Space fluorescence detectors TUS/KLYPVE for study of EECR .

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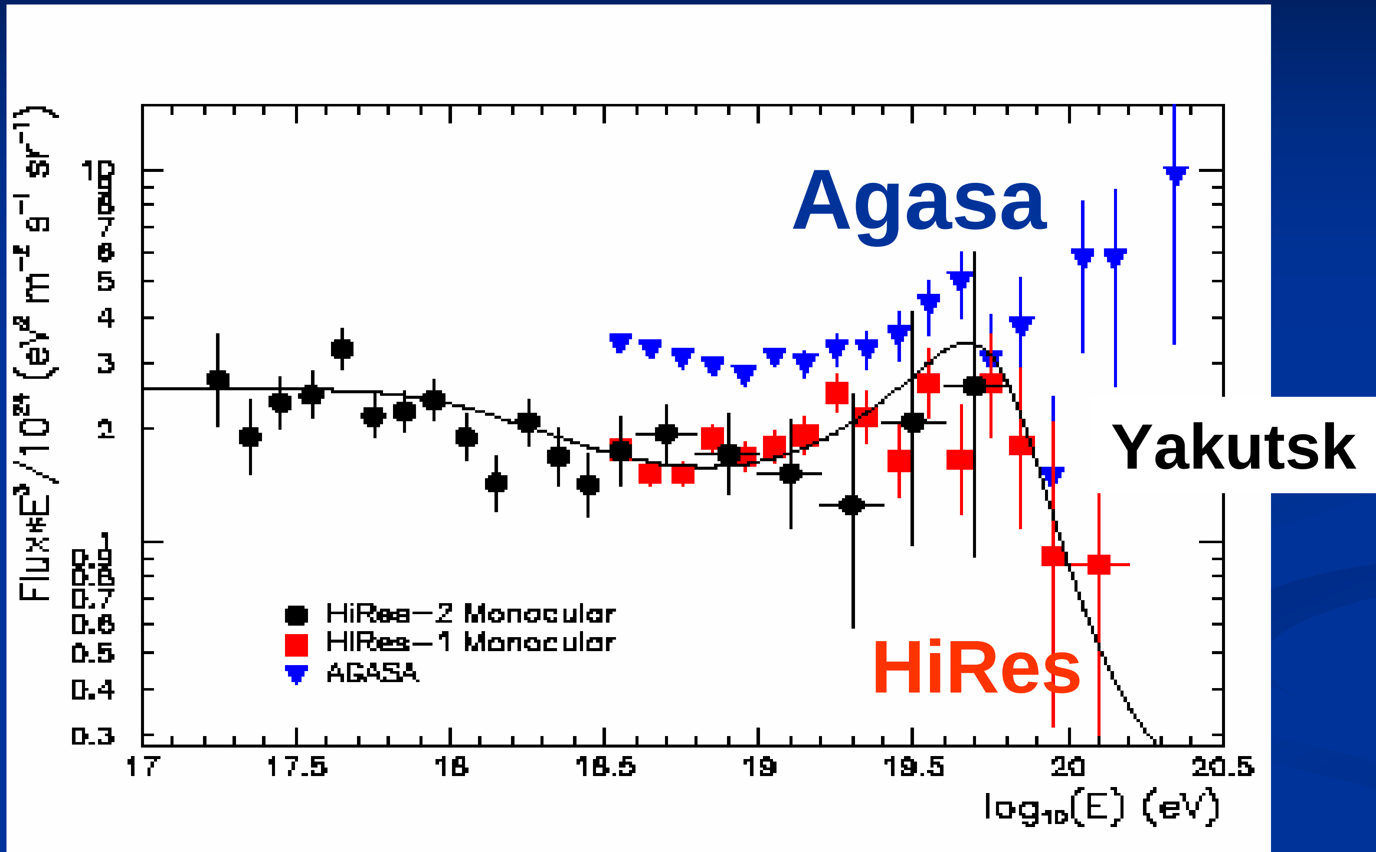
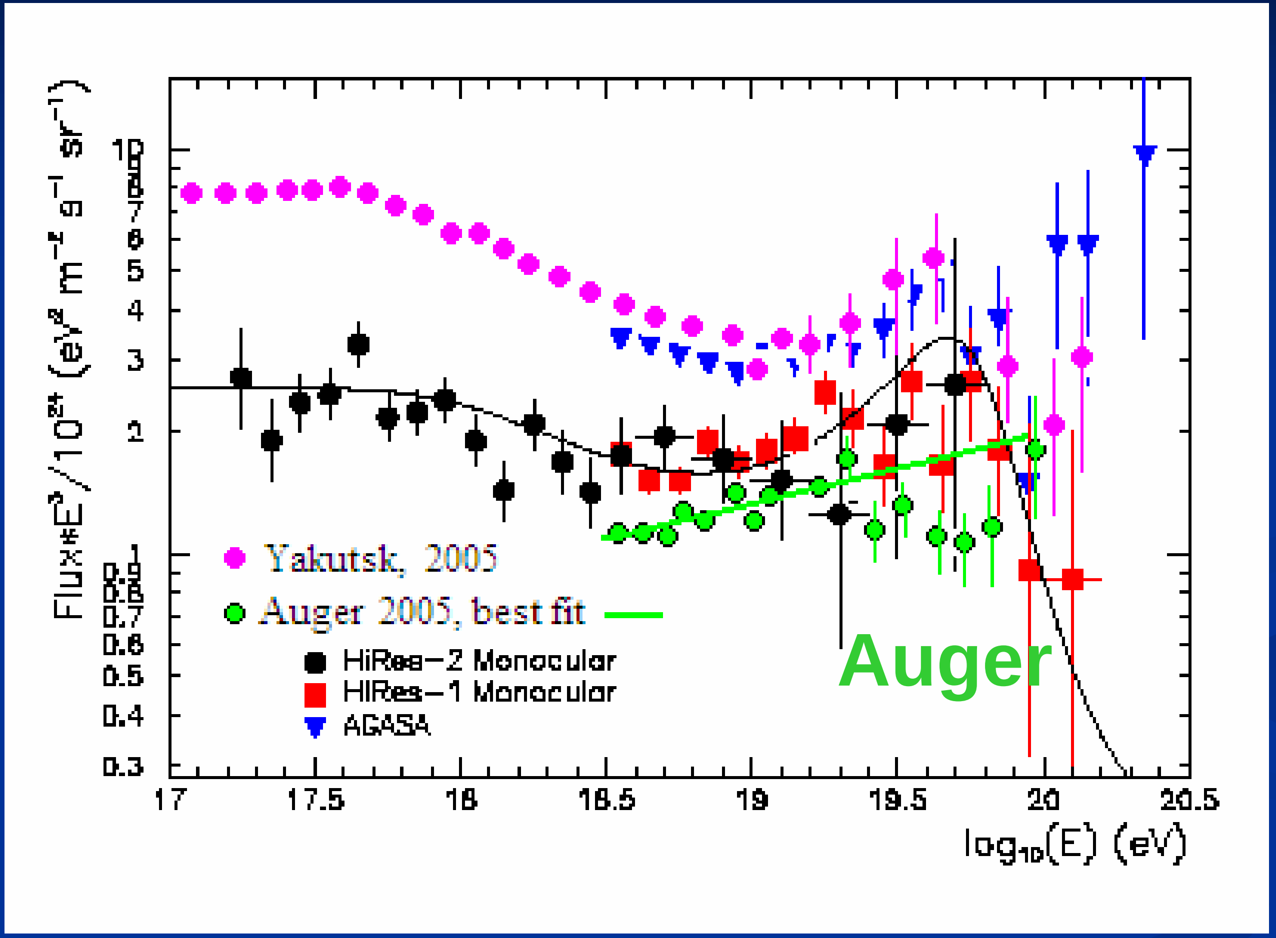
Scientific Problem- Origin Of The Ultra High Energy Cosmic Rays (EECR)



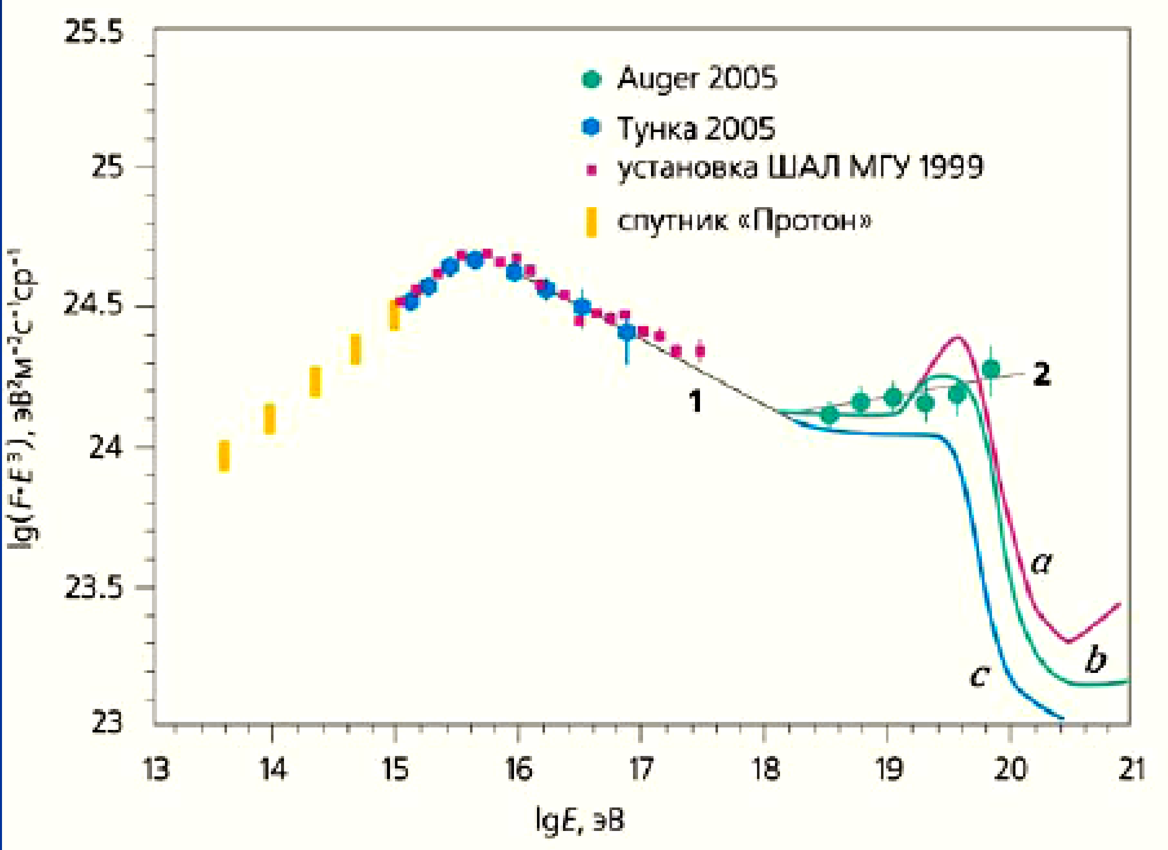
Experimental data of AGASA are against the GZK Cosmic Ray cut off. Data of HiRes confirm the cut off. Yakutsk data agree with the HiRes data. Detectors of the next generation should solve the problem.

Recent experimental data on the energy spectrum of Extreme Energy Cosmic Rays (EECR)



Energy calibration is the main reason of difference in spectra from different experiments. As in case of lower energies the calorimetric data from the atmosphere fluorescence light (Auger energy calibration) are decisive.

The main problem is the existence of the Greisen-Zatsepin-Kuzmin cut off at energy 50 EeV.



Resumably EECR (energies >1 EeV=10^{18} eV)are of extragalactic origin.

Auger data do not show the excess from Galactic center and Galactic plane.

In Fig. curves a,b,c are expectations for various options of the Universe EECR sources.

