GRB Experiments on-board of LOMONOSOV Satellite

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On behalf of the "Lomonosov" collaboration:

EWHA Woman University, Korea; Instituto de Astrofisica de Andalucia, Spain; National Taiwan University, Taiwan; Skobeltsyn Institute of Nuclear Physics, Lomonosov Moscow State University, RF; University of California Berkeley, USA; University of Paris-Sued 11, France; University of Valencia, Spain

GRB2012, Munich, 7-11 May, 2012

Lomonosov (19.11.1711-15.04.1765) as a Physicist:

He regarded heat as a form of motion, suggested the wave theory of light, contributed to the formulation of the kinetic theory of gases, and stated the idea of conservation of matter in the following words: "All changes in nature are such that inasmuch is taken from one object insomuch is added to another. So, if the amount of matter decreases in one place, it increases elsewhere. This universal law of nature embraces laws of motion as well, for an object moving others by its own force in fact imparts to another object the force it loses" (first articulated in a letter to Leonhard Euler dated 5 July 1748).

Lomonosov –Astronomer: has suggested existence of atmosphere of Venus!

Optical emission of gamma-ray bursts and ways of its observations

Prompt emission

Comes directly from source of the GRB, detected as gamma emission with duration from few ms up to minutes;

Carrier of information about the **source**.

Afterglow

Emission is born as a result of interaction of the GRB jets with the environment. Intensity decays as a power law in time and can be observed about several days. Carrier of the information on the CB **environment** near and far from the GRB central engine.

In order to study prompt emission we will not re-point optical camera to GRB position, because it takes too long.

We will rather use camera with the wide FoV and do hope for the significant number of GRBs to happen inside of FoV.

"LOMONOSOV" SPACE MISSION

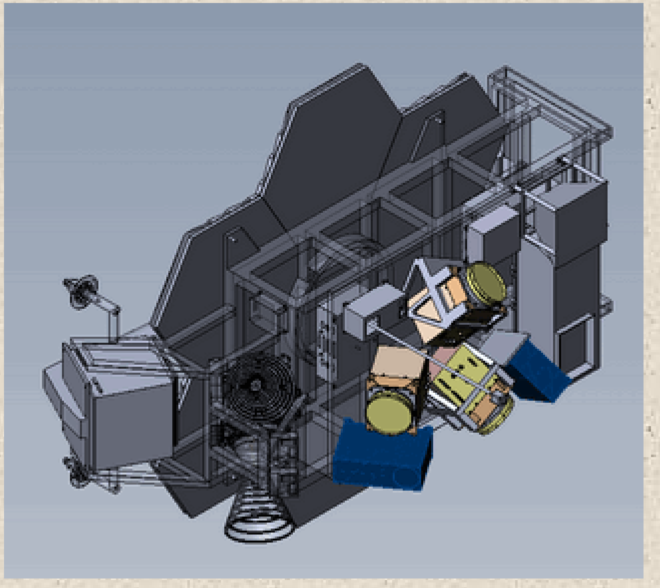
Will be launched in the second half of 2012

Scientific objectives:

- Study of transient events at hard x-ray and soft gamma-ray energies (0.05-1.0 MeV)
- Search and detection of optical transients accompanying GRBs
- Study of transient events in the Earth atmosphere at UV, X-rays
- Study of ultra-high energy cosmic rays → synergy with GRBs
- Earth magnetosphere research

Complex of instruments to study GRBs:

- BDRG – gamma spectrometer
- SHOK – wide field optical camera
- UFFO – composed of the coded mask X-ray telescope, and of UV telescope



Parameters of mission:

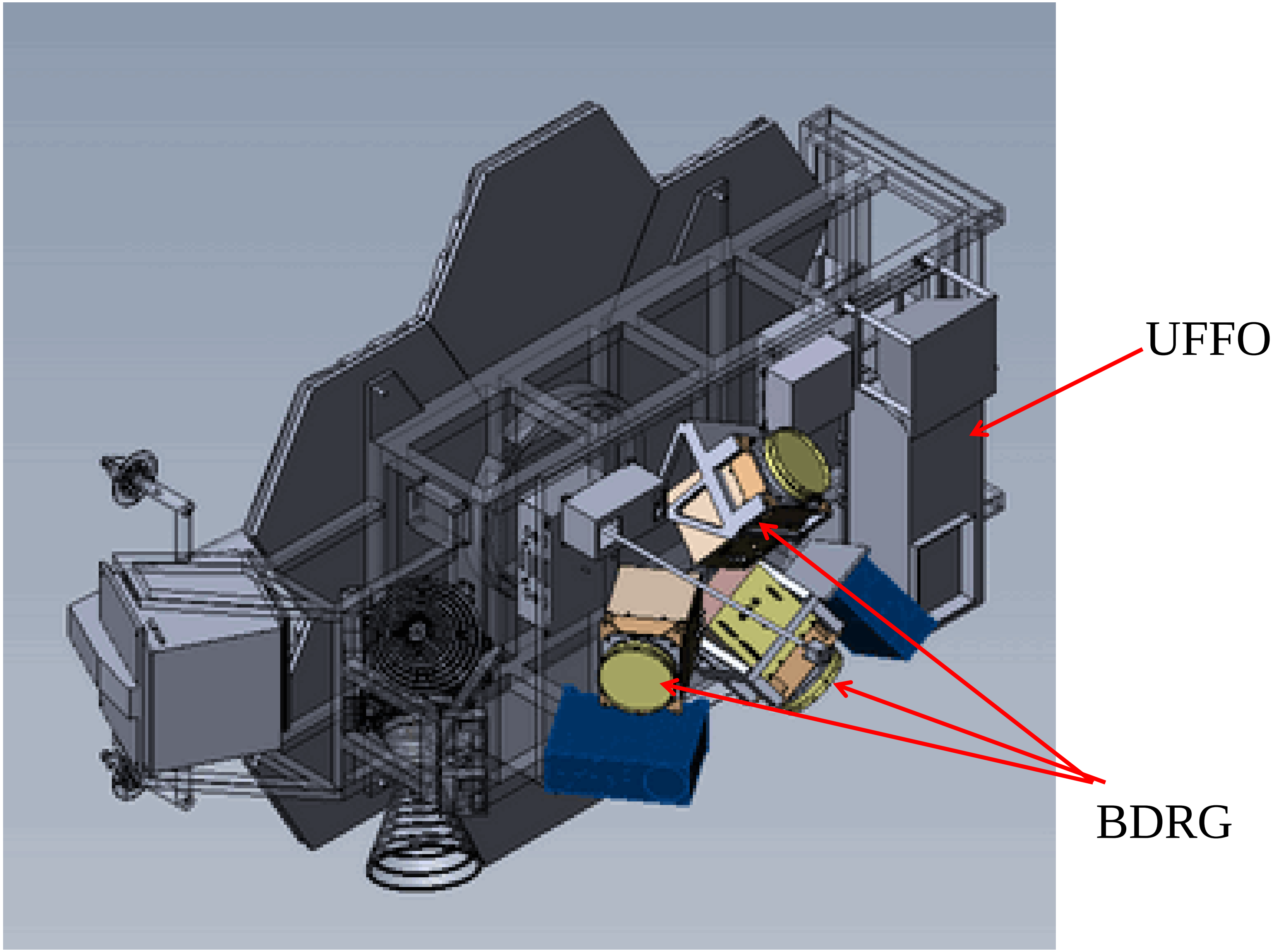
Orbit: 550 km, solar-synchronous

Mass: Spacecraft ~400 kg; Scientific payload ~120kg

Total power ~ 300W

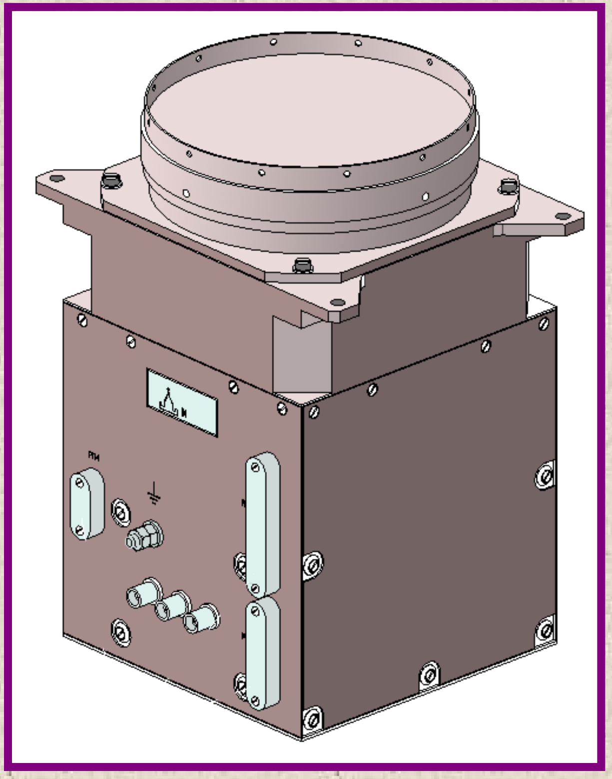
Launch time – fall 2012

Complex of instruments to study GRB:



BDRG on-board “Lomonosov”

1. Produce GRB trigger for SHOT
2. Spectral measurements and timing of GRB at hard x-ray and gamma energies
3. Estimation of GRB coordinates
3. X-ray and gamma-ray all-sky monitoring



BDRG instrument will consist of 3 identical detectors, and the data analysis unit.

