Gamma-ray Transients Detected by GRBAlpha and VZLUSAT-2 CubeSats

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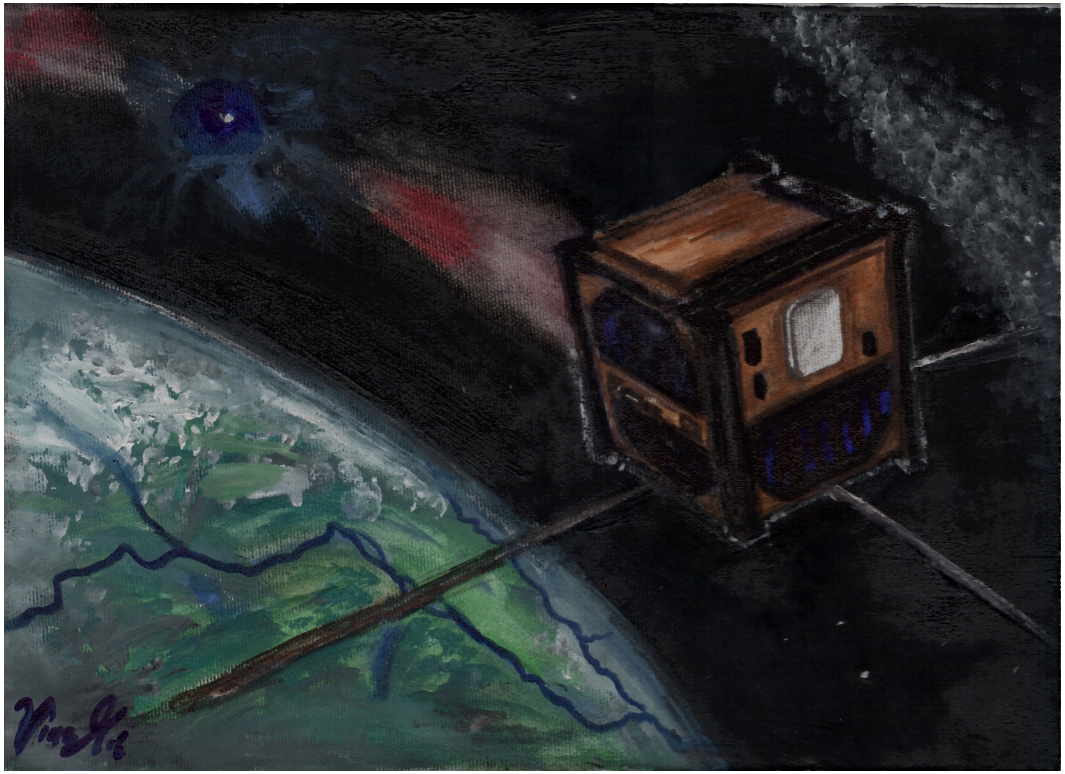
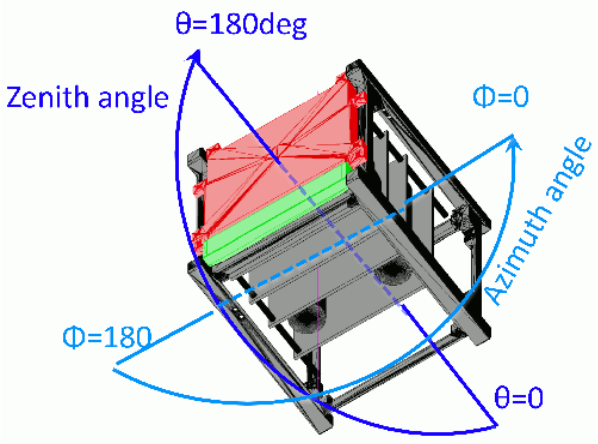
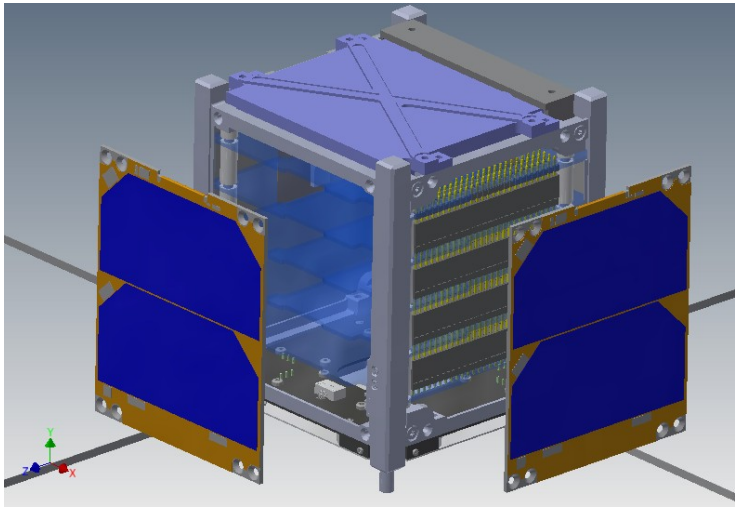


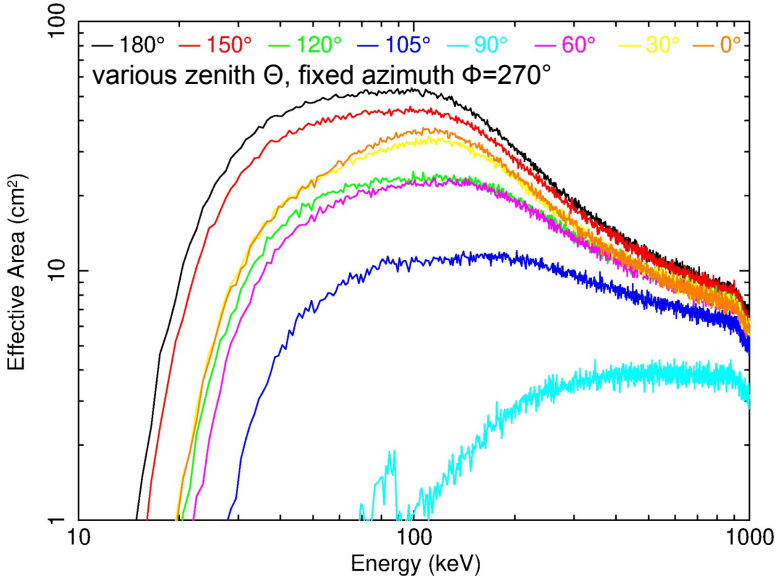
GRBNanosats meeting, 2023/03/07

GRBALPHA:
1ST TECHNOLOGICAL PRECURSOR MISSION TO CAMELOT

- 1-U CubeSat with gamma-ray detector
  - same concept planned for CubeSat fleet CAMELOT
- Small size of scintillator (75x75x5mm^3) readout by 8 MPPCs
- Main goals:
  - confirm detector concept
  - characterize the detector degradation on orbit
  - characterize background at LEO (SSO) for a gamma-ray detector

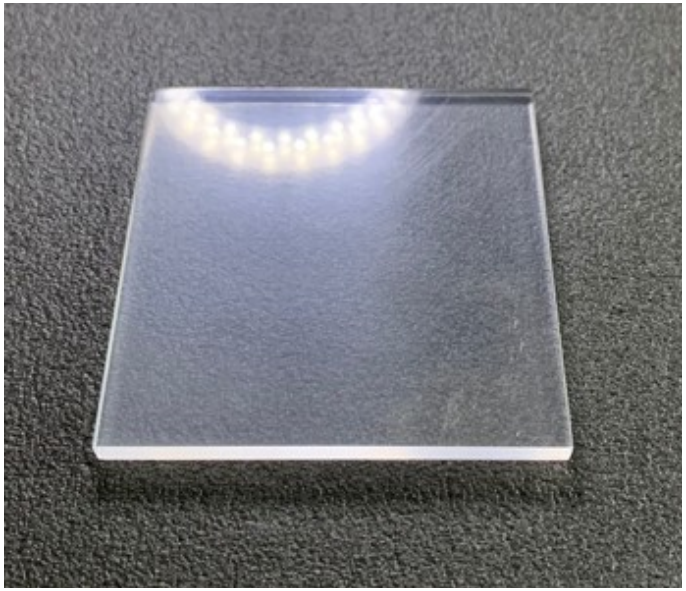




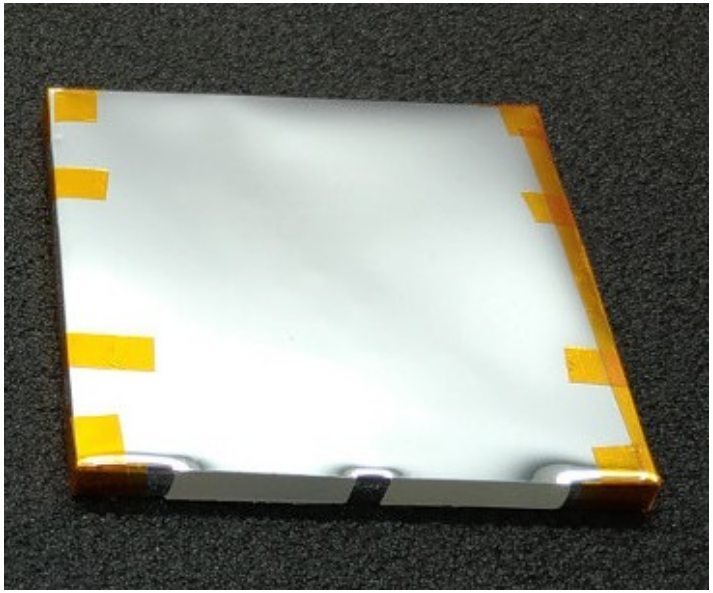


GRBALPHA:
DETECTOR ASSEMBLING

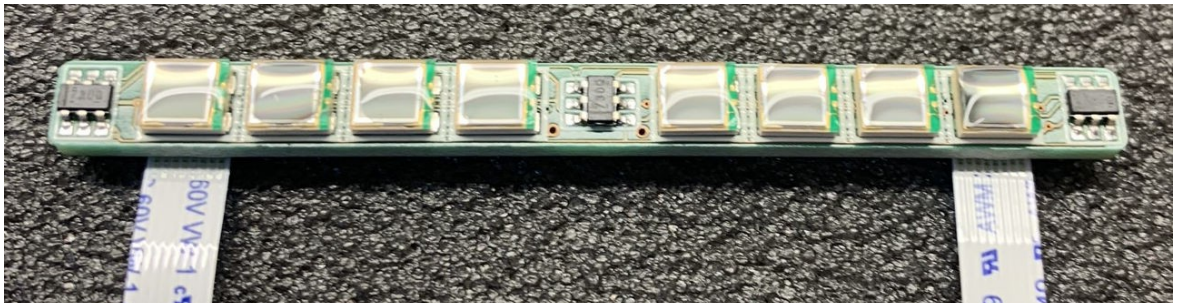
Pál+ 2020



CsI(Tl) scintillator
from Kharkiv (Ukraine)



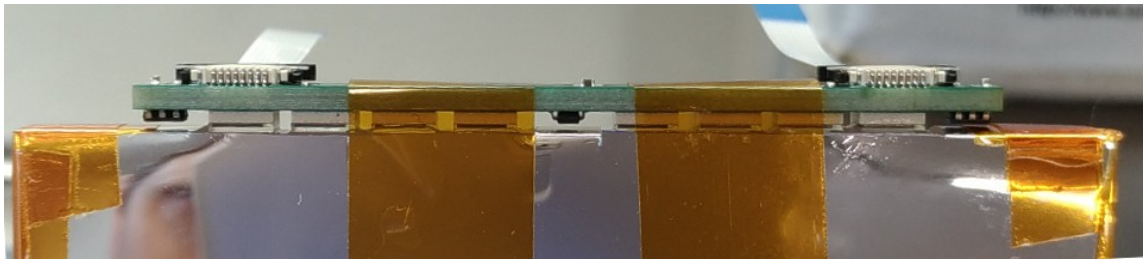
Wrapped in Enhanced
Specular Reflector (ESR)

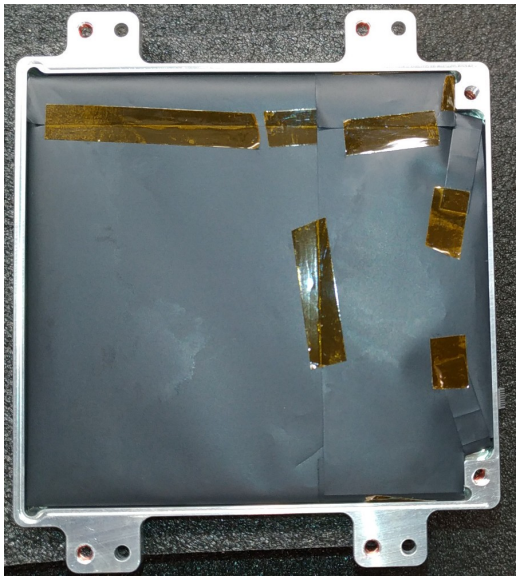


2 readout channels each with 4 MPPCs (S13360-3050 PE) by Hamamatsu

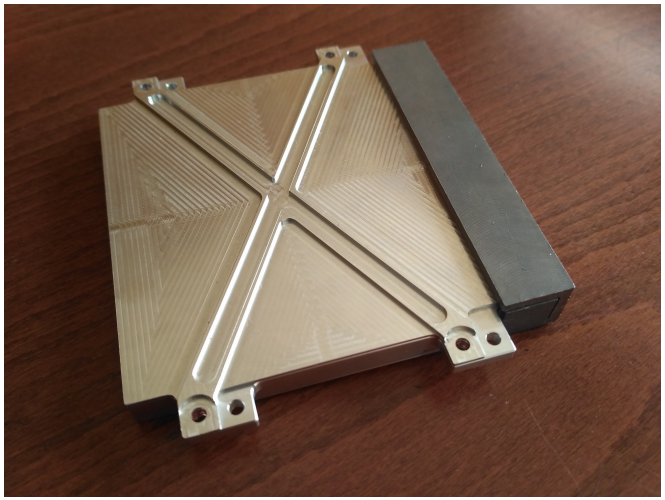
GRBALPHA: DETECTOR ASSEMBLING

- MPPCs are coupled with crystal by optical glue DOWSIL93-500
- Detector is wrapped by optically thick DuPont TCC15BL3 polyvinyl fluoride (PVF) tedlar to prevent light leakage from outside



