

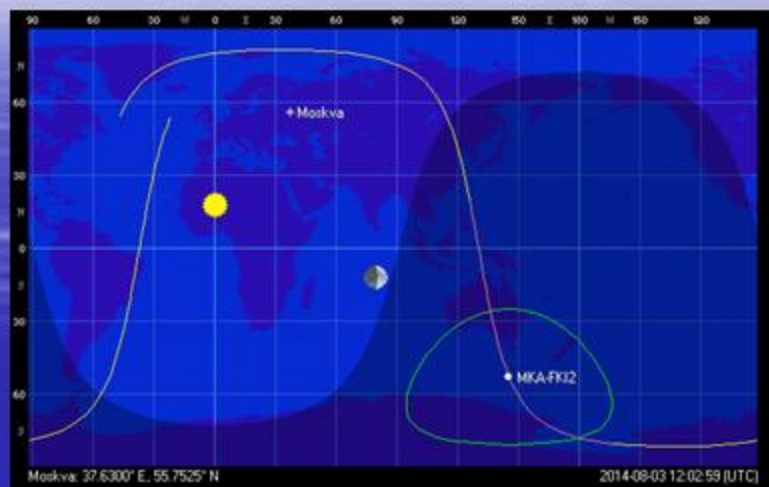
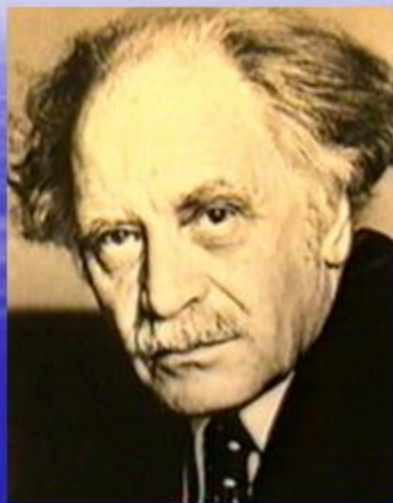
**Кратковременные
возрастания потоков гамма-
излучения из
высокоширотной атмосферы
по данным наблюдений на
спутнике «Ломоносов».**

В.В. Богомолов¹, А.В. Богомолов^{1,2}, Г.К. Гарипов¹,
А.Ф. Июдин¹, И.А. Максимов¹, А.В. Минаев¹, М.И.
Панасюк^{1,2}, В.Л. Петров¹, С.И. Свертилов^{1,2}, И.В. Яшин¹

*¹Московский государственный университет имени М.В.
Ломоносова, Научно-исследовательский институт ядерной
физики имени Д.В. Скобельцына*

*²Московский государственный университет имени М.В.
Ломоносова, физический факультет*

Спутник «Вернов» с комплексом научной аппаратуры РЭЛЕК был выведен на орбиту 8 июля 2014 г.



MKA- 2 (РЭЛЕК)

Norad: 40070U

Inter. ID: 14037B

Запуск.: 2014

.07.08

Период: 99.2 мин.

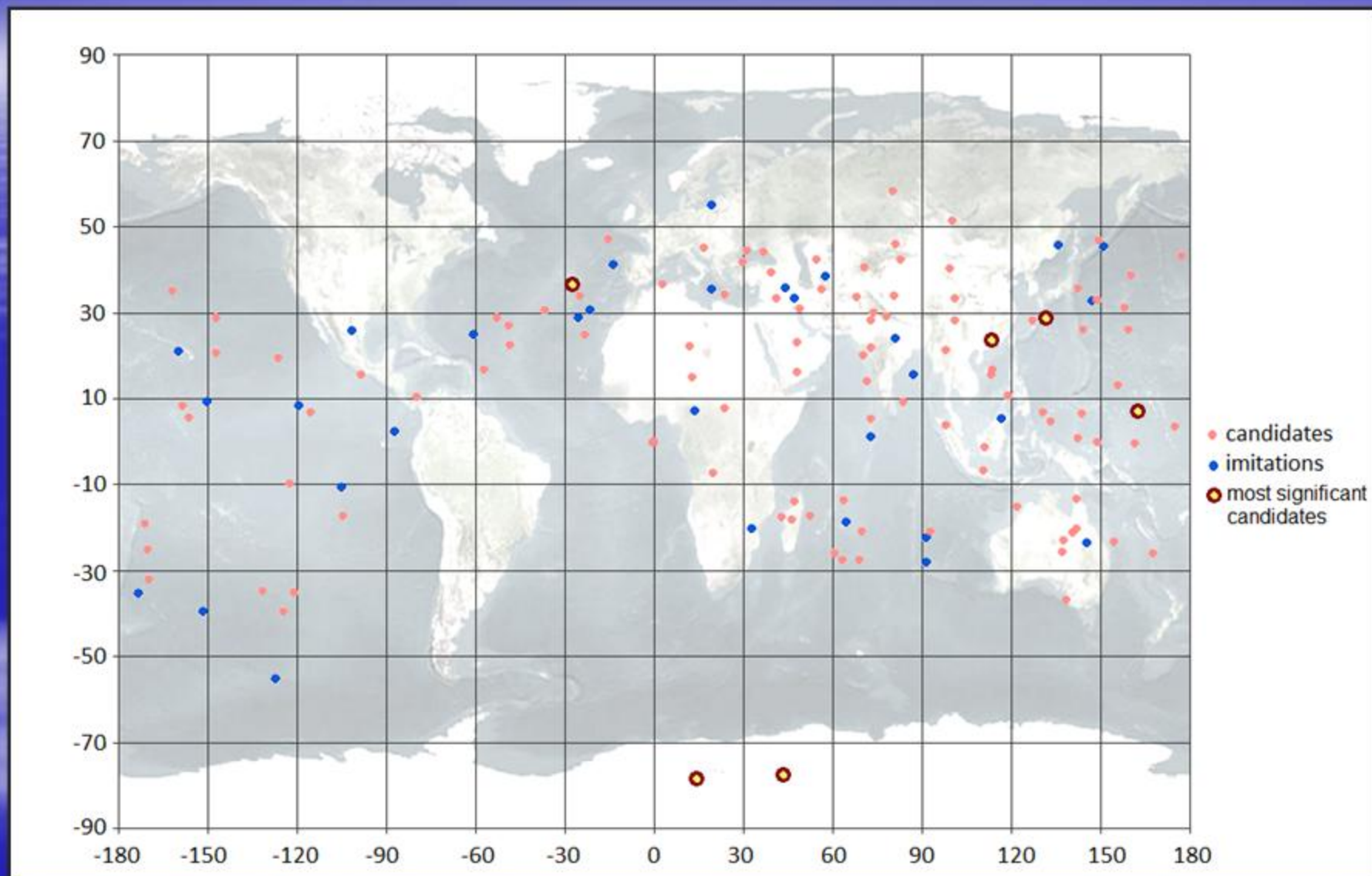
Наклонение: 98.4°

Апогей: 819 км

Перигей: 621 км

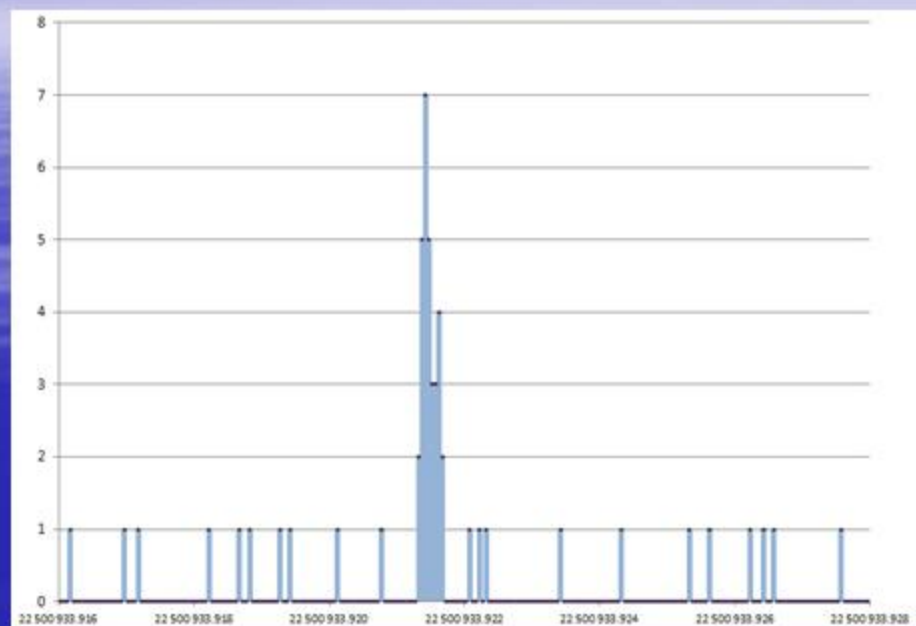


Map of TGF candidates from DRGE/Vernov instrument

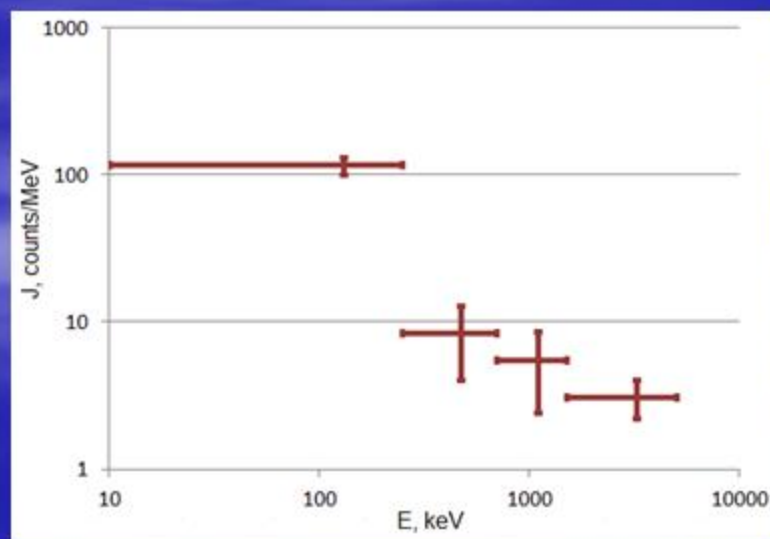
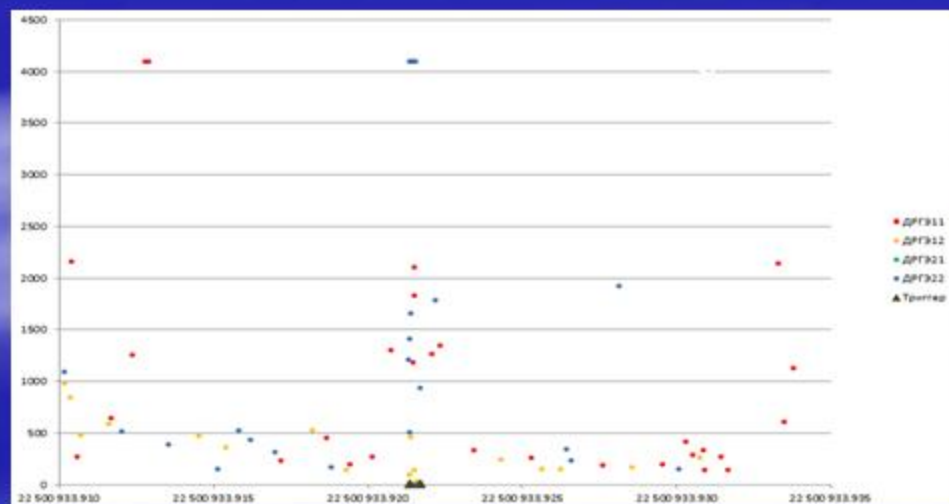
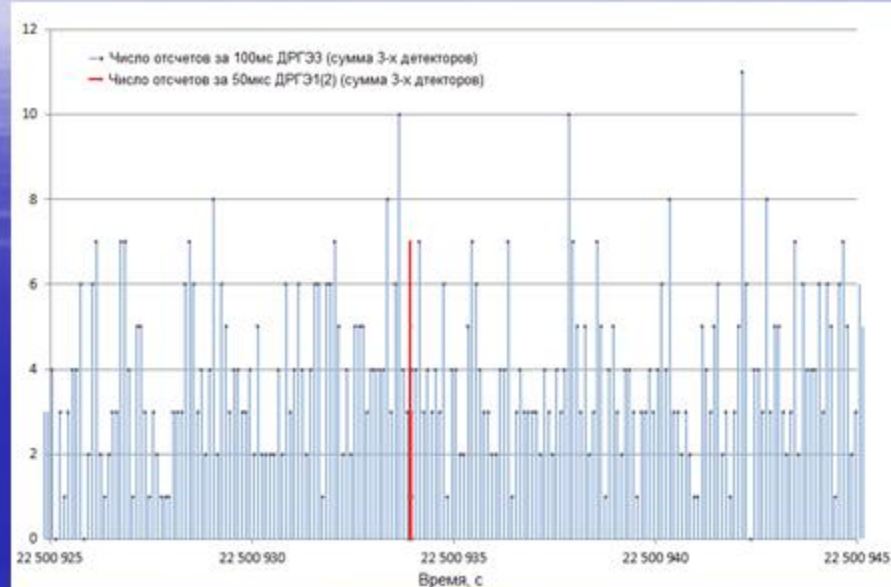


Атмосферная гамма-вспышка (TGF) 2014-09-18-10-15-34

Гамма-излучение ДРГЭ-1(2)



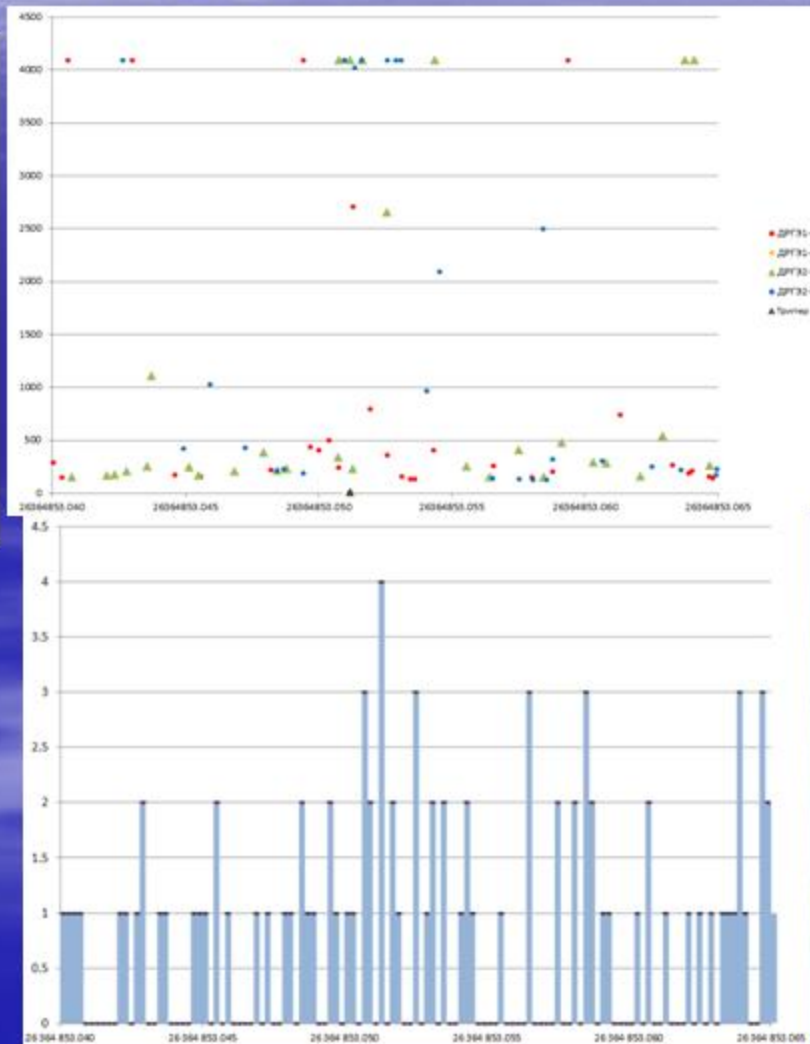
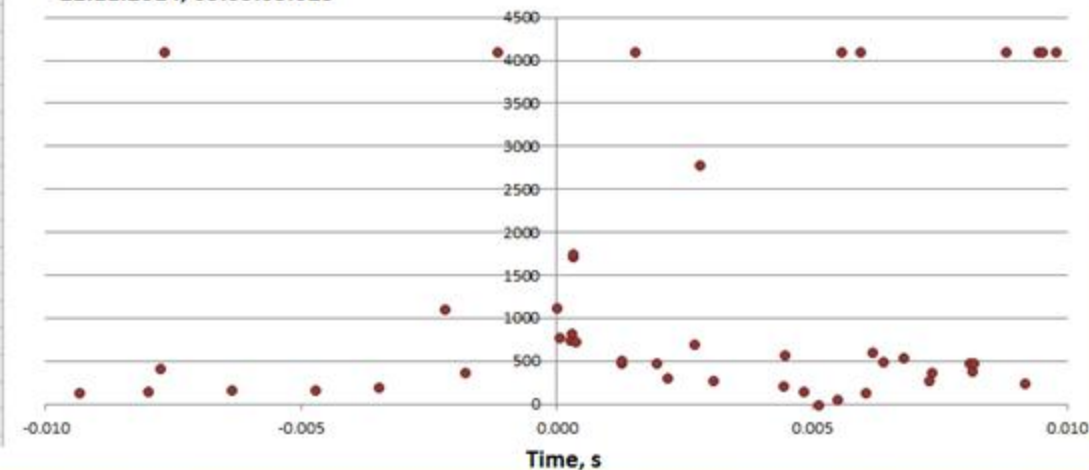
Электроны DRGE-3



Кандидаты в TGF - 2

2014-11-02-03-34-13

22.11.2014, 05:05:03.025



“LOMONOSOV” SPACE MISSION



Was launched 28/04/2016

Scientific objectives:

- Study of ultra-high energy cosmic rays
- phenomena in hard x-rays and soft gamma-rays (0.01-3.0 MeV)
- Search and detection of optical transients accompanying gamma-ray bursts
- study of transient luminosity events in the Earth atmosphere
- magnetosphere physics research

Эксперименты на Российском университетском спутнике «Ломоносов»



Проект реализуется в рамках программы развития МГУ

Проект поддержан Президентом РФ (№ Пр-1796 от 21.06.2010) и утвержден перечнем поручений Президента РФ (Пр-22, пункт 14).

Проект в части эксперимента ТУС осуществляется в рамках ФКП России

Parameters of "Lomonosov" mission:

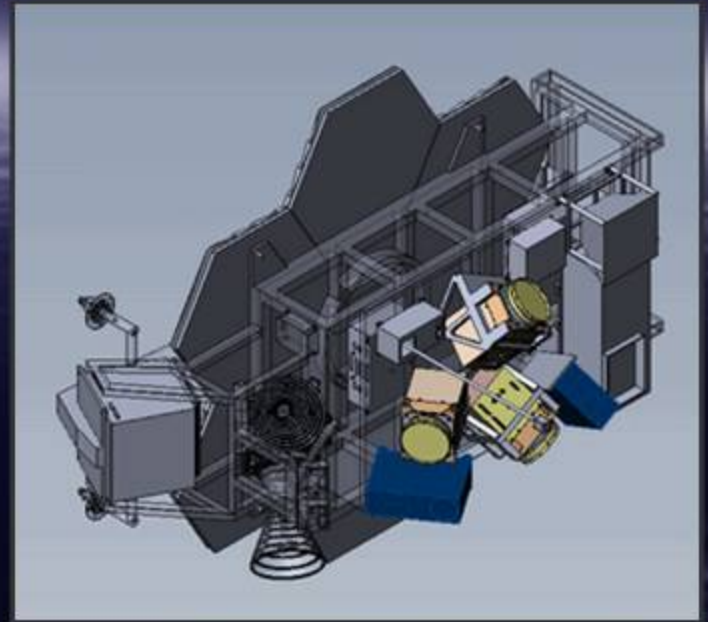
Orbit: ~500 km, polar

Mass: spacecraft ~600kg,
payload ~150kg

Total power ~ 300W

Data amount ~3Gb/day

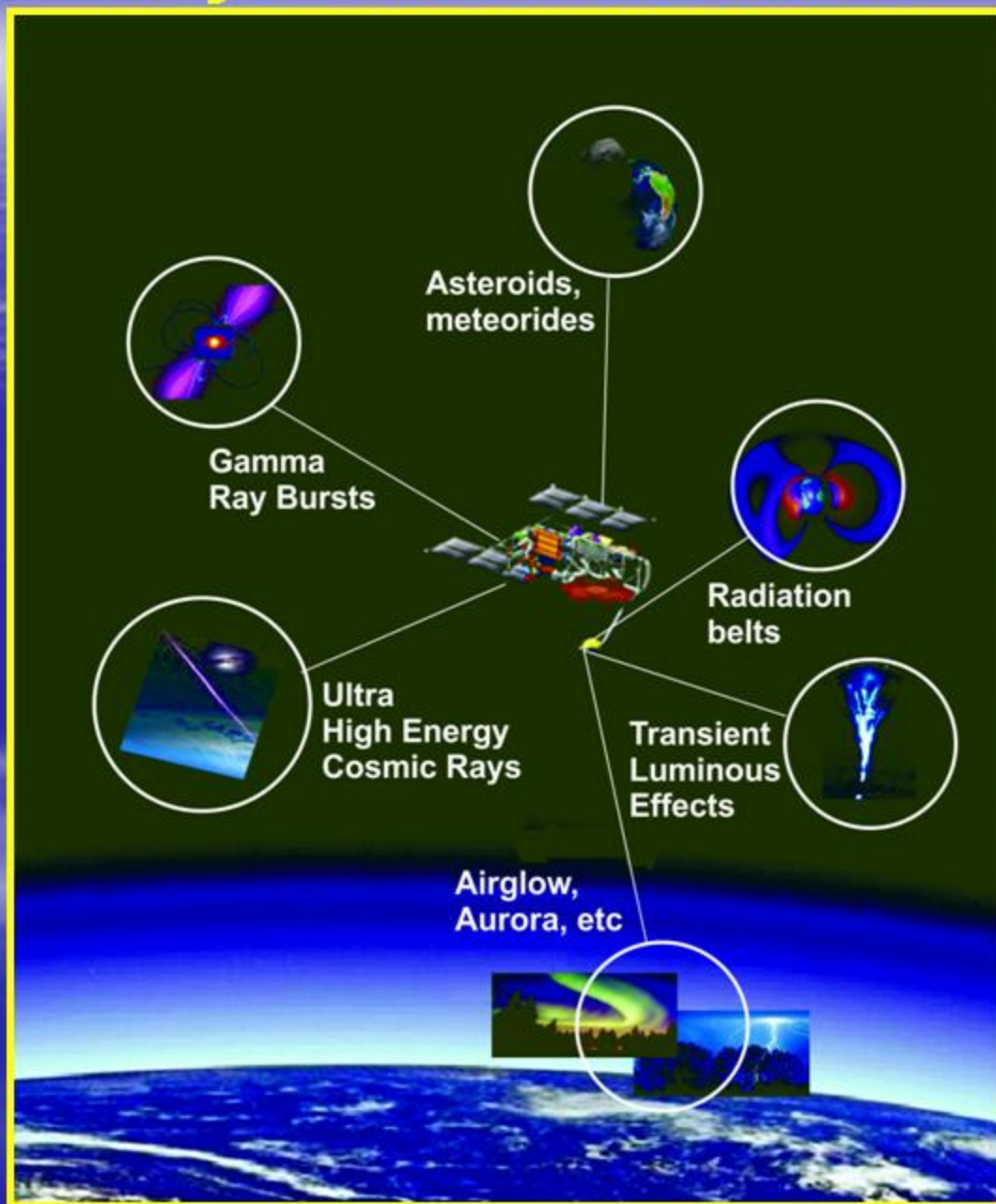
Launch date – 28/04/2016



Complex of instruments:

- **BDRG** – gamma spectrometer
- **SHOK** – wide field optical camera
- **UFFO** – coding mask x-ray telescope + UV telescope
- **TUS** – Telescope for detecting flashes in atmosphere produced by cosmic rays with $E > 5 \cdot 10^{19}$ eV and TLEs
- **DEPRON, ELFIN-L** – particle detectors

Наука «Ломоносова»



Гамма-спектрометры, использующие составной фосвич-детектор на основе NaI(Tl)/CsI(Tl)



1. Постоянный мониторинг в рентгеновском и гамма-диапазонах
2. Измерение энергетических спектров, поиск гамма-линий
3. Выработка триггера всплесковых событий
4. Быстрый тайминг всплесковых событий
5. Определение природы зарегистрированных всплесков

Детектор состоит из находящихся в оптическом контакте тонкого (3мм) кристалла NaI(Tl) и относительно толстого (17мм) кристалла CsI(Tl).

Толщина NaI(Tl) оптимальна для мягкой части энергетического диапазона. CsI(Tl) играет роль активной защиты для мягкого излучения, являясь в то же время основным детектором для более жёстких γ -квантов.

Рабочие диапазоны:

для NaI(Tl) - 0.01-0.5 МэВ

для CsI(Tl) - 0.05-3 МэВ

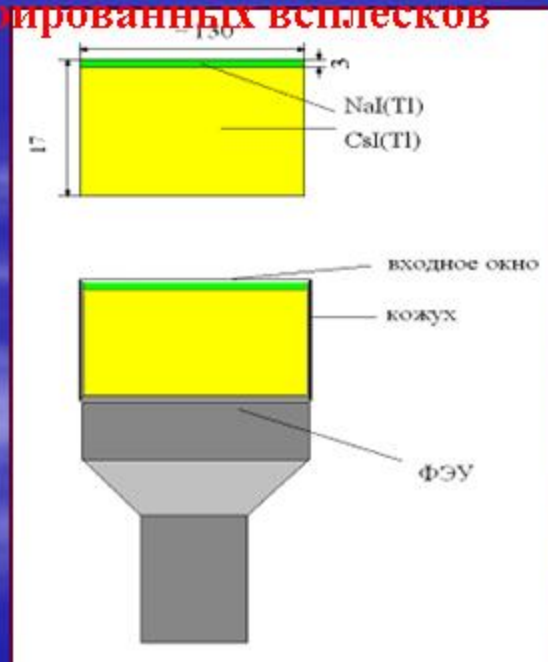


Схема детекторного узла (размеры для прибора БДРГ)

Structure and amount of information from BDRG

Type of frame	Time interval between frames	Data amount, Mb
<u>CONTINUOUS (180 MB PER DAY)</u>		
Monitoring	100ms	87 per day
Spectrum	15s	48 per day
Event mode	15s	50 per day
<u>BURST MODE FOR FAST/SLOW BURST (5 MB PER BURST)</u>		
Monitoring	1-10 ms	1.6 per burst
Spectrum	1-10 s	1.6 per burst
Event mode	Not regular, up to 10^6 events	1.6 per burst

Day portion of BDRG data is about 500-1000 Mb

Several time scales for independent triggering:

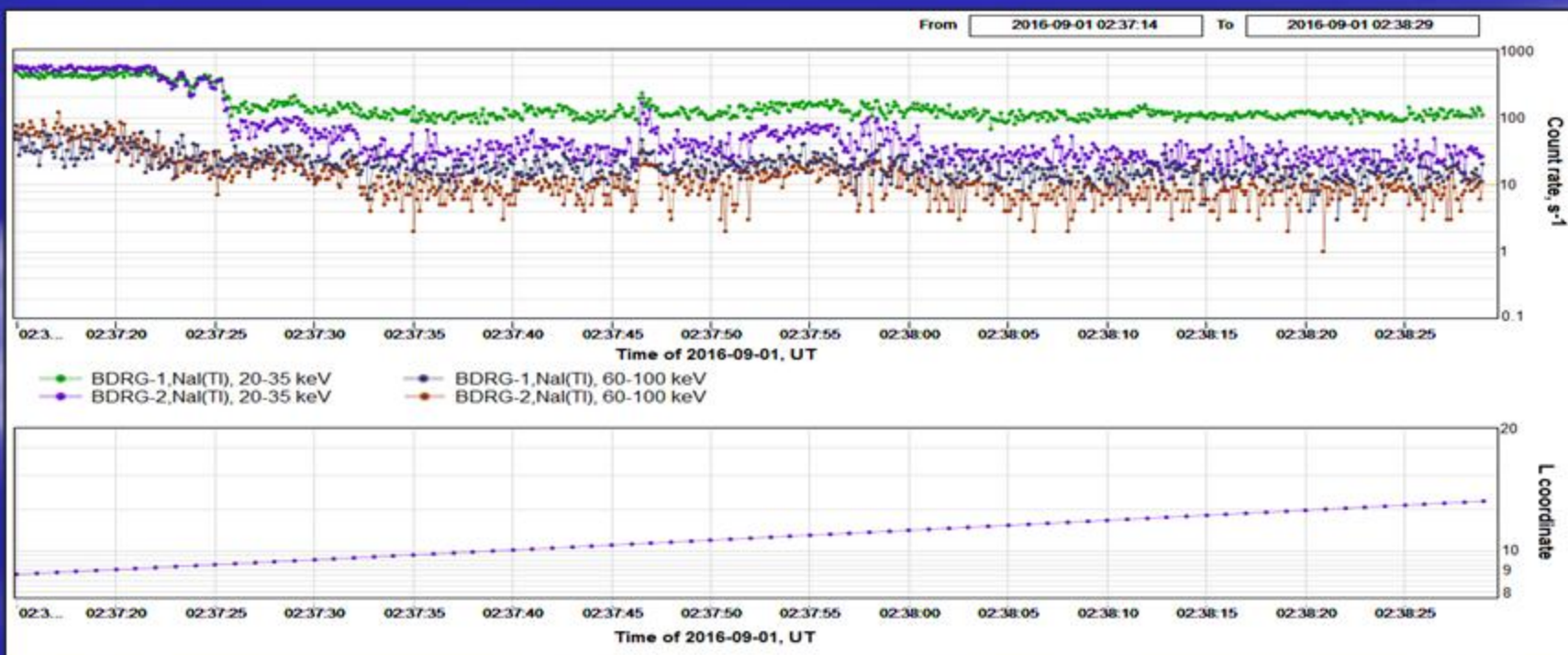
- ✓ **10 ms** interval, 1 ms resolution of transmitted data ("**Fast**")
- ✓ **1 s** interval, 10 ms resolution of transmitted data ("**Slow**")
- ✓ **20 s** interval, enlarged event mode transmitted data ("**SuperSlow**")

BDRG background conditions for GRB triggering

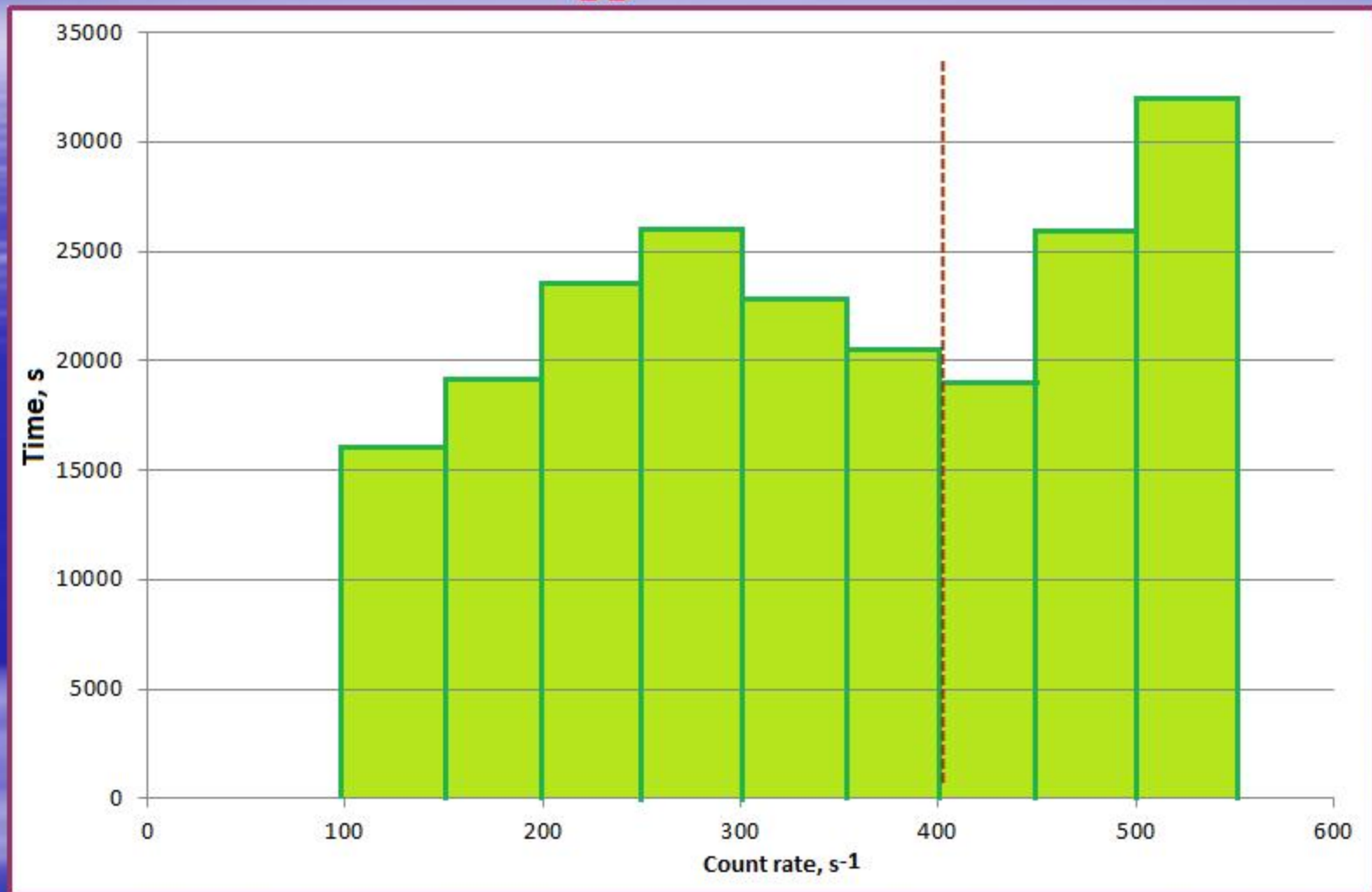


"Lomonosov", September 1, 2016

2:28 - 2:54

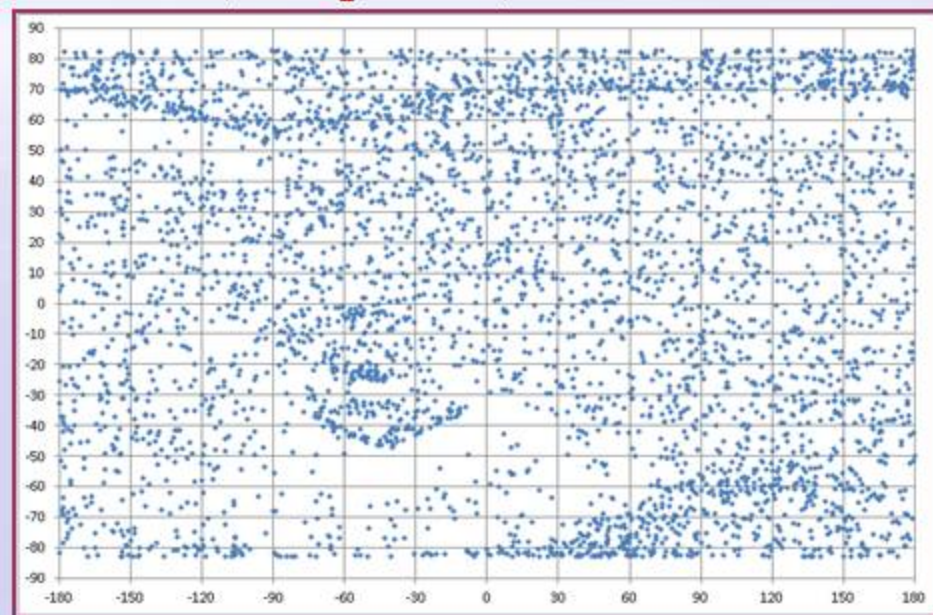
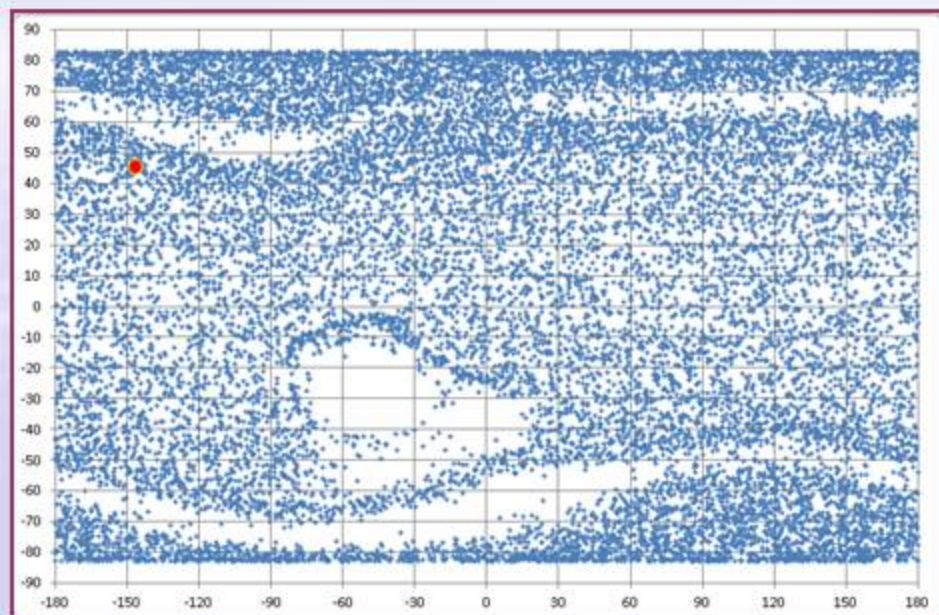