Parameters of each BDRG detector:

Scintillators: 3mm NaI(Tl) +17mm CsI(Tl)
Sensitive area: ~133cm^2
Energy range: 0.01 – 3 MeV
Mass: 5.5 kg
Power: <3W
Power consumption of one unit ~18W

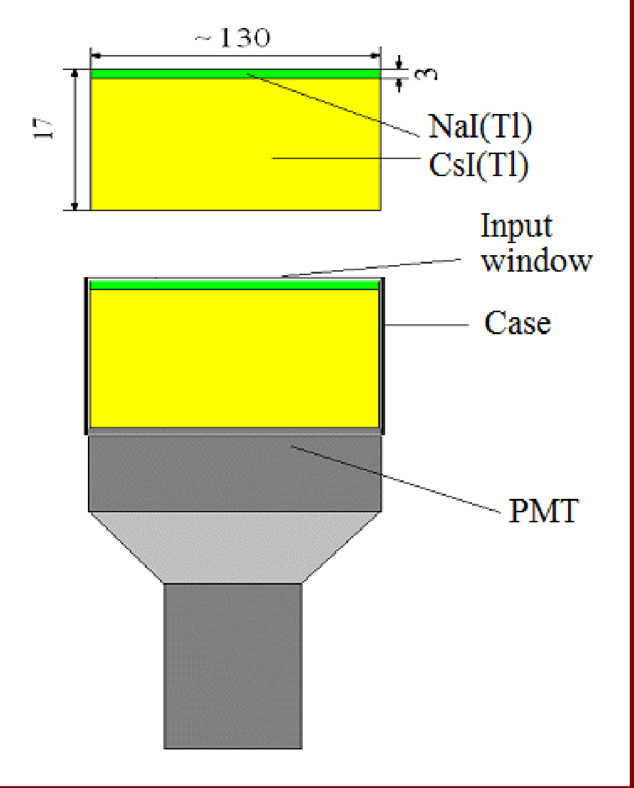
Sensitivity limit - ~10^{-8} erg/cm^2
GRB localization- ~2^o for (very) bright GRBs

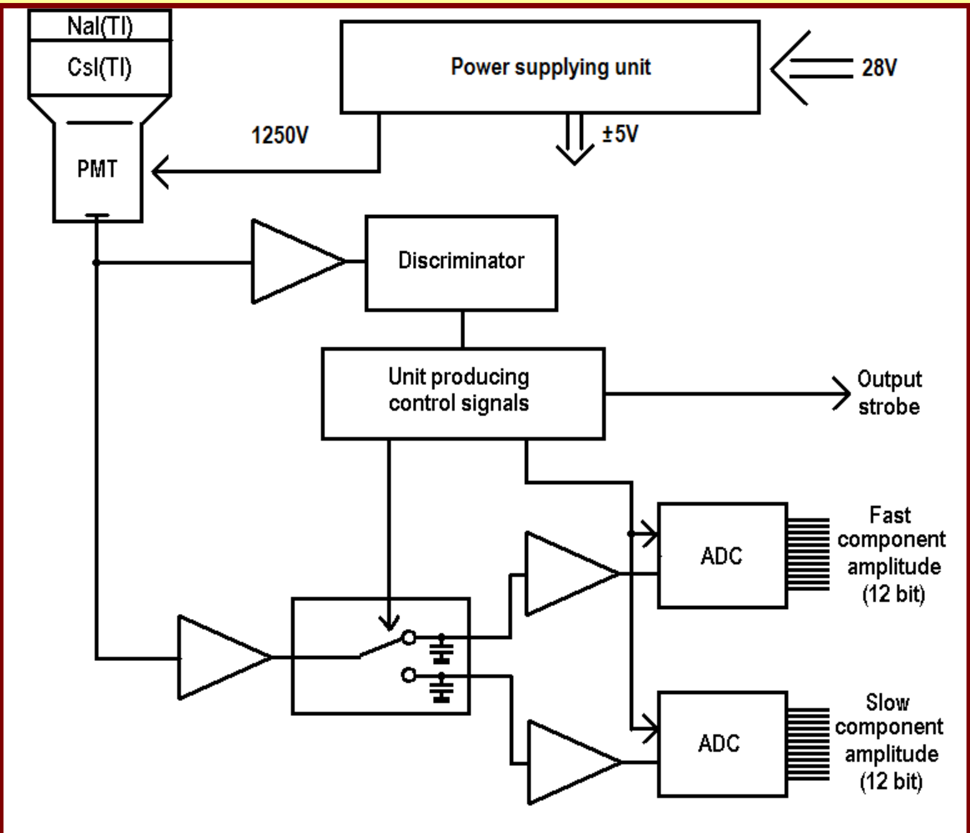
BDRG detector unit

Detector consists of optically coupled thin (3mm) NaI(Tl) with considerably thicker (17mm) CsI(Tl) crystal.

Thickness of NaI(Tl) is optimized for soft part of energy range. CsI(Tl) plays a role of active shield for the soft radiation, and is main detector for the hard one.

Energy ranges are 0.01-0.5 MeV for NaI(Tl) and 0.05-3 MeV for CsI(Tl) crystals, accordingly.



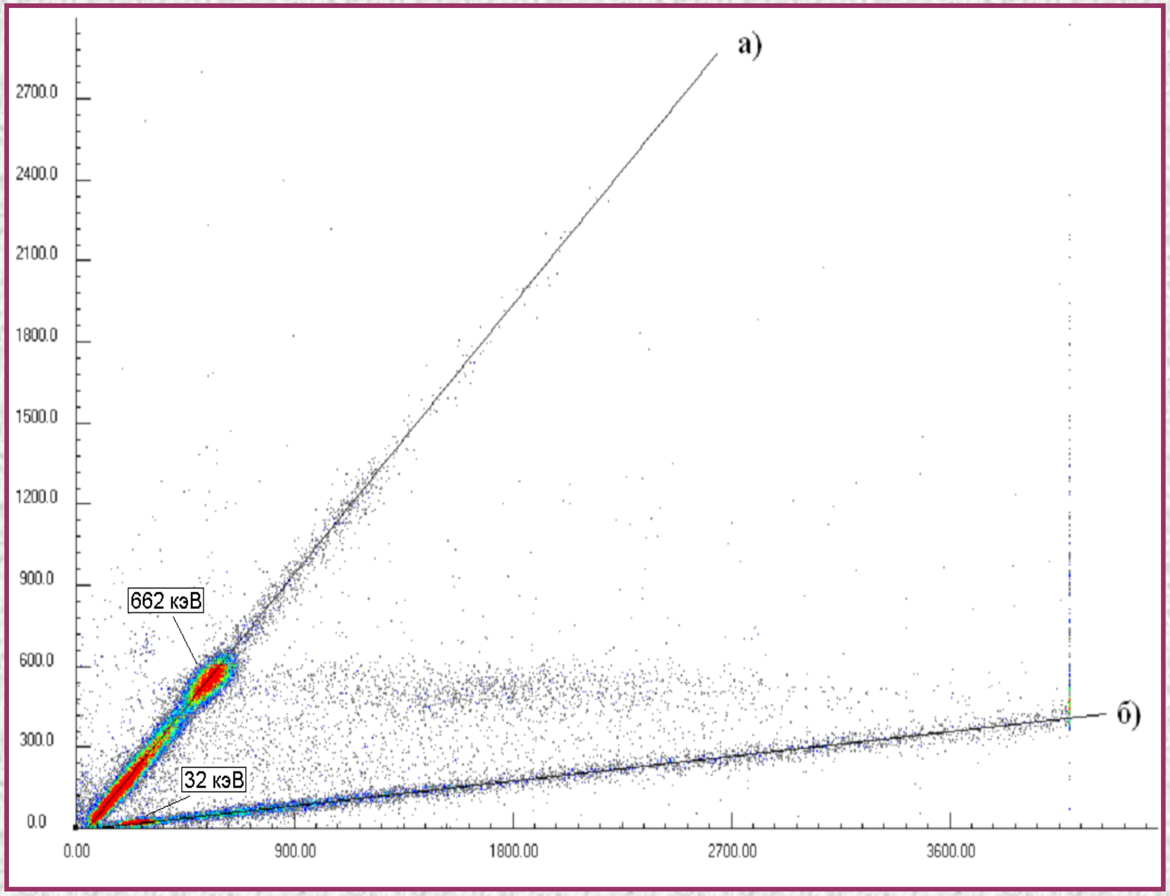


Parallel coded amplitude of PMT signal is integrated for the first ~600ns and during the next ~3μs is read-out by BDRG electronics (BE BDRG) together with request “output strobe”. Data frames, GRB trigger, etc are formed by the BE BDRG