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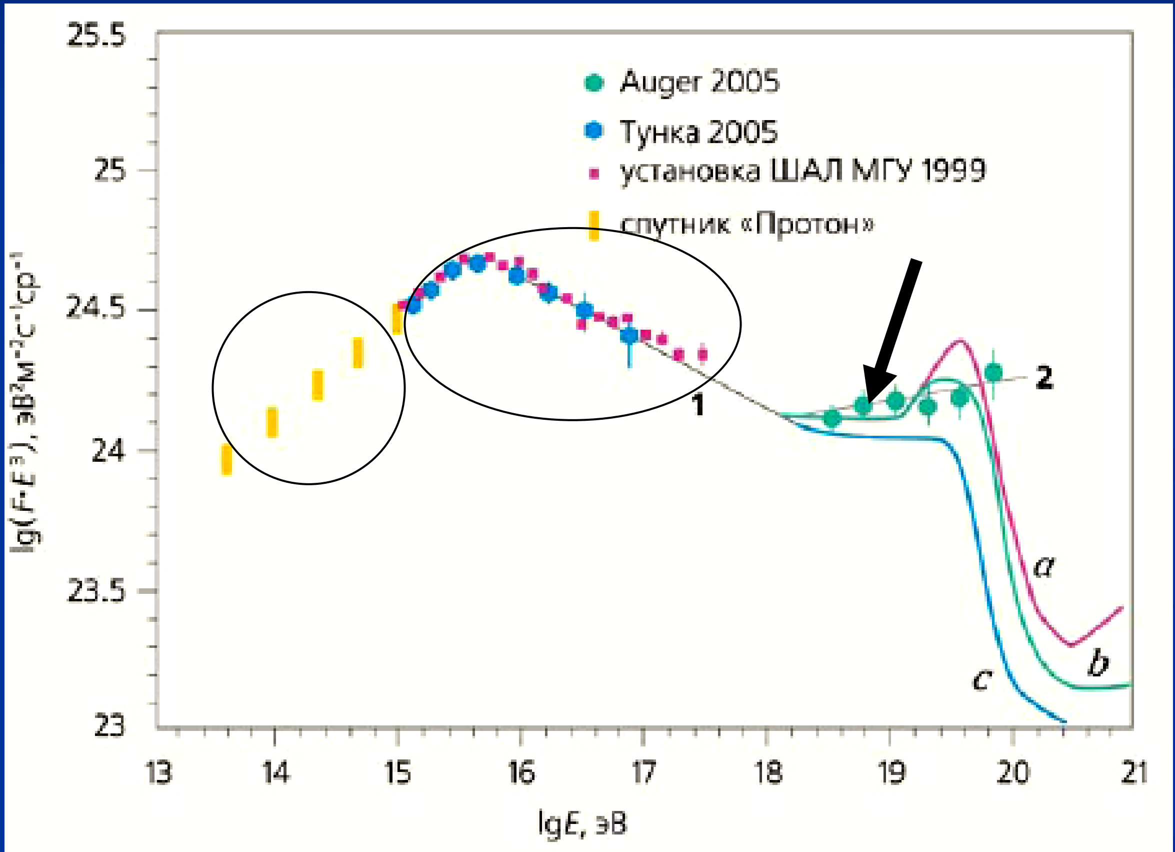
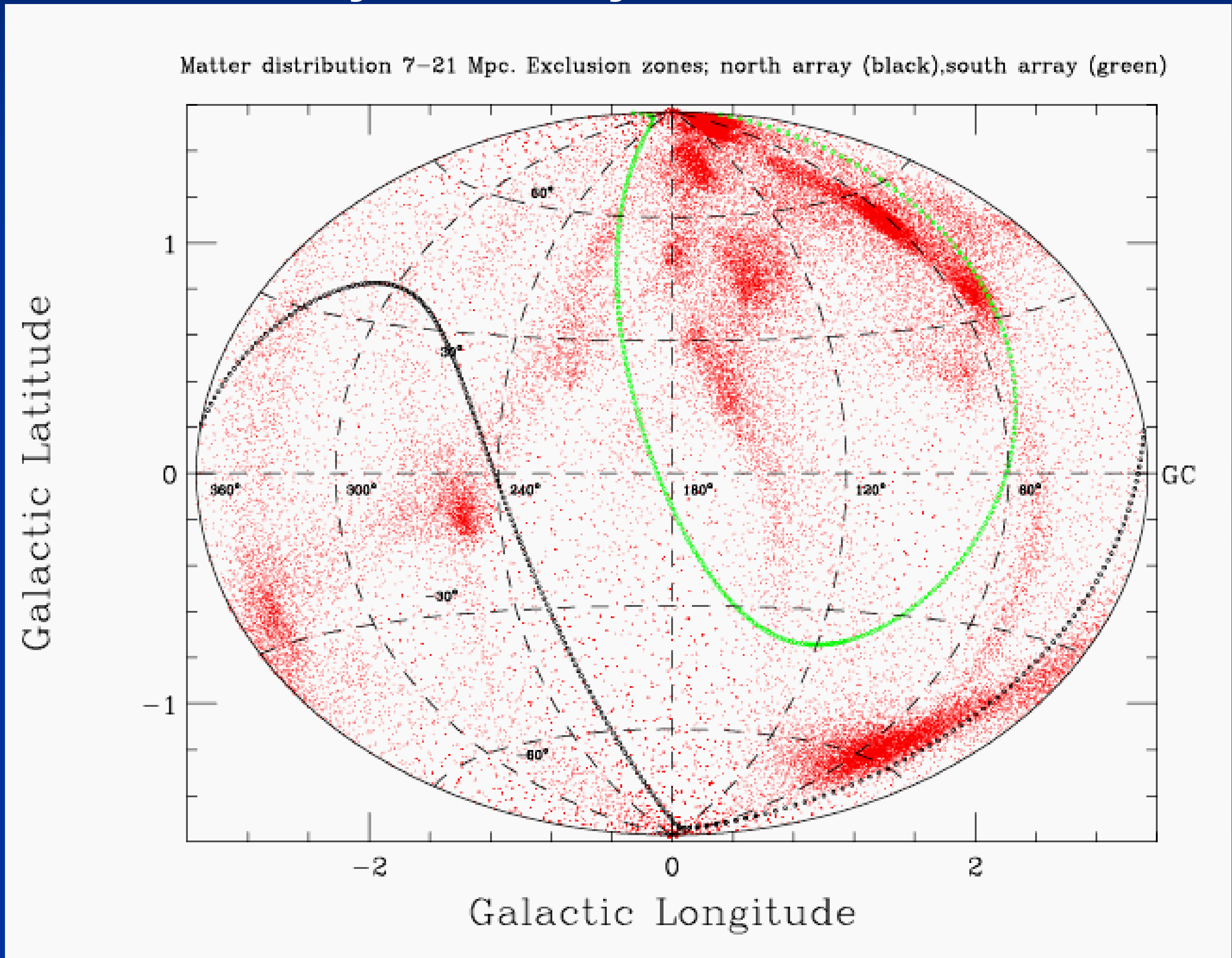
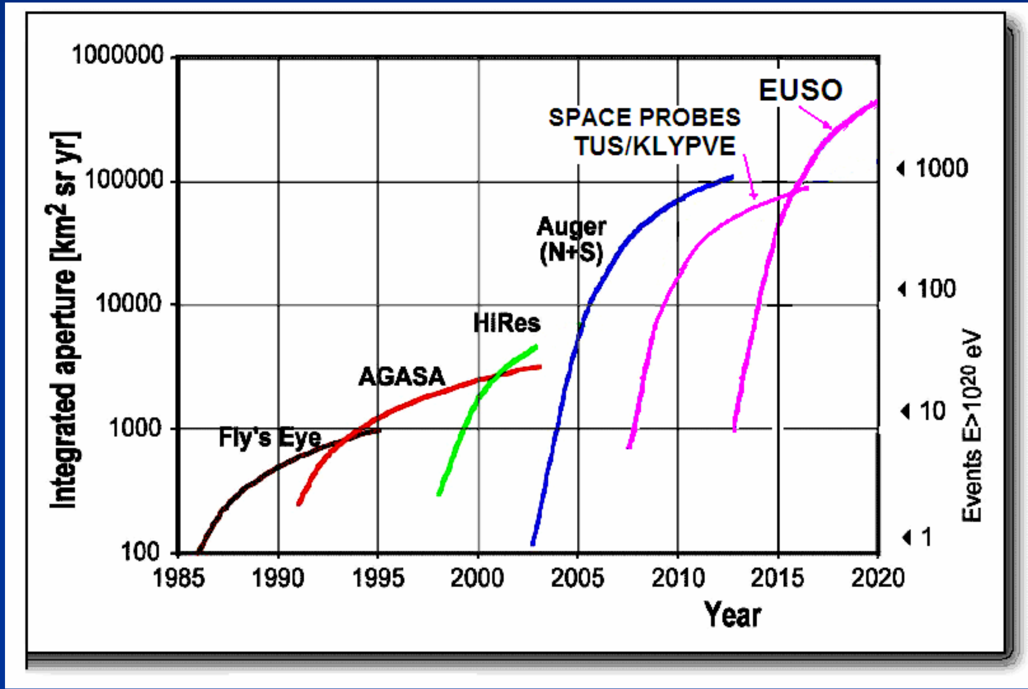


If we use only data of the arrays that measured energy by the calorimetric method ("Proton" satellite data and Cherenkov-TUNKA data) or at least by the electron size method (MSU data) we find steeper spectrum at energy
3 PeV<E<1 EeV
(Khrenov&Panasyuk, 2006, Priroda, #2,p. 17-25)
which better meets the Auger spectrum.

Today the Pierre Auger observatory in the Southern hemisphere is the largest EECR array. But it does not cover an important part of the "local" source map available for observation by the array in the Northern hemisphere.



Before the Northern Auger array will be built the fluorescence space detectors may look for EECR sources in a full sky observation. We hope to launch the TUS and KLYPVE detectors in period 2010-2015.



Note the difference in observation from the satellite and the onground array. The onground particle detector array observes the whole available sky in a day cycle. The satellite fluorescence detector in a day cycle observes only part of the available sky (open for observation from the night side of the Earth). Real whole sky coverage is completed only in a year cycle.

TUS project

In the TUS-type detector the mirror optics with a comparatively narrow FOV is suggested- the “telescope” option of the space detector.

Advantages of this design:

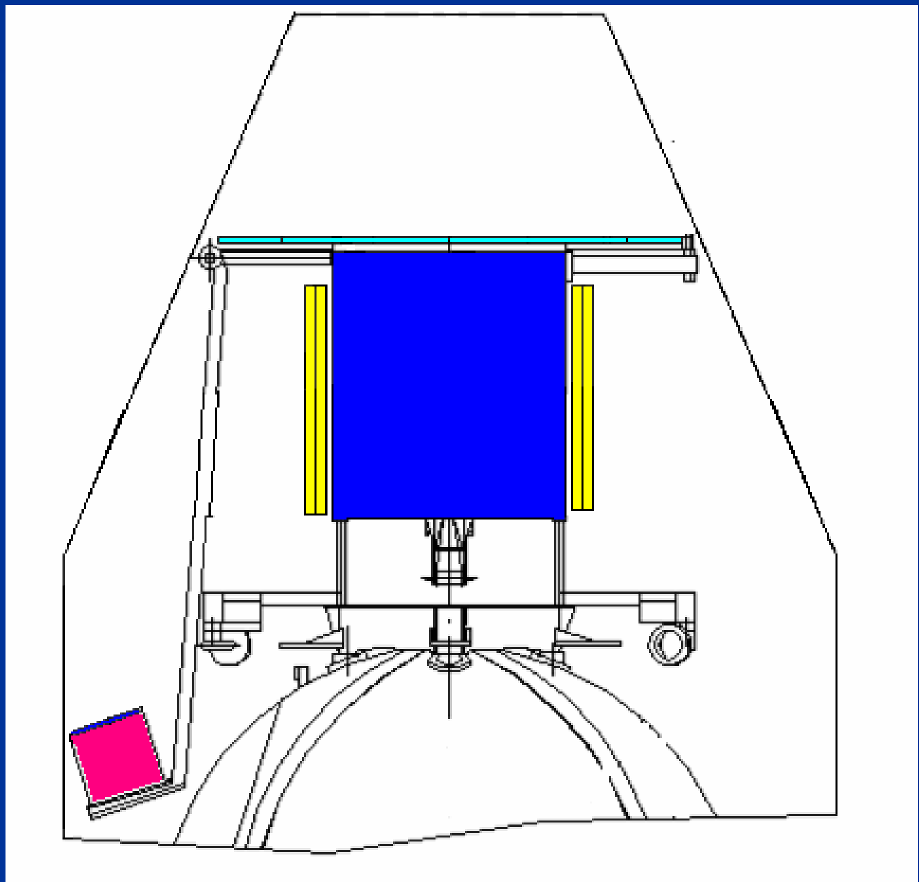
1. Simple optics has been already tested in several ground arrays.

2**. A large mirror (area of ~10 m2) will allow us to start measurements with a “low” energy threshold (~10^{19} eV). With this threshold it will be possible to look for cosmological neutrinos- products of the EECR protons interaction with CBMW photons. It means that we will able to look beyond Greisen-Zatsepin-Kuzmin energy limit.**

3. In future the mirror area enlarged up to 1000 m2 (adaptive optics has to be applied) will allow us to register EECR at very large area of the atmosphere (107 km2) with the help of a telescope at the geostationary orbit.

The TUS detector will be launched on a new platform separated from the main body of the "Foton" satellite (RosCosmos project, Samara enterprise, launching in 2009-2010). Satellite limits for the scientific instrument are: mass 60 kg, electric power 60 Wt, orientation to nadir ±3º .

Preliminary TUS design: 1- in the transportation mode, 2 – in operation.



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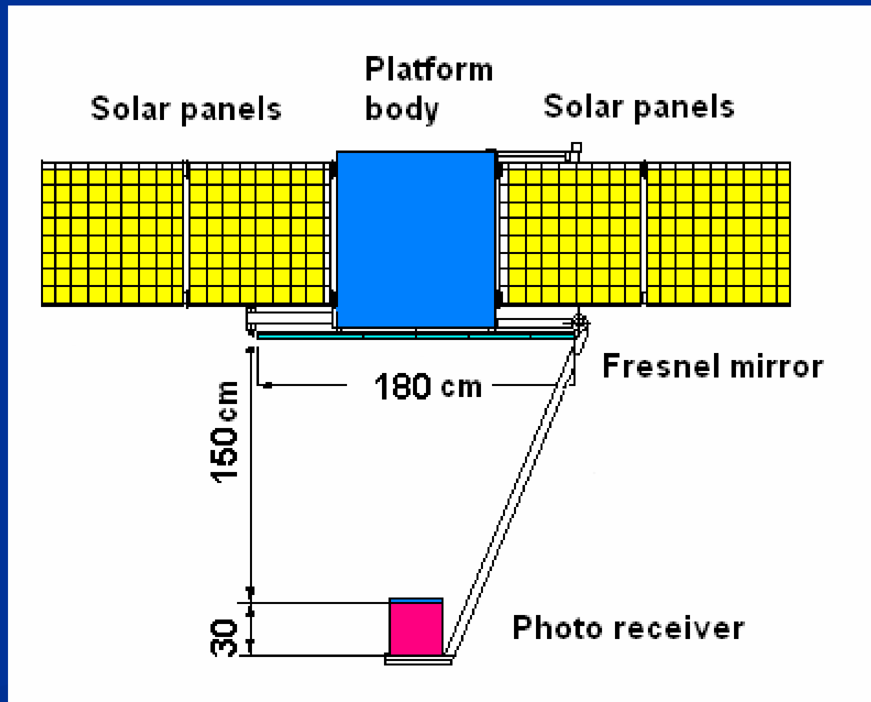
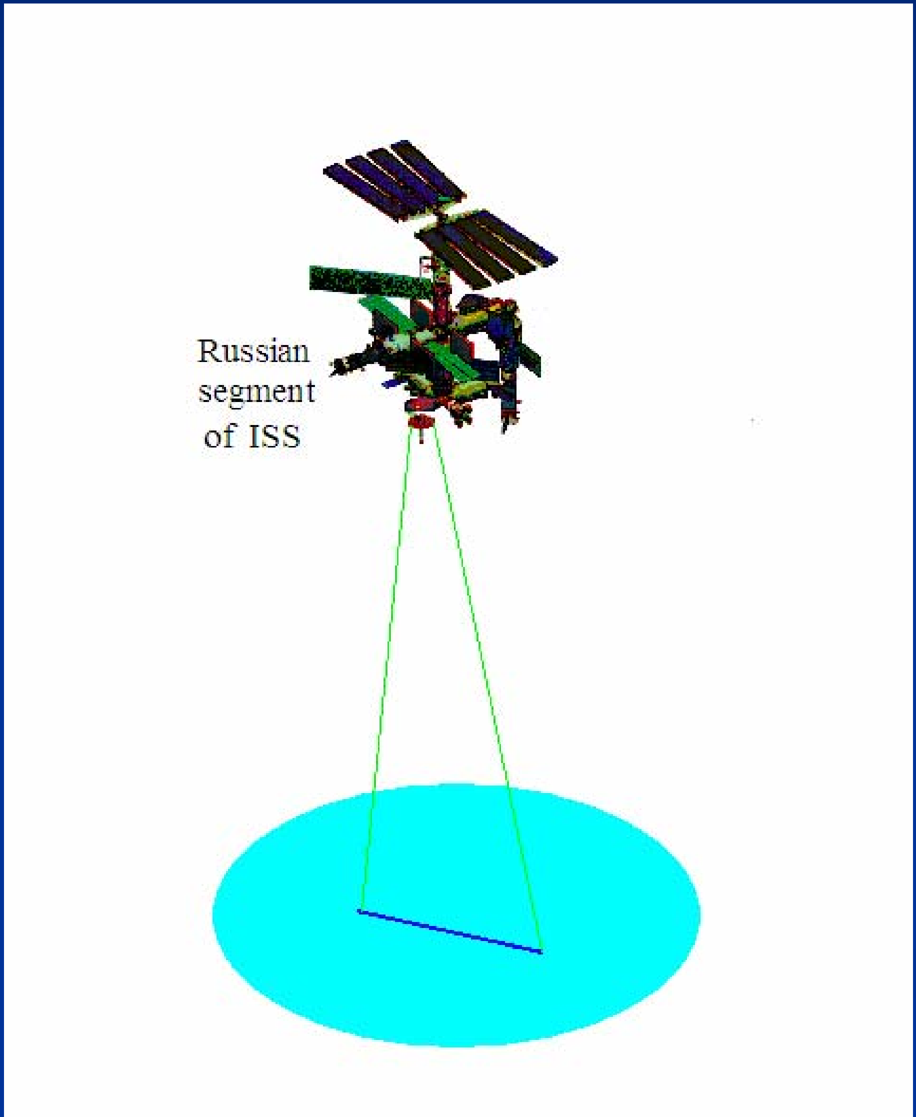
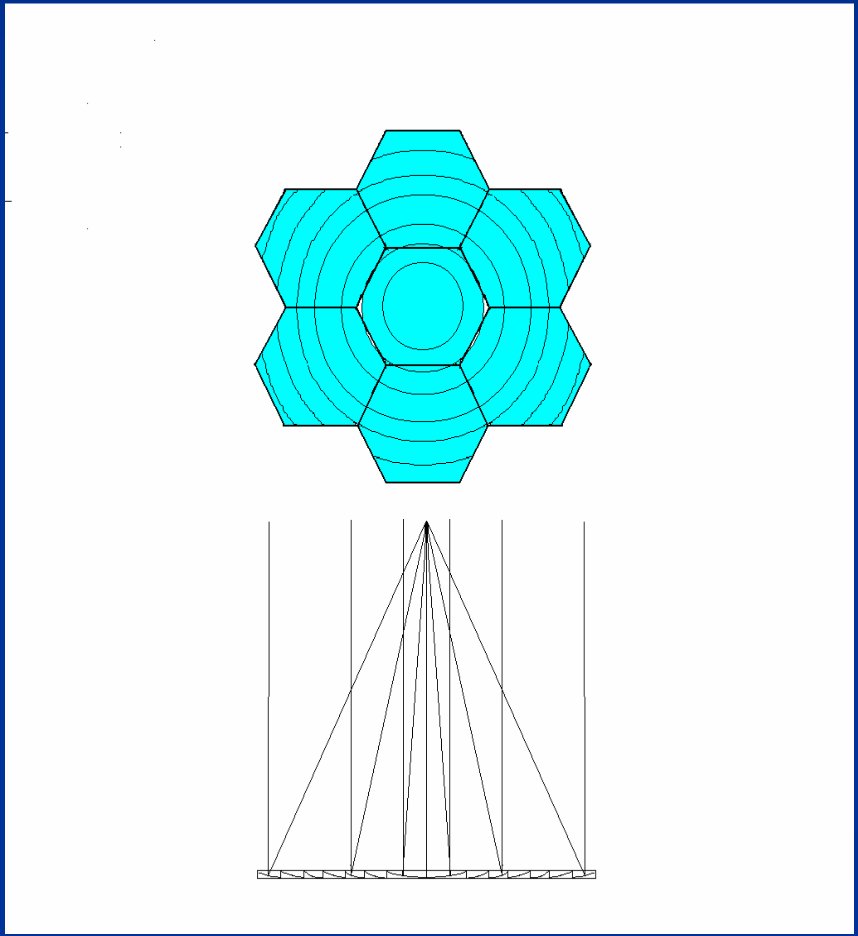


Detector larger than TUS - with mirror area ~10 m^2 is considered as the next step of the EECR space experiment on the Russian Segment of ISS (today it is TUS-M project, it was called KLYPVE before).