Time of observation in gamma-by-gamma data arrays formed after 20-second triggers from 10.2016 to 01.2017



← Equator → ← Polar regions → ← Precipitation and RB border →

Satellite position at the moment of the burst trigger (blue points) and 1ms TGF candidates (red points)



Characteristic time for triggering:

Up - left 10 ms,

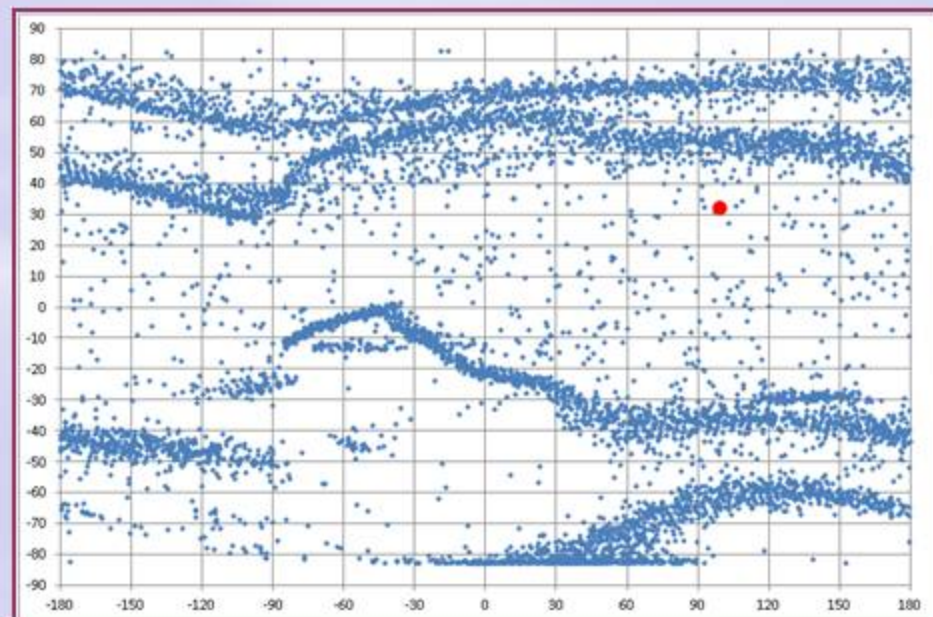
Up - right 1 s,

Down - 20 c

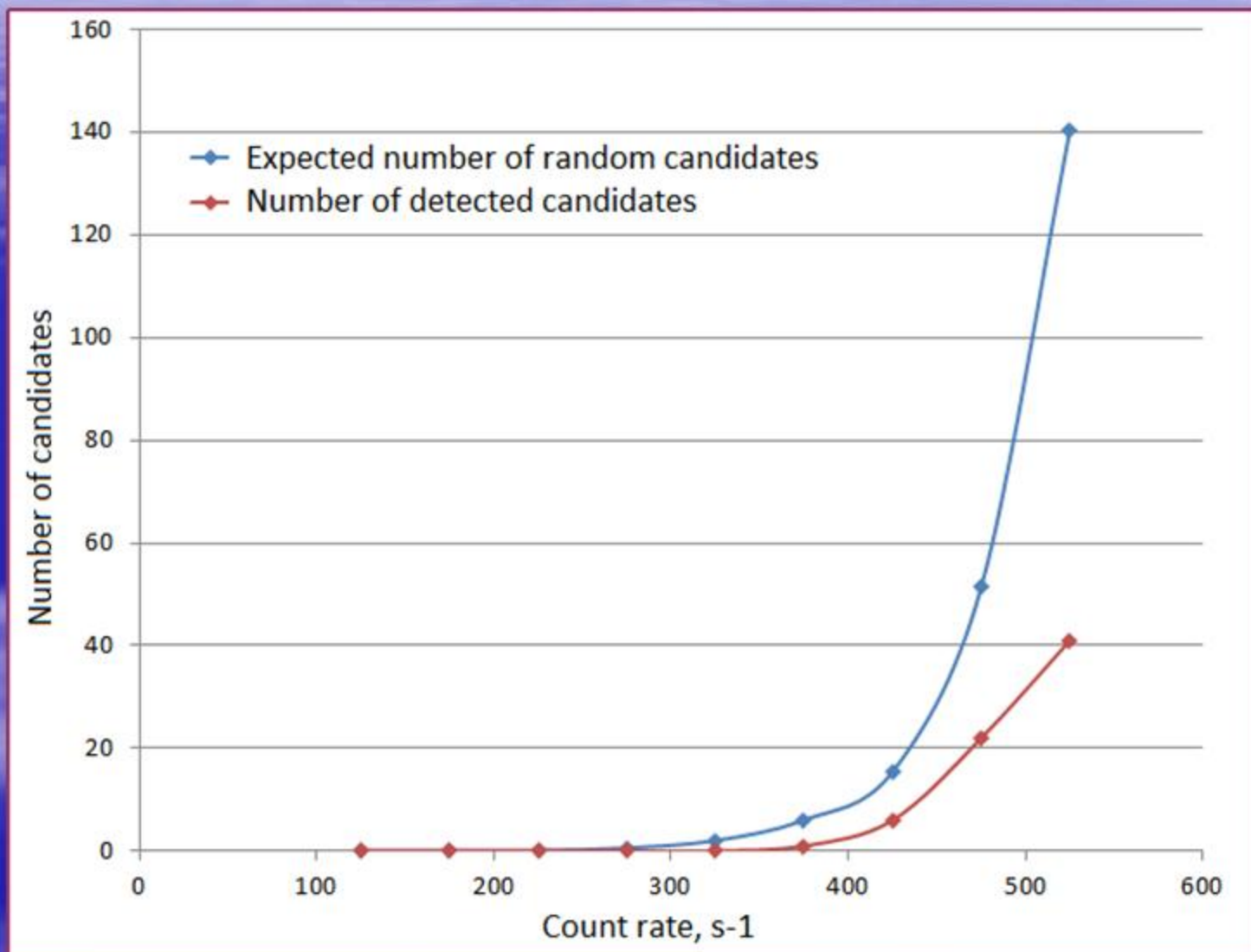
Condition of the candidate selection:

>3 events per 1 ms in each detectors,

count rate <400 s⁻¹



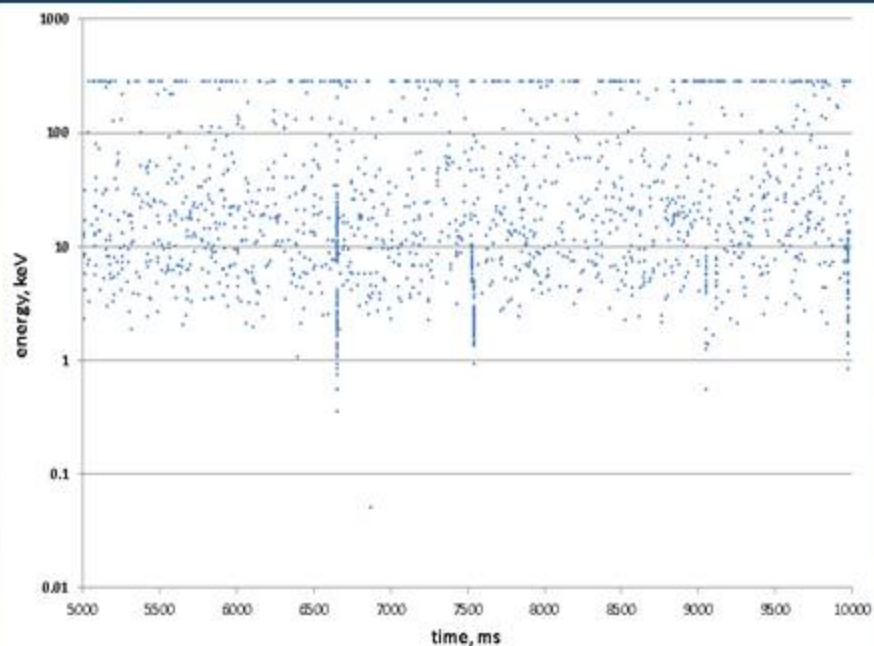
Expected number of random burst candidates for BDRG data collected from 10.2016 to 01.2017 in the event arrays formed after triggers with $T=20$ s in dependence on the background rate



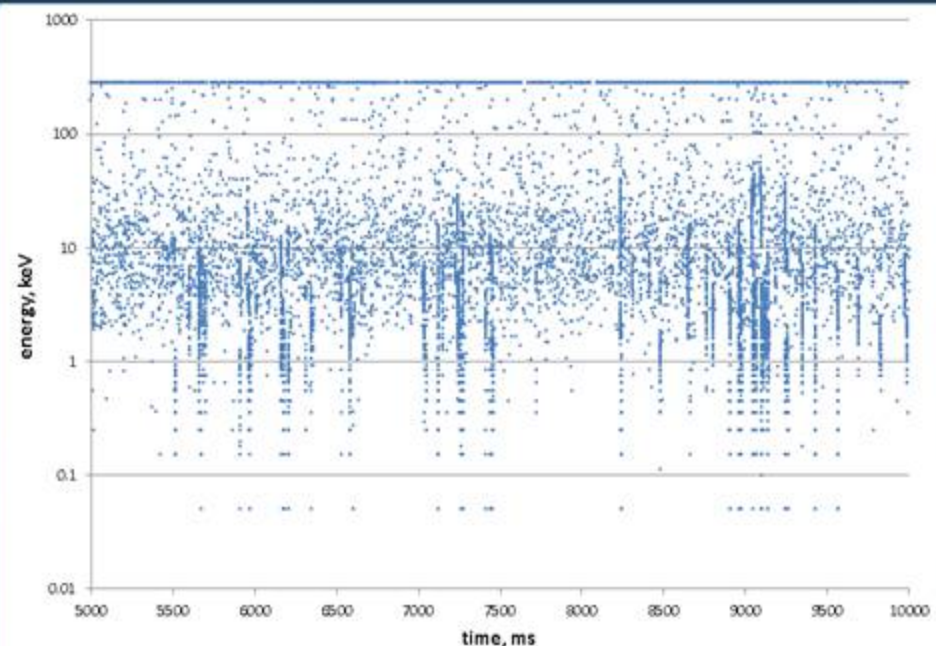
Imitations caused by cosmic rays

Significant part of short increases were related to the registration of heavy charged particles of galactic cosmic rays which cause a bright flare in scintillators, overloading PMTs and sensitive input elements of electronic circuits. In this case, the device records the sequence of noise pulses of decreasing amplitude with total duration of several milliseconds.

Such imitations can be successfully removed by the demand of coincident response in all three detectors

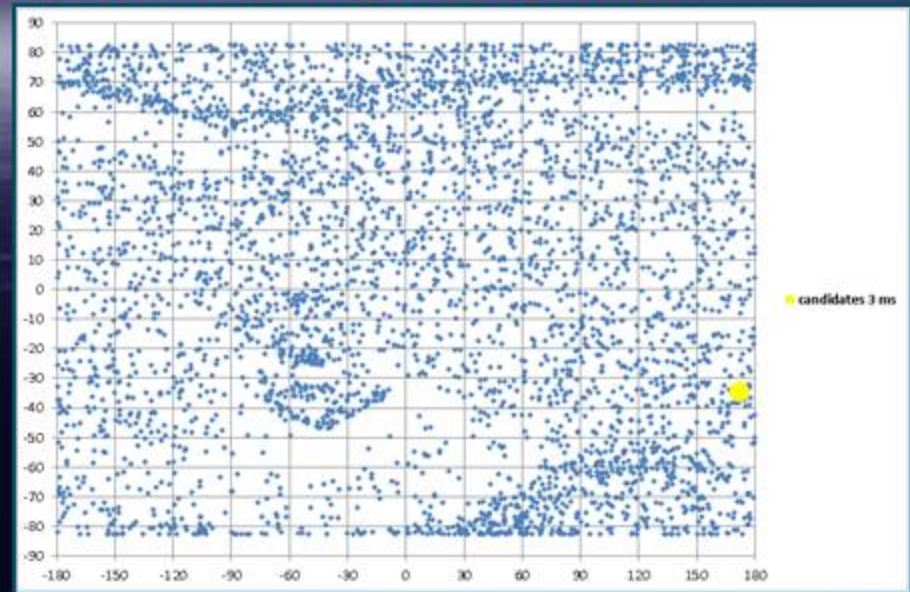
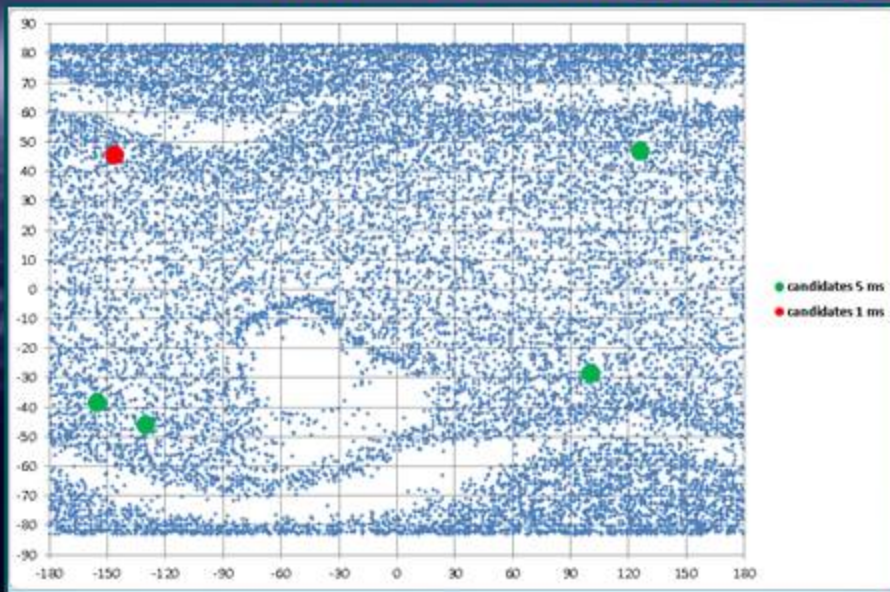


Equator



Polar region

Satellite position at the moment of the burst trigger (blue points) and TGF candidates (red, yellow and green points)



Characteristic time for triggering:

Up - left 10 ms,

Up - right 1 s,

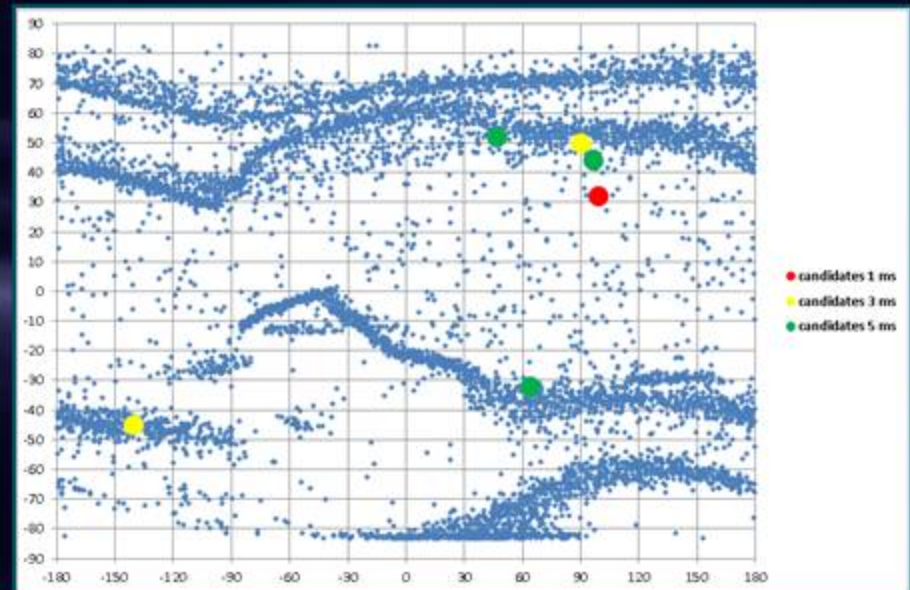
Down - 20 c

Condition of the candidate selection:

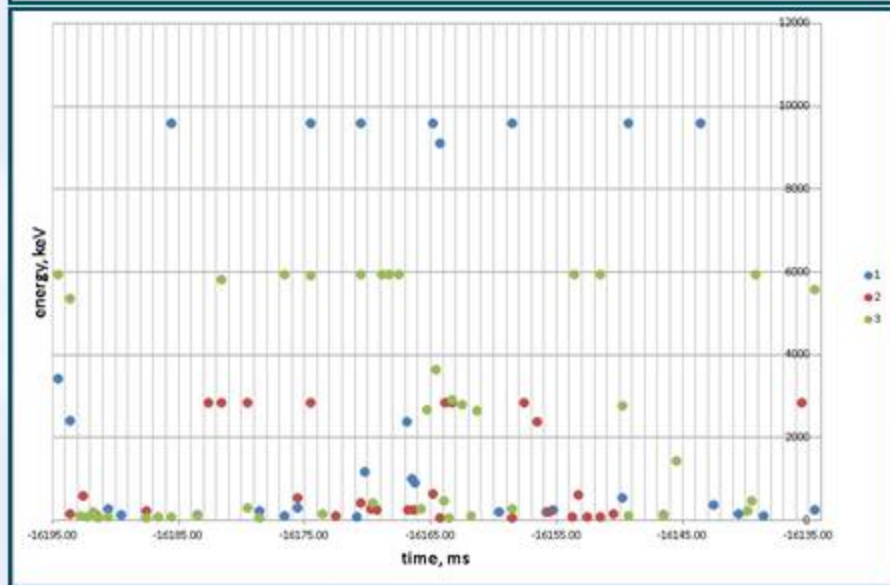
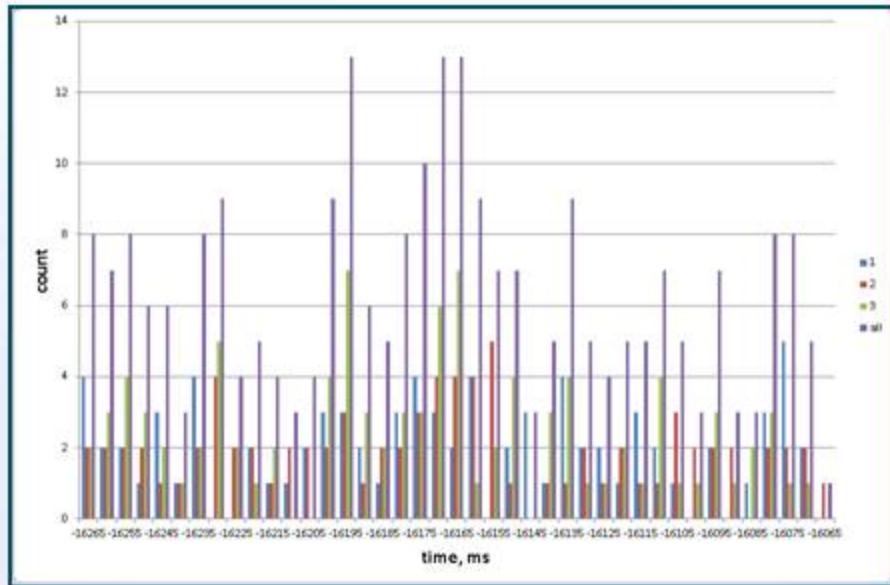
Red: >3 events for 1 ms in each detector, count rate $<400 \text{ s}^{-1}$

Yellow: >4 events for 3 ms in each detector, count rate $<300 \text{ s}^{-1}$

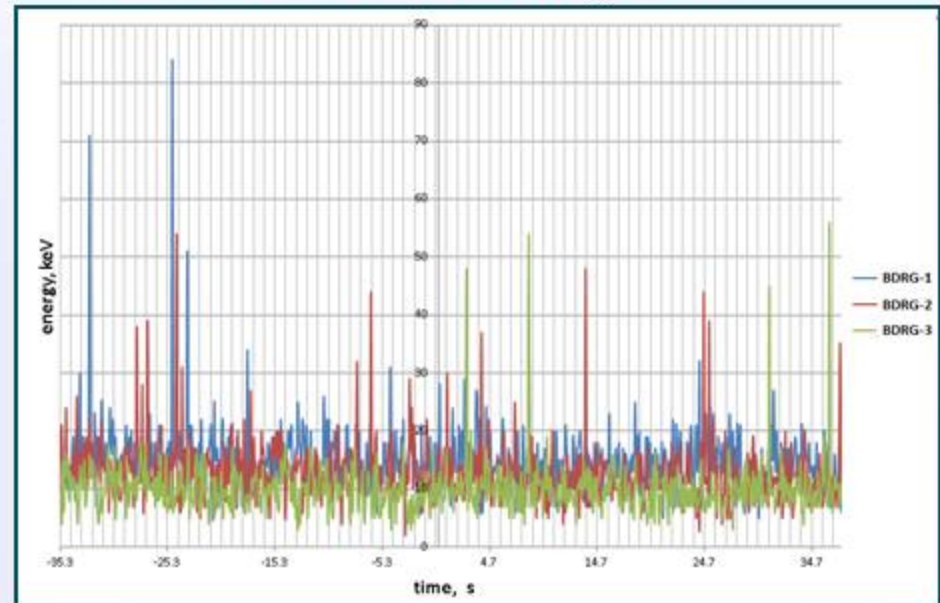
Green: >6 events for 5 ms in most significant detector and >5 events in other detectors, count rate $<300 \text{ s}^{-1}$



Example of TGF-candidate selected by 5 ms criterion



100 ms monitoring data



TGF candidate

Imitations by cosmic rays
(are present in one of detectors
and have characteristic time-
amplitude profile)

Instruments and Collaboration

- **DRGE-1 & DRGE-2** - two identical detectors of X-, gamma-rays and high-energy electrons of high temporal resolution and sensitivity (SINP MSU)
- **DRGE-3** - three axe directed detectors of energetic electrons and protons (SINP MSU)
- **Telescope-T (MTEL-2)** - optical imager (SINP MSU, Korea)
- **DUF** - UV detector (SINP MSU)
- **NChA (LFA)** - low-frequency analyser (Space Res. Inst. RAS, Etvos Univ., Hungary, Lviv Space Center, Ukraine)
- **RChA (RFA)** - radio-frequency analyser (Space Res. Inst. RAS, Space Center, Poland)
- **BE** - module of commands and data collection (NILAKT)

Прибор ДРГЭ

**Прибор ДРГЭ представляет собой комплекс
сцинтилляционных детекторов рентгеновского, гамма-
излучения и электронов.**

Два типа детекторных узлов

ДРГЭ-1, ДРГЭ-2

Рентгеновское и гамма-излучение в диапазоне энергий 0.01-3 МэВ от атмосферных разрядов с высоким временным разрешением (до 15 мкс)



ДРГЭ-3

Электроны в 3-х ортогональных направлениях, вторичные рентгеновские и гамма-кванты, генерируемые электронами.



Блок ДРГЭ-1 (ДРГЭ-2)

Два идентичных фосвич детектора NaI(Tl)/CsI(Tl), оба ориентированы в надир

Физические характеристики:

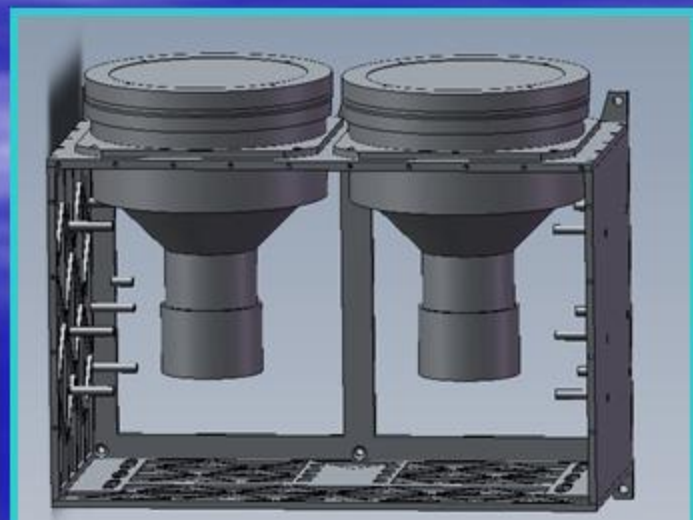
	Х- и гамма кванты	электроны
энергетический диапазон	0.01-3.0 МэВ,	0.2-10.0 МэВ
эффективная площадь	~120 см ² (полная ~500 см ²)	~200 см ² ср (геом. Фактор)
временное разрешение	0.15 мкс	0.15 мкс
чувствительность	~5·10 ⁻⁹ эрг/см ²	~10 ⁻¹ част./см ² с

Технические параметры

масса - < 10.5 кг;

габариты 360×300×180 мм;

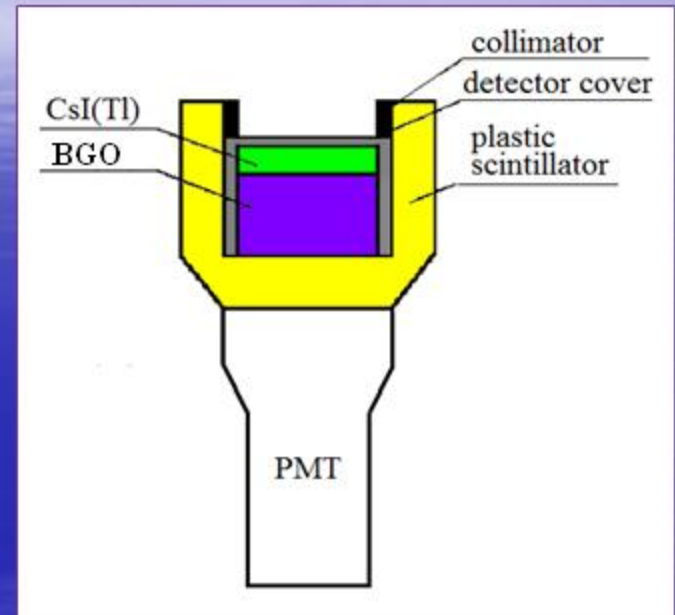
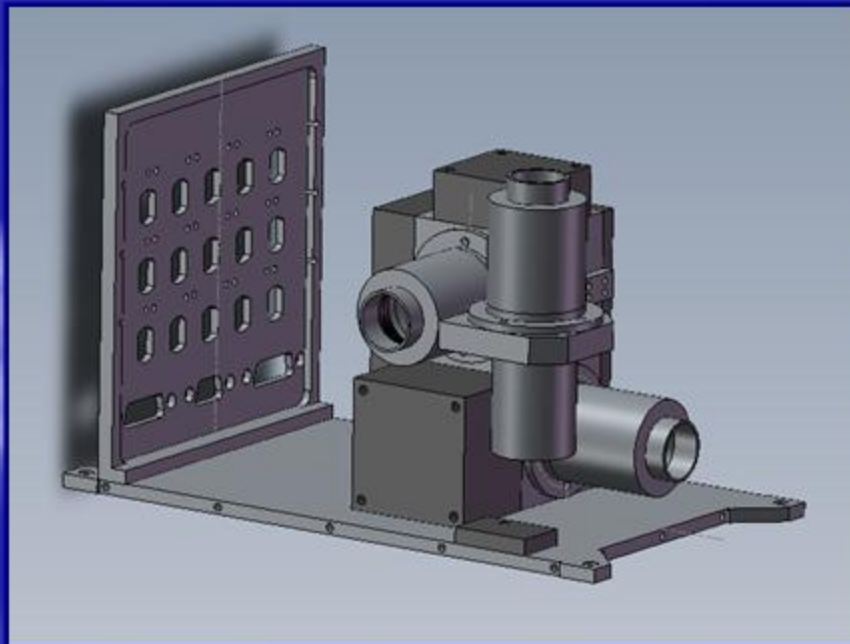
потребление <9 Вт.



Scintillation detectors of DRGE-3

Three identical BGO/CsI(Tl)/plastic scintillator phoswich detectors are directed along three axes mutually normal (as Cartesian coordinate system)

↑
To the sky



Detector consists of optically coupled thin (3mm) CsI(Tl) and considerably thick (17mm) BGO crystals with $\varnothing 20\text{mm}$. Surrounding plastic scintillator is 5mm thick. FOV is formed by cylindrical collimator made of 1mm Cu.

→
Along the geomagnetic field line

Результаты поиска атмосферных гамма-вспышек

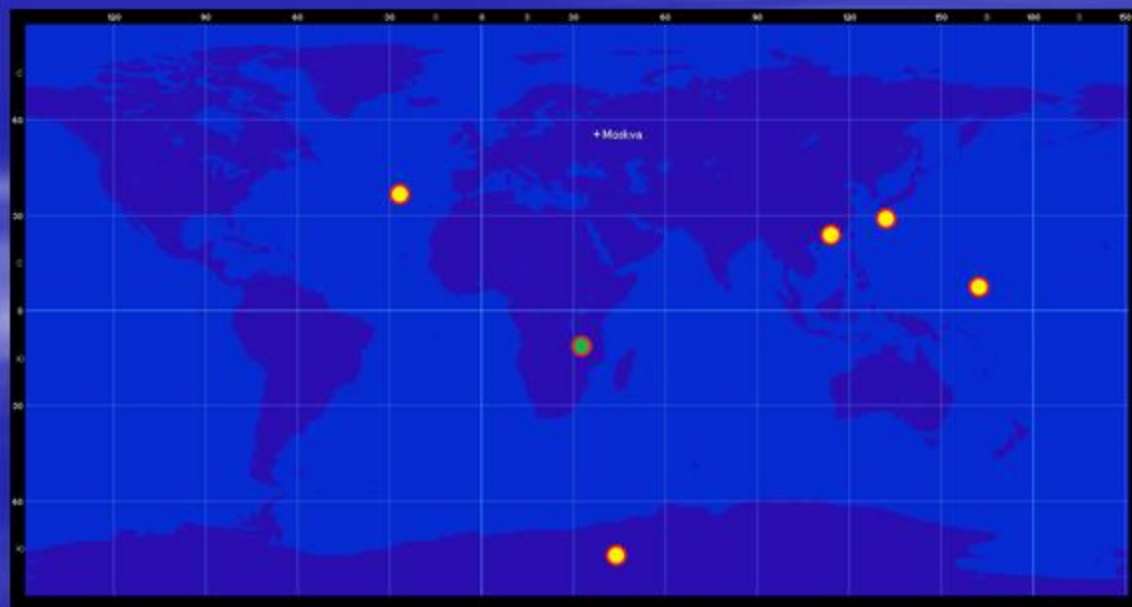
(ТГФ)

Были использованы два критерия отбора быстрых возрастаний

1) ≥ 2 детекторов, ≥ 5 событий с энерговыделением $E > 300$ кэВ за 1 мс.

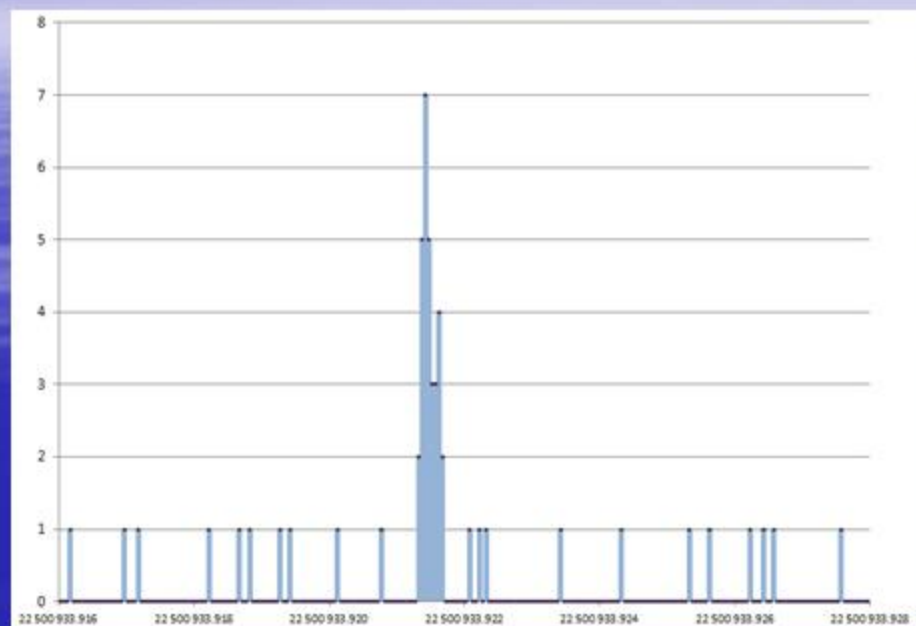
2) ≥ 3 детекторов, ≥ 3 событий с энерговыделением $E > 300$ кэВ за 1 мс.

