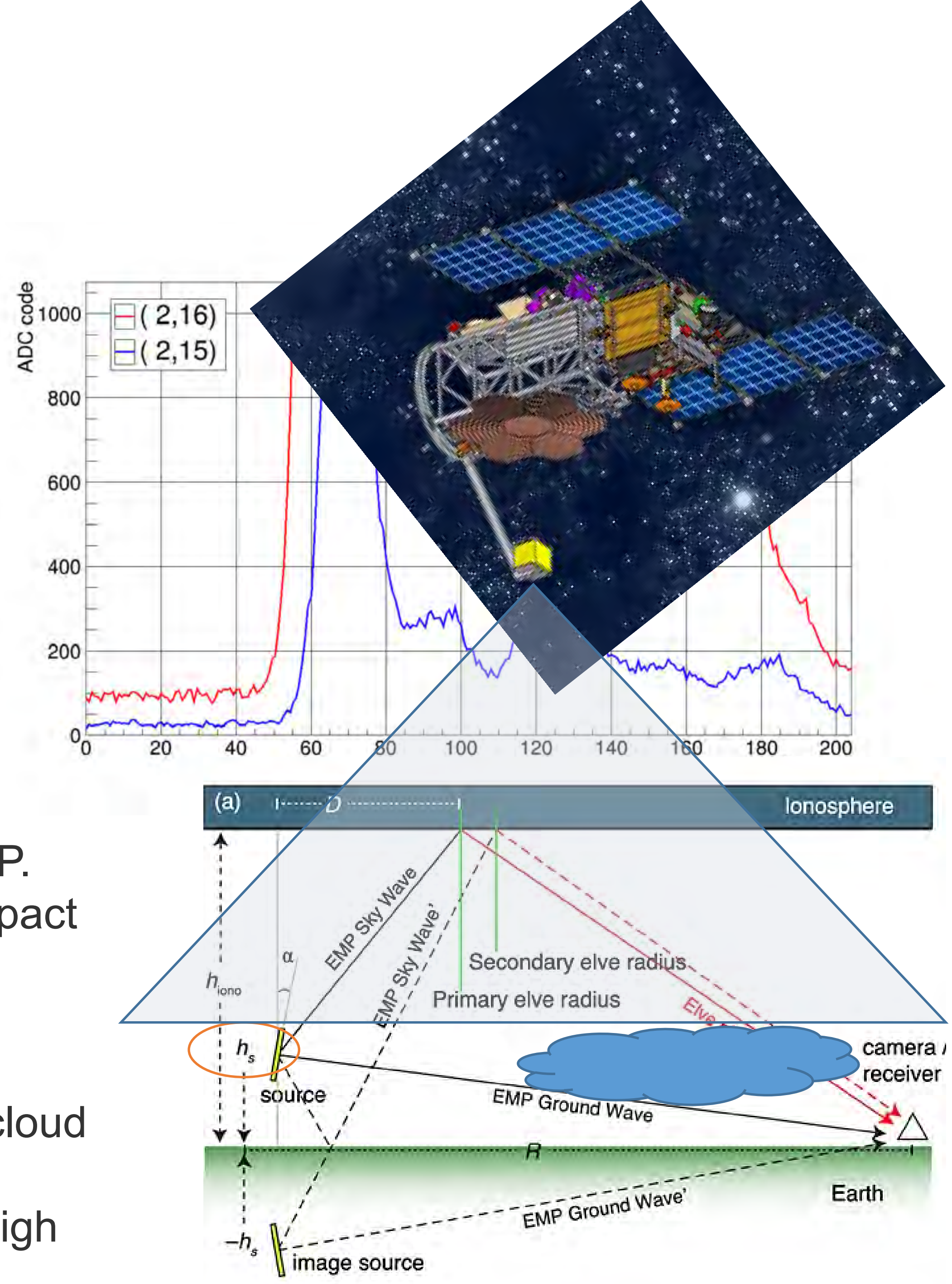




An example of ELVE doublet measurement 10.04.2017 13:06:59 UTC

Multiple elves

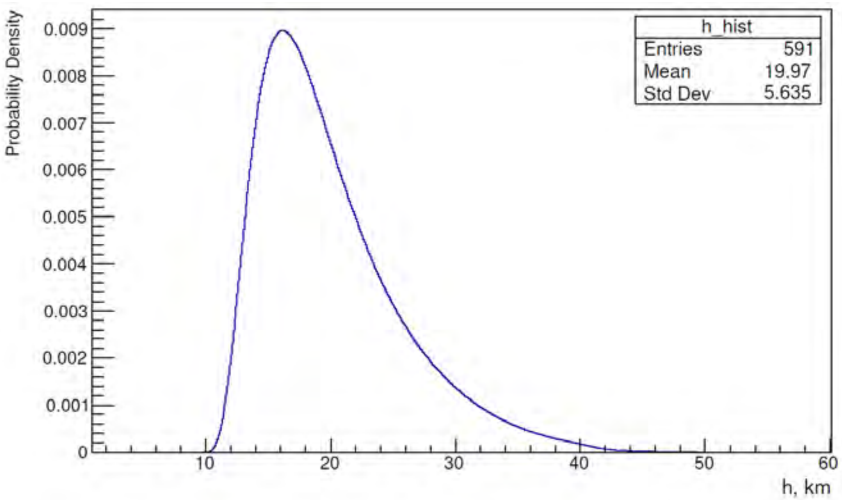




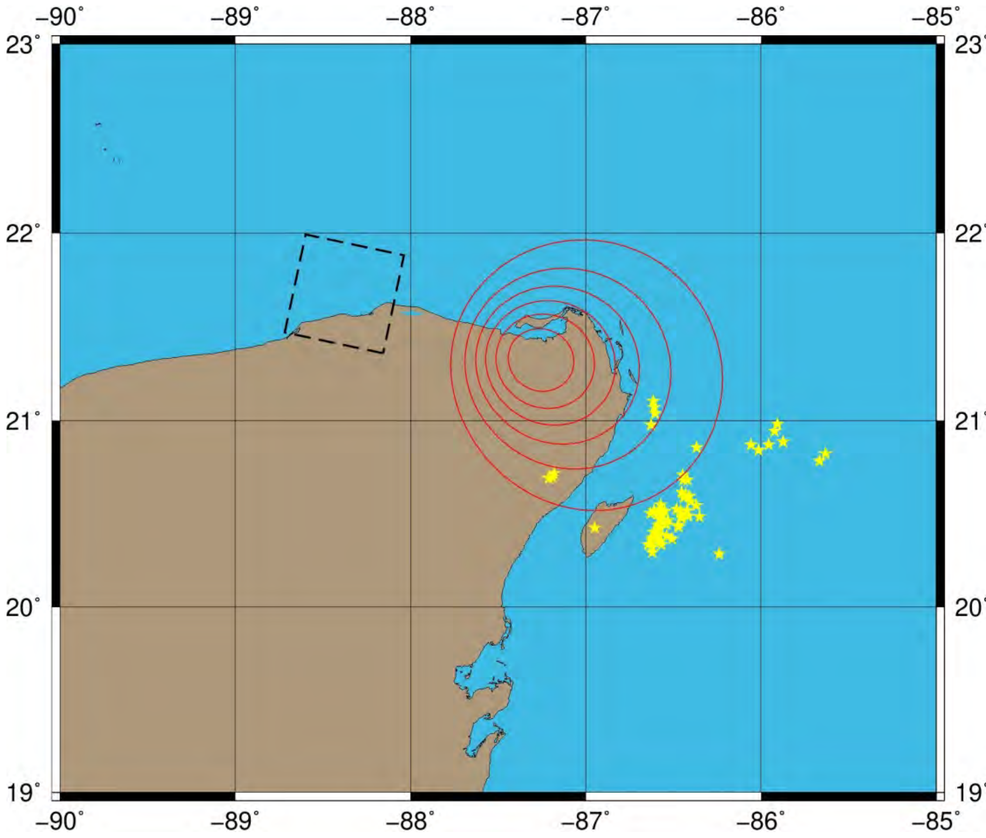
Marshall, R. A., C. L. da Silva, and V. P. Pasko (2015), Elve doublets and compact intracloud discharges, Geophys. Res. Lett., 42

Estimation of height of intensive intracloud discharges can be made using measurements of ring structure with high temporal resolution.

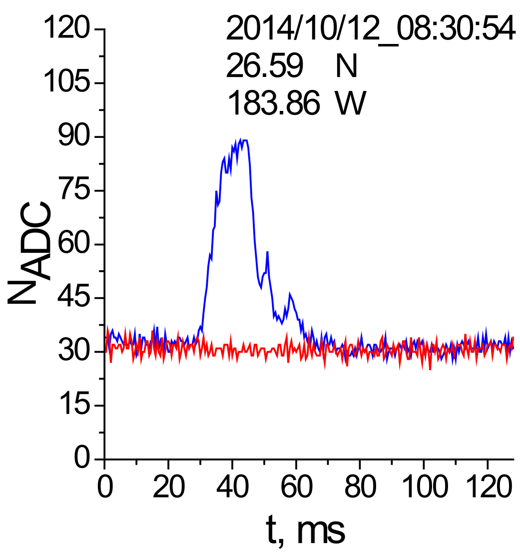
ELVE doublet 22.08.2017 05:03:24 UTC
Results of EMP location reconstruction

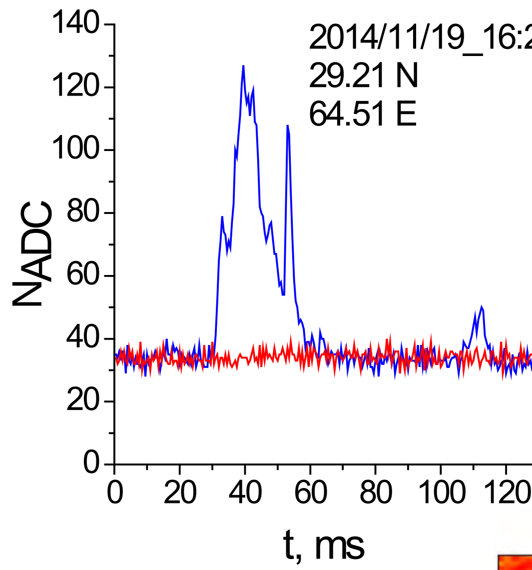


$h = 20.0 \pm 5.6\ km$

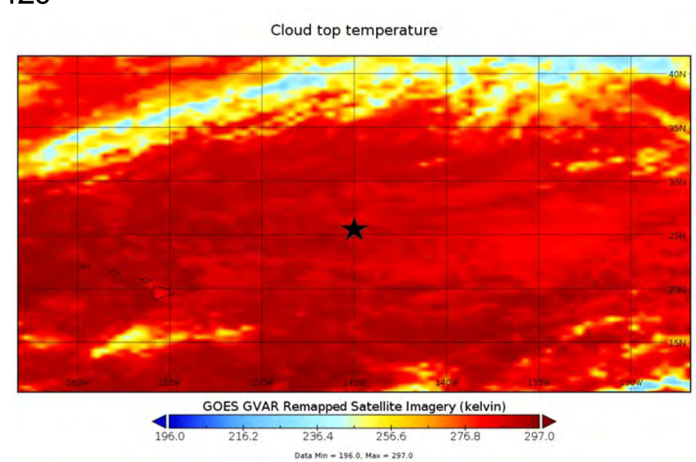


Unusual far-from-thunderstorm flashes. Example of Vernov satellite data



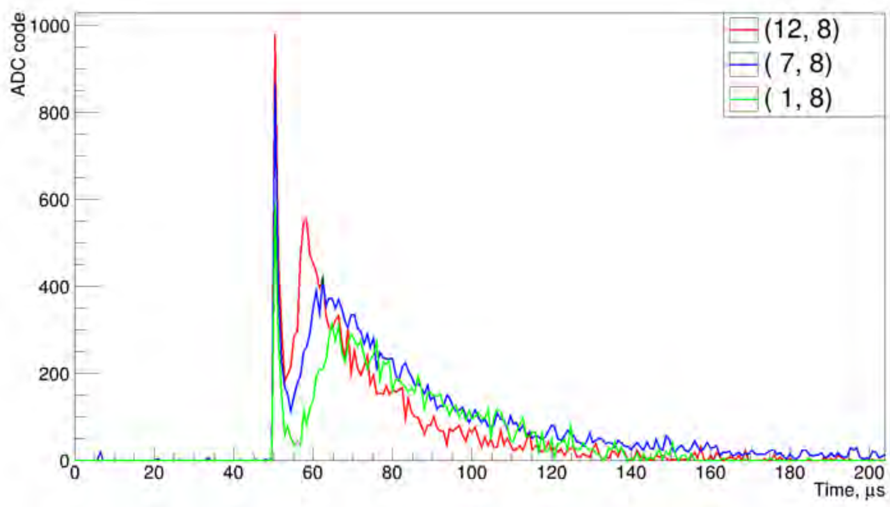


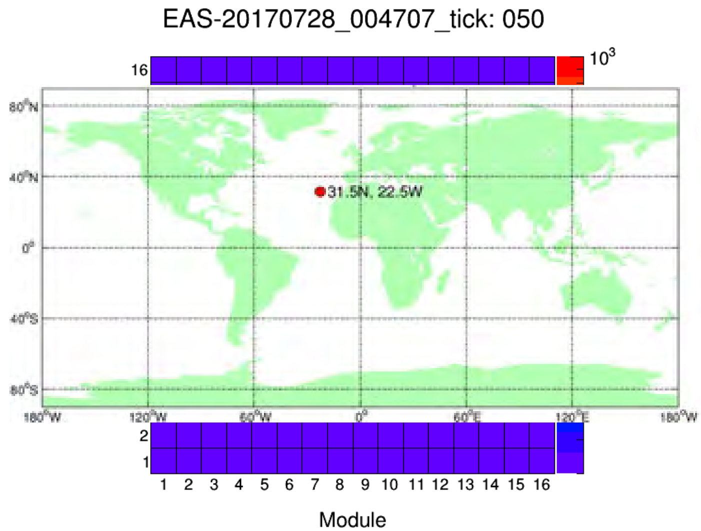
- ✓ No lightning activity according to the data of two ground based lightning networks (WWLLN and Vaisala GLD360) in a large region of ~10^6 km^2 during a 30~min period before and after the registration moment.
- ✓ Study of cloud coverage exclude the possibility of lightning and thunderstorm in the FOV of the detector.