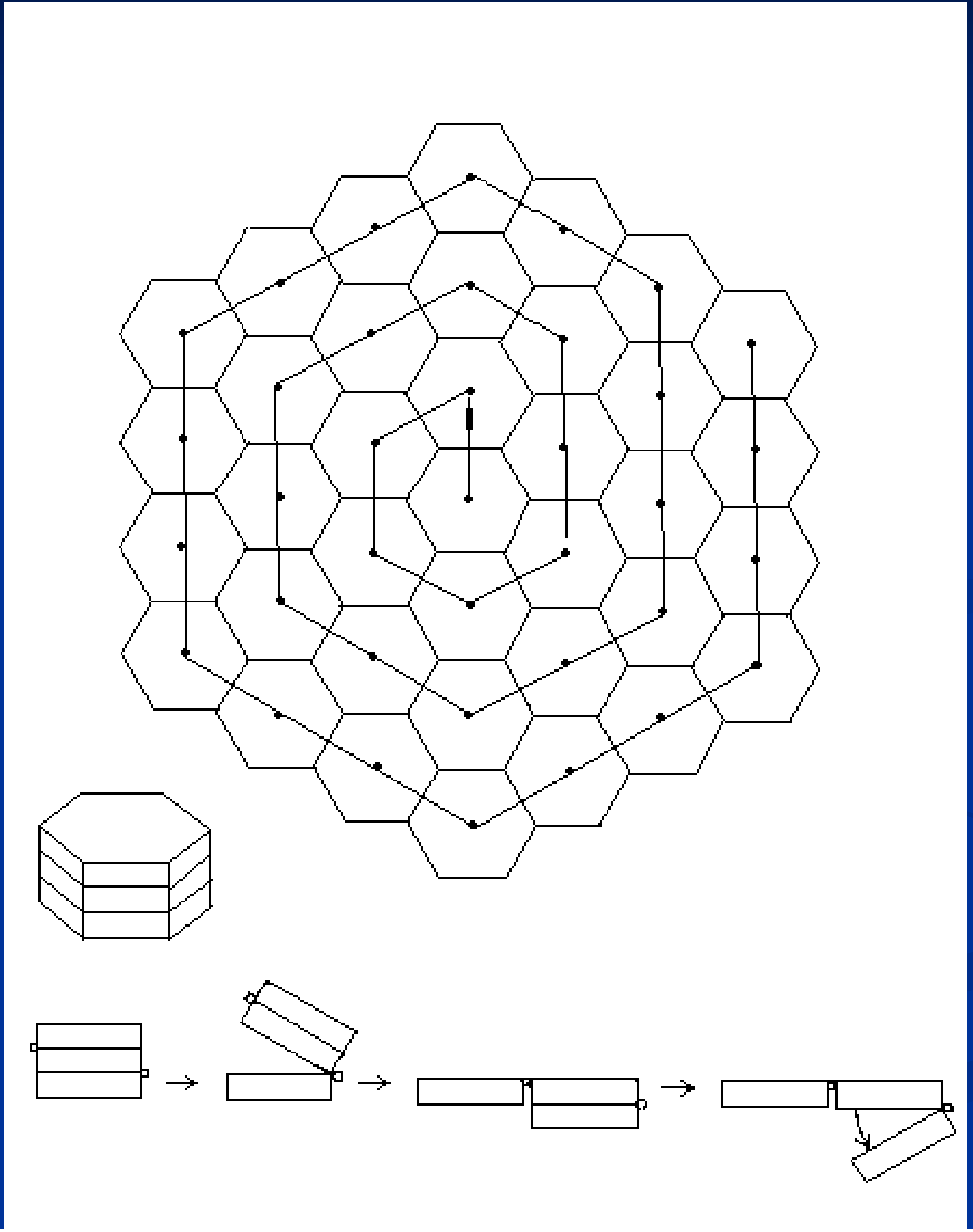
Detector mass – 200 kg,
Electric power - 200 Wt

Limited area under a rocket cover dictates the segmented mirror- concentrator design. In the TUS telescope it consisted of 6 Fresnel type mirror segments.



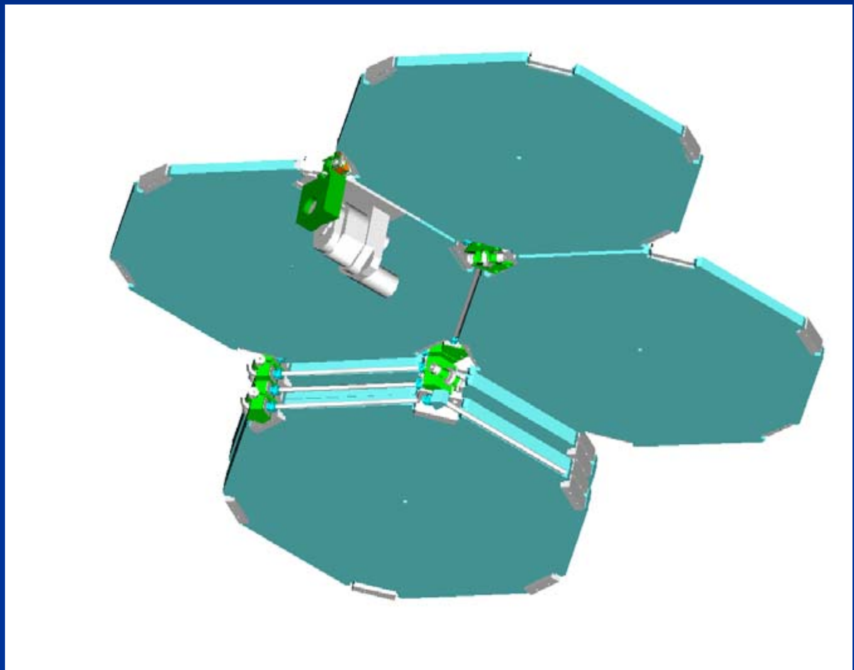
- The mirror- concentrator mass is less than 20 kg for the mirror area 1.4 m^2.
- Accuracy in mirror ring profiles ± 0.005 mm.
- Stability of the mirror construction in the temperature range from –80º to + 60º C.
- The mirror segments will make a plane with the angular accuracy less than 1 mrad.

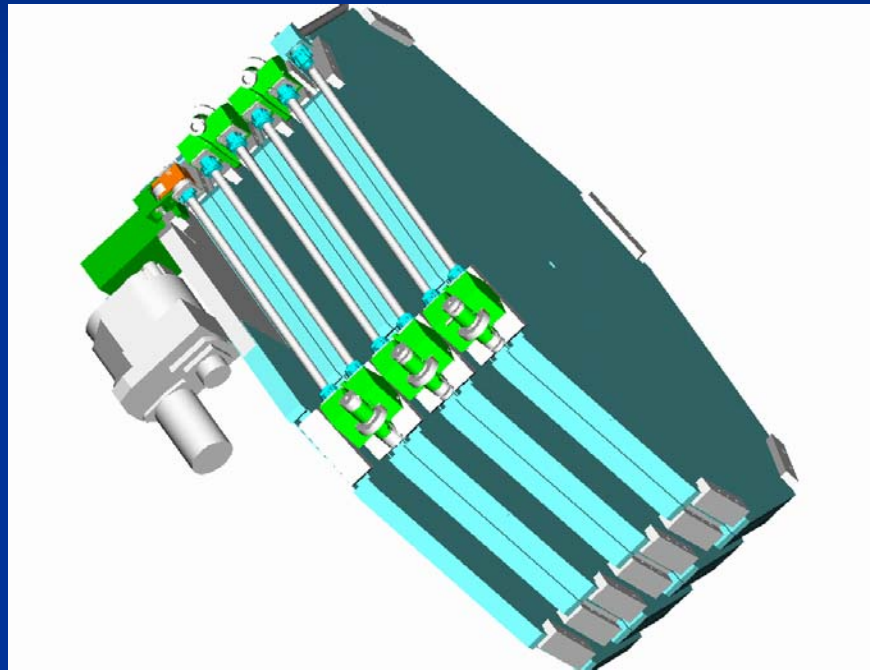
In the TUS-M/KLYPVE detector diameter of the mirror and focal distance is 3 m. Mirror area is 10 m^2 .



Number of Segments is 37.

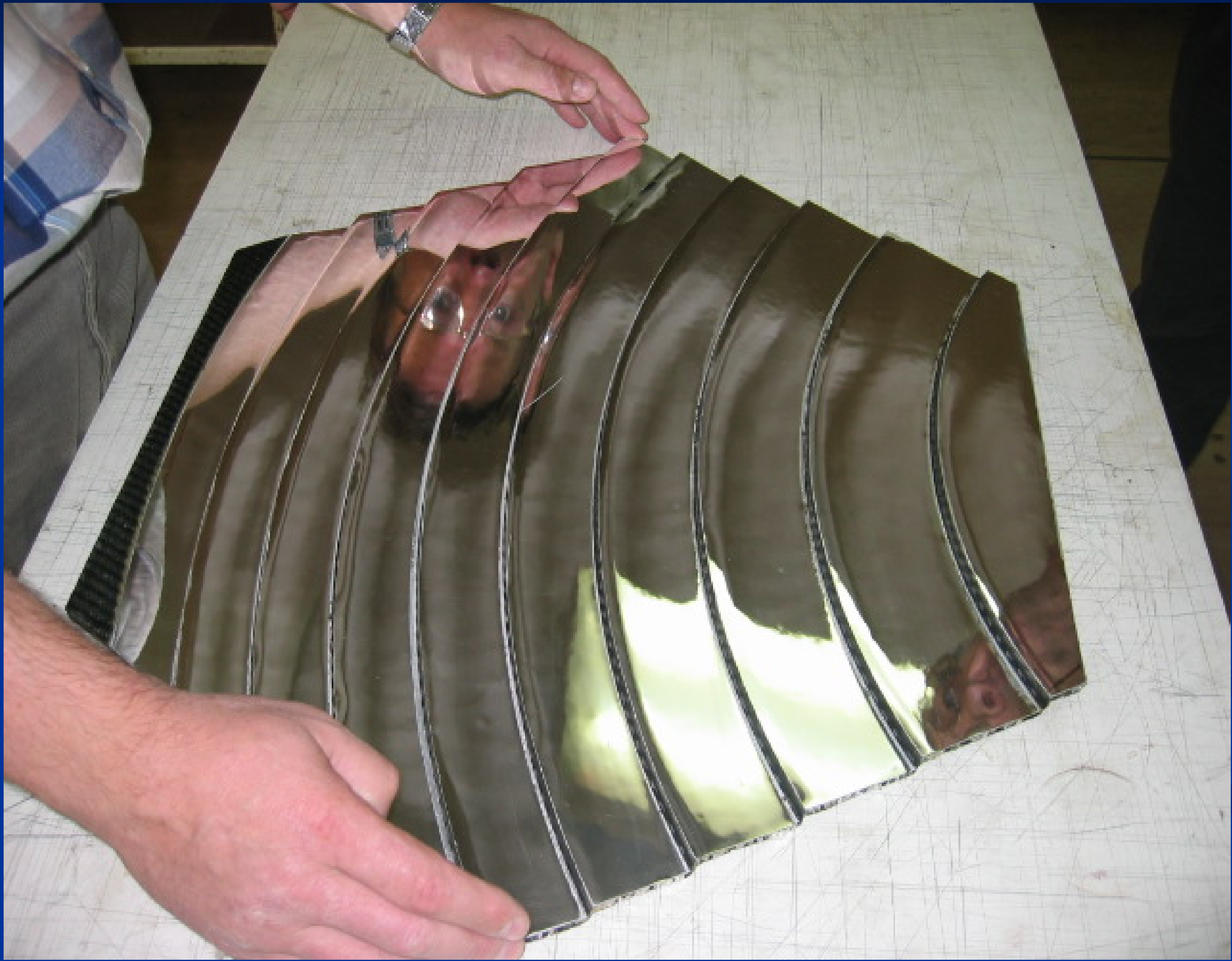
The mechanism of mirror development is designed (Consortium Space Regatta)



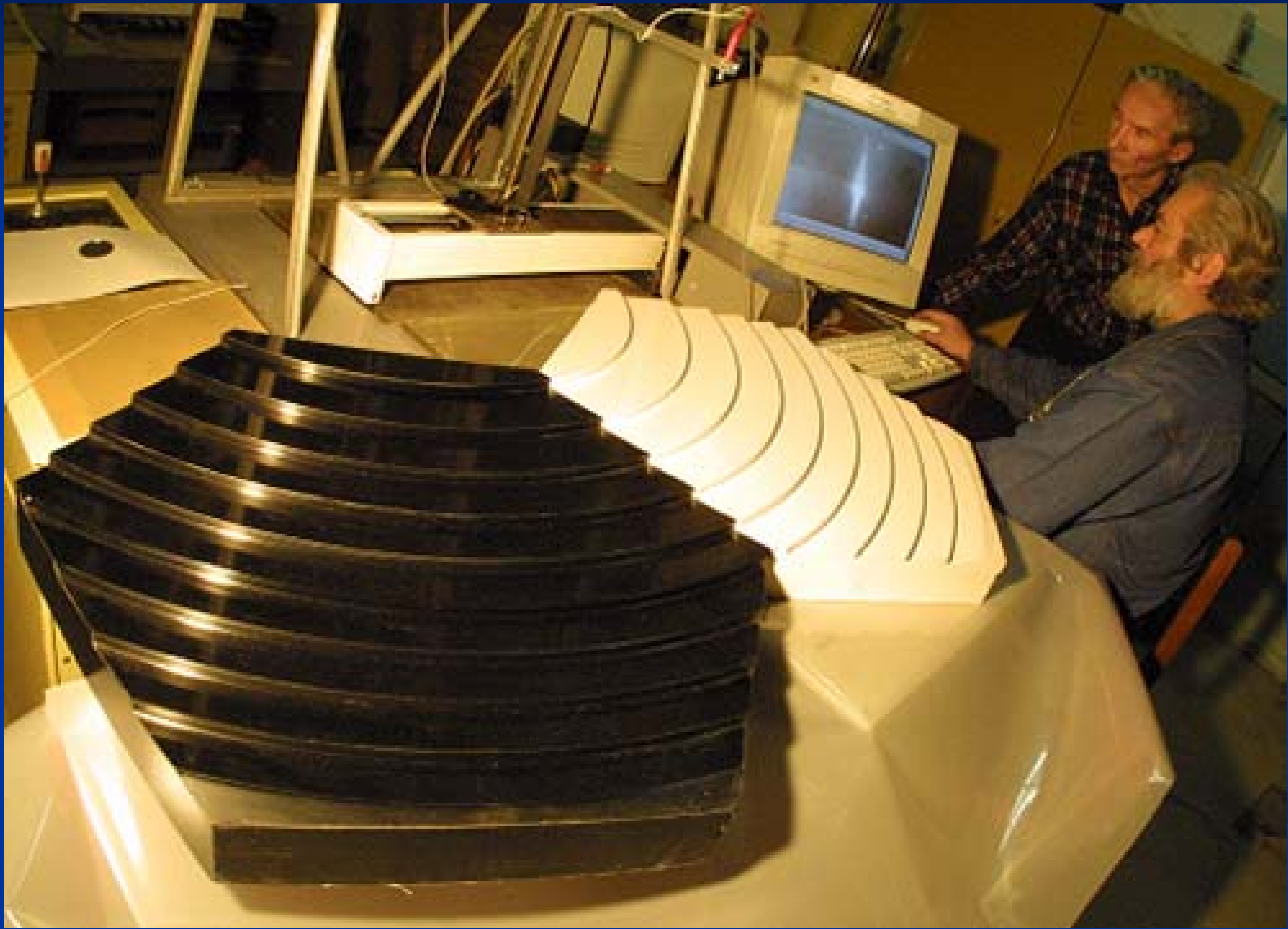


In this mechanism one electric motor moves the segments via axles and cardan joints.