Время	Детекторы	Широта, долгота	Примечания
2014-08-07-22-20-55	1101	26.2W, 35.6N	TGF
2014-08-08-00-31-07	1011	132.04E, 29.4N	
2014-08-16-13-06-55	-111	114.7E, 24.2N	Имитация?
2014-09-18-10-15-34	1001	160.4E, 8.3N	TGF
2014-10-11-06-46-20	11-1	32.4E, 12.4S	GRB
2014-11-02-03-34-14	1011	40.7E, 77.6S	

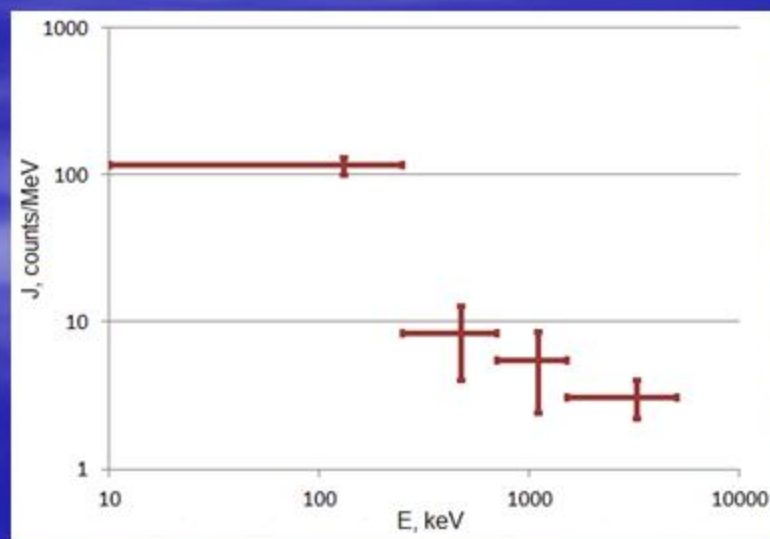
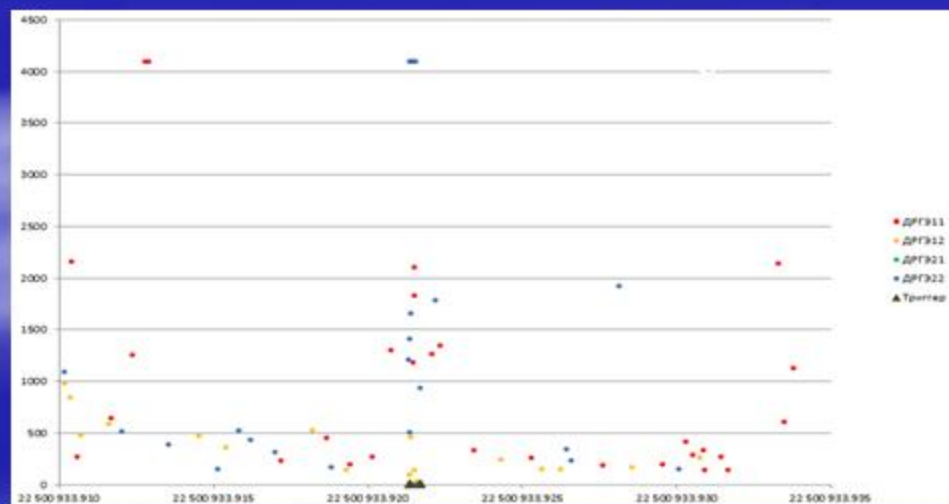
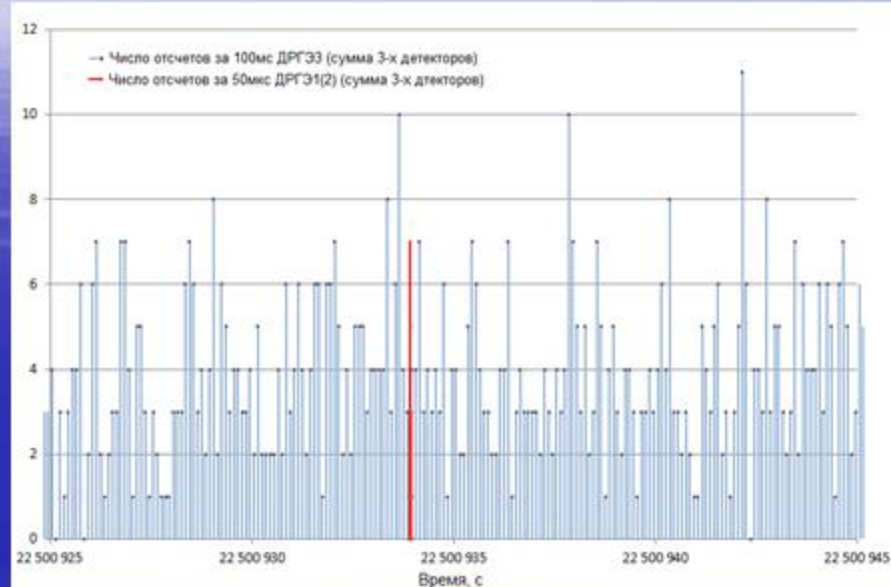


Атмосферная гамма-вспышка (TGF) 2014-09-18-10-15-34

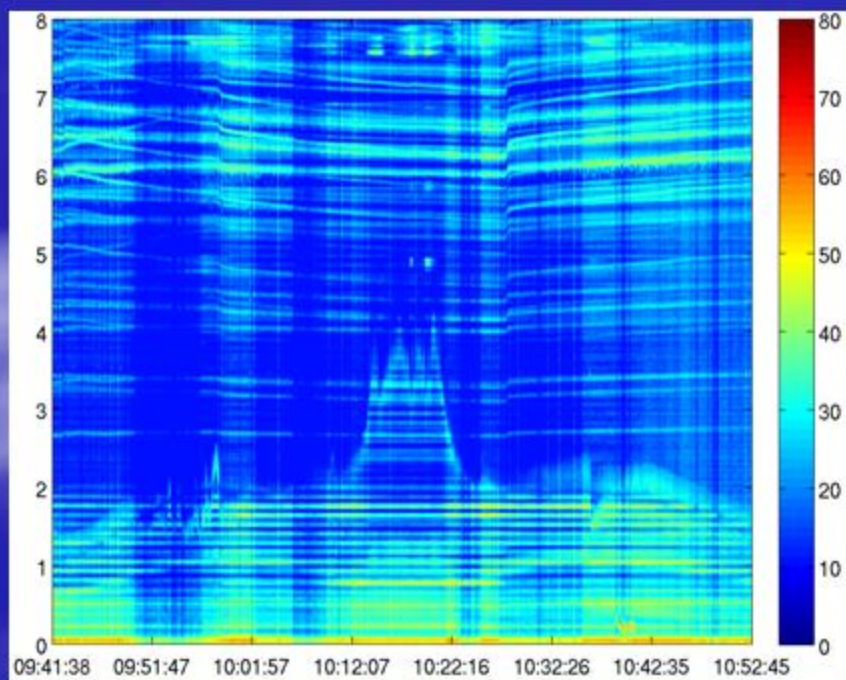
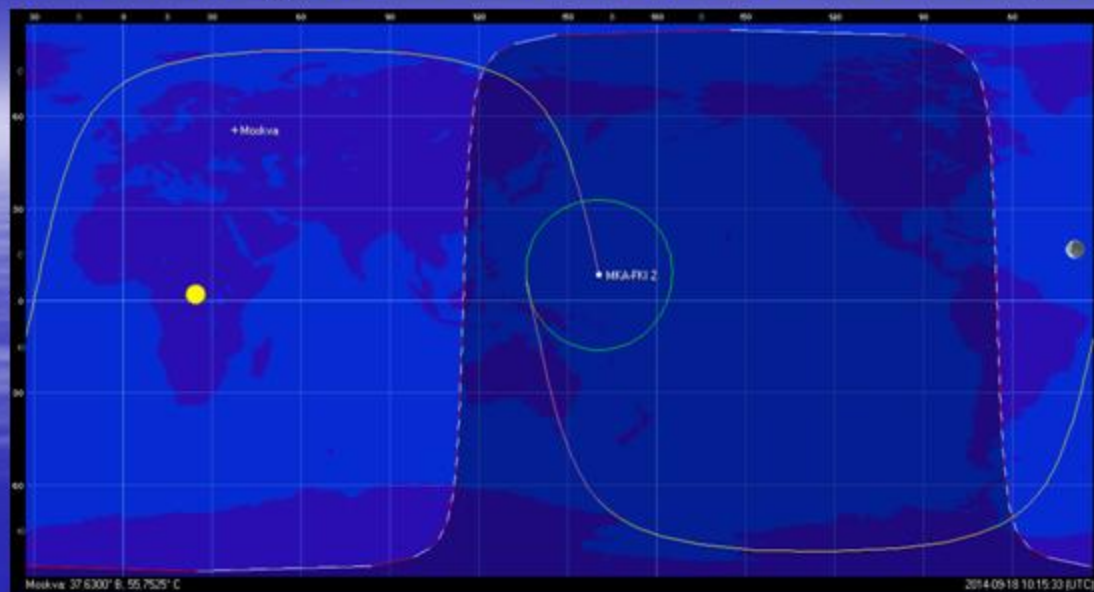
Гамма-излучение ДРГЭ-1(2)



Электроны DRGE-3

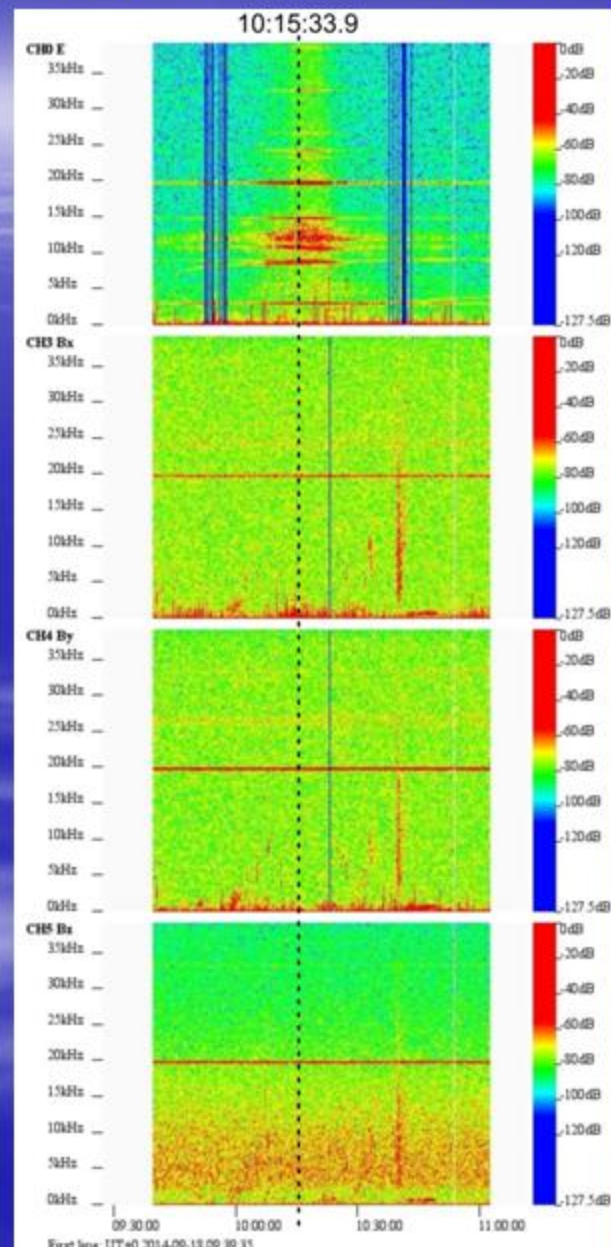


Атмосферная гамма-вспышка (TGF) 2014-09-18-10-15-34



РЧА

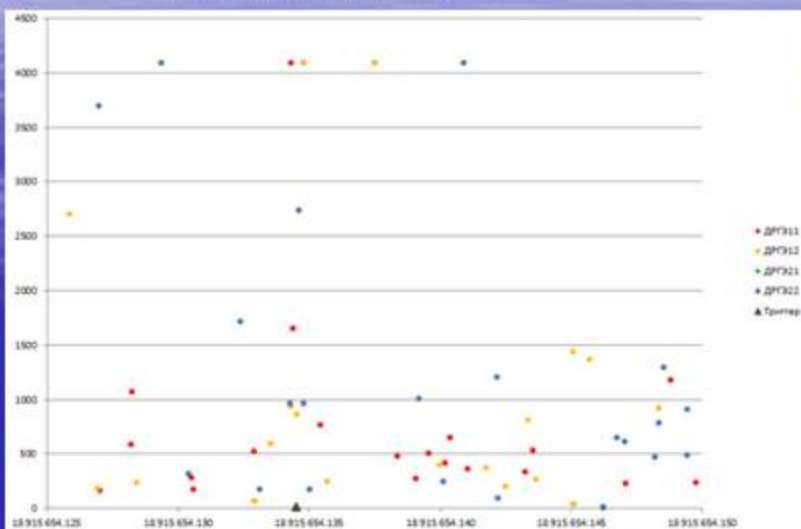
НЧА



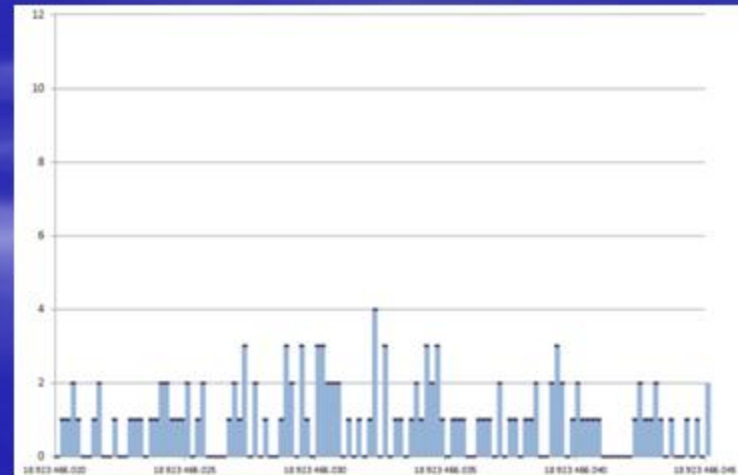
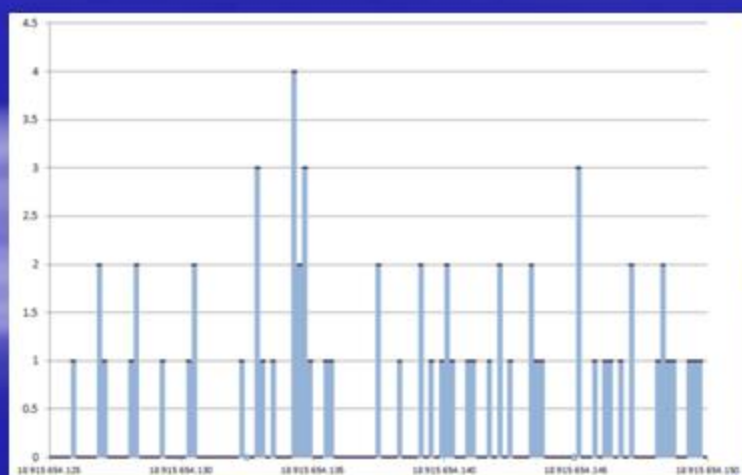
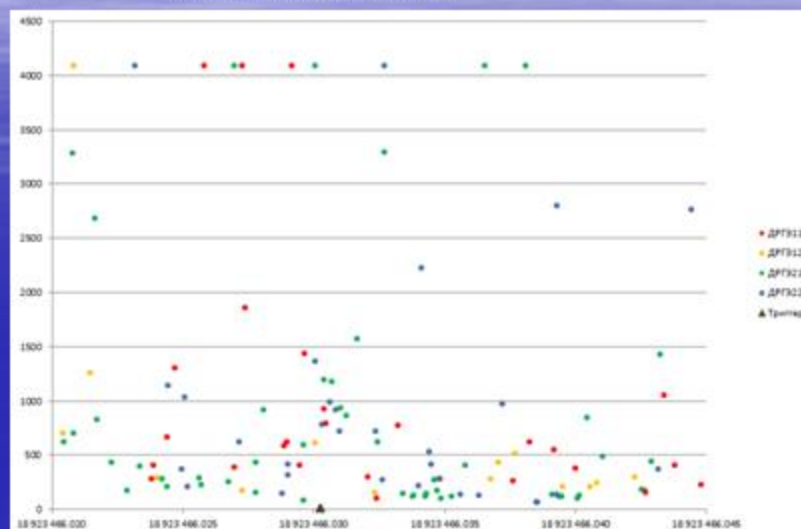
Кандидаты в TGF -

1

2014-08-07-22-20-54

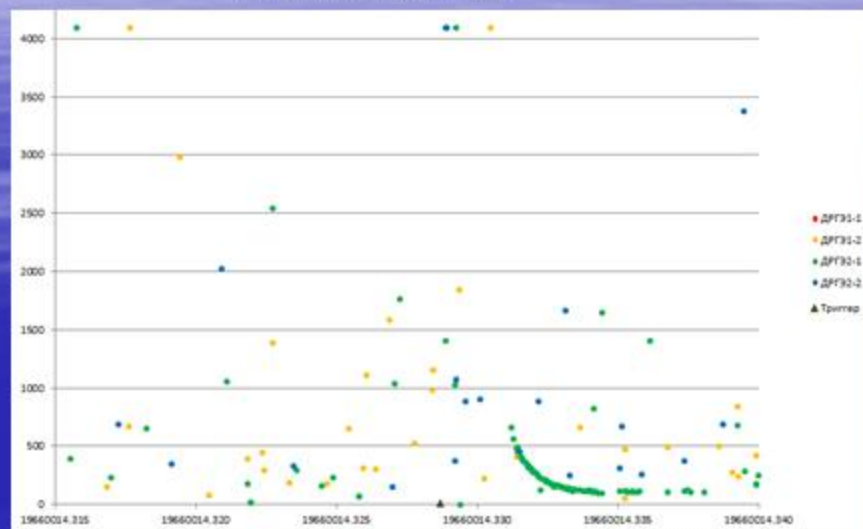


2014-08-08-00-31-06

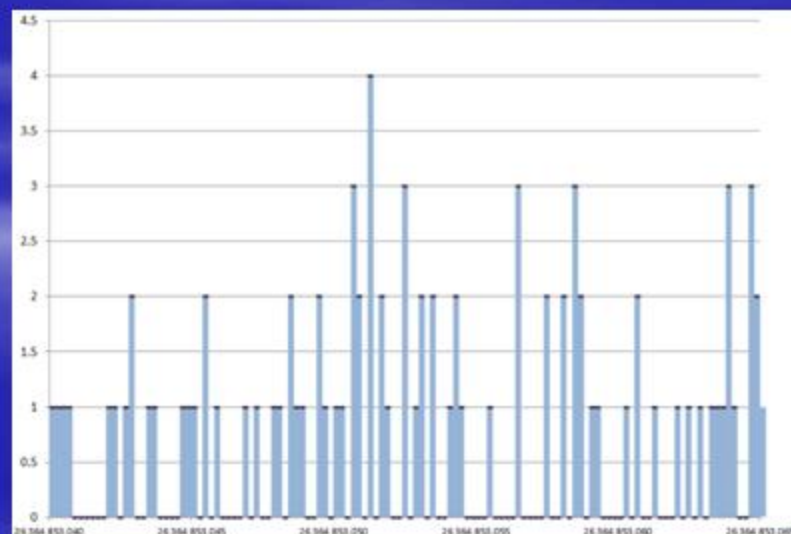
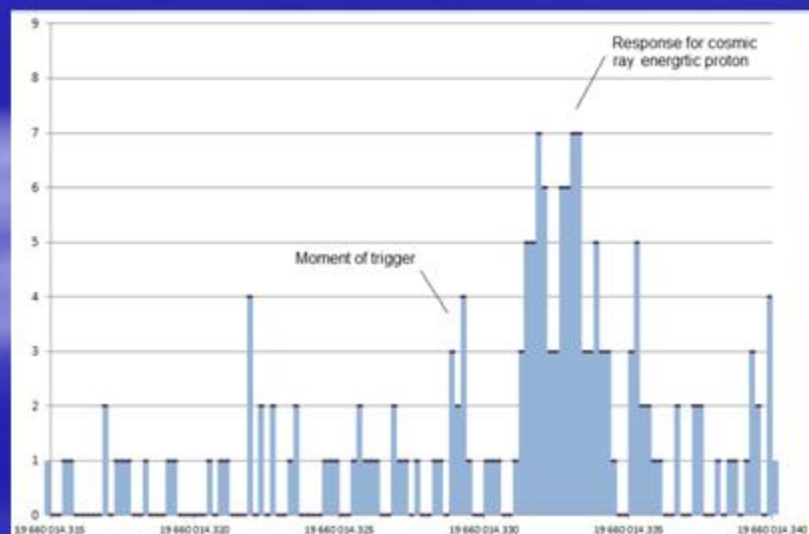
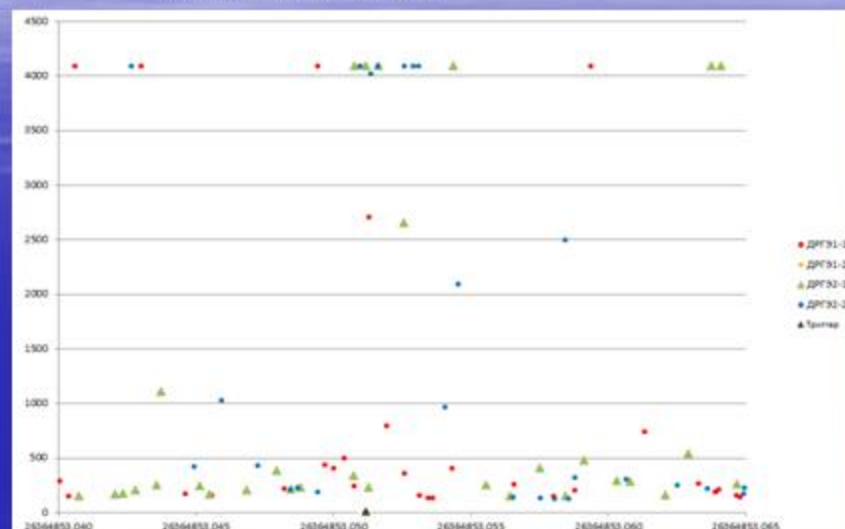


Кандидаты в TGF - 2

2014-08-16-13-06-54



2014-11-02-03-34-13

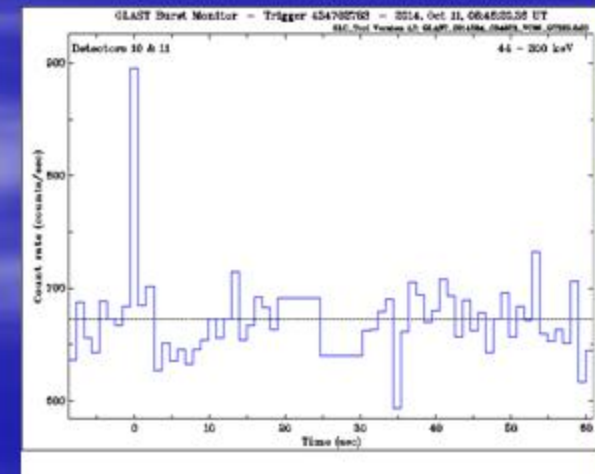
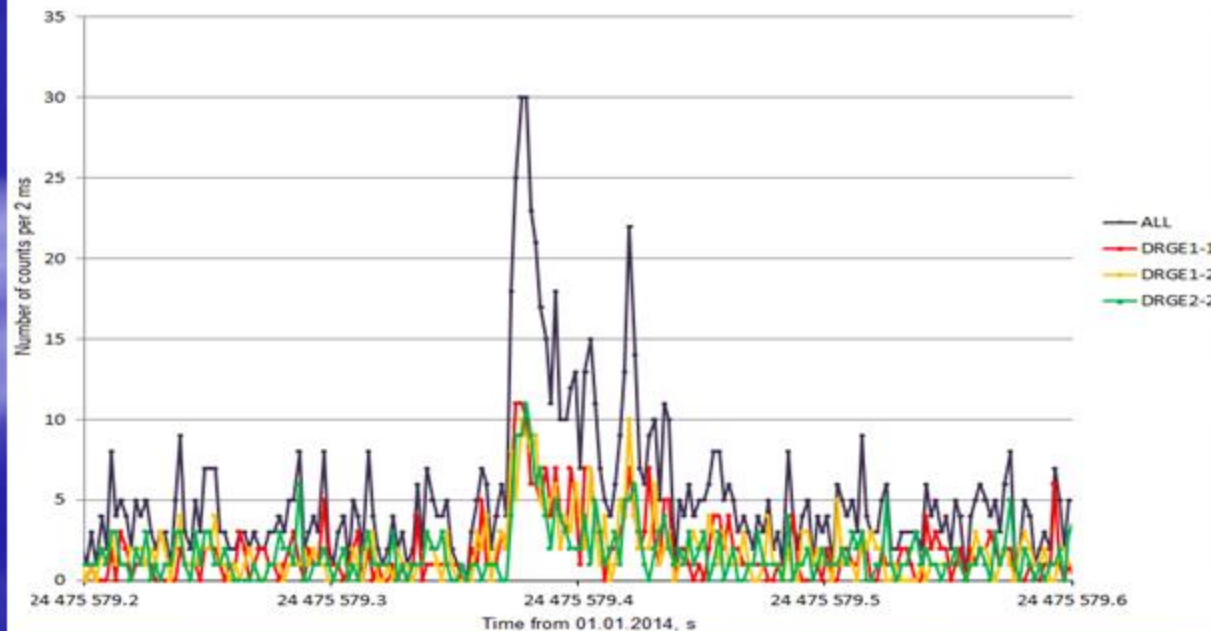
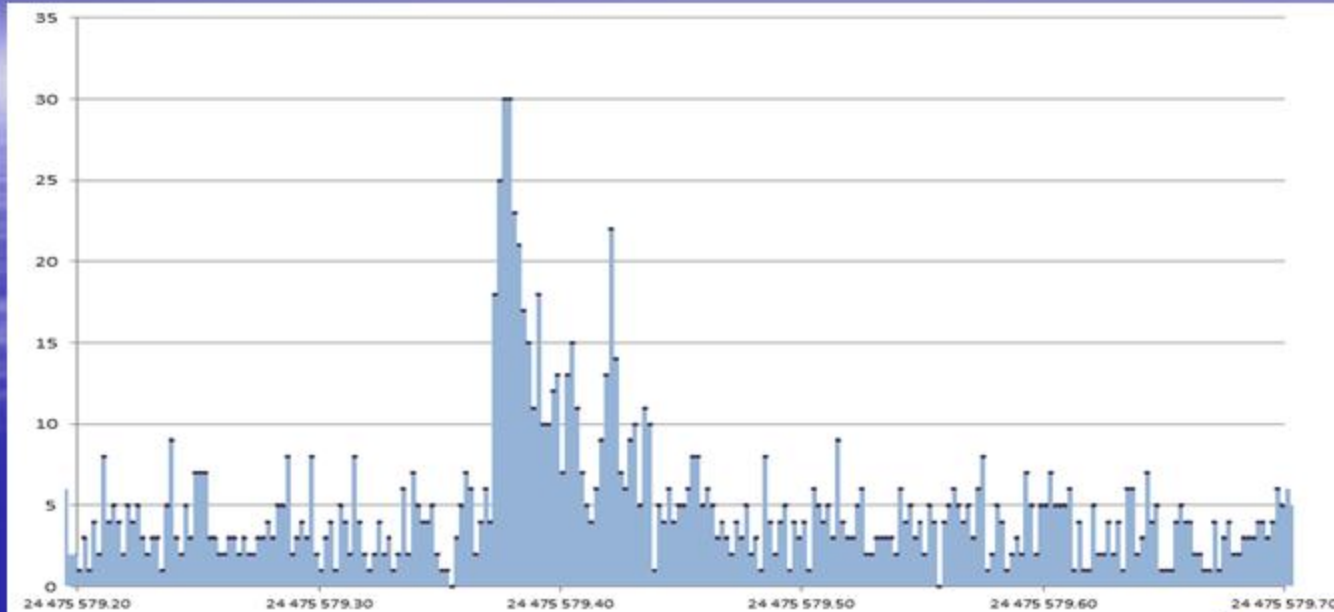


Космический гамма-всплеск (GRB) 2014-10-11-06-46-20

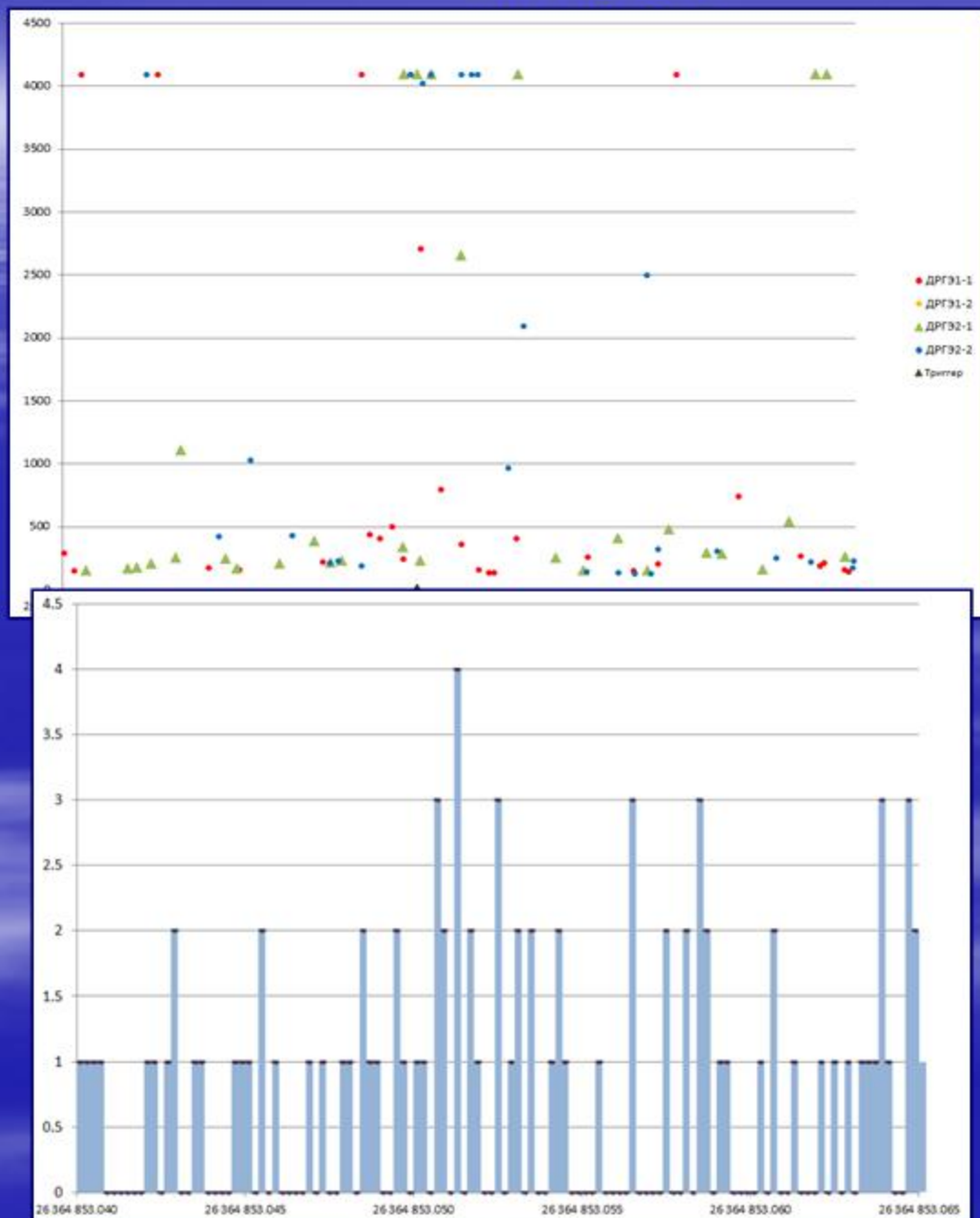
РЭЛЕК
ДРГЭ-1(2)

Подробность
профиля
(размер
бина)
2 мс

Fermi
GBM



2014-11-02-03-34-14



Discussion on candidate №5 at latitude 77.6S

Some peculiarities in comparison with other candidates:

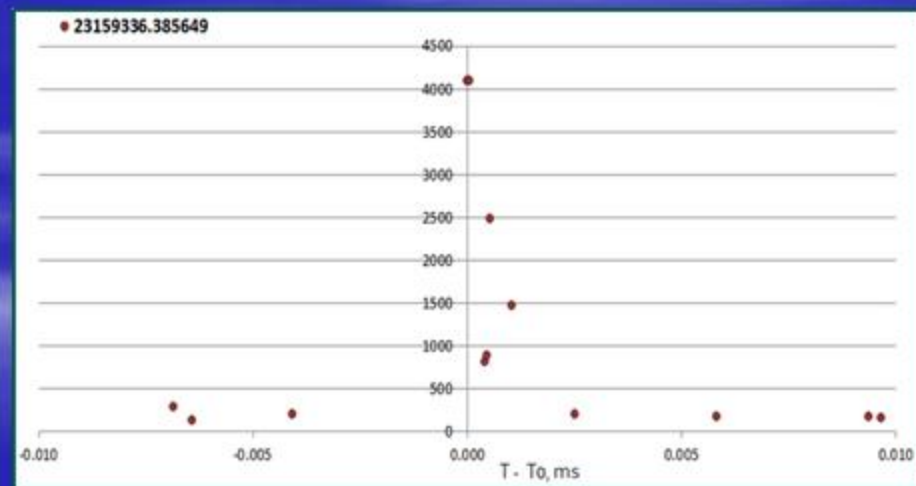
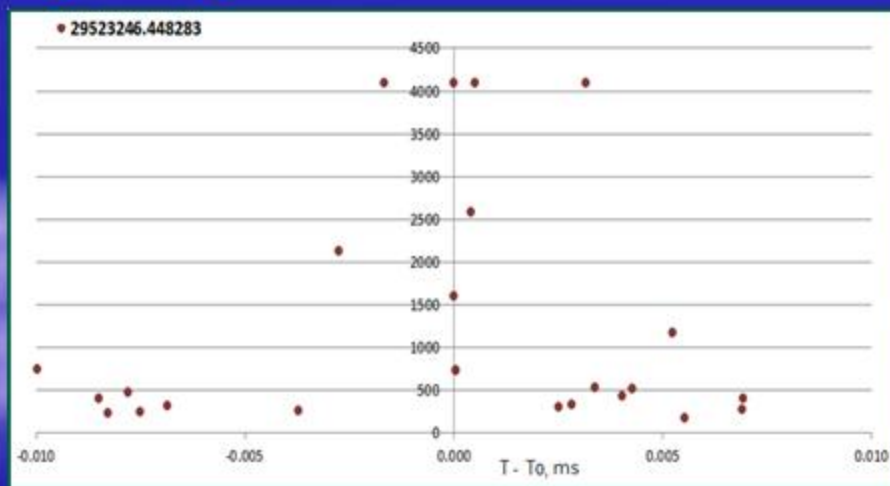
- Total duration more than the duration of other candidates (2.6 mc)
- Most gamma-events have the power beyond the upper limit of the range of the instrument. Other candidates have the majority of events within the range.
- It is observed by three detectors.
- It is not accompanied by radio bursts (according to the RFA device data) like the other, "classical", candidates.
- Is located away from areas of thunderstorms.

