# GRB-DETECTING NANOSATELLITES GRBALPHA AND VZLUSAT-2



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## **GRBALPHA**

- 1-U CubeSat with gamma-ray detector (~60-900 keV)
- Small size (75x75x5mm<sup>3</sup>) of Csl(Tl) scintillator readout by 8 MPPCs (SiPMs)



Effective area based on GEANT4 MC simulations



# GRBALPHA: DETECTOR ASSEMBLING



Pál+ 2020



CsI(TI) scintillator

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 wrapped by optically thick DuPont TCC15BL3 tedlar (PVF) to prevent light leakage from outside
- Launched to 550 km SSO on March 22, 2021







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

DuPont Tedlar TCC15BL3 wrapping

# VZLUSAT-2: WITH 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 (VZLU)
- Two detectors (75x75x5mm<sup>3</sup>) 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: TESTING, INTEGRATION, LAUNCH





Test of GRB detectors on the satellite bus

GRB detectors integrated into EM of the satellite



Integration of VZLUSAT-2 FM



• Launched to 540 km SSO by Falcon 9 is on Jan 13th 2022



## LIST OF TRANSIENTS OBSERVED BY GRBALPHA

https://monoceros.physics.muni.cz/hea/GRBAlpha/

#### Launched to 550 km SSO on March 22, 2021

#### ~200 gamma ray transients by 2024/11/11



**102 Gamma-Ray Bursts** (17 short / 85 long)



**92 Solar Flares** 



**2 Soft Gamma Repeaters** SGR 1935+2154 (magnetar)

#### 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	<u>PNG, EPS</u>	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	<u>PNG, EPS</u>	1		Solar Orbiter/STIX GOES		
GRB 230207B	2023-02-07 04:40:47.9	10	319.7	~70-890	25.0	PNG, EPS	<u>PNG, EPS</u>	1	<u>33303/PDF</u>	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	<u>PNG, EPS</u>	1	<u>33273/PDF</u>	Fermi/GBM INTEGRAL/SPI-ACS CALET/CGBM MAXI/GSC ASTROSAT/CZTI Swift/BAT-GUANO AGILE/MCAL		

## LIST OF TRANSIENTS OBSERVED BY VZLUSAT-2

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

#### 120 gamma ray transients by 2024/07/12



57 Gamma-Ray Bursts (10 short / 47 long)



**58 Solar Flares** 



**5 Soft Gamma Repeaters** SGR 1935+2154 and SGR 1806-20 (magnetars)

#### 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	<u>PNG, EPS</u>	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	<u>PNG, EPS</u>	1		Fermi/GBM GECAM-B GOES	
Solar flara	no. 0	2023-02-11 15:46:21	79	489.3	~40-890	51.9	PNG, EPS	PNG, EPS	1		Fermi/GBM GOES GPRAlphe	
Solar hare	no. 1	2023-02-11 15:45:35	78	370.1	~40-890	103.2	PNG, EPS	PNG, EPS	1		KONUS-Wind Solar Orbiter/STIX	
GRB 230126A	no. 0	2023-01-26 18:20:46	14	41.3	~40-890	5.1	PNG, EPS	PNG, EPS	1	<u>33246/PDF</u>	Fermi/GBM	
GRB 230114B	no. 1	2023-01-14 20:40:54	<1	88.3	~40-890	4.9	PNG, EPS	PNG, EPS	1	<u>33218/PDF</u>	KONUS-Wind INTEGRAL/SPI-ACS	
GRB 230114A	no. 1	2023-01-14 16:59:17	5	56.5	~40-890	6.7	<u>PNG</u> , <u>EPS</u>	PNG, EPS	1	<u>33170/PDF</u>	Fermi/GBM INTEGRAL/SPI-ACS	
Solar flare	no. 0	2023-01-11 01:53:58	72	2842.0	~40-890	273.7	<u>PNG, EPS</u>	<u>PNG, EPS</u>	1		Fermi/GBM GOES	
	no. 1	2023-01-11 01:53:26	57	1119.4	~40-890	159.5	PNG, EPS	<u>PNG, EPS</u>	1		KONUS-Wind Solar Orbiter/STIX	
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	X11 class

## **GRBALPHA: EXAMPLE GRB DETECTIONS**



- 100th burst: GRB 241026A at z=2.8, light travel time 11.5 Gyr
- Two GRBs were detected 8 hours apart
- Demonstration that nano-satellites can host payloads sensitive enough to routinely detect GRBs!