A sample of the mirror segment.



The mirror replica profiles are being measured (JINR).



The mirror development mechanism is being tested (Consortium Space Regatta, RSC “Energia”).

The TUS Photo Receiver , comprising 256 PM tubes.

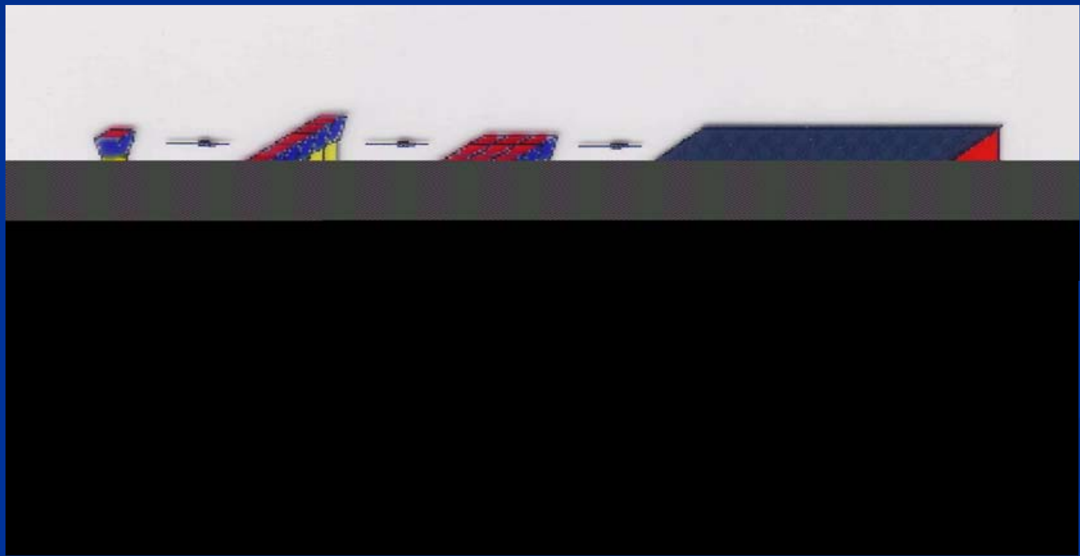
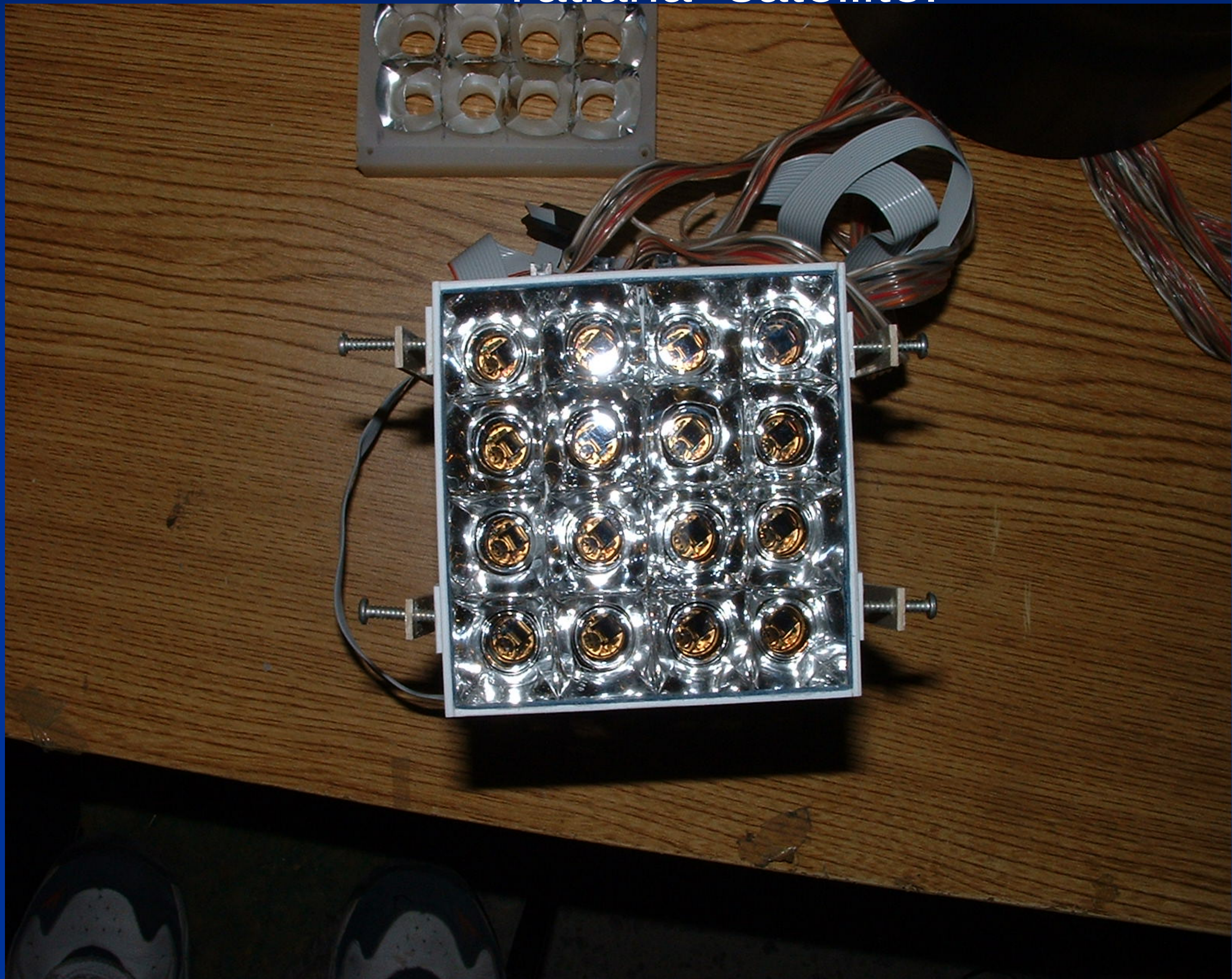


Photo receiver is consisted of 16 pixel rows and columns.

Every pixel is a PM tube (Hamamatsu R1463, 13 mm diameter multialcali cathode) with a square window mirror light guide.
16 PM tubes (a row) has a common voltage supply and are controlled by one data acquisition unit.
UV filter cover all pixel windows.

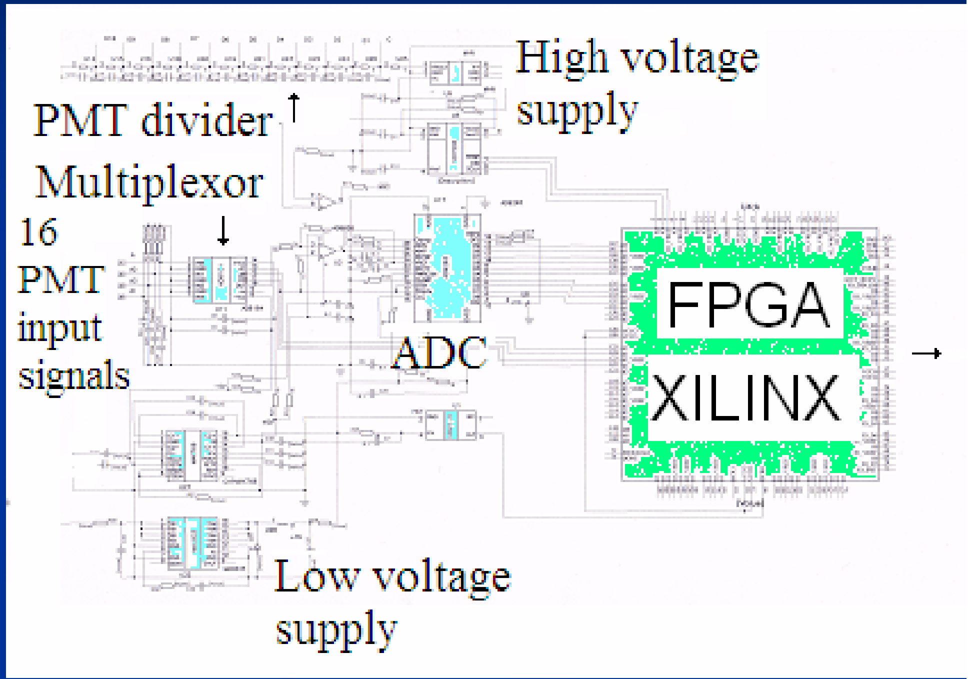
The TUS photo receiver prototype: 4x4=16 PM tubes. It was tested in the Puebla University (Mexico). Now one pixel is operating in space- as the UV detector of the “Universitetsky-Tatiana” satellite.



Electronics.

256 photo receiver pixels are grouped in 16 clusters.
In every cluster the PM tube analog signal is transmitted to one ADC with the help of multiplexer (20 MHz frequency).
Every 0.8 µsec the digital signal is recorded in the FPGA memory. The digital information is also coming to the trigger system.
The final trigger is worked out in the TUS FPGA where the map of triggered pixels is analyzed.

Energy consumption per a channel is 10 mWt. The TUS energy consumption is less than 40 Wt.

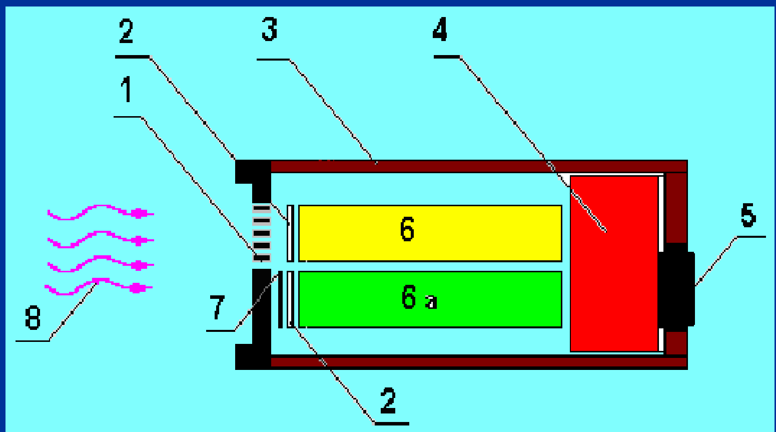


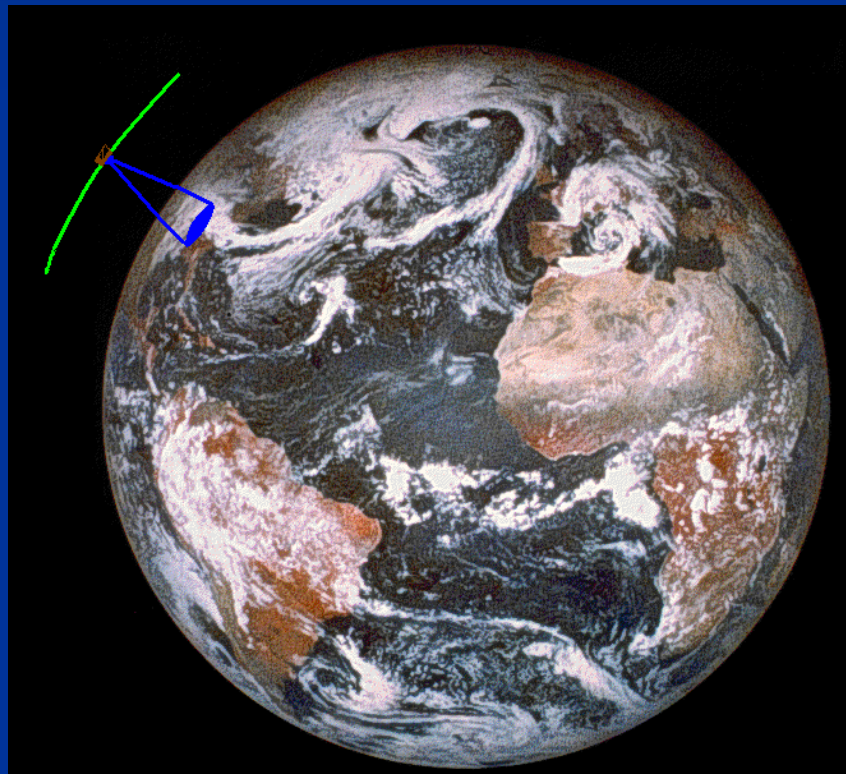
16 channels module of the TUS electronics

UV background

UV detector based on the pixel design of the TUS telescope is measuring UV from the atmosphere on board the "Universitetsky-Tatiana" satellite. Polar orbit height-950 km. Measurements started from January 2005.

UV detector





Summary of the “Universitetsky-Tatiana” detector results.