Discussion on physical interpretation:

- Can be indirectly linked to variations of electron fluxes observed in this area. However, a device that measures the flux of electrons (DRGE-3) registered no significant bursts.
- Cannot be interpreted as the response of the device to the showers from cosmic rays, as well as activation with the formation of short-lived isotopes

Next step of TGF search

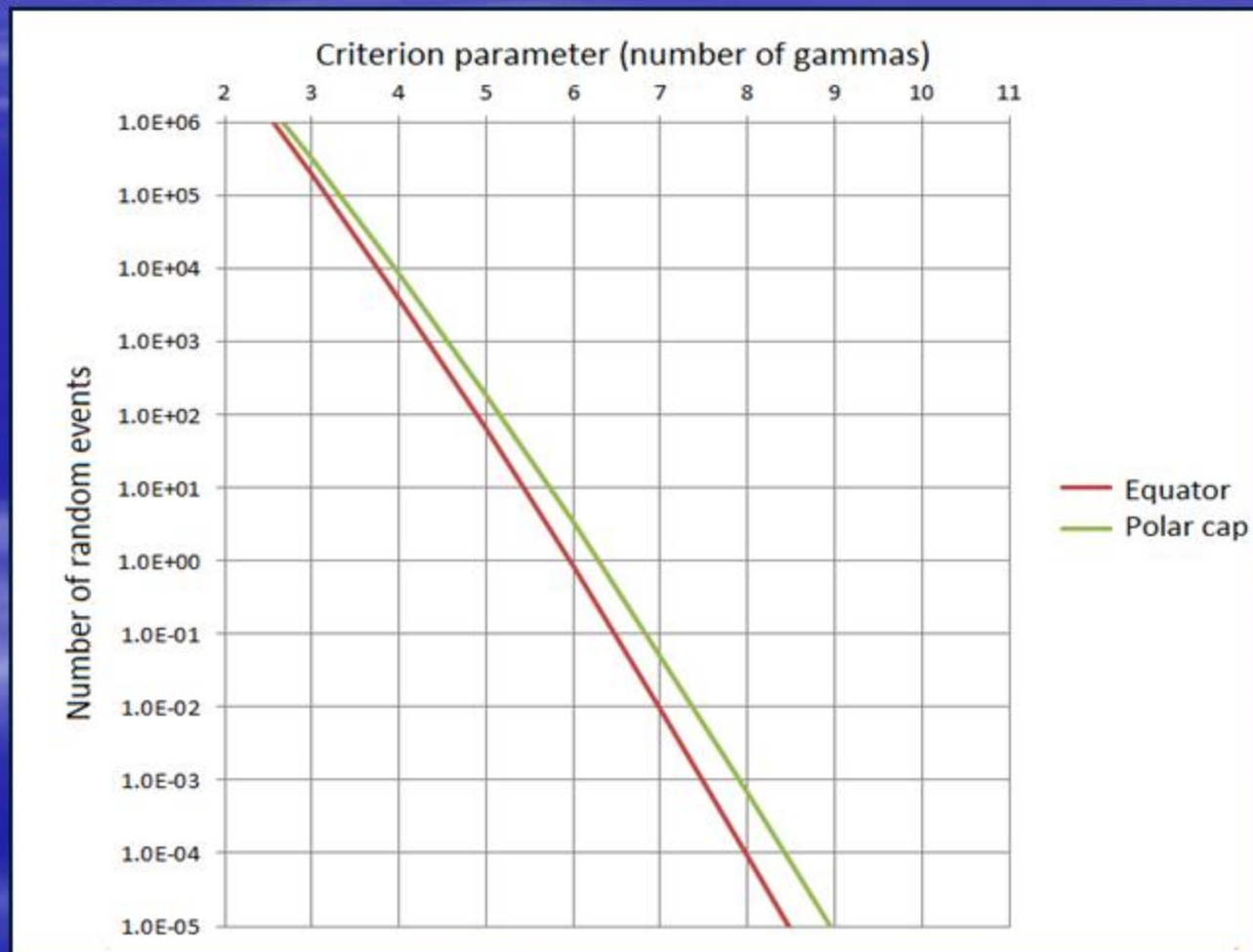
- New method of cleaning data from TGF imitations by particles, based on more accurate analysis of the time profile of candidate was realized. It allows to conduct a search of TGF according to the individual detectors (without coincidence). This will increase the analyzed observation period of almost 2 times
- We plan to search with shorter times (~ 500 mcs) at the equator and at high latitudes at the level defined statistical confidence
- We plan to compare both the previous and newly selected candidates with RFA data with ~ 100 ms temporal resolution, WWLLN, and other ground-based lightning networks.

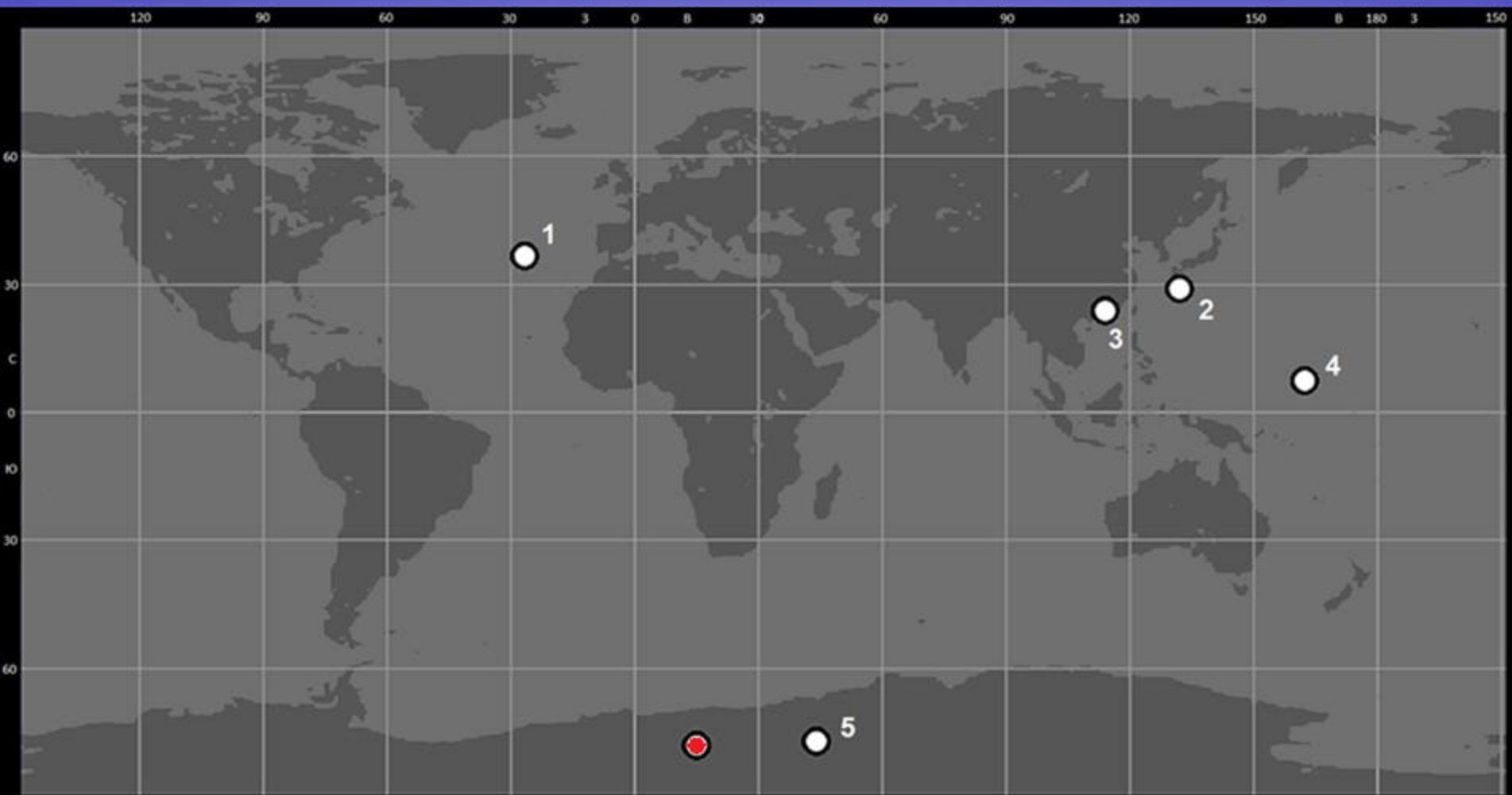


Some candidates obtained as a preliminary result of selection of 6 events for 600 μ s from the detector DRGE-1 without coincidences

Expected number of random events for all time of observation

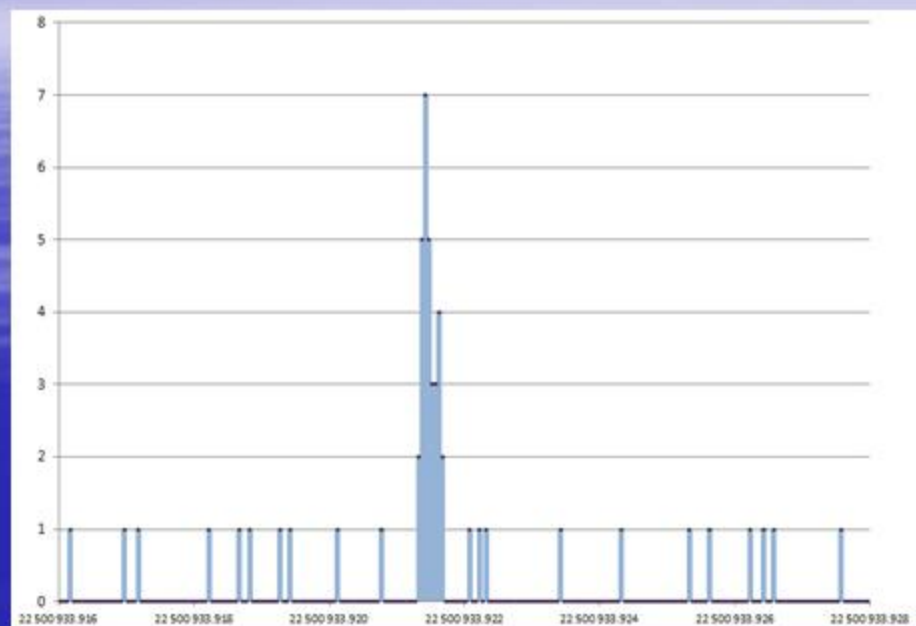
The figure shows the dependence of the expected number of random candidates on the selection parameter, expressed by the number of counts detected over 0.4 ms. This dependence is calculated by multiplying the probability of accidental imitation on single interval (defined by Poisson distribution for taken background level), at the observation time.



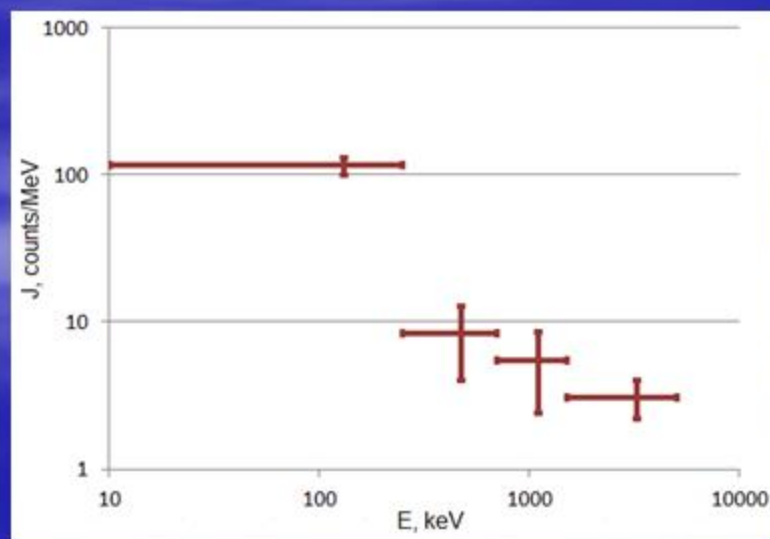
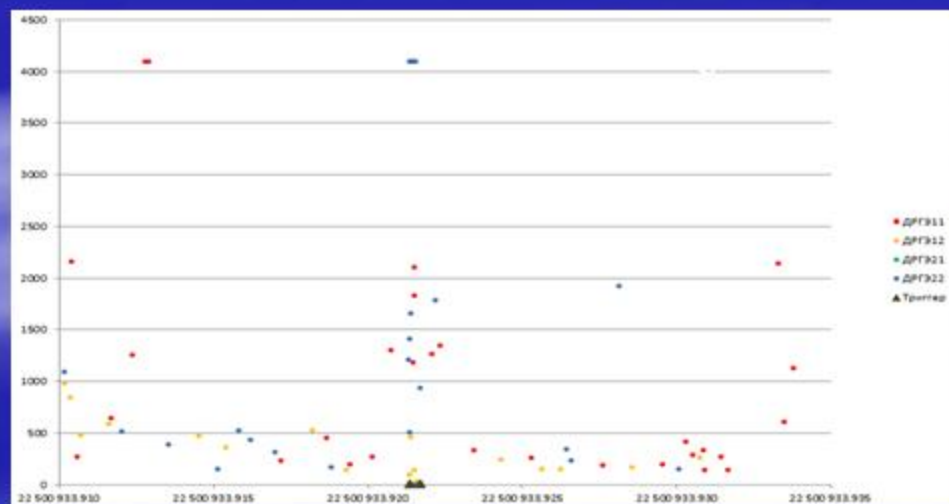
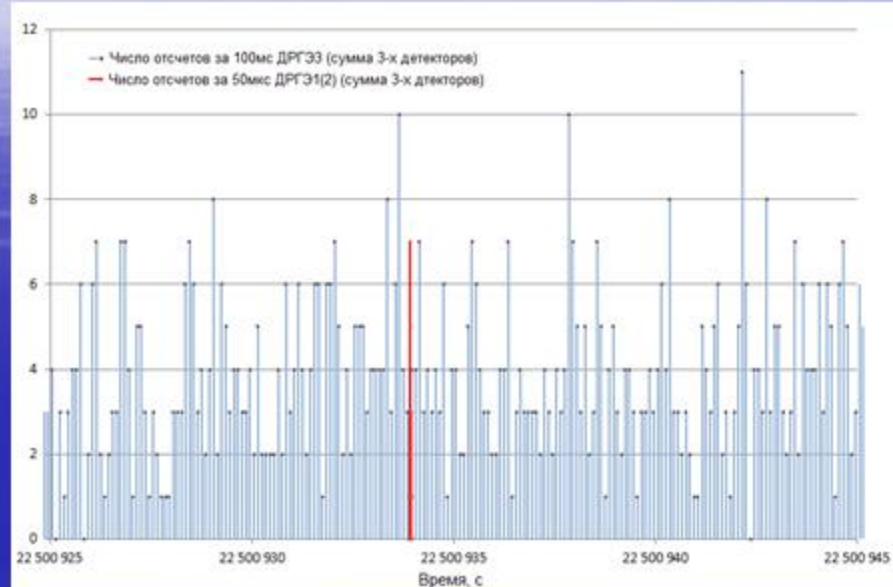


Атмосферная гамма-вспышка (TGF) 2014-09-18-10-15-34

Гамма-излучение ДРГЭ-1(2)



Электроны DRGE-3



По данным сетей WWLLN и Vaisala GLD360 не зарегистрированы грозы в пределах ± 10 мин от моментов регистрации всплесков и 1000 км от подспутниковых точек регистрации и сопряженных к ним.

02.11.2014 03h34m14s UTC

-69.50 - широта, 59.41 - долгота,

высота спутника 658 км

сопряженная точка:

latgeo[deg]= 78.3899918

longeo[deg]= -4.2896266

22.11.2014 05h05m03s UTC

-78.63 - широта, 13.30 - долгота,

высота спутника 761 км

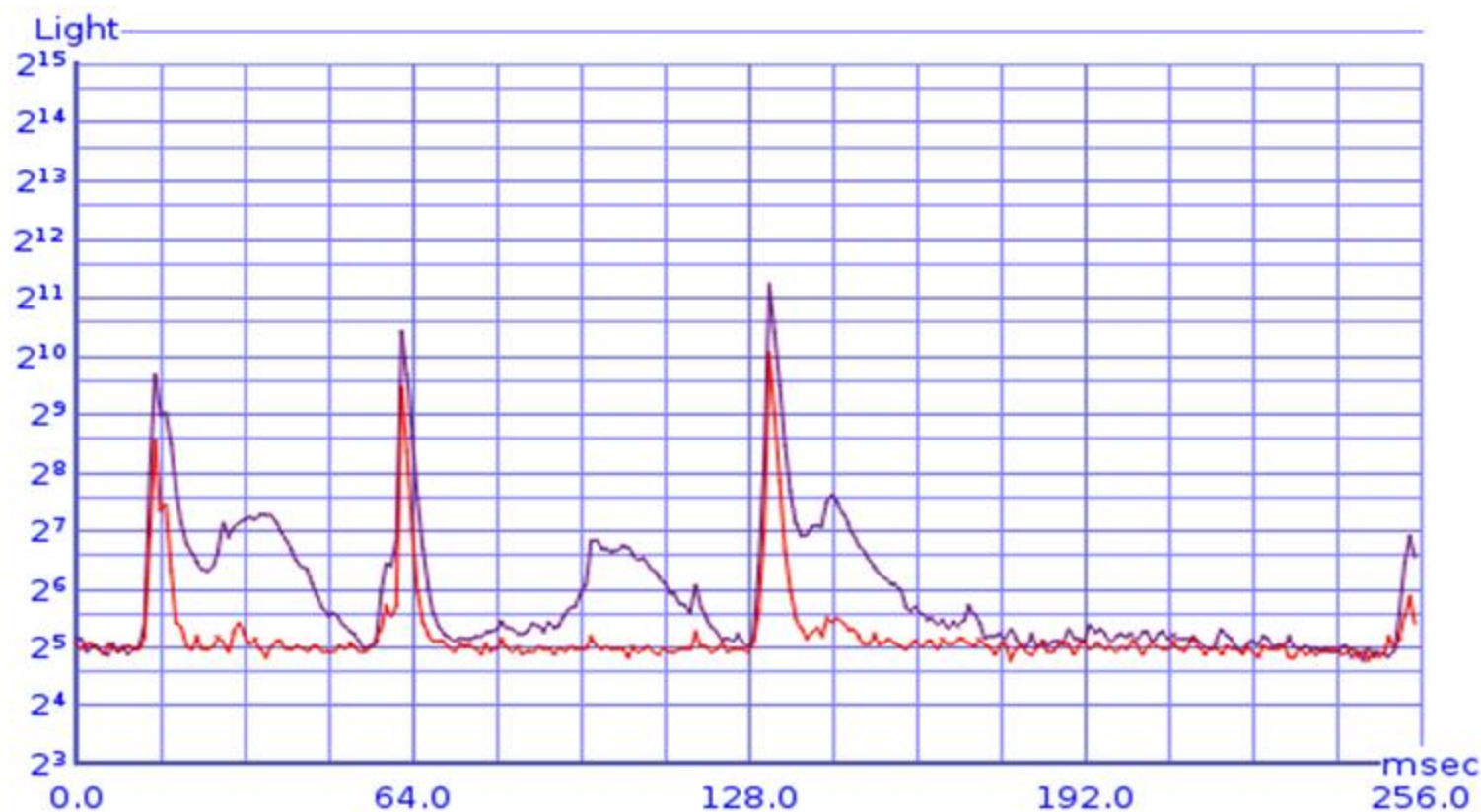
нет сопряженной точки, т.к. исходная точка лежит в области открытых силовых линий.



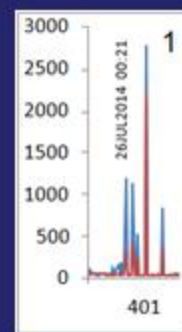
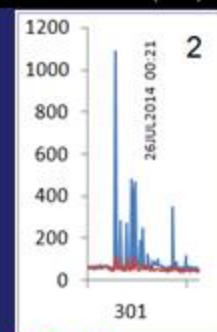
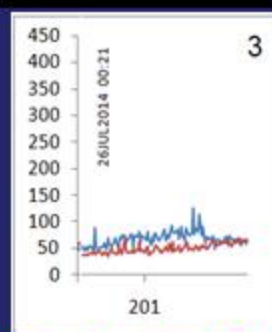
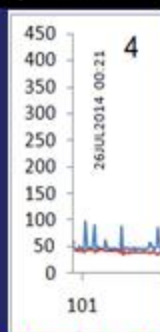
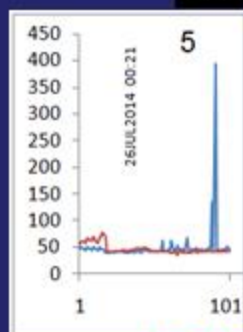
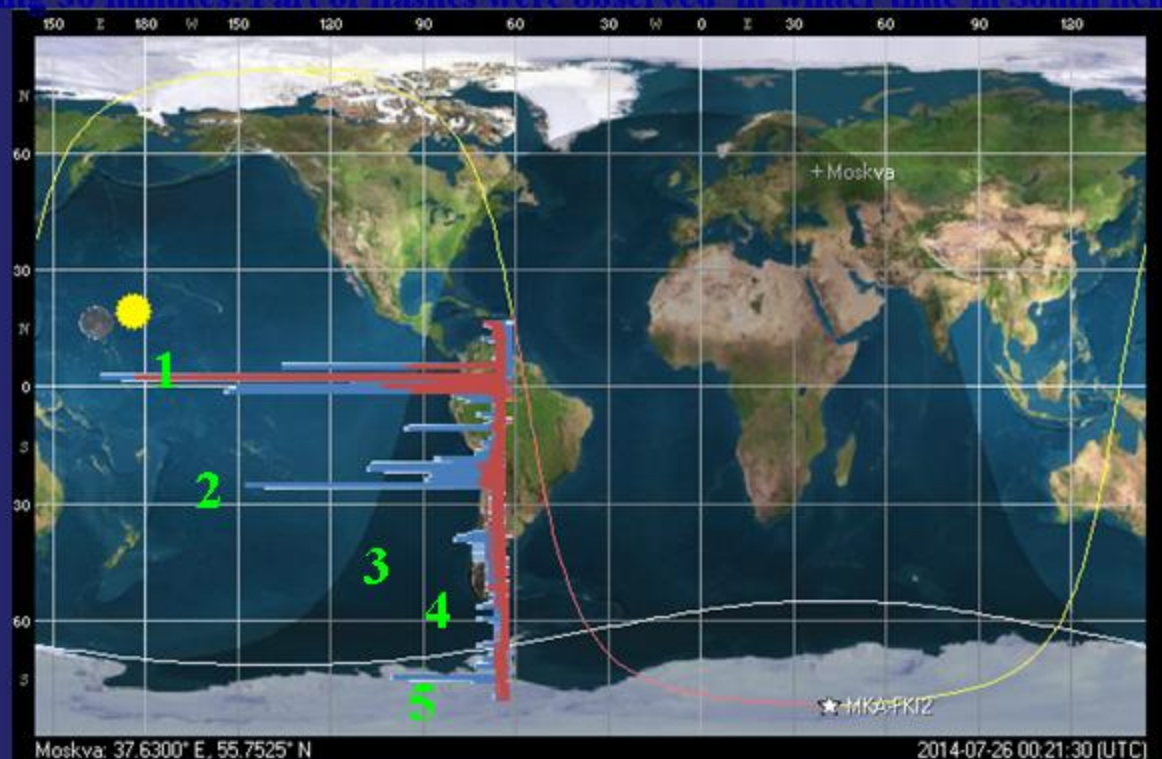
Наблюдение ультрафиолетовых и оптических вспышек прибором ДУФ

Пример электрического разряда облако-ионосфера, инициированного молнией.
(эльфы, спрайты, голубые струи)

2014-Nov-21 19:36:47.18735.5: lat=-0.723, lon=22.094, U=39712V,
Ultraviolet (max = 2362, sum = 24683)
Infrared (max = 1053, sum = 12105)

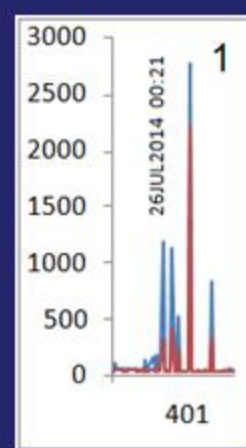
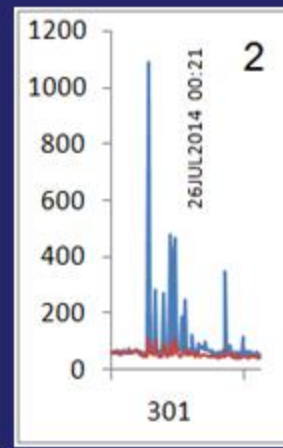
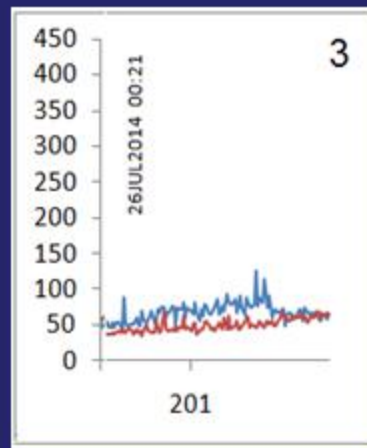
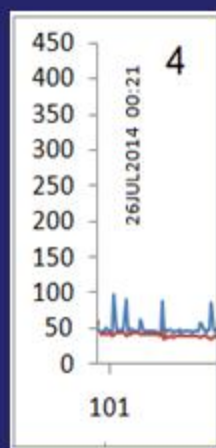
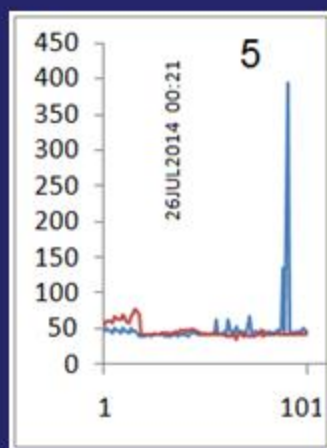
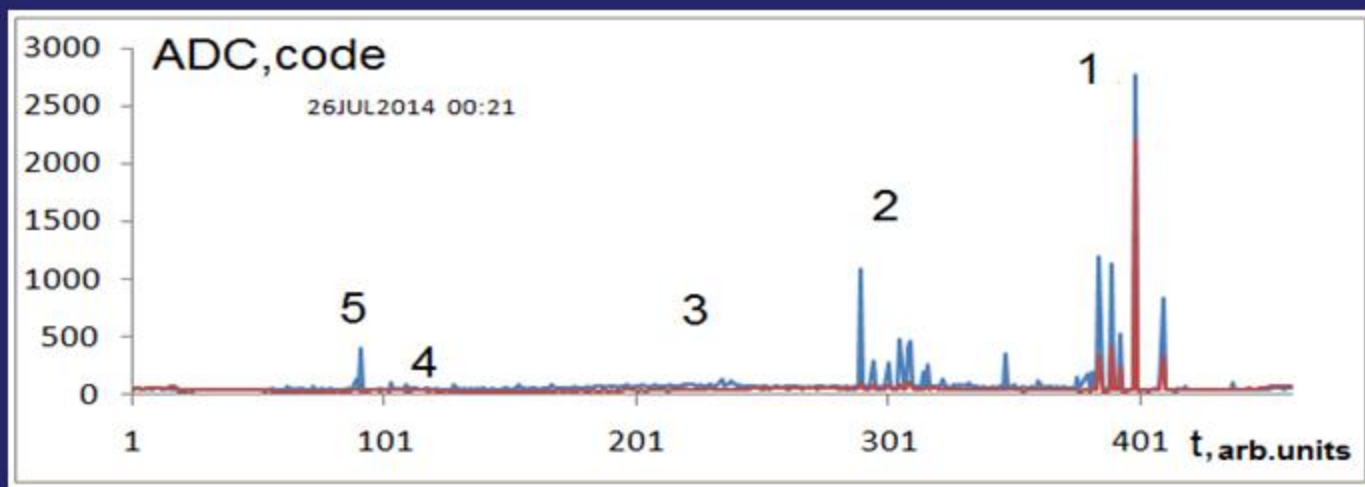


Example of amplitude distribution of different flashes along satellite ground track on the map, which were observed on the night side of the orbit from 82 degrees south latitude to 16 degrees north latitude during 30 minutes. Part of flashes were observed in winter time in South hemisphere.



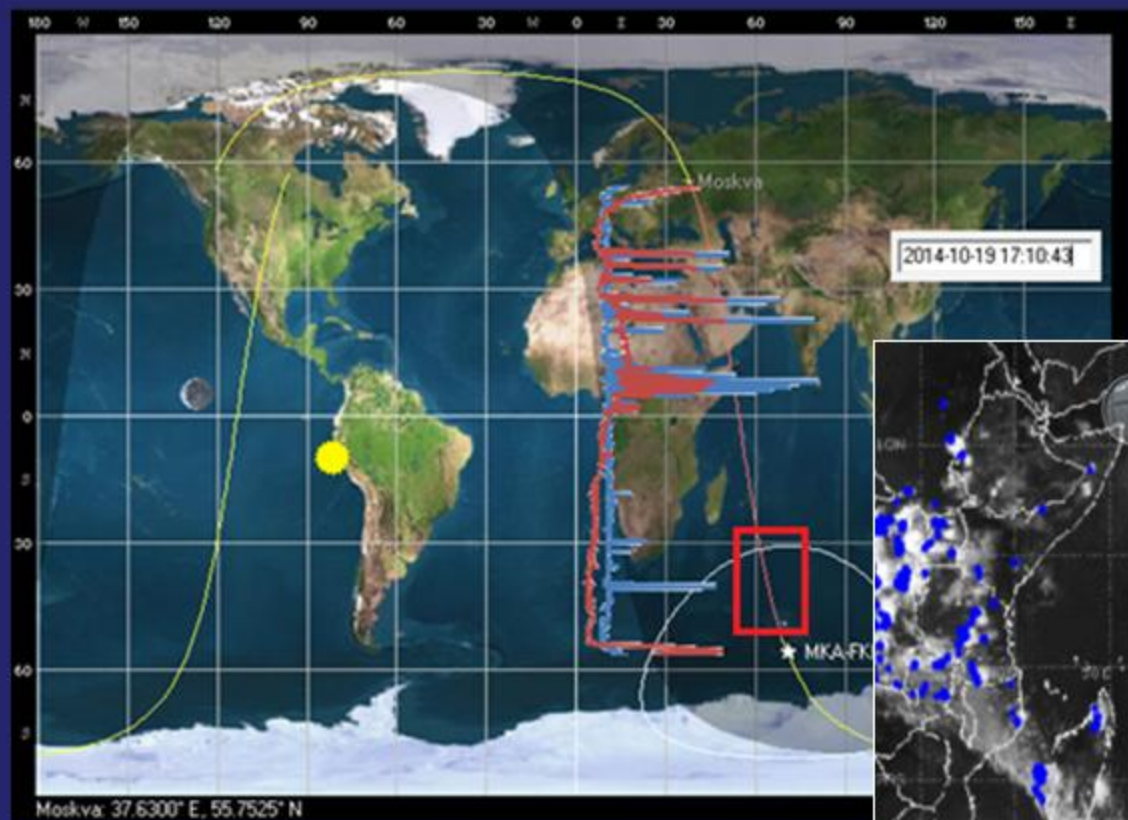
- 1 – UV - IR lightning flashes signals. 2- UV- blue flashes, UV/IR>10.
 3- light glow produced by SAA particles in detector optical parts
 4- low value noise like signals. 5- high latitudes flashes

Example of distribution of amplitudes of five different types of 35 flashes detected on the night side of one orbit from 82 degrees south latitude to 16 degrees north latitude during 30 minutes

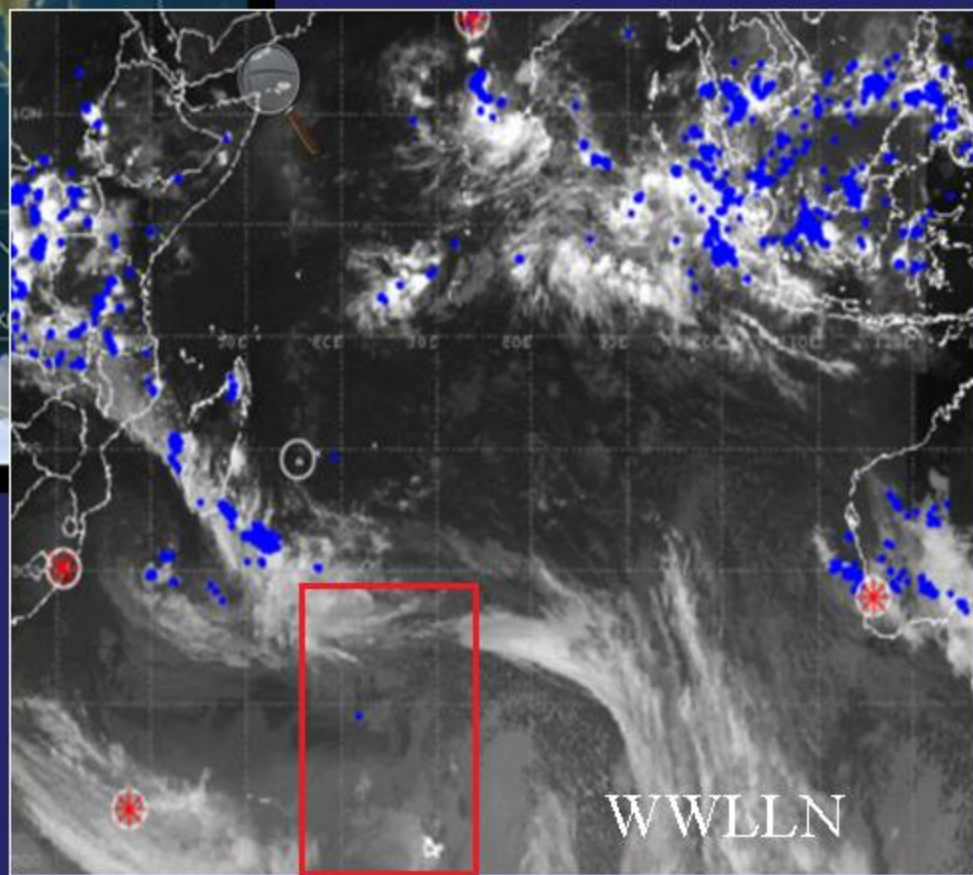


**1 – UV - IR flashes from lightings. 2- UV- blue flashes (UV/IR>10),
3- light glow produced by SAA particles in detector optical parts
4- low altitude noise like signals. 5- high latitudes flashes**

Example of events detected in cloudless region in winter time



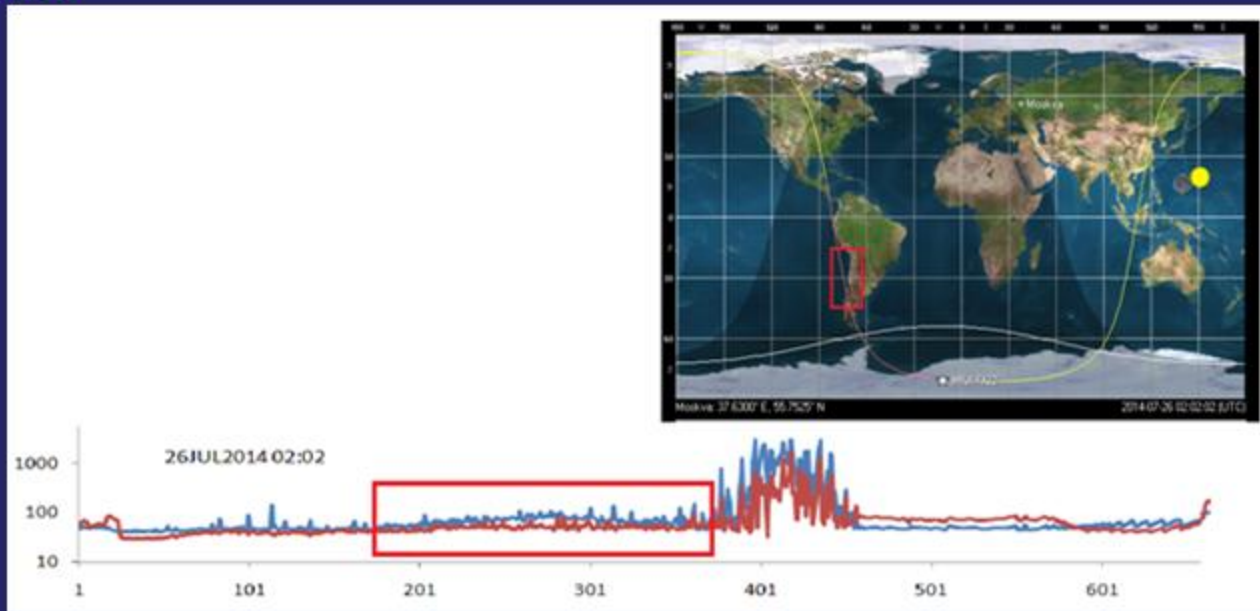
at the same time in the same region there were not detected thunderstorms