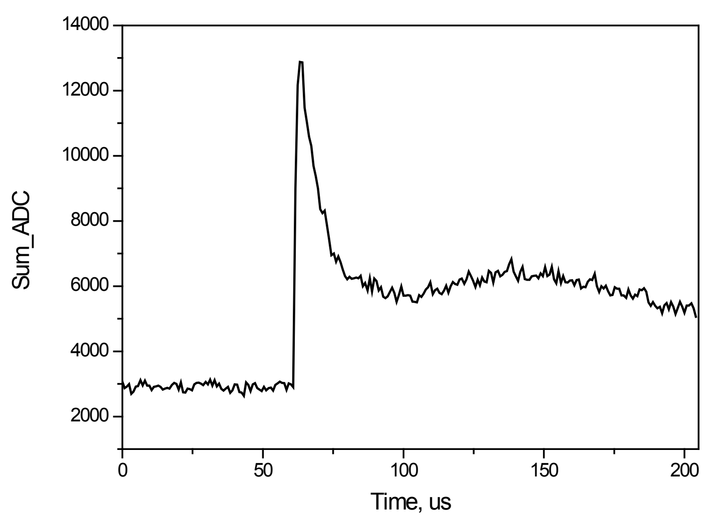


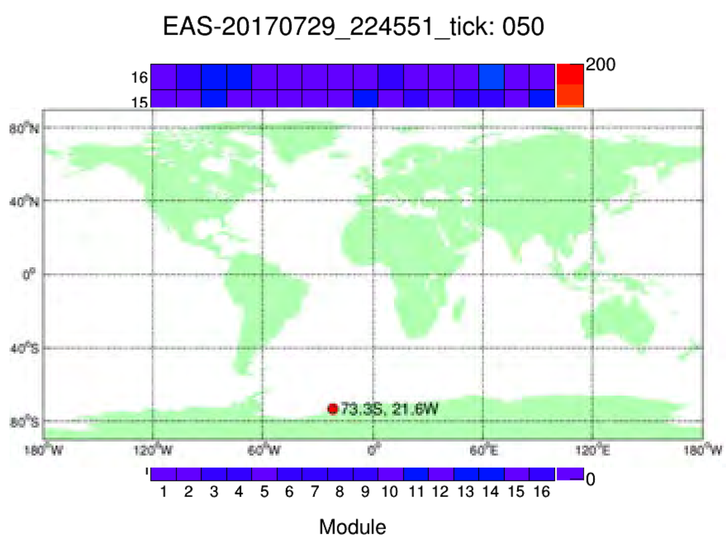
P. A. Klimov *et al.*, "UV Transient Atmospheric Events Observed Far From Thunderstorms by the Vernov Satellite," in *IEEE Geoscience and Remote Sensing Letters*, vol. 15, no. 8, pp. 1139-1143, Aug. 2018.

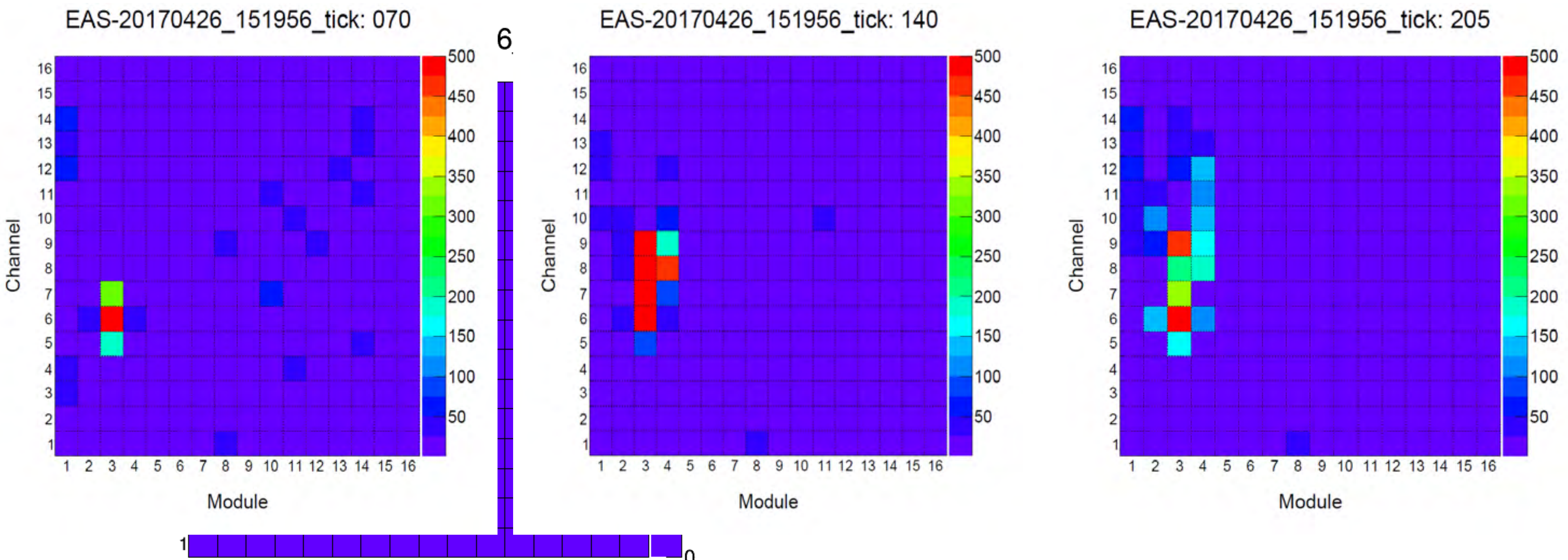
Unusual clear sky flashes
(examples of TUS data)



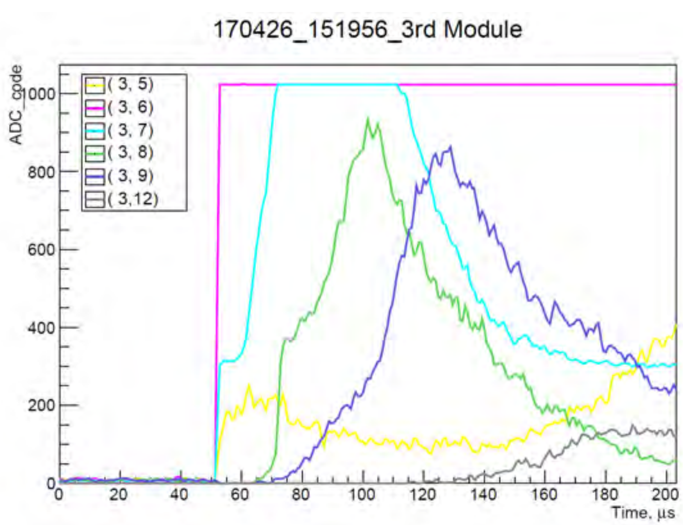


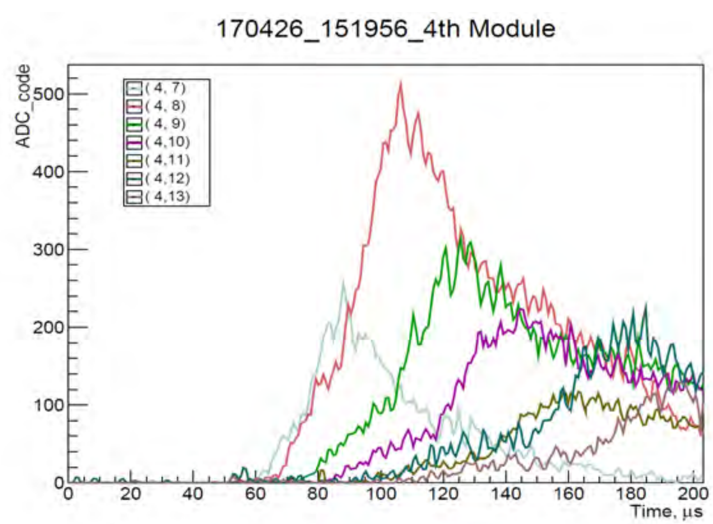




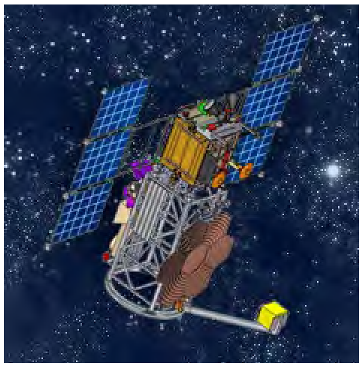


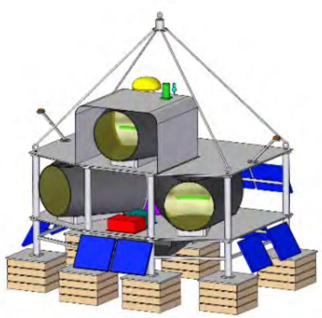
Bright object moving the speed of light in clear sky conditions after the initial flash.



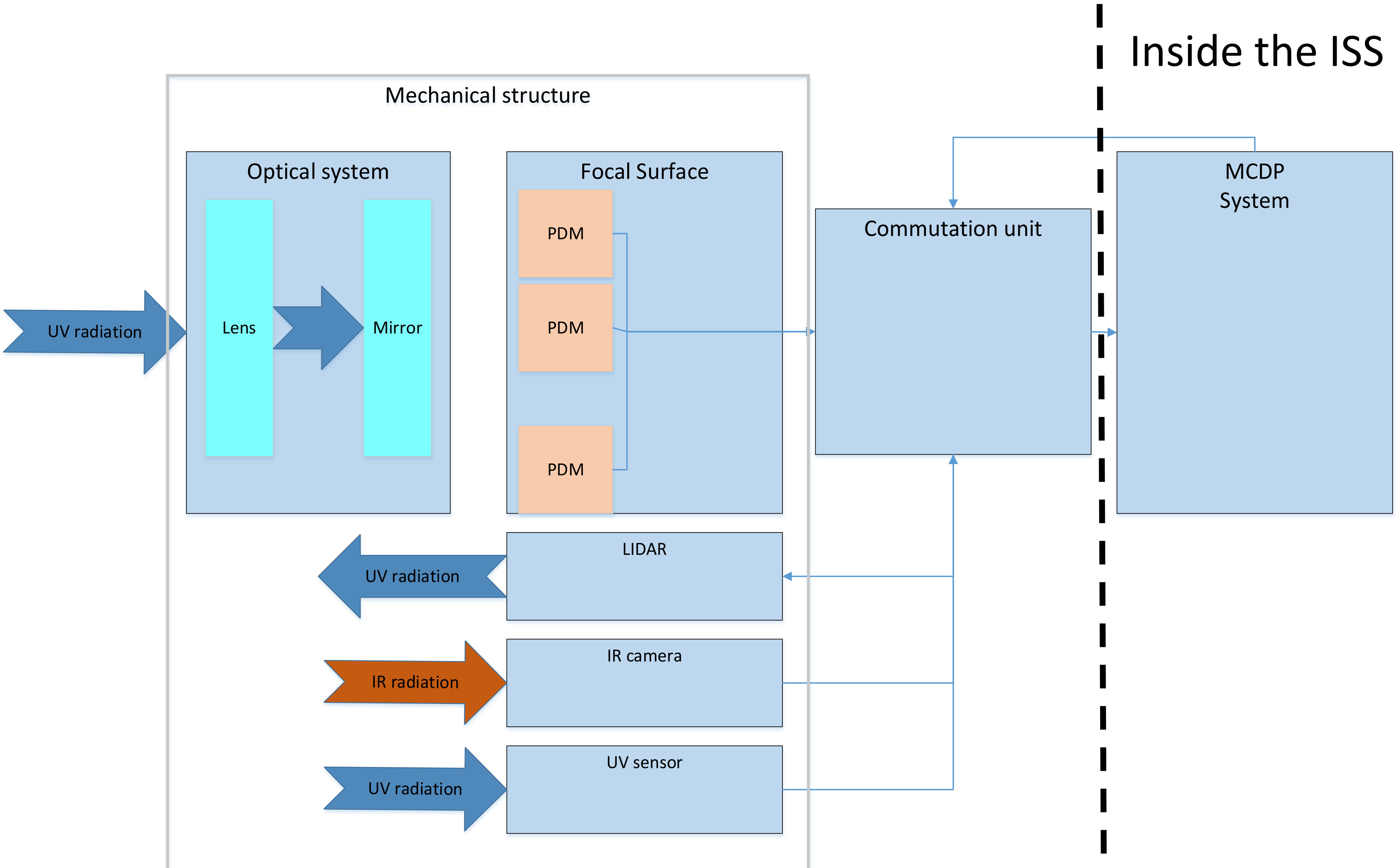


KLYPVE (K-EUSO) is a next step of UHECR measurements from space





K-EUSO simplified block-scheme

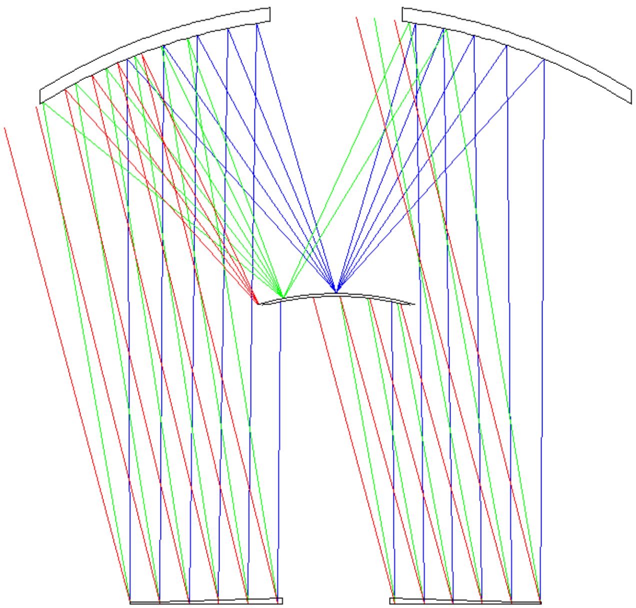


Two versions of K-EUSO

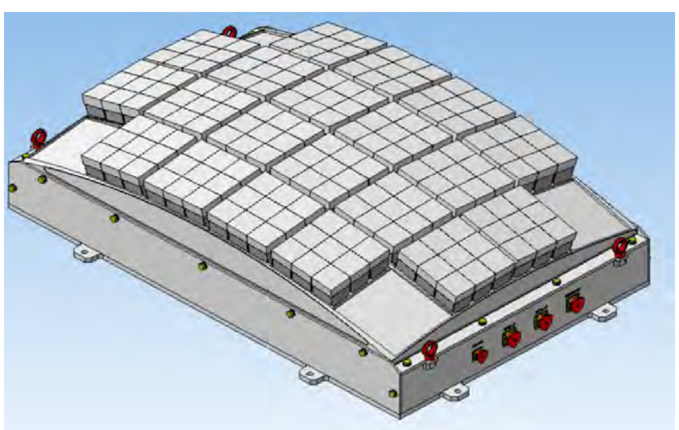
Parameter	Variant		Note
	A	B	
Mass, kg	~500	880	Total mass of the whole equipment
Dimensions, mm	∅ 3600x3700	∅ 4000x3700	Main part of the telescope
Wavelength, mn	300-400	300-400	
Assembling	EVA	Automatical	
Transprotation	Progress	Dragon	

Variant A – option according to the technical requirements with delivery in a modular form on Progress cargo
Variant Б – perspective variant with improved scientific and technical characteristics