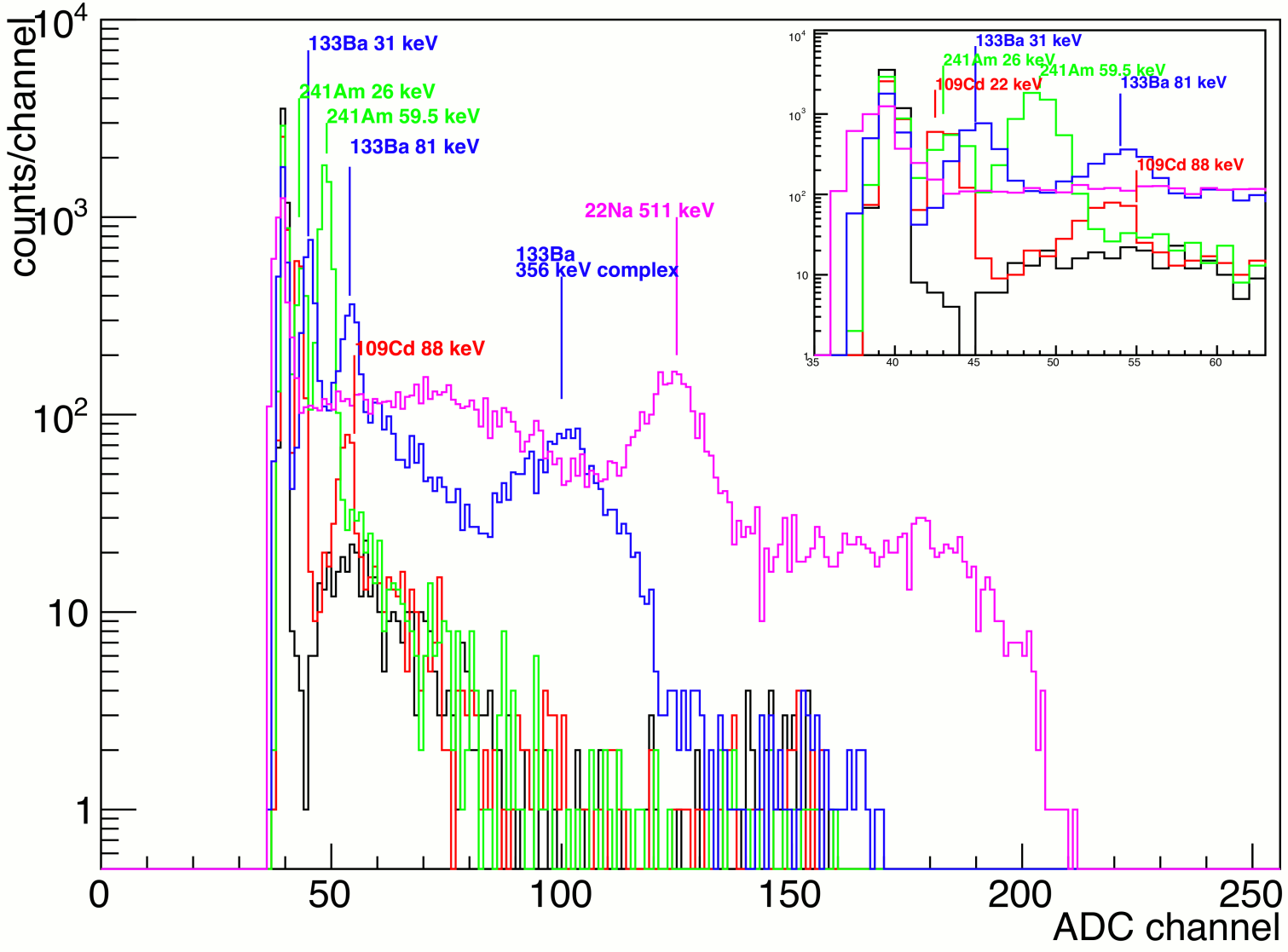


DuPont Tedlar TCC15BL3 wrapping



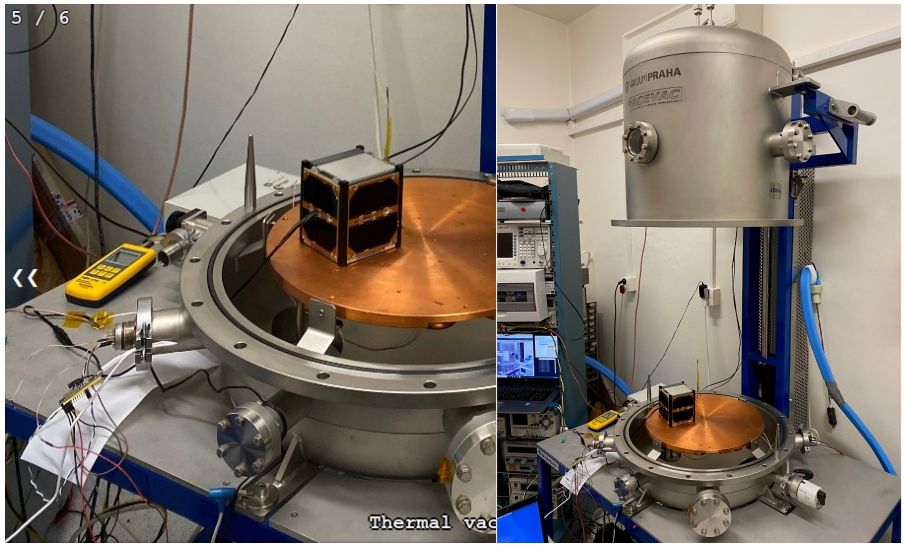
Assembled detector with 2.5mm thick Pb-Sb alloy to reduce MPPC degradation by trapped protons in SAA

GRBALPHA:
ON GROUND GAIN CALIBRATION

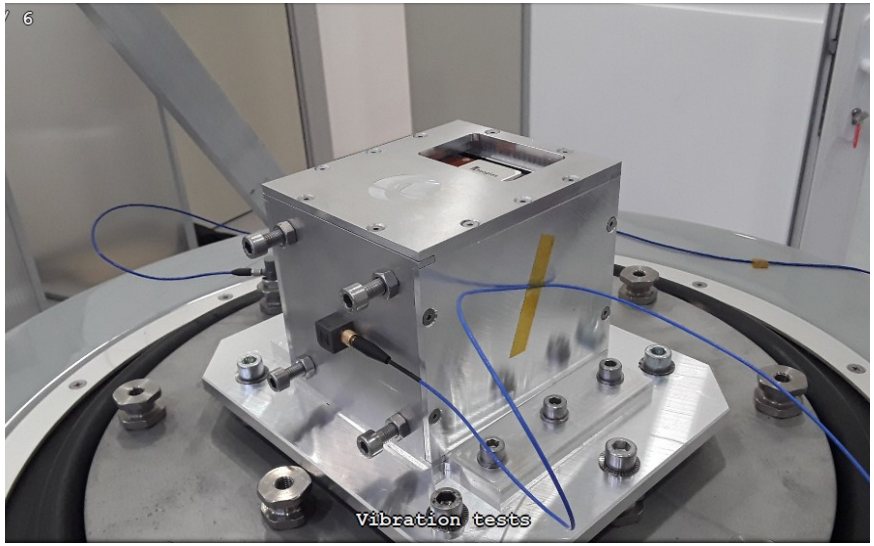


For readout ch 0

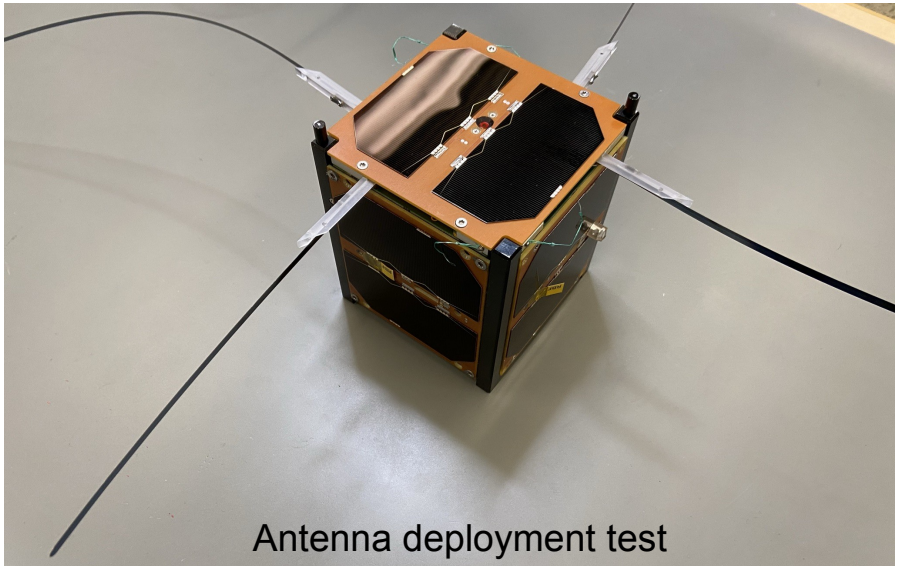
GRBALPHA: ENVIRONMENTAL TESTS



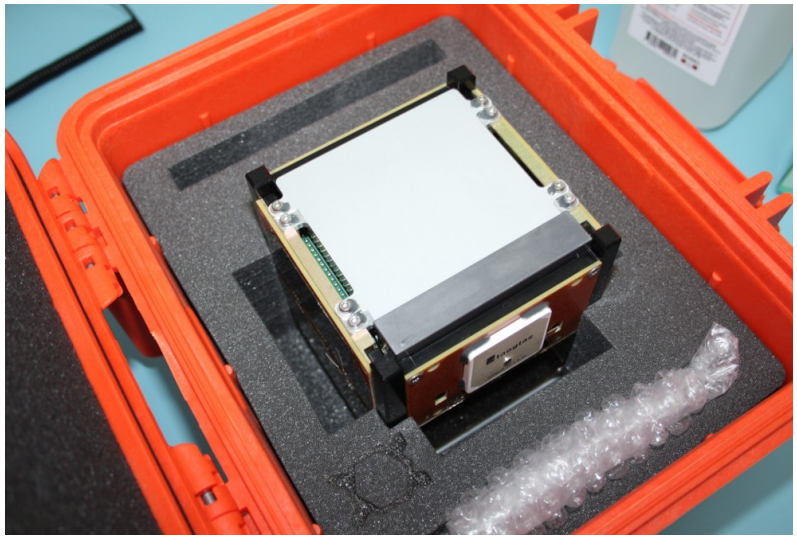
Thermal vacuum test



Vibration tests by Remred ltd. in Budapest



Antenna deployment test

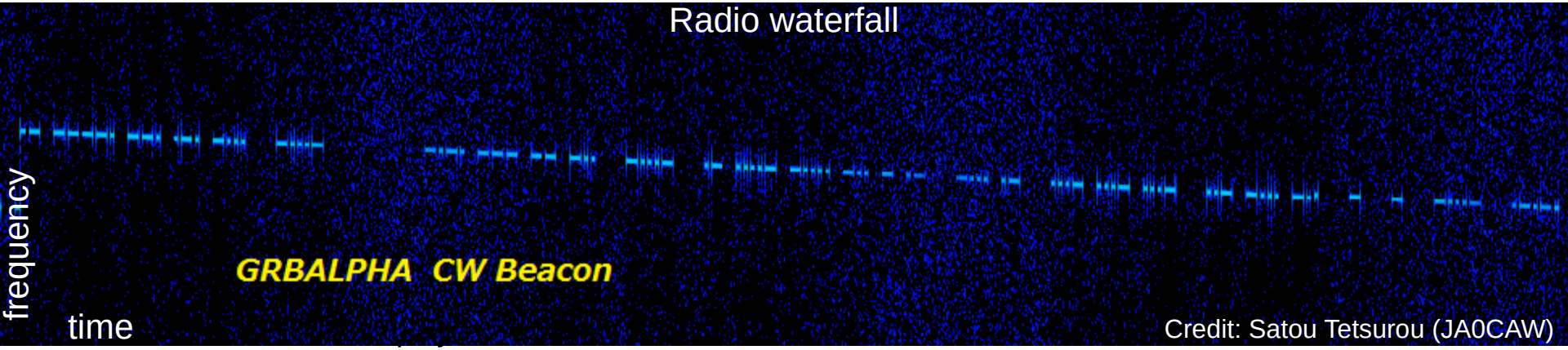


Ready for shipment to launch provider

GRBALPHA: LAUNCH AND FIRST RADIO SIGNALS

https://grbalpha.konkoly.hu/

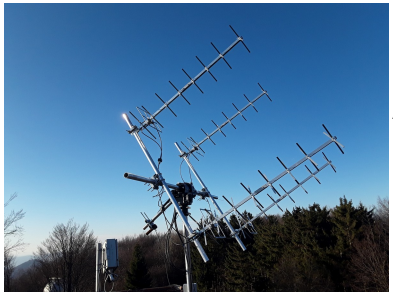
- Launched to 550 km SSO on March 22, 2021
- For downlink we are using amateur radio bands in UHF at 437.025 Mhz
- 1st confirmation that GRBAlpha is alive came ~5 hours after launch from radioamateur in Brisbane
- 1st pass over ground station in Brno was ~15 hours after launch
- Anyone can catch our data packets, see SatNOGS network



One of the first observation by radioamateurs listening to our beacon with Morse code

GS in Brno University of Technology (Czech)

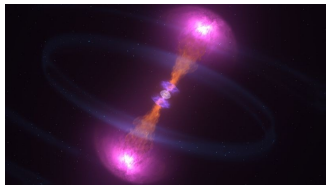
GS in Košice Technical University (Slovakia)



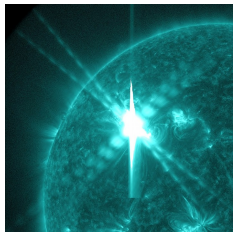
GS in Piszkéstető Astronomical Institute (Hungary)

LIST OF TRANSIENTS OBSERVED BY GRBALPHA

- https://monoceros.physics.muni.cz/hea/GRBAlpha/
- By today:



- **24 Gamma-Ray Bursts**
  (3 short / 21 long)



- **10 Solar flares**

- **2 Soft gamma repeater bursts**
  1935+2154 (magnetar)