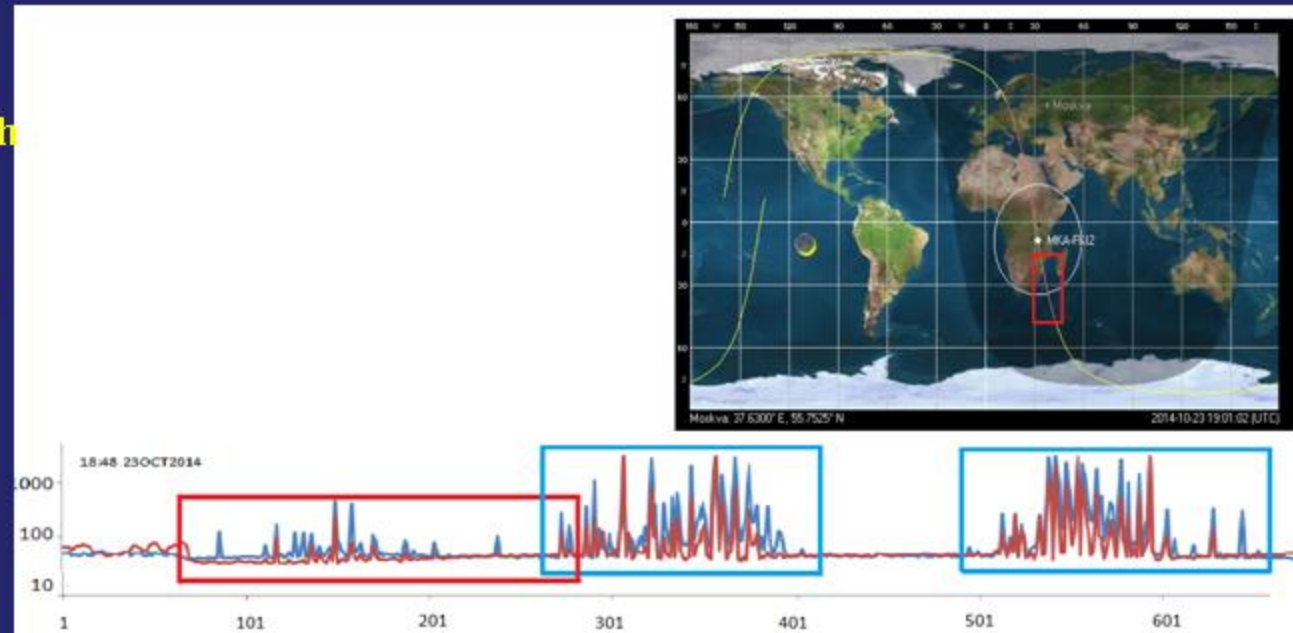
Example of some differences of the signals recorded in SAA and to the south from the East coast of Africa



Signals in SAA have not clearly distinguishable peaks

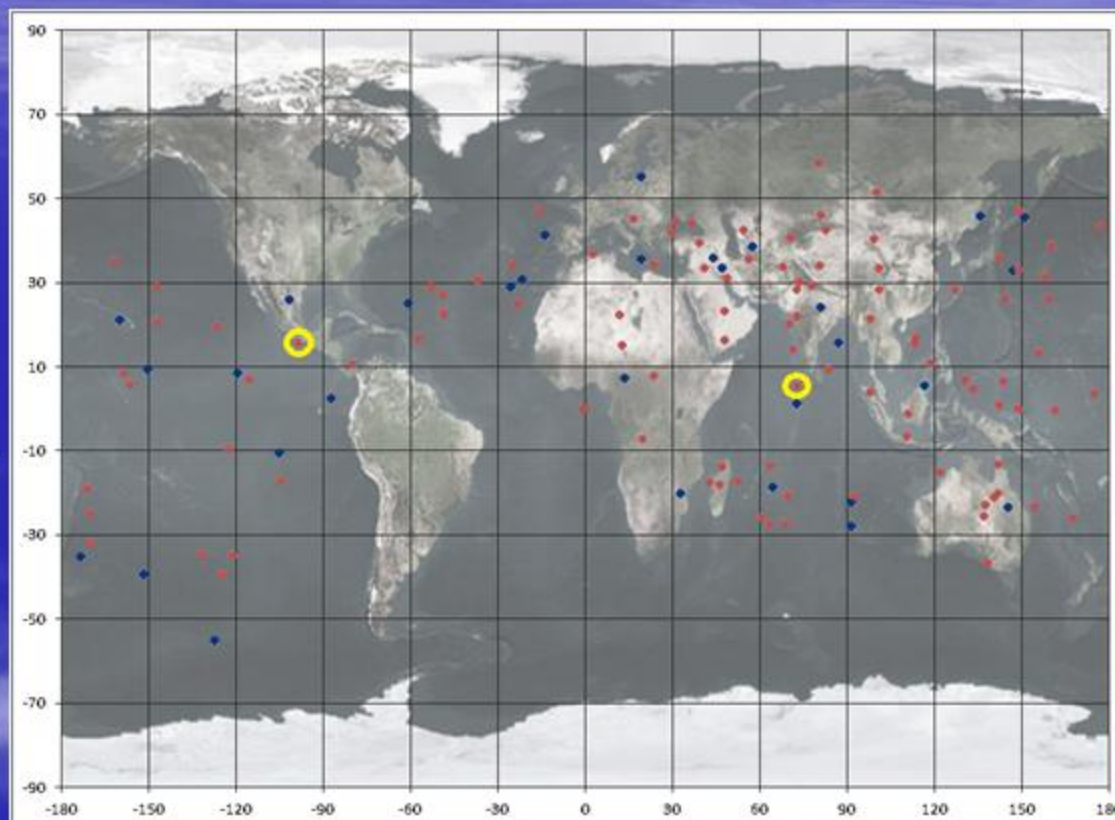
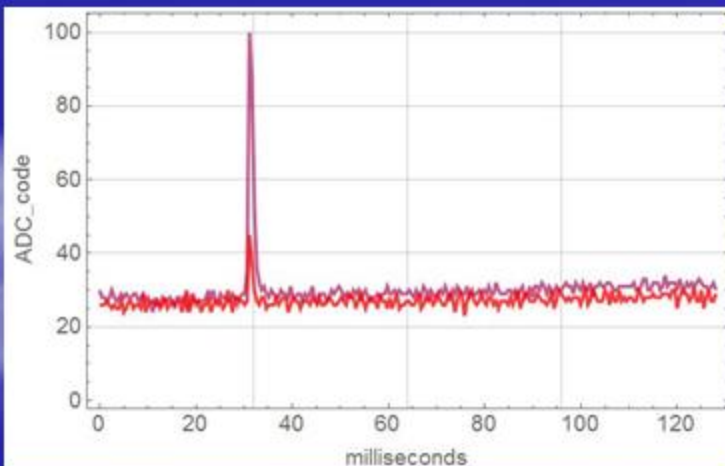
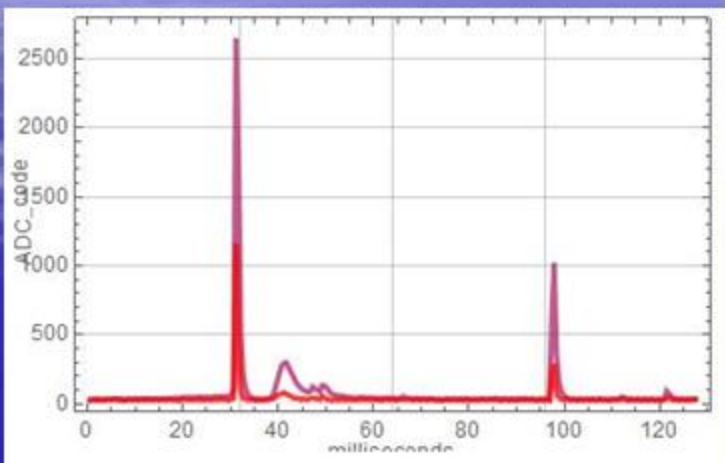


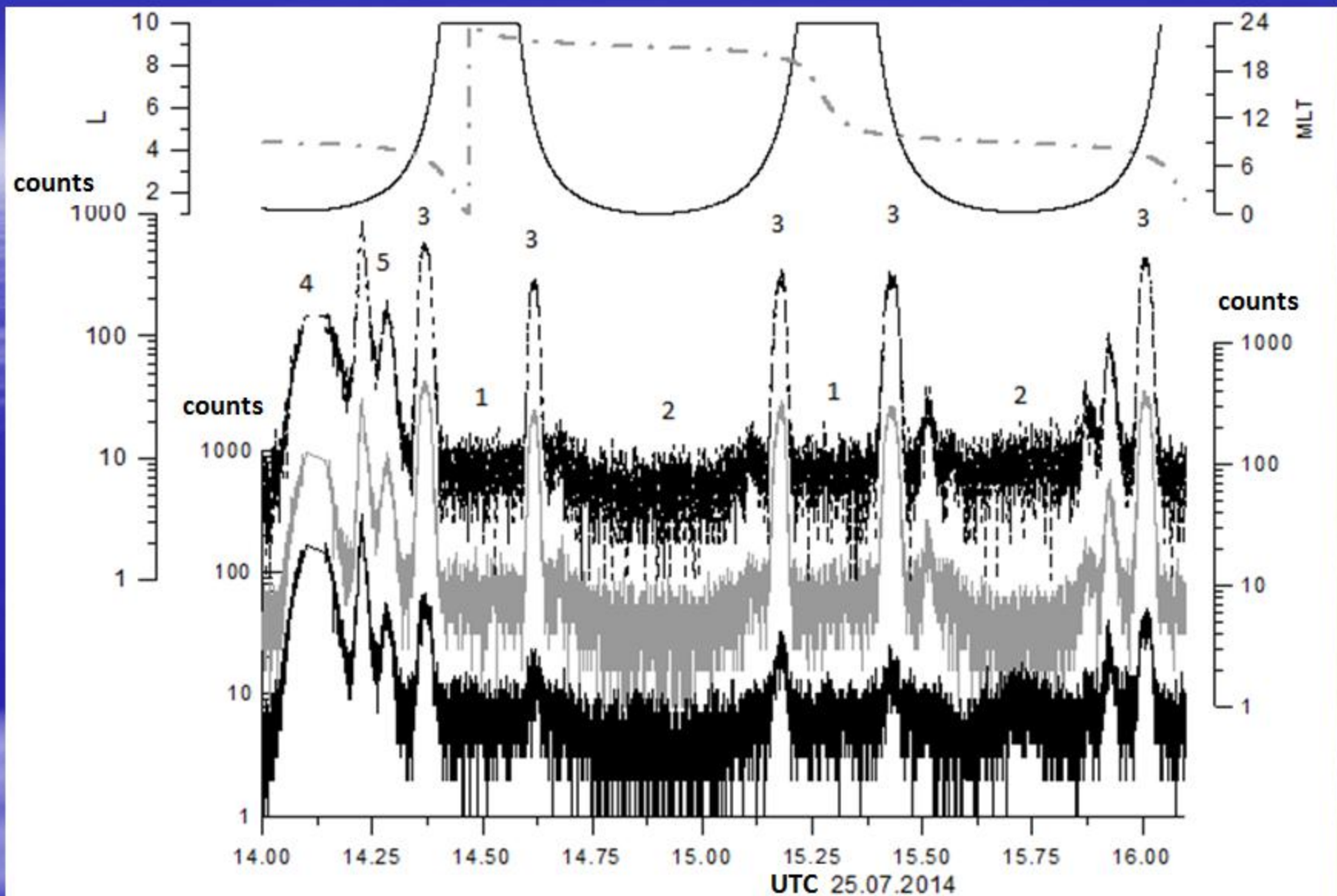
Signals to the East from South Coast of Africa have clearly distinguishable peaks in the presence of charged particles and gamma rays.



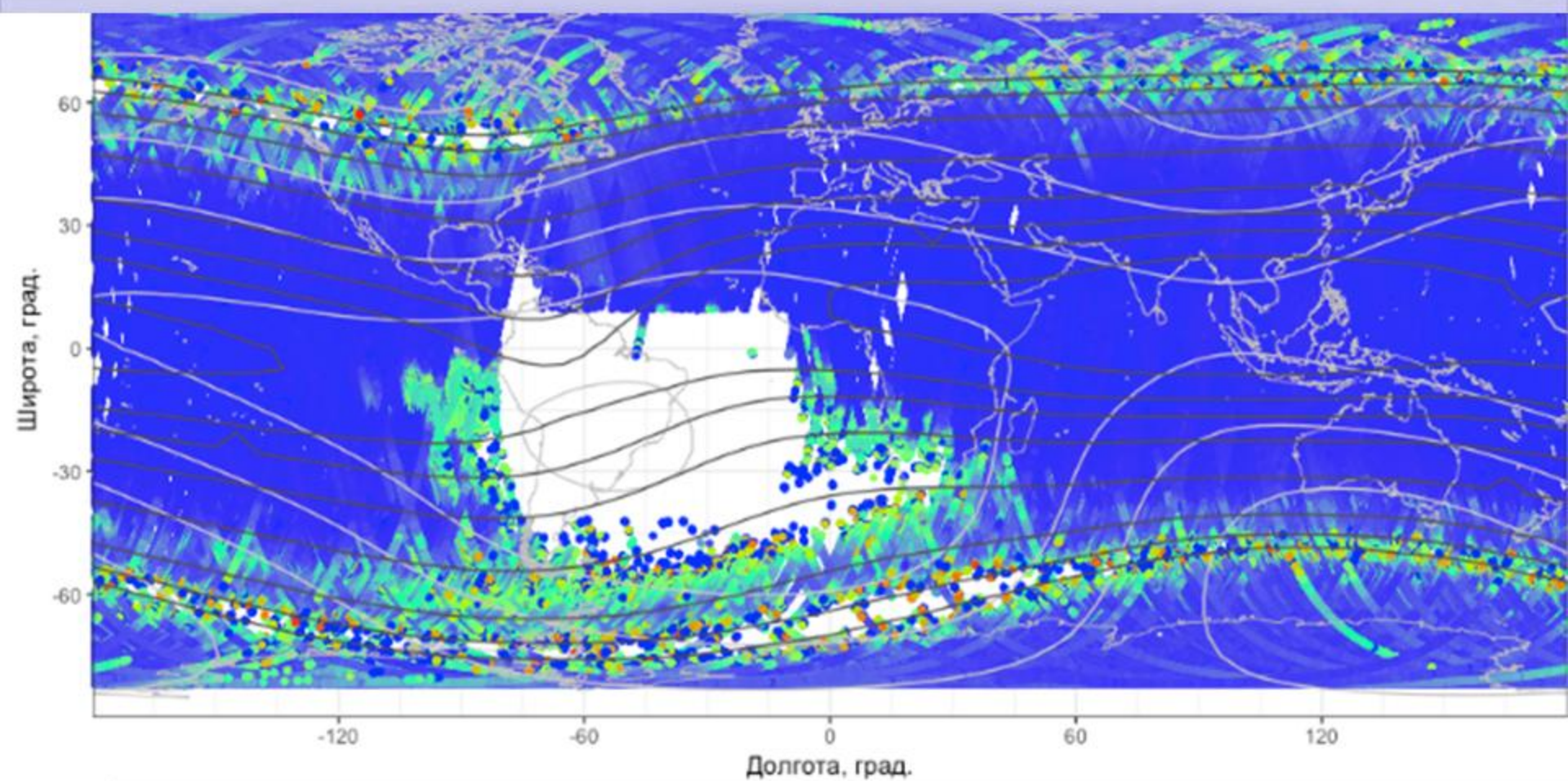
Comparison with UV flashes

UV data are obtained by DUV for 42 of TGF candidates, 2 events were accompanied by UV flashes

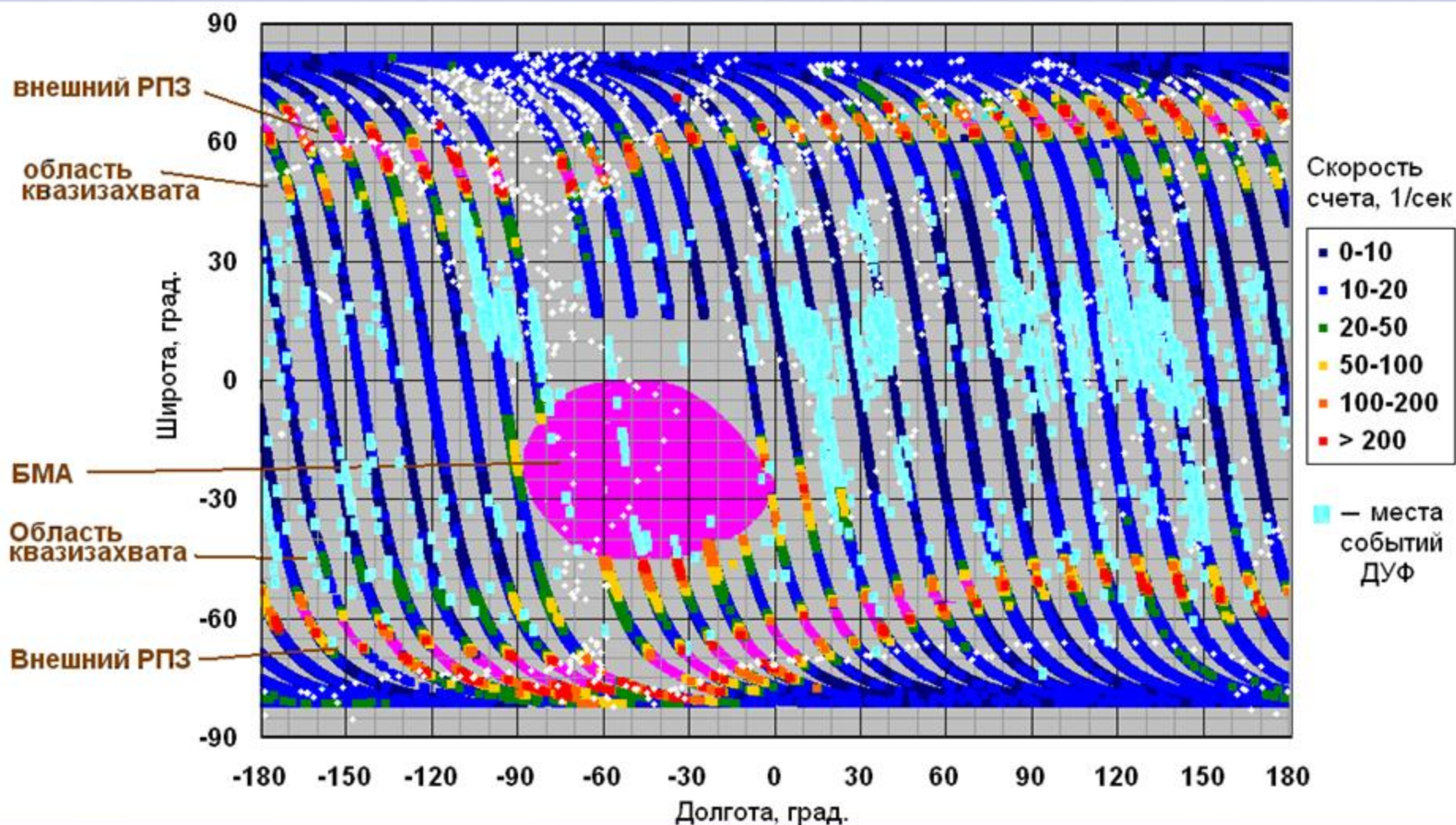




DRGE-31, DRGE-32, DRGE-33 counts along orbit, 1 – polar cap, 2 – near equator, 3 – outer belt, 4- Brazil Anomaly, 5 – precipitation and quasi-trapped particles



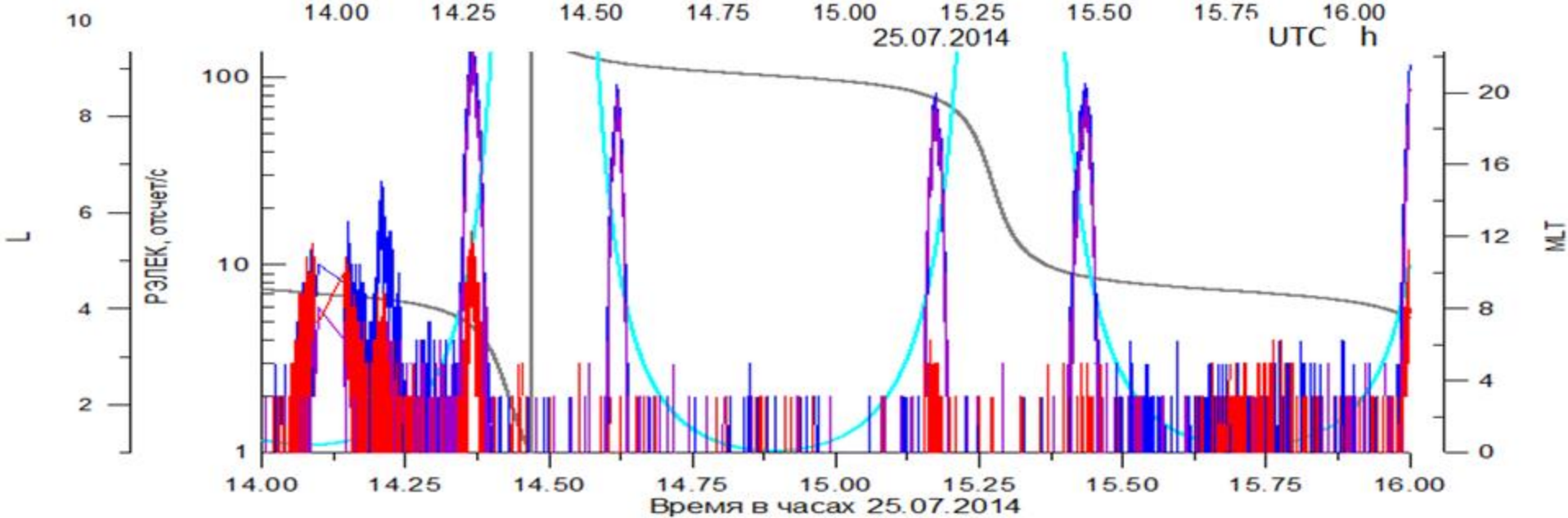
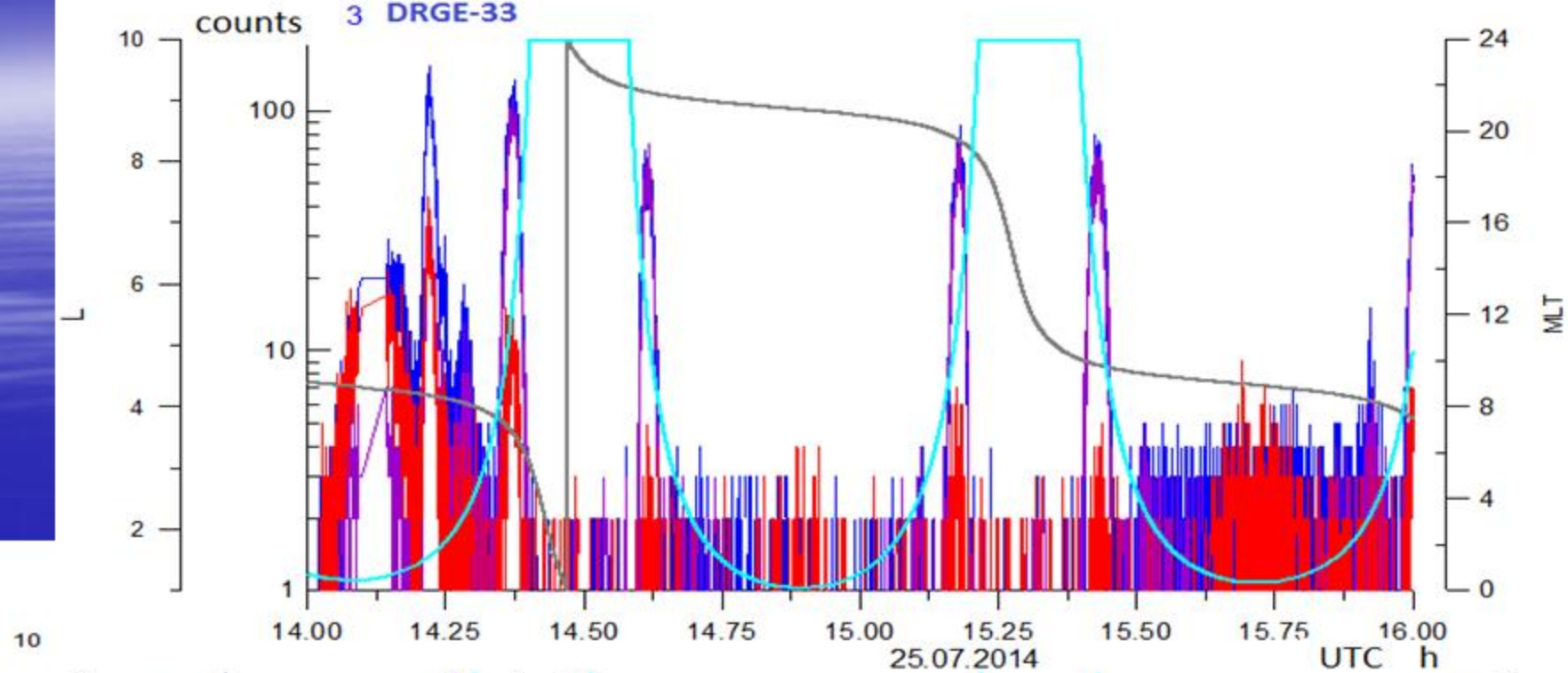
Сравнение географического распределения вспышек, наблюдаемых прибором ДУФ, с картой потоков электронов, измеренных прибором ДРГЭ-3 (РЭЛЕК)



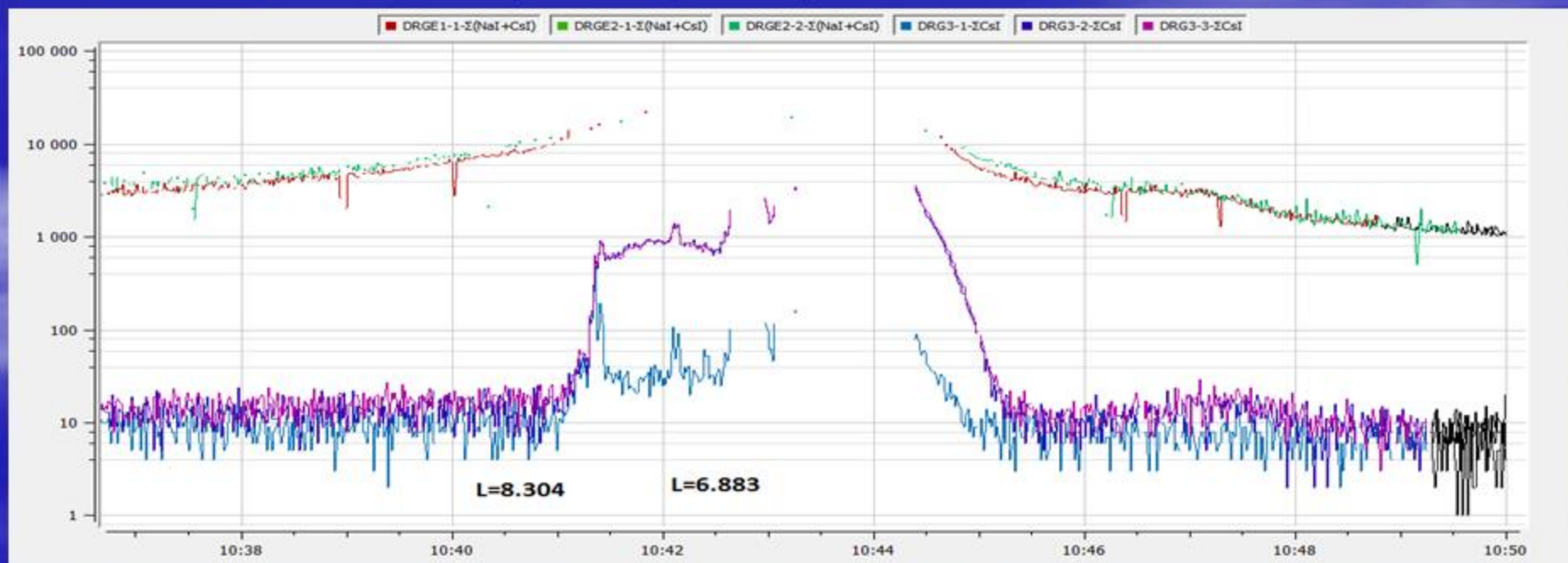
1 DRGE-31, $E_e = 235-300$ keV

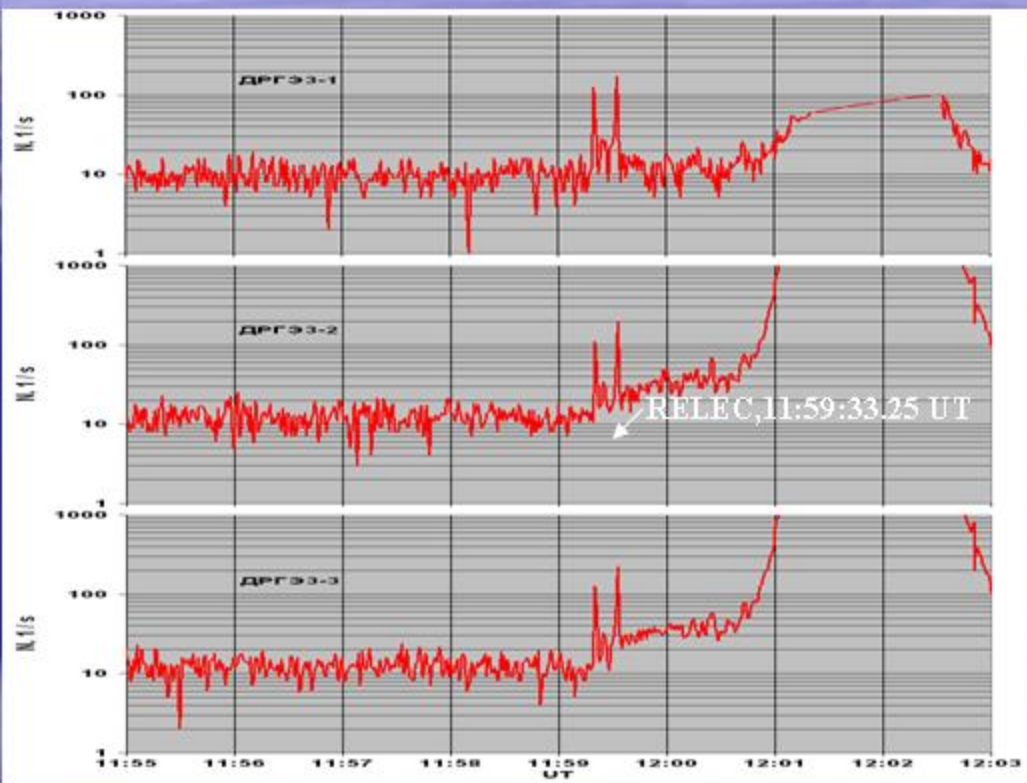
2 DRGE-32

3 DRGE-33

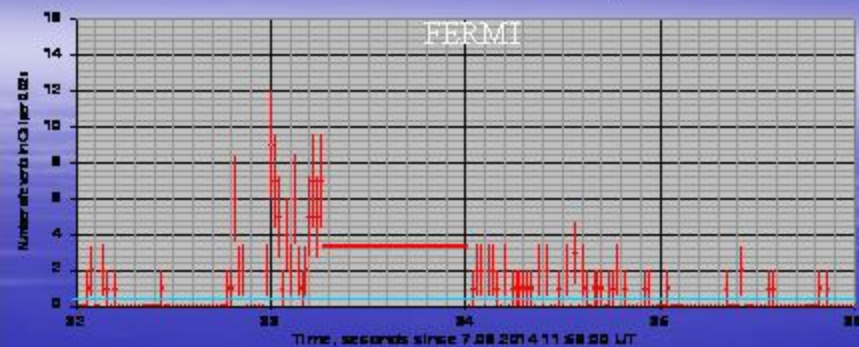


В ходе эксперимента в различных энергетических каналах построены детальные временные профили интенсивности магнитосферных электронов в областях высыпаний. Как известно, высыпания электронов из радиационных поясов связаны, прежде всего, с волновой активностью в разных диапазонах длин волн и частот (от 0.1 Гц до 15 МГц). Такие высыпания неоднократно наблюдались в ходе полета спутника «Вернов» в различных областях околоземного пространства, в том числе, в полярных областях, при пересечении дрейфовых оболочек, соответствующих высокоширотной границе внешнего радиационного пояса ($L \sim 8.3, 6.9, 5.9$). По-видимому, эти высыпания связаны с областью изотропизации на высокоширотной границе внешнего пояса и могут быть обусловлены рассеянием на электромагнитных (ЭМ) волнах низкой частоты, в частности ионно-циклотронных (ЭМИЦ) волнах.