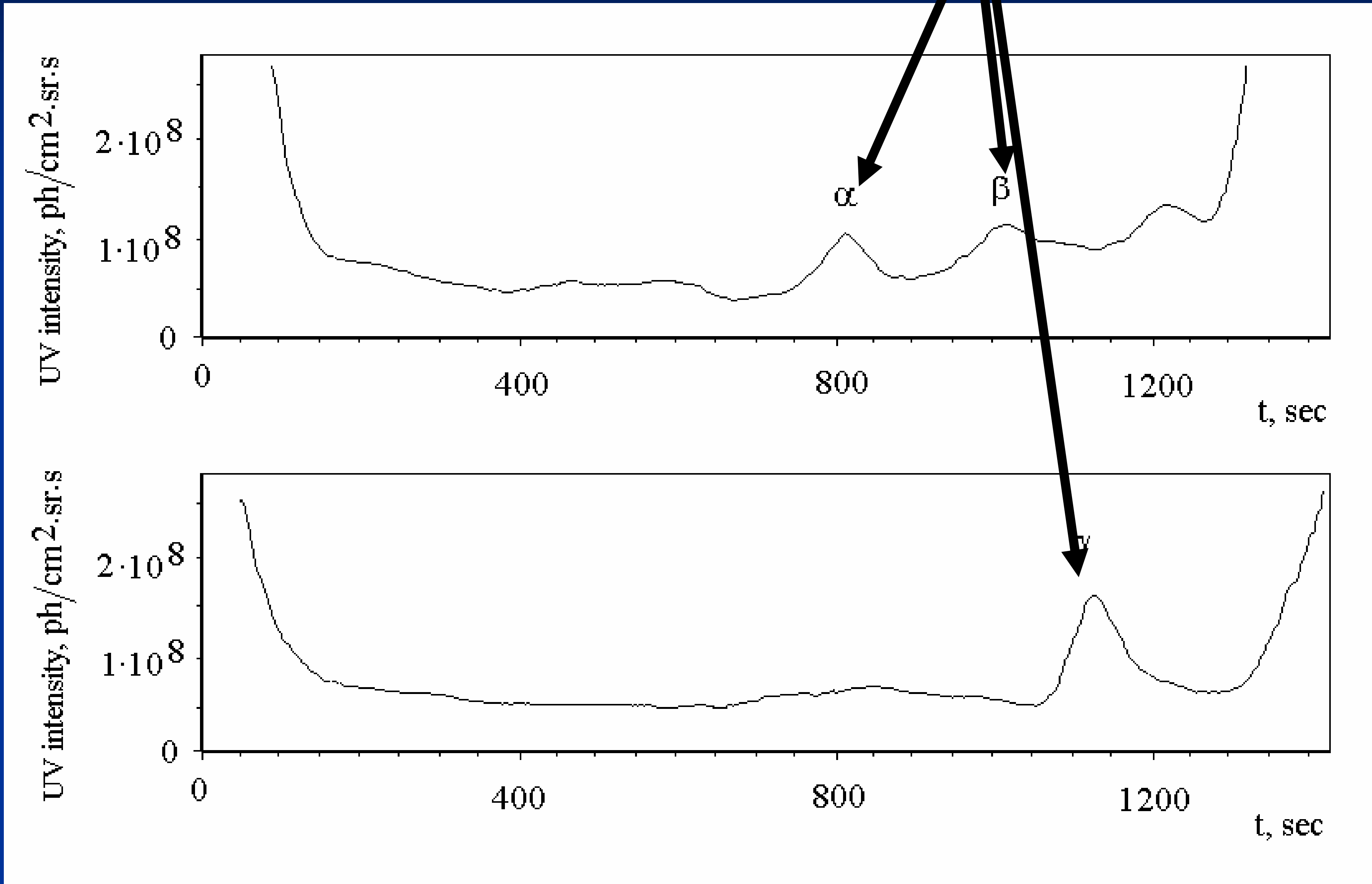
1. UV (300-400 nm) night atmosphere intensity observed from space is:

- Moonless nights: from 3 10^7 ph/cm^2 s sr to 10^8 ph/cm^2 s sr . Minimum intensity are observed in some regions above the ocean, maximum above dry continent (Australia). Lights from the brightest cities have intensity up to 2 10^8 ph/cm^2 s sr Aurora lights- up to 5 10^8 ph/cm^2 s sr
- At moon nights the maximum intensity is 3 10^9 ph/cm^2 s sr (full moon at zenith, light scattered by clouds) and it decreases with the moon zenith angle and phase.
- Minimum intensity is observed when the detector looks to the night Earth limb, it is 2 10^7 ph/cm^2 s sr .

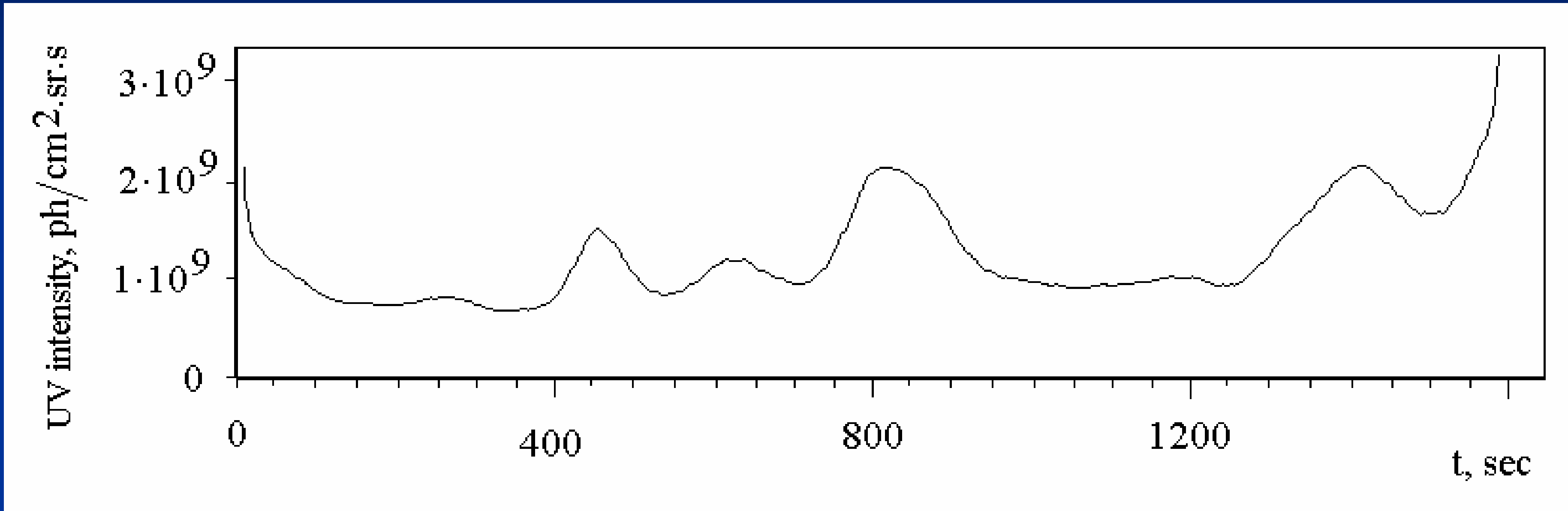
2. Background signal from the light generated by charged cosmic particles in the glass elements of the detector is negligible to compare with the atmosphere light even at the South Atlantic anomaly.

3. Extremely bright UV flashes are observed with duration of 1-100 ms. They are concentrated in the equatorial region, energy in one UV flash radiated in the atmosphere is of the order of 10^4-10^6 J. The rate of such flashes is approximately one per orbit.

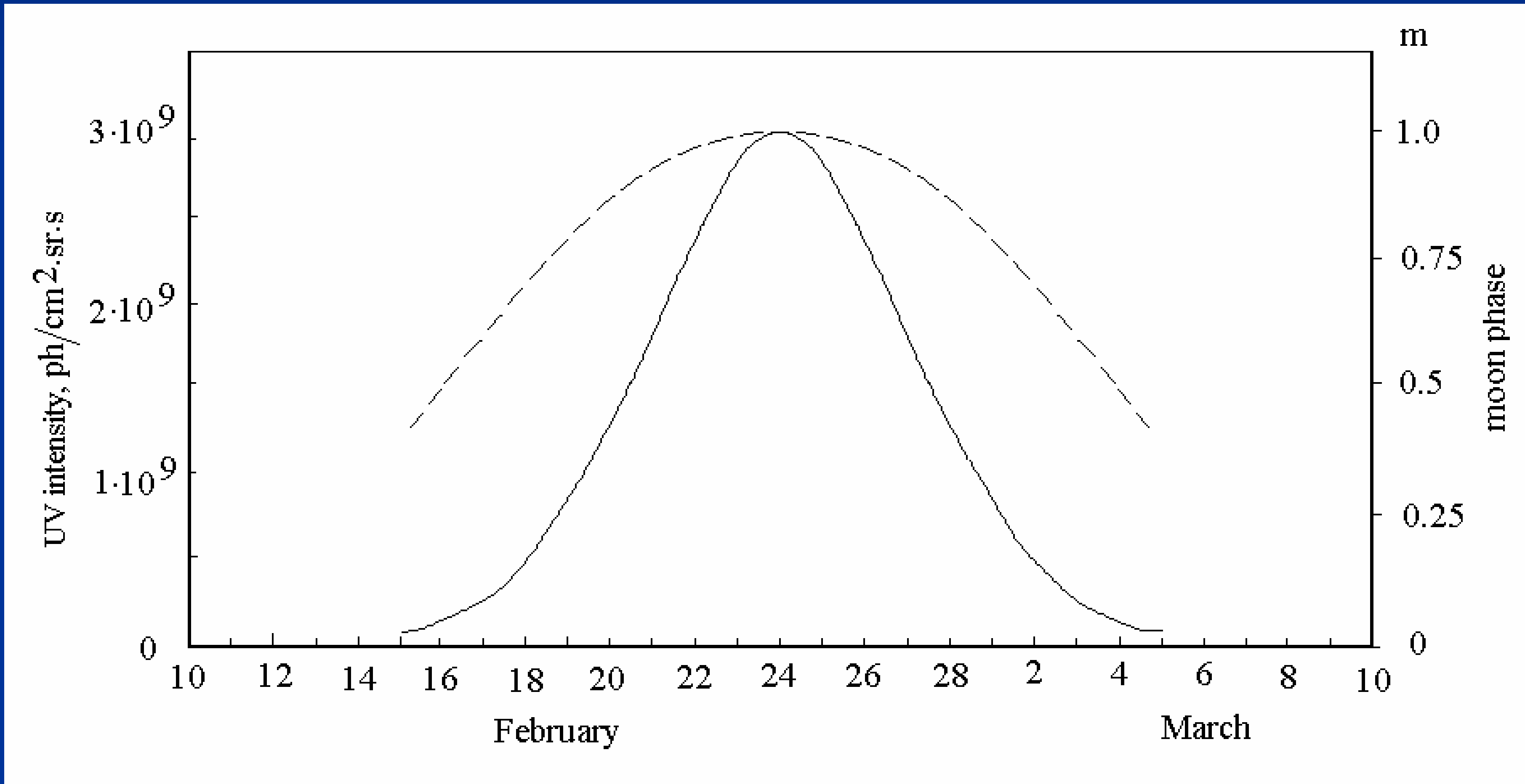
UV light intensity, measured by the “Tatiana” detector- moonless night side of the Earth. Peaks are from the large city lights.



UV intensity on the night side of the Earth at full moon.

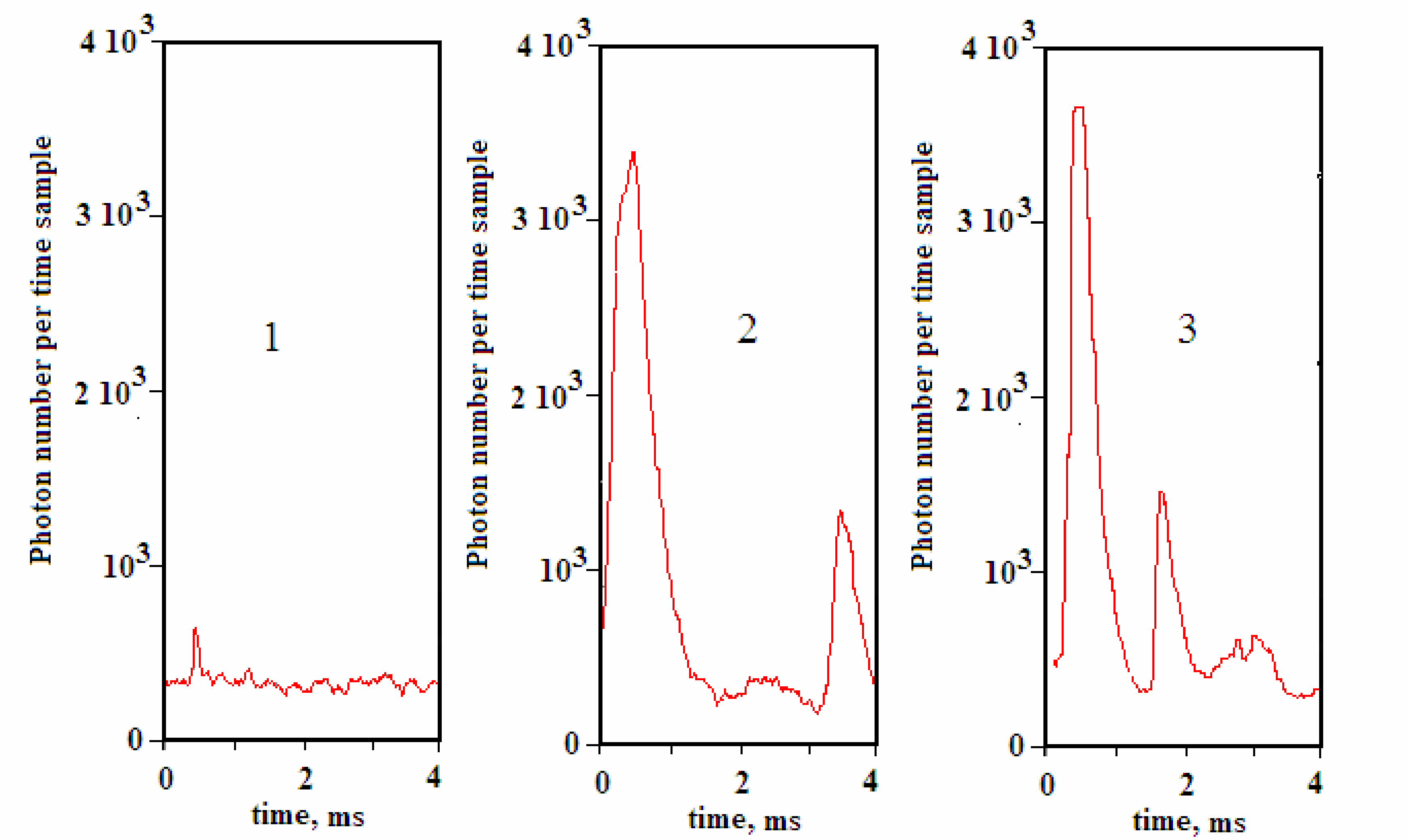


Average UV intensity per circulation (at the night side) during one moon month. Dashed line is the moon phase.
In 8 days of the moon month the average UV intensity is more than 10 times higher than at moonless night.