BDRG calibration

Isotope	Energy(keV)
^{241}Am	26.34 59.54
^{181}Hf	57 133 345.9 482.2
^{137}Cs	32 661.7
^{60}Co	1173 1333
^{207}Bi	74 569.7 1063.7 1770
^{40}K (Bg)	1460
^{208}Tl (Bg)	2614

List of isotopes

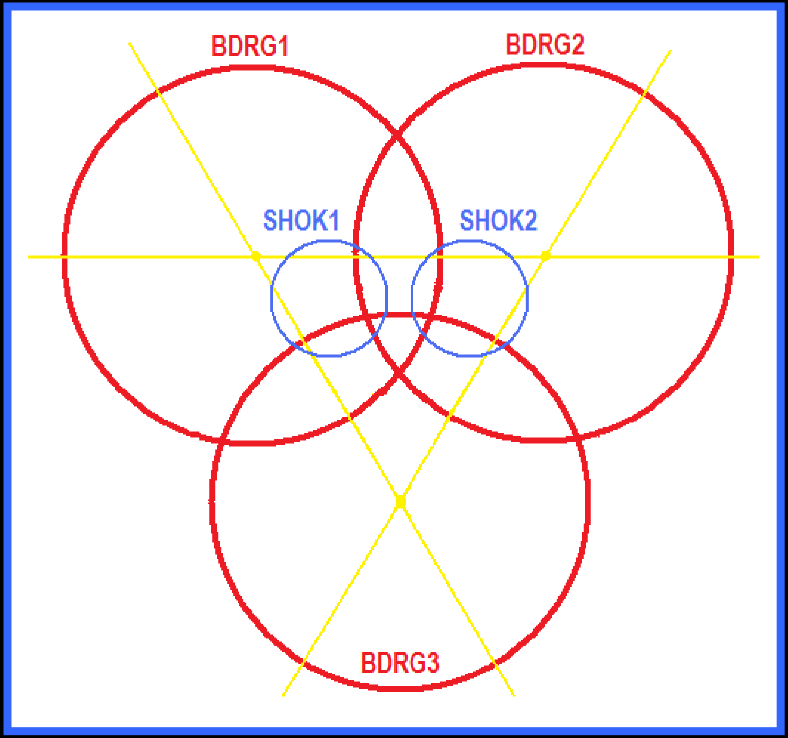


Example of 2D-diagram (slow part of PMT pulse vs fast one) for ^{137}Cs gamma-rays. Upper line is for CsI(Tl), the bottom one is for NaI(Tl)

Production of GRB trigger

Axes of 3 BDRG detectors are shifted by 90° relatively to each other.

Cosine angular diagram of detectors (FWHM ~60°) allows to determine the coordinates of GRB with accuracy about several degrees for bright GRBs.



Trigger logics

Main mode: BDRG1 → SHOK1 (any or if the source is inside of camera FOV)
BDRG2 → SHOK2 (any or if the source is inside of camera FOV)

Redundant mode: BDRG1 → SHOK1, SHOK2
BDRG2 → SHOK1, SHOK2
BDRG3 → SHOK1, SHOK2
Threshold levels will increase

For any trigger the burst mode information will be collected from all BDRG detectors

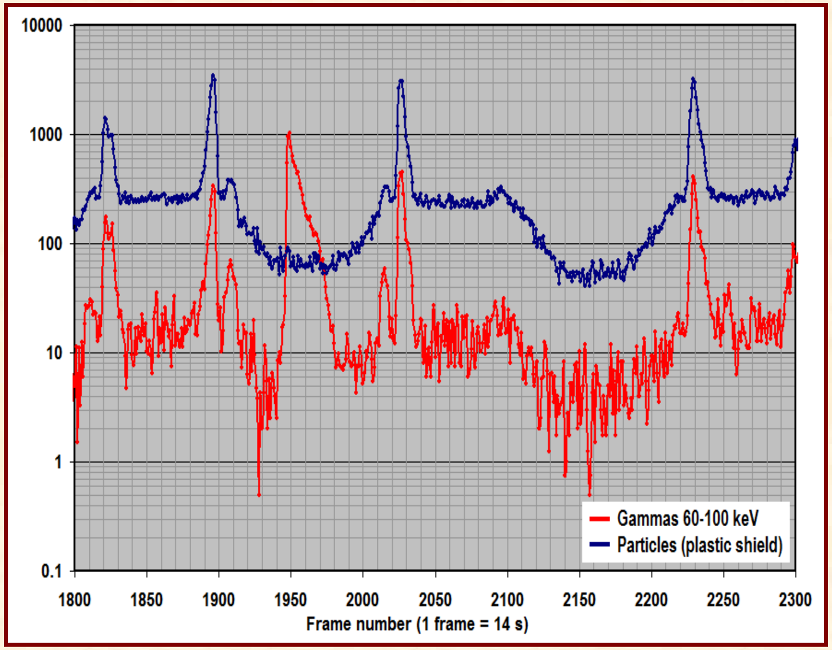
3-Levels of trigger

- Internal trigger: BDRG DATA & SHOCK IMAGES ARE COLLECTED
- Trigger for UFFO: → FAST POINTING
- Trigger for alerts via GlobalStar network

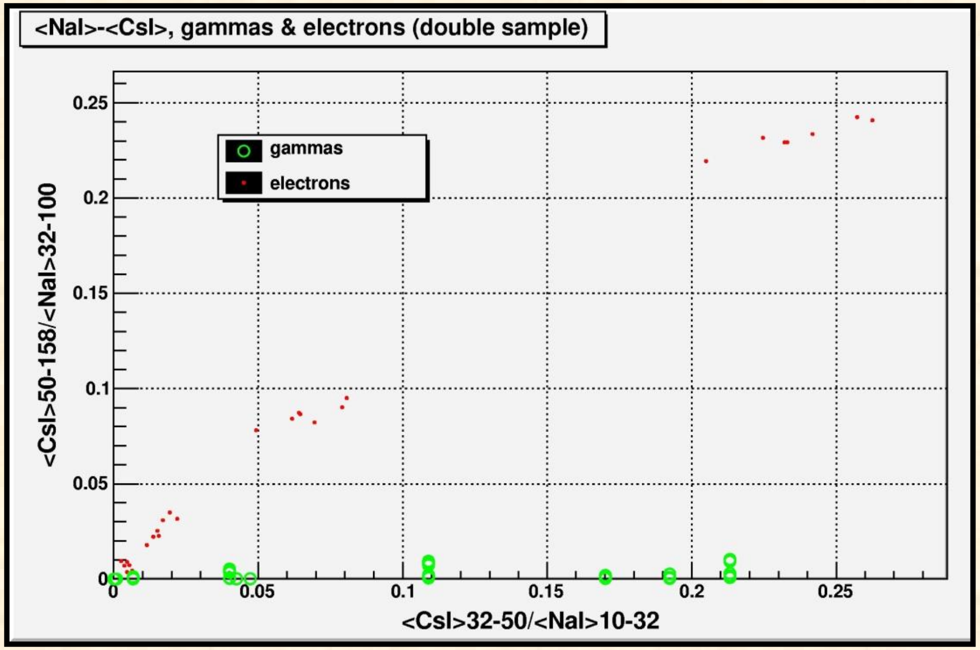
Production of GRB trigger from BDRG detector box

Conditions:

1) Fast rise of hard x-rays count-rate (energy bin of 25-50 keV is used)
2) No increase of charged particle rates (data from particle detector)
3) Not too high rate in hard X-rays
4) Gamma/electron selection criteria based on NaI(Tl)/CsI(Tl) ratio



An example of gamma-ray and particle readings (from SPRN/Coronas-F)



Criteria to distinguish GRB from electrons

Several time scales for independent triggering:

- ✓ 10 ms interval, 200 ms history for analysis, 1 ms resolution of transmitted data
- ✓ 1 s interval, 20 s history for analysis, 50 ms resolution of transmitted data
- ✓ 20 s interval, 400 s history for analysis, 1 s resolution of transmitted data

Burst trigger parameters that can be changed by command during the experiment active phase

- ✓ Number of standard deviations in hard x-ray channel necessary for the trigger
- ✓ Thresholds of particle channel count-rate necessary to reject the trigger
- ✓ The level of saturation rate of x-ray channel at which trigger is not set
- ✓ Parameters of gamma/electron selection criteria based on NaI(Tl)/CsI(Tl) ratio (energy channels and threshold).
- ✓ The time interval duration when gamma/electron data are analyzed

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Alerts, produced by Lomonosov mission will be sent to ground station via GlobalStar modem and then transmitted to GRB alert world net. GRB coordinates will be sent 3 times: at the moment of trigger and twice after they are refined.

Alerts from GRB alert net will be received by Lomonosov mission. They will be used to fix optical images in memory for their later transfer to ground if GRB is in the camera’s FOV.

Structure and amount of information from BDRG

shown for 3 detector boxes (preliminary)

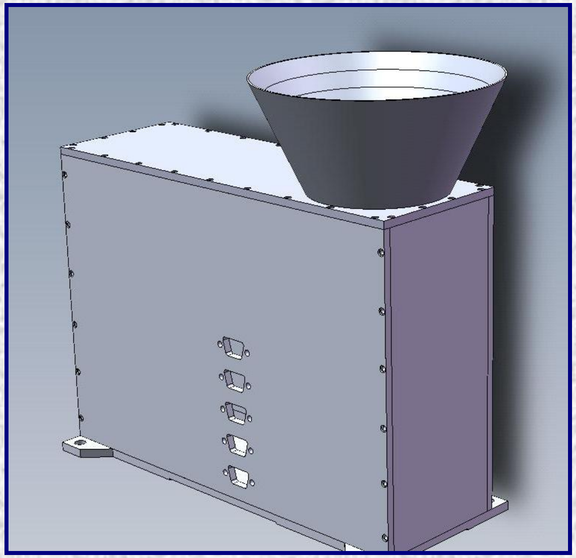
Continuous:

Type of frame	Description	Time interval between frames	Day amount, Mb
Monitoring	Number of events in NaI(Tl) and in CsI(Tl) separately in wide energy channels (8 channels for each part) for each BDRG box	1s	9
Spectrum	724 channel amplitude spectra for NaI(Tl) and CsI(Tl) for each BDRG box	60s	12
2D-diagram	Amplitudes of "Fast" and "slow" component (12 bit for each) for 1000 events for each BDRG box. Time markers are included every 100 ms.	60s	14
			Total: 35

Burst mode (for fast/slow burst):

Type of frame	Description	Time interval between frames (rise-slope)	Burst amount, Mb
Monitoring	Number of events in NaI(Tl) and in CsI(Tl) separately in wide energy channels (8 channels for each part) for each BDRG box	1-10 ms / 10-100 ms	1.4
Spectrum	1000 channel amplitude spectra for NaI(Tl) and CsI(Tl) for each BDRG box	5-10s / 20s	0.3
2D-diagram	Sequence of 12 bit amplitudes of "Fast" and "slow" component for every gamma-quantum for up to 100000 events during burst. Time markers are included every 100 ms.	Not regular	0.3
			Total: 2

Parameters of SHOK optical cameras for "Lomonosov" space mission



Two identical SHOK boxes with wide-field cameras and processor unit for image analysis are planned to be used

Photo of SHOK optical camera

FOV: 20º x 40º

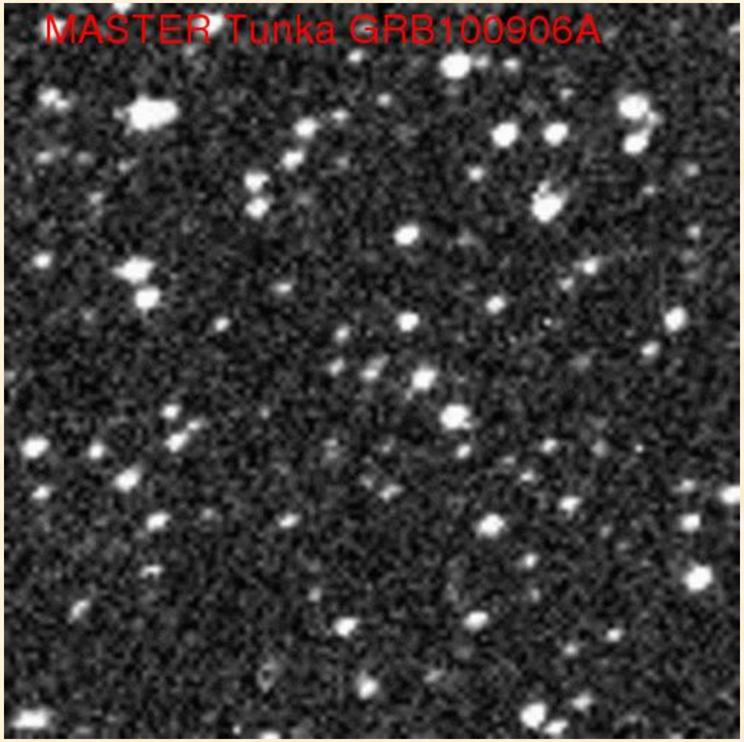
Time resolution: 0.2s

Sensitivity: 11 st.mag

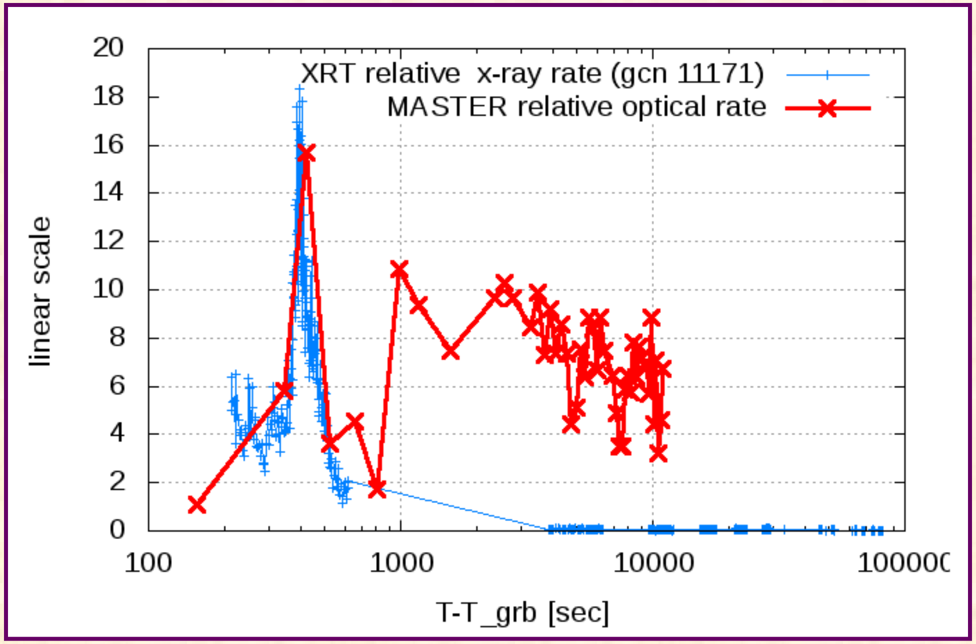
Mass ~5kg

Power ~27W (most of it is used by processor)

Prototype: Observations with robotic telescopes MASTER



Video of GRB100906Aobtained with robotic telescope “MASTER” (Tunka)



Light curve of GRB100901 in optical (MASTER) and X-ray (Swift) ranges

Information of SHOK optical cameras transferred to ground

For each GRB pictures taken from ~1 minute before trigger to ~2 minutes after trigger with time binning of 0.2s will be transmitted (total FOV frames). Data volume is ~700 Mb/GRB

Between GRB triggers the difference between frames sequence in time will be analyzed; parts of FOV (several degrees) with most significant point-like transients will be transferred to ground station(s).

