GRB-DETECTING NANOSATELLITES GRBALPHA, VZLUSAT-2 AND GRBBETA

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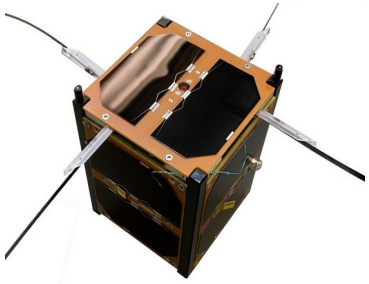
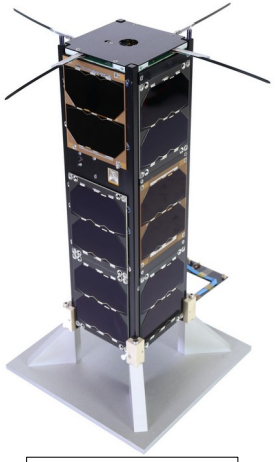
for GRBAlpha, VZLUSAT-2, GRBBeta collaborations



GRBAlpha



VZLUSAT-2

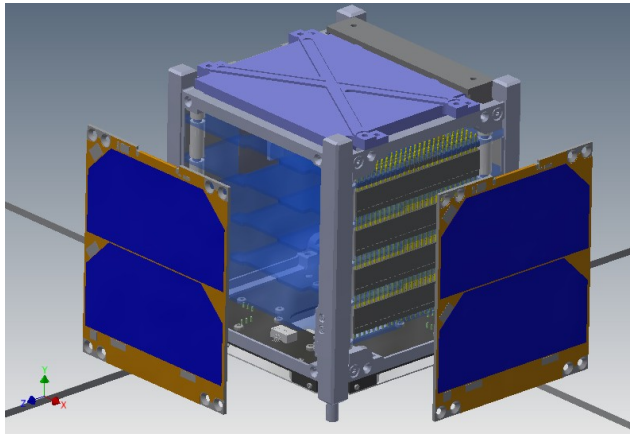
GRBBeta

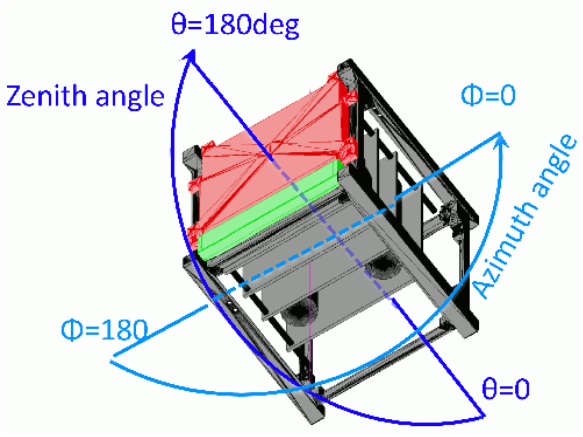
Tatra Astro Summit 2025, Stará Lesná, Slovakia, 2025/09/24

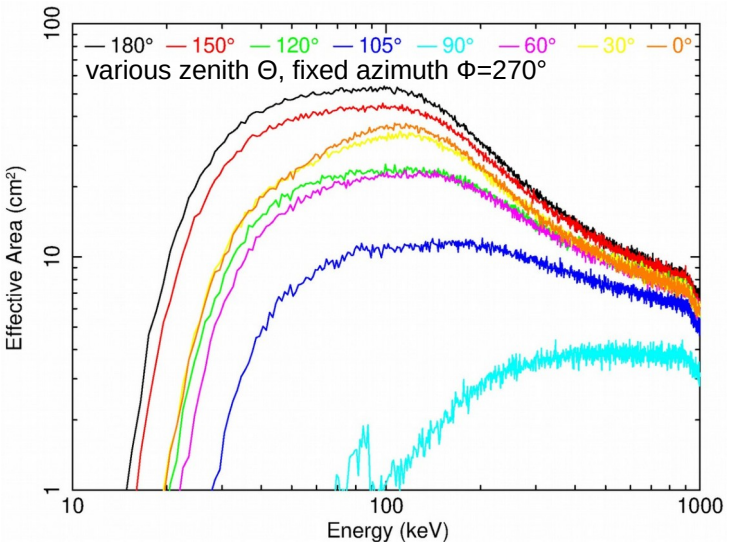
GRBALPHA IN SPACE SINCE 2021

https://grbalpha.konkoly.hu

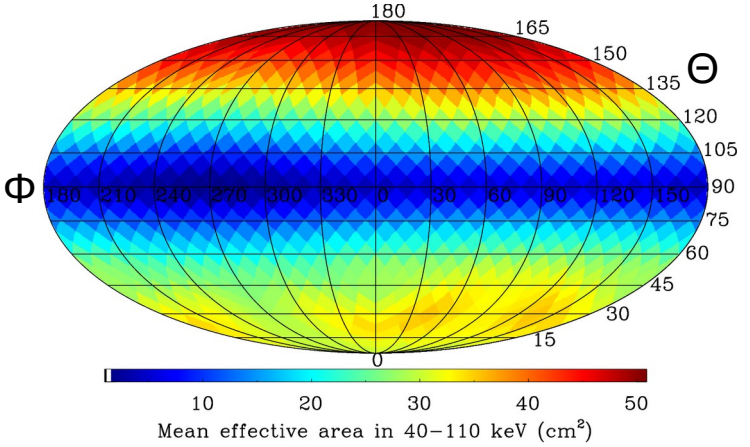
- 1-U CubeSat with gamma-ray detector (~60-900 keV)
- Small size (75x75x5mm^3) of CsI(Tl) scintillator readout by 8 MPPCs (SiPMs)