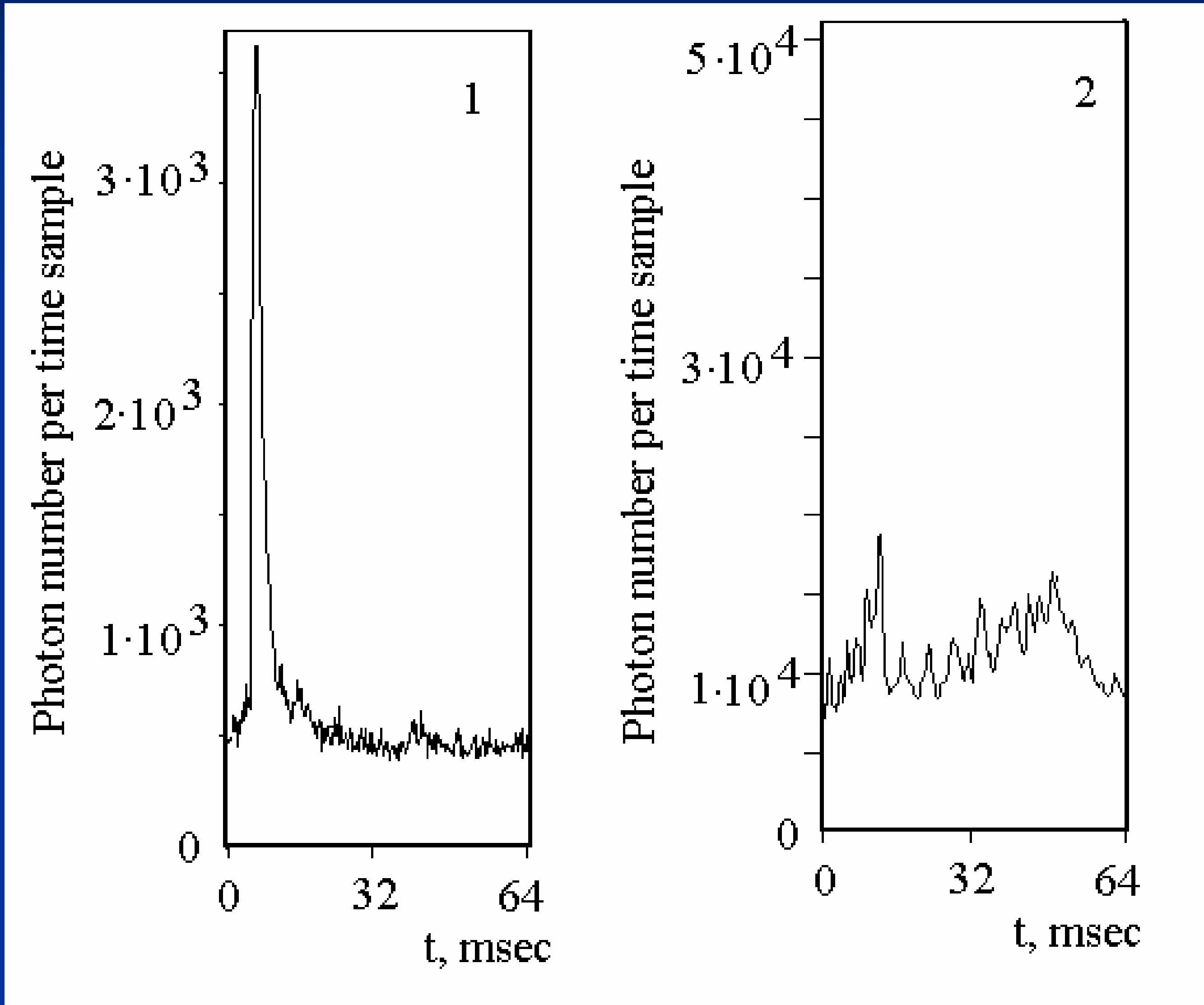


TLE’s in UV

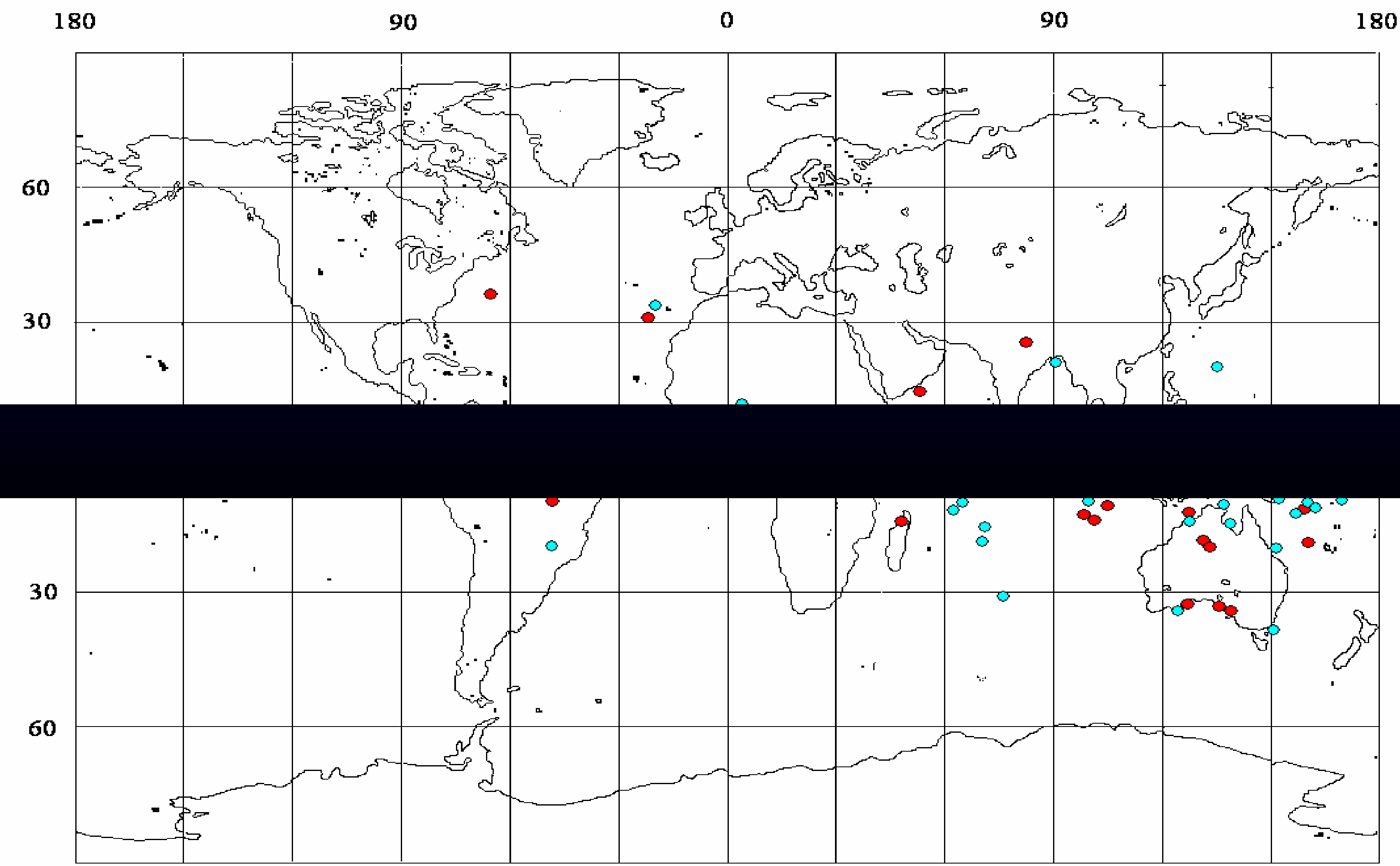
UV flashes measured by the “Tatiana” detector.
Oscilloscope trace 4 ms. UV energy in the atmosphere 10-100 kJ.



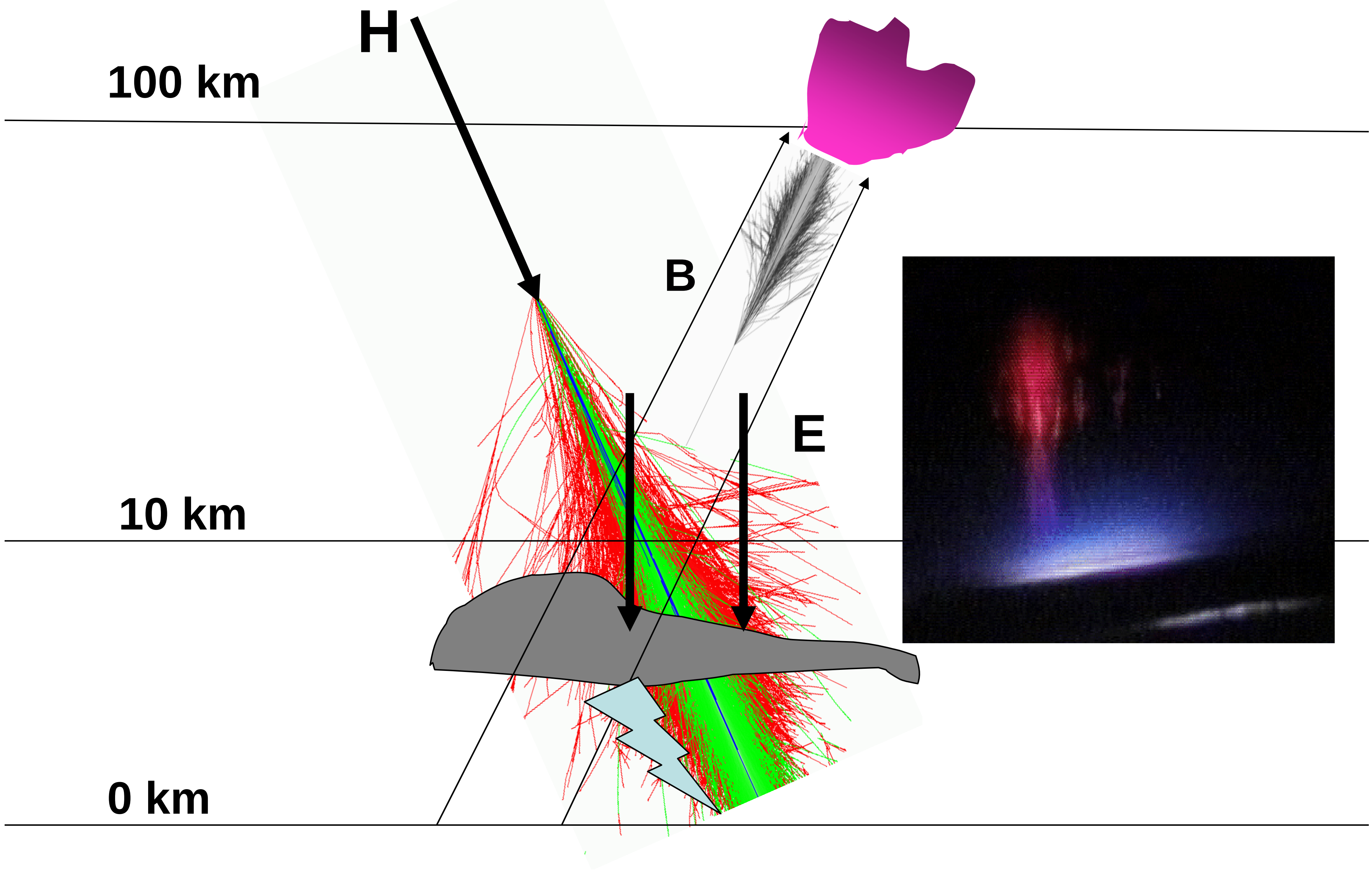
UV flashes measured by the “Tatiana” detector. Oscilloscope trace- 64 ms. UV energy in the atmosphere 0.1-1MJ.



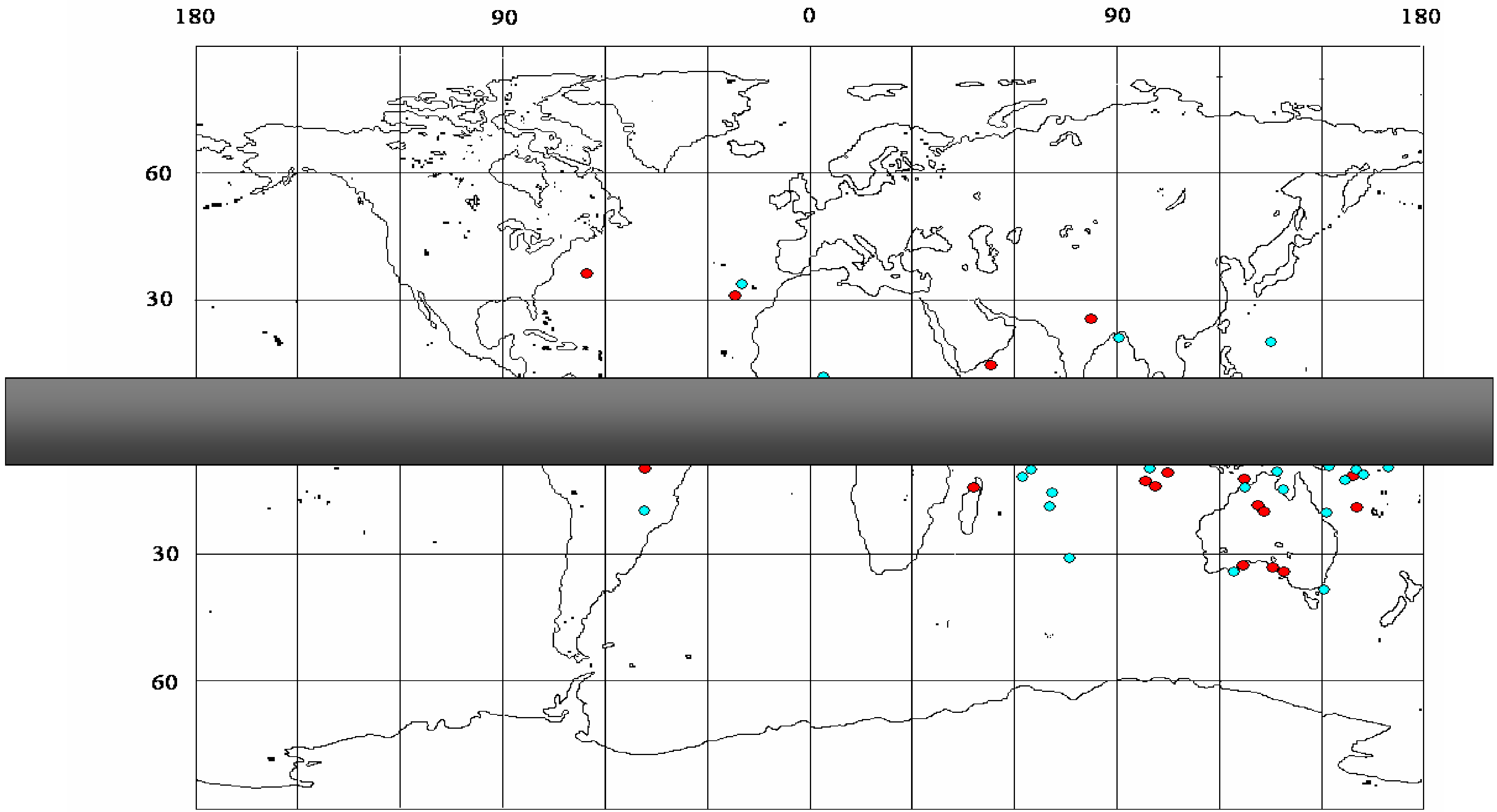
UV flash distribution over the world map. 50 of 83 registered flashes are in the equatorial belt 10º N- 10º S.



TLE's



UV flash distribution over the world map. 50 of 83 registered flashes are in the equatorial belt 10^{o} N- 10^{o} S.



TLE observstions by TUS

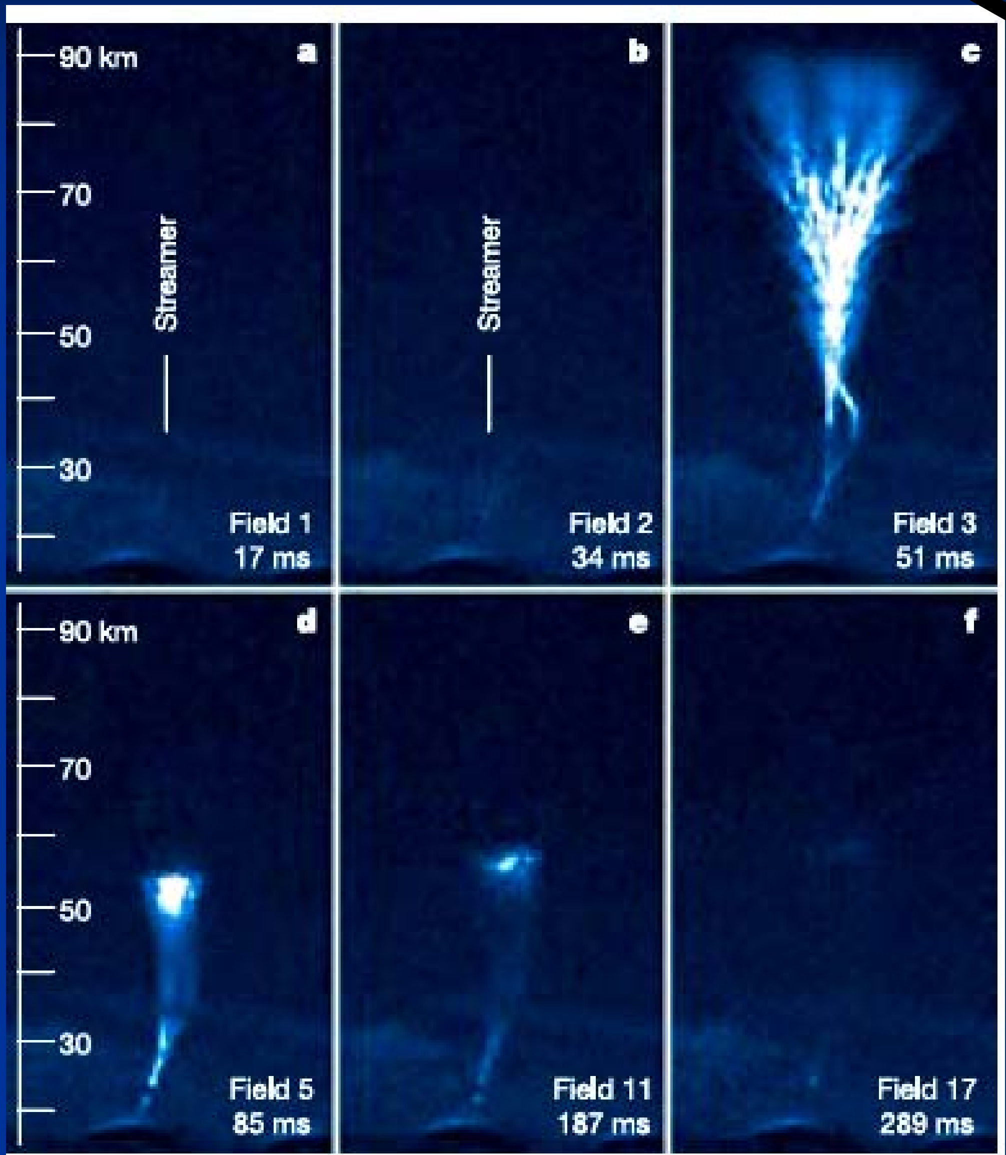
The TUS/TUS-M space detectors will be used for other researches:

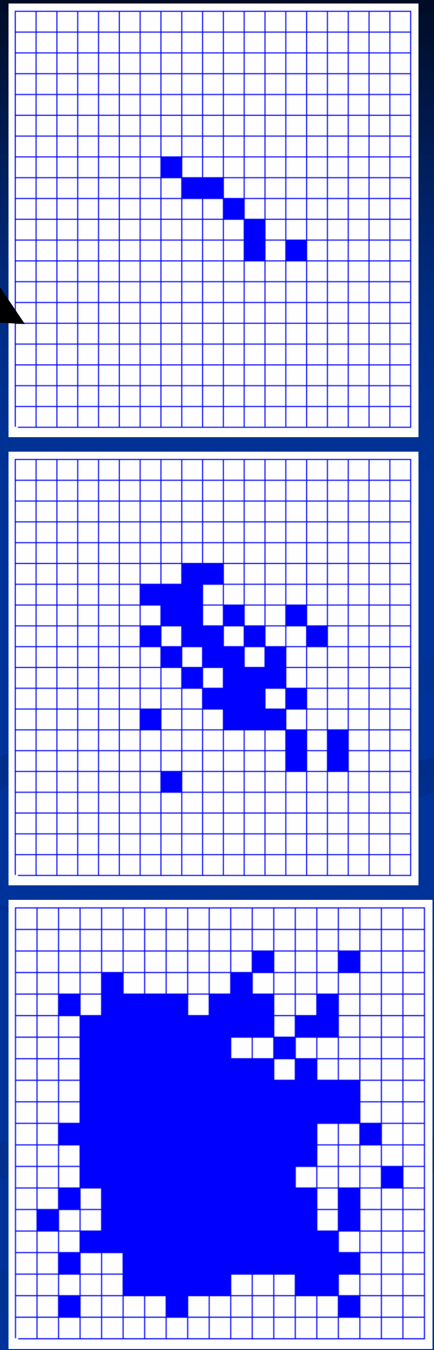
1. For observation of the UV atmosphere flashes with resolution in time 0.8 μs and in space 2-4 km. Due to large mirror aperture the sensitivity of the detector will allow to observe the beginning of the discharge in the atmosphere and to reveal the origin of the flashes.

2. For observation of the micro meteors with the kinetic energy threshold of about 100J (solar system meteors of size ~mm).

3. For a search of sub-relativistic dust grains (velocity ~10^9 -10^{10} cm/s) not observed yet by other methods.

Development of the TLE's flash in video (observed, left) and in TUS pixels (expected).





The following features of the detector are taken into account in the simulation:

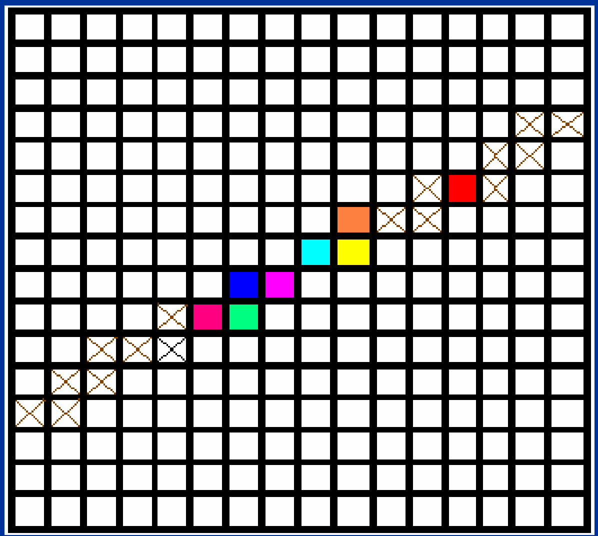
1. *Reflectivity* of the aluminum mirror- 0.83.
2. *Increasing of the focal spot with off- axis angle* (in average 2 pixels are registering signal at the TUS detector FOV edge).
3. *Light collection by the square pixel light guide* (in average 0.75 of light coming to the pixel is guided to the PM tube).
4. *Quantum efficiency* of the PM tube- 0.2.
5. *Efficiency of the measuring signal in ADC* time samples t_s =0.8 μs by front- end electronics with RC=ts .
6. *Event selection system operating in 2 steps: signal threshold in one pixel and n-fold coincidences of the neighbor pixels.*

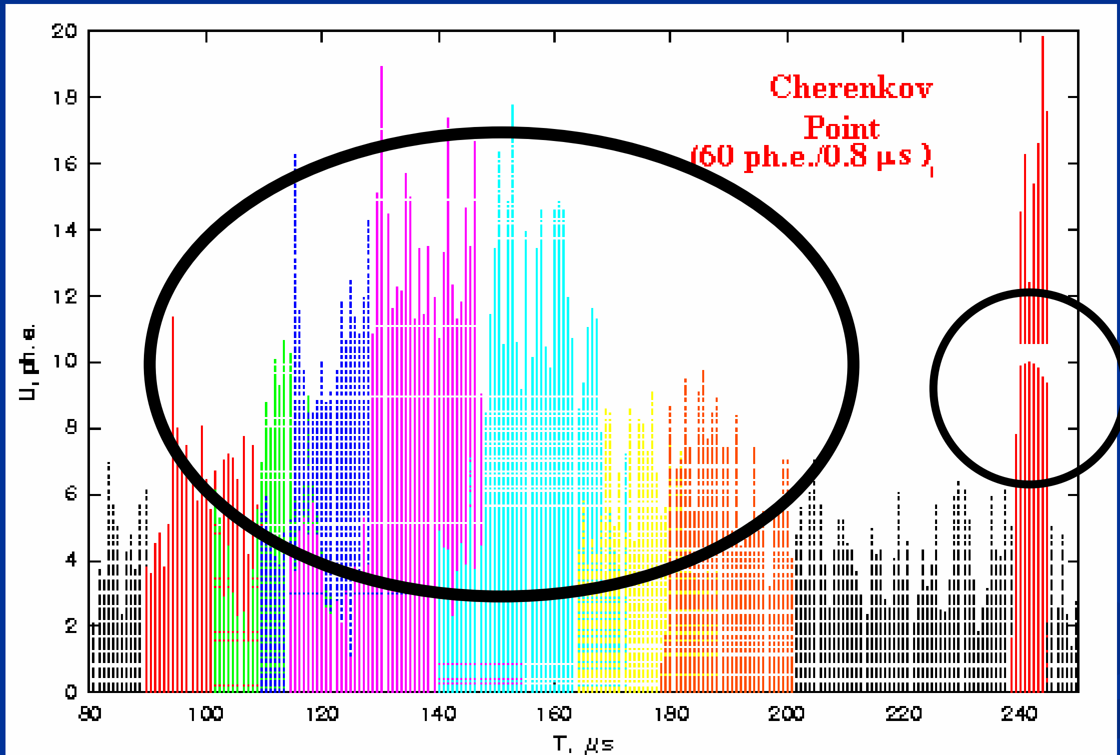
As a final result the energy threshold of the TUS/TUS-M detectors were calculated as a function of the background atmosphere UV intensity.

Simulation of EECR measurements

Example of the EAS, “measured” by the TUS-M detector

E_0=100 EeV, θ_0=75°, φ_0=25°, Moonless night; $\sigma E_0 / E_0 \sim$ 10 %, $\sigma\theta_0 \sim$ 1.5°, $\sigma\varphi_0 \sim$ 1°.

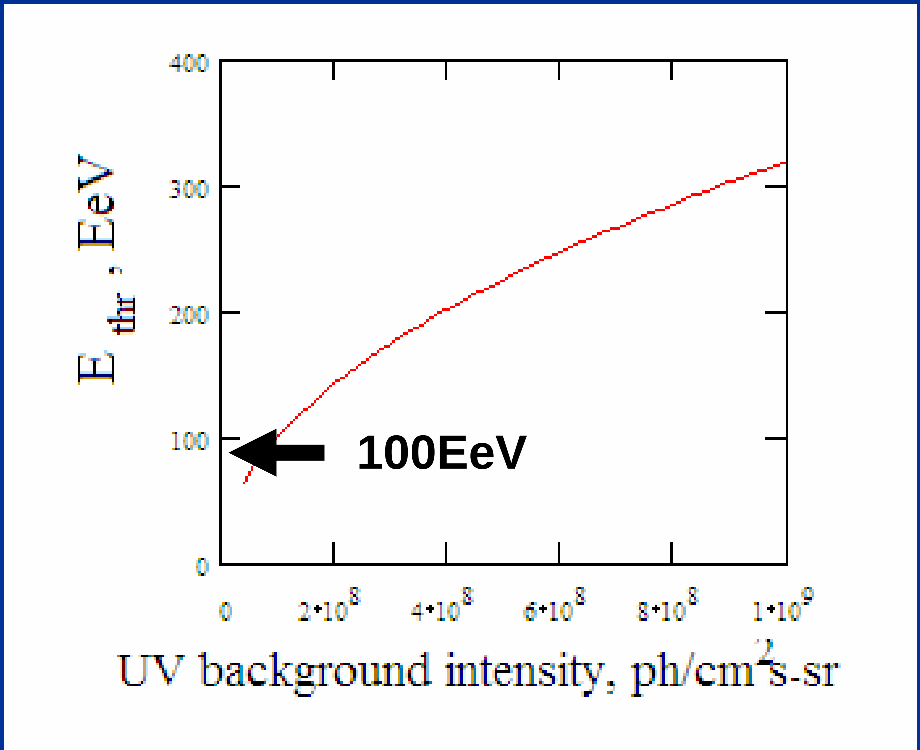




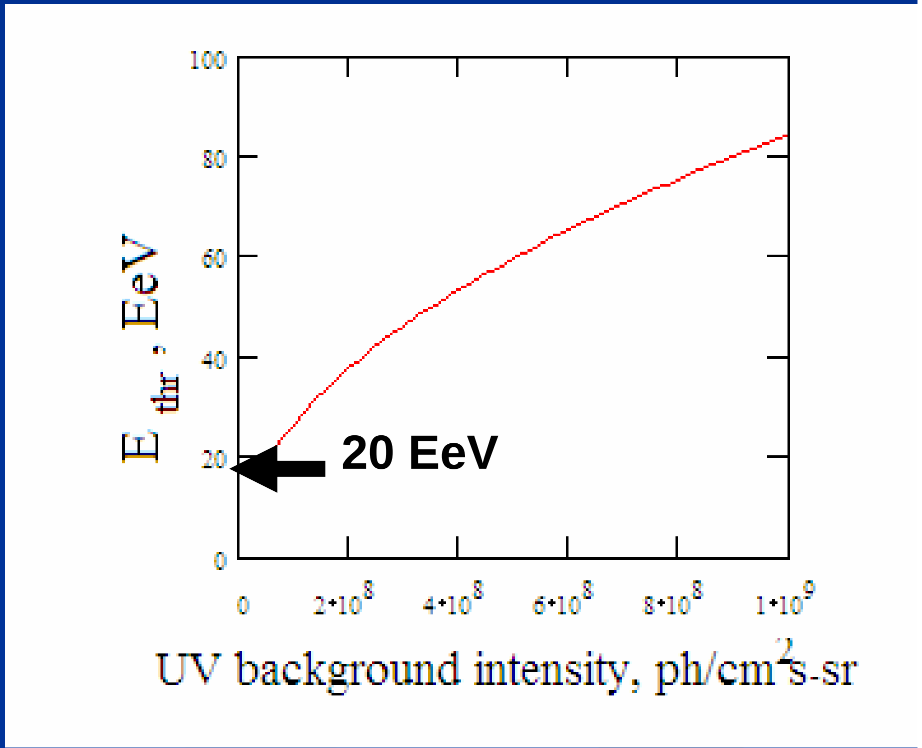
In the near horizontal tracks the scattered Cherenkov light from the atmosphere is negligible to compare with fluorescence. The Cherenkov scattered from the clouds or ground is a strong signal.

Energy threshold for TUS and TUS-M/KLYPVE detectors as a function of the background UV intensity. In EAS of E_{thr} the signal in the shower maximum is equal to 3sigma of the background and 3-fold coincidence of pixels were taken. E_{thr} **are presented in EeV**.

TUS



TUS-M



EECR events rate

The rate of EECR events measued by the space detector depends on the time available for observation at the night side of the Earth.

For the orbit with inclination 52º (ISS) the expected duty-time during one year is:

moon phase <40%, UV intensity <10^8 ph/cm^2 s sr)- **1350 hours**,

moon phase <75%, UV intensity <2 10^8 ph/cm^2 s sr) – **2050 hours**.

The TUS geometrical factor for measuring EAS of zenith angles 50º -80º is **5000 km^2 sr**.

The new energy Auger calibration predicts the low intensity of EECR events (E_{thr} =100 EeV) : 0.0035 events/km^2 sr year (twice lower than AGASA had).

So, in the TUS detector we expect 4 events per year (Ethr =100 EeV) .

Operation of the TUS-M detector is more effective in collection of lower energy events: in one year of operation it will detect of about 150 events above the energy threshold 20 EeV.

Conclusion

1. The space experiments will give an independent evidence for EECR particles and their rate. The space observation has the advantage of whole sky coverage by one and the same detector.

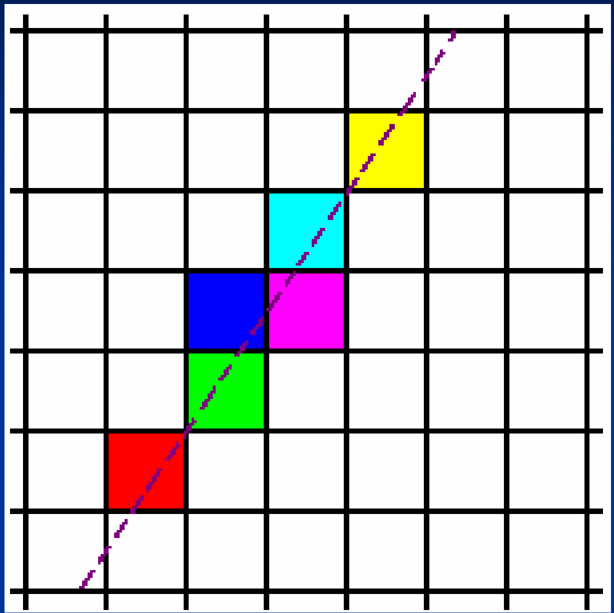
2. The main goal of the first TUS experiment is to approve the new method of space observation of EECR and its techniques.