Majority of such events are expected to be produced by the Earth orbiting objects.

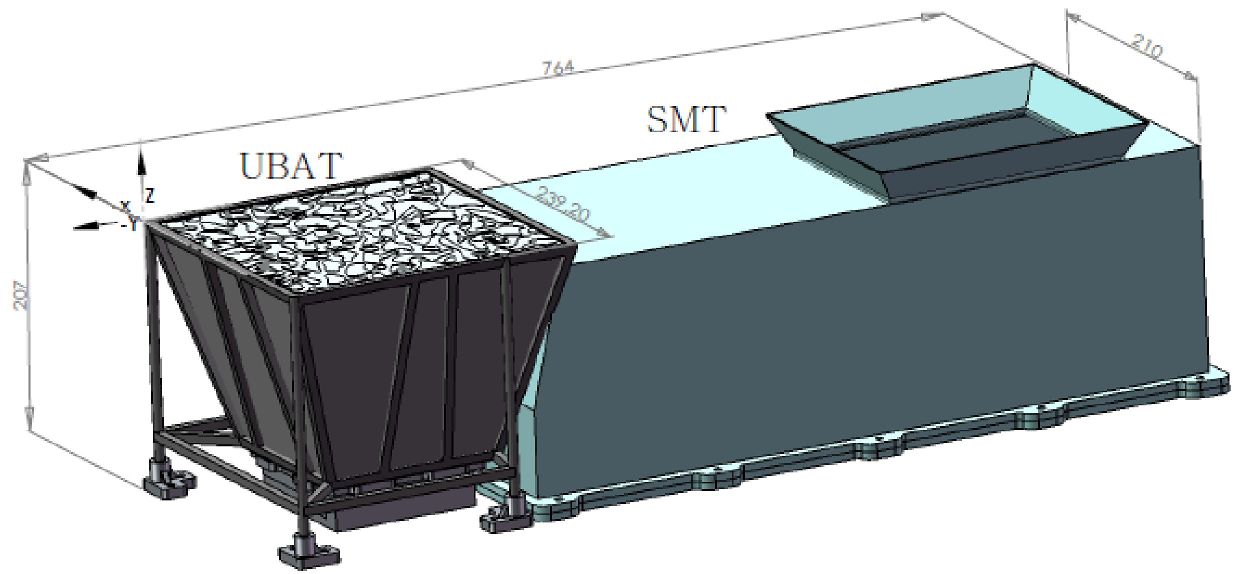
UFFO - Ultra Fast Flash Observatory

Consists of: Burst **A**lert & Trigger **T**elescope
and **S**lewing **M**irror **T**elescope

Aiming to:

-observe GRB at UV, Gamma & X-rays; internal trigger formation.

Size: 600x600x200 mm;
Power: 20 W;
Mass: 20 кг;
Rate: ~100 Mb/day

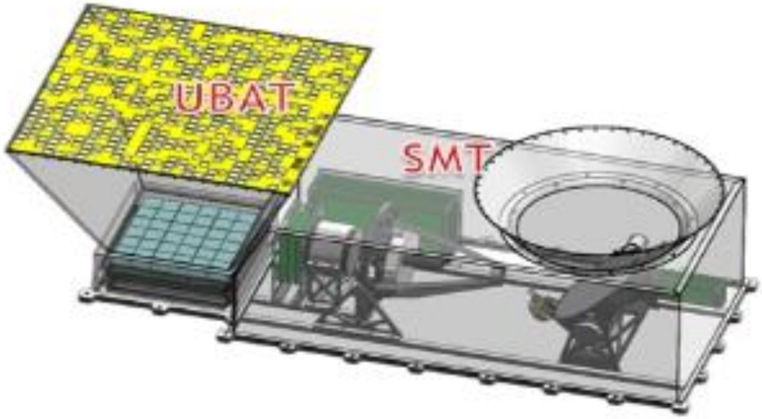


EWHA Woman Univ. (Korea); DTU, Denmark; UCB,USA; Bergen Univ., Norway; University of Valencia, Spain; SINP /MSU, RF

To learn more about UFFO, UFFO-100 and UFFO-300

See poster:
P-VI-2: “The UFFO Pathfinder mission on “Lomonosov” for fast GRB X-ray and optical location”, P.H. Connell, V. Reglero, Il Park, et al.(~50 co-authors);

and poster:
P-VI-3: “ The Ultra-Flast Flash Observatory Program: Pathfinder and Beyond”, B. Grossan, I.H. Park, A.J. Castro-Tirado, et al.;



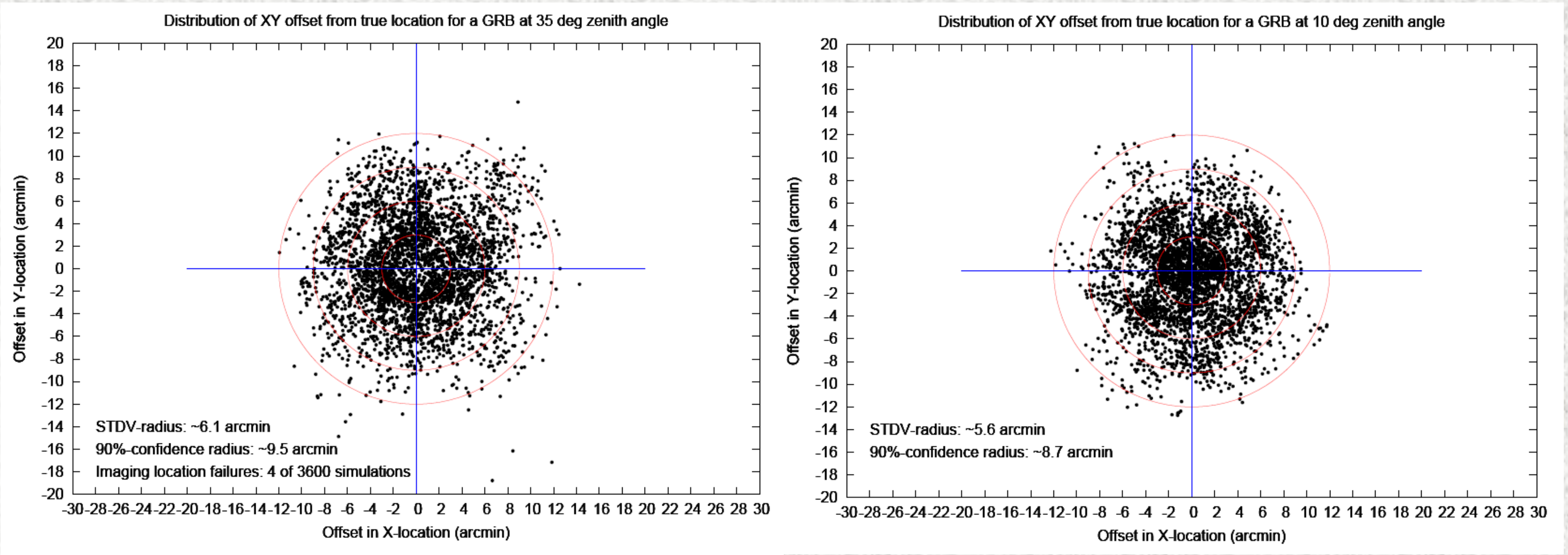
UFFO pathfinder

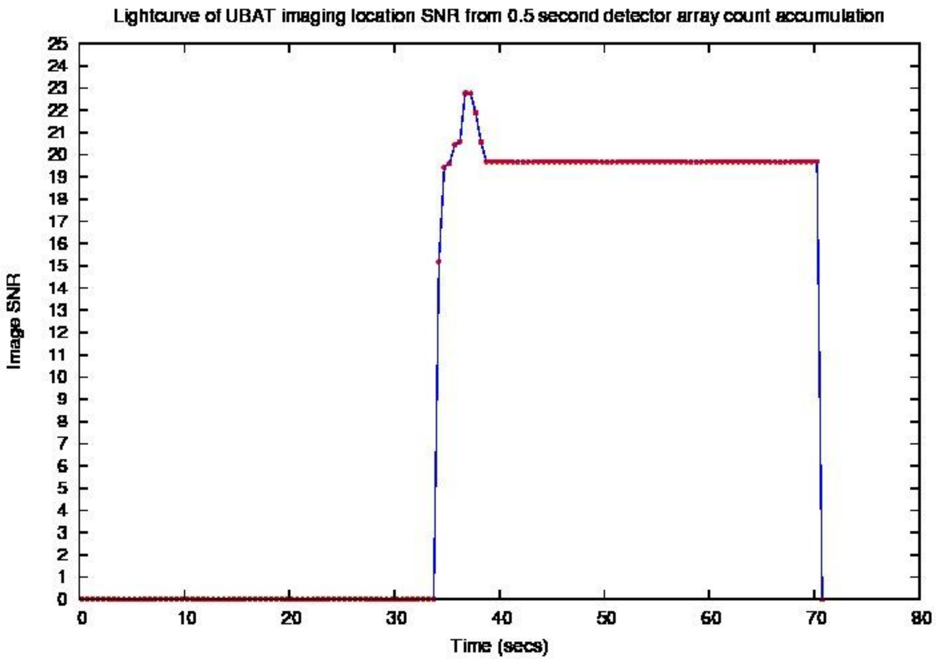
Specifications of UBAT and SMT in UFFO Pathfinder