- **1 X-ray binary outburst**
  LS V +44 17 / RX J0440.9+4431

List of transients observed by the GRBAlpha nanosatelite

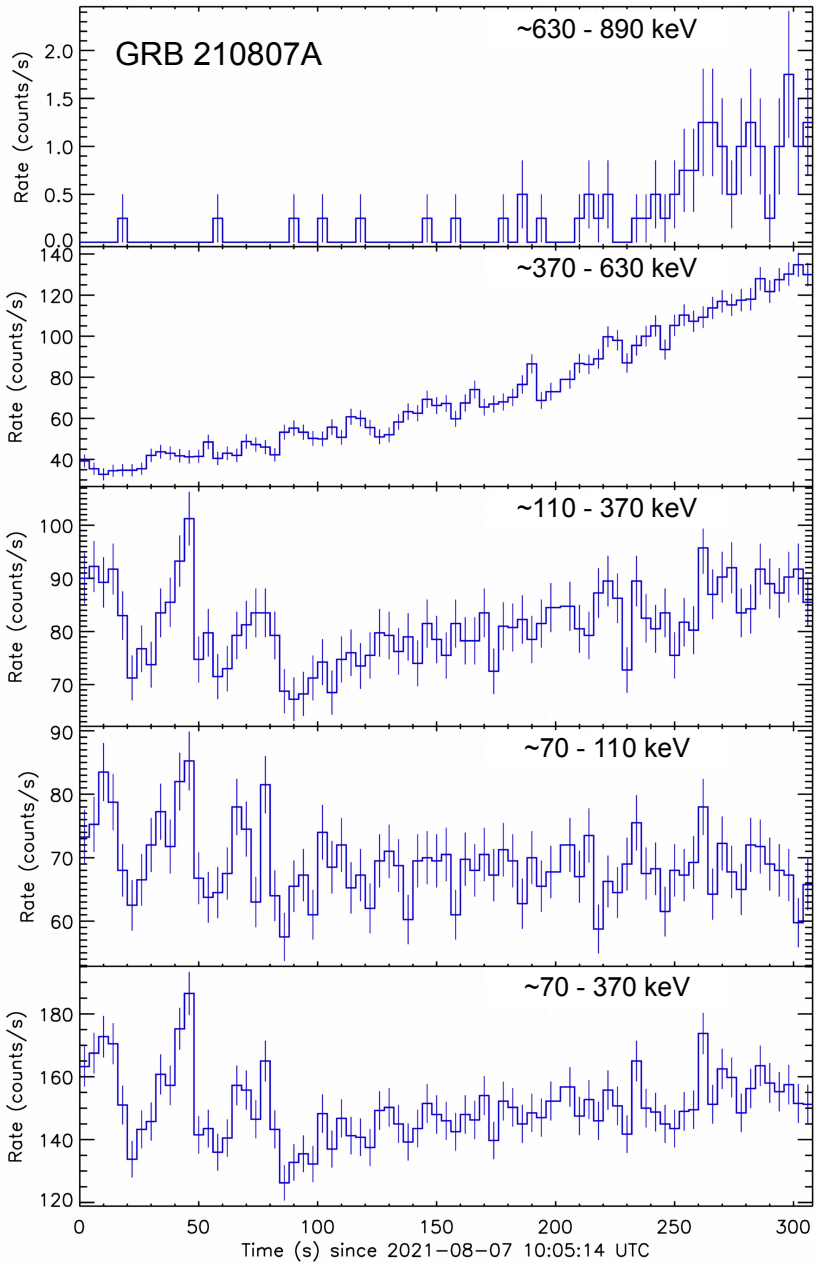
The list contains gamma-ray transients observed by GRBAlpha

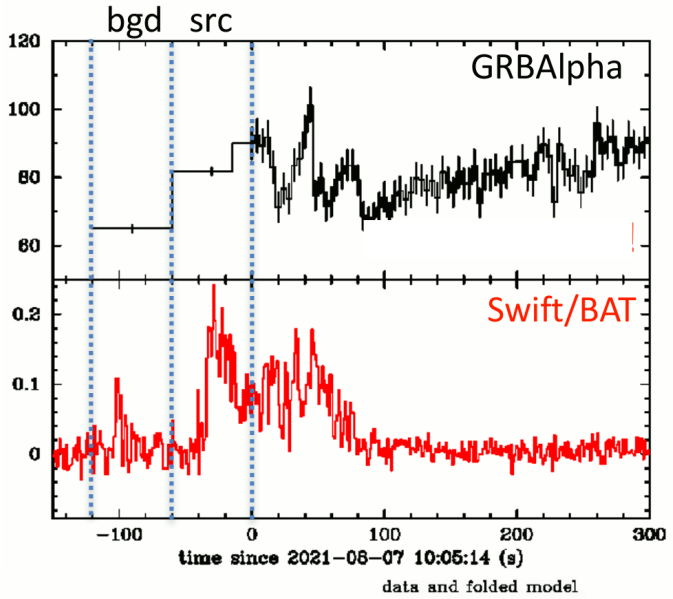
- **Event type/name** denotes the type of the detected event like GRB, Solar flare etc.
- **Peak time** denotes the time when the detected count rate from the event was maximal
- **T90** is the time interval, in which 90 per cent of all counts in the given energy band from the event are observed
- **Count rate** is the detected count rate of the event at the peak time
- **Band** is the energy range for which the T90 duration and the count rate was calculated
- **S/N** is the maximal significance of the signal detected in any of the energy bands (either in one bin at the peak or integrated over T90)
- **Raw LC** is the raw light curve without the background subtraction
- **Bkg-sub LC** is the light curve with background subtracted
- **LC res.** is the light curve resolution
- **GCN circ.** is the GCN circular number where this detection was reported
- **References** give the list of other instruments which detected the same event

Event type/name	Peak time (UTC)	T90 [s]	Count rate [cnt/s]	Band [keV]	S/N [σ]	Raw LC	Bkg-sub LC	LC res. [s]	GCN circ.	References	Comment
Solar flare	2023-02-22 13:47:59.9	135	148.7	~70-890	36.9	PNG, EPS	PNG, EPS	1		CALET/CGBM GECAM GOES	
LS V +44 17 / RX J0440.9+4431	2023-02-11 17:36:18.9	13	45.7	~70-890	7.5	PNG, EPS	PNG, EPS	1	33320/PDF	Fermi/GBM	Be/X-ray binary outburst
Solar flare	2023-02-11 15:45:57.9	59	420.3	~70-890	78.8	PNG, EPS	PNG, EPS	1		Solar Orbiter/STIX Fermi/GBM VZLUSAT-2 Wind/Konus GOES	
Solar flare	2023-02-10 03:00:33.9	12	52.7	~70-890	9.8	PNG, EPS	PNG, EPS	1		Solar Orbiter/STIX GOES	
GRB 230207B	2023-02-07 04:40:47.9	10	319.7	~70-890	25.0	PNG, EPS	PNG, EPS	1	33303/PDF	INTEGRAL/SPI-ACS CALET/CGBM Swift/BAT-GUANO AGILE/MCAL	
GRB 230204B	2023-02-04 21:47:02.9	207	141.0	~70-890	25.1	PNG, EPS	PNG, EPS	1	33273/PDF	Fermi/GBM INTEGRAL/SPI-ACS CALET/CGBM MAXI/GSC ASTROSAT/CZTI Swift/BAT-GUANO AGILE/MCAL	
GRB 230102A	2023-01-02 00:22:13.0	<1	78.6	~70-890	5.6	PNG, EPS	PNG, EPS	1	33143/PDF	Fermi/GBM AGILE/MCAL	
maybe solar flare	2022-12-29 18:19:44.4	163	53.7	~70-890	12.7	PNG, EPS	PNG, EPS	1		CALET/CGBM GOES	
GRB 221206B	2022-12-06 12:22:48.9	8	495.8	~70-890	35.8	PNG, EPS	PNG, EPS	1	33028/PDF	Fermi/GBM Wind/Konus INTEGRAL/SPI-ACS Swift/BAT-GUANO	
GRB 221127A	2022-11-27 08:27:10.2	3	38.3	~70-890	3.0	PNG, EPS	PNG, EPS	1	32991/PDF	Fermi/GBM	
GRB 221122A	2022-11-22 02:43:26.2	2	45.2	~70-890	4.3	PNG, EPS	PNG, EPS	1	32977/PDF	GECAM	
GRB 221119A	2022-11-19 15:02:55.2	54	299.8	~70-890	23.5	PNG, EPS	PNG, EPS	1	32953/PDF	GECAM INTEGRAL/SPI-ACS Fermi/GBM	
GRB 221112A	2022-11-12 06:18:04.2	15	39.6	~70-890	3.4	PNG, EPS	PNG, EPS	1	32937/PDF	Fermi/GBM	

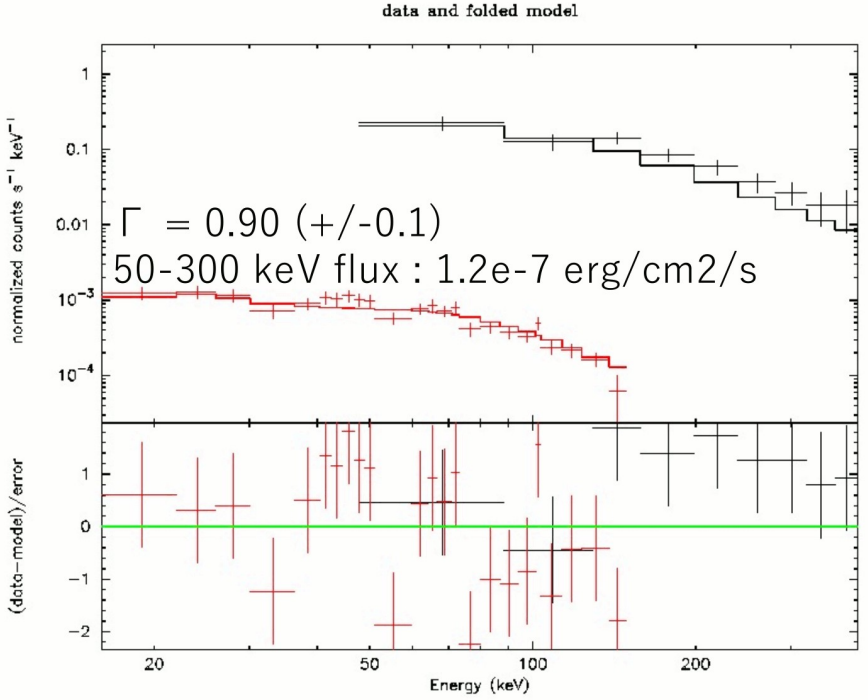
GRBALPHA: 1ST GRB DETECTION

1ST GRB EVER DETECTED BY 1U SIZE CUBESAT!

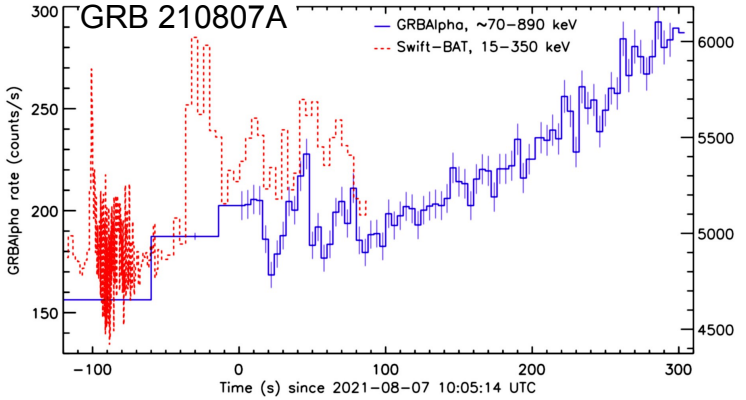


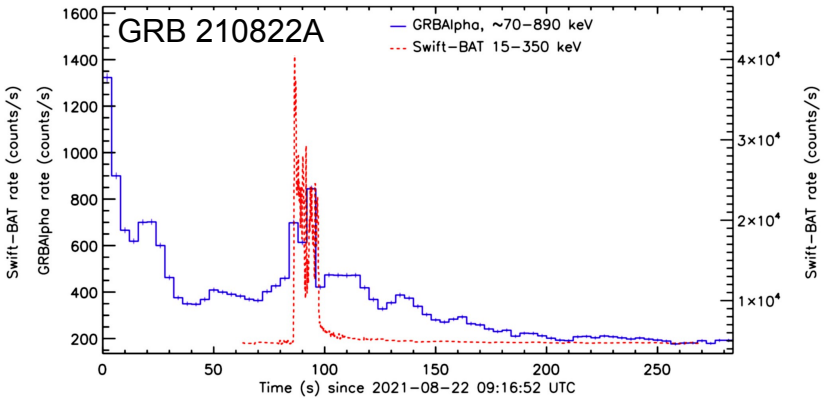


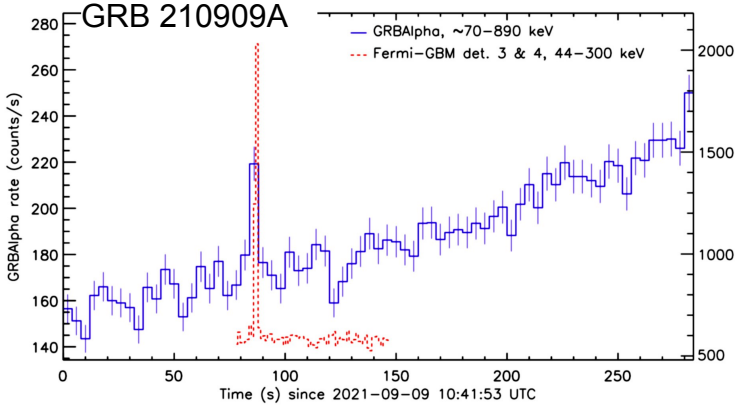
- measured high resolution spectrum
- performed joint spectral fit GRBAlpha + Swift/BAT