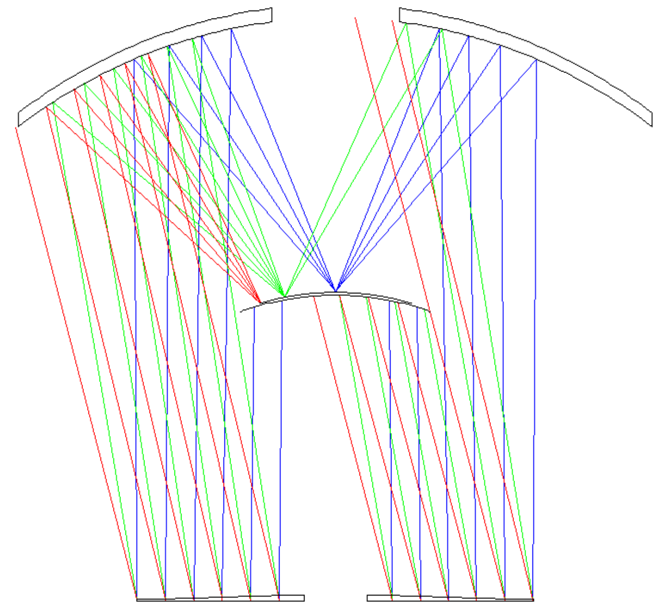
Variant A



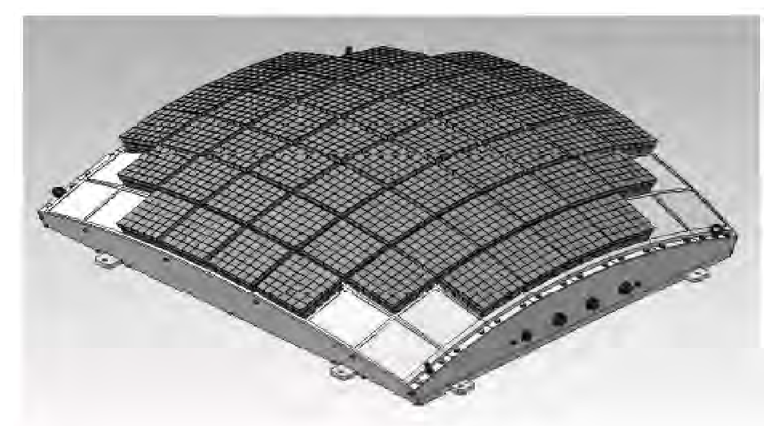
$D_{mirr} = 3{,}6$ m, $\Omega_0 = 0.15$ sr



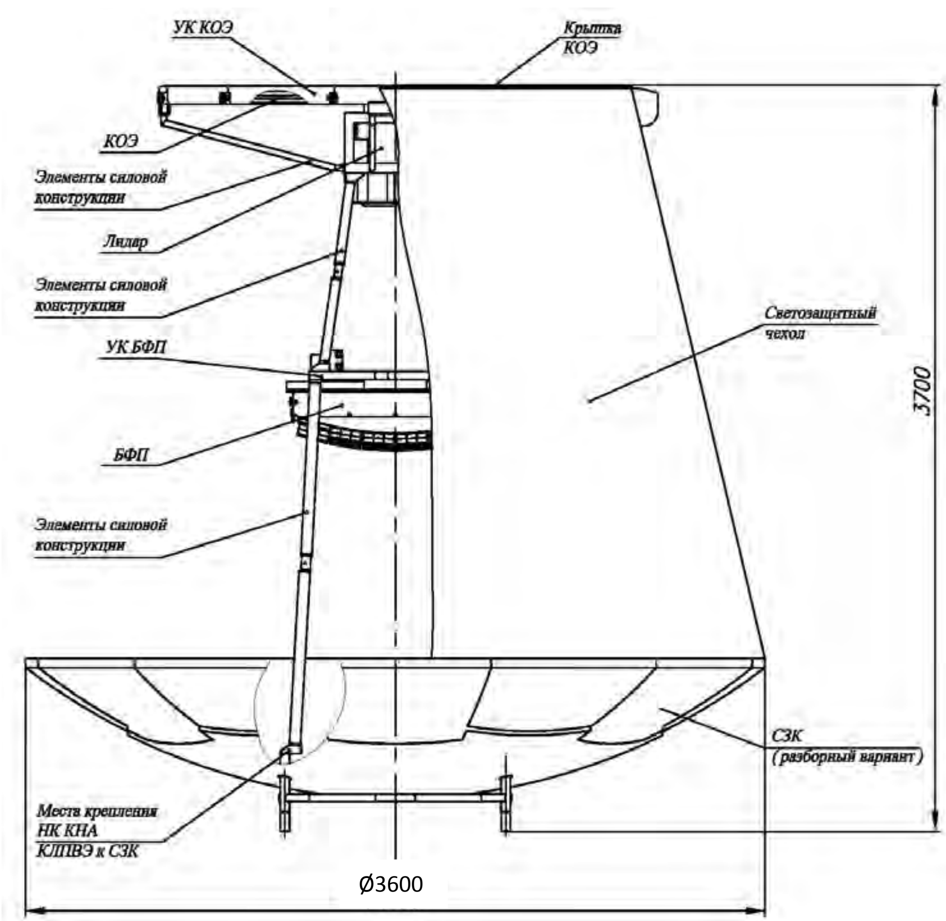
Variant B



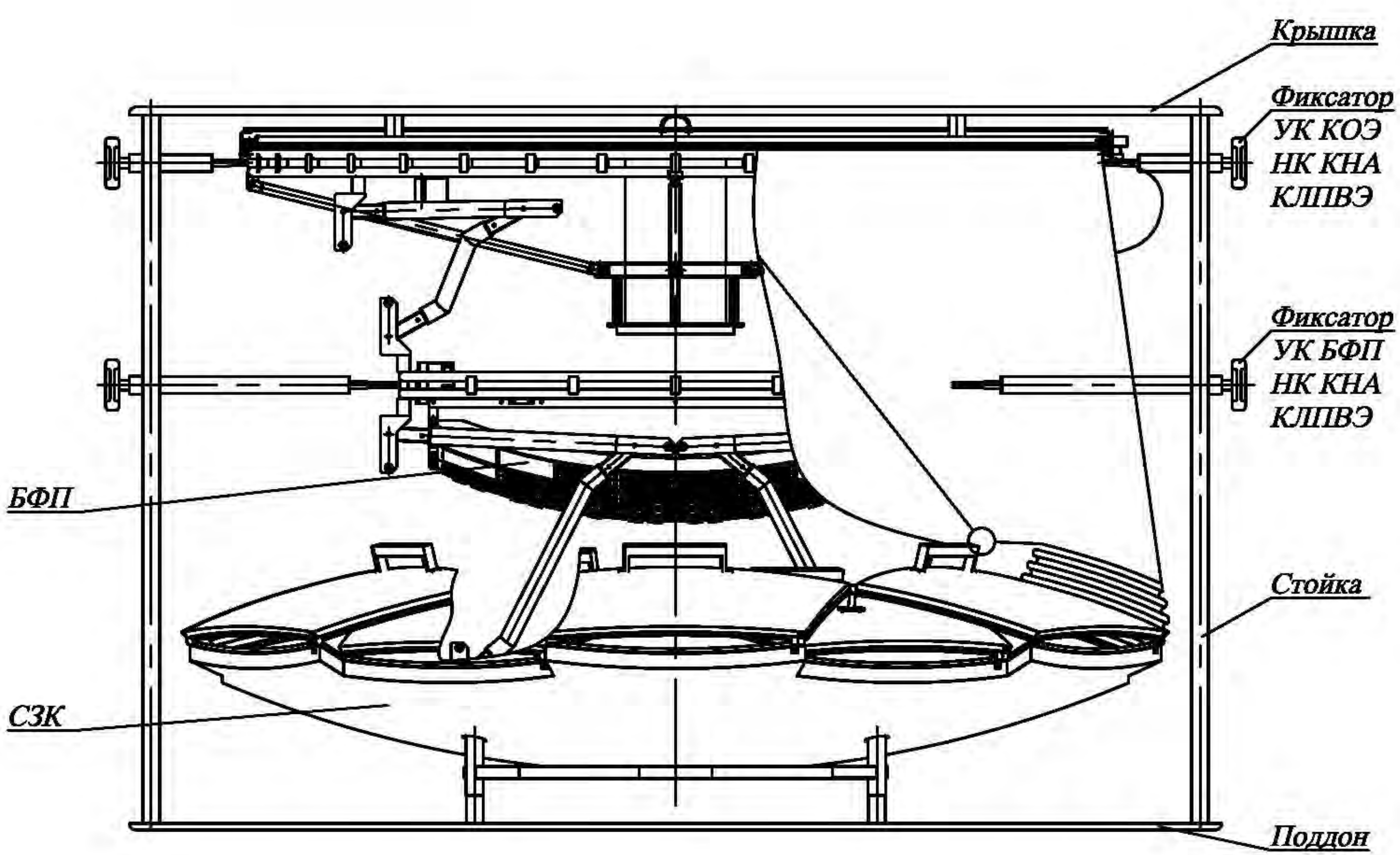
$D_{mirr} = 4$ m, $\Omega_0 = 0.38$ sr

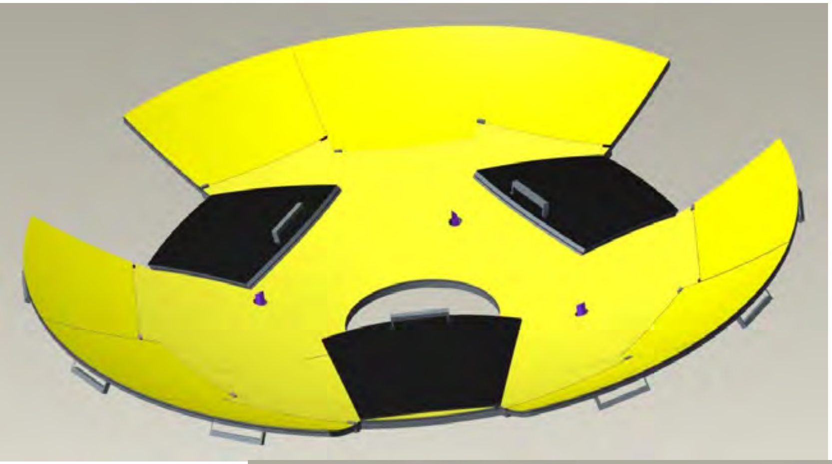


K-EUSO. Variant A

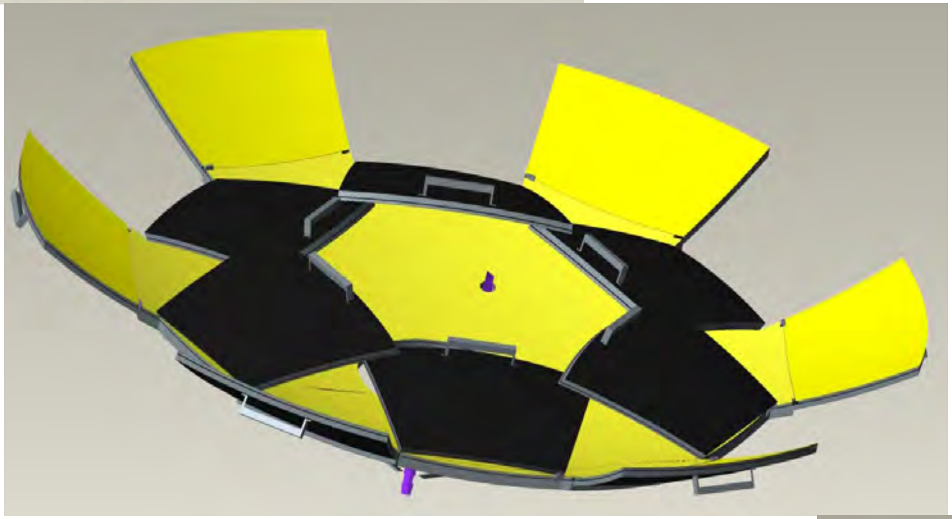


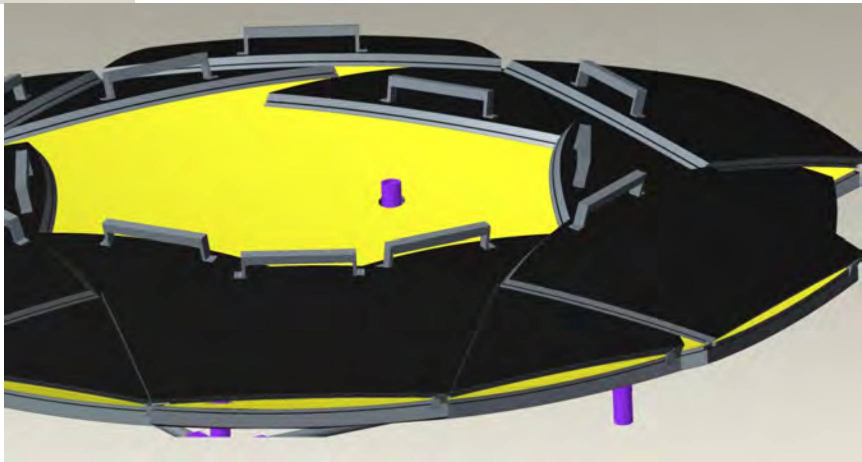
K-EUSO. Variant B (during transportation)



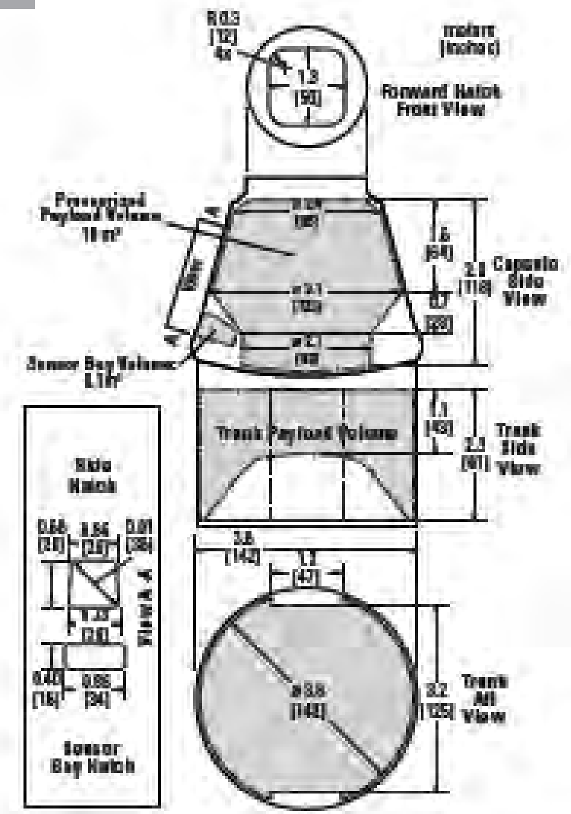


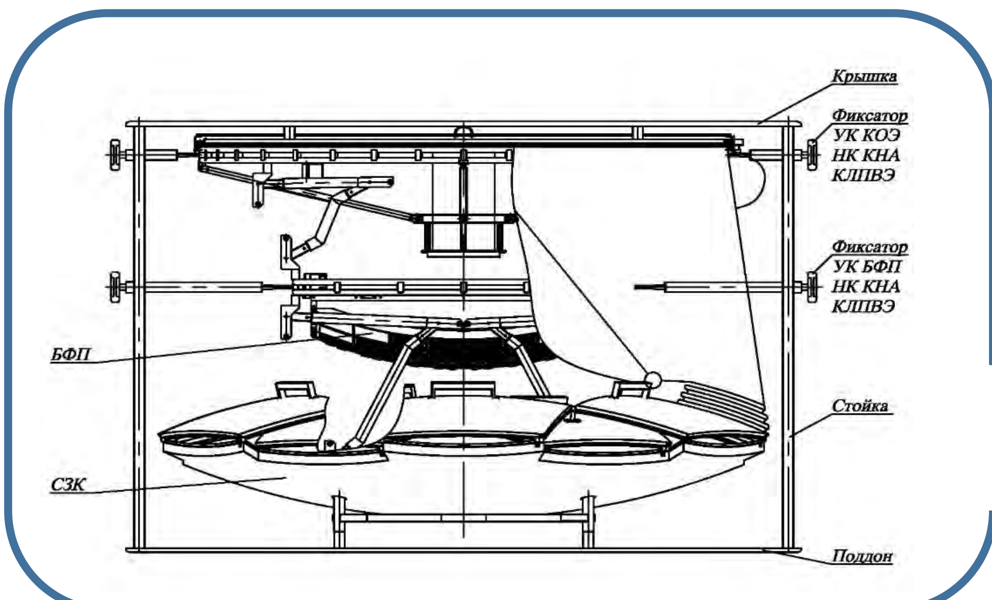
Mirror for the variant B



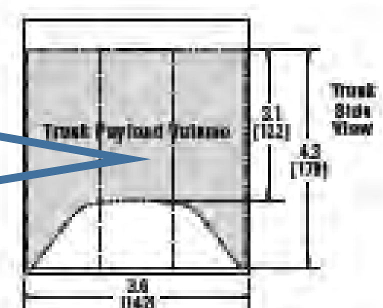


DragonLab™
Fast track to flight.