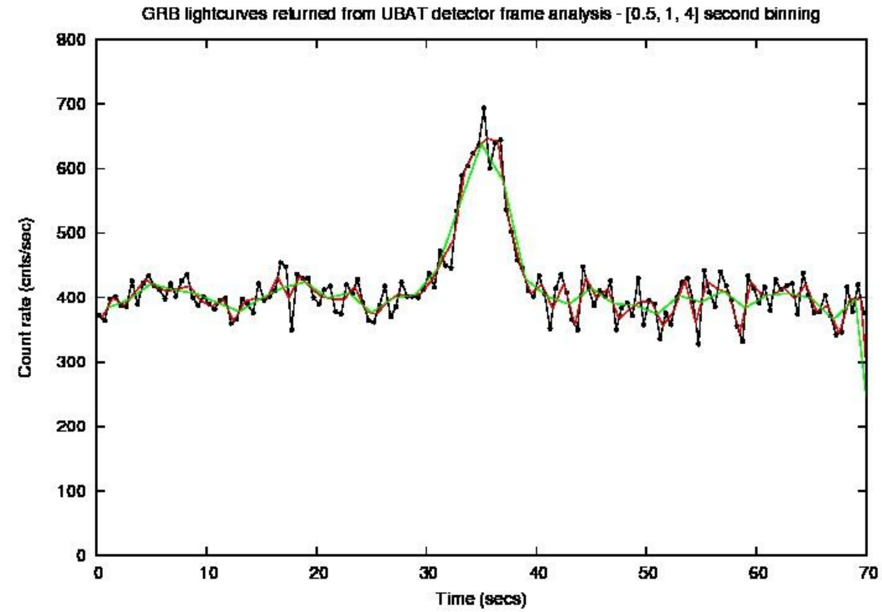
UBAT (UFFO Burst Alert Telescope)	Coded mask aperture camera	SMT (Slewing Mirror Telescope)	Ritchey-Chrétien + MMA with rotator
FOV	~1.85 sr (90.2°x 90.2°)	Aperture	10 cm diameter
PSF	**≤ 10 arcmin in PSLC at 7 sigma**	F-number	11.4
Detector	LSO+ MAPMT	FOV	17 x 17 arcmin
Detector energy range	5 ~ 200 keV	Coverage of FOV	60° x 60° (MMA), 90° x 90° (RP)
Number of pixels	48 x 48	Detector	Intensified CCD
Pixel size	2.88 x 2.88 x 2 mm^3	Detection Element	256 x 256 pixels
Effective area	191.1 cm^2	Pixel Scale	4 arcsec
Energy resolution	2keV FWHM @ 60 keV	Location Accuracy	0.5 arcsec
Quantum efficiency	99% @ 100 keV	Wavelength Range	200 nm ~ 650 nm
Sensitivity	310 mCrab in 10 s exposure at 5.5σ 4~50 keV (TBD)	Sensitivity	B=19.5 in white light in 100 sec exposure at 5σ
Bright limit	TBD	Bright Limit	mv = 6 mag
Mass	10 kg	Mass	10.5 kg
Volume	400.8 x 400.8 x 365 mm^3	Volume	374 x 622 x 180 mm^3
Power consumption	10 Watts	Power consumption	10 Watts

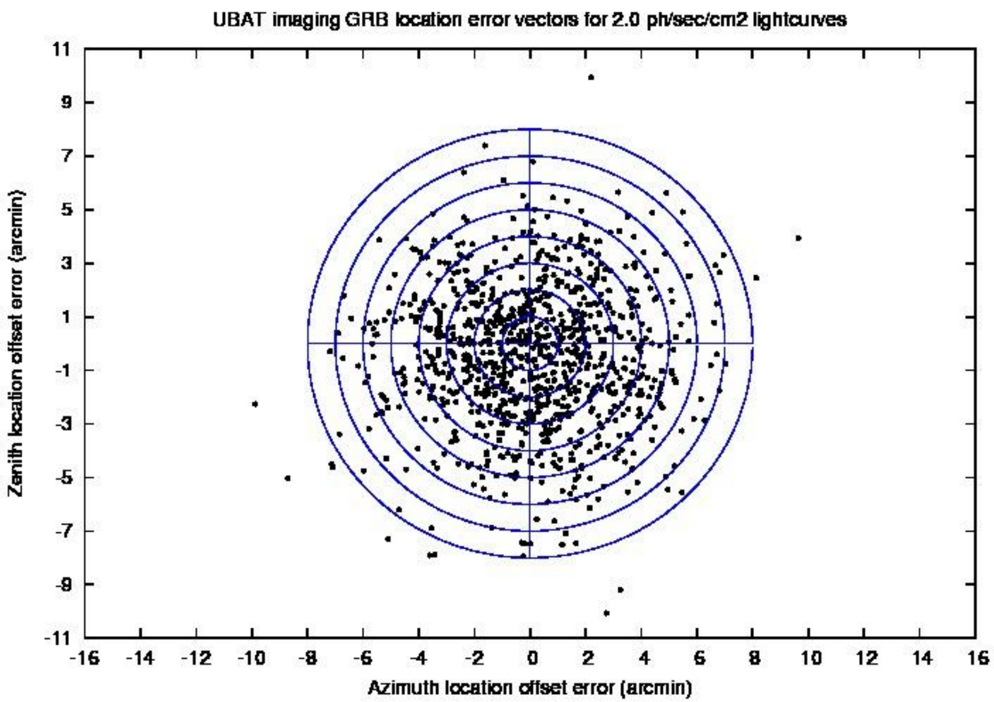
Accuracy of GRB localization with UFFO/UBAT

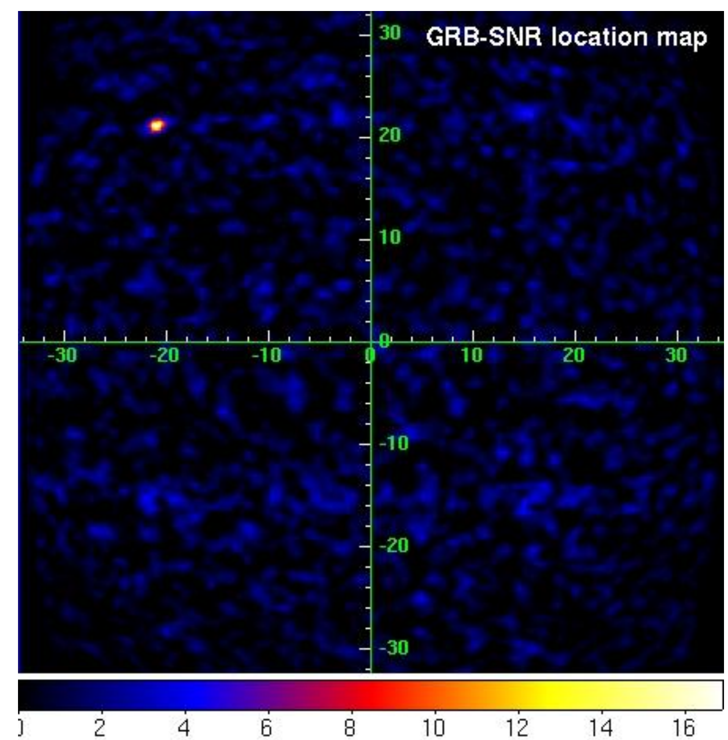
Result of modeling for GRB 5 ph/cm2/s mean over 5s



