GRBAlpha and VZLUSAT-2 CubeSats Observing the Gamma-Ray Sky

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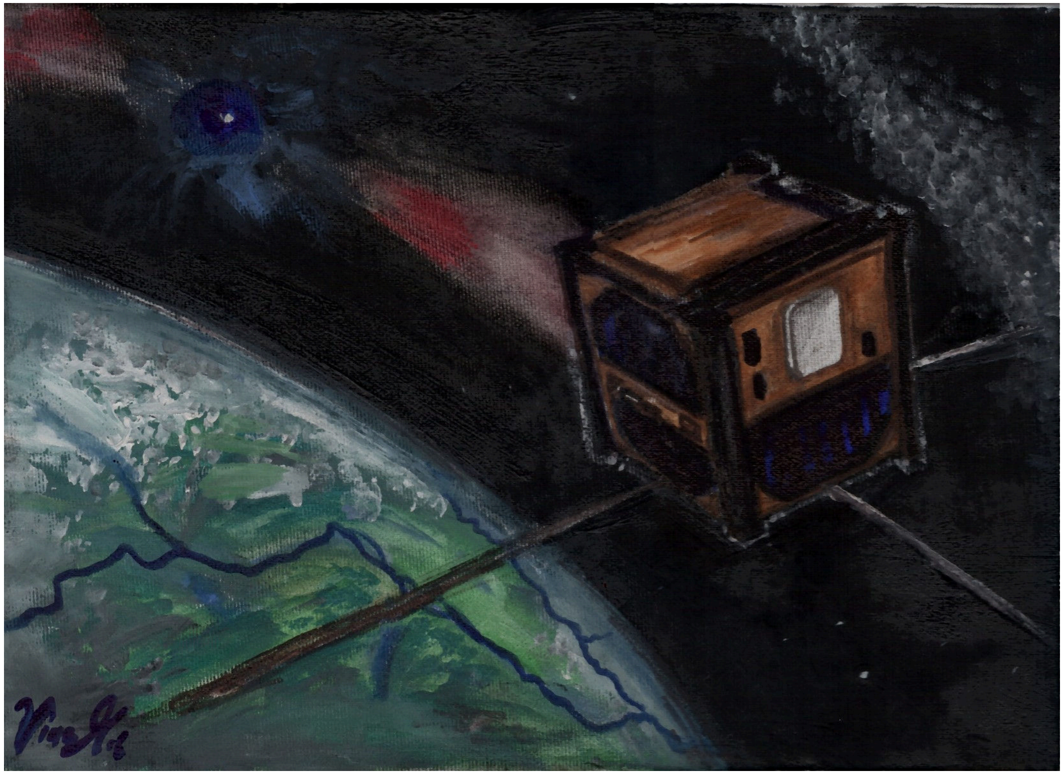
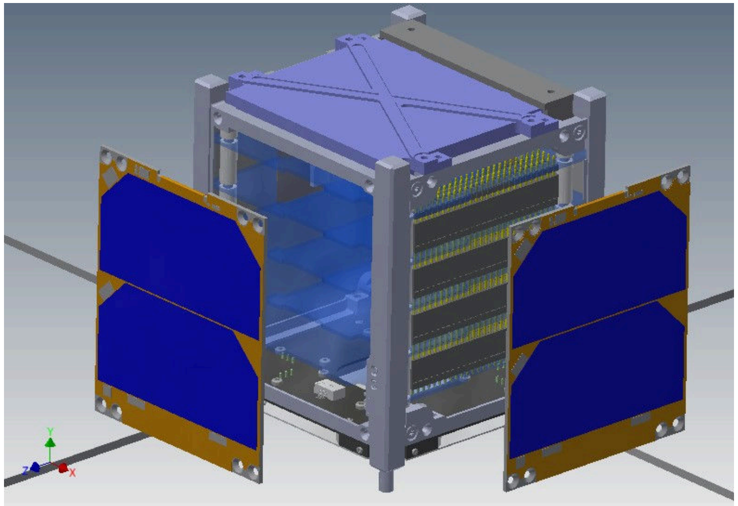


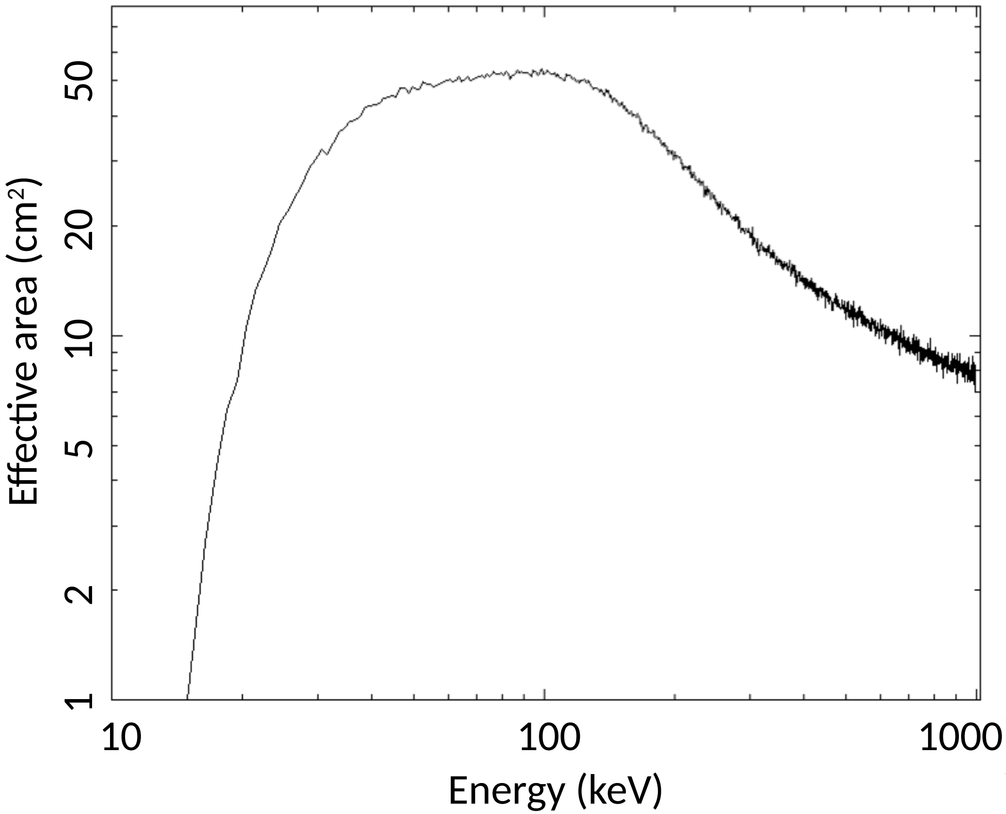
András Pál, Masanori Ohno, Norbert Werner, László Mészáros, Balázs Csák, Marianna Dafčíková, Filip Münz, Nikola Husáriková, Vladimír Dániel, Juraj Dudáš, Marcel Frajt, Peter Hanák, Ján Hudec, Milan Junas, Jakub Kapuš, Miroslav Kasal, Martin Koleda, Robert Laszlo, Pavol Lipovský, Maksim Rezenov, Miroslav Šmelko, Petr Svoboda, Hiromitsu Takahashi, Martin Topinka, Tomáš Urbanec, Jean-Paul Breuer, Teruaki Enoto, Zsolt Frei, Yasushi Fukazawa, Gábor Galgóczi, Filip Hroch, Yuto Ichinohe, László L. Kiss, Hiroto Matake, Tsunefumi Mizuno, Kazuhiro Nakazawa, Hirokazu Odaka, Helen Poon, Nagomi Uchida, Yuusuke Uchida

AXRO 2022, Praha, 2022/12/07

GRBALPHA:
1ST TECHNOLOGICAL PRECURSOR MISSION TO CAMELOT

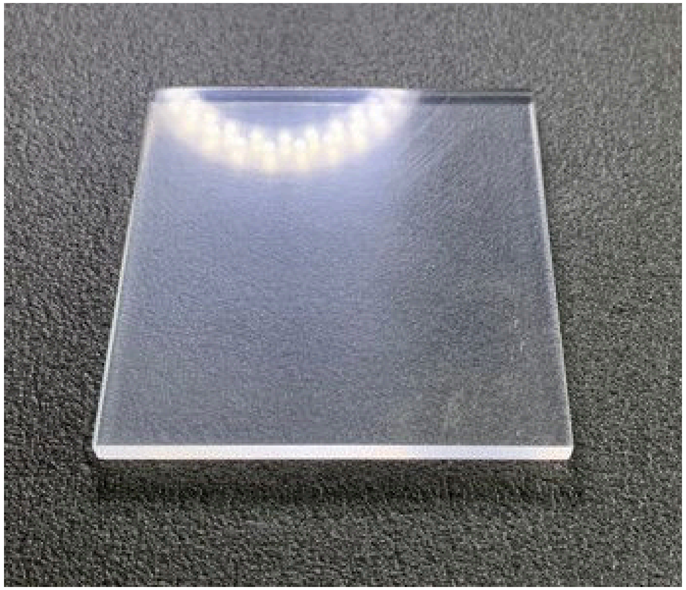
- 1-U CubeSat with gamma-ray detector - same concept planned for CubeSat fleet CAMELOT
- Small size of scintillator ($75x75x5mm^3$) readout by 8 MPPCs
- Main goals:
  - confirm detector concept
  - characterize the detector degradation on orbit
  - characterize background at LEO (SSO) for a gamma-ray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



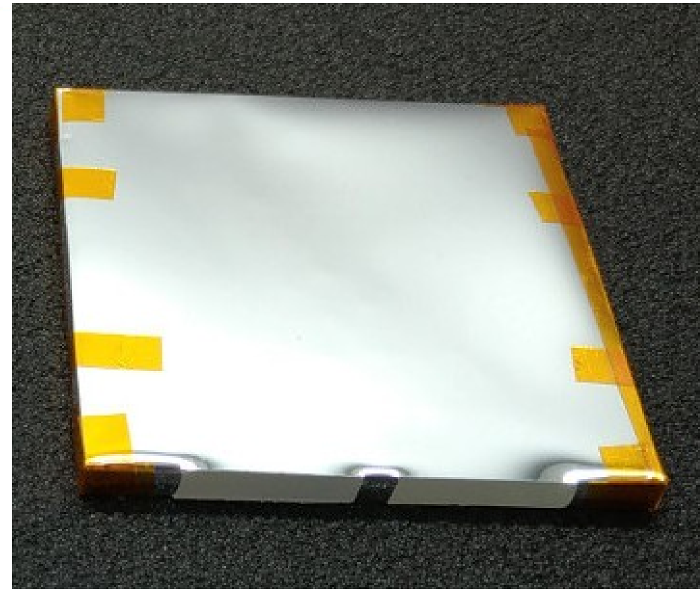


GRBALPHA: DETECTOR ASSEMBLING

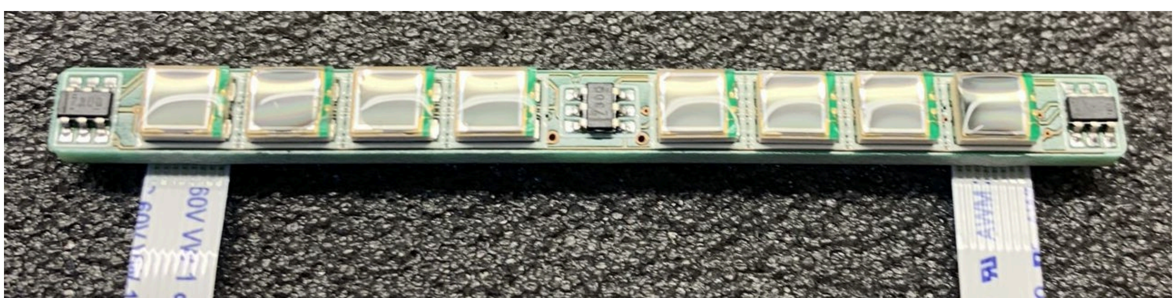
Pál+ 2020



CsI(Tl) scintillator
from Kharkiv (Ukraine)