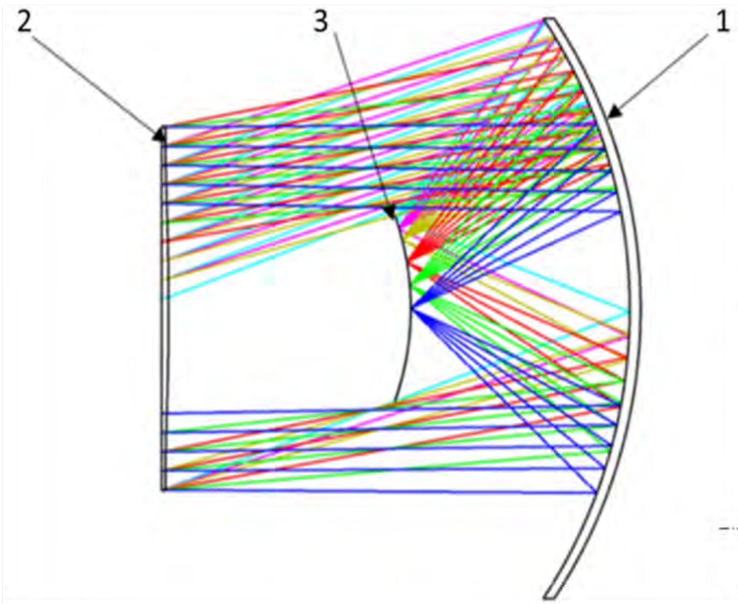
OPTIONAL TRUNK EXTENSION

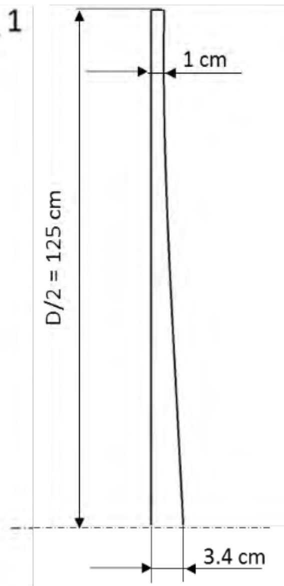


Masses and dimensions in variant A

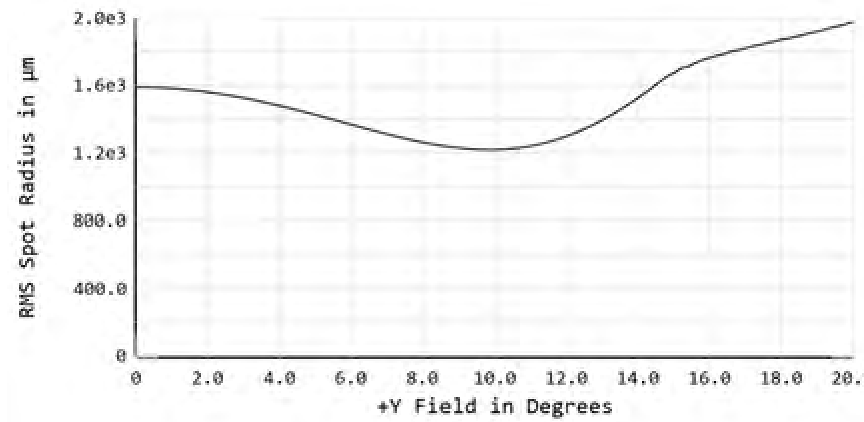
№	Наименование	Dimensions, mm	Mass, kg	Пояснение
1	Mirror		110	вне ГО
	Diameter	3600		
	Radius of curvature	3450		
	Dimensions in operation mode Dimensions in transportation mode	∅ 3600x825 Less 1200x700		With mirror frame
2	Commutation unit	225x260x70	3.3	вне ГО
3	Photo detector	1180x780x300	112	вне ГО
4	LIDAR	450x350x250	17	вне ГО
5	IR camera	130x350x250	15	вне ГО
6	MCDP system	400x330x150	10	ГО
7	Mechanics	In operation mode 3600x3600x3700	130	вне ГО
8	UV sensor	200x200x300	10	вне ГО
9	Lens	2500x50	100	
	Итого:		507,3	

K-EUSO optical system





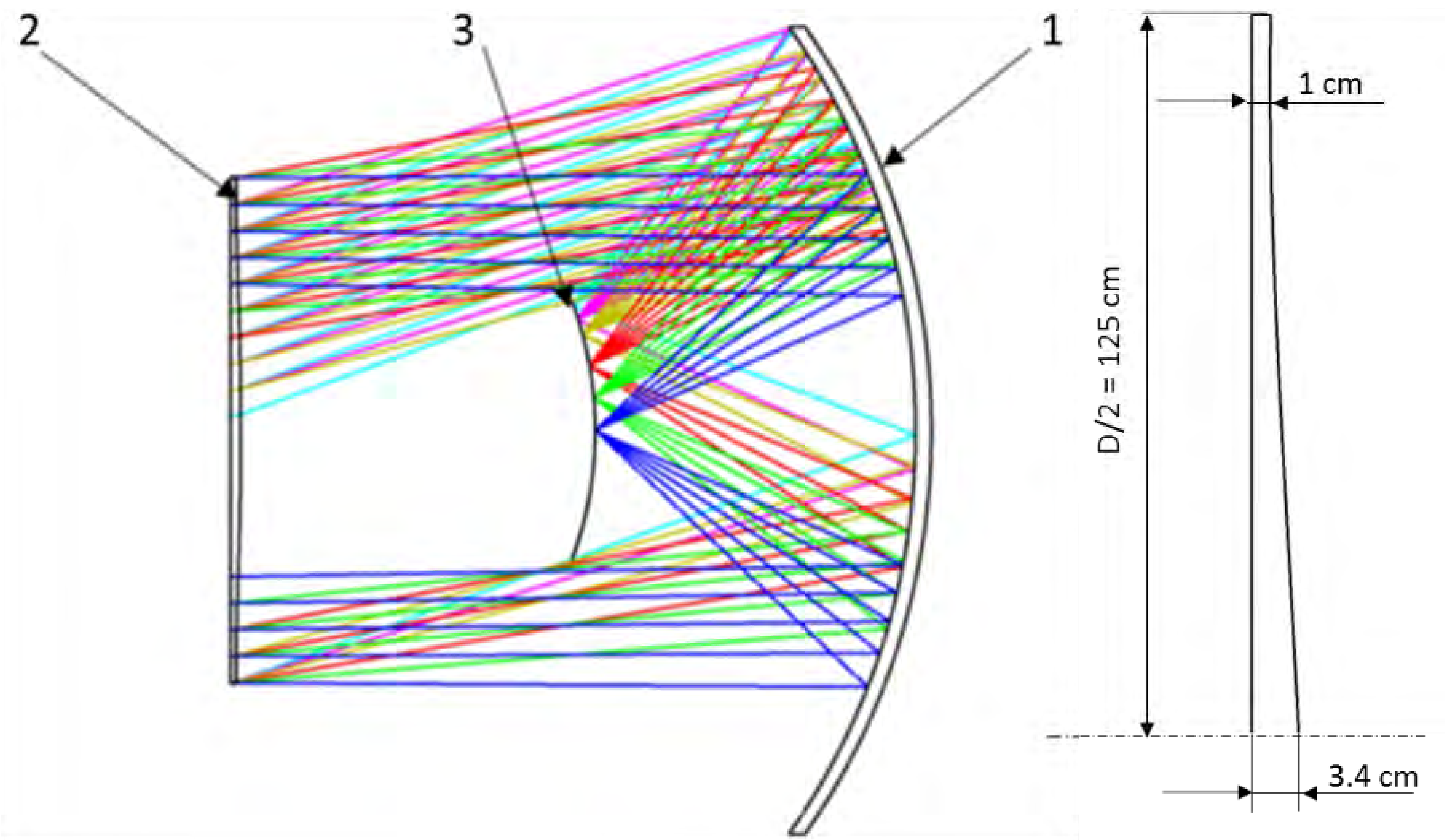
System characteristics obtained as a result of optimization of the parameters of the optical system.



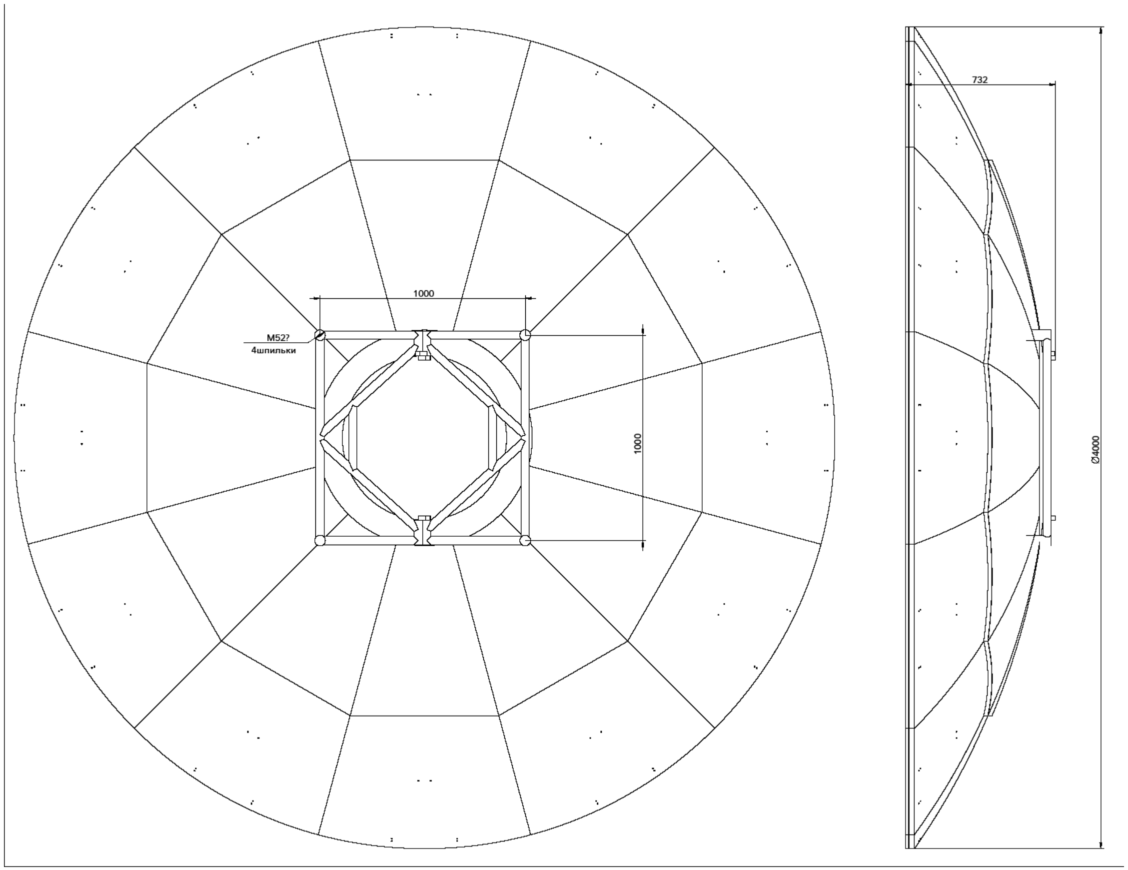
Parameter	Value, cm
Entrance Pupil Diameter	250
Mirror diameter	400
Radius curvature of mirror	345
Radius curvature of FS	180
Axial length	342.6
Distance from M to FS	161.5

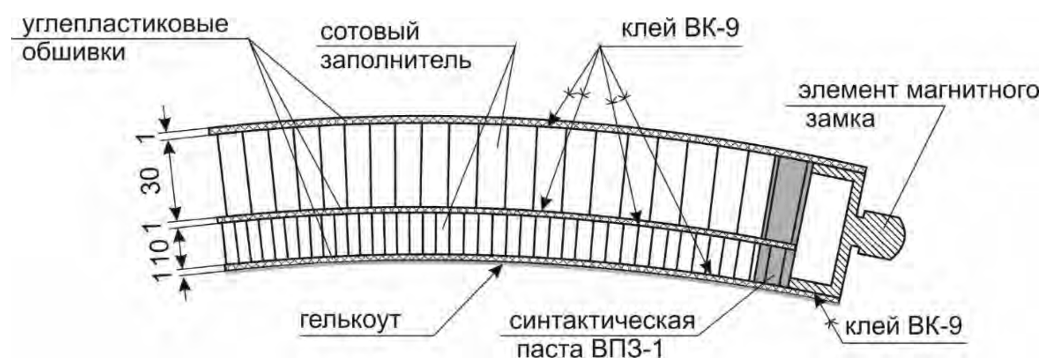
Field angle	**0˚**	**5˚**	**10˚**	**15˚**	**20˚**
Energy fraction	**0,74**	**0,92**	**0,89**	**0,75**	**0,55**

Reliability and quality of the OS is largely determined by the complexity of the elements