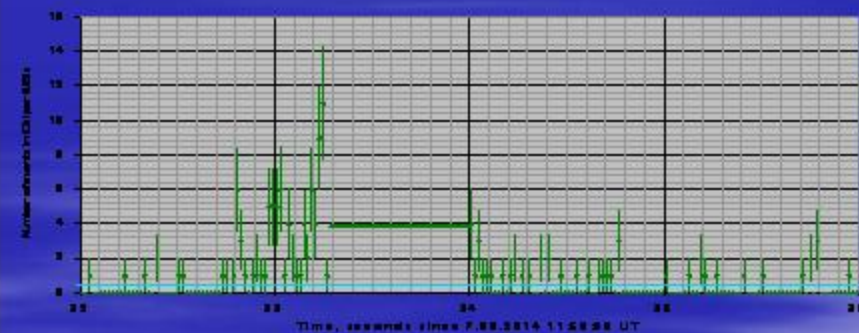




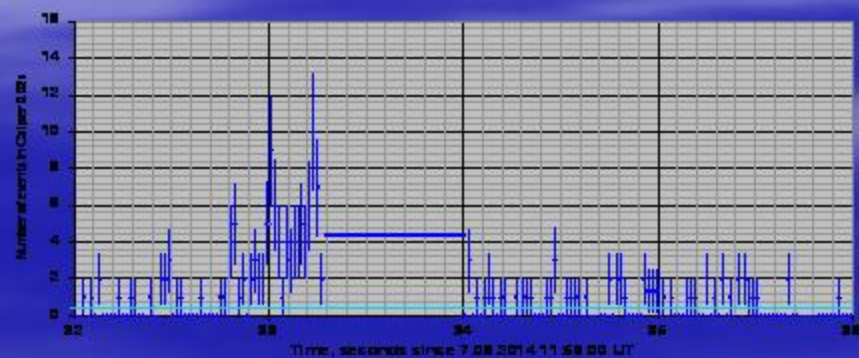
RELEC, DRGE3-1



RELEC, DRGE3-2

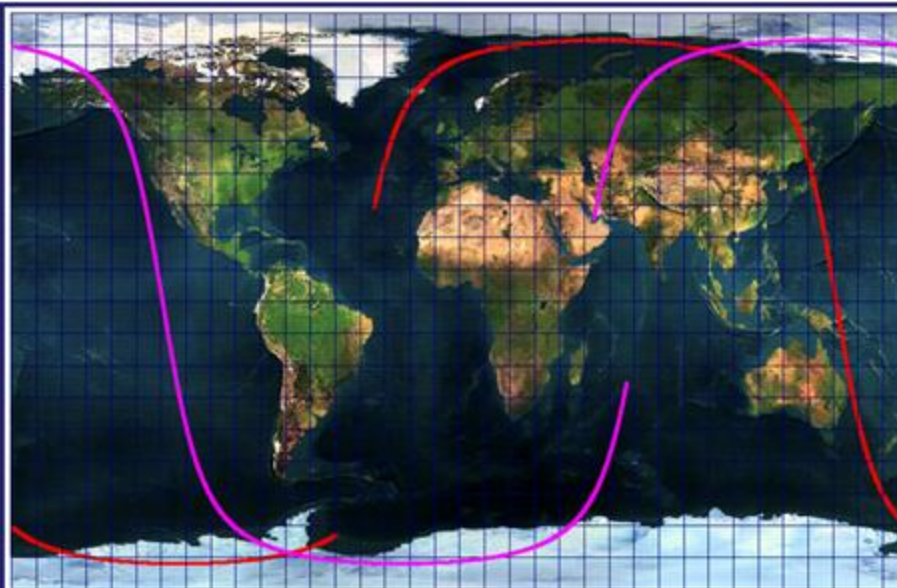
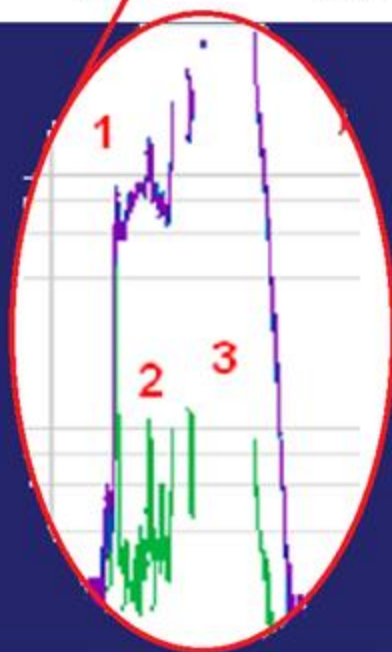
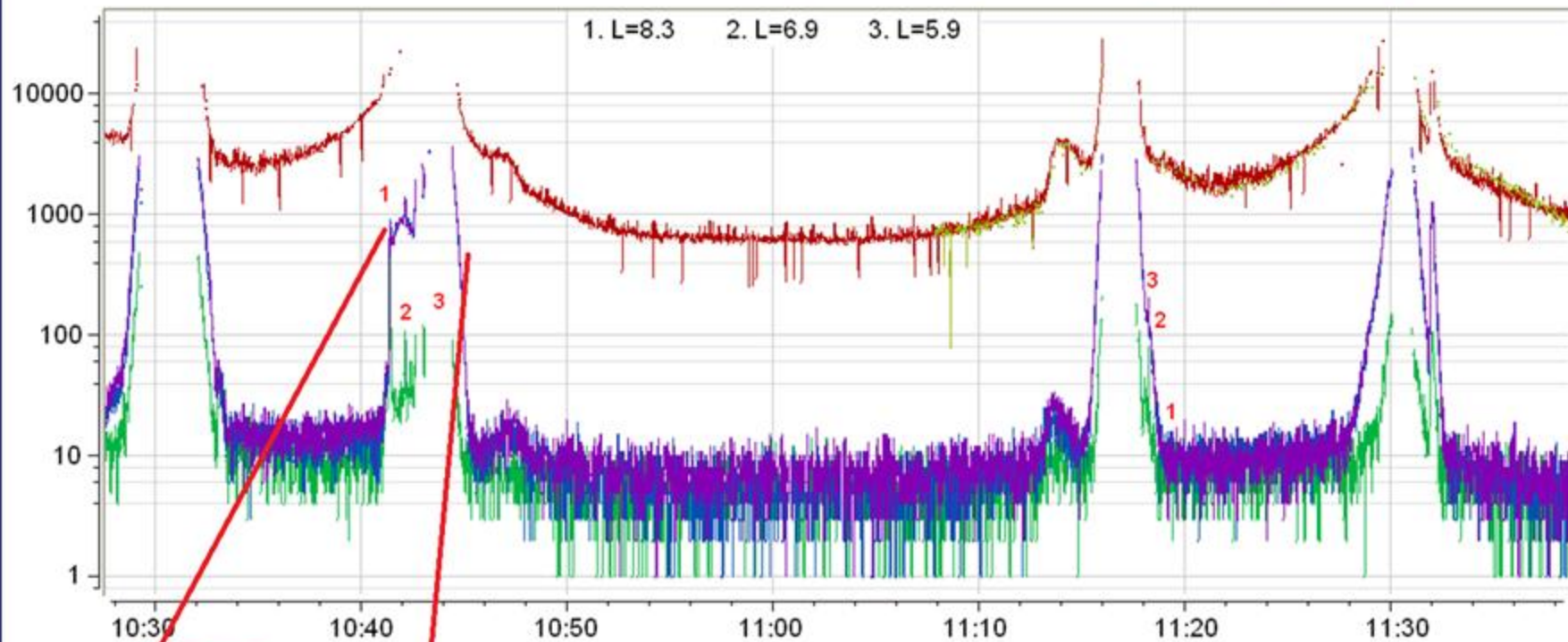


RELEC, DRGE3-3

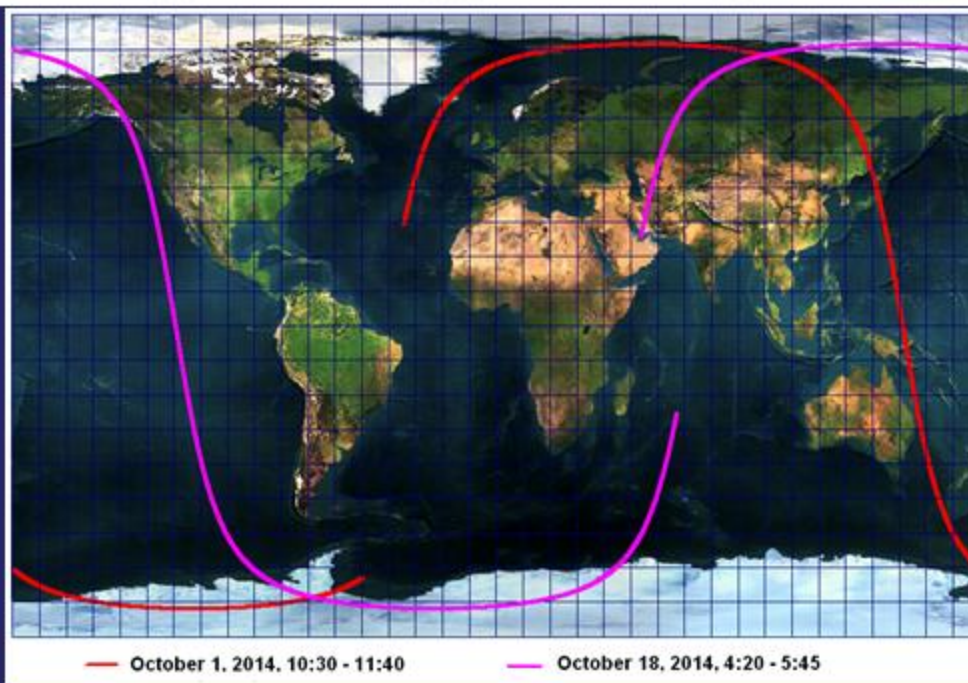
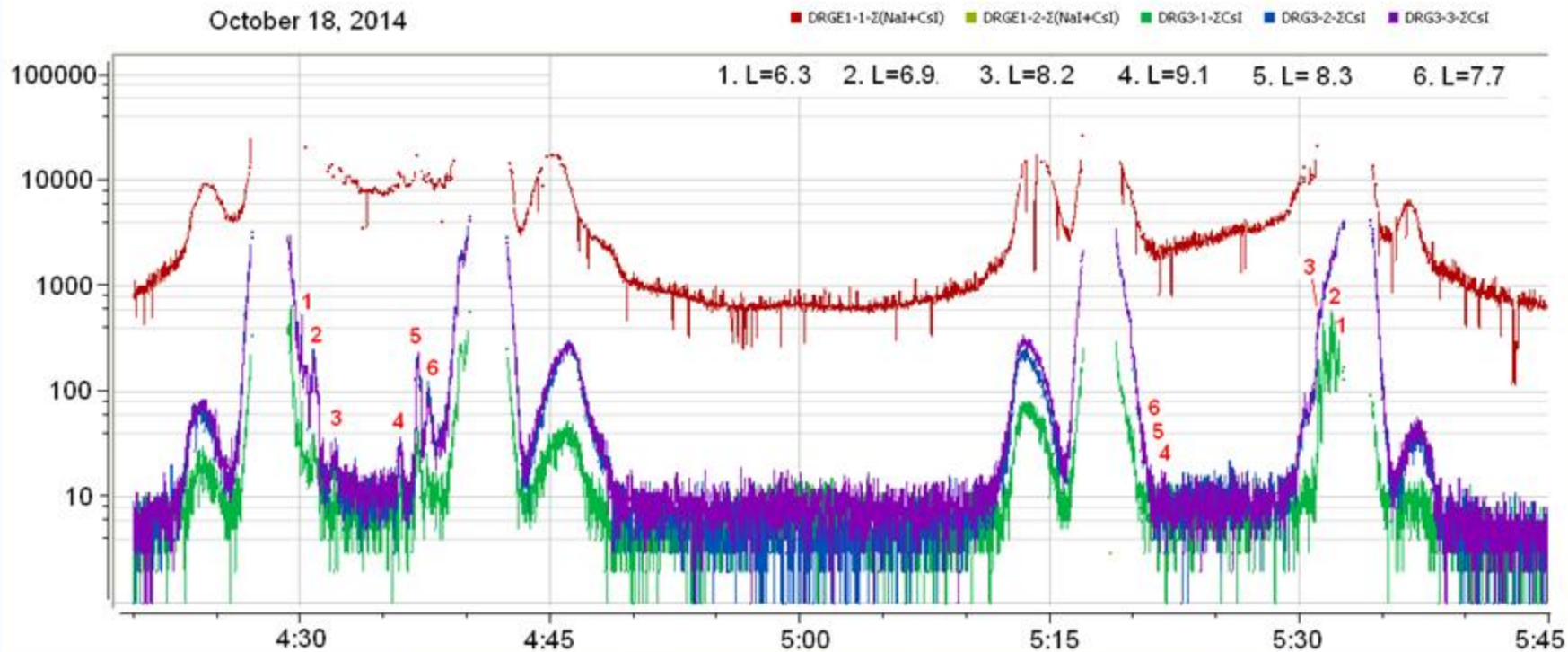


October 1, 2014

■ DRGE1-1-Z(NaI+CsI) ■ DRGE1-2-Z(NaI+CsI) ■ DRG3-1-ZCsI ■ ■ DRG3-2-ZCsI ■ DRG3-3-ZCsI

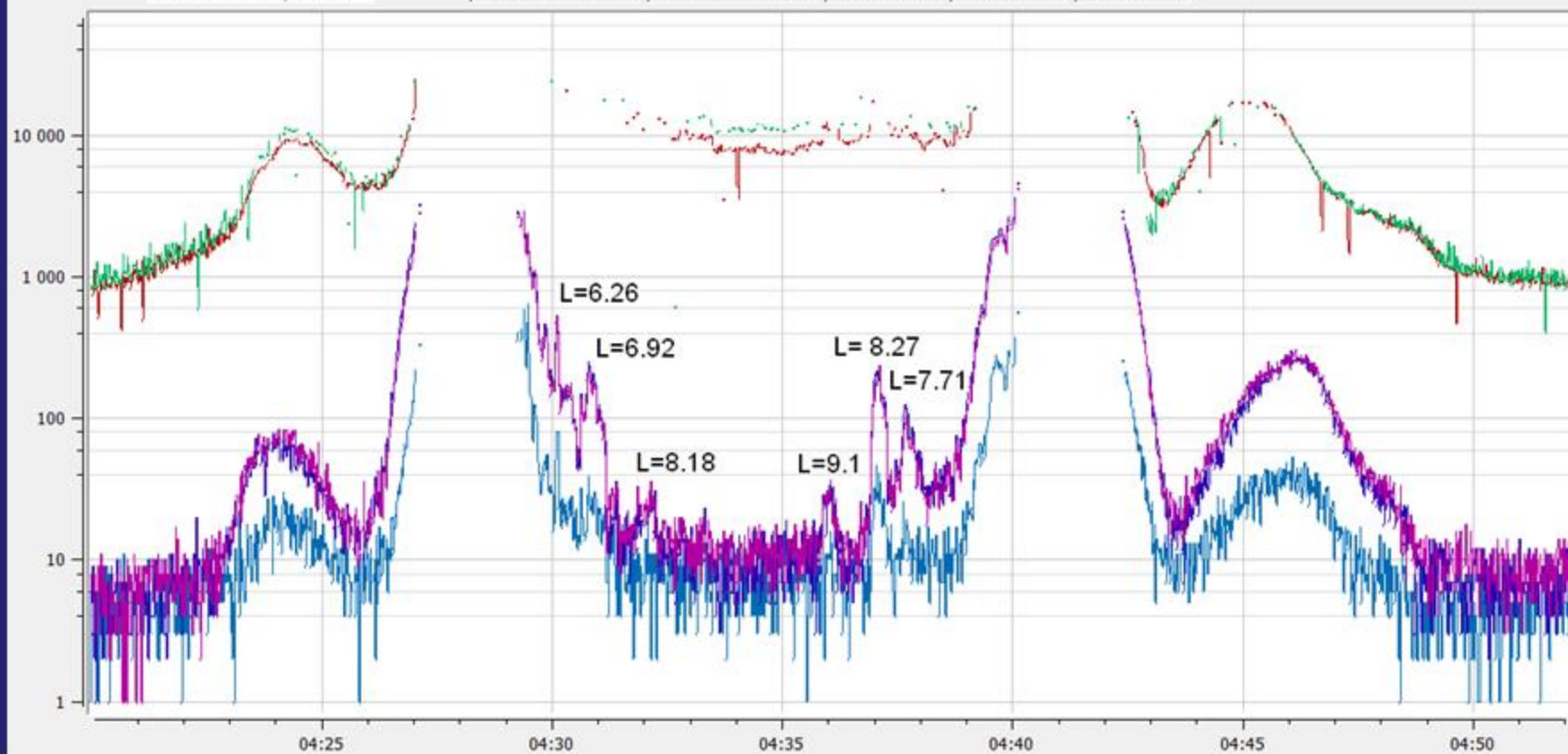


October 18, 2014

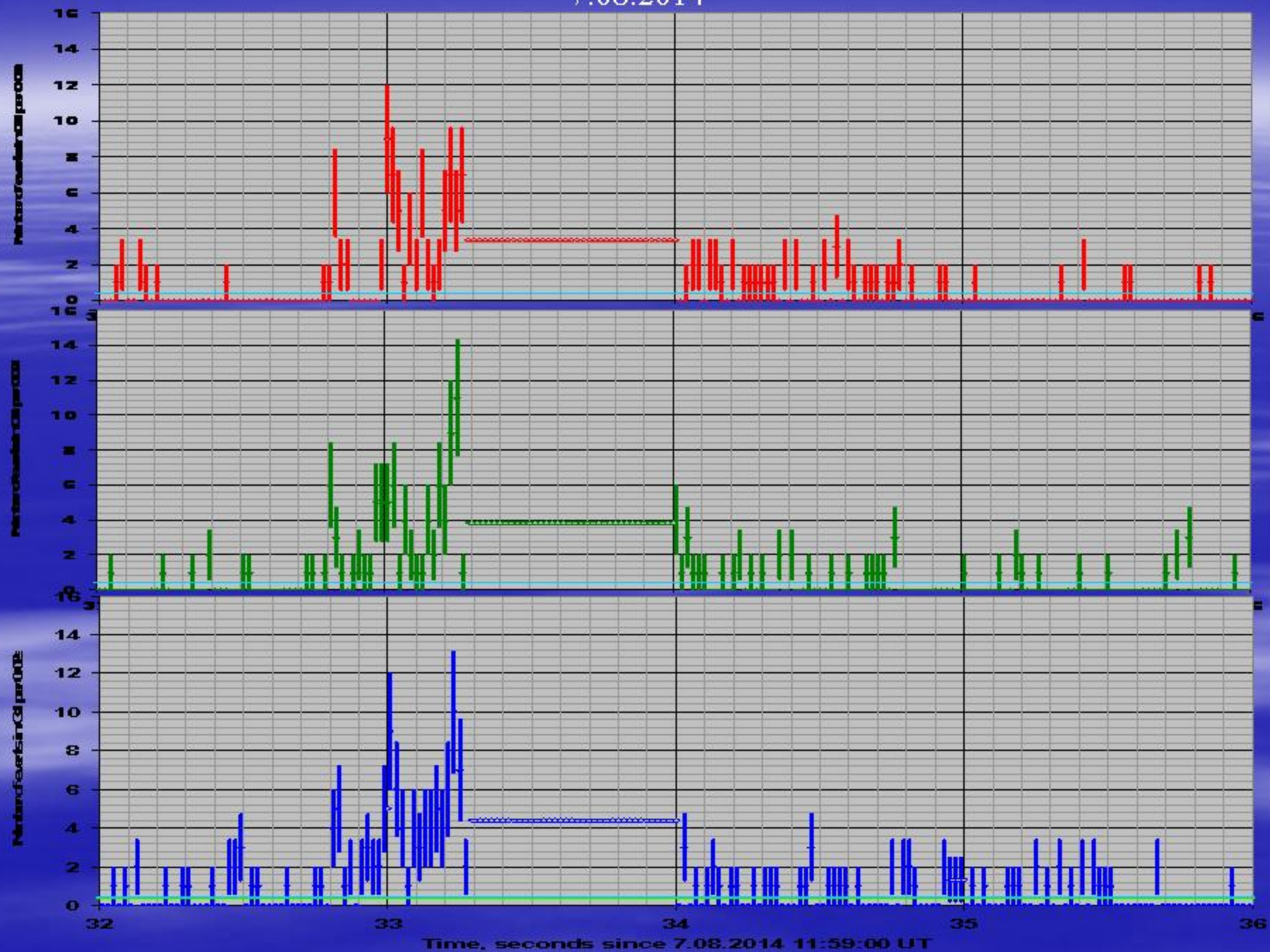


October 18, 2014

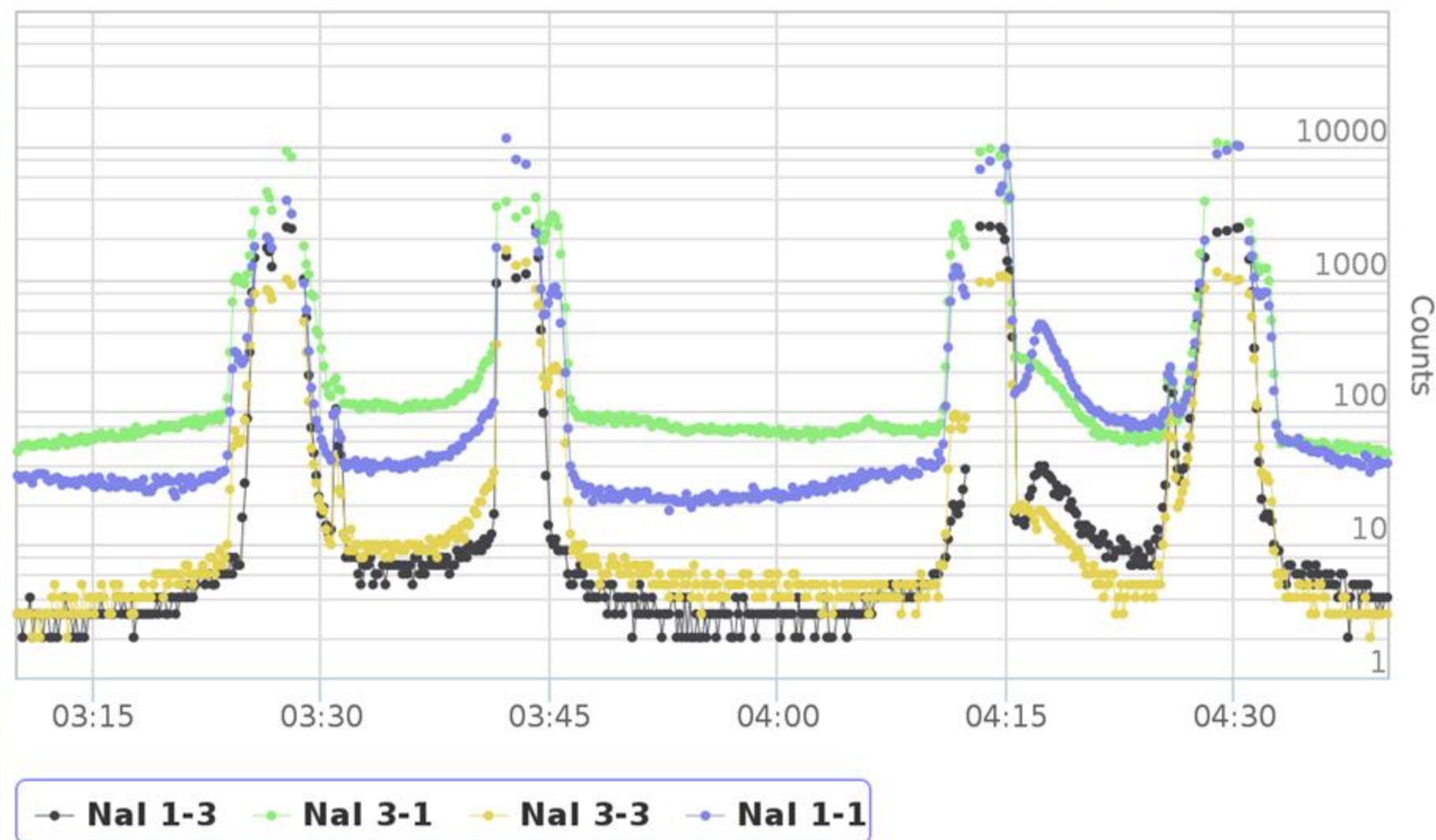
■ DRGE1-1-Σ(NaI+CsI) ■ DRGE2-2-Σ(NaI+CsI) ■ DRG3-1-ΣCsI ■ DRG3-2-ΣCsI ■ DRG3-3-ΣCsI



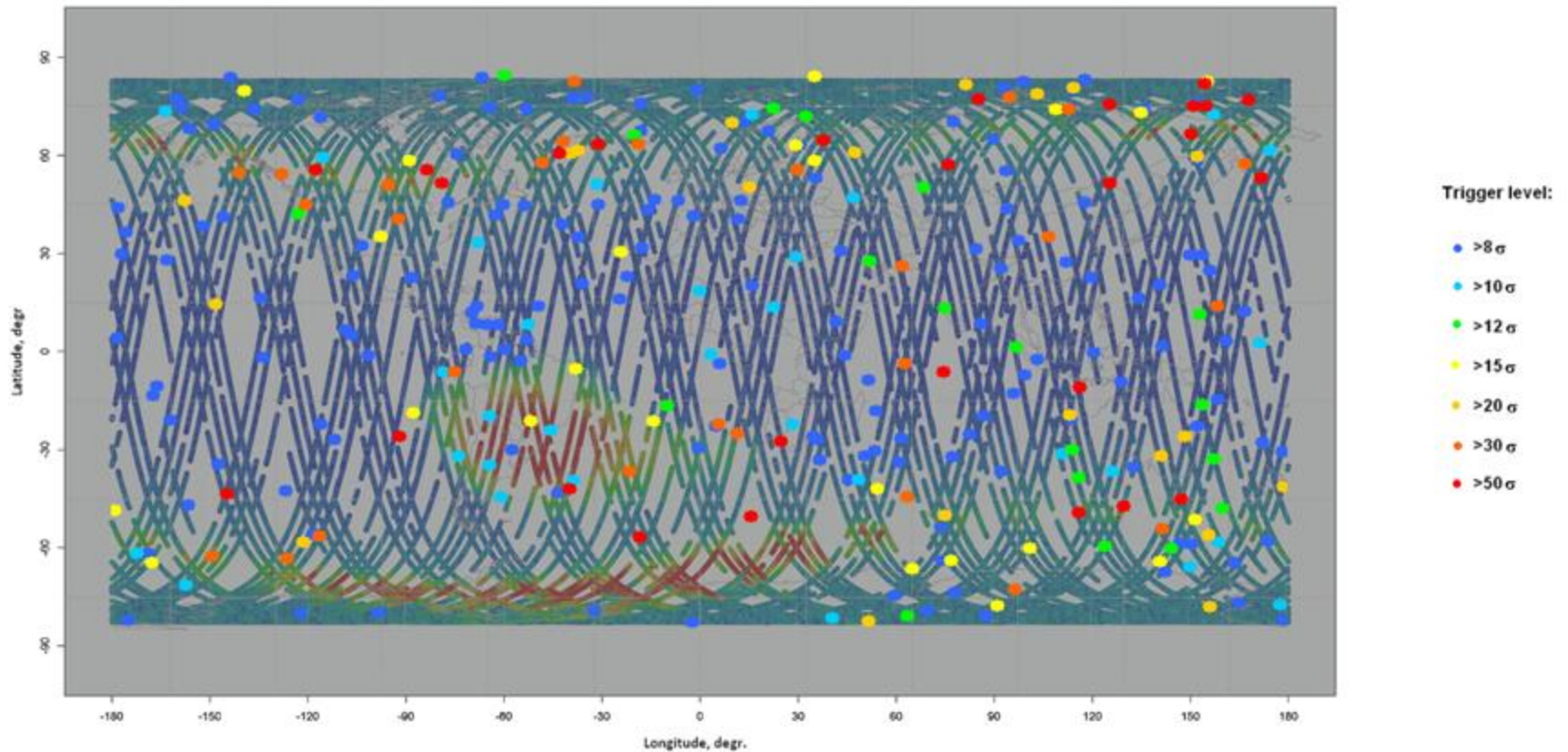
7.08.2014



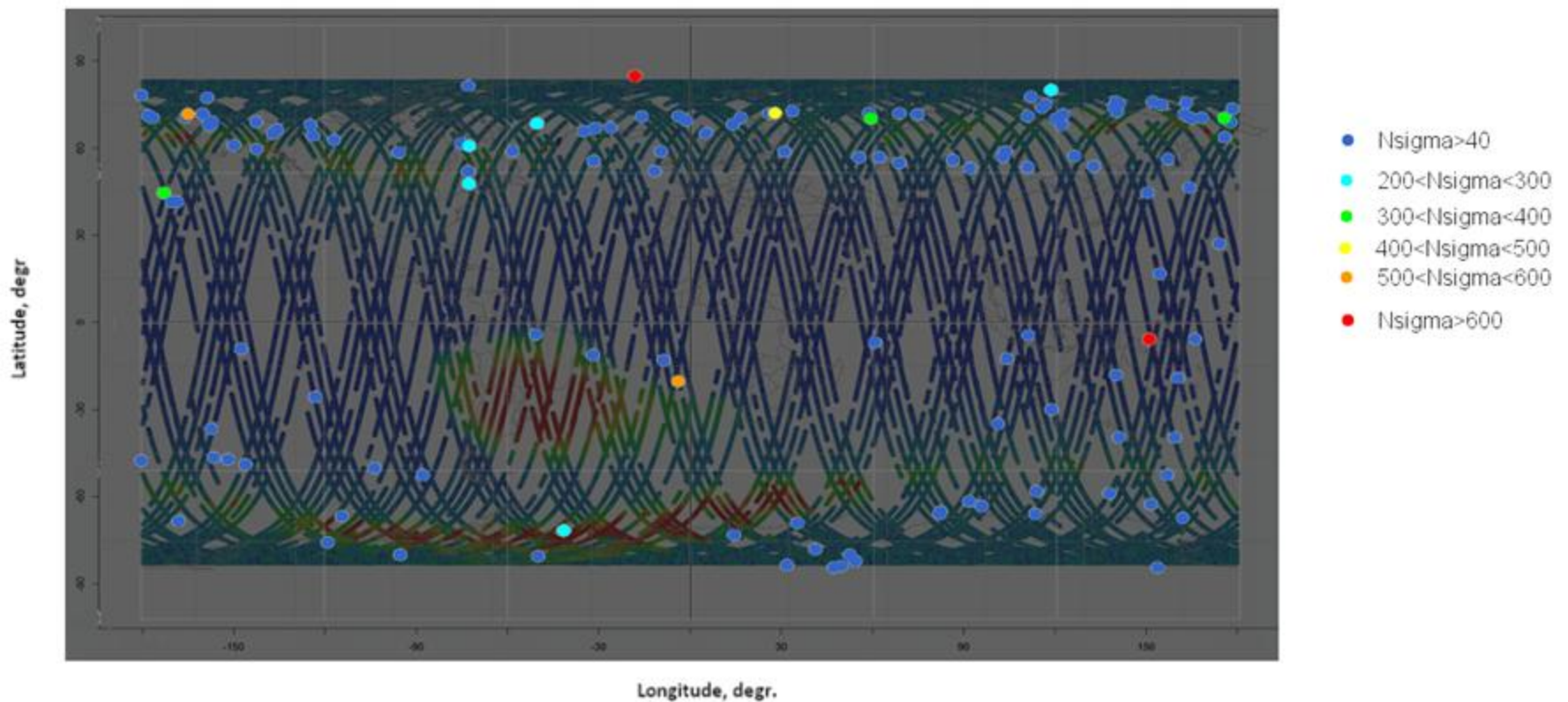
Первые данные БДРГ



Map of burst triggers slow

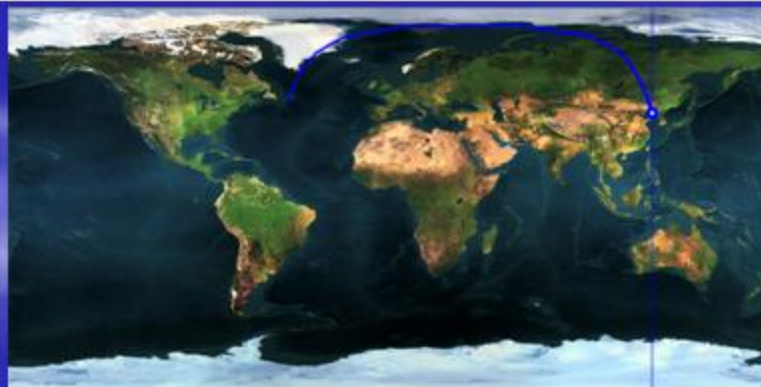


Map of burst triggers sslow



"Lomonosov", 30.08.2016





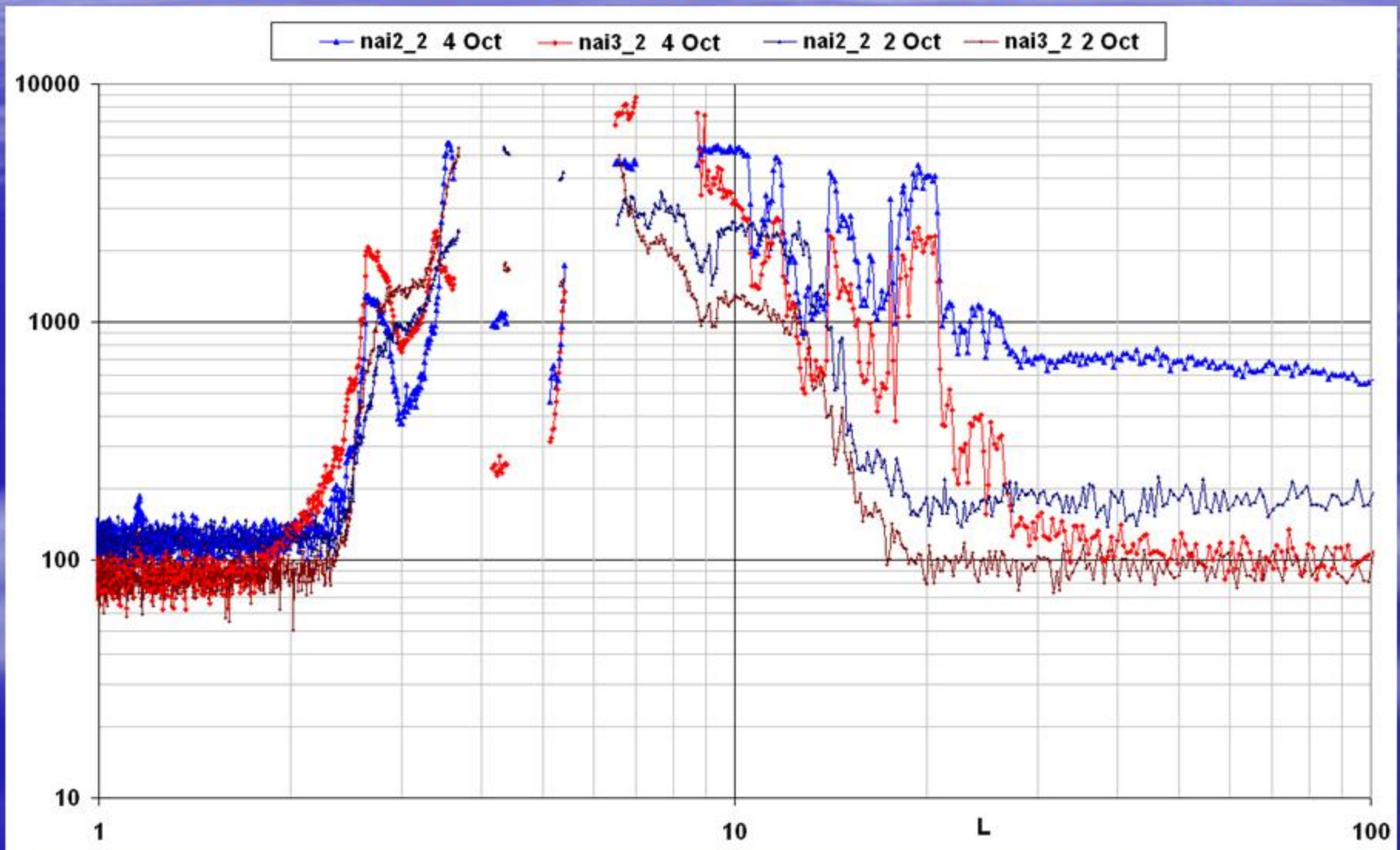
"Lomonosov", September 1, 2016

2:28 - 2:54

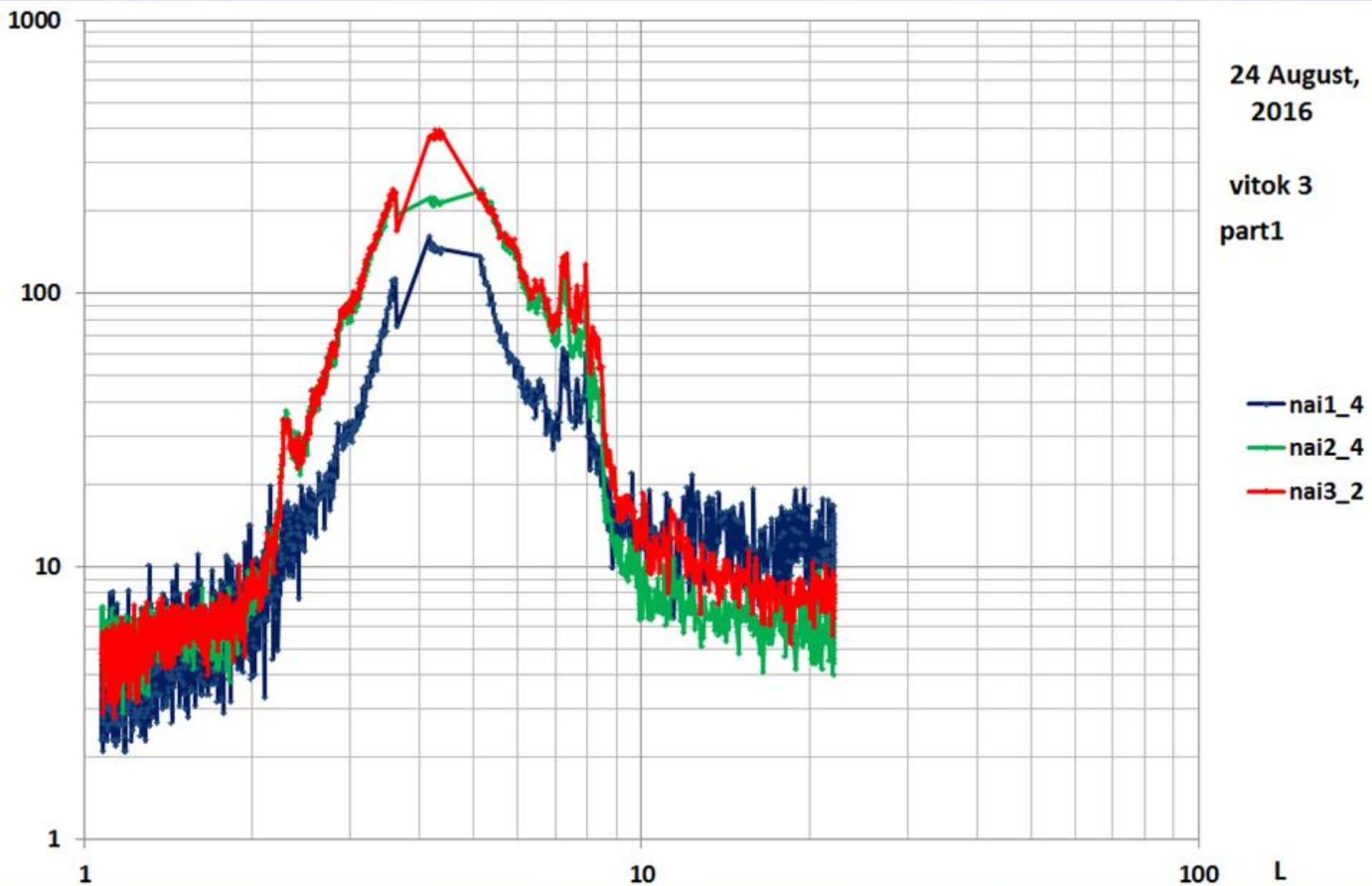


The same sub-relativistic electron precipitation were also observed in Lomonosov mission, which has the similar to Vernov satellite solar-synchronous orbit with altitude 490 km.