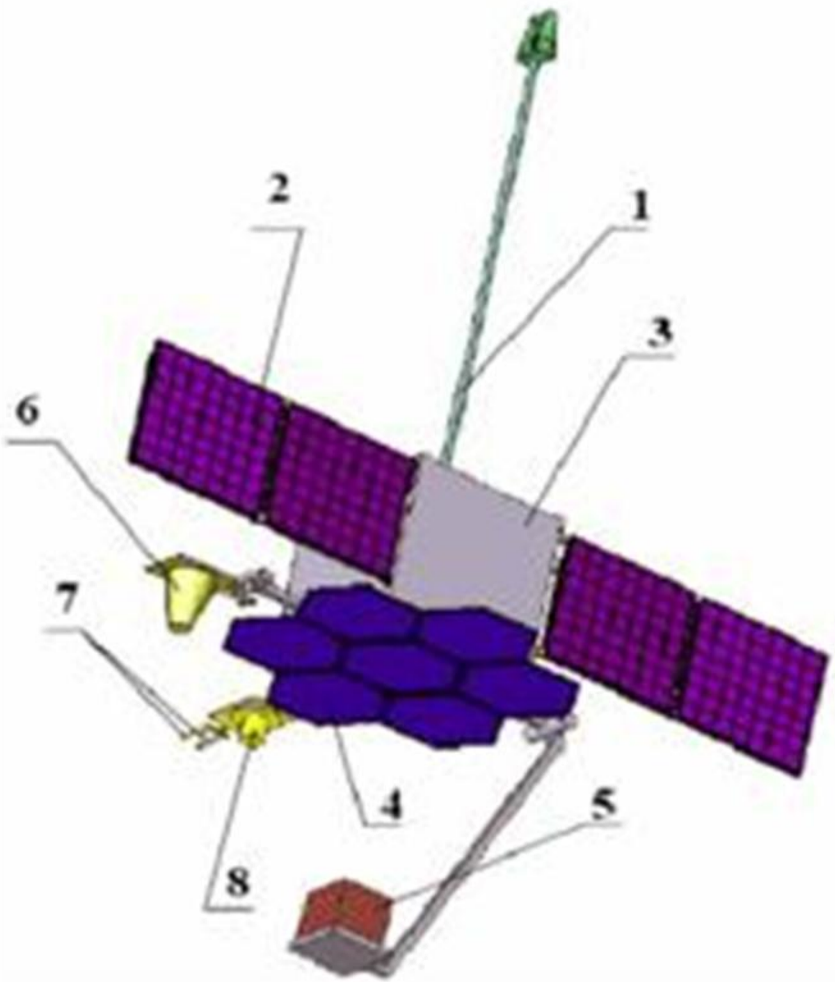

Lightcurve of UBAT imaging location SNR from 0.5 second detector array count accumulation
Image SNR
Time (secs)


GRB lightcurves returned from UBAT detector frame analysis - [0.5, 1, 4] second binning
Count rate (cnts/sec)
Time (secs)


UBAT imaging GRB location error vectors for 2.0 ph/sec/cm2 lightcurves
Zenith location offset error (arcmin)
Azimuth location offset error (arcmin)


GRB-SNR location map

TUS at work on-board of “Lomonosov”



1 - gravitational beam

2 – solar panels

3 – platform body

4 – TUS Fresnel mirror-concentrator

5 – electronical block of photo reciever

6 – antenna on-board control system

7 - magnitometrs

8 – antenna for transfer of scientific information

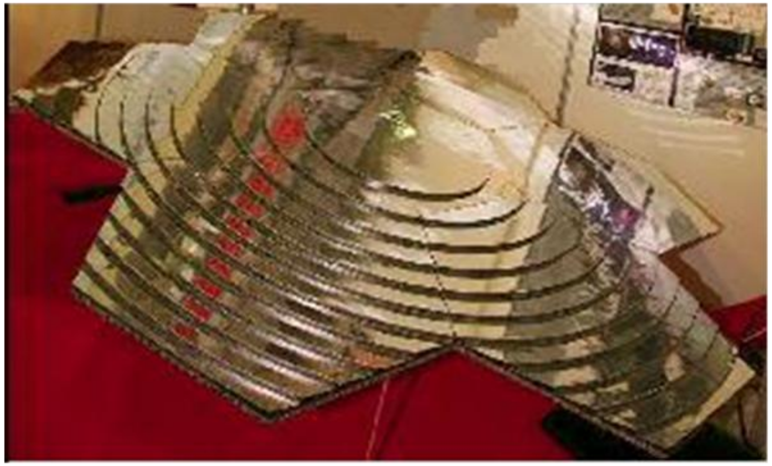
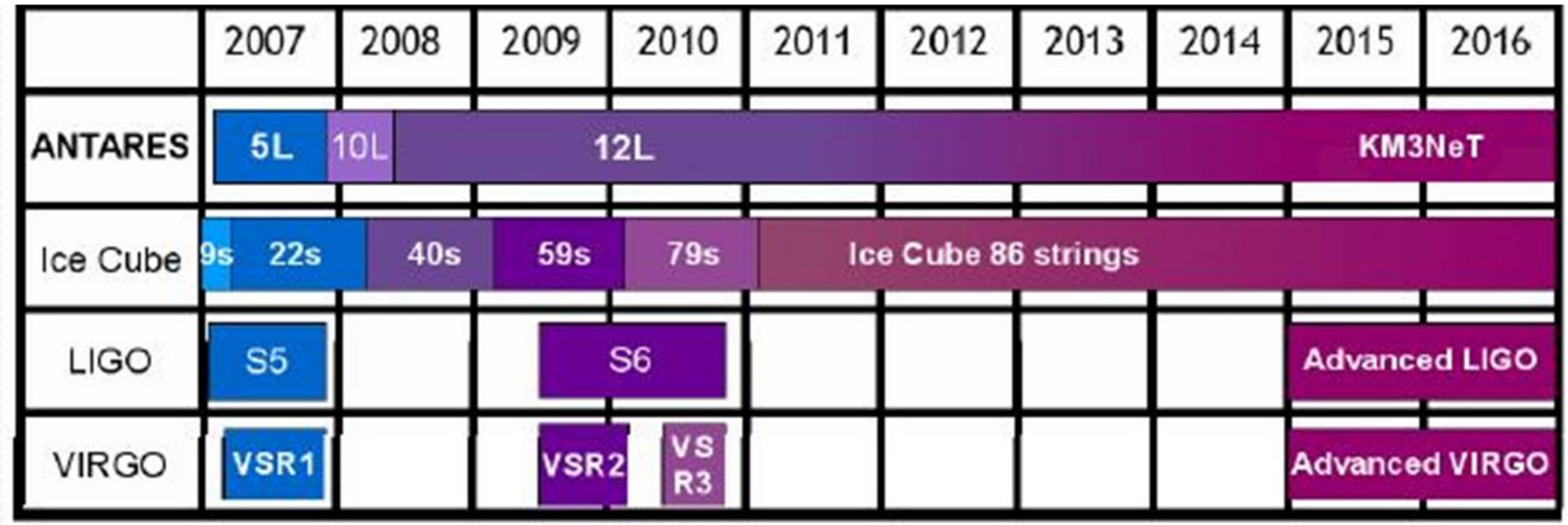


Figure 7. The full scale Fresnel mirror prototype

Figure 8. The tuning points on the back mirror side

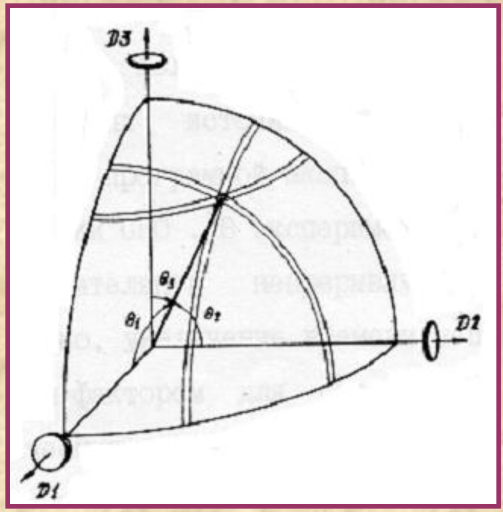
GRB satellites, plus EAS network combined with neutrino observatories data may provide much better constrains on the UHECR origin



THANK YOU!