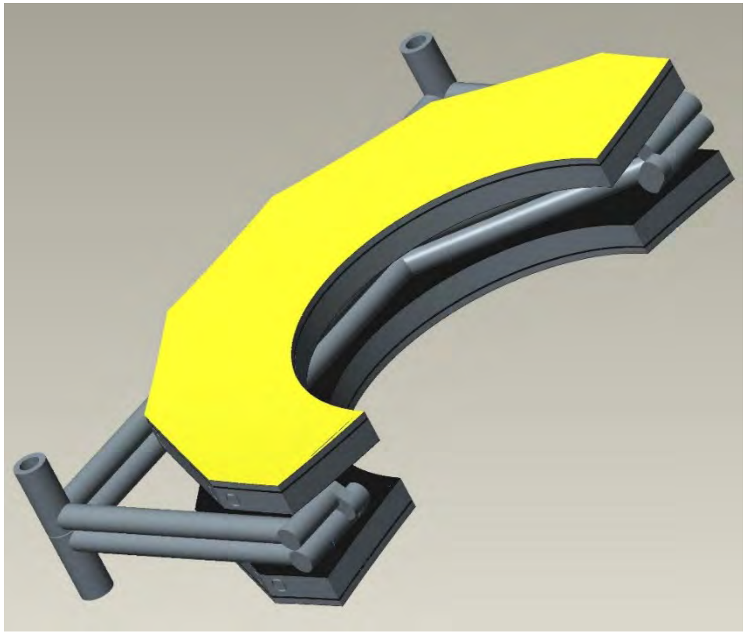


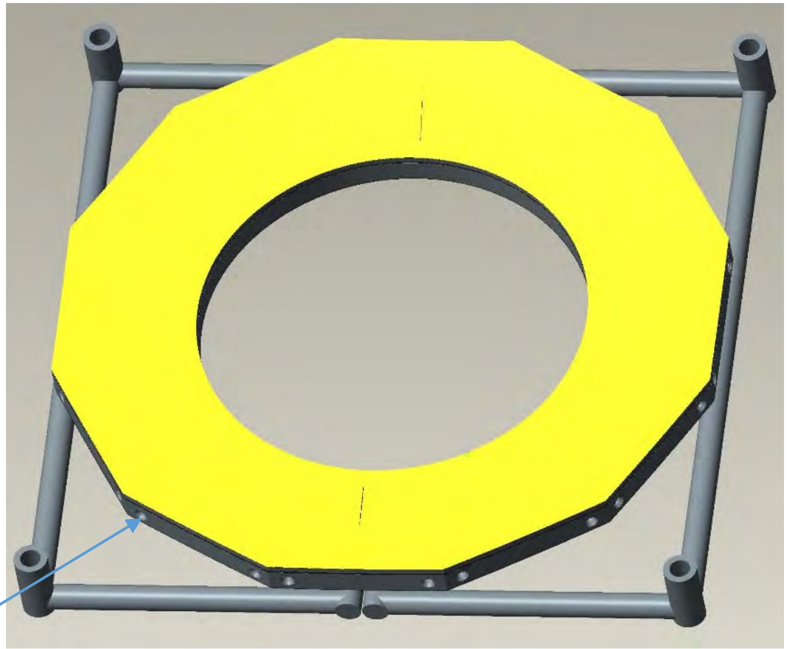
K-EUSO mirror



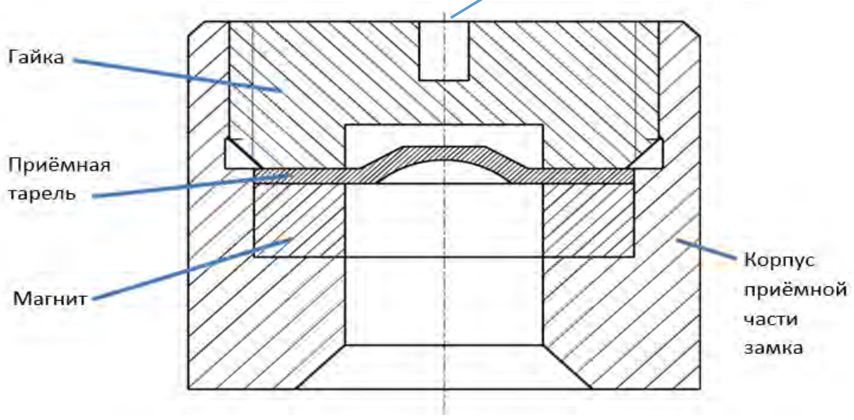


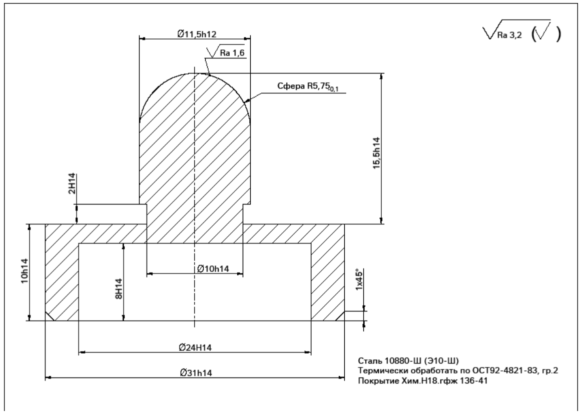
Central part of the mirror

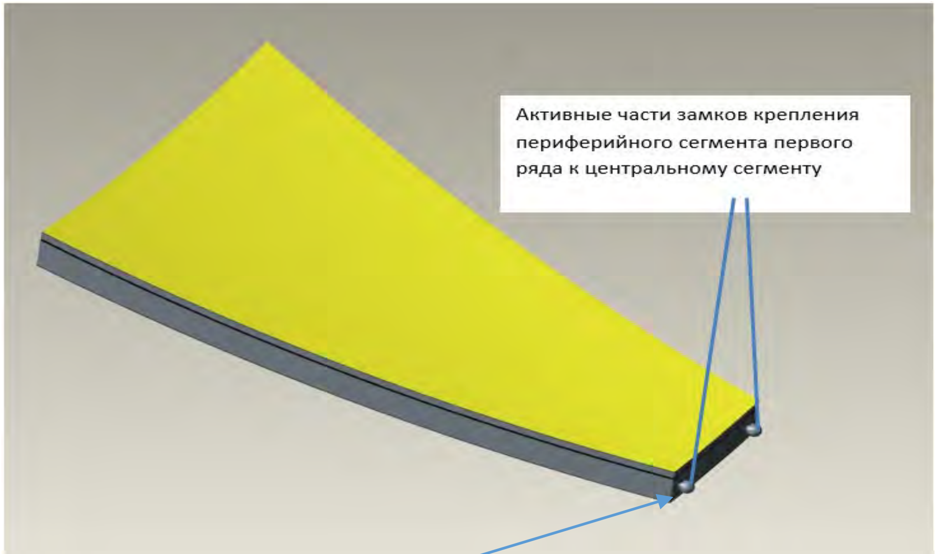


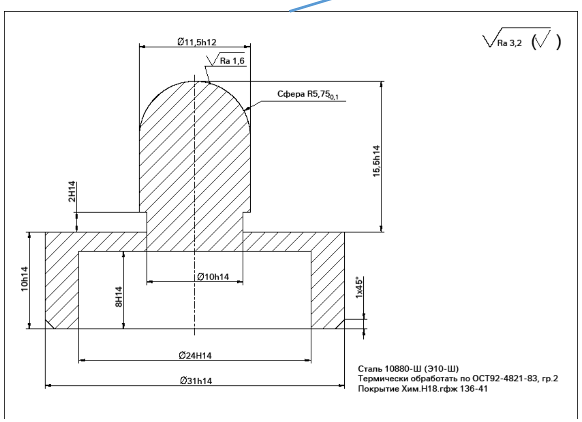


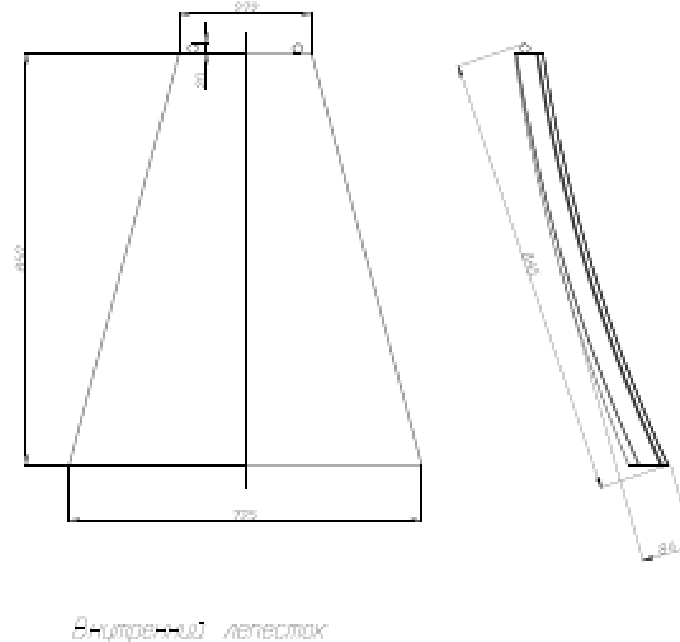
Magnetic lock

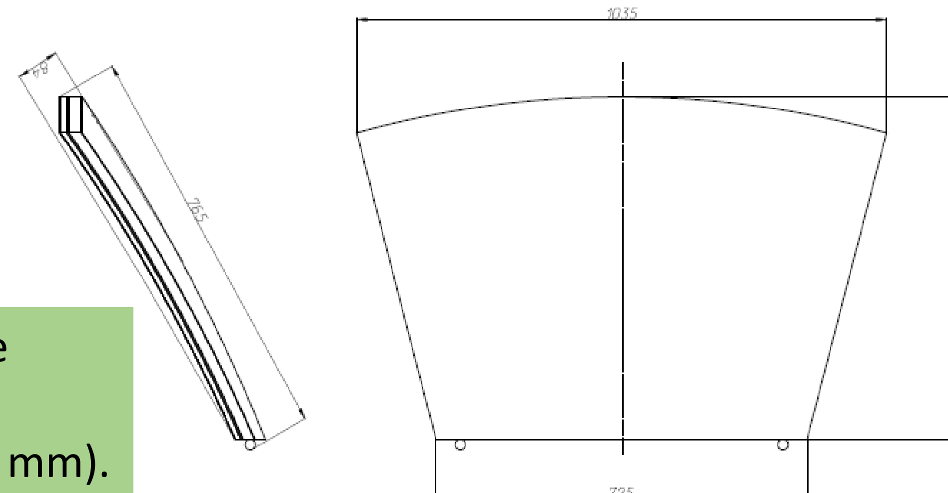






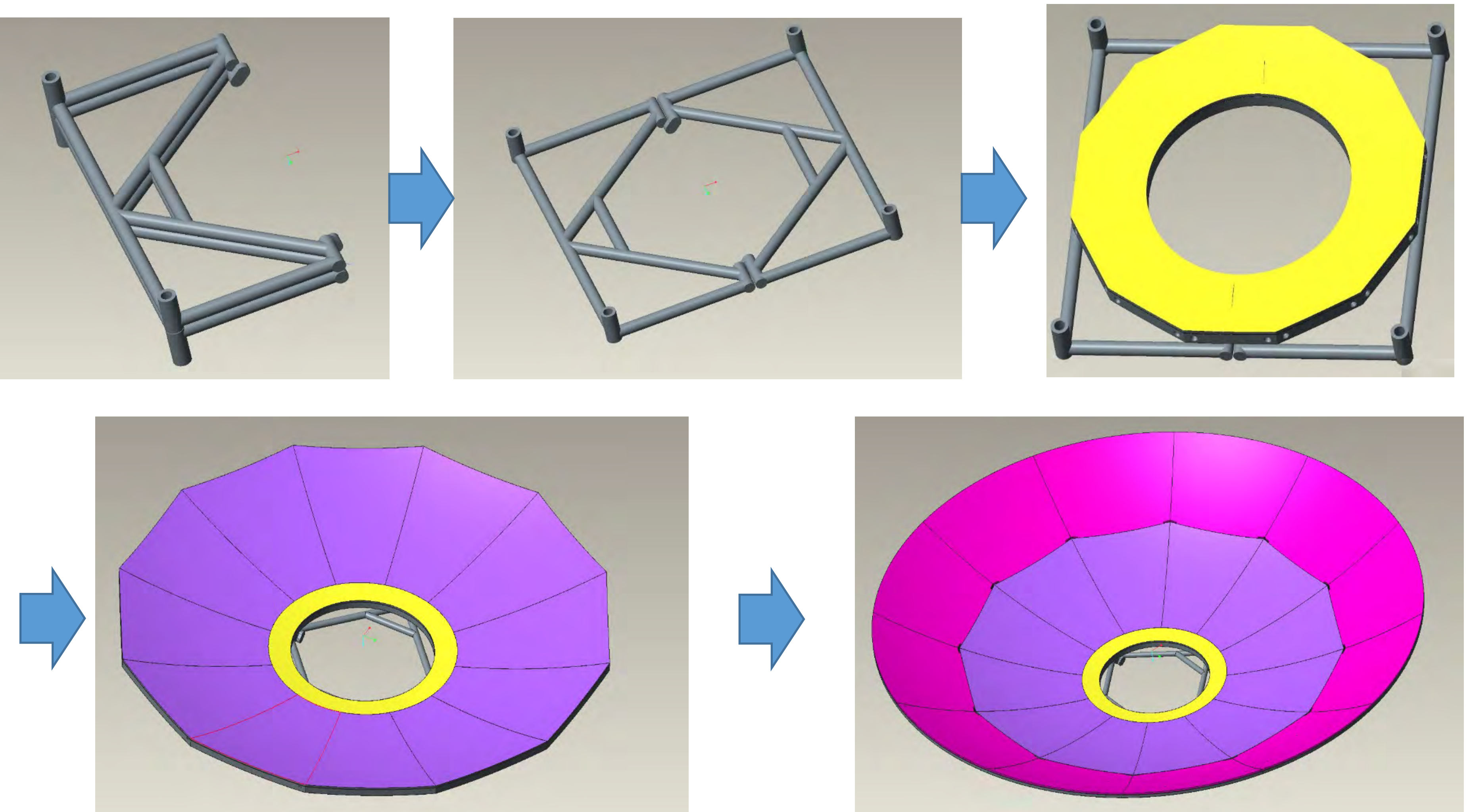




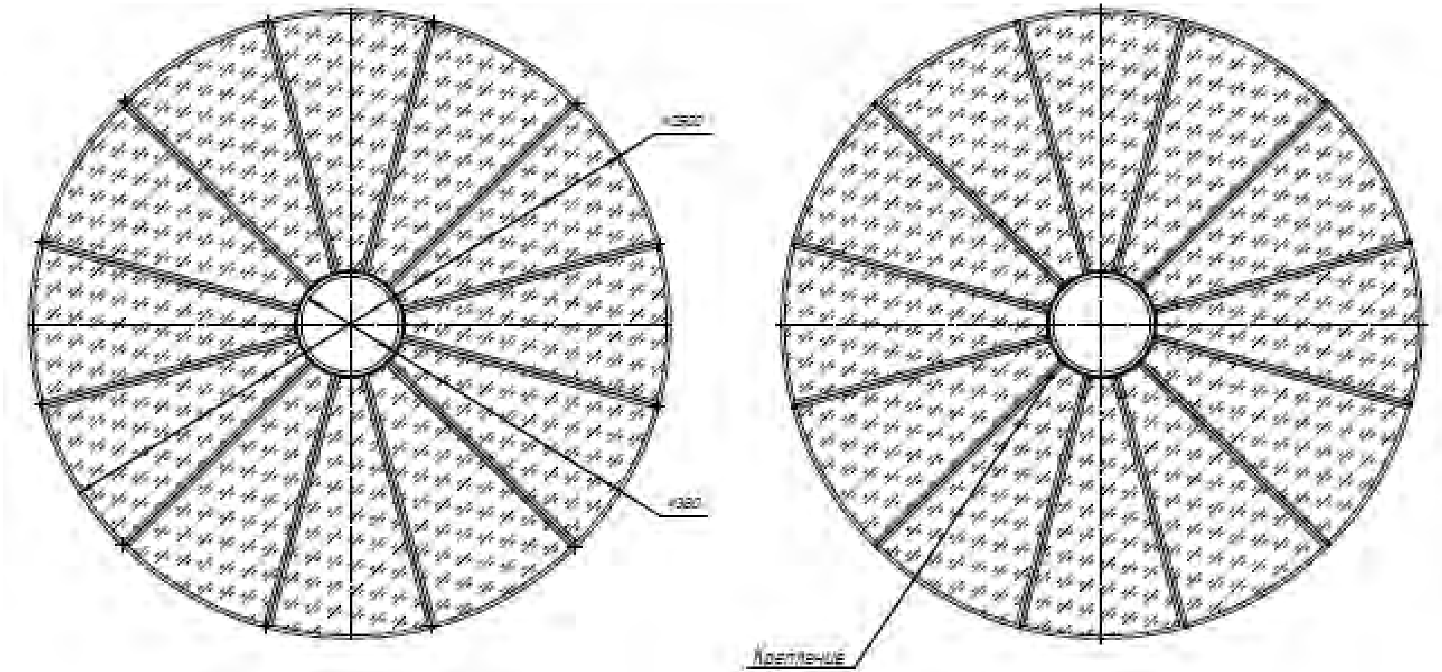


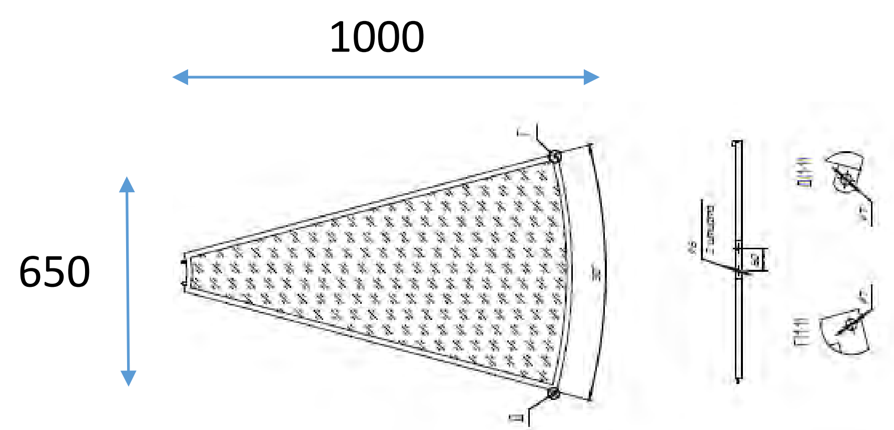
- ✓ The overall dimensions of the parts of the mirror satisfy the requirements for transportation at the Progress (1200x700 mm).
- ✓ Magnetic locks provide simplicity and accuracy of assembly in the process of EVA.