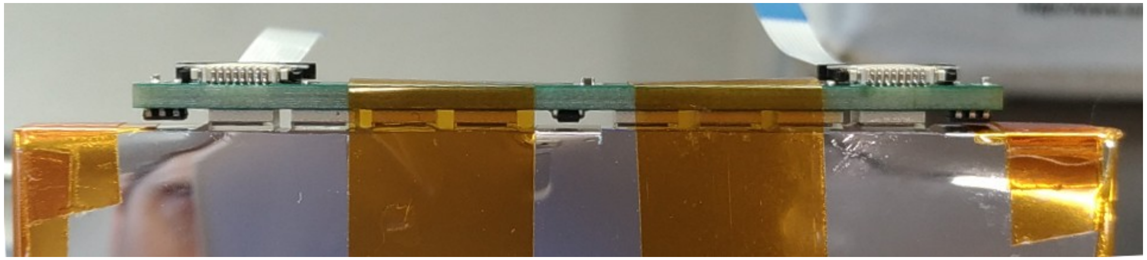
Wrapped in Enhanced
Specular Reflector (ESR)

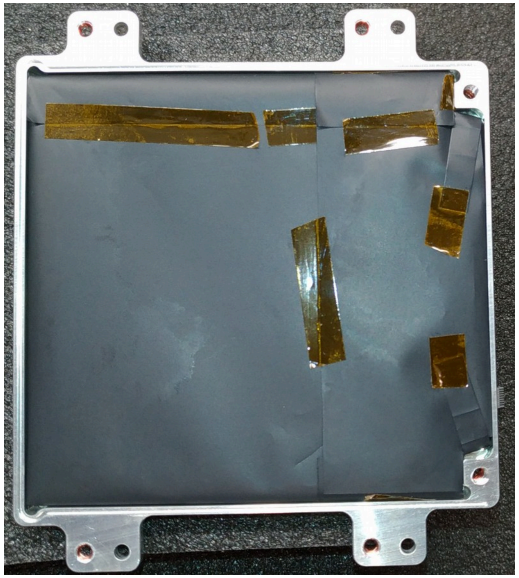


2 readout channels each with 4 MPPCs (S13360-3050 PE) by Hamamatsu

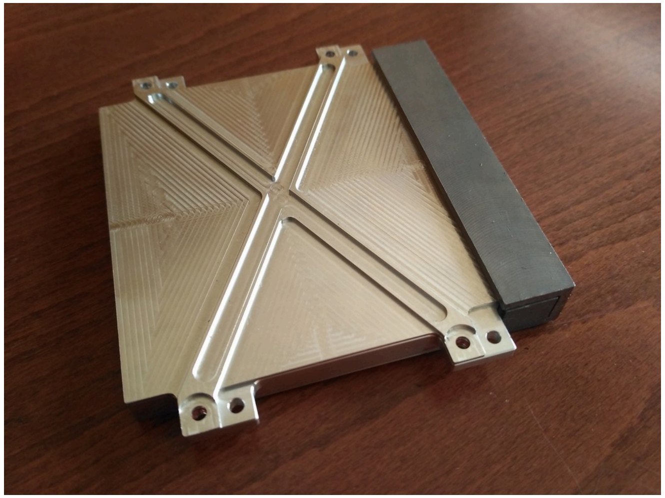
GRBALPHA:
DETECTOR ASSEMBLING

- 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



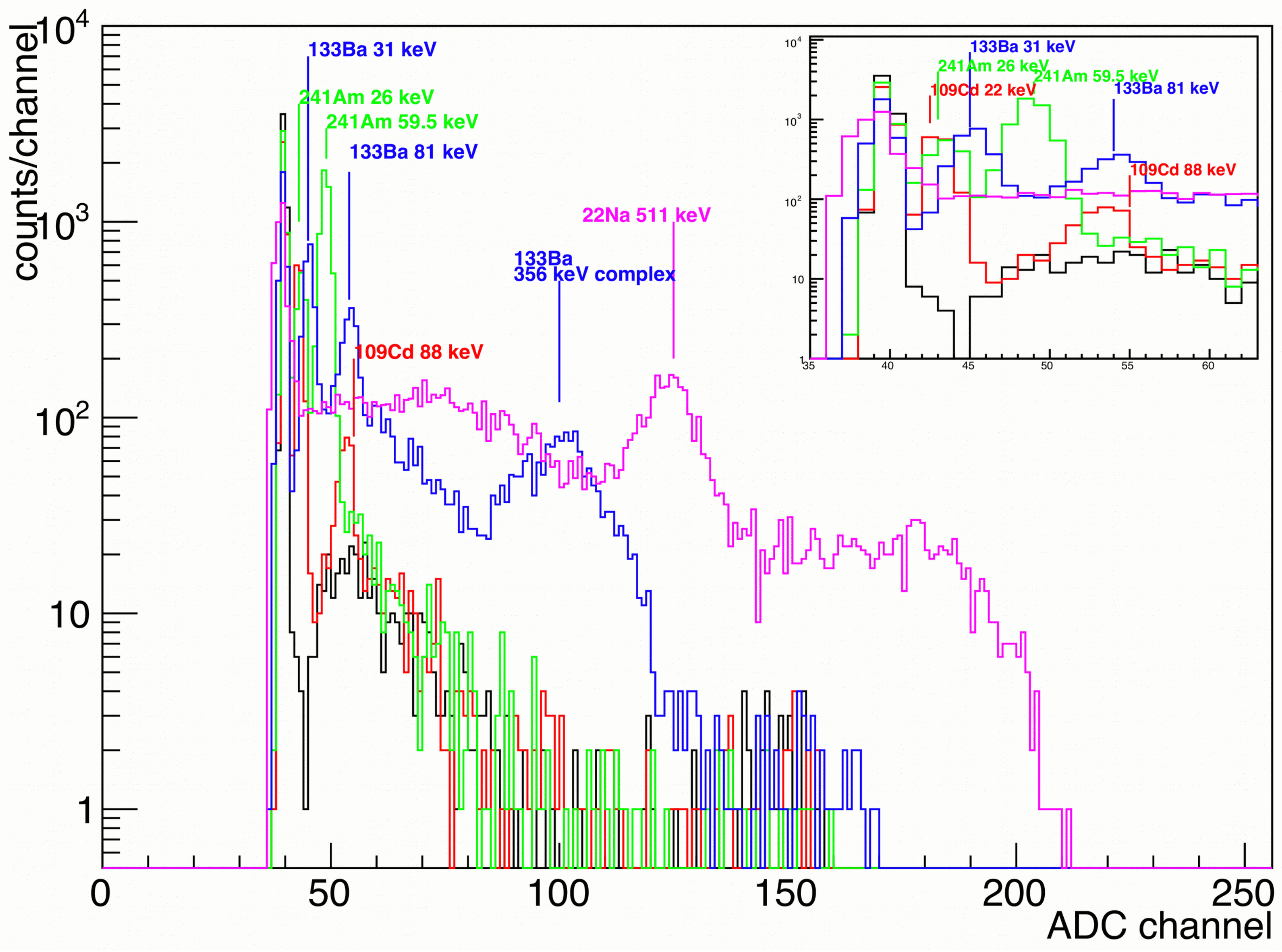


DuPont Tedlar TCC15BL3 wrapping



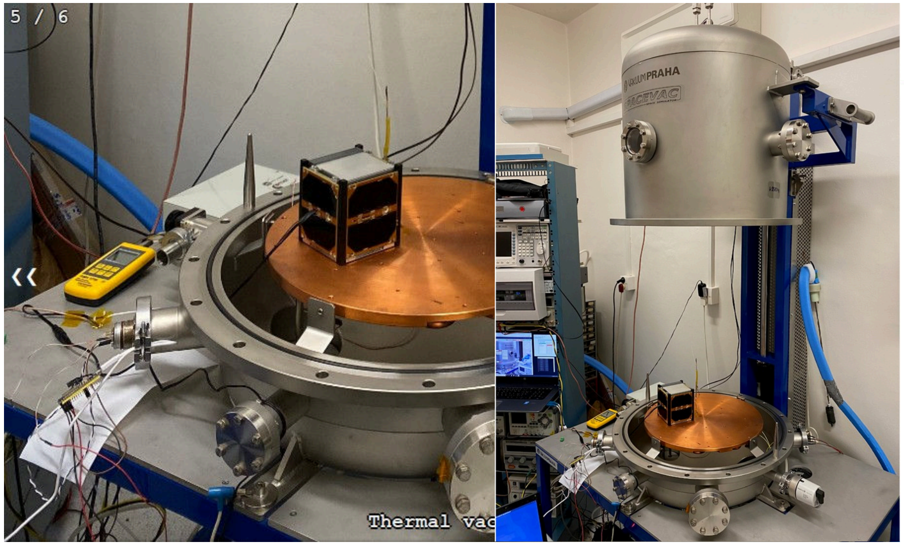
Assembled detector with 2.5mm thick Pb-Sb alloy to reduce MPPC degradation by trapped protons in SAA