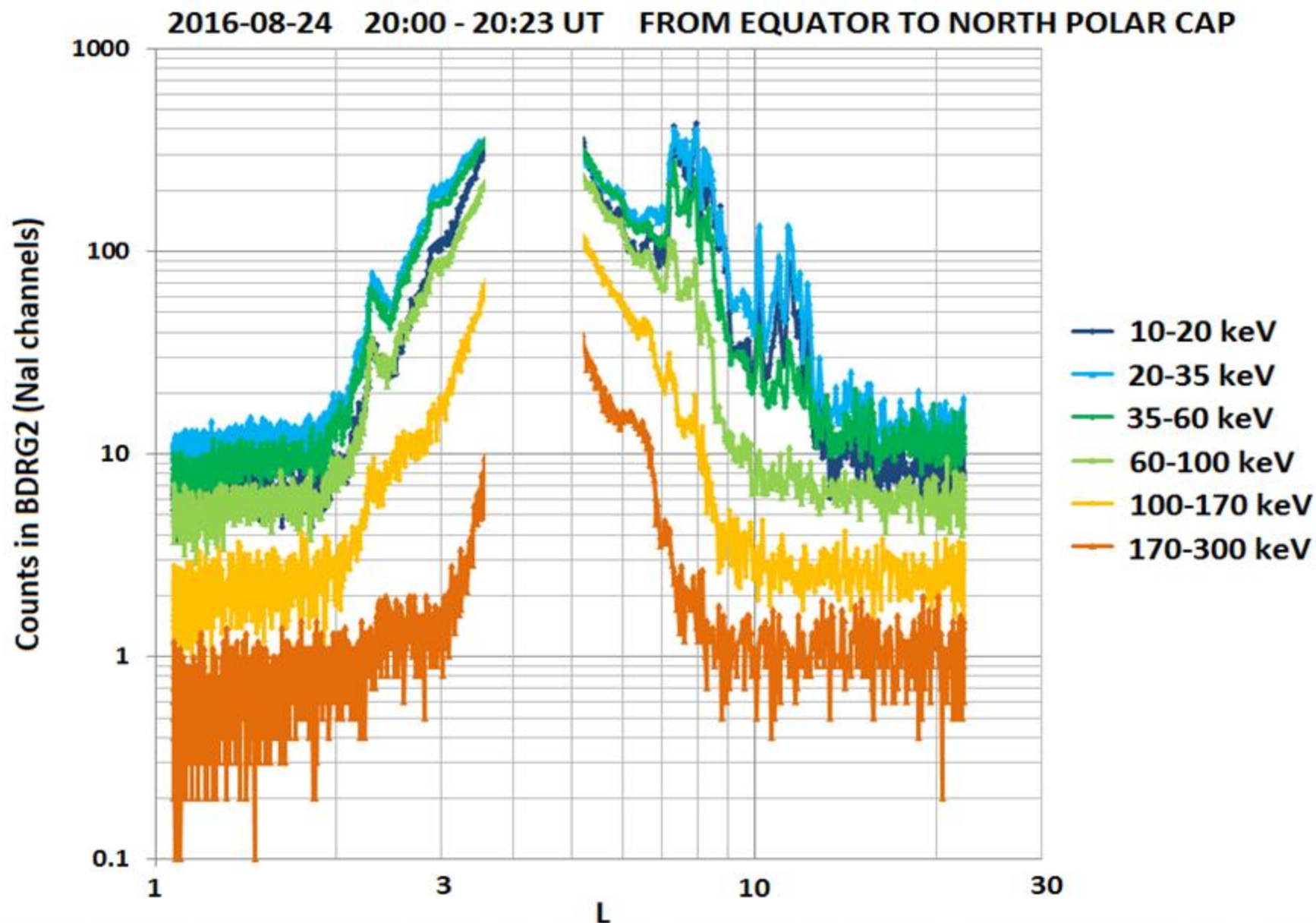
BDRG-2 and BDRG-3 data, similar orbits 2016 October 2, 4

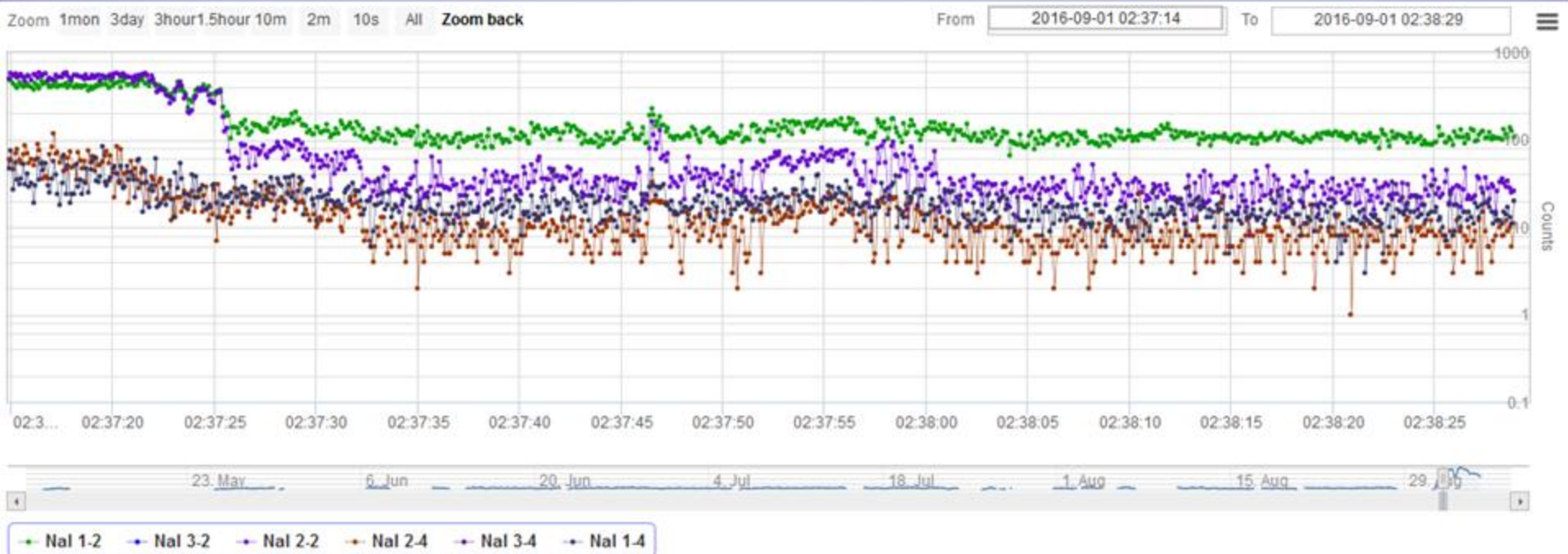


БДРГ

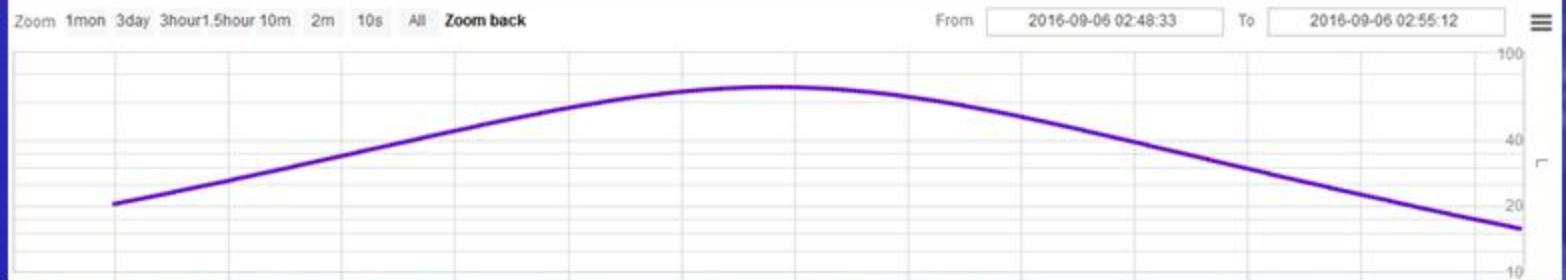
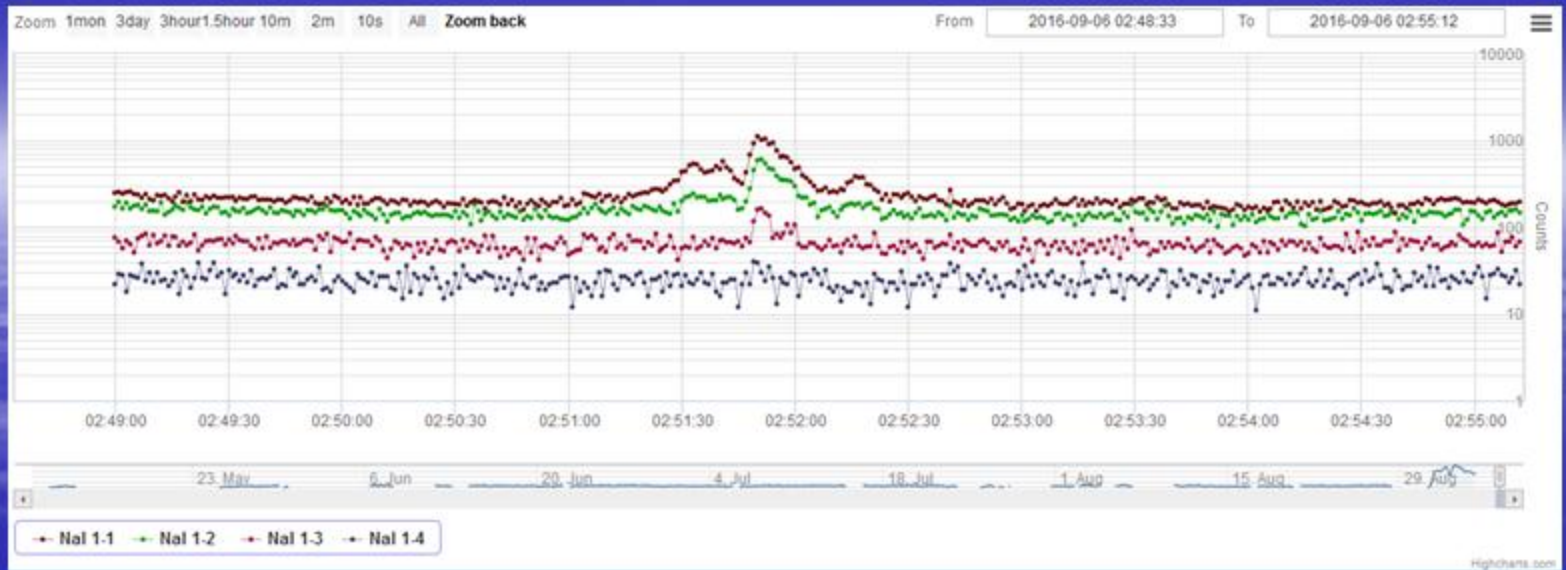


БДРГ



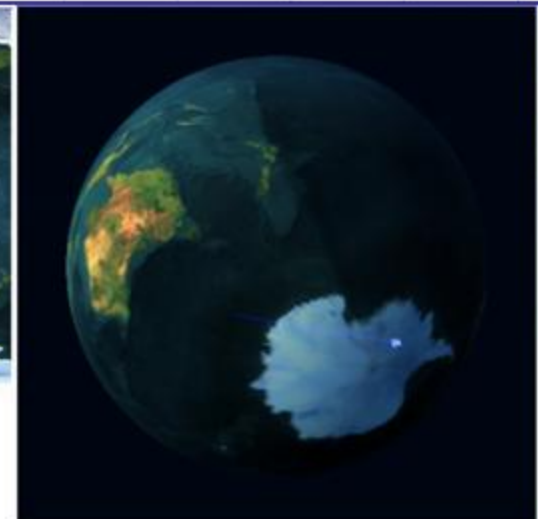




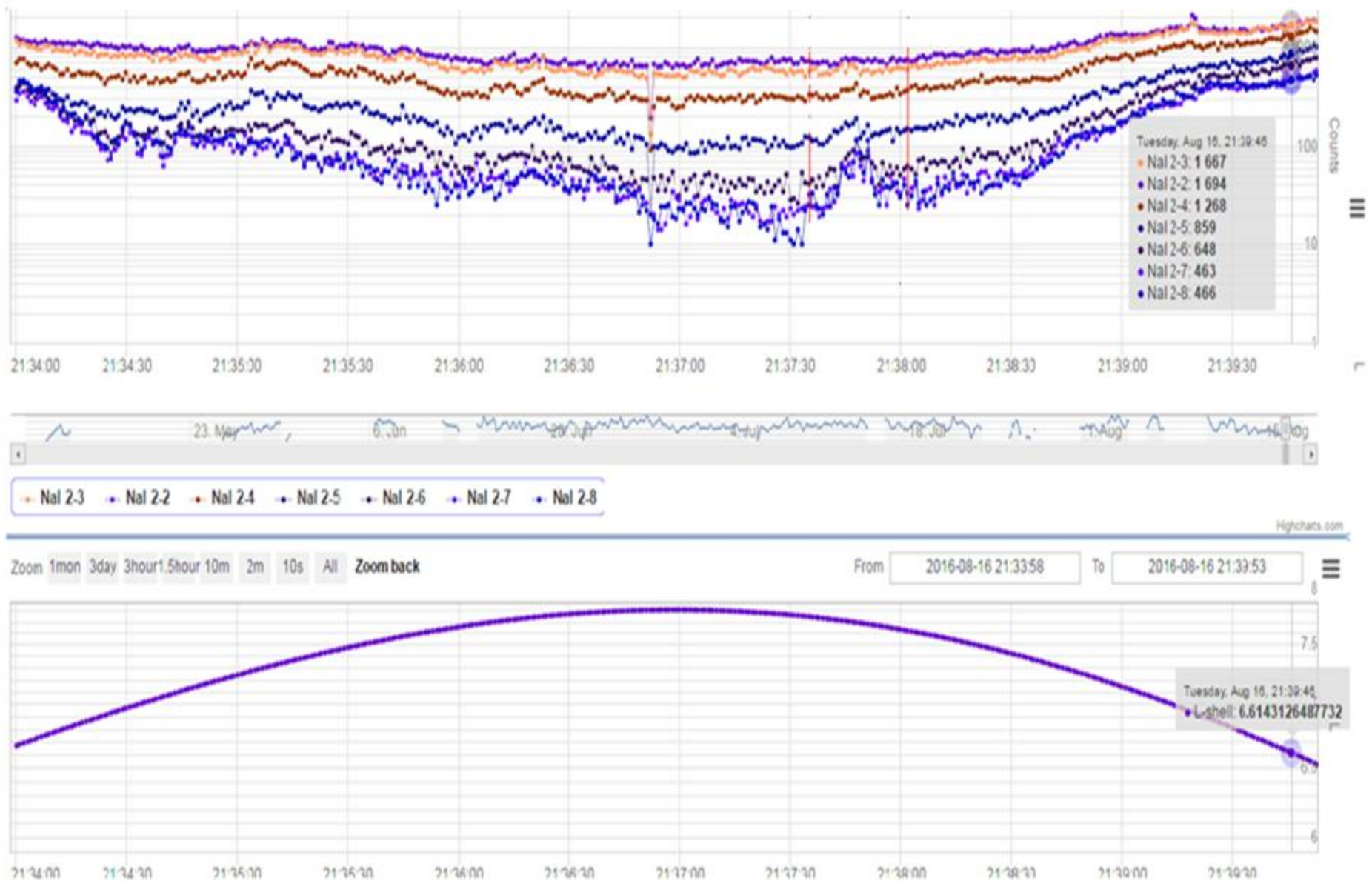


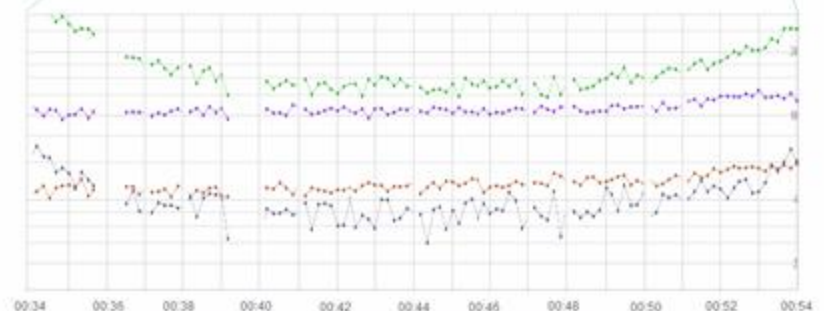
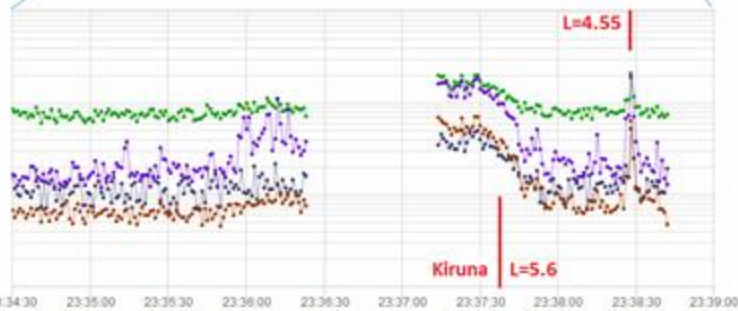
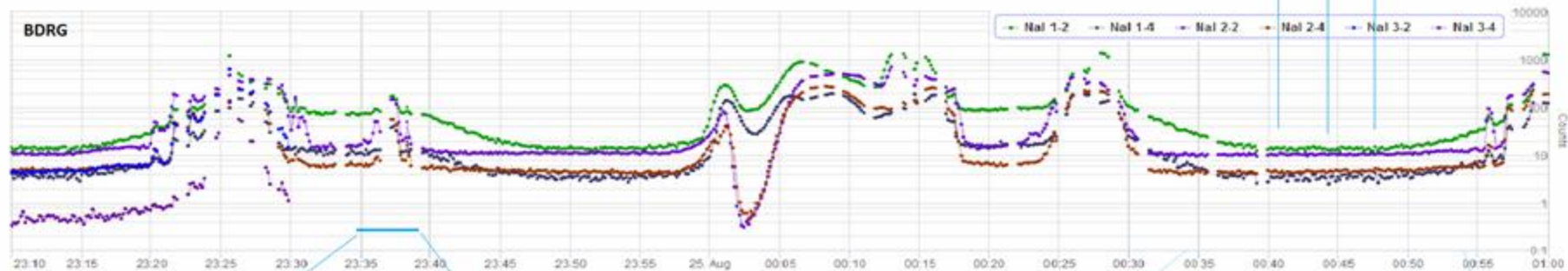
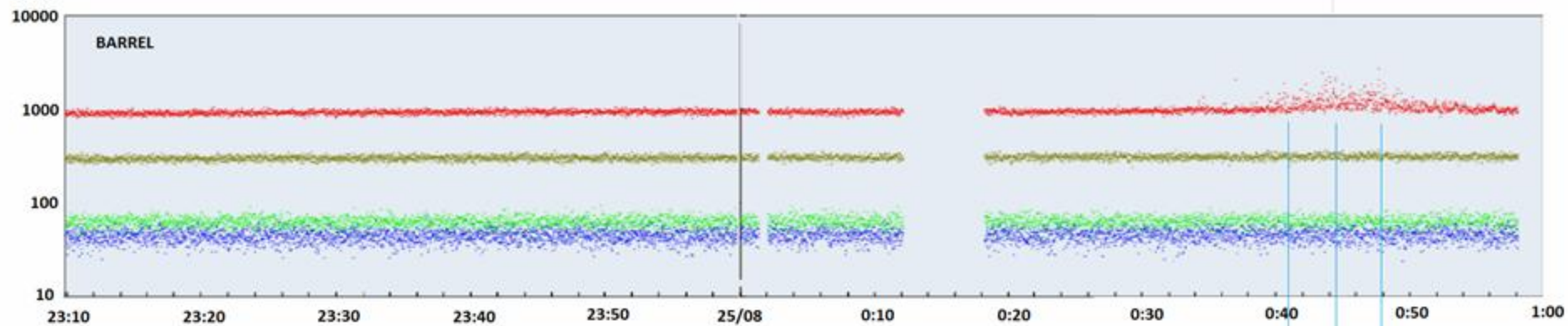
"Lomonosov", September 6, 2016

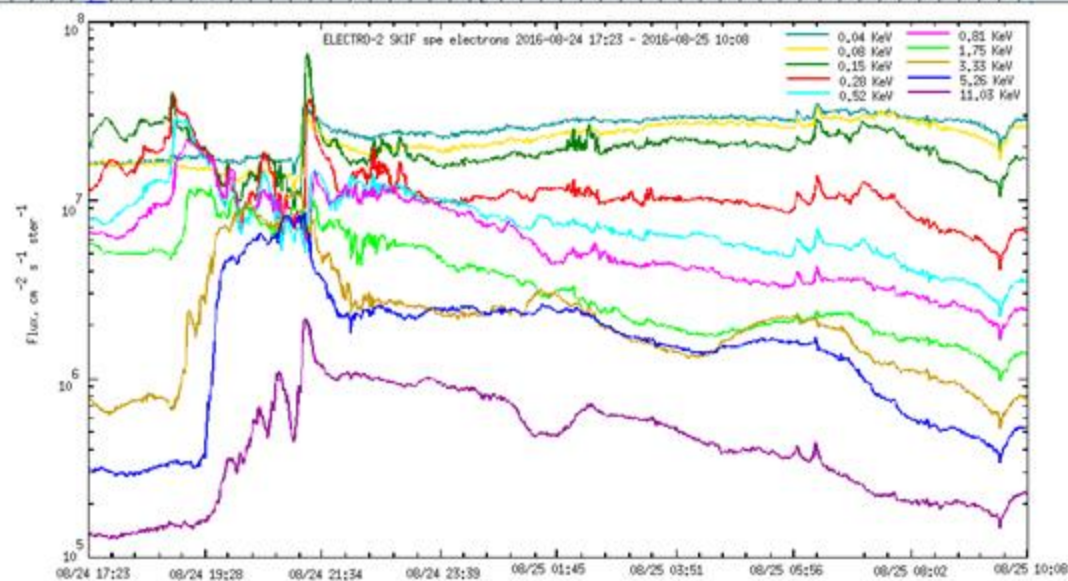
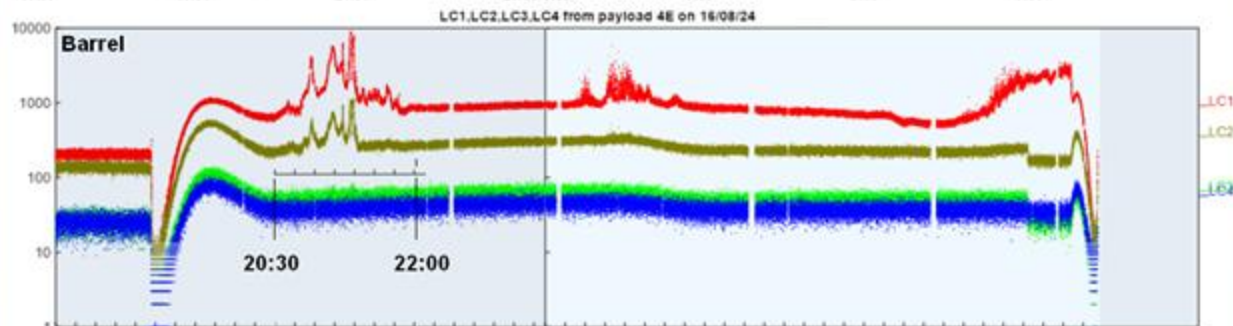
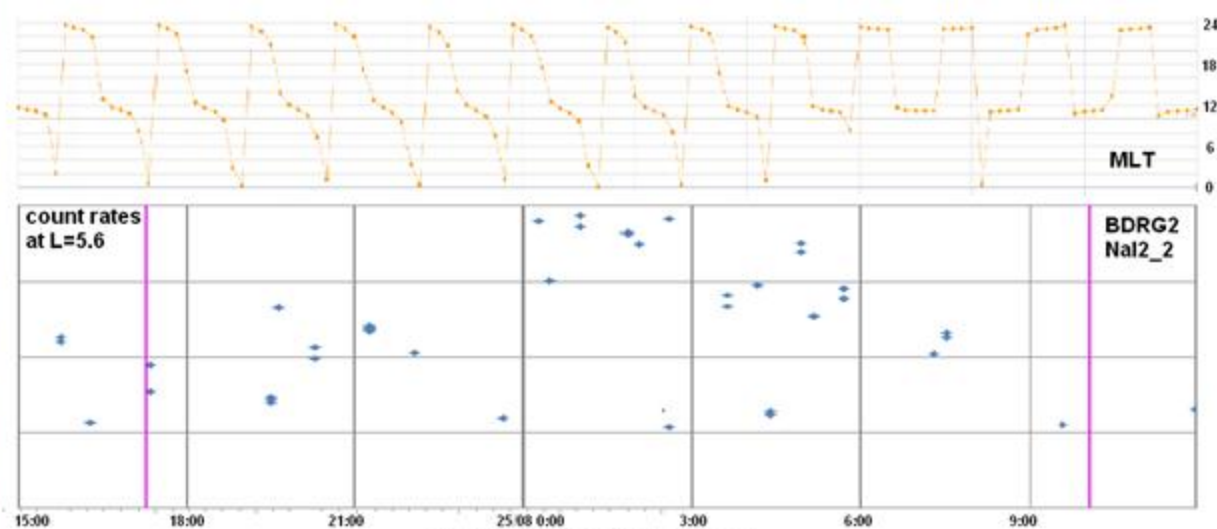
2:48 - 2:58