Mirror structure for EVA

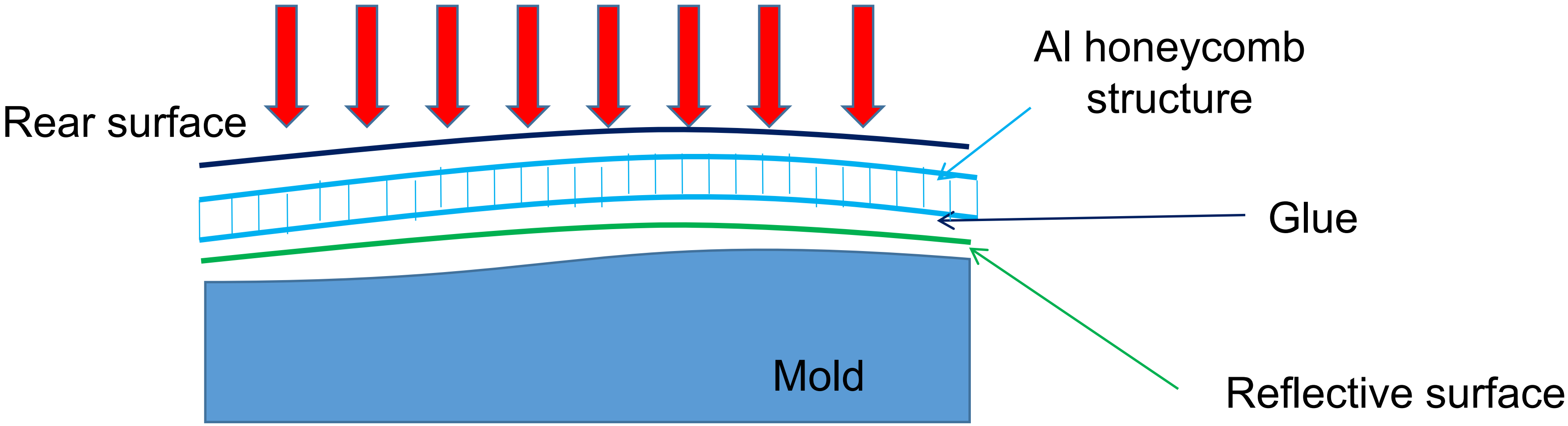


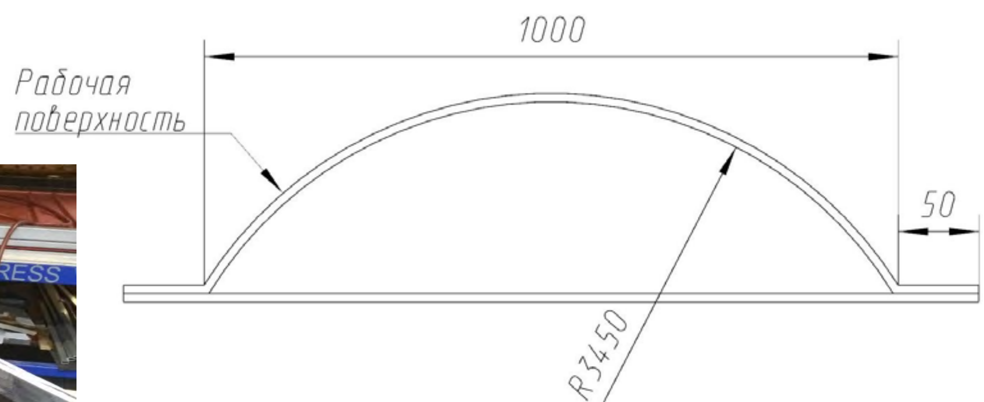
Lens segmentation



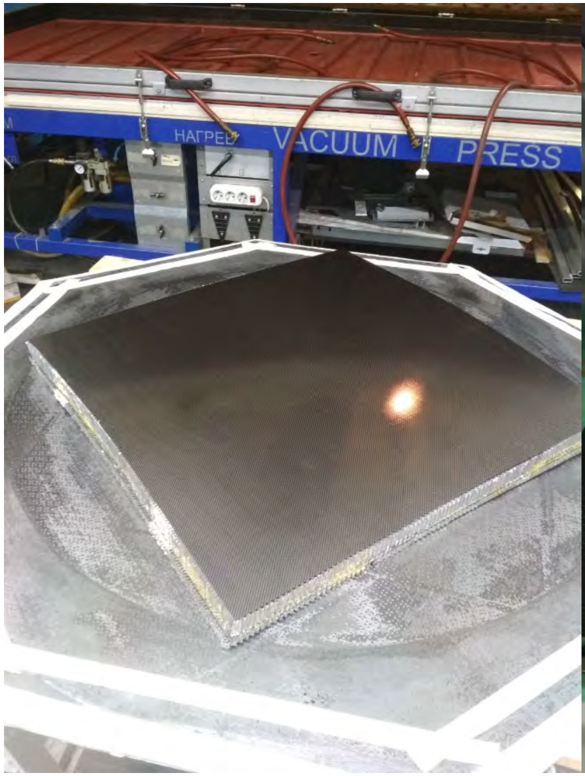


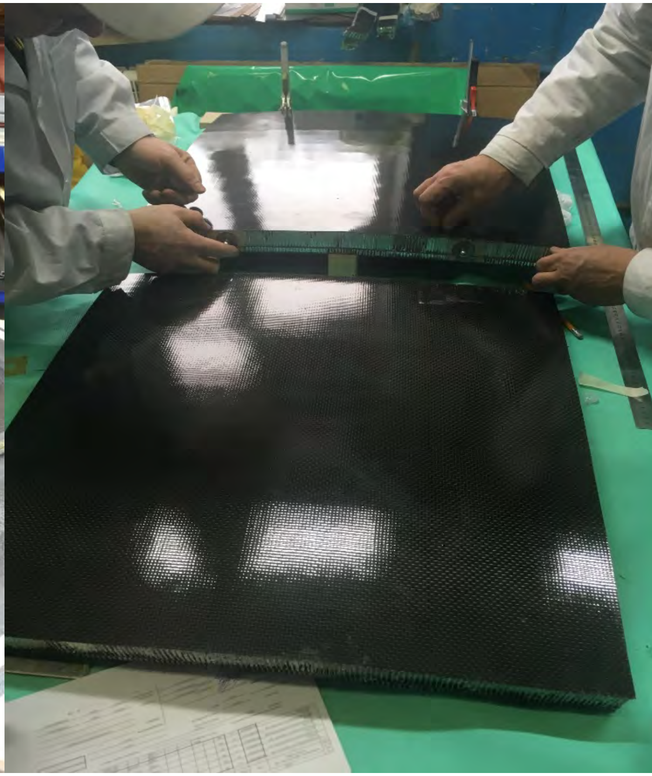
Mirror model production





Mirror model production



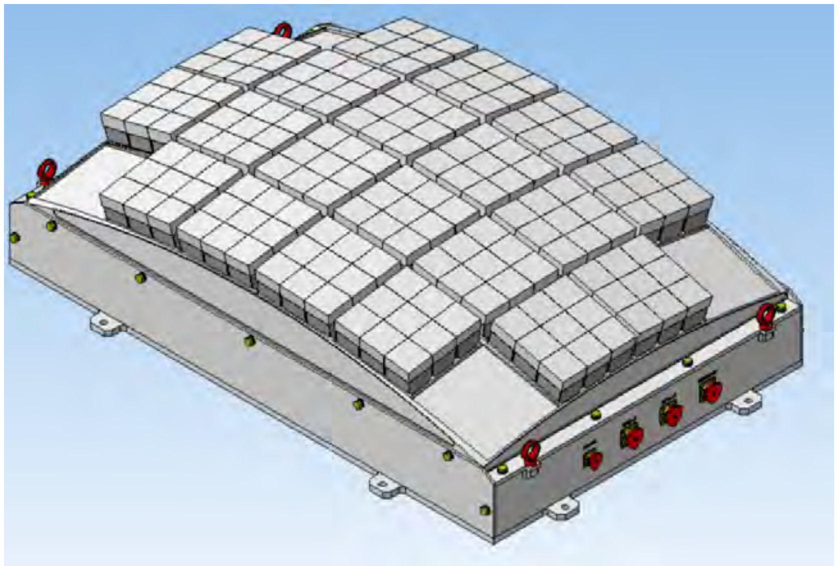


1) Size of one segment 700x700 mm;
2) Mass of one segment is ~1.8 kg
3) Mirror reflection coefficient – 95%;

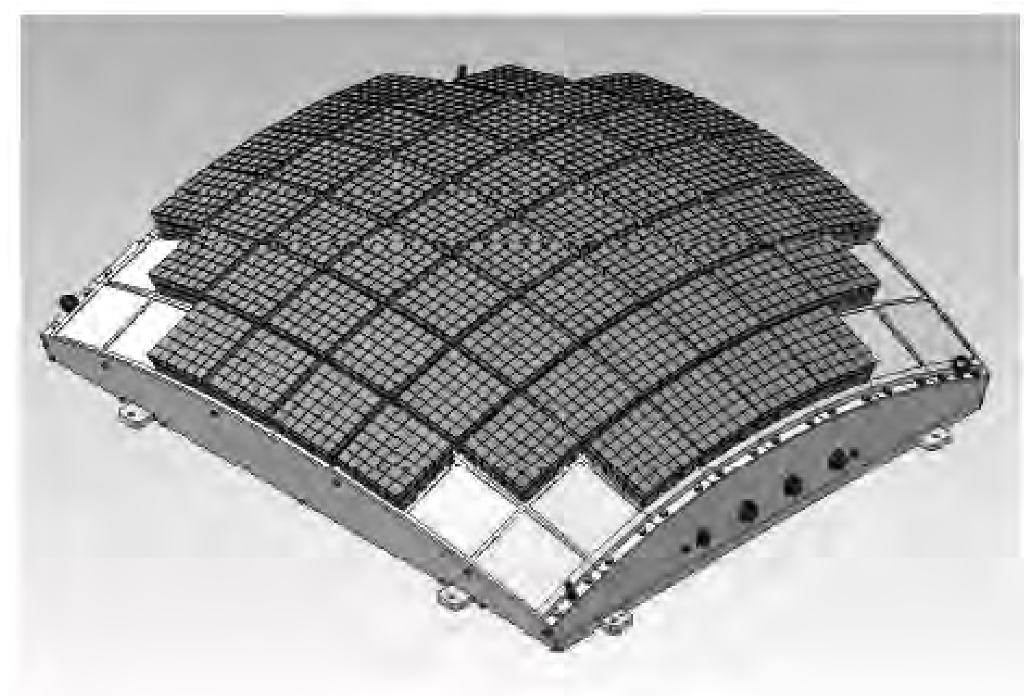
- Quality of the mirror (PSF, efficiency) is being studed.

Photo detector (focal surface)

Variant A

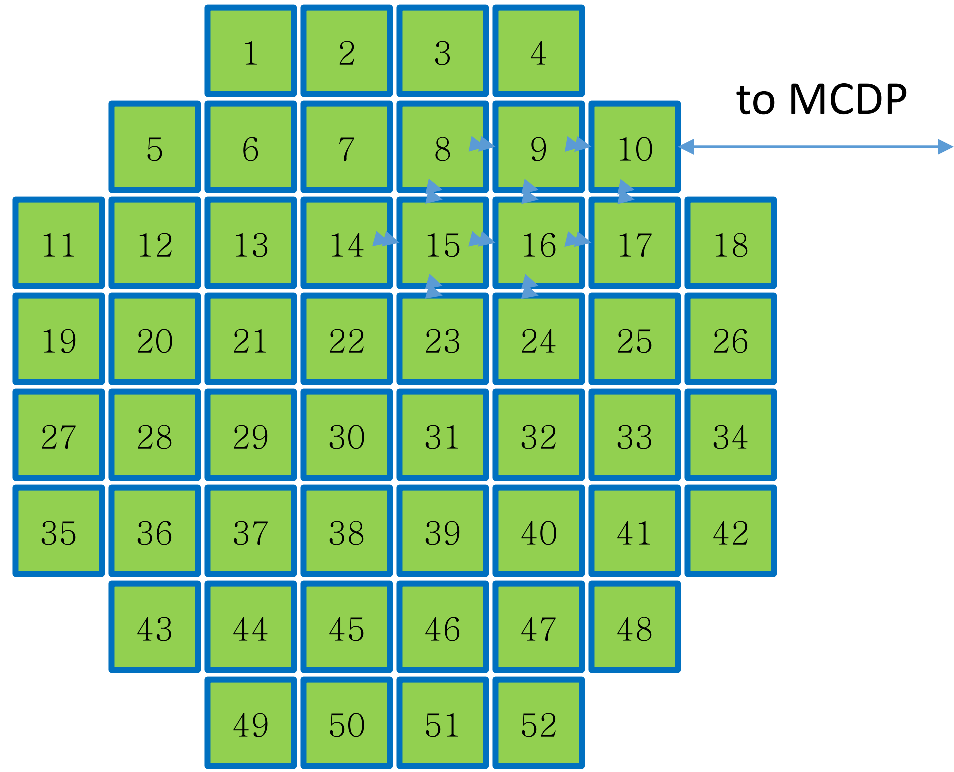


Variant B

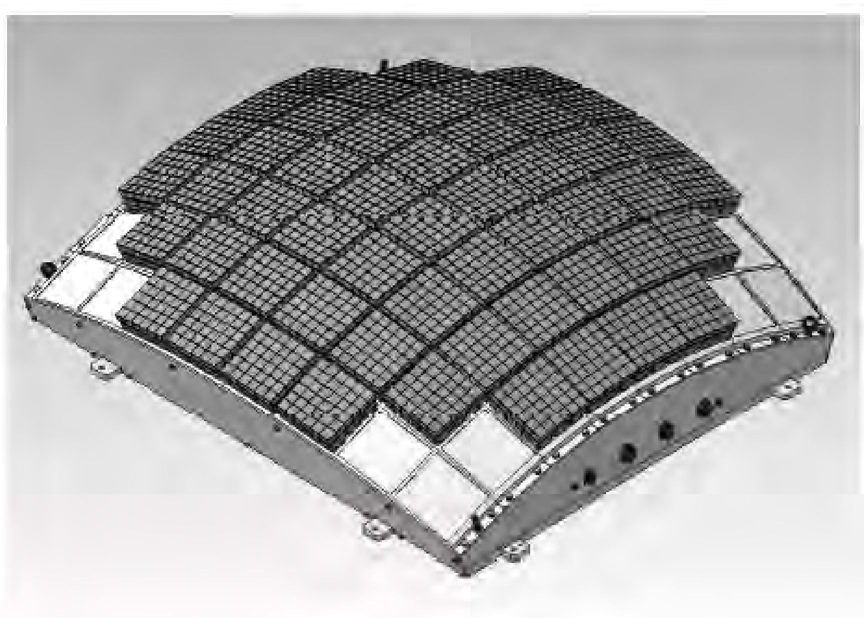


Focal surface has a modular structure. In the developed variants of FS, the number of modules is either 20 (version A) or 52 (option B). The photosensitive surface of the modules is located on the spherical focal surface of the FS. The modules are networked by three types of links.