GRBALPHA:
ON GROUND GAIN CALIBRATION

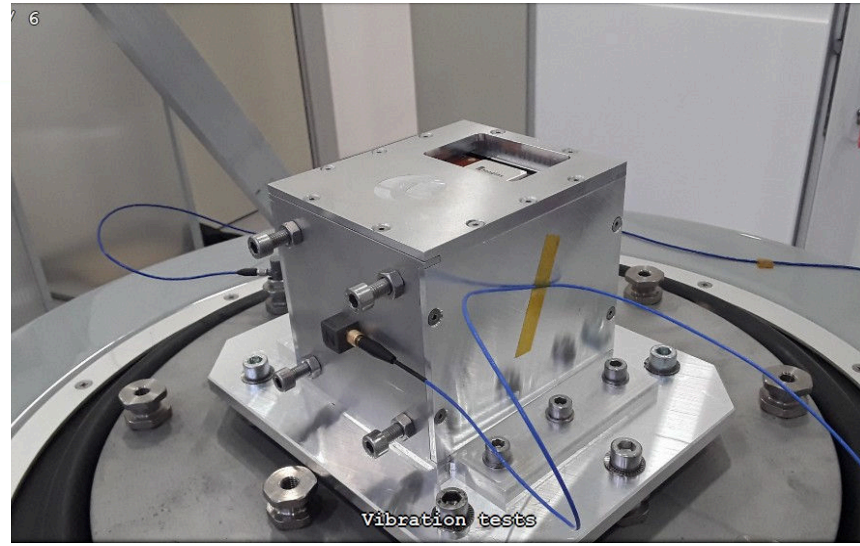


For readout ch 0

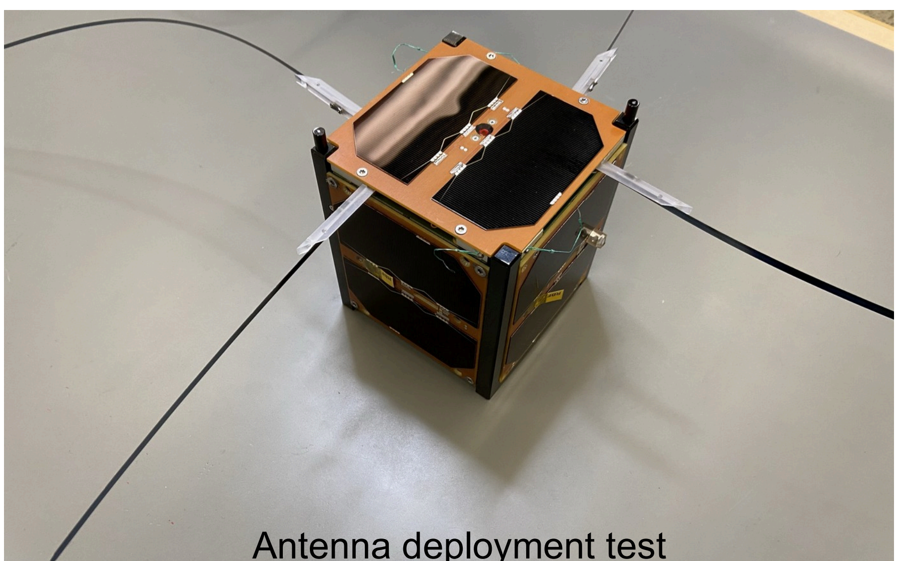
GRBALPHA:
ENVIRONMENTAL TESTS



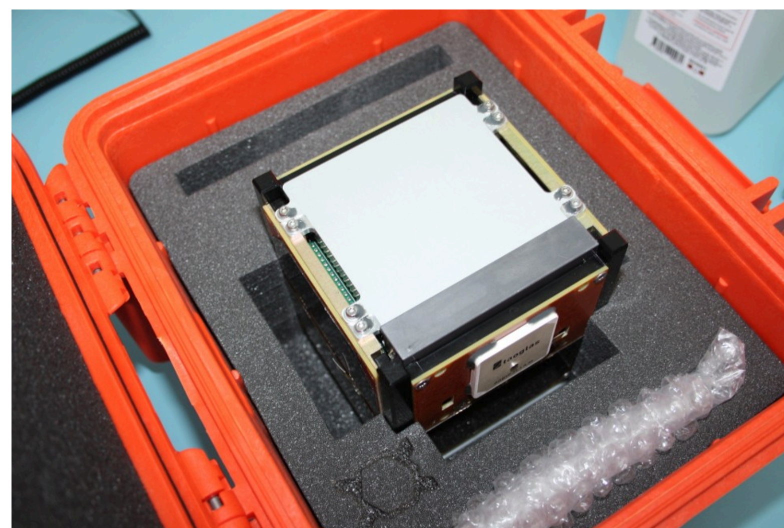
Thermal vacuum test



Vibration tests by Remred ltd. in Budapest



Antenna deployment test

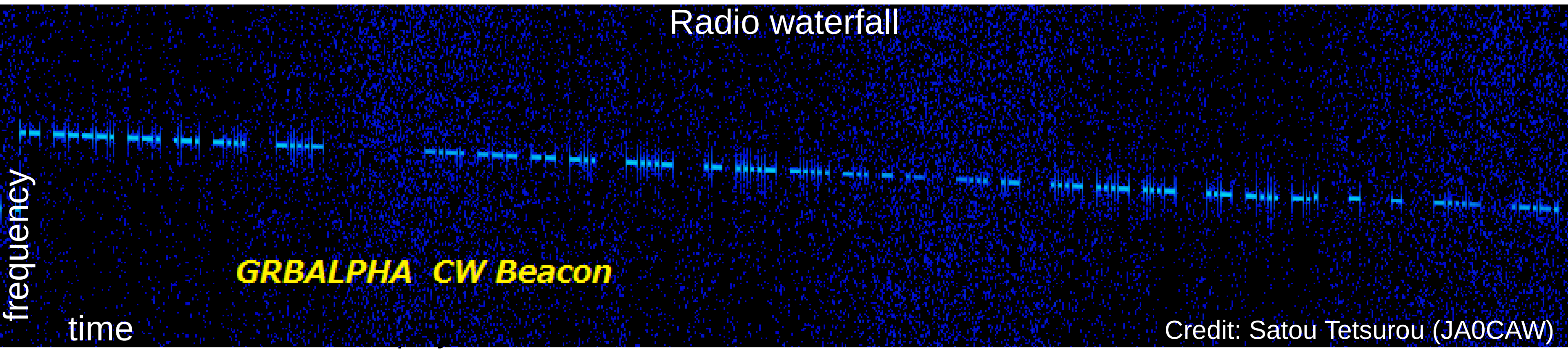


Ready for shipment to launch provider

GRBALPHA: LAUNCH AND FIRST RADIO SIGNALS

https://grbalpha.konkoly.hu/

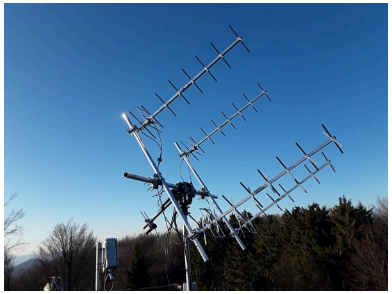
- Launched to 550 km SSO on March 22, 2021
- For downlink we are using amateur radio bands in UHF at 437.025 Mhz
- 1st confirmation that GRBAlpha is alive came ~5 hours after launch from radioamateur in Brisbane
- 1st pass over ground station in Brno was ~15 hours after launch
- Anyone can catch our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

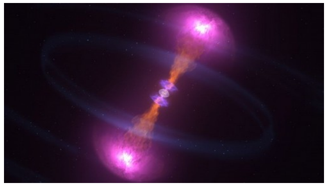
GS in Košice Technical University (Slovakia)



GS in Piszkéstető Astronomical Institute (Hungary)

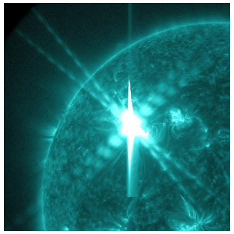
LIST OF TRANSIENTS OBSERVED BY GRBALPHA

- https://monoceros.physics.muni.cz/hea/GRBAlpha/
- By 2022/12/07:



- **19 Gamma-Ray Bursts** (GRBs)

- **2** bursts from **soft gamma repeater** SGR 1935+2154 (magnetar)



- **5 Solar flares**

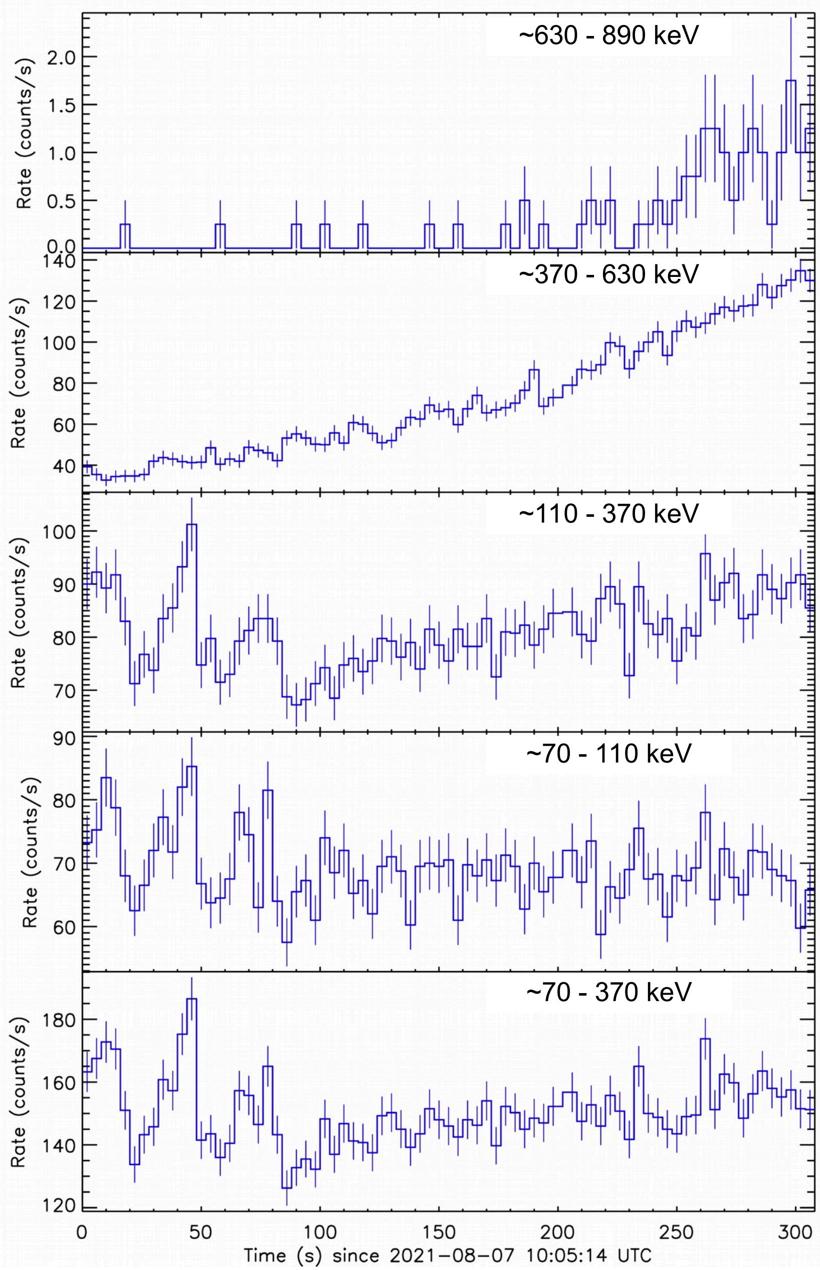
List of transients observed by the GRBAlpha nanosatellite

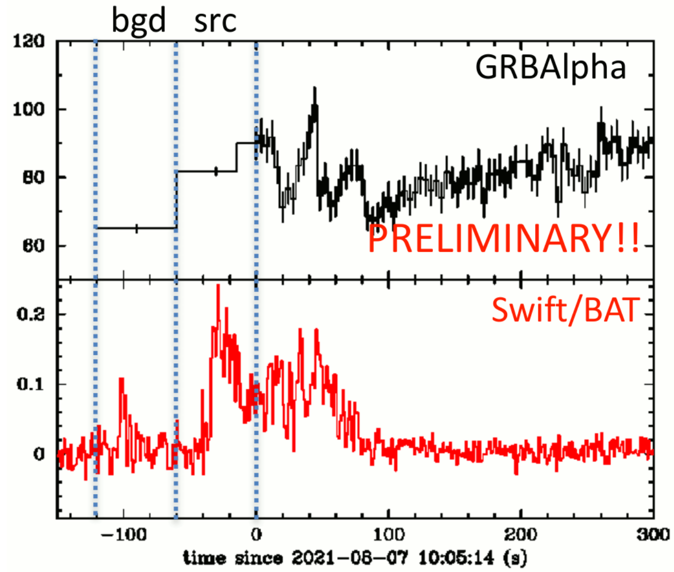
The list contains gamma-ray transients observed by GRBAlpha