Estimation of GRB position from BDRG data

Standard aproach (cosine shape of FOV)



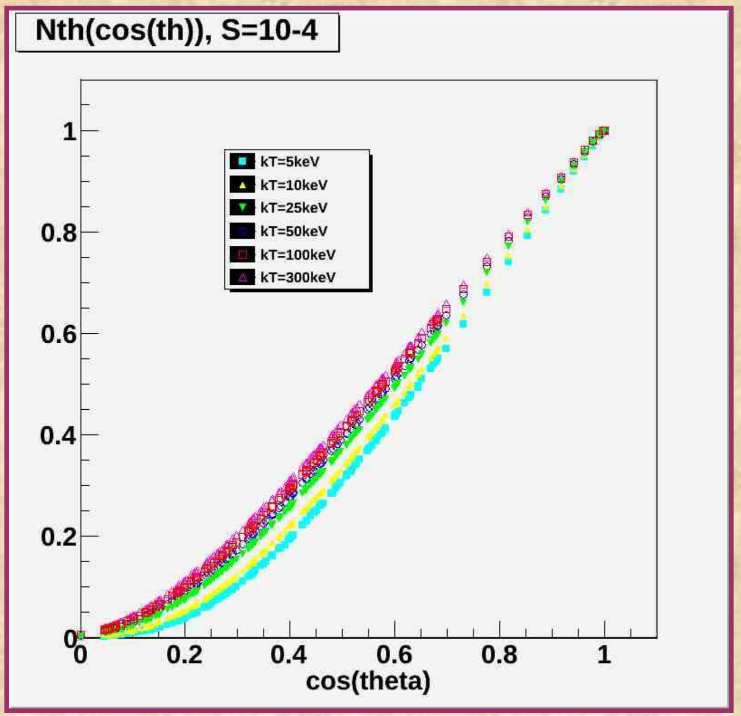
$$\cos\theta_1 = \frac{N_1}{\sqrt{N_1^2 + N_2^2 + N_3^2}}$$

$$\cos\theta_2 = \frac{N_2}{\sqrt{N_1^2 + N_2^2 + N_3^2}}$$

$$\cos\theta_3 = \frac{N_3}{\sqrt{N_1^2 + N_2^2 + N_3^2}}$$

Corrections for finite efficiency (results of Geant modeling)

$$N(\cos\Theta) = N_0 * [a + (1-a)*(\cos\Theta)^{\alpha}]$$

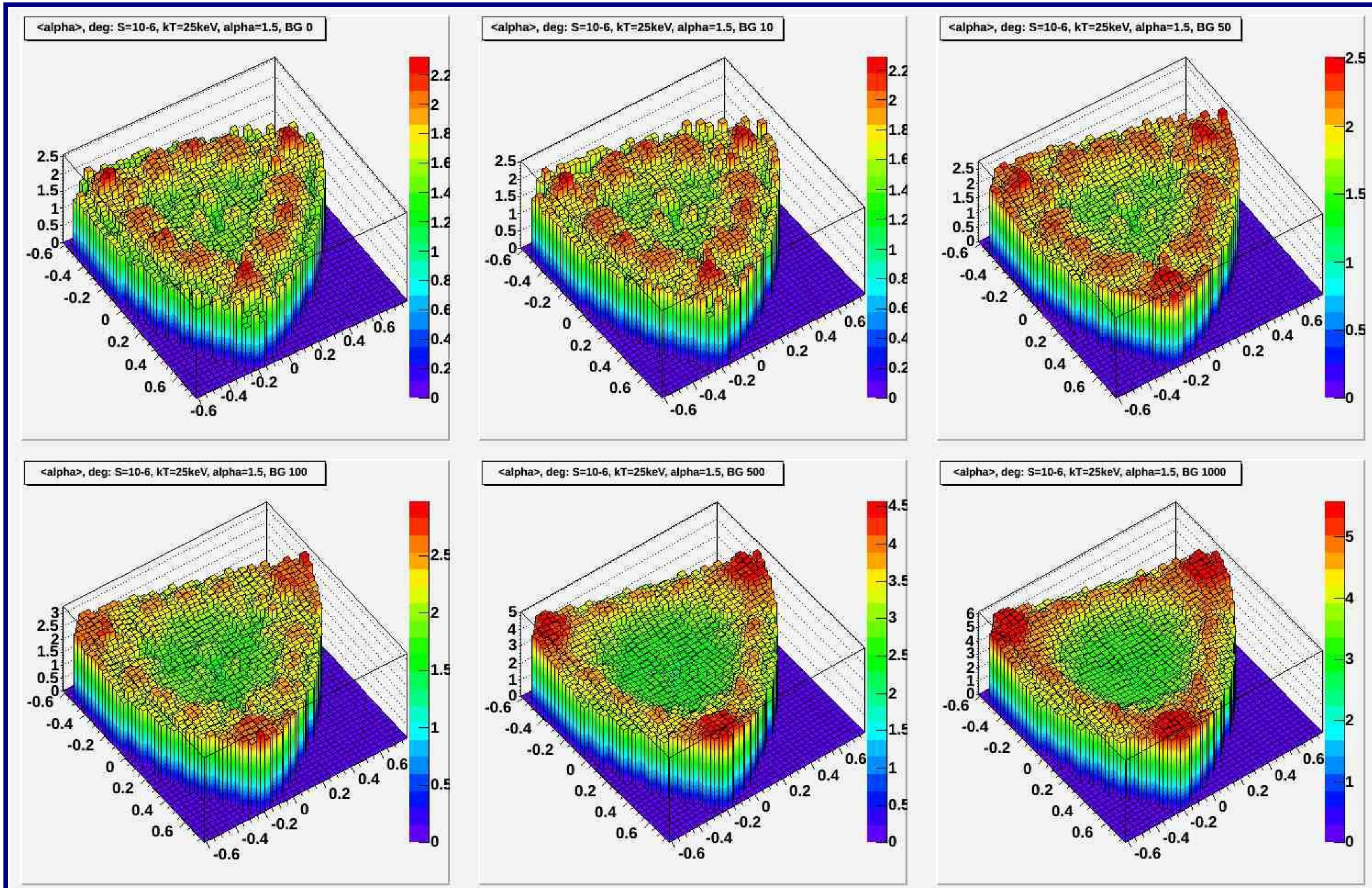


N(cosΘ) for different kT, $S=10^{-4}$.

Simulation code used: GEANT 3.21
Primary gamma-ray spectra simulated:
$F(E) \sim E^{-1}\exp(-E/kT)$,
kT= 5, 10, 25, 50, 100, 300 keV
Primary energy band considered: 10 keV – 10 MeV
Fluences considered: $S = 10^{-6}, 10^{-5}, 10^{-4}$ erg cm^{-2}
Burst duration: 1 s

Accuracy of GRB localization from BDRG data:

Results of GEANT numeric modeling for GRB with kT=25 keV, I=10^{-6} erg cm^{-2}



Accuracy of GRB localization from BDRG data:

Dependence on fluence, kT and background rate
(the results of GEANT numerical modeling)

fluence	kT, keV	Background rate, Hz					
		0	10	50	100	500	1000
1.0E-07	5	18.5	27	36	40	48	52
1.0E-07	10	8.4	10.3	16.5	21	33	38
1.0E-07	25	5.2	6	9.5	12	21	27
1.0E-07	50	5	5.6	9	11	19.2	25
1.0E-07	100	5.5	7	11	14	24	28
1.0E-07	300	8.5	11.5	19	24	37	43
1.0E-06	5	8	8.5	10.5	13	21	26
1.0E-06	10	4.5	4.5	5	5.5	8	10
1.0E-06	25	2.2	2.2	2.5	2.8	4.5	5.2
1.0E-06	50	2	2	2.4	2.7	4.5	5.2
1.0E-06	100	2.4	2.5	2.8	3.4	5.2	6.3
1.0E-06	300	3.7	4.1	4.5	5.2	8.3	10.5
1.0E-05	5	7	7	7	7	7	8
1.0E-05	10	4.5	4.5	4.5	4.5	4.5	4.5
1.0E-05	25	1.8	1.8	1.8	1.8	1.8	1.8
1.0E-05	50	1.6	1.6	1.6	1.6	1.6	1.8
1.0E-05	100	2.2	2.2	2.2	2.2	2.4	2.4
1.0E-05	300	3	3	3	3	3	3.5
1.0E-04	5	7	7	7	7	7	7
1.0E-04	10	4.5	4.5	4.5	4.5	4.5	4.5
1.0E-04	25	1.8	1.8	1.8	1.8	1.8	1.8
1.0E-04	50	1.6	1.6	1.6	1.6	1.6	1.6
1.0E-04	100	2.2	2.2	2.2	2.2	2.2	2.2
1.0E-04	300	3	3	3	3	3	3