## GRBALPHA OBSERVED GRB 221009A (BOAT) !

- GRBAlpha observed GRB 221009A in 13 spectral bands and 4s resolution
- Detector was not saturated, but at the peak the rate was effected by pileup
- At GRB peak GRBAlpha measured ~22 000 count/s in the ~80-950 keV energy band (for 50 cm<sup>2</sup> detector)



### GRBALPHA OBSERVED GRB 221009A (BOAT) !

- 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 ratio
- Liso > 8.4x10<sup>52</sup> erg/s (4 s scale) in the 1 10 000 keV
- Eiso > 1.5x10<sup>54</sup> erg in 1 10 000 keV (> 2.5 solar rest-mass energy)
- Řípa et al. 2023, A&A, 677, L2



# VZLUSAT-2 AND GRBALPHA JOINT DETECTIONS: GRB 230307A

- 2nd brightest GRB ever detected
- Long GRB (T<sub>90</sub> = 30 s) with identified kilonova pointing the merger involving a NS !
- JWST provided the infrared spectrum of a kilonova identifying elements heavier than iron



## **GRB DETECOR SENSITIVITY**

Complementary cumulative distribution functions of peak flux and fluence Fermi/GBM GRBs with marked weakest events detected also by GRBAlpha and VZLUSAT-2



### **GRBALPHA: HALF-YEAR BACKGROUND MAP**

- Averaged detected count rate in half year at ~540 km
- Such a map will be useful in future to control a rate trigger algorithm for autonomous GRB detection



# MPPCS ARE SHIELDED BY LEAD ALLOY ON GRBALPHA AND VZLUSAT-2

- We simulated how much of total ionizing (TID) and non-ionizing dose (TNID) can be expected in MPPCs for various shielding at low-Earth orbit (500 km) using ESA's MULASSIS tool
- Including trapper p+, solar energetic p+, CR, secondary p+, secondary neutrons
- Based on simulations decided to use 2.5 mm thick PbSb alloy



## **DEGRADATION OF MPPC DUE TO RADIATION DAMAGE**

- MPPCs are new to be used for spaceborne detectors
- It is known that SiPMs / MPPCs are prone to radiation damage, but limited measurements from space yet!
- STPSat-5/SIRI-1 at LEO reported a significant increase of leakage current over 1 year of J-series SensL 60035 SiPMs
- GRID-02 characterized the ageing of ON Semi MicroFJ-60035-TSV SiPMs over 3 months and reported a gradual increase of dark current





## NOISE PEAK (DARK NOISE) EVOLUTION AND LOW-ENERGY THRESHOLD

- We measured radiation degradation of MPPCs at LEO for longer than 3 years !
- Noise peak evolution observed in the background spectra of the GRB detectors over 1st year on orbit



### MEASURED LOW-ENERGY THRESHOLD EVOLUTION, DCR AND SIMULATED TID/TNID





# **GRBBETA (2U)**

- Gamma detector unchanged
- Testing several technologies

   inter-satellite transmitter module
  - S-band communication
  - IR position Sun sensors
  - attitude control
  - NUV sensor to test at LEO for QUVIK, including optics (LUVS team, Toronto, CA)
- Launched this summer (2024/07/09) by the European's new rocket Ariane 6
- Satellite is in commissioning phase. GRB detector works well.









## SUMMARY

#### • GRBAlpha:

- since launch still functional in orbit >3 years
- detected ~200 transients up to now (GRBs, solar flares, SGRs)
- detector concept proven

#### • VZLUSAT-2:

- since launch still functional in orbit >2 year
- detected ~120 transients up to now
- both CubeSats map background at LEO
- we characterized aging of Hamamatsu MPPCs over 3 years at LEO

#### • <u>GRBBeta:</u>

- launched and in commissioning phase

#### • Details in publications:

- Řípa et al. 2024, arXiv:2411.00607
- Münz et al. 2024, Proc. of SPIE, 13093, 130936J
- Pál et al. 2023, A&A, 677, A40
- Řípa et al. 2023, A&A, 677, L2
- 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