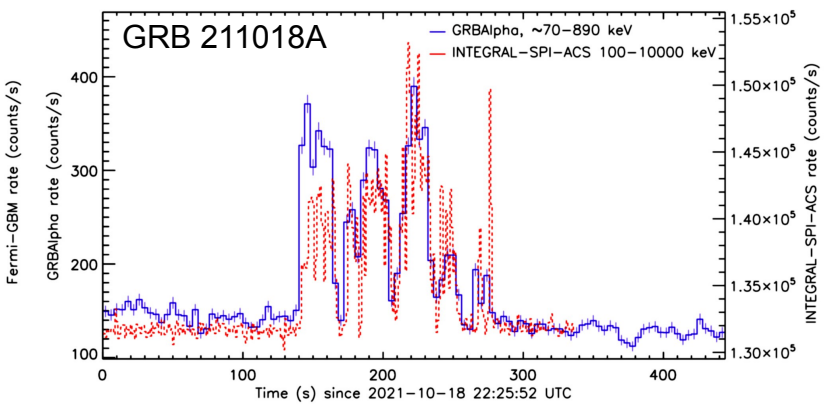


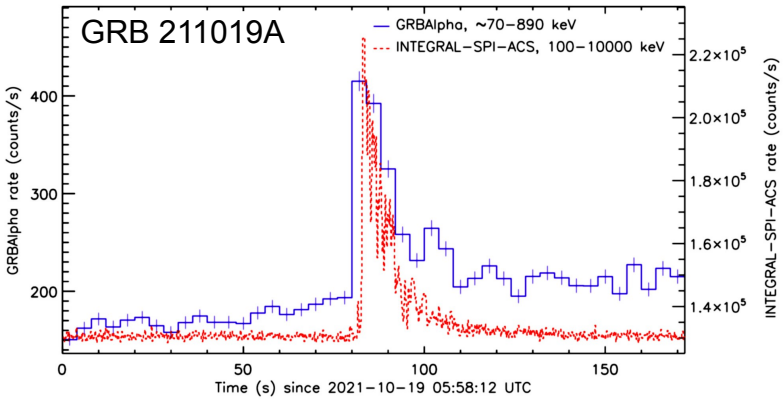
GRBALPHA: GRB DETECTIONS







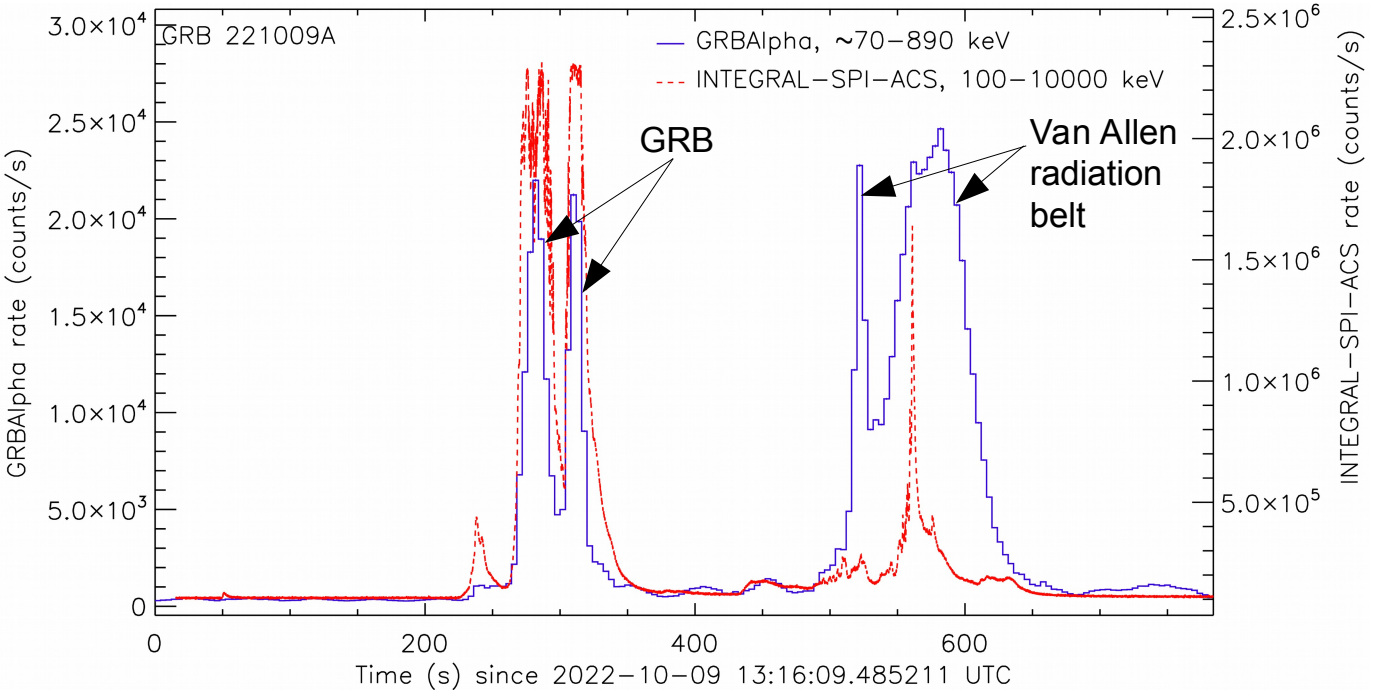


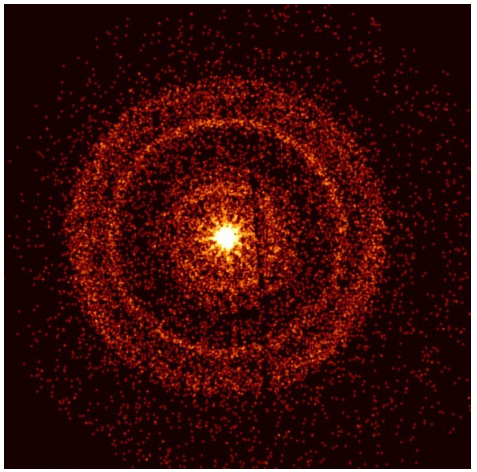


- GRB detections by GRBAlpha confirmed by other missions: Swift/BAT, Fermi/GBM, INTEGRAL/SPI-ACS
- Long and short GRBs
- Long GRB 210822A at z=1.736, light travel time **10 Gyr**
- Two GRBs were detected 8 hours apart
- Demonstration that nano-satellites can host payloads sensitive enough to routinely detect GRBs !

GRBALPHA: GRB 221009A
THE BRIGHTEST GRB EVER OBSERVED!

- **The most intense GRB ever recorded in the 55 years history of GRB science**
- Detected also by several other instruments: Fermi/GBM+LAT, Swift, INTEGRAL, Wind-KONUS, AGILE etc.
- So bright that it saturated larger detectors
- **At peak GRBAlpha measured ~22 000 count/s** in the ~80-950 keV energy band (for a 50 cm^2 detector)
- At redshift z = 0.151 (740 Mpc)
- **LHAASO and Carpet 2 observed very high energy photons reaching 18 TeV and potencially 251 TeV**
  - questioning fundamental physics
  - such high energy photons should not propagate a long distance due to their interaction with CMB and extragalactic background light.
- **Swift/XRT and XMM-Newton observed bright rings around the GRB 221009A afterglow** as a result of X-rays scattered by dust within our galaxy

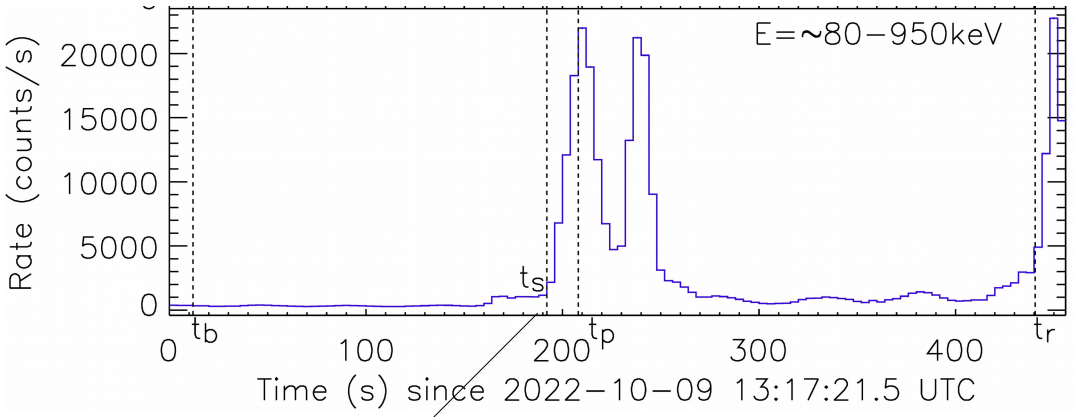


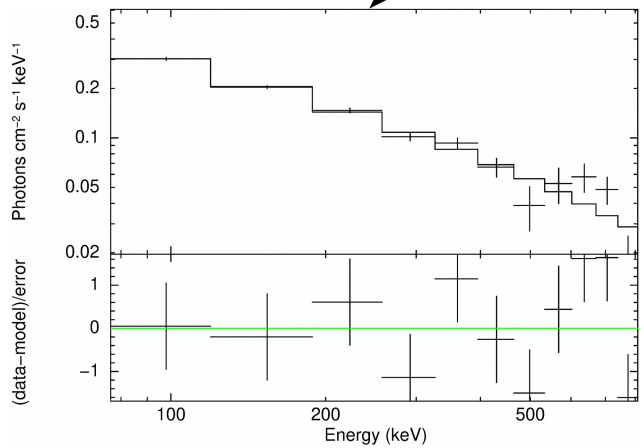


Credit: NASA/Swift/A. Beardmore

GRBALPHA: GRB 221009A
THE BRIGHTEST GRB EVER OBSERVED!

- GRBAlpha recorded light curves in 13 energy bands with 4s time resolution
- Detector was not saturated, but at the peak the rate was effected by pileup
- Unknown GRBAlpha's attitude at the time of the GRB, we had to find the most probable direction
- Spectral fitting was done in region not effected by pileup at t_s = 13:20:33.5 UTC
- Then we scaled up the peak flux to the peak time by the count ration
- Liso > 8.4 × 10^52 erg/s (4 s scale) in the 1 − 10 000 keV
- Eiso > 1.5 × 10^54 erg in 1 - 10 000 keV





CPL
α = 0.7 ± 0.1
E0 = 750 (+410,-200) keV
A = 8 (+6,-4) ph keV/cm2/s

$$N(E) = A\left(\frac{E}{1\text{keV}}\right)^{-\alpha} \exp\left(-\frac{E}{E_0}\right)$$

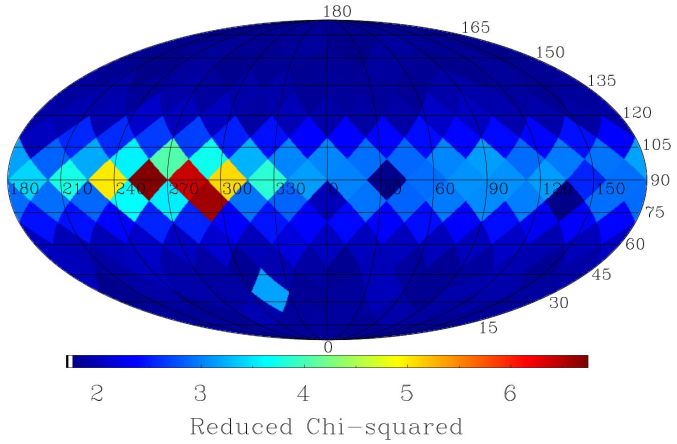
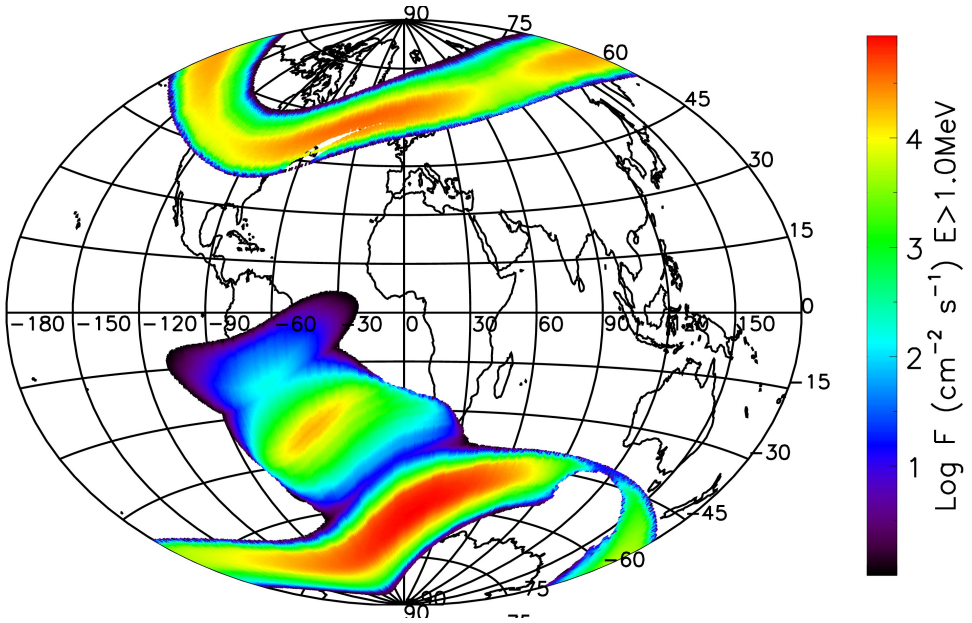


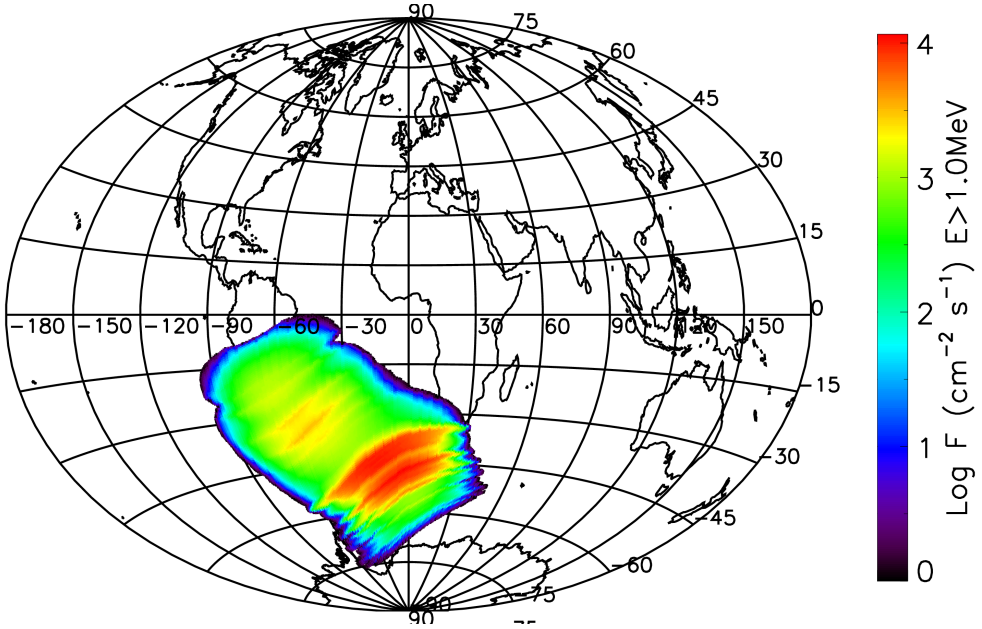
Fig. 7. The reduced χ^2 map of the best fits with CPL model for different angles Θ (vertical) and Φ (horizontal) in degrees.