- **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

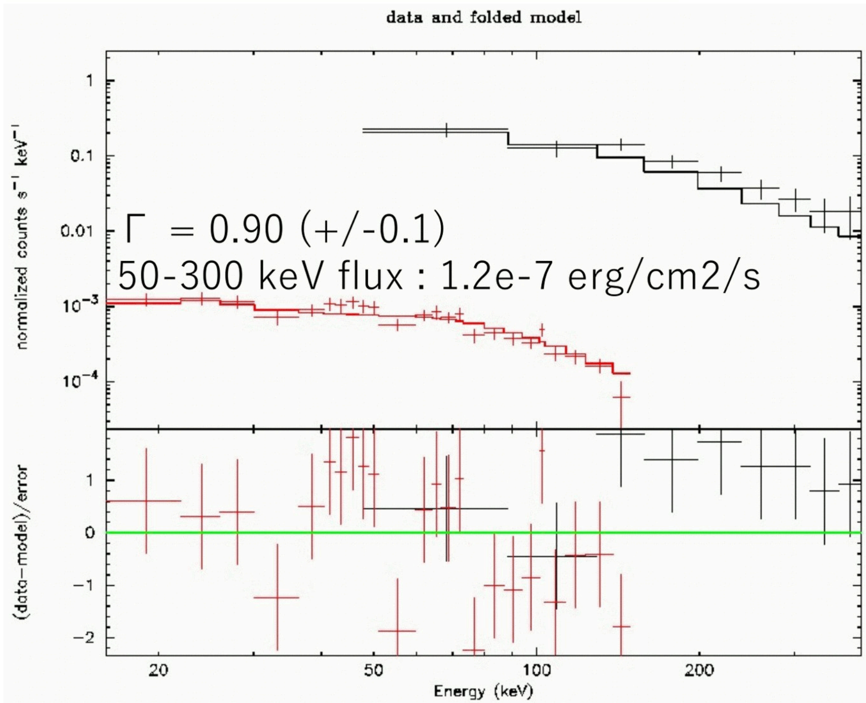
Event type/name	Peak time (UTC)	T90 [s]	Count rate [cnt/s]	Band [keV]	S/N [σ]	Raw LC	Bkg-sub LC	LC res. [s]	GCN circ.	References	Comment
GRB 221119A	2022-11-19 15:02:55.2	54	299.8	~70-890	23.5	PNG, EPS	PNG, EPS	1	32953	GECAM INTEGRAL/SPI-ACS Fermi/GBM	
GRB 221112A	2022-11-12 06:18:04.2	15	39.6	~70-890	3.4	PNG, EPS	PNG, EPS	1	32937	Fermi/GBM	
Solar flare	2022-11-11 13:49:12.2	10	92	~70-890	7.4	PNG, EPS	PNG, EPS	1		Fermi/GBM GOES GECAM	
Solar flare	2022-11-11 05:54:49.2	44	52	~70-890	4.6	PNG, EPS	PNG, EPS	1		Fermi/GBM GOES	
GRB 221107A	2022-11-07 01:22:58.2	265	105.8	~70-890	9.3	PNG, EPS	PNG, EPS	1	32917	Fermi/GBM Swift/BAT GECAM	
GRB 221029A	2022-10-29 01:05:27.8	36	57.3	~70-890	9.8	PNG, EPS	PNG, EPS	4	32890	Fermi/GBM INTEGRAL/SPI-ACS	
GRB 221022B	2022-10-22 22:56:11.8	32	170.5	~70-890	22.8	PNG, EPS	PNG, EPS	4	32844	Fermi/GBM AGILE/MCAL Wind/Konus Astrosat/CZTI INTEGRAL/SPI-ACS	
GRB 221020A	2022-10-20 05:23:59.8	16	67.8	~70-890	11.3	PNG, EPS	PNG, EPS	4	32815	Fermi/GBM	
SGR 1935+2154	2022-10-14 17:27:39.8	16	265.6	~70-890	51.5	PNG, EPS	PNG, EPS	4	32814	Insight-HXMT INTEGRAL/SPI-ACS	
SGR 1935+2154	2022-10-14 07:12:27.8	4	63.0	~70-890	11.0	PNG, EPS	PNG, EPS	4	32794	Fermi/GBM Wind/Konus	
GRB 221009A	2022-10-09 13:20:52	>250	~22000	~70-890		PNG, EPS		4	32685	Fermi/GBM AGILE/MCAL INTEGRAL/SPI-ACS Wind/Konus	Extraordinarily bright GRB
GRB 220927A	2022-09-27 05:36:25.2	8	97.4	~70-370	19.7	PNG, EPS	PNG, EPS	4	32622	Fermi/GBM INTEGRAL/SPI-ACS Wind/Konus	
GRB 220926B	2022-09-26 10:38:21.2	4	24.6	~70-240	4.8	PNG, EPS	PNG, EPS	4	32781	INTEGRAL/SPI-ACS	
GRB 220915A	2022-09-15 05:13:42.8	12	42.4	~70-300	8.4	PNG, EPS	PNG, EPS	4	32629	Fermi/GBM INTEGRAL/SPI-ACS Wind/Konus	
likely Solar Flare	2022-09-04 12:13:29.3	12	44.0	~70-890	8.6	PNG, EPS	PNG, EPS	3		Fermi Swift/BAT	We acknowledge help by Aaron Tohuvavohu
GRB 220829A	2022-08-29 14:37:50.4	6	123.6	~70-890	14.8	PNG, EPS	PNG, EPS	3	32697	Fermi/GBM INTEGRAL/SPI-ACS Wind/Konus	
GRB 220826B	2022-08-26 10:21:20.4	9	37.5	~70-890	5.0	PNG, EPS	PNG, EPS	3	32696	Fermi/GBM	
Solar Flare	2022-08-16 00:08:38	60	40.4	~70-890	11.4	PNG, EPS	PNG, EPS	4		Fermi/GBM	
Solar Flare	2022-08-15 14:35:06	108	160.1	~70-890	35	PNG, EPS	PNG, EPS	4		Fermi/GBM	
GRB 211019A	2021-10-19 05:59:34	36	229.1	~70-630	40	PNG, EPS	PNG, EPS	4	30946	Fermi/GBM INTEGRAL/SPI-ACS Wind/Konus	
GRB 211018A	2021-10-18 22:29:34	112	253.2	~70-630	45	PNG, EPS	PNG, EPS	4	30945	Fermi/GBM INTEGRAL/SPI-ACS Wind/Konus	
GRB 210909A	2021-09-09 10:43:19	8	50.5	~70-370	8.8	PNG, EPS	PNG, EPS	4	30840	Fermi/GBM Wind/Konus INTEGRAL/SPI-ACS	
GRB 210822A	2021-08-22 09:18:26	8	398.1	~70-370	46	PNG, EPS		4	30697	Swift/BAT Astrosat/CZTI GECAM-B Fermi/LAT Wind/Konus	near outer Van Allen radiation belt
GRB 210807A	2021-08-07 10:06:00	>80	47.4	~70-370	8.0	PNG, EPS	PNG, EPS	4	30624	Swift/BAT INTEGRAL/SPI-ACS	

GRBALPHA: 1ST GRB DETECTION
1ST GRB EVER DETECTED BY 1U SIZE CUBESAT!

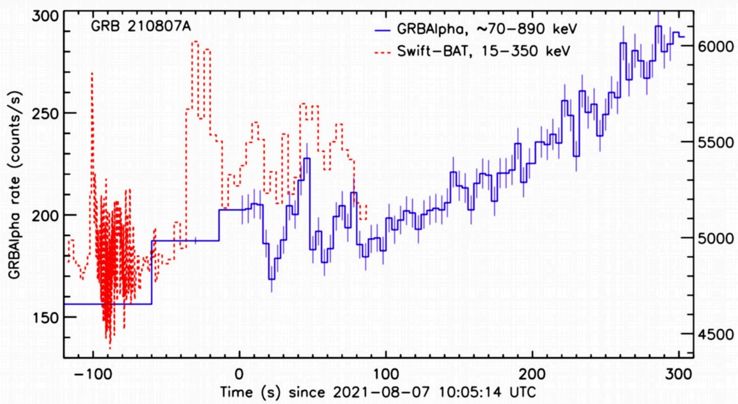


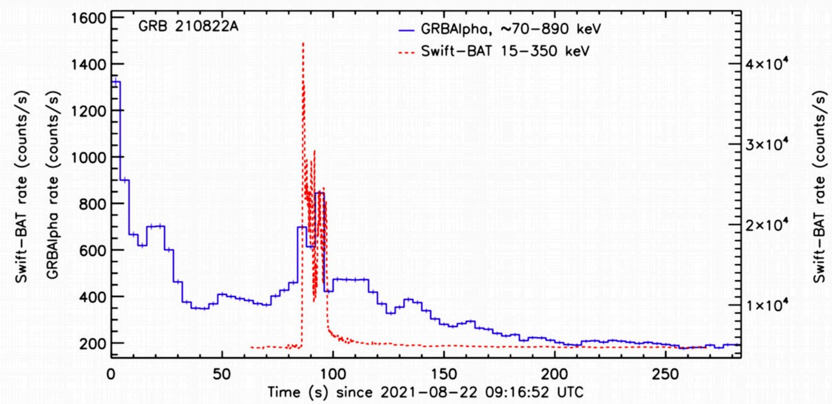


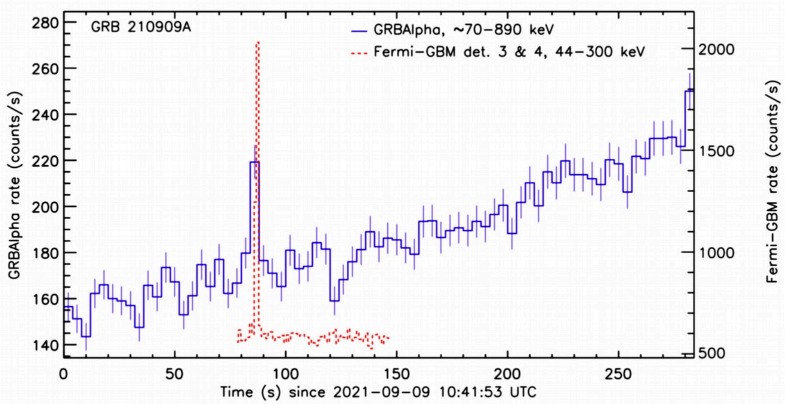
- GRB 210807A
- measured high resolution spectrum
- performed joint spectral fit GRBAlpha + Swift/BAT

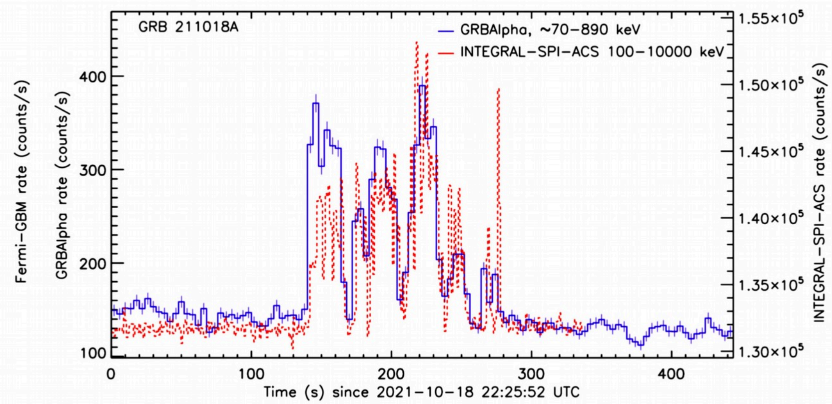


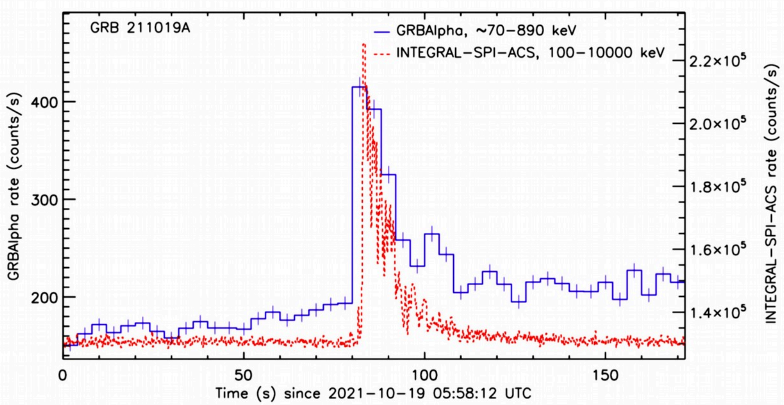
GRBALPHA: GRB DETECTIONS







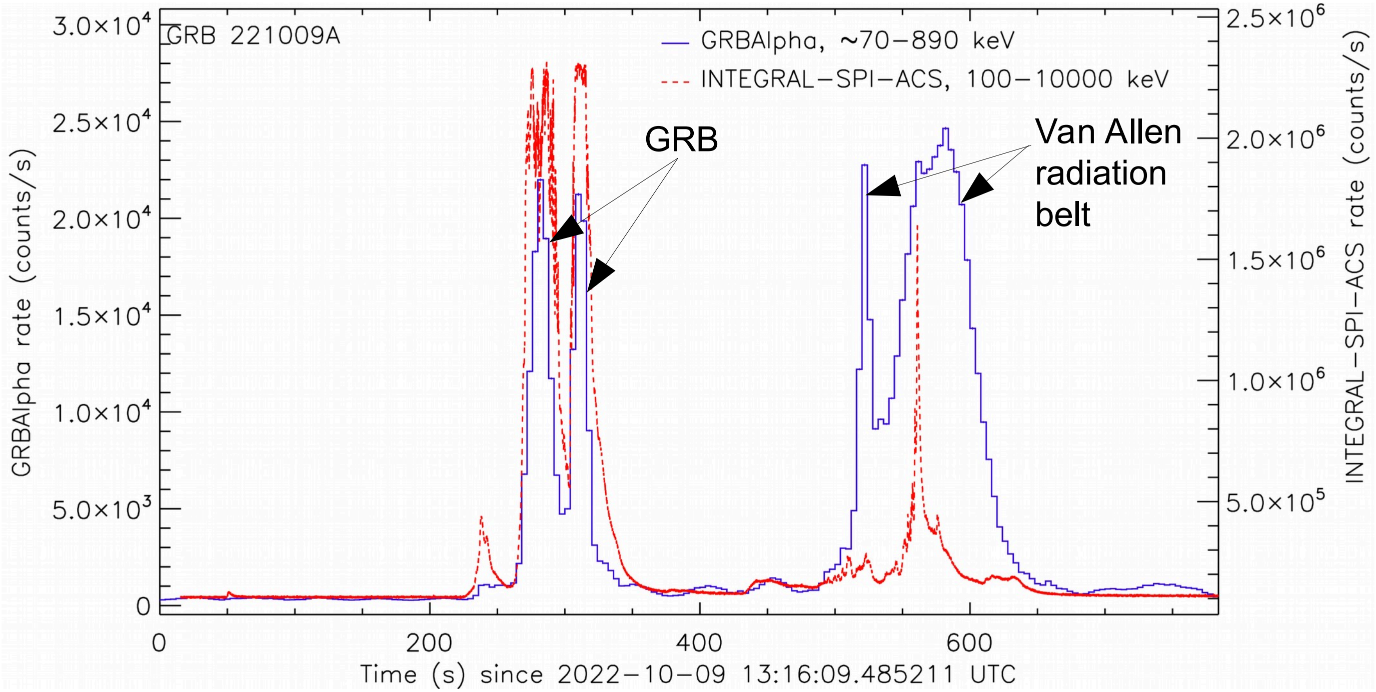


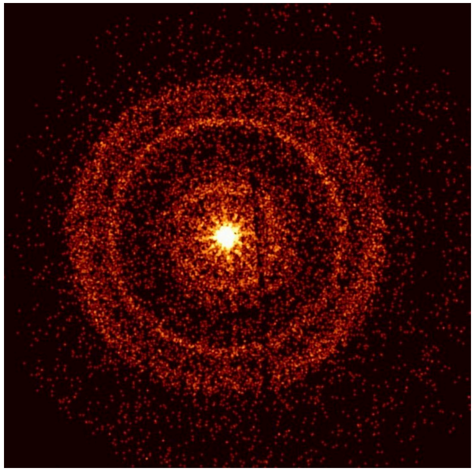


- GRB detections by GRBAlpha confirmed by other missions: Swift/BAT, Fermi/GBM, INTEGRAL/SPI-ACS
- Long and short GRBs
- Long GRB 210822A at z=1.736, light travel time **10 Gyr**
- Two GRBs were detected 8 hours apart
- Demonstration that nano-satellites can host payloads sensitive enough to routinely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

GRBALPHA: GRB 221009A
THE BRIGHTEST GRB EVER OBSERVED!