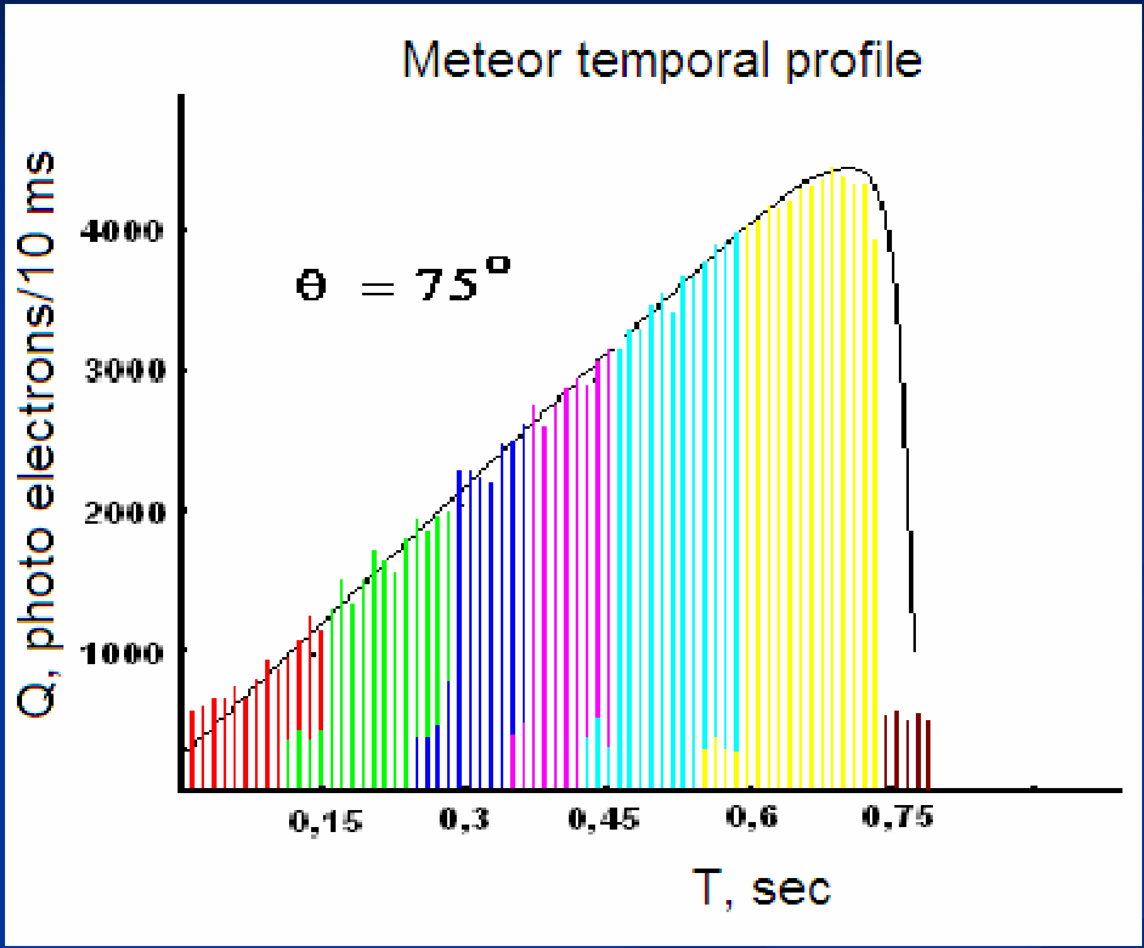
3. Other phenomena of fluorescence light in the atmosphere (UV flashes in the atmosphere electric discharges, micro meteors, sub-relativistic dust grains) could be studied by the TUS- type detectors.

4. The experience in operation of the first simple imaging fluorescence detectors will help to design the wide FOV imaging detectors.

Thank you

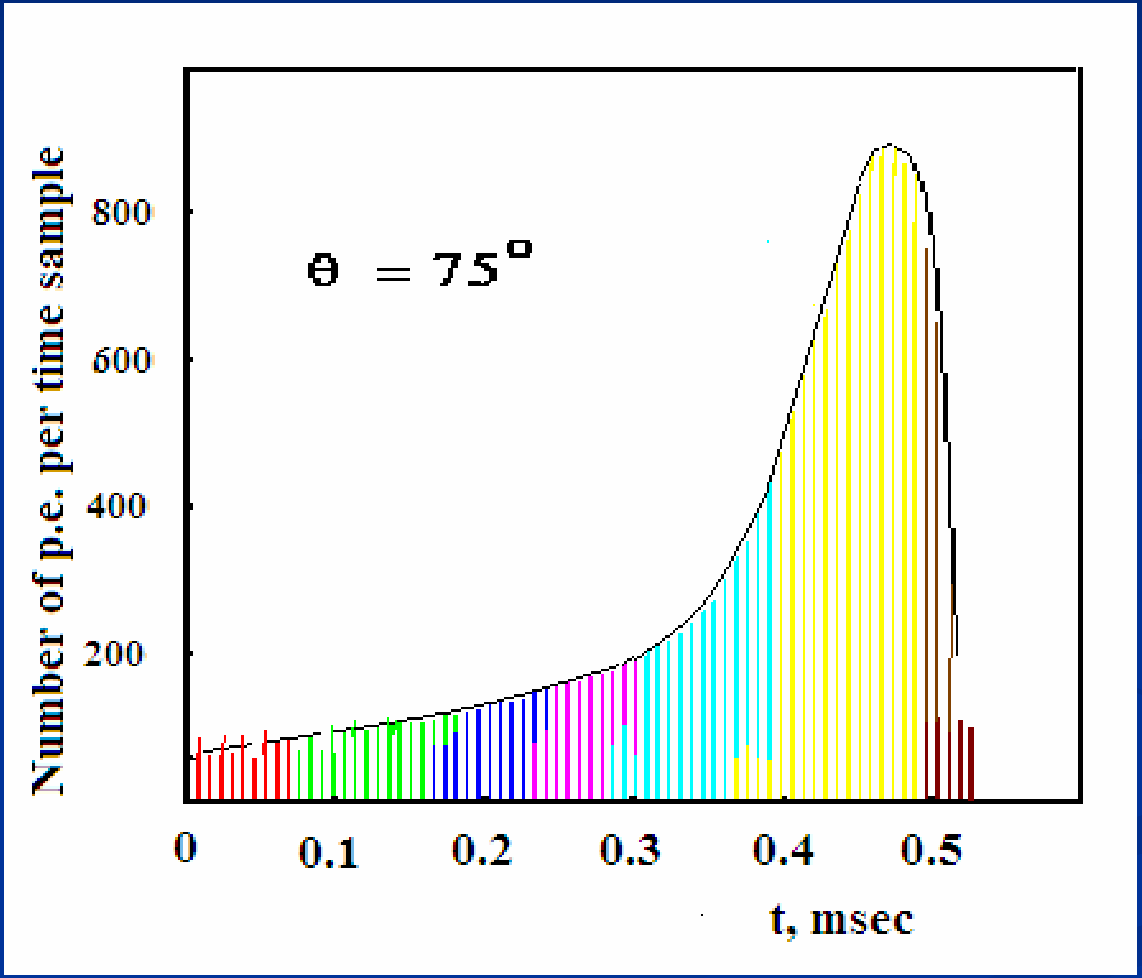
Simulation of the micro meteor registration by TUS



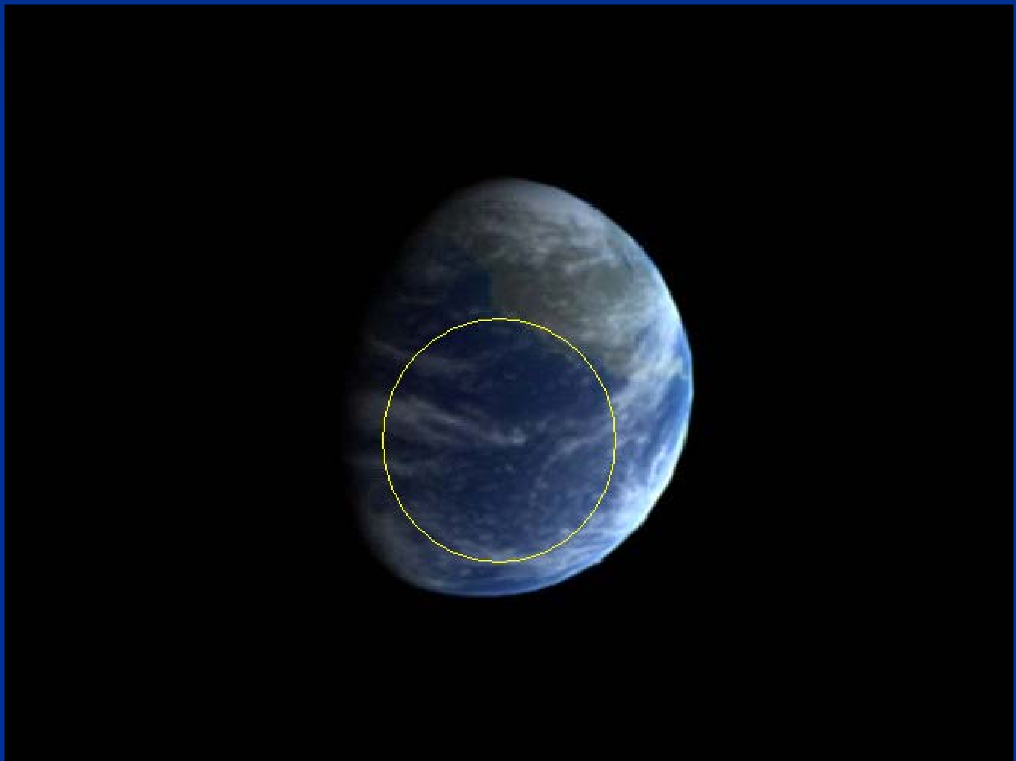


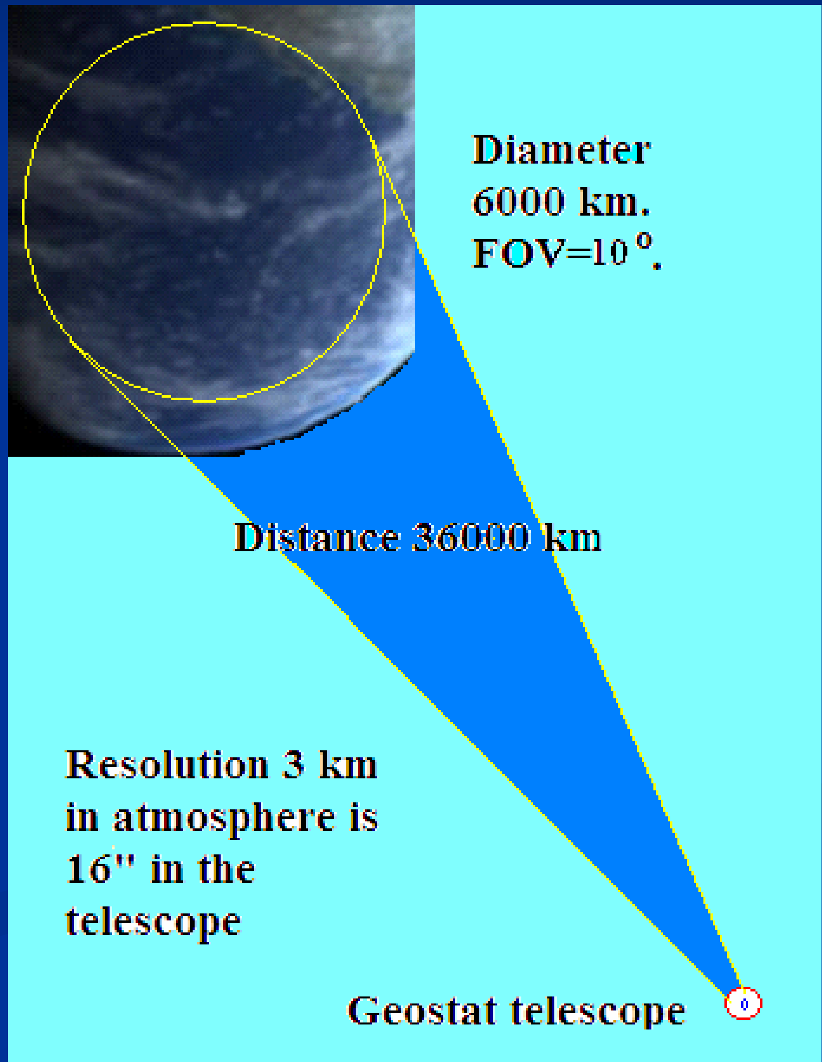
The meteor threshold kinetic energy – 100J. Expected rate- 100 per day.

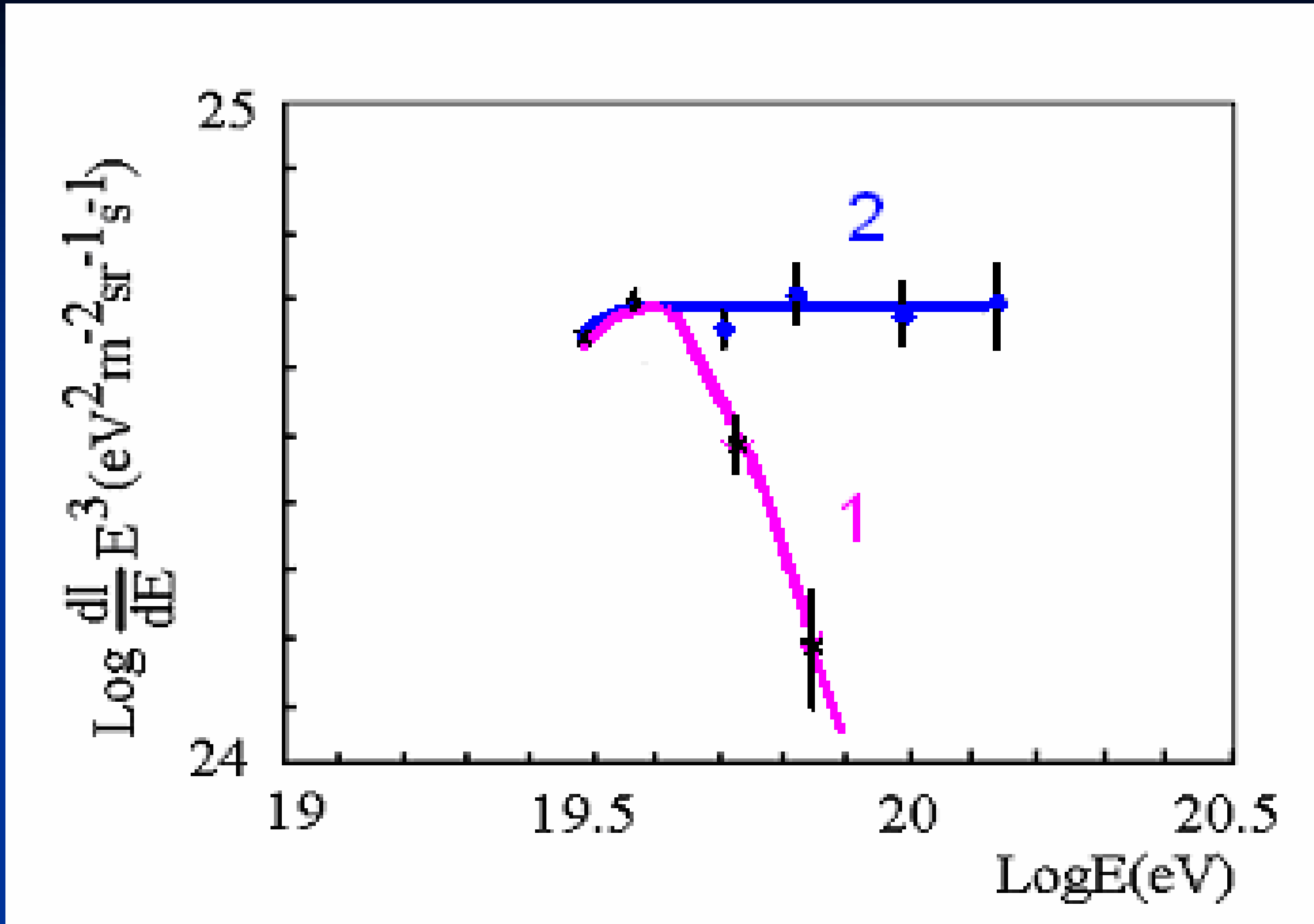
Expected signal profile from the sub-relativistic (velocity 10^{10} cm/s) dust grain. Energy 20J.



Telescope on the geostationary orbit. Mirror diameter 30 m, resolution 16’’ (3 km in the atmosphere). Energy threshold 10^{20} eV. Observed area $3x10^{7}$ km^2 . Future observation of EAS, initiated by UHE neutrinos.







Energy spectrum of EECR expected as a result of the TUS operation in 2 years. 1- as predicted by data of Yakutsk and HiRes, 2- as predicted by data of AGASA.