DUTY CYCLE FOR A GRB INSTRUMENT LARGELY AFFECTED BY TRAPPED CHARGED PARTICLES

- Trapped electrons **model**, E>1 MeV, 550 km, AE-8 MAX

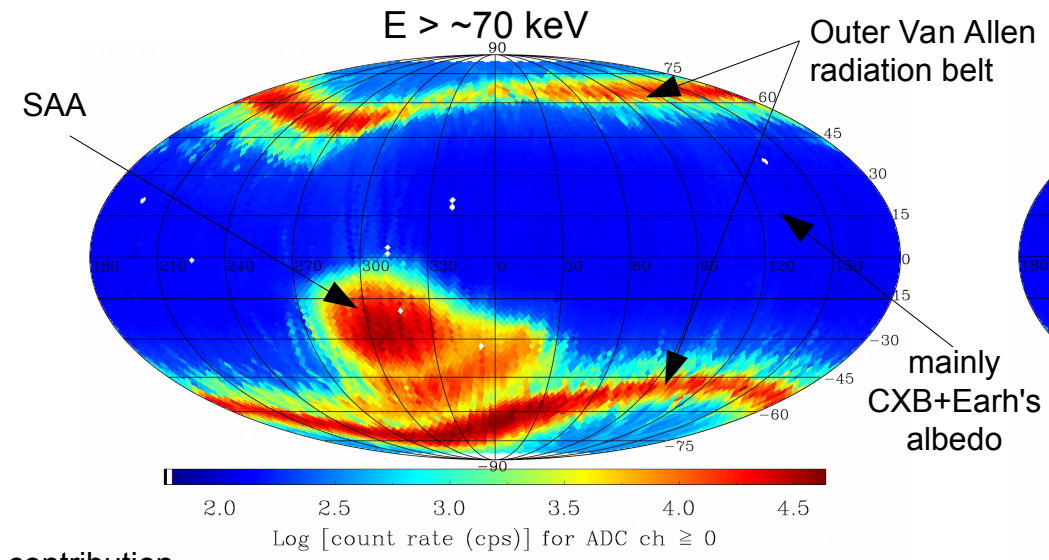


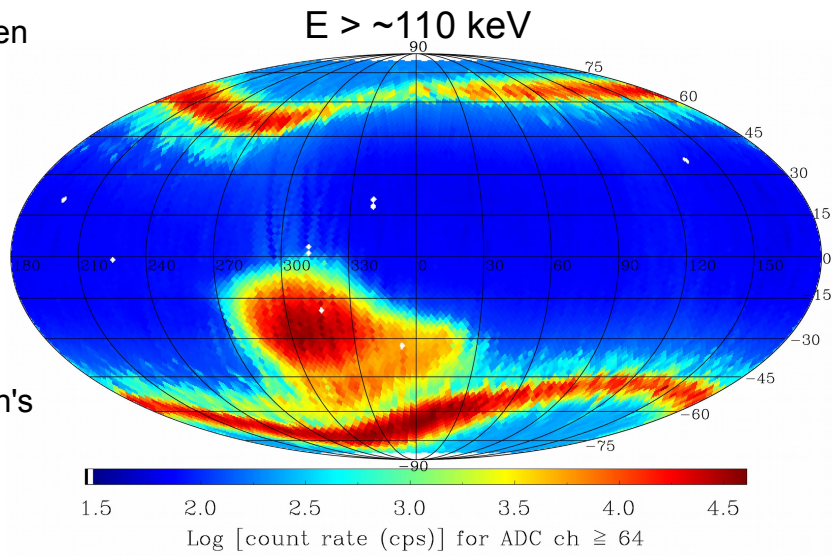
- Trapped protons **model**, E>1 MeV, 550 km, AP-8 MIN

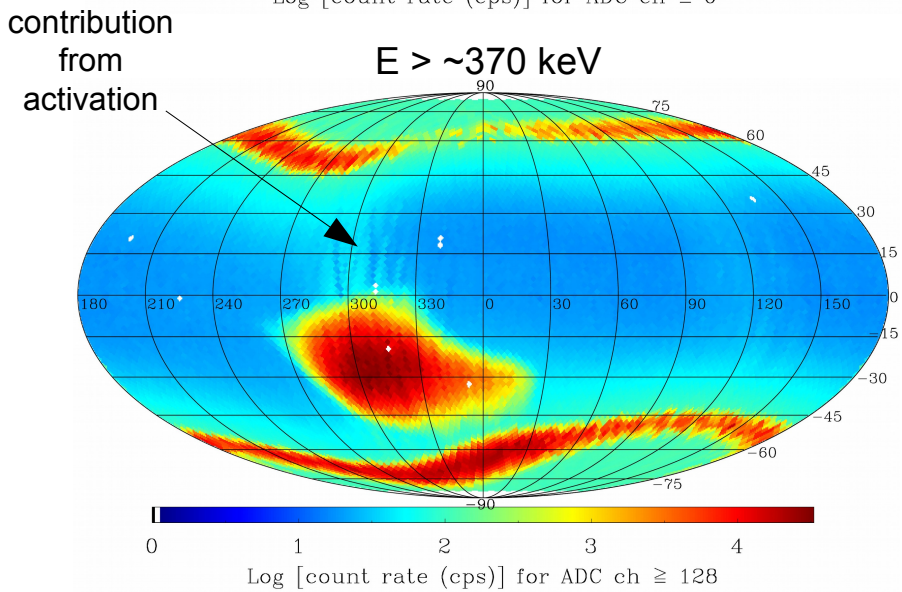


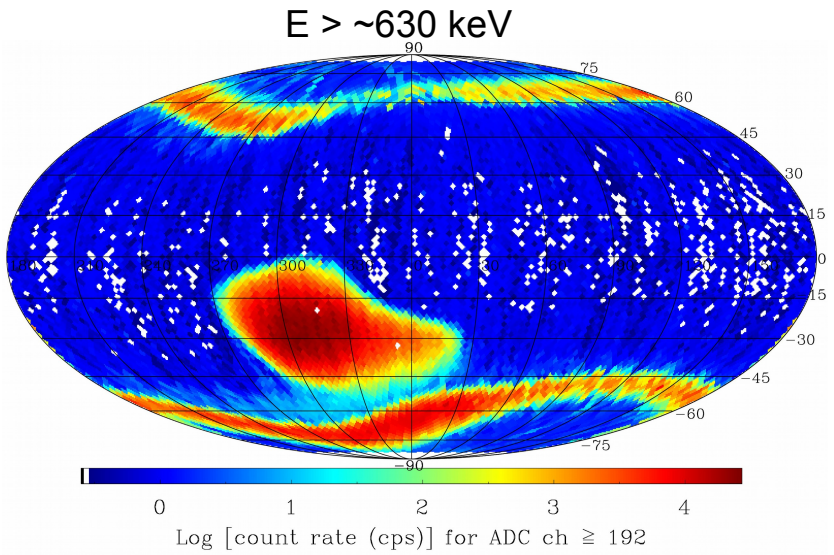
GRBALPHA: LAST 6 MONTHS BACKGROUND MAP

- Averaged detected count rate in last 6 months at 550 km
- Such a map will be useful in future to control a rate trigger algorithm for autonomous GRB detection



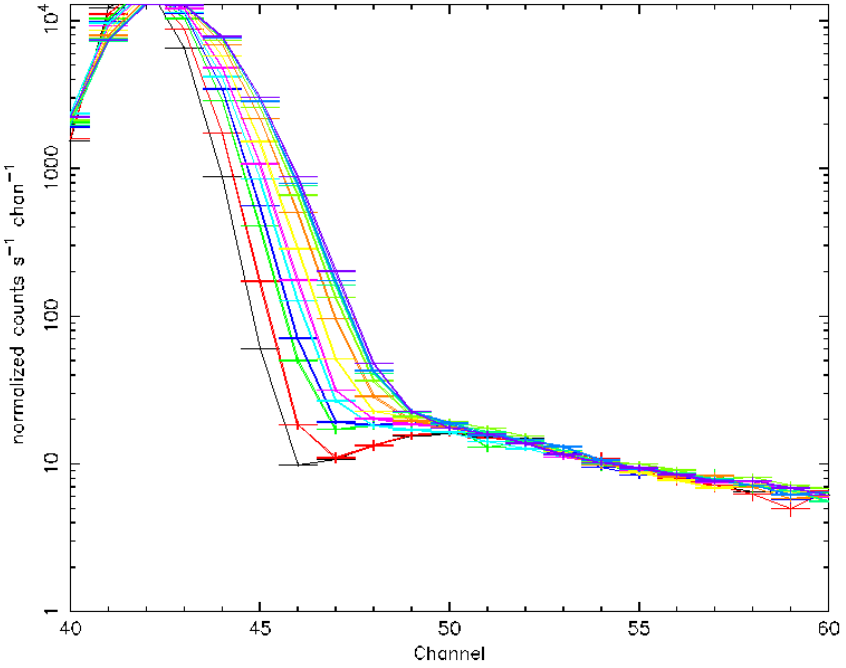


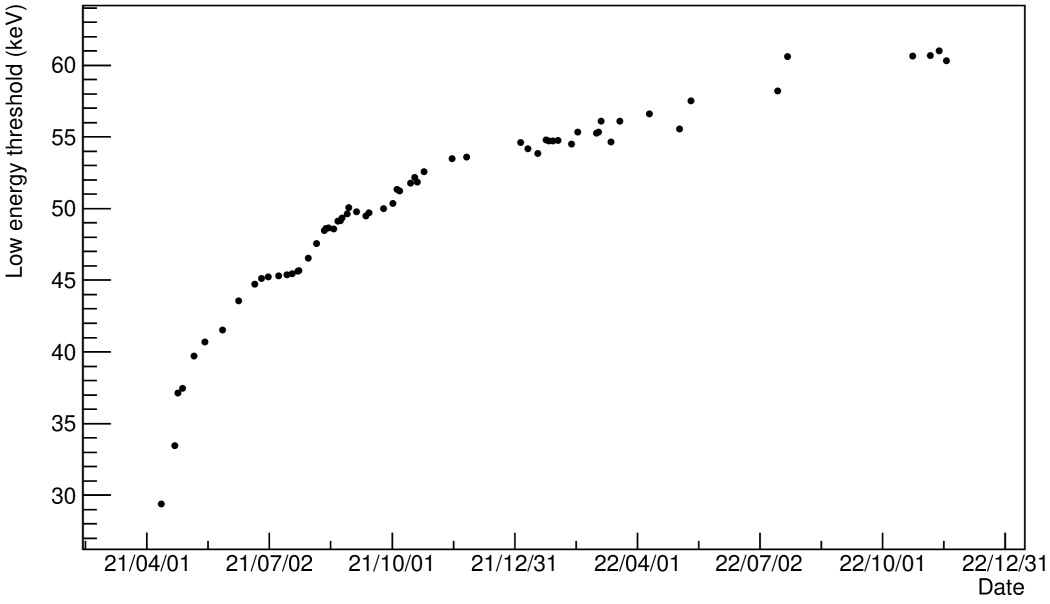




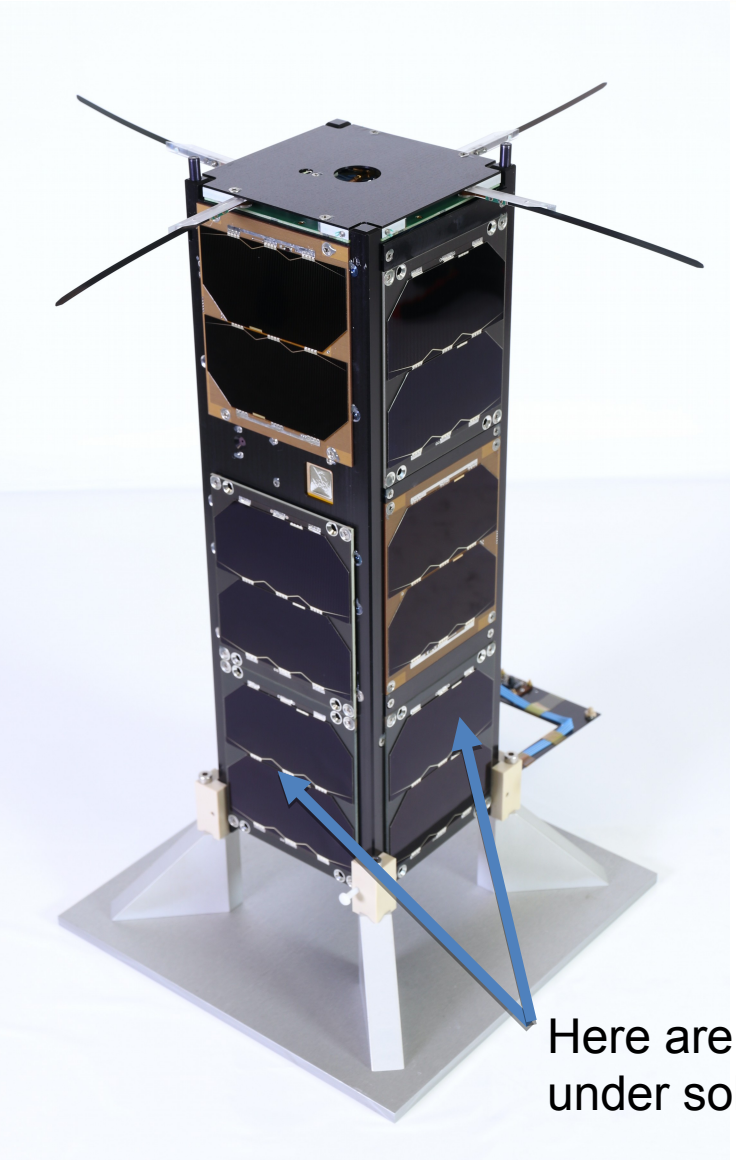
GRBALPHA: DEGRADATION OF MPPC IN SPACE

- Increasing of dark current (noise) due to the radiation damage of silicon lattice structure of MPPCs mainly by energetic protons in SAA
- Noise peak becomes wider and the low-energy threshold increases
- Expected from the ground beam experiment
- Before launch the low-energy threshold was ~10 keV
- 20 months after launch the low-energy threshold is ~60 keV and the the degradation remains at acceptable level