Focal surface



- ✓ 52 (20) PDMs united in a network
- ✓ Each PDM has fact connections to his neighbors
- ✓ 4 PDMs has Ethernet connection with Commutation unit and MCDP
- ✓ Power consumption ~10 W/PDM



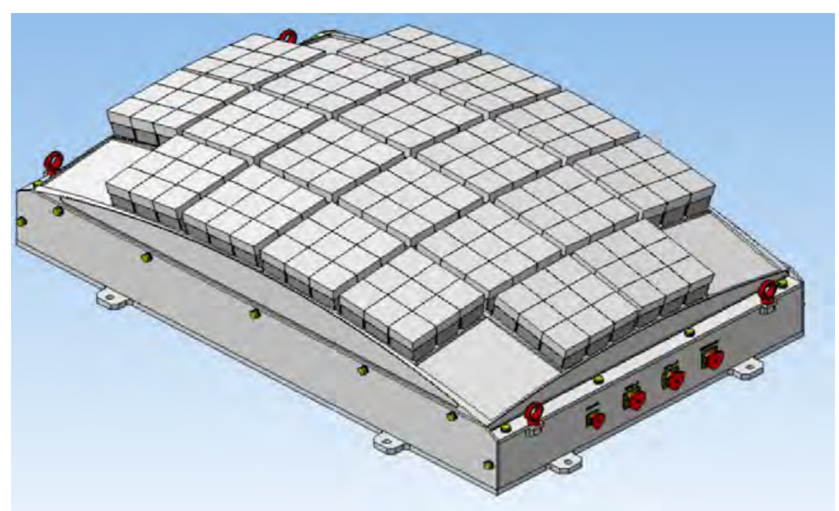


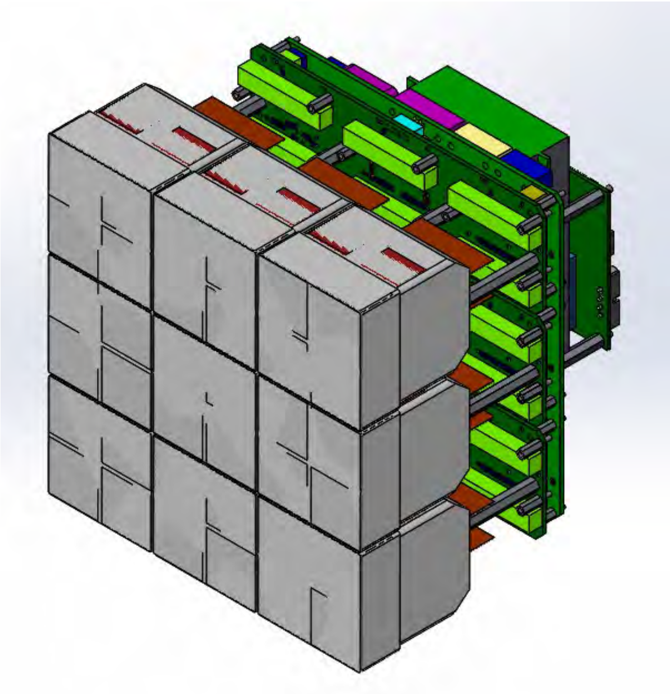
Photo detector module (PDM)

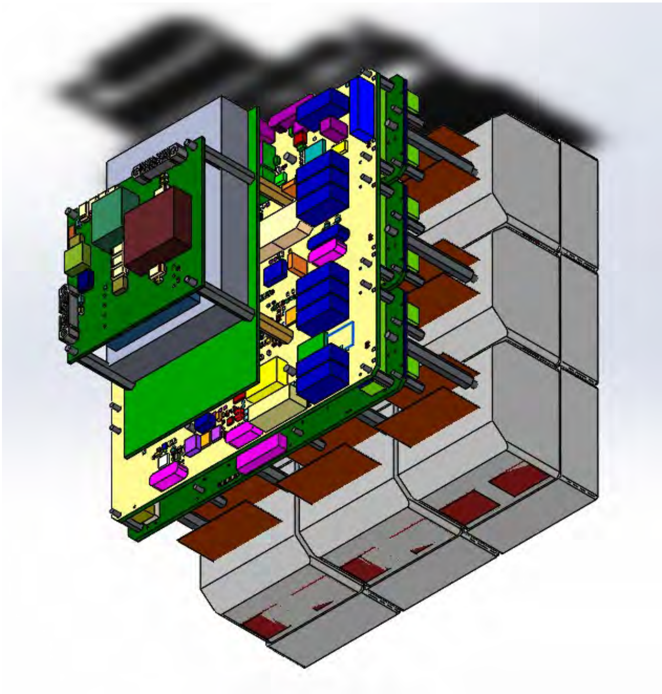
One PDM has 36 MAPMT (2304 pixels).

4 MAPMTs united into EC (elementary cell) with common HVPS and 4 SPACIROC-3 (ASICs for p.e. counting).

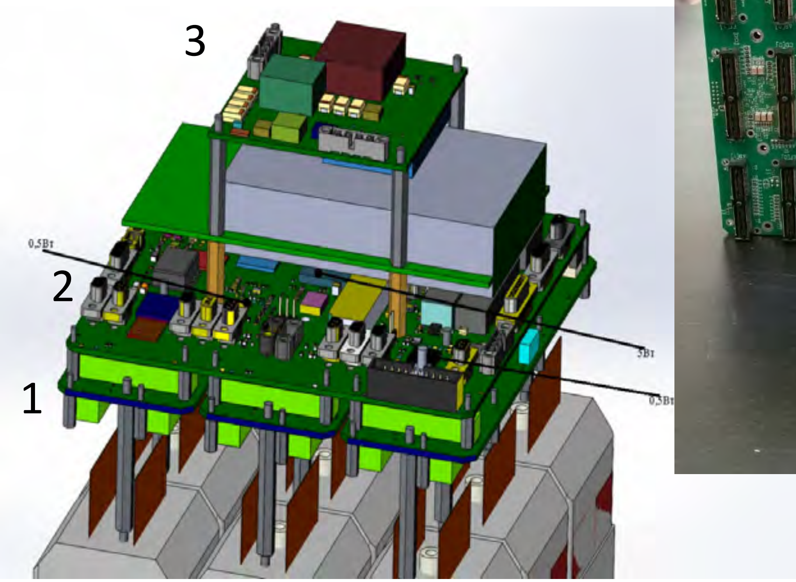
Data analyses in PDM-DP boards, based on XILINX Zynq system on chip.

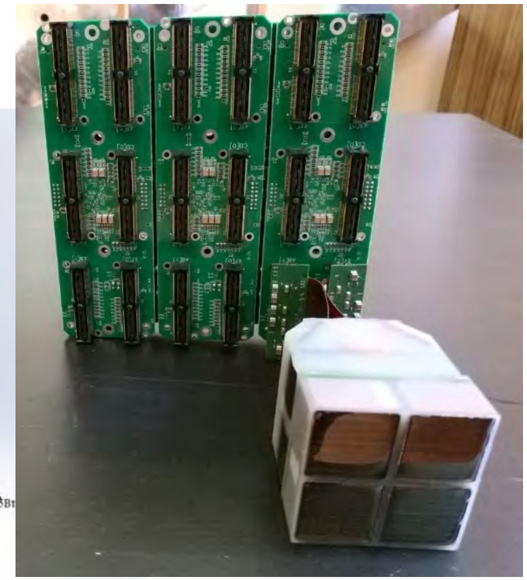
The Zynq chip contains a Xilinx Kintex7 FPGA, with an embedded dual core ARM9 CPU processing system and is responsible for of the majority of the data handling including data buffering, configuration of the SPACIROC3 ASICs, triggering, synchronisation and interfacing with the MCDP. Data buffering in PDM DDR memory (~1 Gbyte).