- **The most intense GRB (in terms of fluence) ever recorded in the 55 years history of GRB science**
- Detected also by several other instruments: Fermi, Swift, INTEGRAL, Wind-KONUS etc.
- So bright that it saturated larger detectors
- **At peak GRBAlpha measured ~22 000 count/s** in the ~70-890 keV energy band (for a 50 cm^2 detector)
- It was at redshift z= 0.15 (~2 Gly), isotropic energy release E_{iso}~$3.0x10^{54}$ erg
- **LHAASO and Carpet 2 observed very high energy photons reaching 18 TeV and 251 TeV** challenging fundamental physics. Such high energy photons should not propagate a long distance in the Universe due to their interaction with CMB and extragalactic background light.
- Swift X-Ray Telescope observed **bright rings around the GRB 221009A afterglow as a result of X-rays scattered by dust within our galaxy**

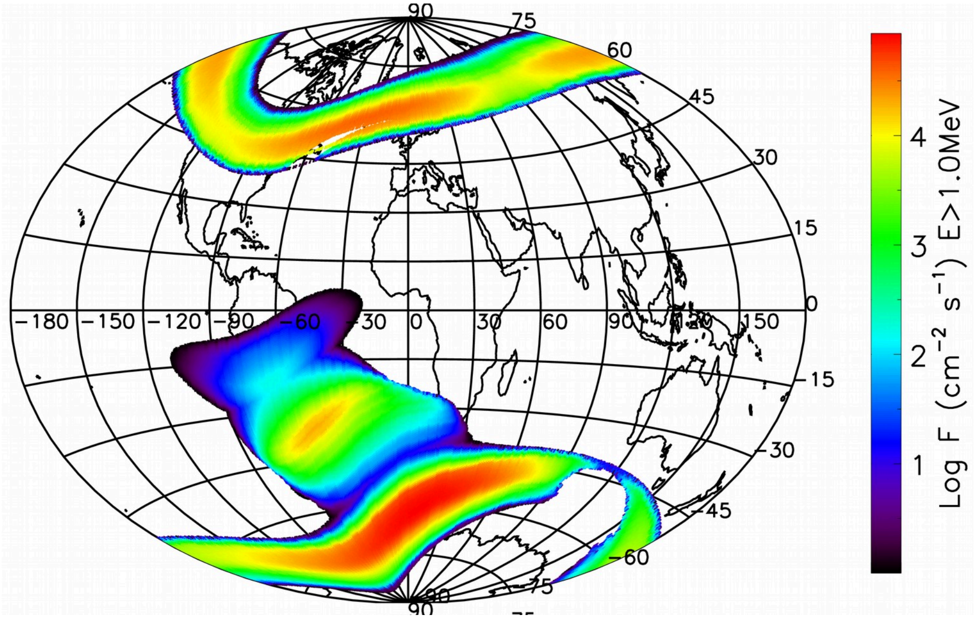




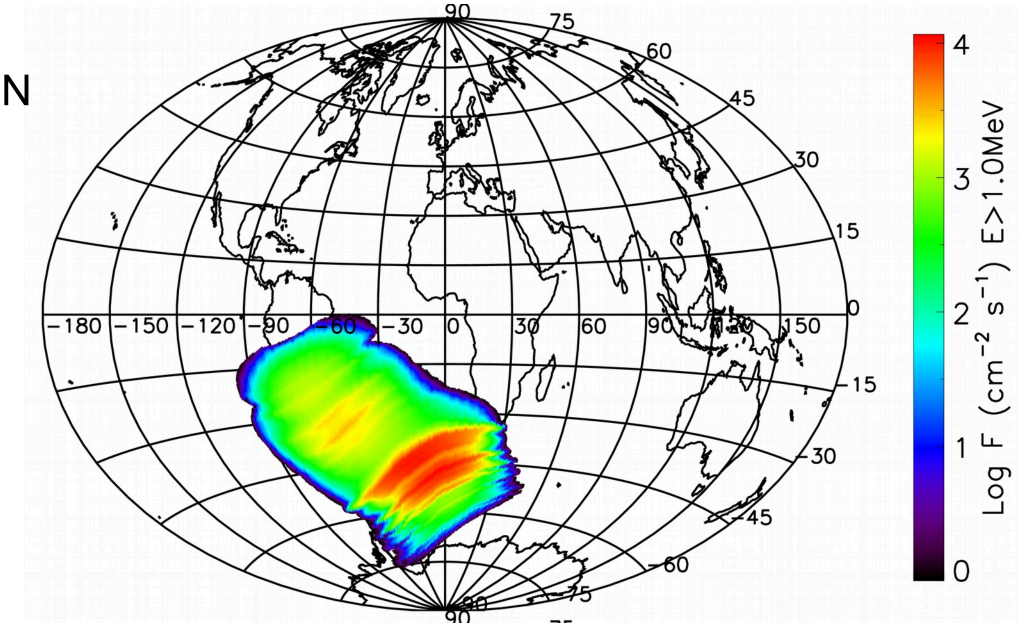
Credit: NASA/Swift/A. Beardmore

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

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

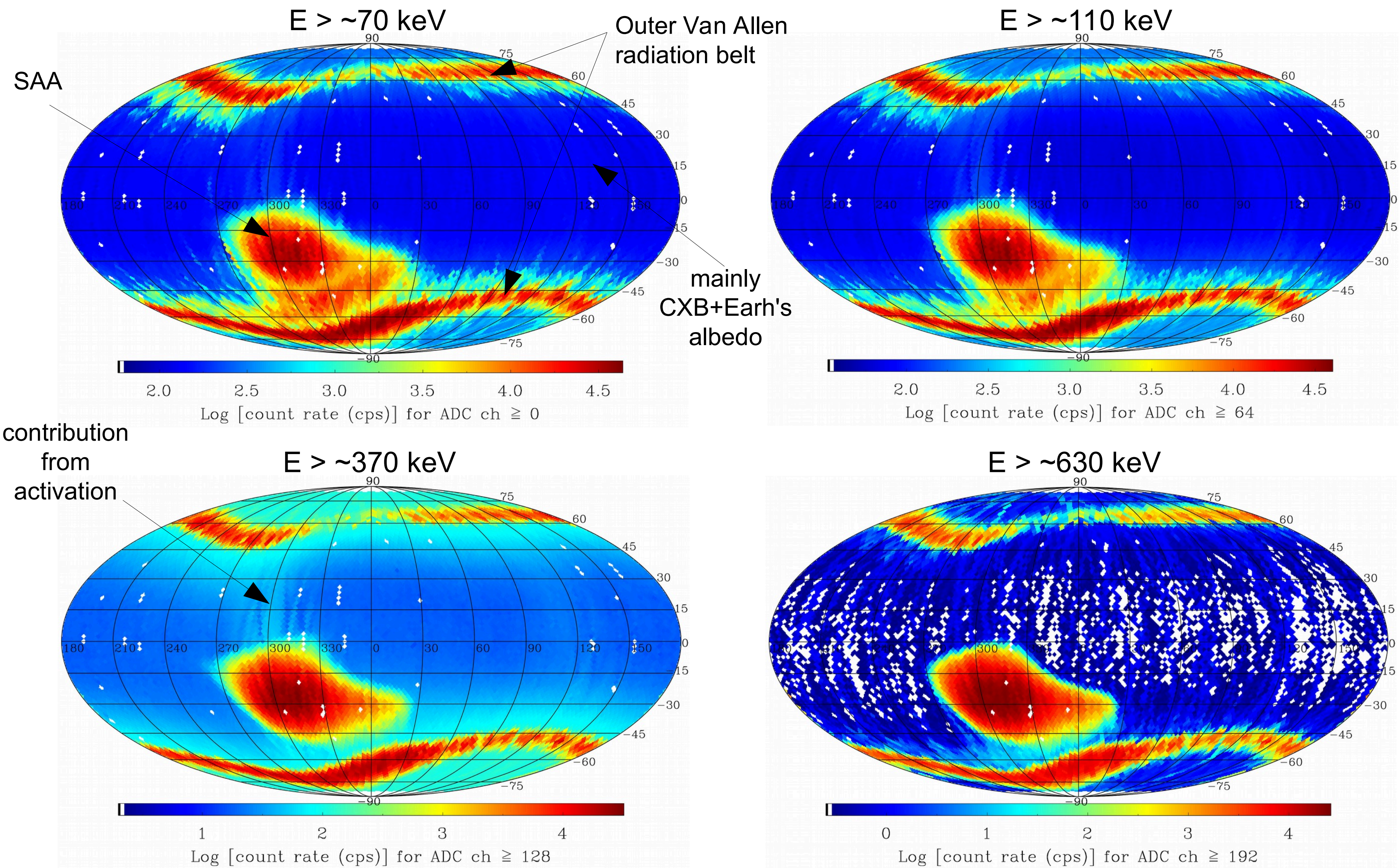


- Trapped protons **model**, E>1 MeV, 550 km, AP-8 MIN



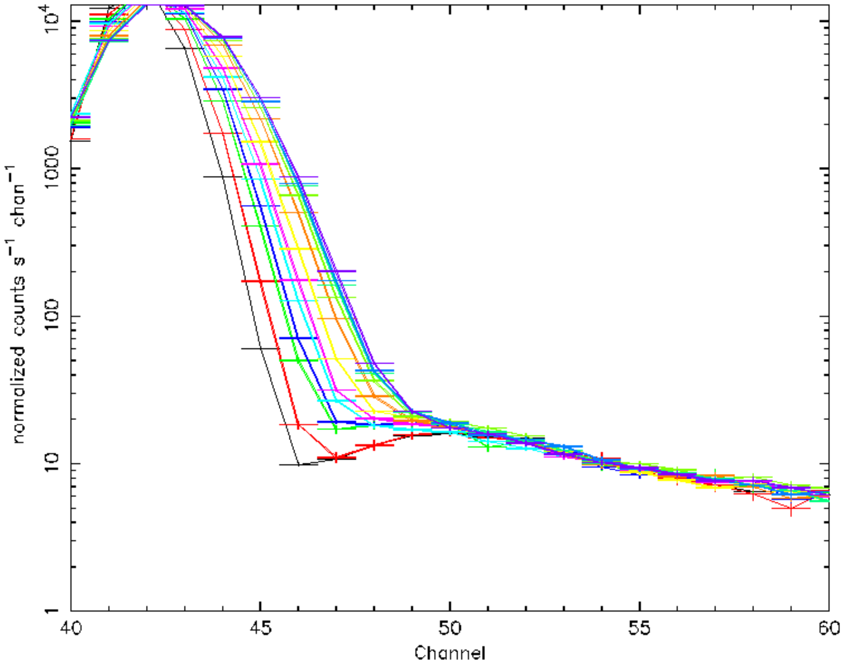
GRBALPHA: 3.5 MONTHS BACKGROUND MAP

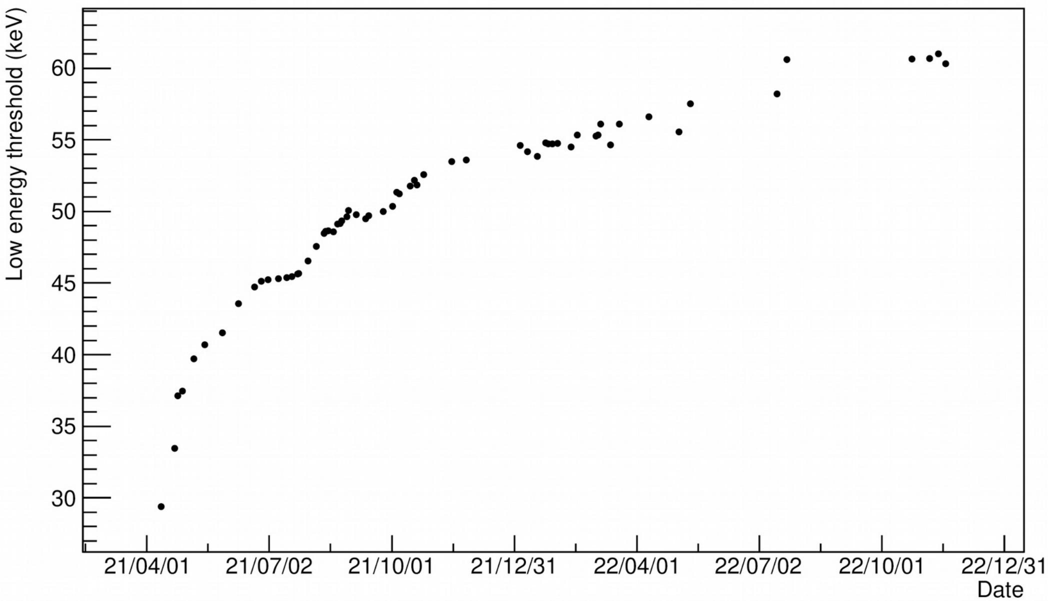
- Satellite tracks with the averaged detected count rate (when overlap) in last 3.5 months
- Such a map will be useful in future to control a rate trigger algorithm for autonomous GRB detection