VZLUSAT-2:
WITH OUR TWO GRB DETECTORS

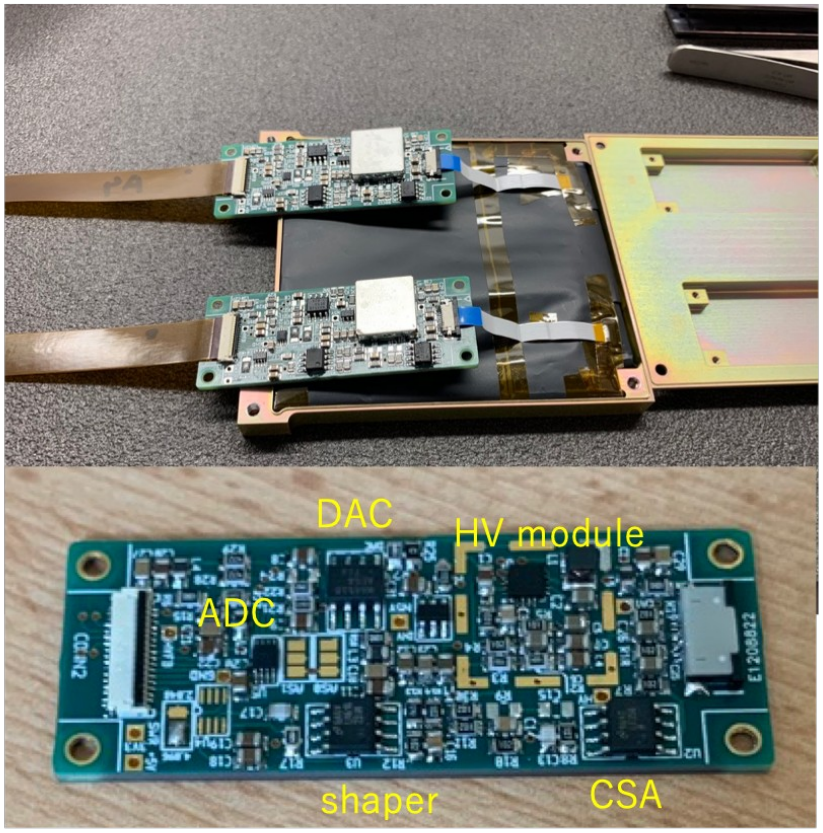


Here are our detectors
under solar panels

- VZLUSAT-2 is a technology mission (3U size) with an Earth observing camera as a primary payload developed by Czech Aerospace Research Centre
- Two detectors (75x75x5mm^3) as a secondary payload
- The detector concept, the MPPCs and electronics are the same as on GRBAlpha

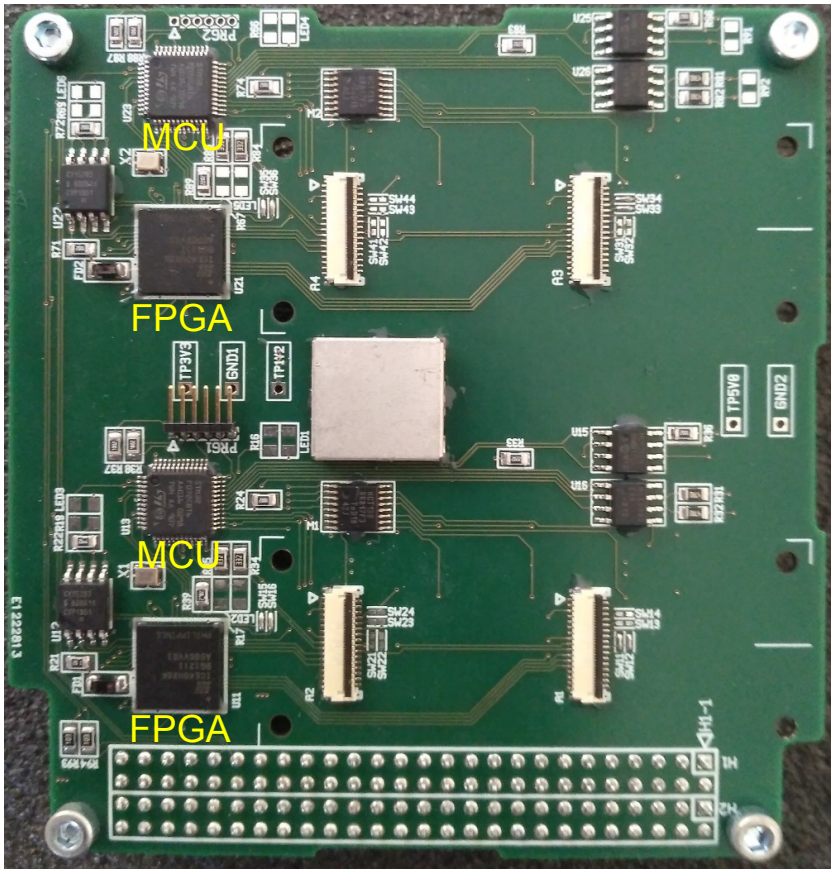
VZLUSAT-2:
DETECTOR ASSEMBLING AND ELECTRONICS

Compact analog electronics



- A simple CSA (LF356)+ shaping amplifier (LM6142)
- 12-bit sampling ADC (LTC2315-12)
- HV supply module (LT3482) controlled by DAC

Digital board



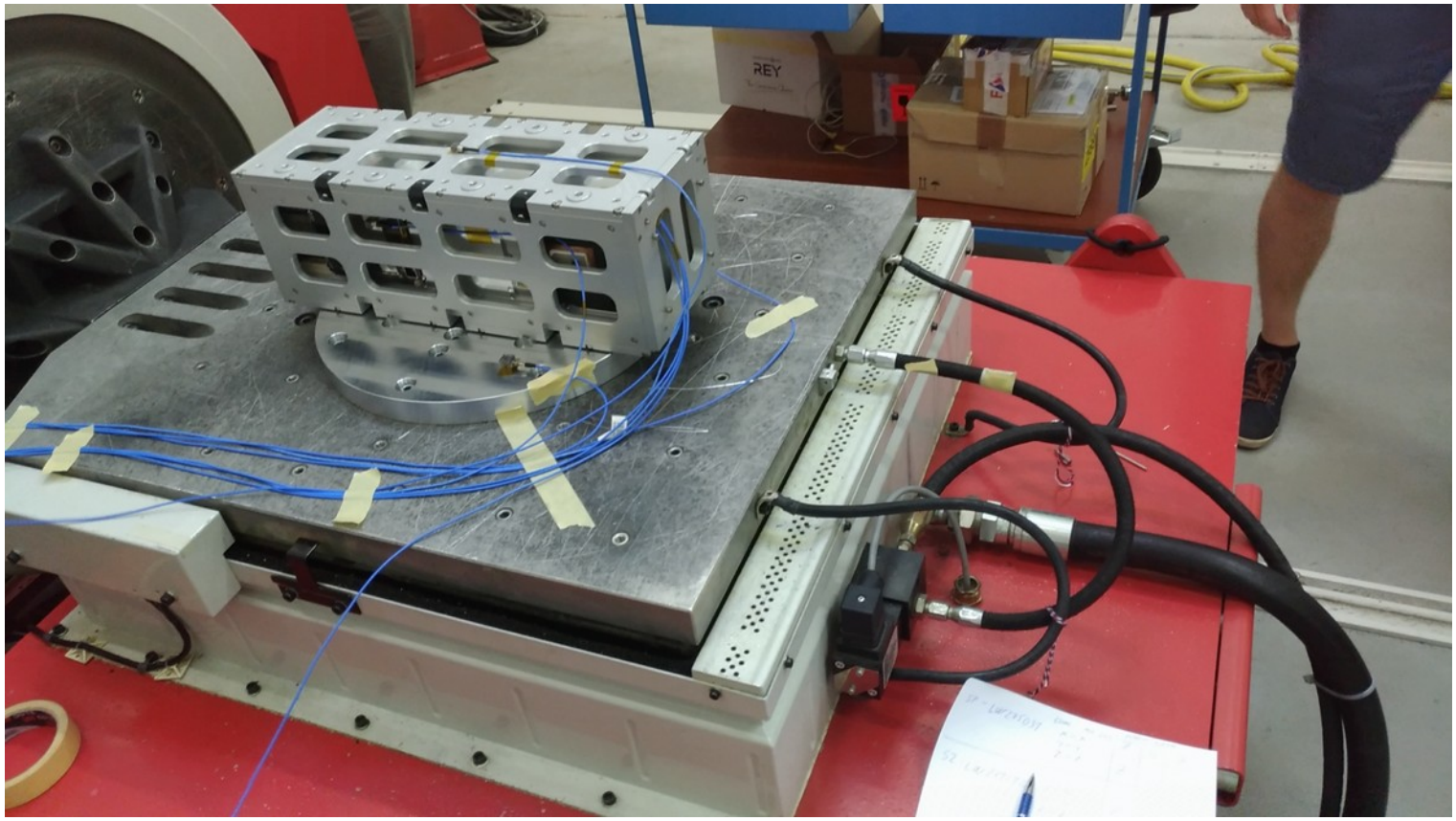
- FPGA - iCE40HX8K-BG121
- MCU - STM32F072CBT7 ARM Cortex-M0

VZLUSAT-2:
DETECTORS READY

Weight: 2 x 280 + 50 g

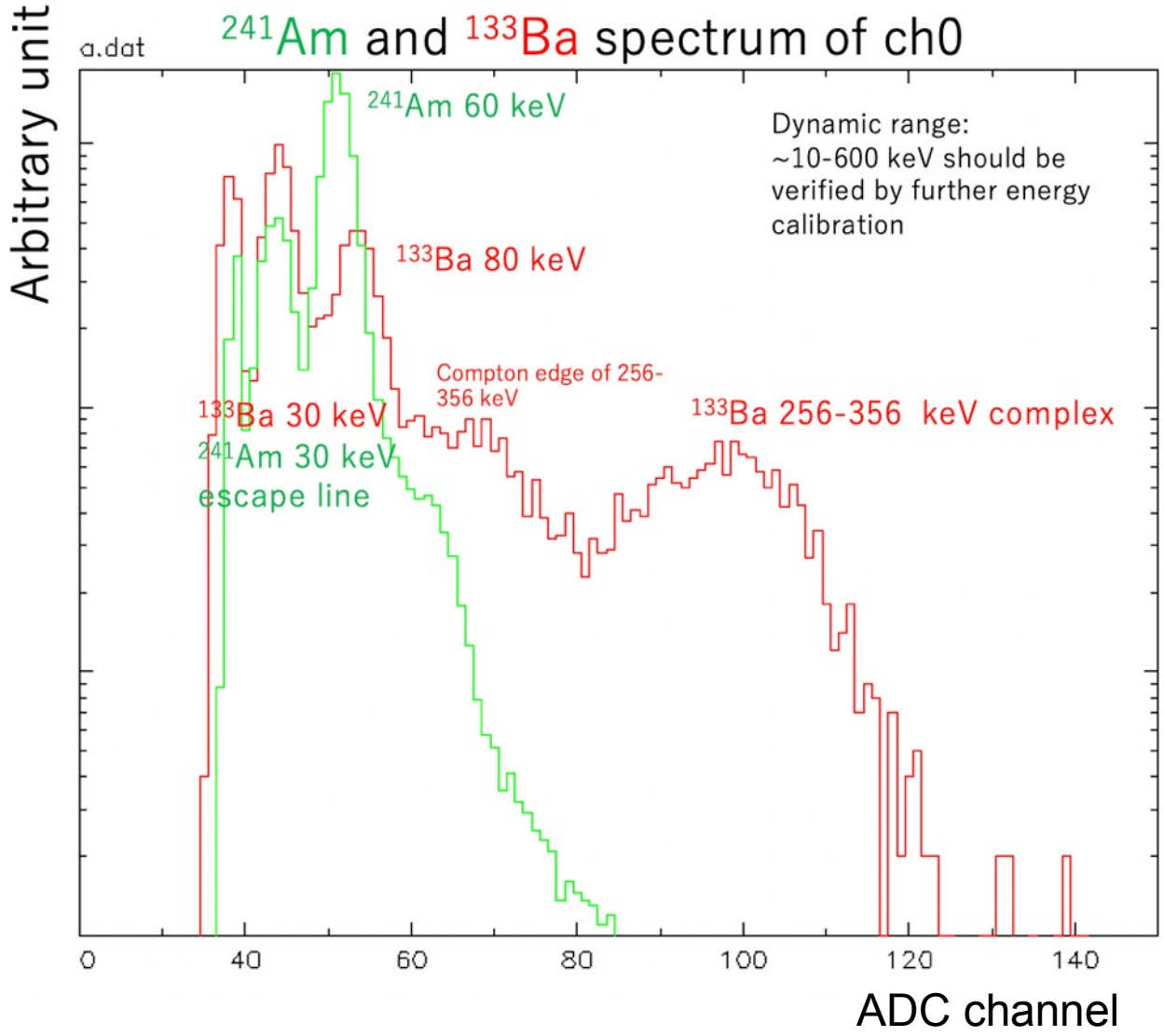
Power: 0.7 W

VZLUSAT-2:
ENVIRONMENTAL TESTS IN
CZECH AEROSPACE RESEARCH CENTRE (VZLU)



Vibration tests, shock tests, and thermo-vacuum tests

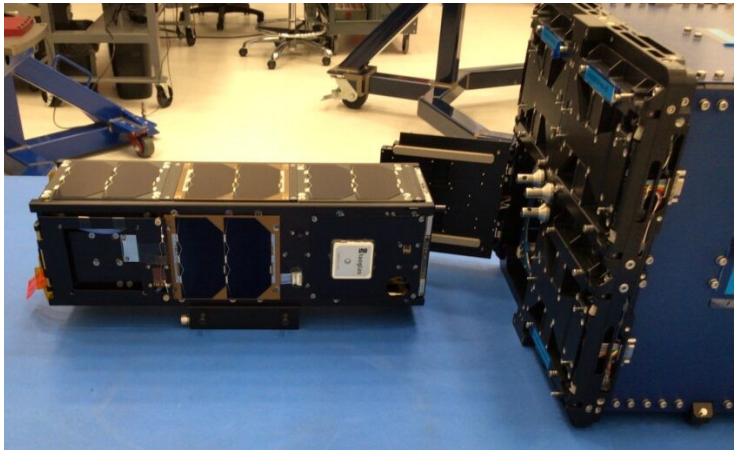
VZLUSAT-2:
RADIOISOTOPE SPECTRA



- Test with radioisotope sources showed lines from ^{241}Am and ^{133}Ba

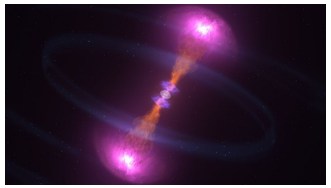
VZLUSAT-2:
SATELLITE FINISHED AND LAUNCHED

- Satellite was assembled, went through environmental tests and was shipped to USA in Sep 2020
- It was launched to 540 km SSO by Falcon 9 is on Jan 13th 2022

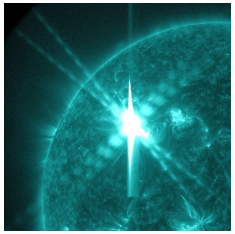


LIST OF TRANSIENTS OBSERVED BY OUR DETECTORS ON VZLUSAT-2

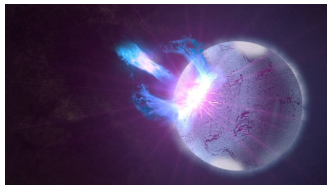
- https://monoceros.physics.muni.cz/hea/VZLUSAT-2/
- By today:



- **12 Gamma-Ray Bursts**
  (2 short / 10 long)



- **13 Solar flares**



- **4 Soft gamma repeater bursts**
  1935+2154 (magnetar)

List of transients observed by the GRB detectors on the VZLUSAT-2 nanosatelite

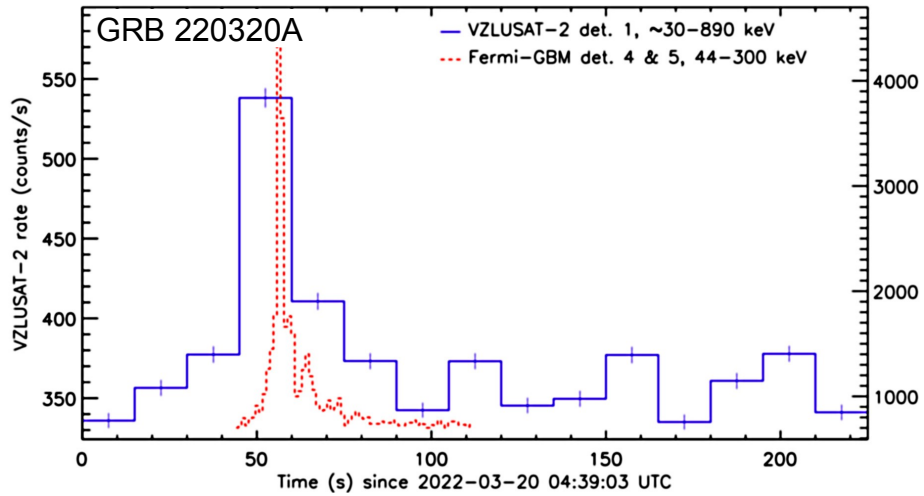
The list contains gamma-ray transients observed by the GRB detectors on VZLUSAT-2

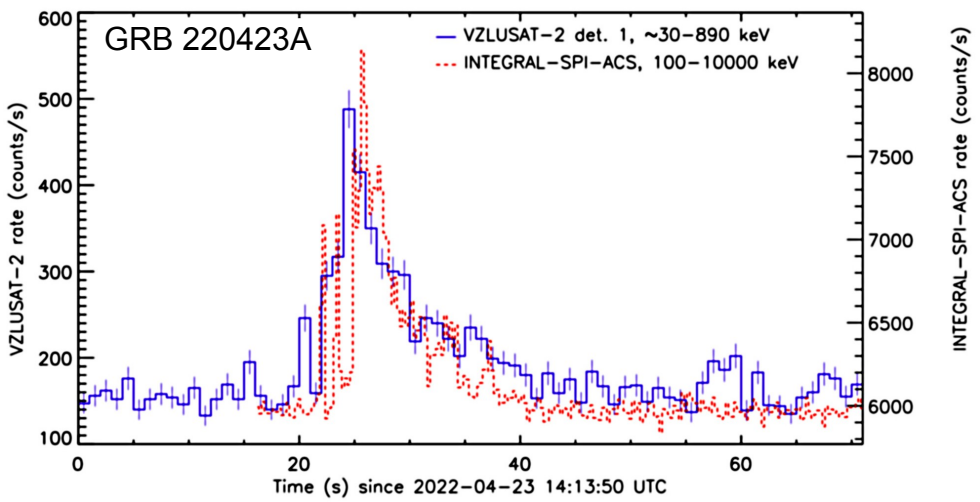
- **Event type/name** denotes the type of the detected event like GRB, Solar flare etc.
- **Det. unit** is the number of the detector unit (no. 0 or no. 1).
- **Peak time** denotes the time when the detected count rate from the event was maximal
- **T90** is the time interval, in which 90 per cent of all counts in the given energy band from the event are observed
- **Count rate** is the detected count rate of the event at the peak time
- **Band** is the energy range for which the T90 duration and the count rate was calculated
- **S/N** is the maximal significance of the signal detected in any of the energy bands (either in one bin at the peak or integrated over T90)
- **Raw LC** is the raw light curve without the background subtraction
- **Bkg-sub LC** is the light curve with background subtracted
- **LC res.** is the light curve resolution
- **GCN circ.** is the GCN circular number where this detection was reported
- **References** give the list of other instruments which detected the same event

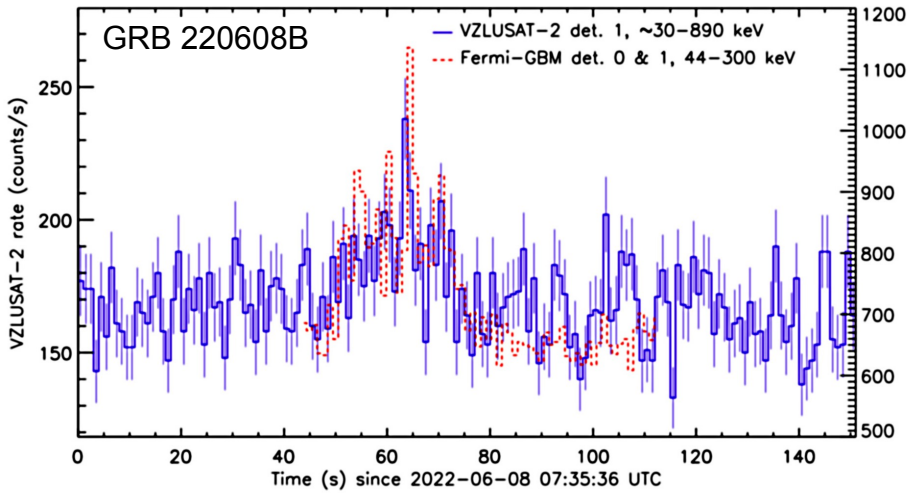
Event type/name	Det. unit	Peak time (UTC)	T90 [s]	Count rate [cnt/s]	Band [keV]	S/N [σ]	Raw LC	Bkg-sub LC	LC res. [s]	GCN circ.	References	Comment
Solar flare	no. 1	2023-02-24 17:13:51	35	48.5	~40-890	9.2	PNG, EPS	PNG, EPS	1		Fermi/GBM Solar Orbiter/STIX GOES	
Solar flare	no. 1	2023-02-20 14:55:26	121	218.1	~40-890	49.9	PNG, EPS	PNG, EPS	1		Fermi/GBM GECAM-B GOES	
Solar flare	no. 0	2023-02-11 15:46:21	79	489.3	~40-890	51.9	PNG, EPS	PNG, EPS	1		Fermi/GBM GOES GRBAlpha KONUS-Wind Solar Orbiter/STIX	
	no. 1	2023-02-11 15:45:35	78	370.1	~40-890	103.2	PNG, EPS	PNG, EPS	1			
GRB 230126A	no. 0	2023-01-26 18:20:46	14	41.3	~40-890	5.1	PNG, EPS	PNG, EPS	1	33246/PDF	Fermi/GBM	
GRB 230114B	no. 1	2023-01-14 20:40:54	<1	88.3	~40-890	4.9	PNG, EPS	PNG, EPS	1	33218/PDF	KONUS-Wind INTEGRAL/SPI-ACS	
GRB 230114A	no. 1	2023-01-14 16:59:17	5	56.5	~40-890	6.7	PNG, EPS	PNG, EPS	1	33170/PDF	Fermi/GBM INTEGRAL/SPI-ACS	
Solar flare	no. 0	2023-01-11 01:53:58	72	2842.0	~40-890	273.7	PNG, EPS	PNG, EPS	1		Fermi/GBM GOES CALET/CGBM KONUS-Wind Solar Orbiter/STIX	
	no. 1	2023-01-11 01:53:26	57	1119.4	~40-890	159.5	PNG, EPS	PNG, EPS	1			
Solar flare	no. 0	2023-01-10 22:46:39	64	909.2	~40-890	108.8	PNG, EPS	PNG, EPS	1		Fermi/GBM GOES CALET/CGBM INTEGRAL/SPI-ACS GECAM-B KONUS-Wind Solar Orbiter/STIX	X1.1 class
	no. 1	2023-01-10 22:46:38	132	4532.5	~40-890	296.9	PNG, EPS	PNG, EPS	1			
Solar flare	no. 1	2023-01-10 17:47:48	35	90.1	~40-890	10.4	PNG, EPS	PNG, EPS	1		Fermi/GBM Solar Orbiter/STIX	
Solar flare	no. 0	2023-01-10 02:13:19	19	100.0	~40-890	17.7	PNG, EPS	PNG, EPS	1		Fermi/GBM GECAM-B GOES Solar Orbiter/STIX	
Solar flare	no. 1	2023-01-06 18:47:28	21	26.1	~40-890	5.6	PNG, EPS	PNG, EPS	1		Fermi/GBM GOES	

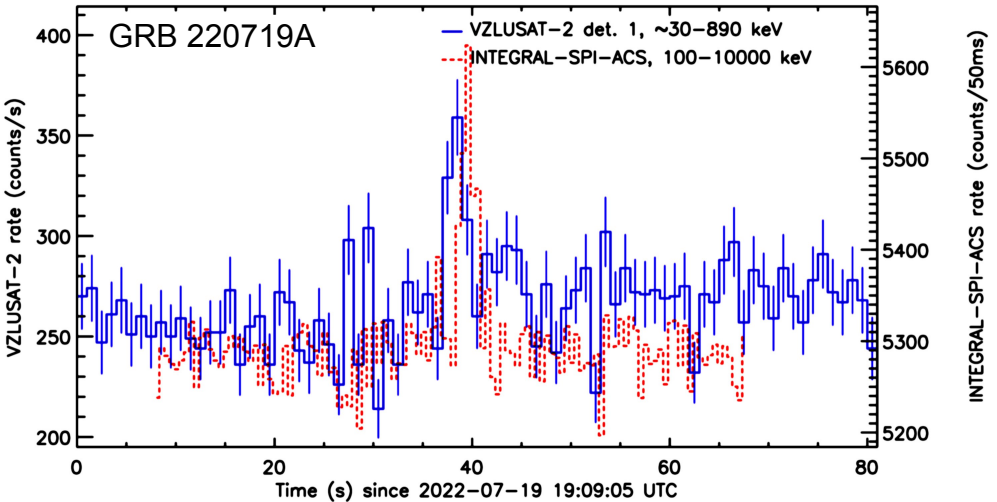
VZLUSAT-2: GRB DETECTIONS

- Some of detected GRBs compared with light curves from Fermi/GBM or INTERGAL/SPI-ACS
- The 1st GRB was detected with 15s resolution during commissioning phase (background mapping)
- Other GRBs were observed with 1s resolution