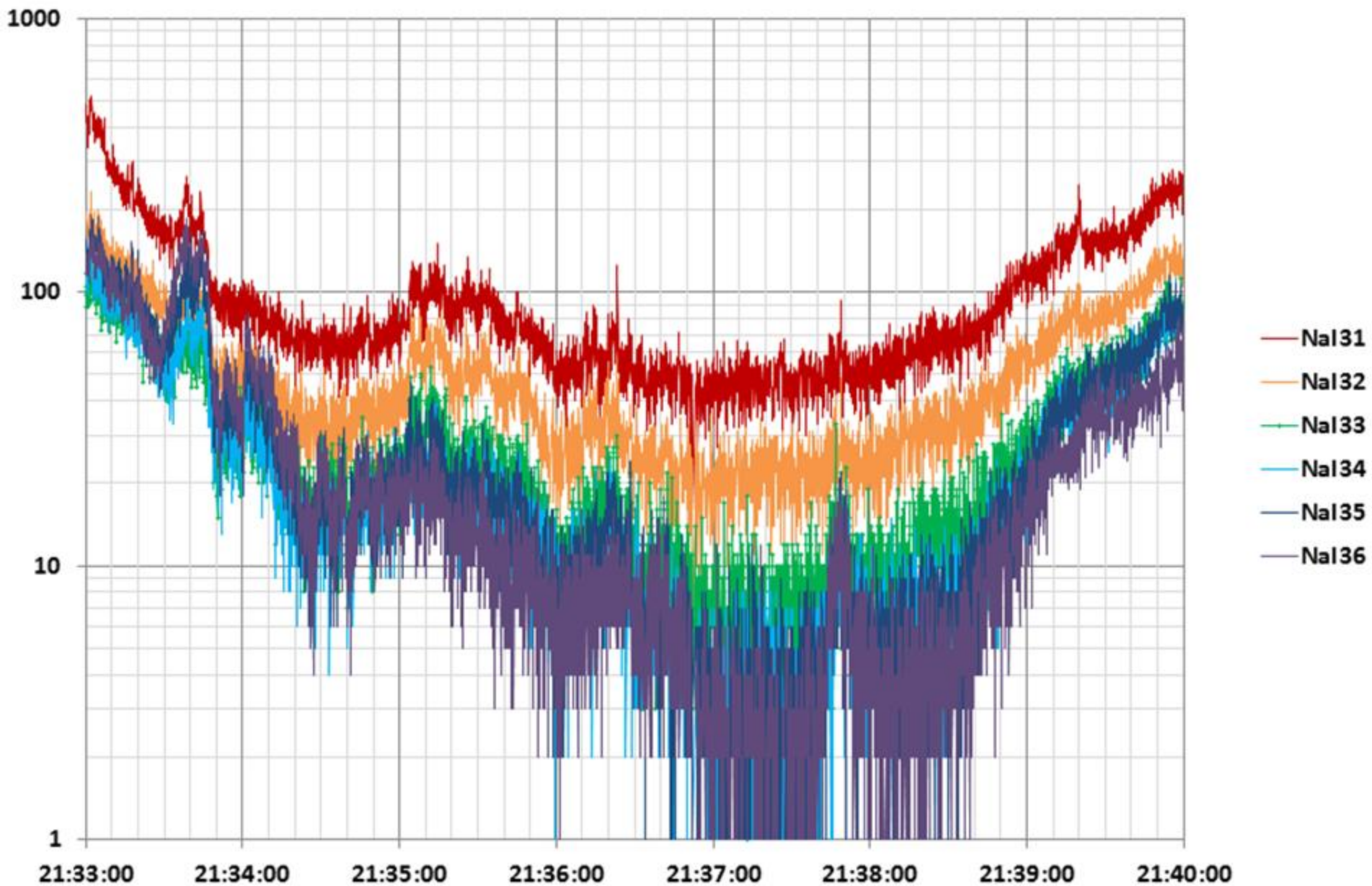
BDRG NaI



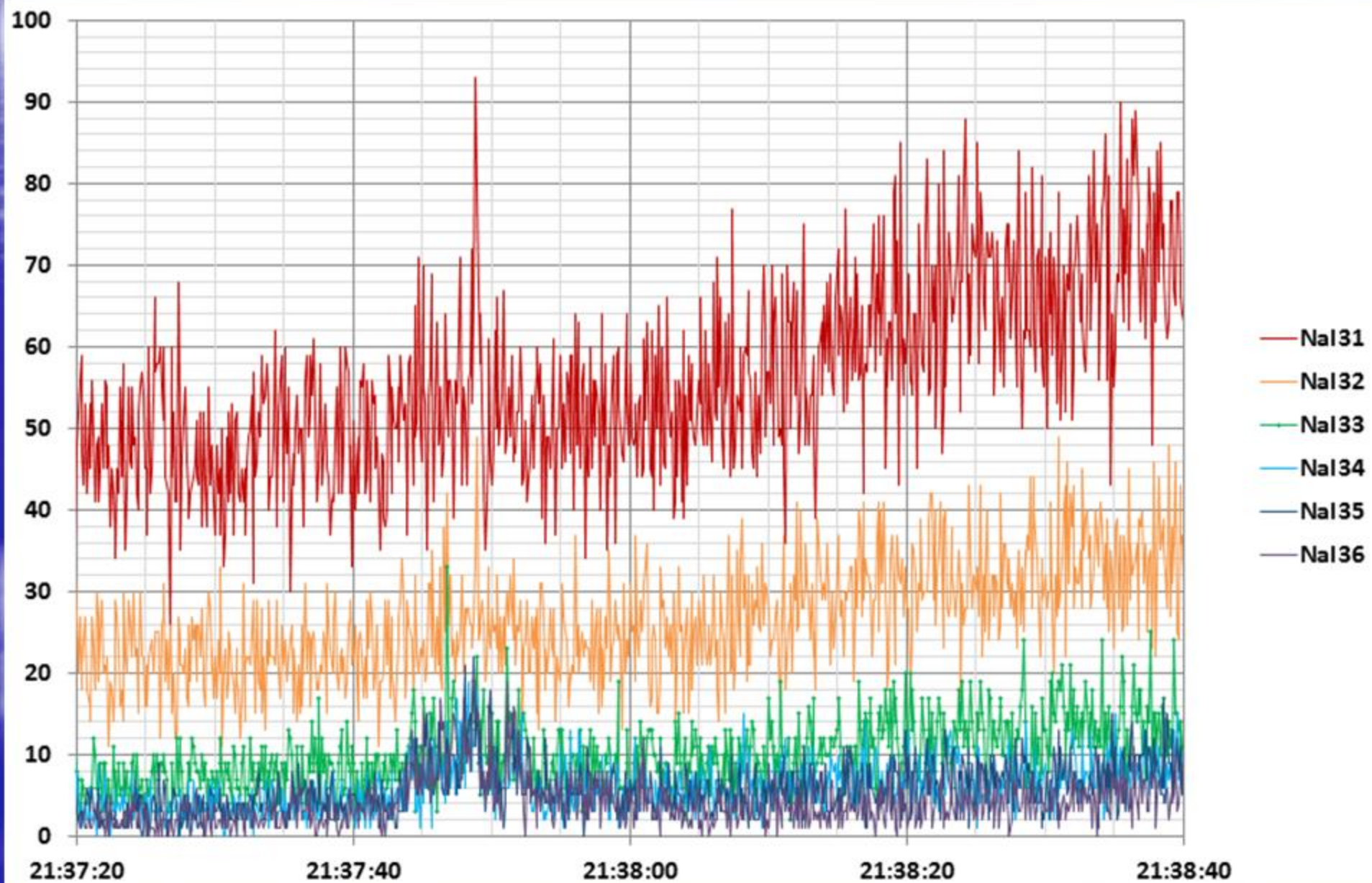




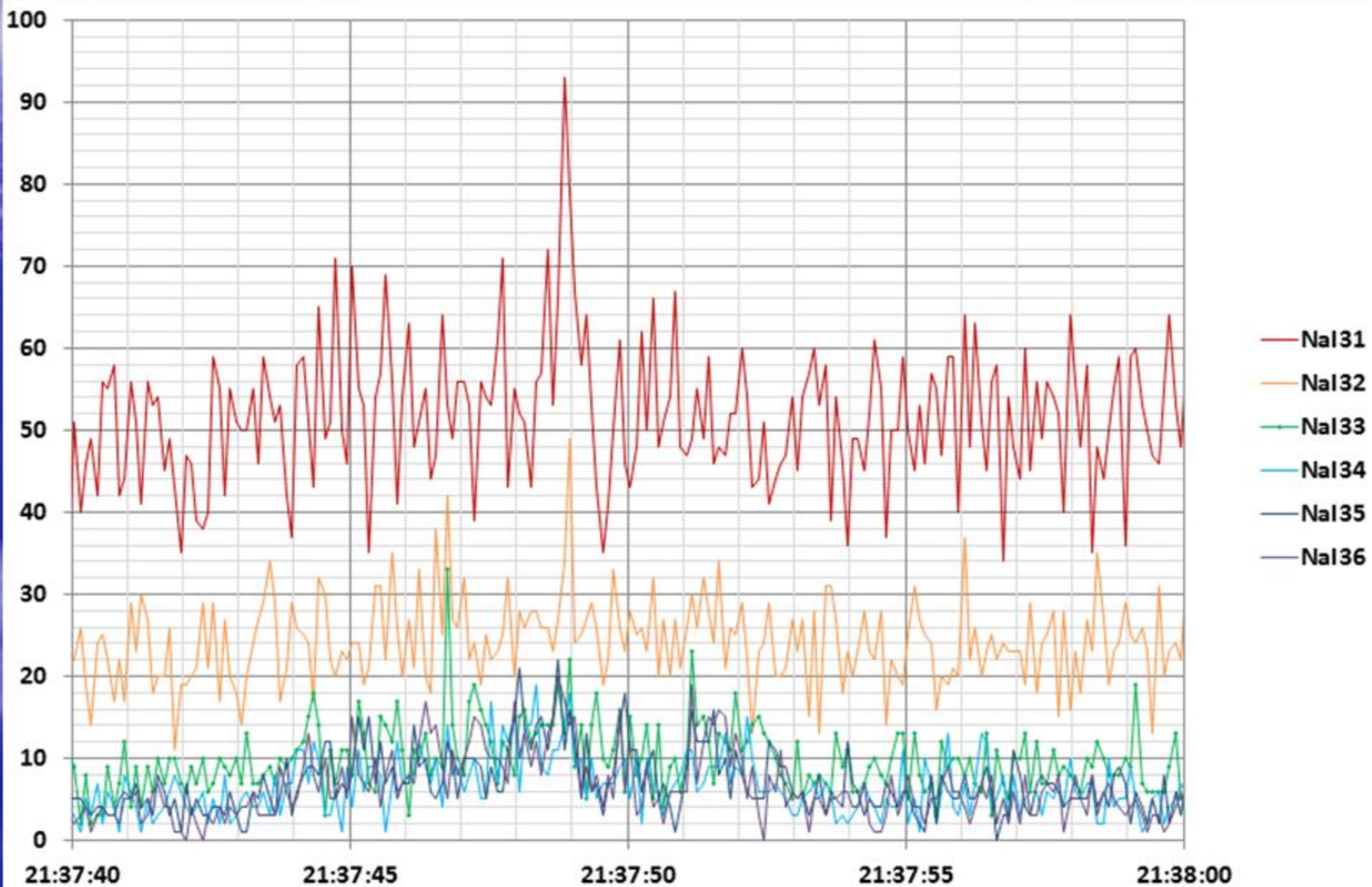
BDRG 3 NaI



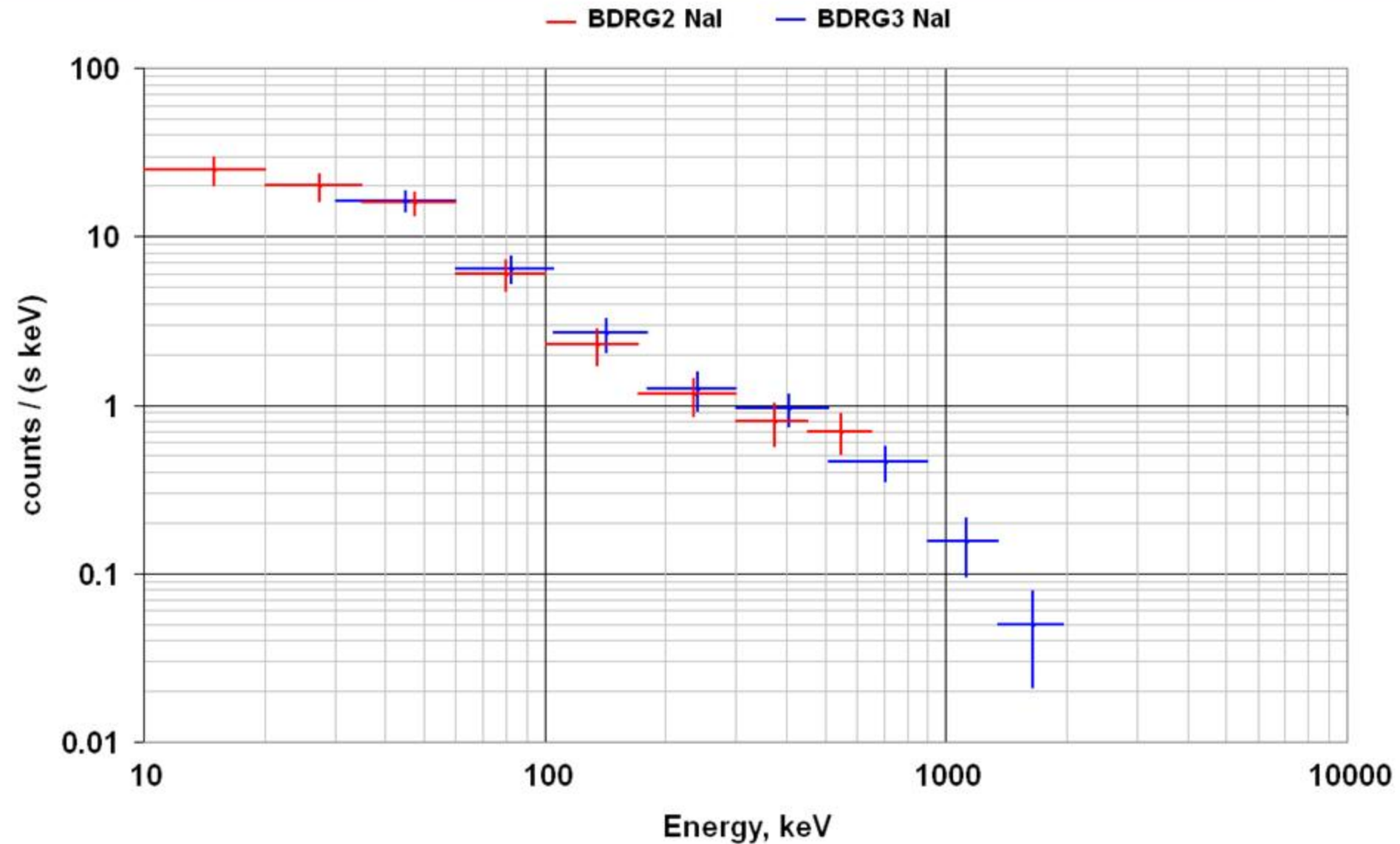
BDRG 3

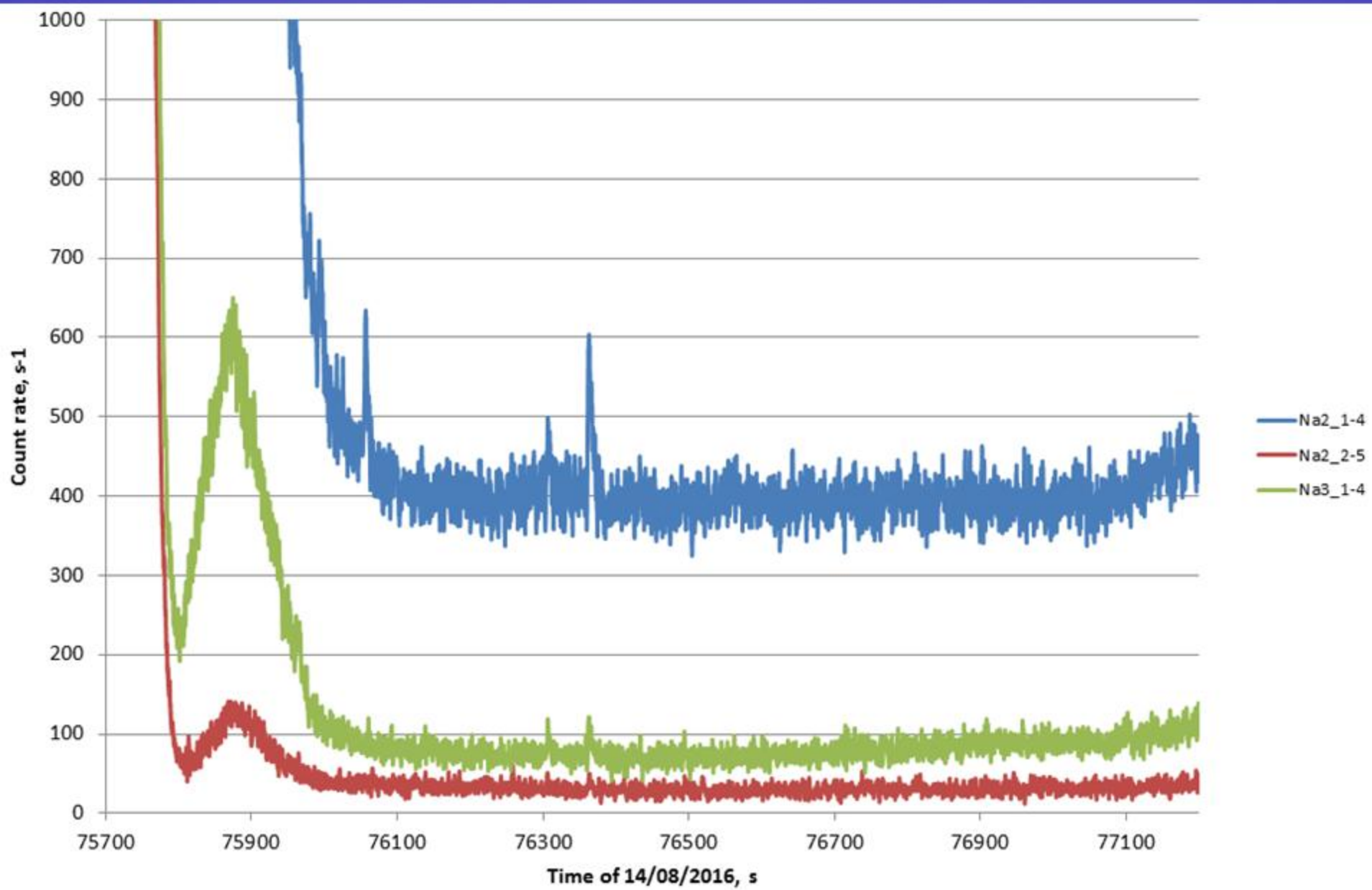


BDRG 3



Аппаратурный спектр БДРГ 16.08.2016г в 21:37:49

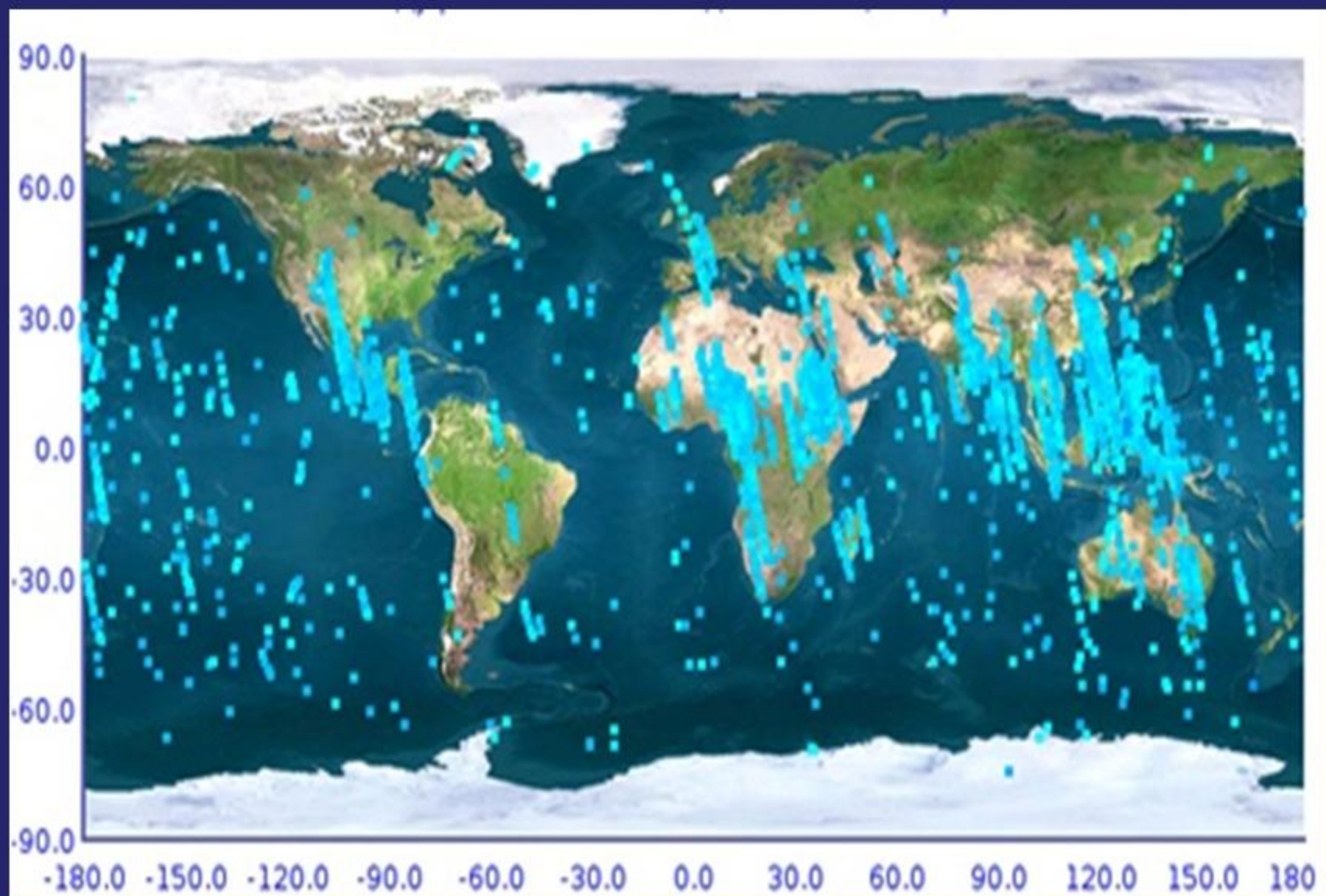




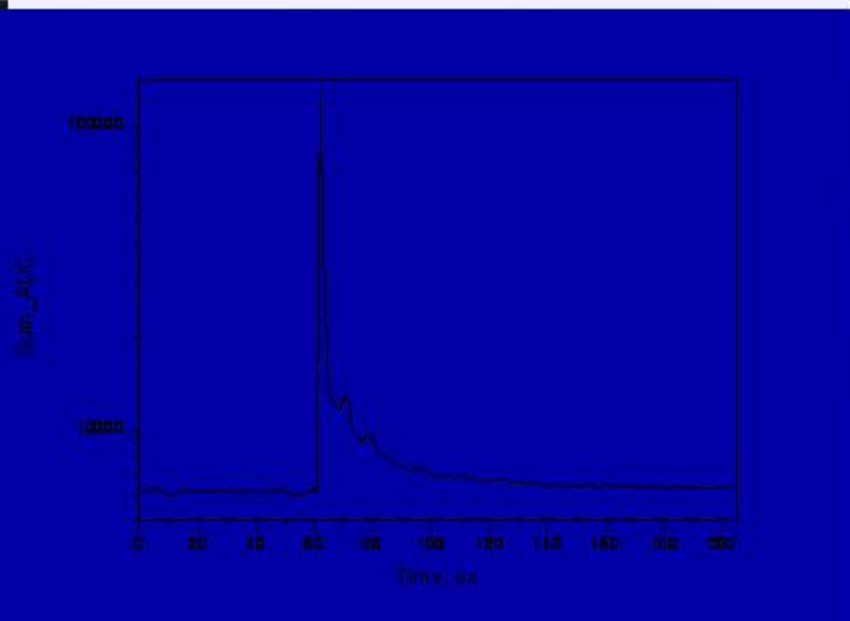
Заключение

- 1. Зарегистрированы гамма-вспышки из атмосферы Земли в высокоширотных областях вне зон грозовой активности**
- 2. Во время регистрации вспышек не наблюдались высыпания высокоэнергичных электронов**
- 3. Высыпания электронов регулярно наблюдаются на внутренней кромке внешнего пояса (т.н. область изотропизации), возрастания интенсивности электронов также наблюдаются и в области полярной шапки**
- 4. Источник зарегистрированных вспышек гамма-излучения по-видимому находится в атмосфере Земли и не связан с грозовой активностью и высыпаниями электронов**

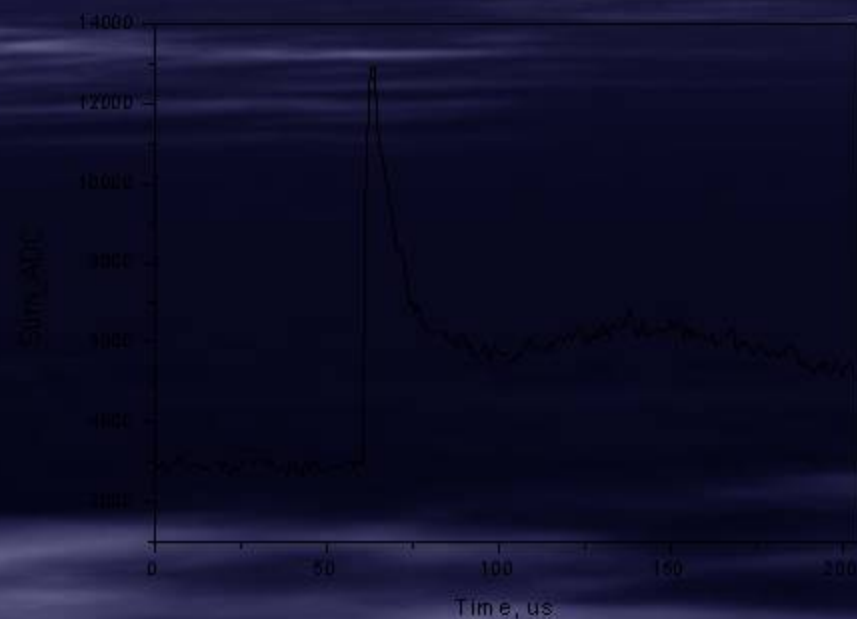
Global distribution of detected flashes



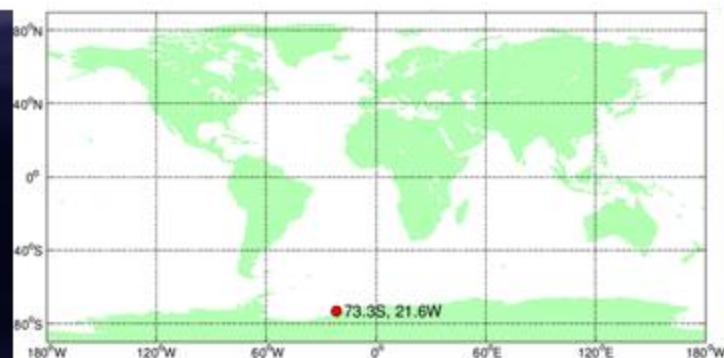
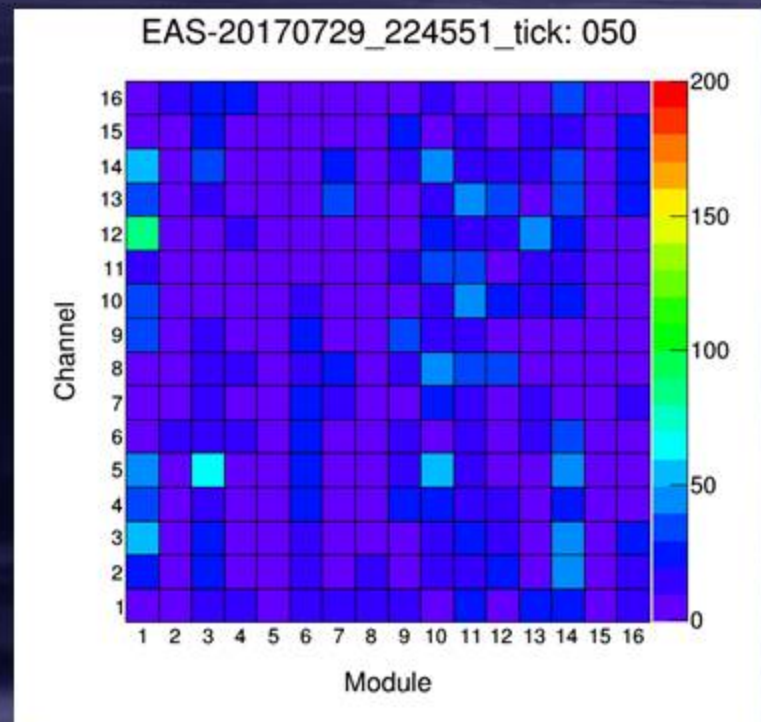
UV flash over the Barents Sea



UV flash above Antarctica

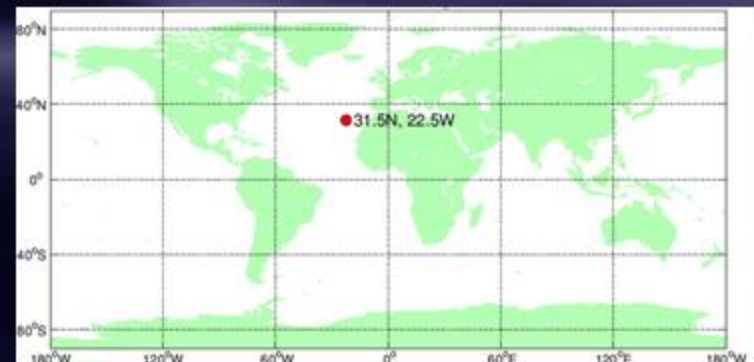
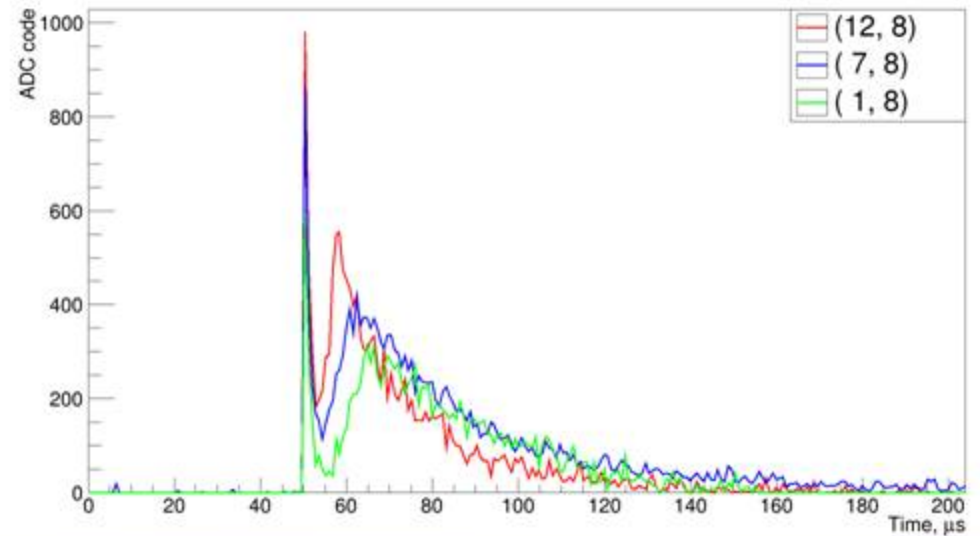
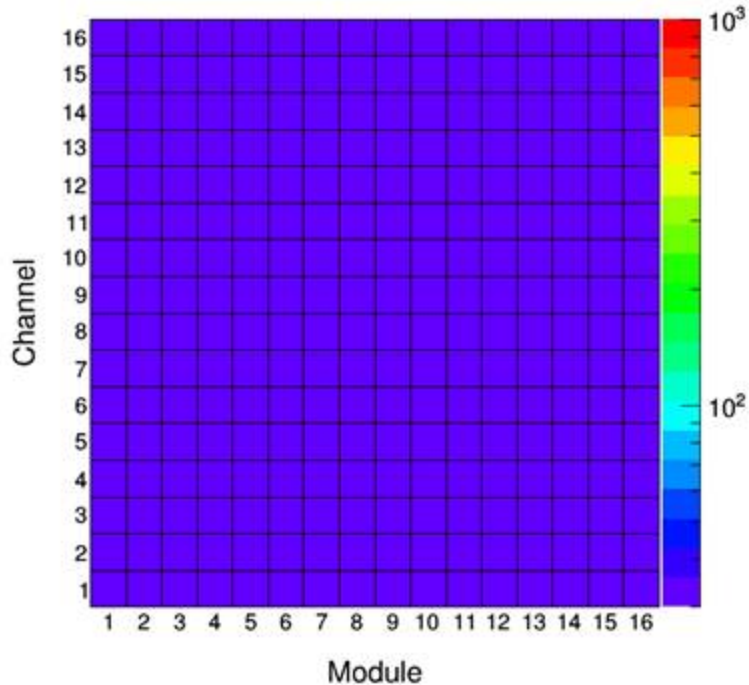


There is a lightning in the conjugate point of geomagnetic field according to Vaisala GLD360.

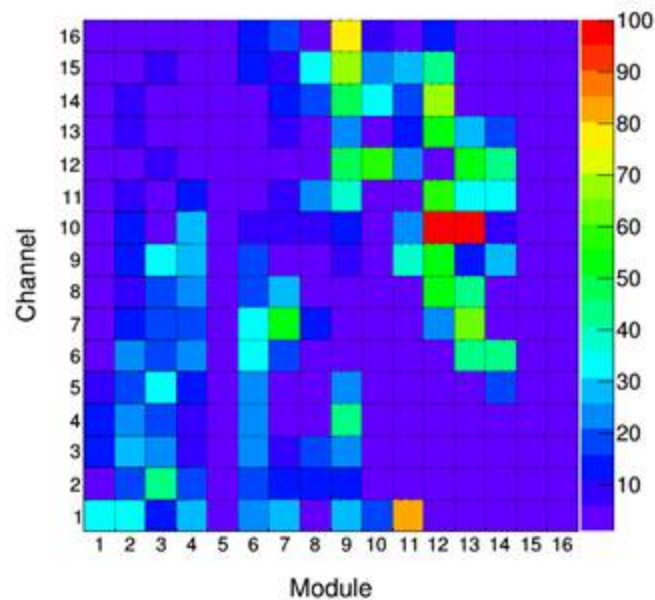


Far from thunderstorm UV flash above the Atlantic ocean

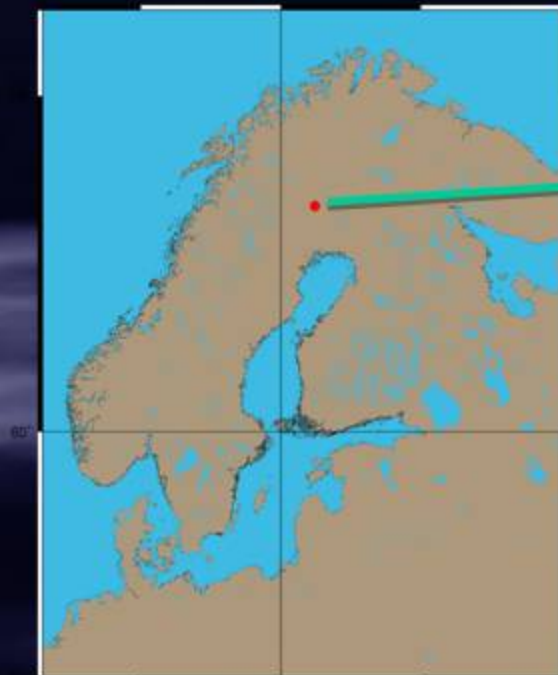
EAS-20170728_004707_tick: 050



METEOR-20161226_224720_ticks: 001 - 255

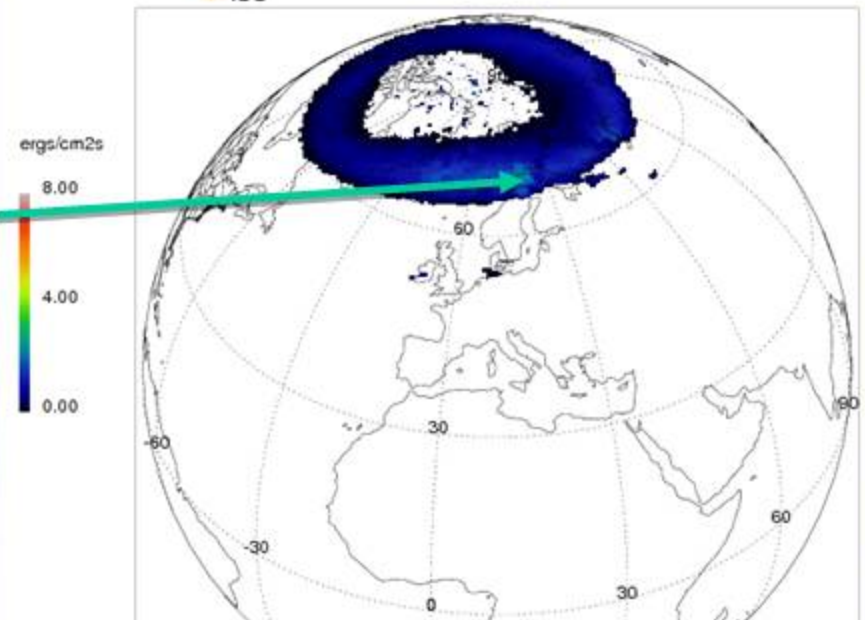


Interesting event in Aurora region above Sweden 6.6 ms resolution 26 12 2016



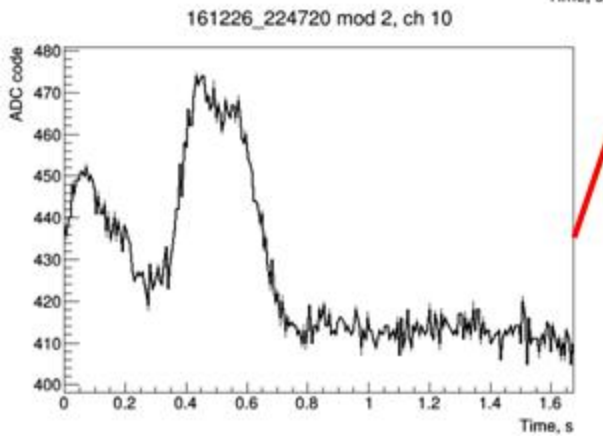
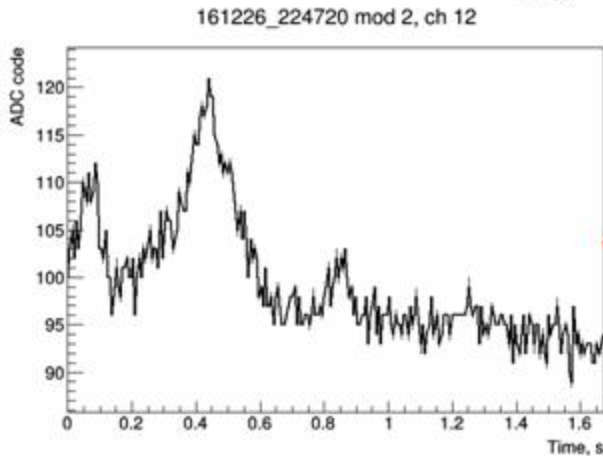
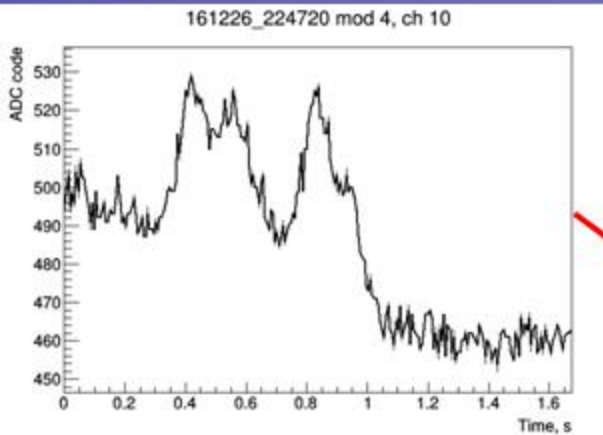
all,e+i 2016/12/16 22:45:00 9.7 GW

ISS

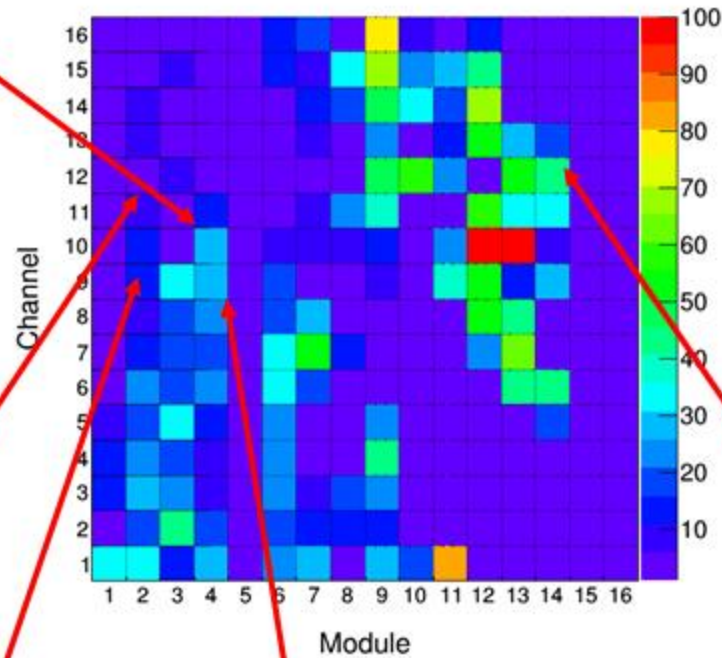


<https://iswa.ccmc.gsfc.nasa.gov/iswaSystemWebApp/>

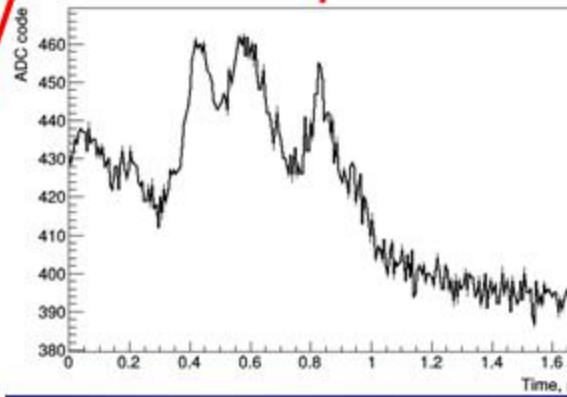
Space-time structure of the event



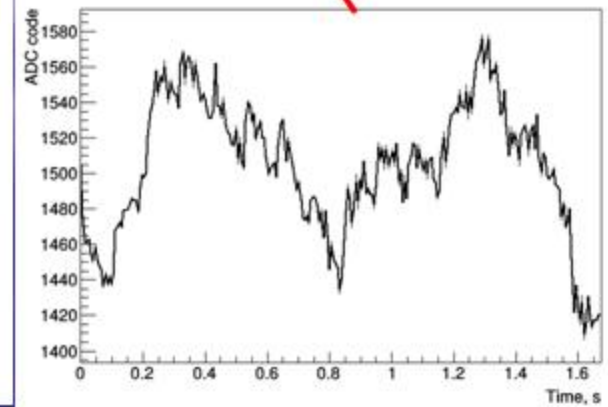
METEOR-20161226_224720_ticks: 001 - 255



161226_224720 mod 4, ch 9



161226_224720 mod 14, ch 13



Conclusion:

1. The short gamma-ray flashes from atmosphere were detected in polar regions in the experiment on-board Vernov satellite (2 times in Antarctic)
2. Duration of these flashes is about several milliseconds being some longer than one expected for TGFs
3. No significant change of the flux of electrons is observed by DRGE-3 at the correspondent moment
4. Several candidates to atmospheric flashes were detected in Lomonosov mission during the search for the bursts with the characteristic time 1 ms, 3 ms and 5 ms. All of the candidates are detected in the regions of inner boundary of the electron radiation belts. Their nature is not clear yet.

For future experiments:

- Multi-pixel detectors are useful for better coincidence technique
- The detectors with angular resolution are needed to detect a point source

Acknowledgments:

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No RFMEFI60717X0175