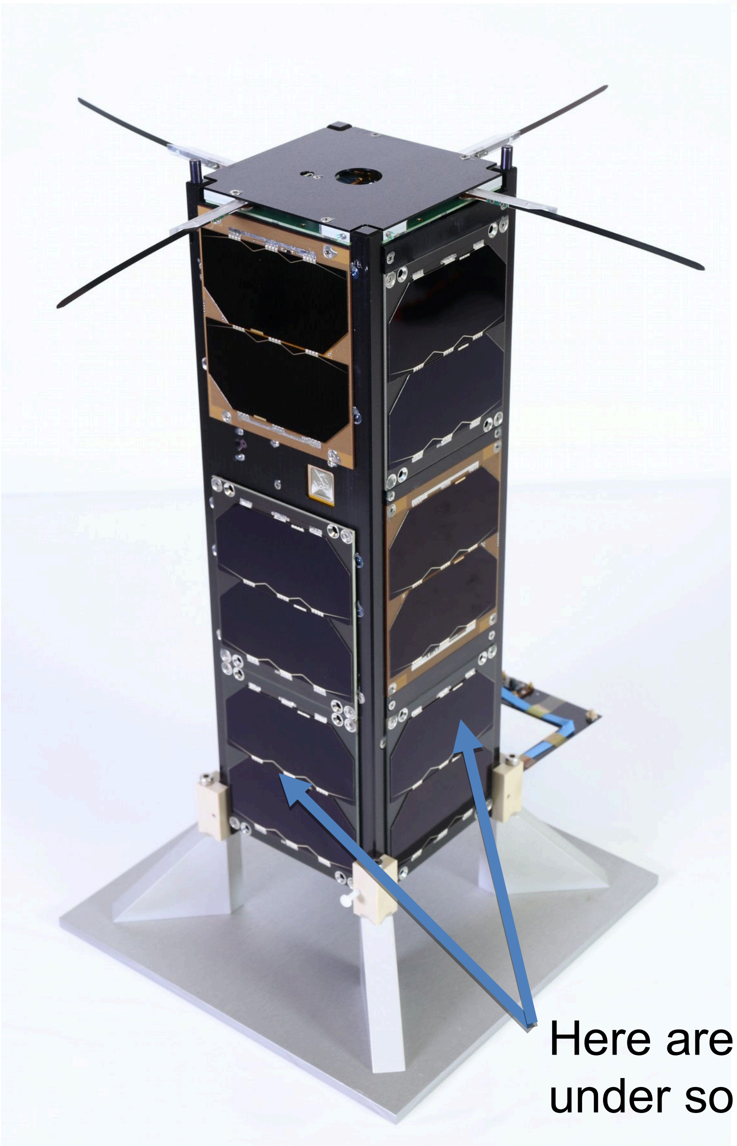
GRBALPHA: DEGRADATION OF MPPC IN SPACE

- 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

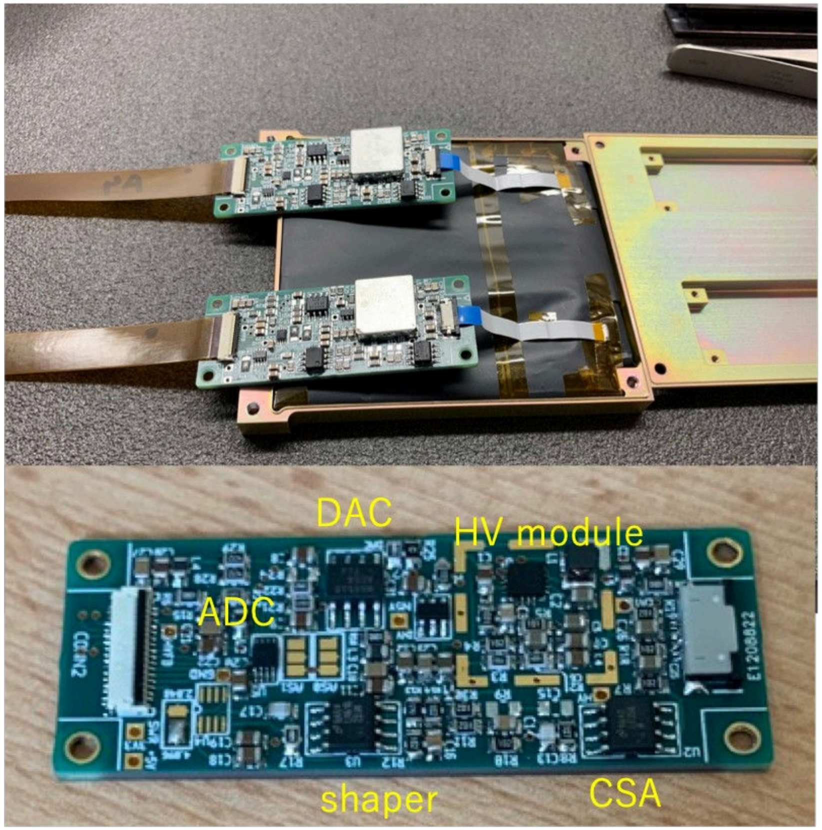


- VZLUSAT-2 is a technology mission (3U size) with an Earth observing camera as a primary payload developed by Czech Aerospace Research Centre
- Two detectors ($75x75x5mm^3$) as a secondary payload
- The detector concept, the MPPCs and electronics are the same as on GRBAlpha

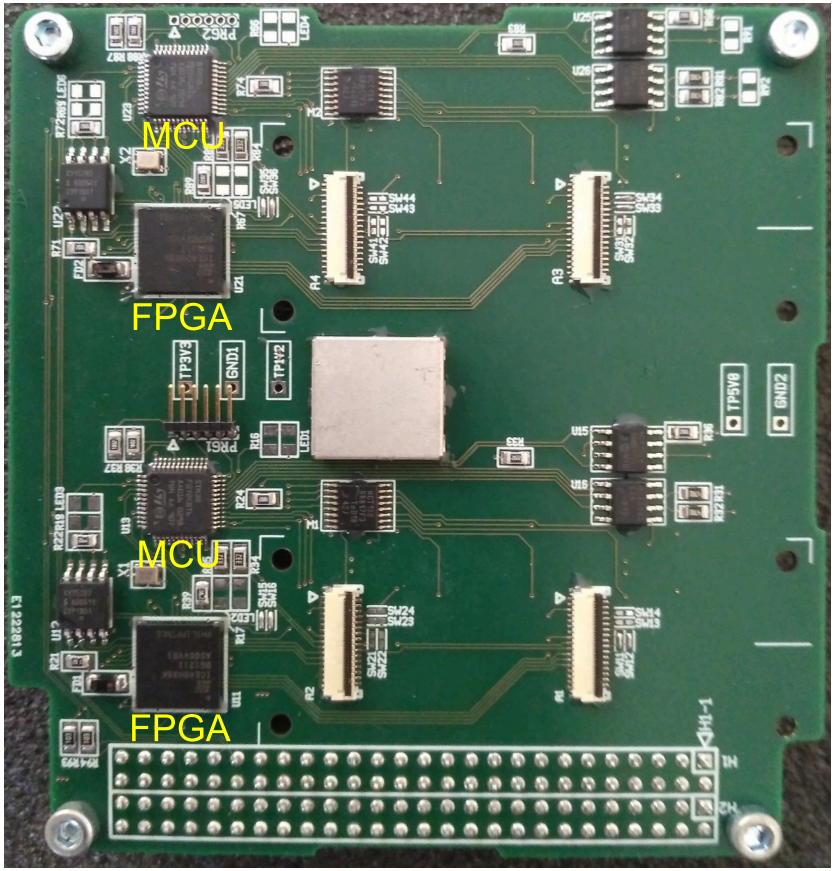
Here are our detectors under solar panels

VZLUSAT-2:
DETECTOR ASSEMBLING AND ELECTRONICS

Compact analog electronics



Digital board



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

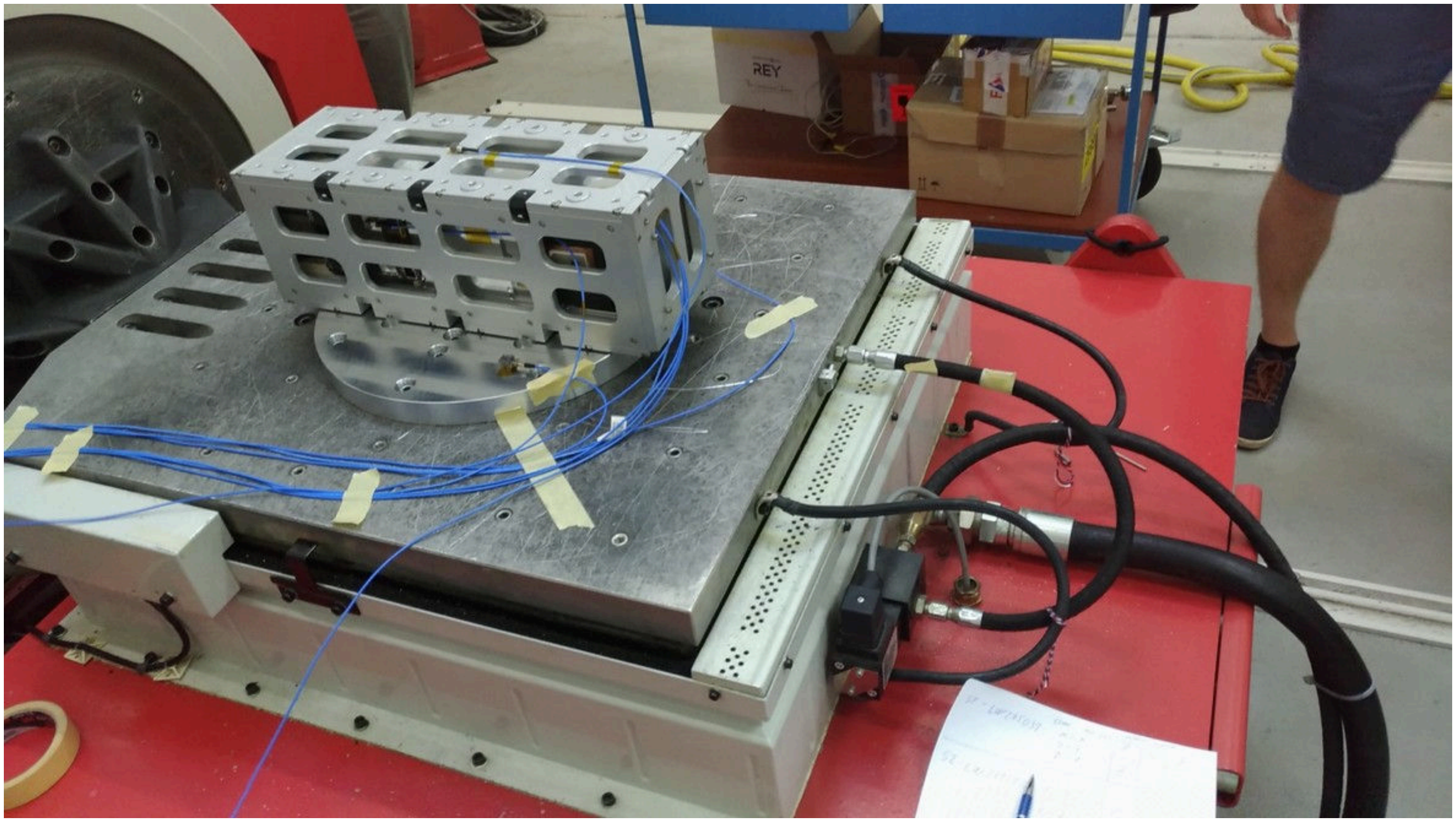
- FPGA - iCE40HX8K-BG121
- MCU - STM32F072CBT7 ARM Cortex-M0