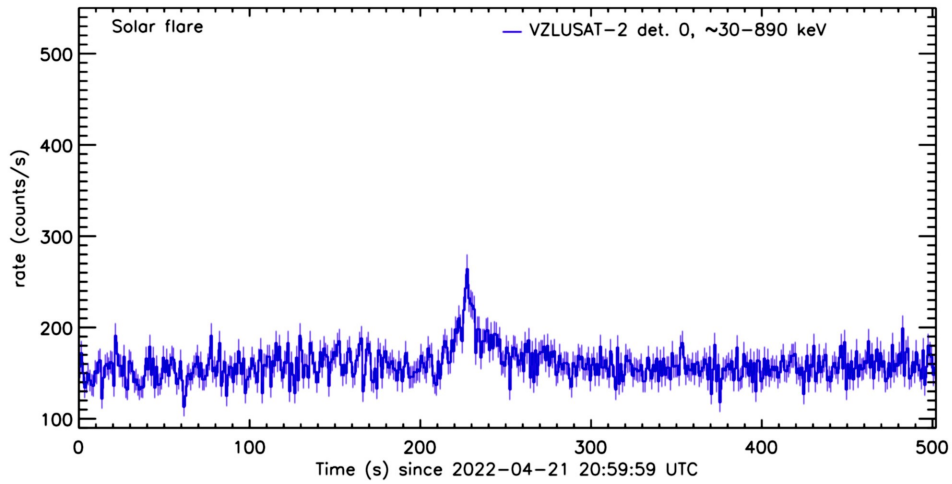




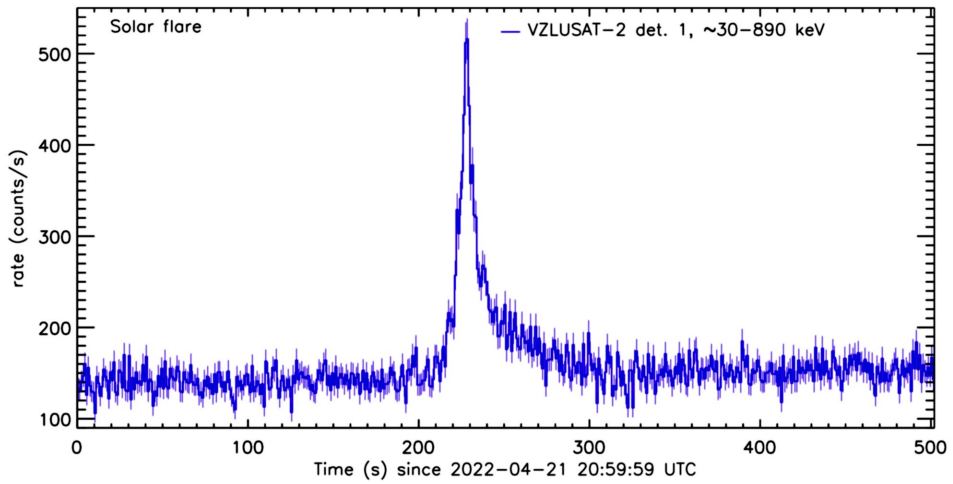
VZLUSAT-2: SOLAR FLARE DETECTIONS

- **Solar flares** observed by VZLUSAT-2 compared with detections by Fermi/GBM

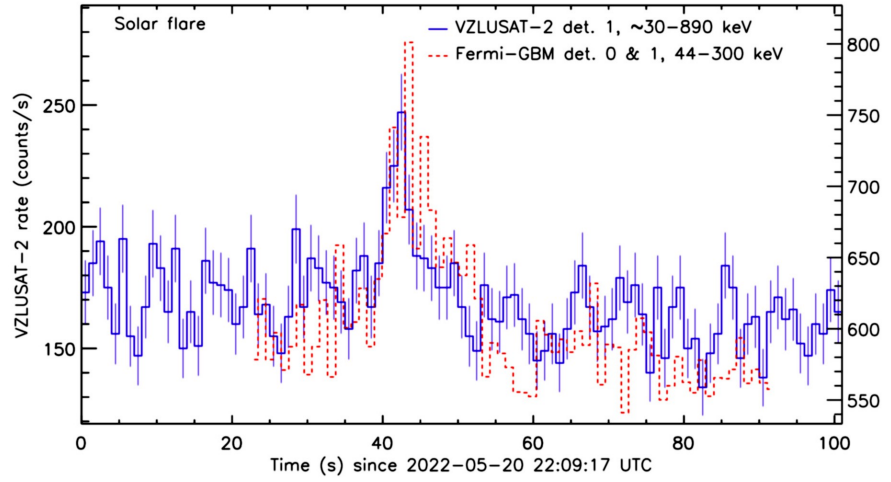
DETECTOR UNIT 0



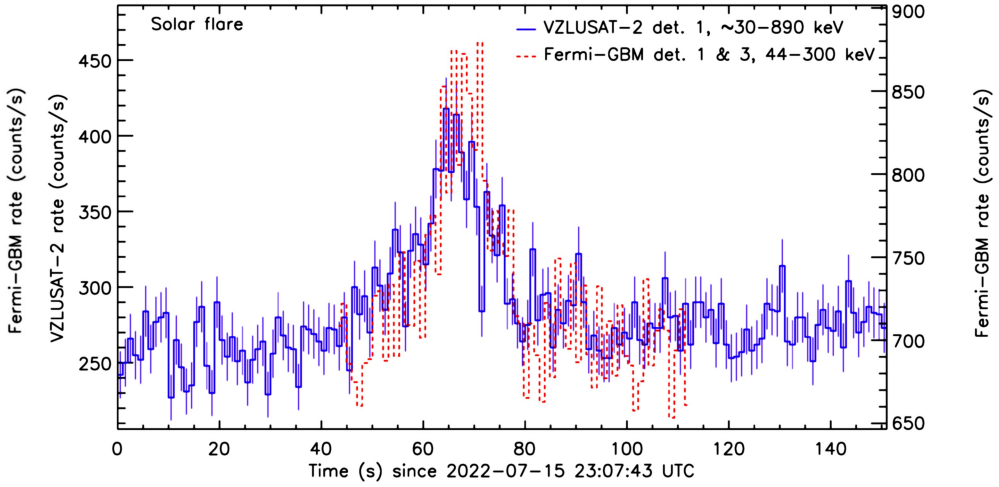
DETECTOR UNIT 1



DETECTOR UNIT 1

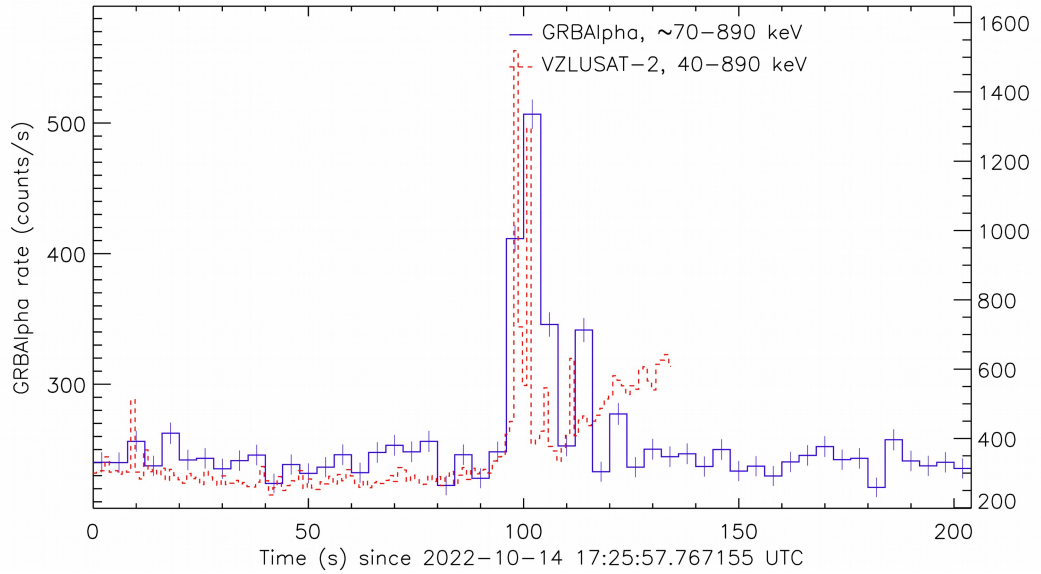


DETECTOR UNIT 1

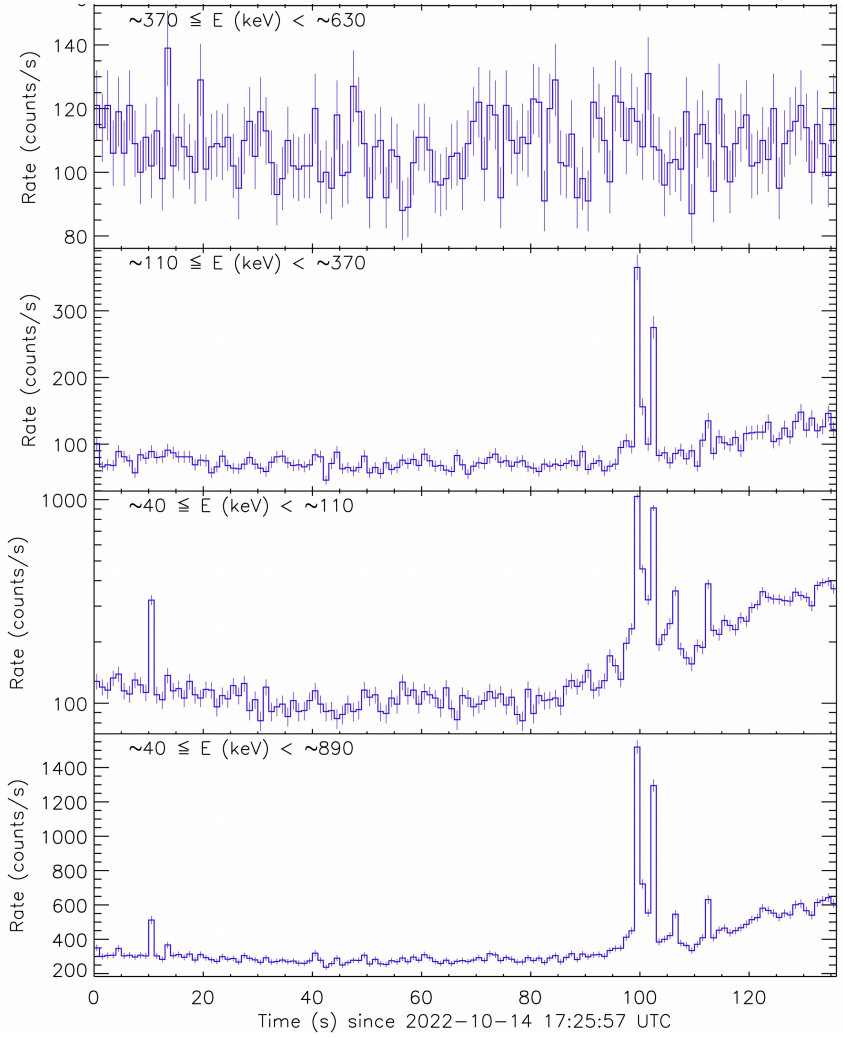


VZLUSAT-2 AND GRBALPHA JOINT DETECTION OF SGR 1935+2154

- **Soft gamma repeater SGR 1935+2154**
- Measured with 1s resolution for VZLUSAT-2 and 4s for GRBAlpha



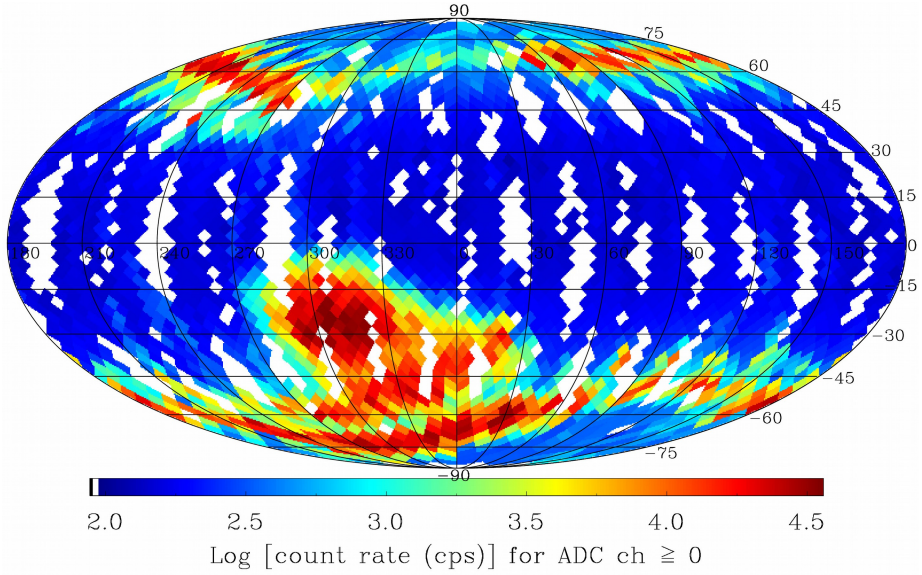
VZLUSAT-2 DETECTOR UNIT 1



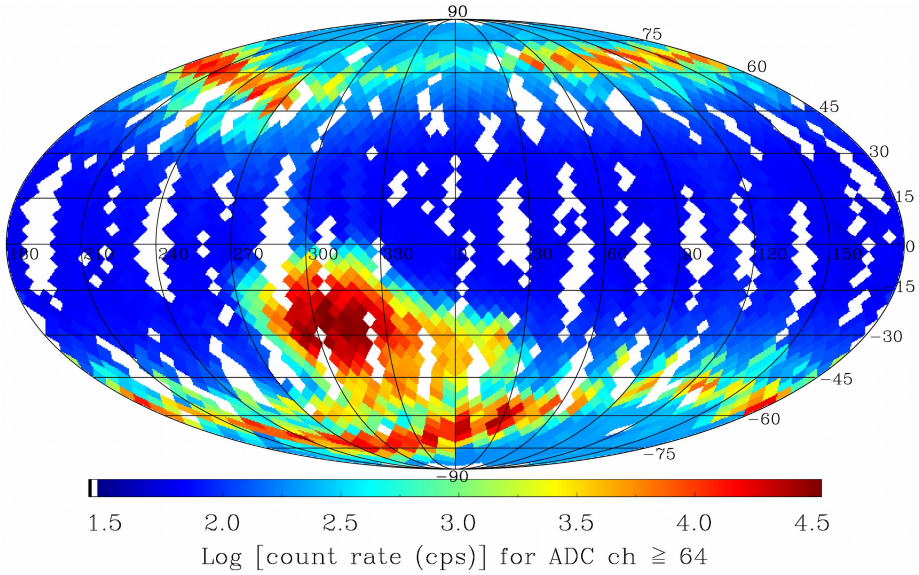
VZLUSAT-2:
MEASURED BACKGROUND MAPS

- Background maps collected from detector unit 1 in past 11 months at 540 km

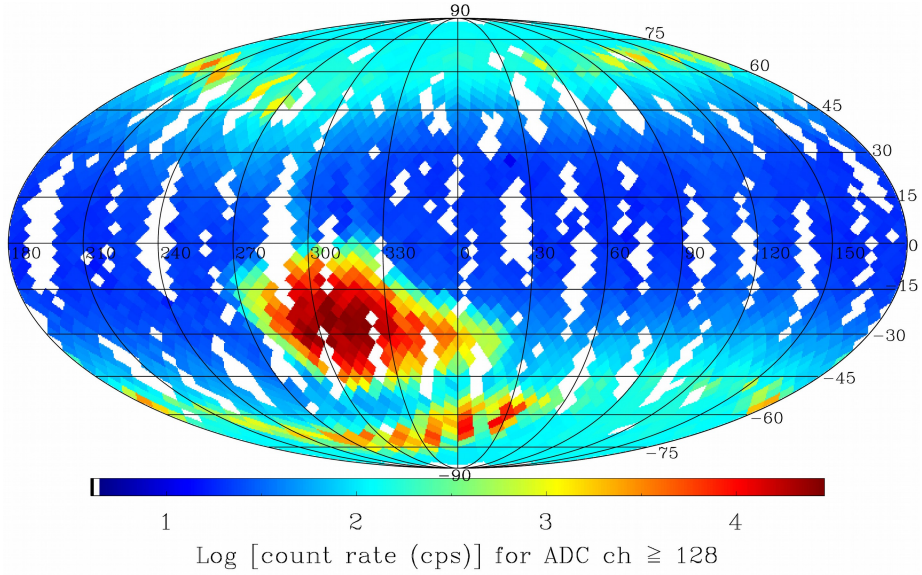
E > ~40 keV



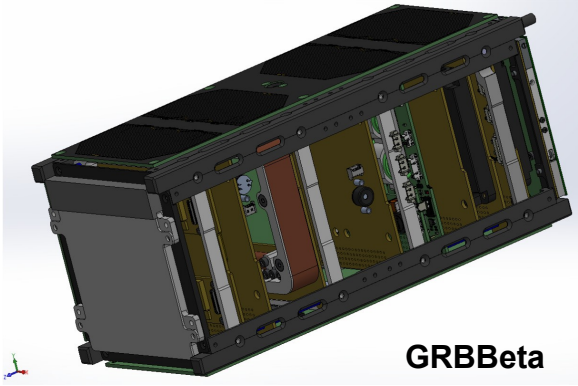
E > ~110 keV



E > ~370 keV



SUMMARY



- **GRBAlpha successes:**
  - since launch still functional in orbit almost 2 years
  - detector concept proven
  - detected 37 transients (GRBs, Solar flares, SGRs)
  - mapping background at LEO
  - provides data of in orbit aging of Hamamatsu's MPPCs
- **VZLUSAT-2:**
  - since launch still functional in orbit 1 year
  - detected 29 transients (GRBs, Solar flares, SGRs)
  - mapping background at LEO
- **Near future:**
  - GRBBeta (2U size) next technological precursor mission with improved onboard software, inter-satellite communication, testing of IR sun-sensor system for attitude determination, launch expected in 2023/2024
- **Recent publications:**
  - Pál et al. 2023 (submitted to A&A), arXiv:2302.10048
  - Řípa et al. 2023 (submitted to A&A), arXiv:2302.10047
  - Řípa et al. 2022, Proc. of SPIE, 11444, 114444V
  - Mészaros et al. 2022, Proc. of SPIE, 12181, 121811L
  - Pál et al. 2020, Proc. of SPIE, 12181, 121811K