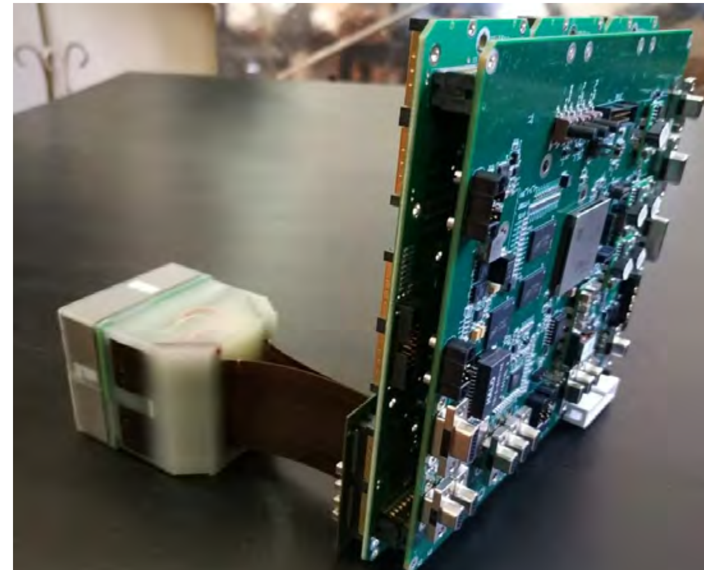




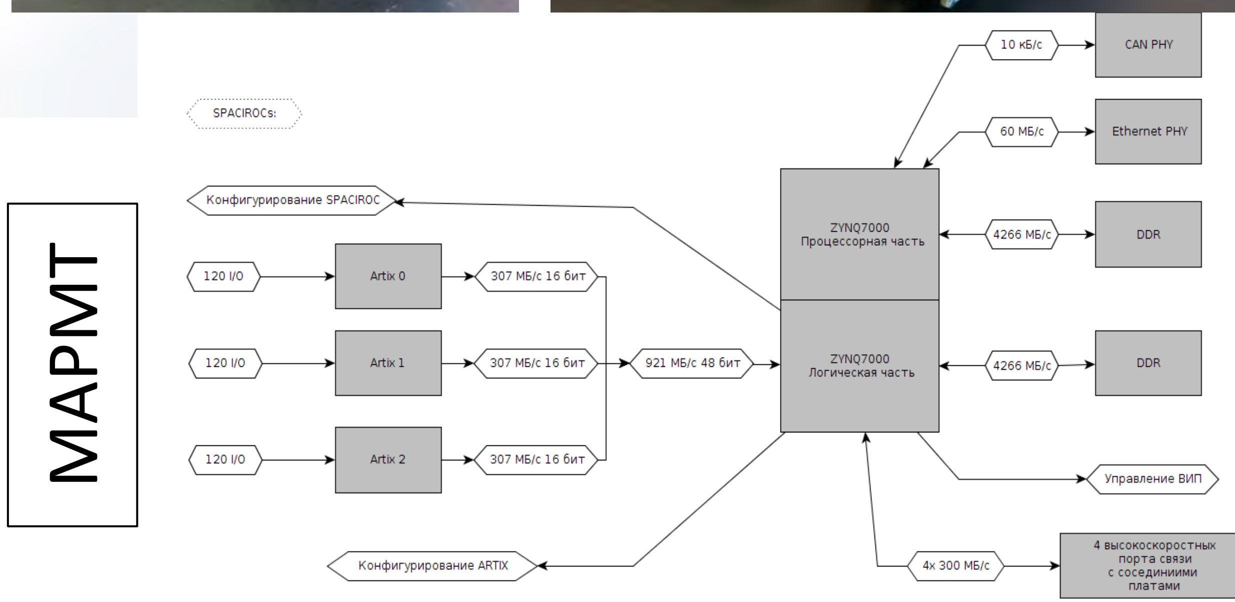
PDM DP



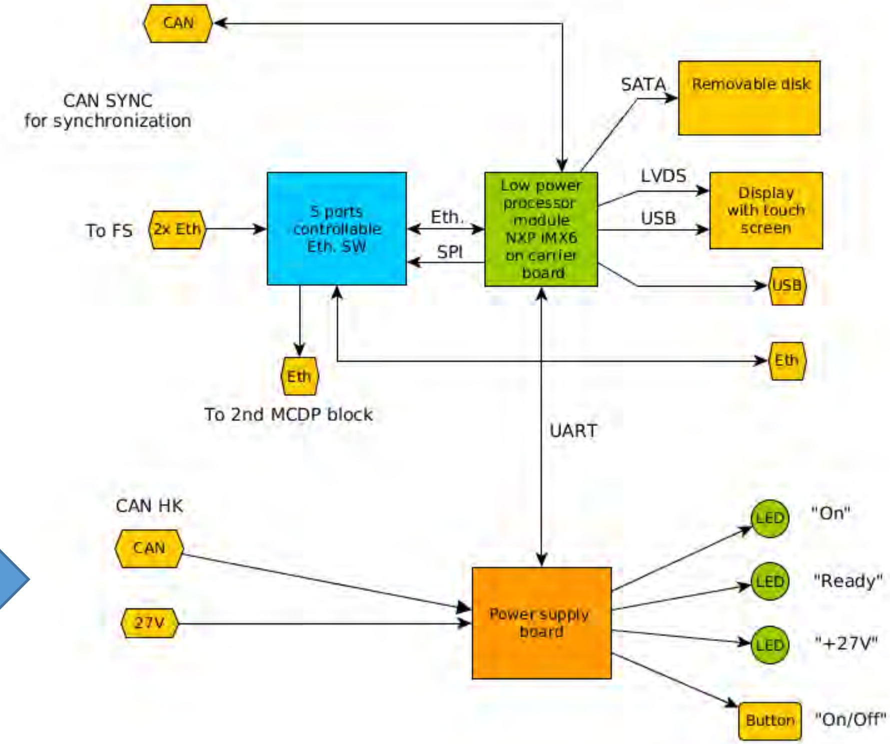




1. Cross-board
2. Processor board
3. Power board

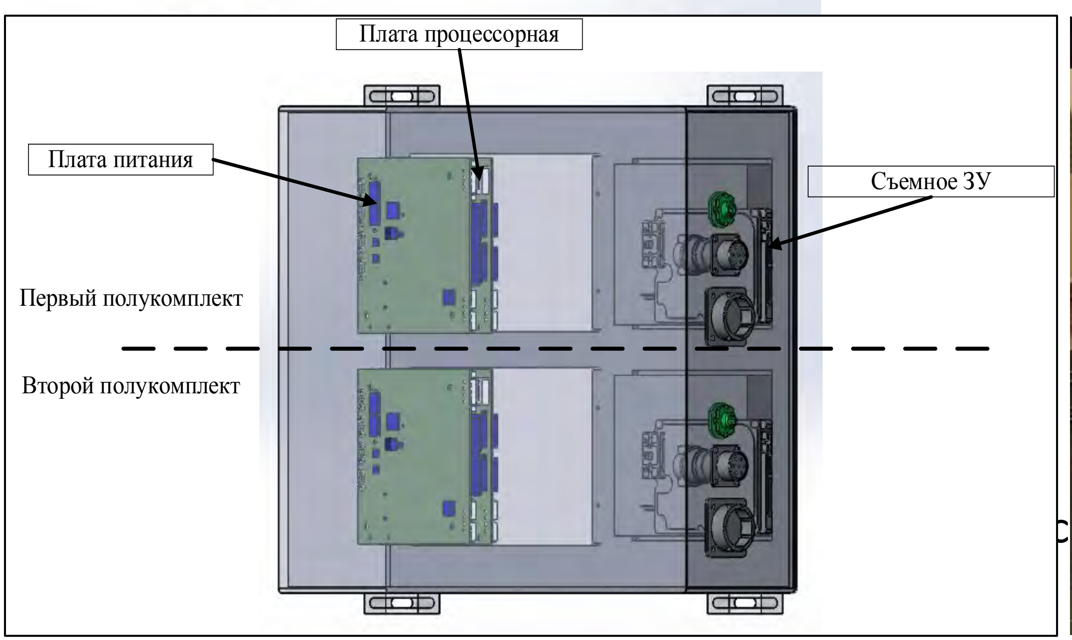


Mission Control and Data Processing System

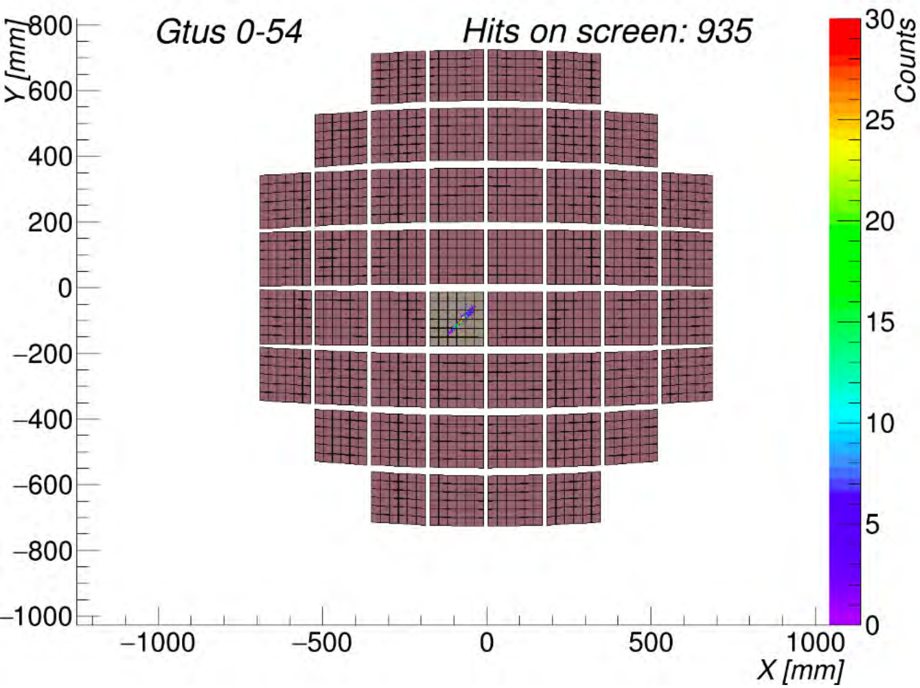


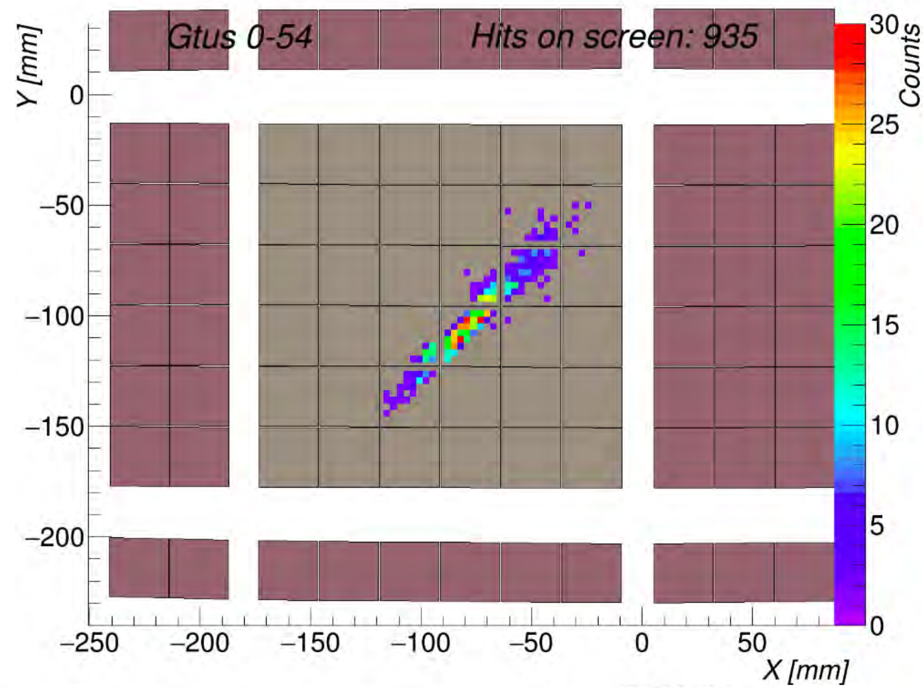
Block-scheme of one half-pack

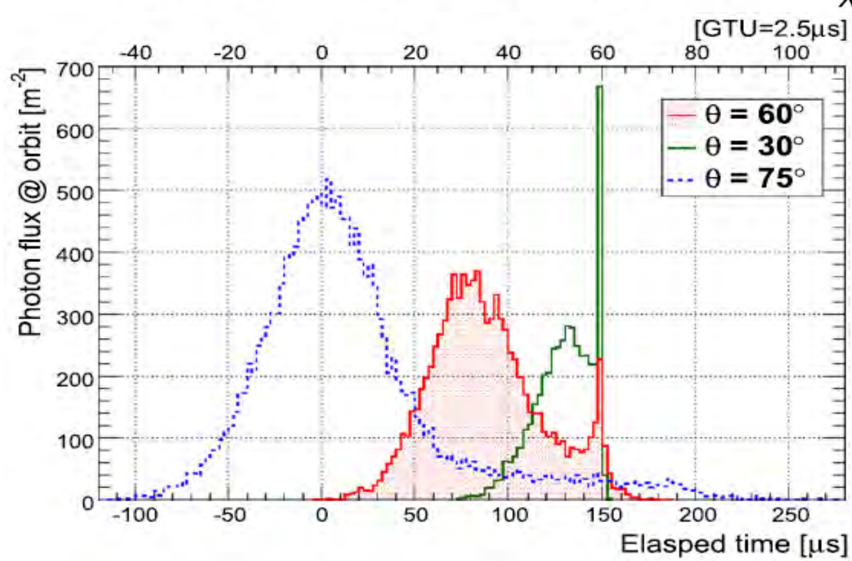
3D view



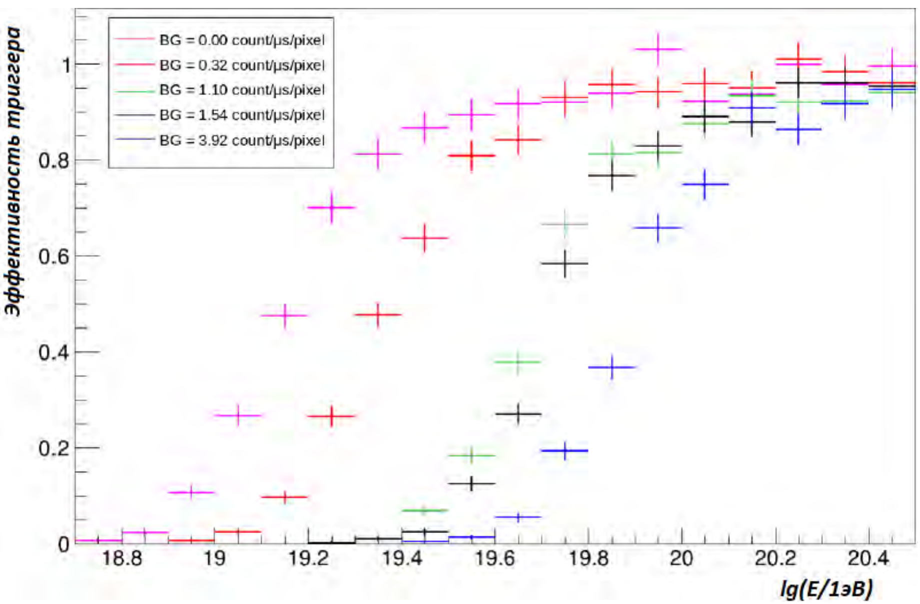
EAS track on the focal surface



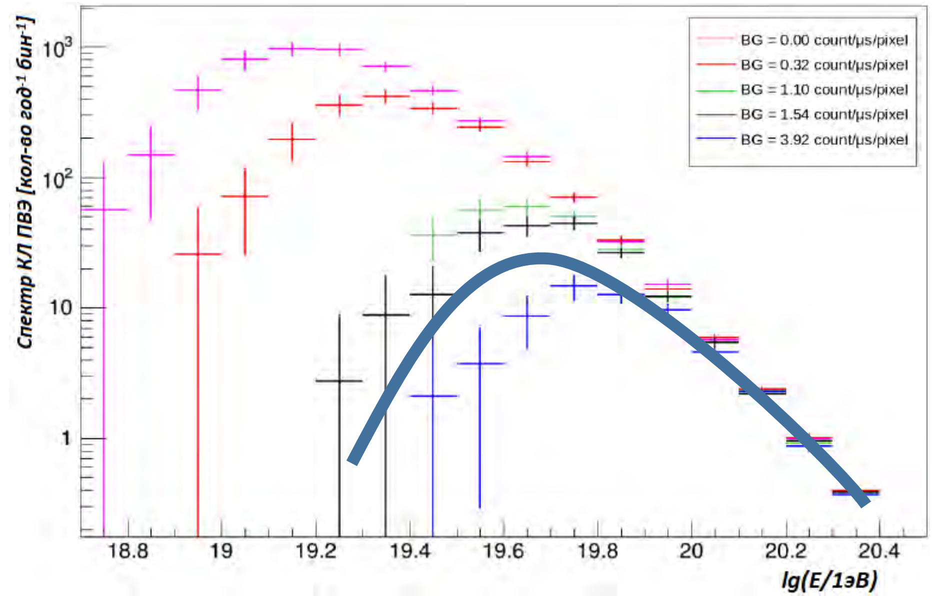




Efficiency of trigger system and expected number of events



Figures by Alessandro Liberatore



PAO spectrum (ICRC2017)

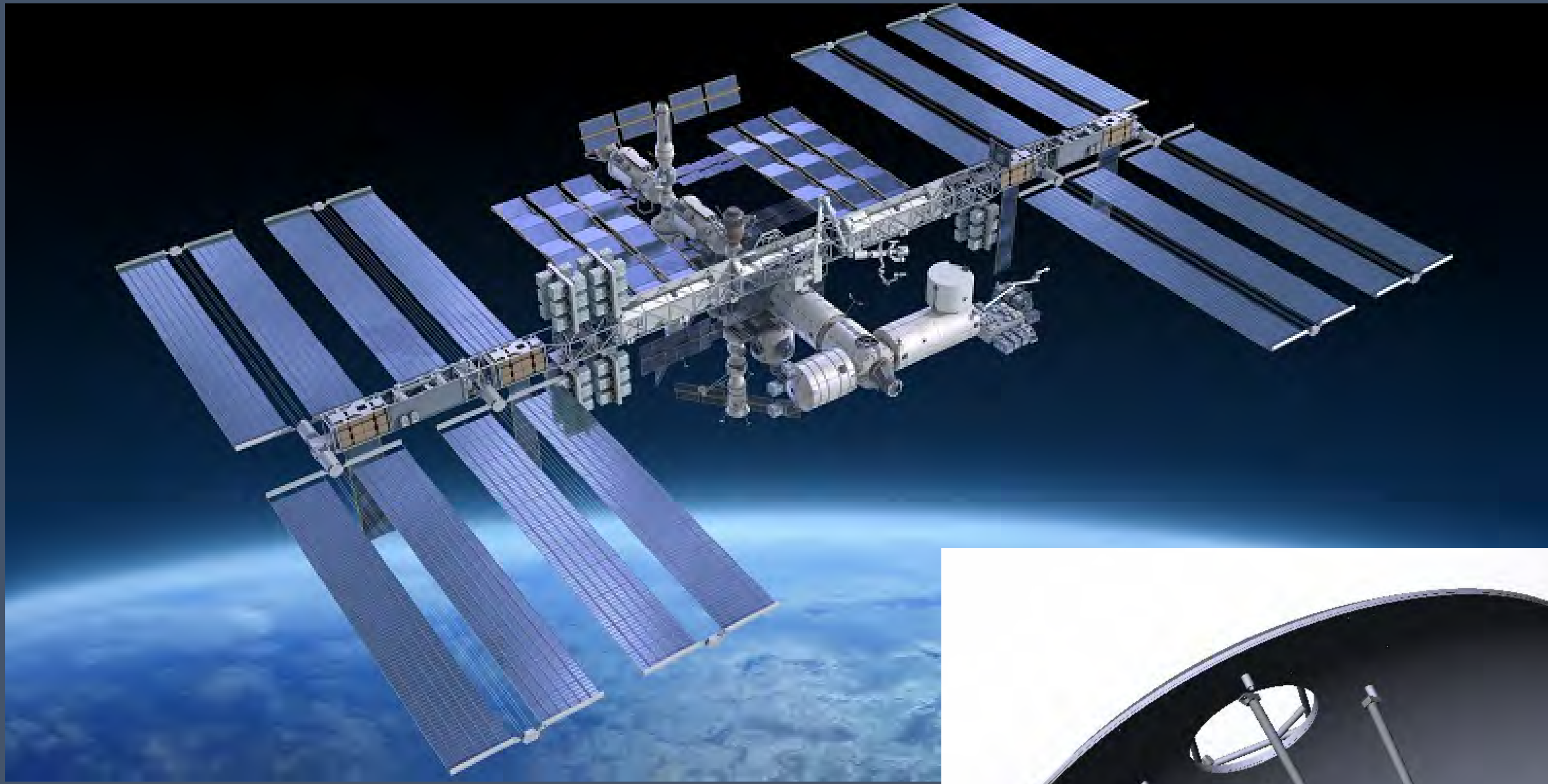
lg(E/1 eV)	19,4	19,5	19,6	19,7	19,8	19,9	20,0	20,1	20,2	20,3	20,4
>=E [EeV]	22	28	35	45	56	71	89	112	141	178	224
A	120	96	68	42	22	10,3	4,5	1,8	0,7	0,3	0,08
B	313	250	177	109	58	27	12	5	1,9	0,7	0,2

Conclusions

- ✓ KLYPVE-EUSO is included into Long-term program of experiments on board the Russian Segment of the ISS. It is the next step of measurements of UHECR from space with statistics ~100 events per year with energy >100 EeV.
- ✓ The technique is tested in various pathfinders as EUSO Balloon and TUS.
- ✓ 2019 Conceptual design stage.
- ✓ 2020 – Engineering model.
- ✓ 2022 – Flight model and launch.

Next steps

- ✓ Integration and transportation studies
- ✓ Optimization of the mechanical structure to minimize events loss and adopt to EVA.
- ✓ Phase B to finalize the detectors structure



Thank you for your attention!