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

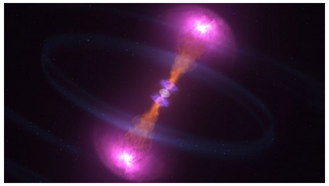
VZLUSAT-2:

SATELLITE FINISHED AND LAUNCHED

- Satellite was assembled, went through environmental tests and was shipped to USA in Sep 2020
- It was launched to 550 km SSO by Falcon 9 is on Jan 13th 2022

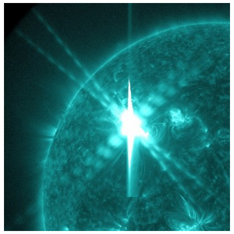
LIST OF TRANSIENTS OBSERVED BY OUR DETECTORS ON VZLUSAT-2

- https://monoceros.physics.muni.cz/hea/VZLUSAT-2/
- By 2022/11/25:



- **8 Gamma-Ray Bursts**

- **4** bursts from **soft gamma repeater** SGR 1935+2154 (magnetar)



- **3 Solar flares**

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

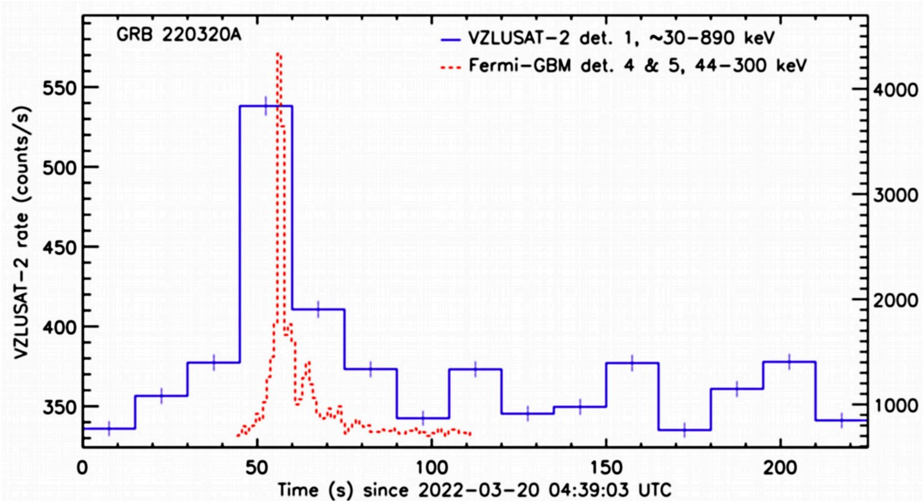
The list contains gamma-ray transients observed by the GRB detectors on VZLUSAT-2

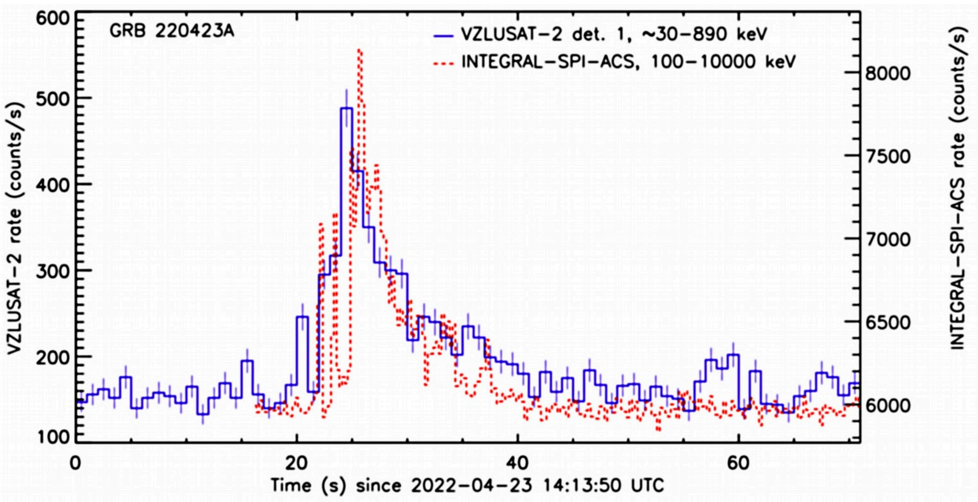
- **Event type/name** denotes the type of the detected event like GRB, Solar flare etc.
- **Det. unit** is the number of the detector unit (no. 0 or no. 1).
- **Peak time** denotes the time when the detected count rate from the event was maximal
- **T90** is the time interval, in which 90 per cent of 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

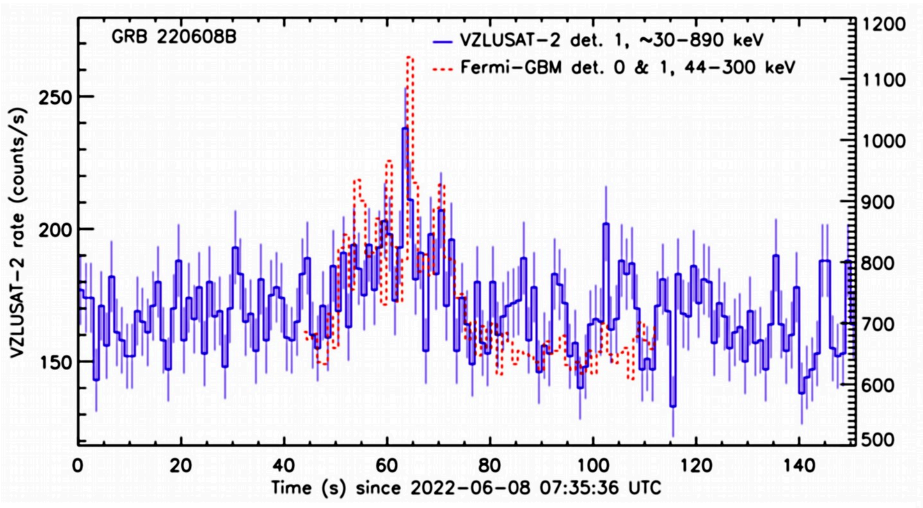
Event type/name	Det. unit	Peak time (UTC)	T90 [s]	Count rate [cnt/s]	Band [keV]	S/N [σ]	Raw LC	Bkg-sub LC	LC res. [s]	GCN circ.	References	Comment
GRB 221028A	no. 0	2022-10-28 13:16:26	23	88.0	~30-890	7.1	PNG, EPS	PNG, EPS	1	32904	Swift/BAT AGILE/MCAL+AC INTEGRAL/SPI-ACS Wind/Konus	
	no. 1	2022-10-28 13:16:26	26	69.3	~30-890	5.5	PNG, EPS	PNG, EPS	1			
SGR 1935+2154	no. 1	2022-10-14 17:27:36	8	1169.6	~30-890	70.4	PNG, EPS	PNG, EPS	1	32814	Insight-HXMT INTEGRAL/SPI-ACS Fermi/GBM	
SGR 1935+2154	no. 1	2022-10-13 22:41:28	<1	1187.7	~30-890	125.5	PNG, EPS	PNG, EPS	1	32797	Wind/Konus Fermi/GBM	
SGR 1935+2154	no. 1	2022-10-13 02:02:43	1	170.1	~30-890	16.5	PNG, EPS	PNG, EPS	1	32797	Wind/Konus	
SGR 1935+2154	no. 1	2022-10-12 23:26:41	<1	178.2	~30-890	17.6	PNG, EPS	PNG, EPS	1	32797	Fermi/GBM INTEGRAL/ISGRI AGILE/AC	
GRB 220912A	no. 1	2022-09-12 00:50:23	36	103.2	~30-890	9.2	PNG, EPS	PNG, EPS	1	32624	Fermi/GBM Astrosat/CZTI	
GRB 220719A	no. 1	2022-07-19 19:09:43	7	99.7	~30-890	6.2	PNG, EPS	PNG, EPS	1	32463	Wind/Konus INTEGRAL/SPI-ACS	
Solar flare	no. 1	2022-07-15 23:08:47	36	154.7	~30-890	10.9	PNG, EPS	PNG, EPS	1		Fermi/GBM	
GRB 220608B	no. 1	2022-06-08 07:36:39	27	74.9	~30-890	5.9	PNG, EPS	PNG, EPS	1	32196	Fermi/GBM	
Solar flare	no. 1	2022-05-20 22:09:59	11	81.0	~30-890	6.3	PNG, EPS	PNG, EPS	1		Fermi/GBM	
GRB 220423A	no. 0	2022-04-23 14:14:14	37	321.8	~30-890	28.3	PNG, EPS	PNG, EPS	1	31965	CALET/CGBM INTEGRAL/SPI-ACS Wind/Konus	
	no. 1	2022-04-23 14:14:14	23	325.9	~30-890	28.2	PNG, EPS	PNG, EPS	1			
Solar flare	no. 0	2022-04-21 21:03:46	59	107.4	~30-890	9.6	PNG, EPS	PNG, EPS	1	31949	Wind/Konus	
	no. 1	2022-04-21 21:03:47	61	371.4	~30-890	38.3	PNG, EPS	PNG, EPS	1			
GRB 220320A	no. 1	2022-03-20 04:39:55	15	179.2	~30-370	46.6	PNG, EPS	PNG, EPS	15	31803	Fermi/GBM Wind/Konus CALET/CGBM Astrosat/CZTI INTEGRAL/SPI-ACS	

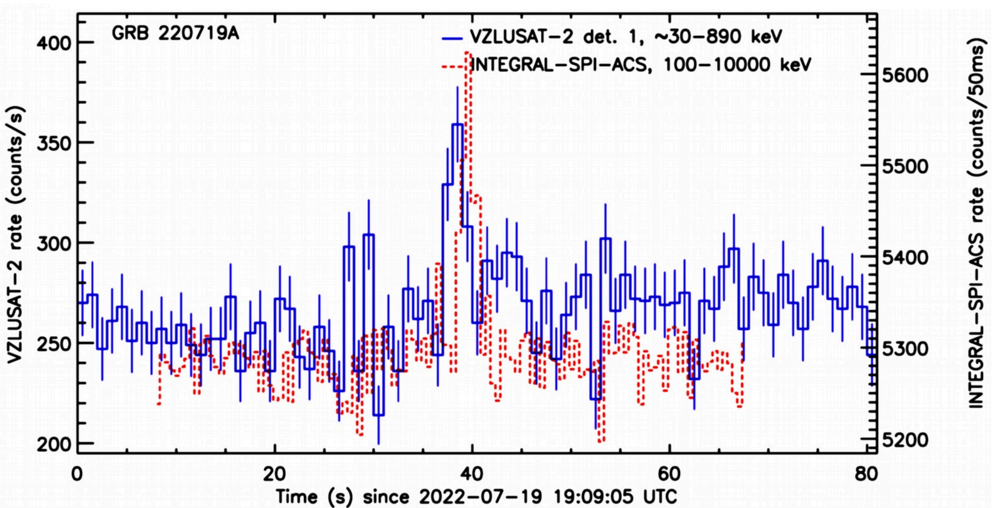
VZLUSAT-2: GRB DETECTIONS

- **7 GRBs** detected so far, either with detector unit no. 0, 1 or both
- Compared with detections by Fermi/GBM or INTERGAL/SPI-ACS
- The 1st GRB was detected with 15s resolution during commissioning phase (background mapping)
- Other GRBs were obtained with 1s resolution





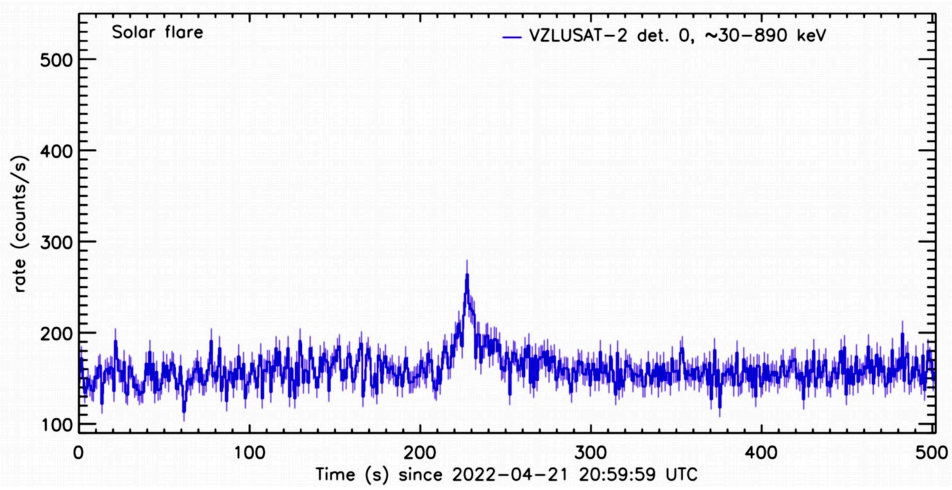




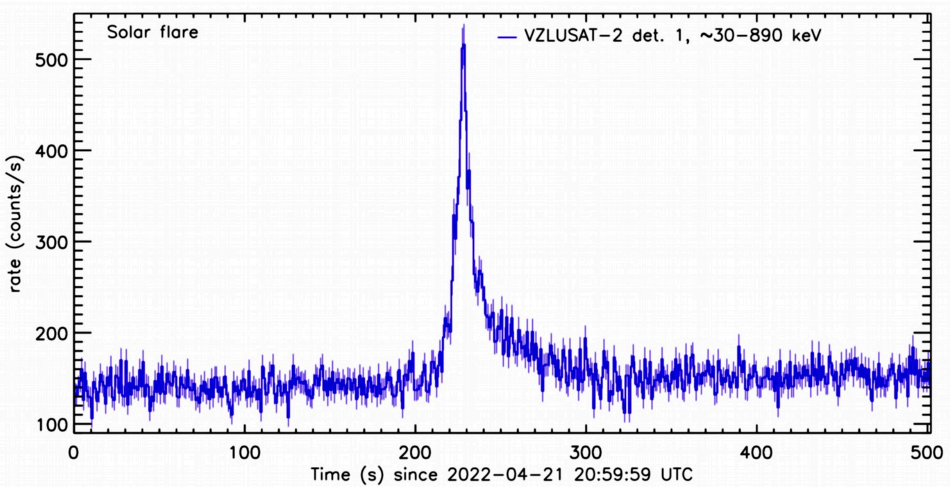
VZLUSAT-2: SOLAR FLARE DETECTIONS

- **3 Solar flares** detected so far
- Compared with detection by Fermi/GBM
- Measured with 1s resolution

DETECTOR UNIT 0



DETECTOR UNIT 1



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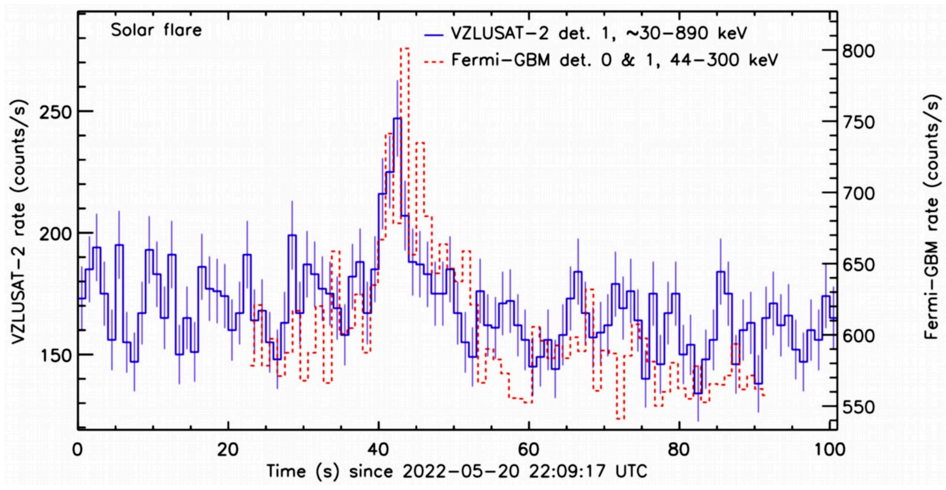
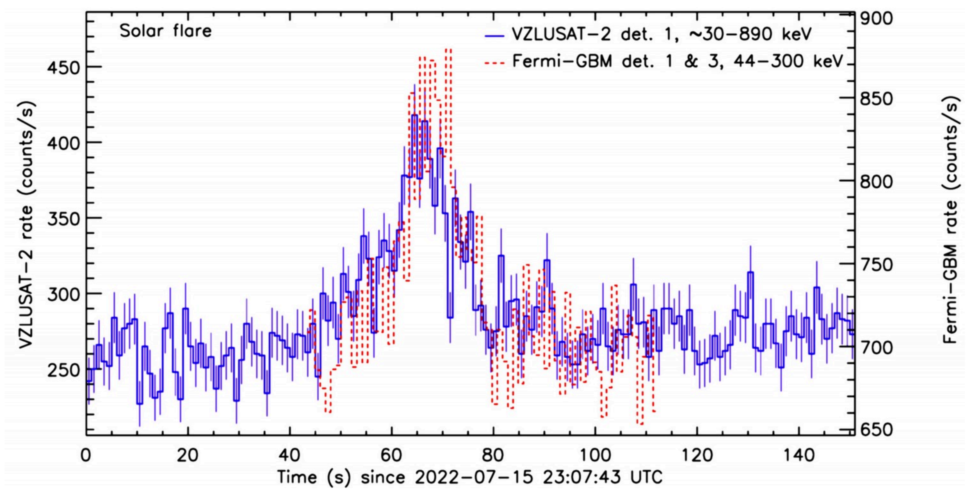
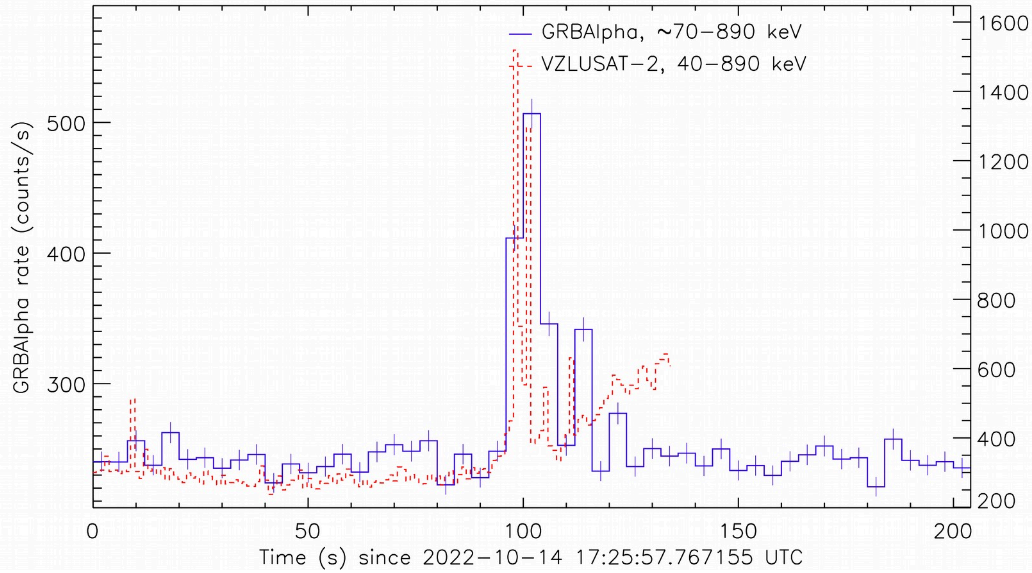


DETECTOR UNIT 1

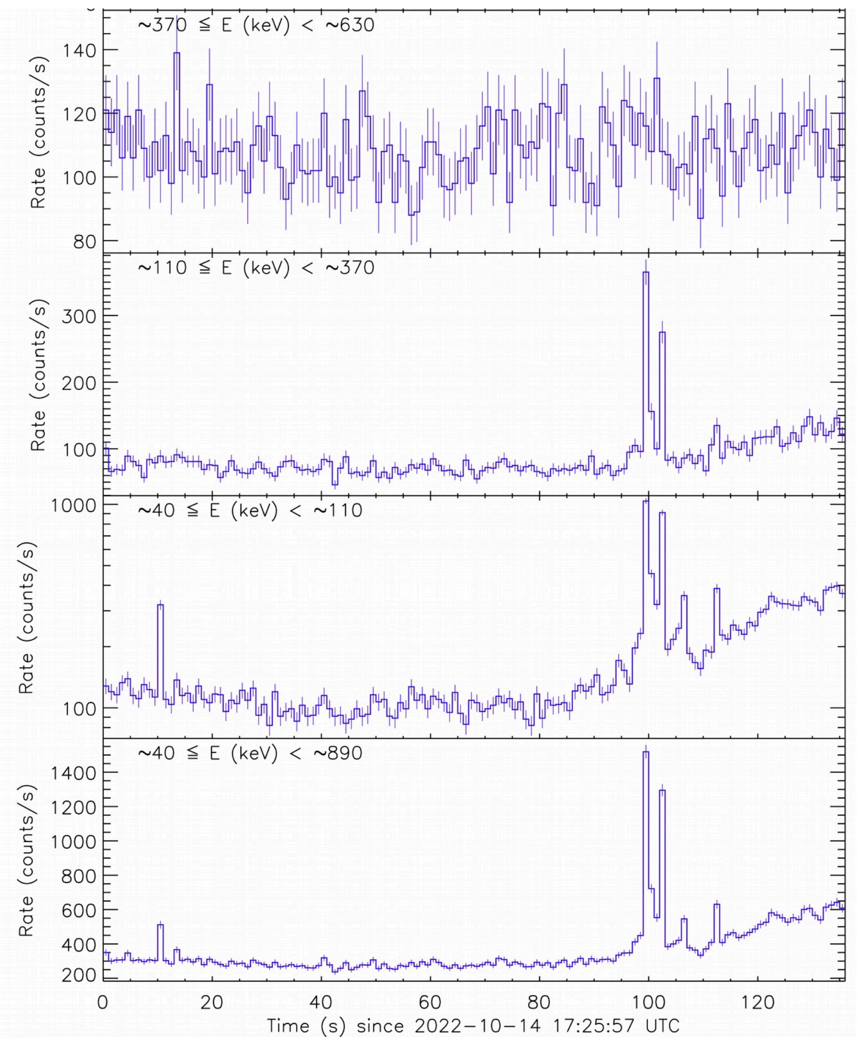


VZLUSAT-2 AND GRBALPHA JOINT DETECTION OF SGR 1935+2154

- Burst from **soft gamma repeater SGR 1935+2154**
- Measured with 1s resolution for VZLUSAT-2 (4 s for GRBAlpha)



VZLUSAT-2 DETECTOR UNIT 1

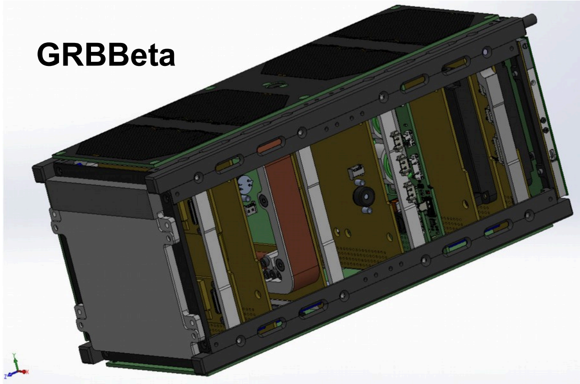


SUMMARY

- **GRBAlpha successes:**
  - since launch still functional in orbit 20 months
  - detector concept proven
  - detected 18 GRBs
  - mapping background at LEO
  - provides data of in orbit aging of Hamamatsu's MPPCs

- **VZLUSAT-2:**
  - since launch still functional in orbit 10 months
  - detected 7 GRBs
  - 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 second half of 2023



THANK YOU !