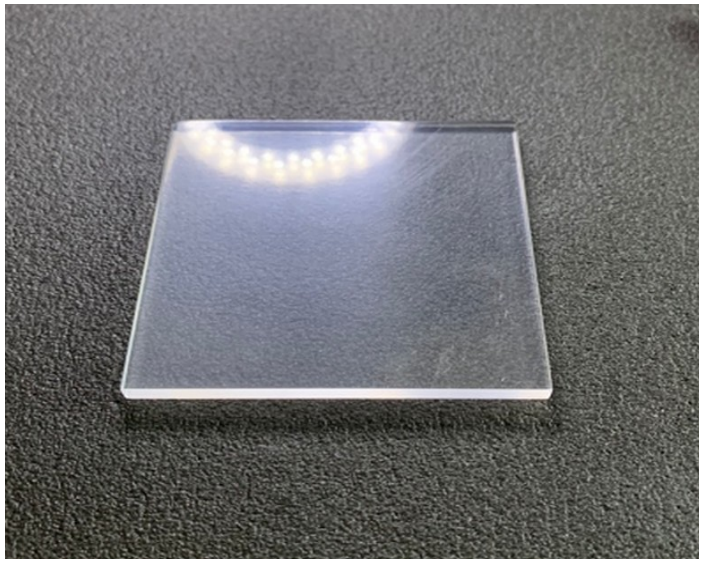




- Effective area based on GEANT4 MC simulations

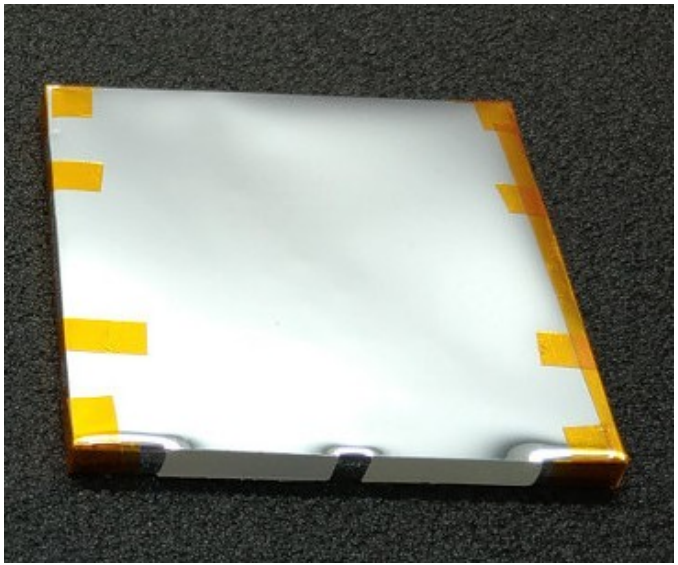


GRBALPHA:
DETECTOR ASSEMBLING

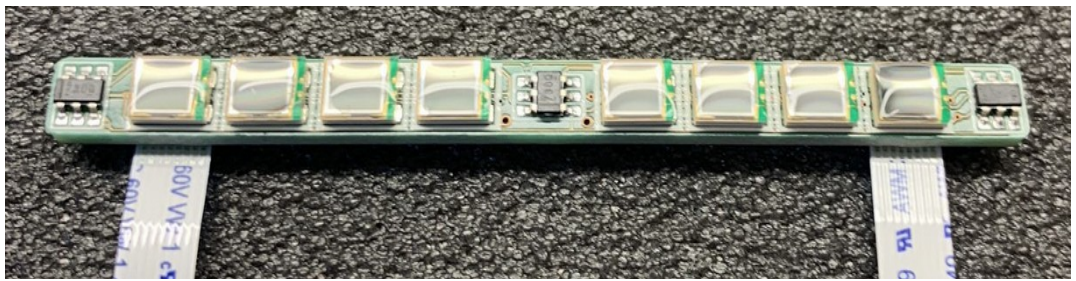


CsI(Tl) scintillator

Pál+ 2020



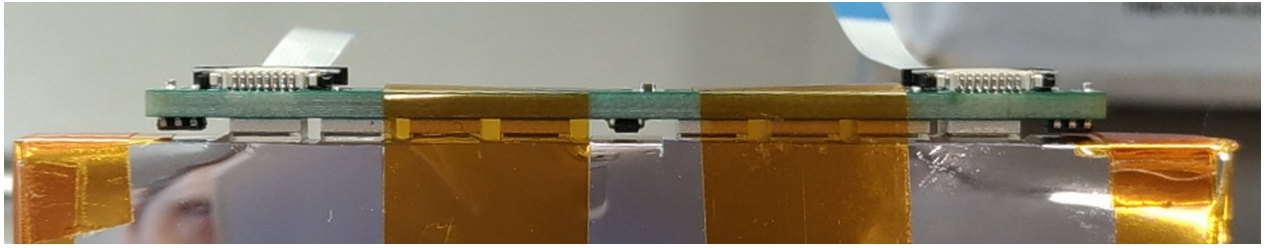
Wrapped in Enhanced Specular Reflector (ESR)

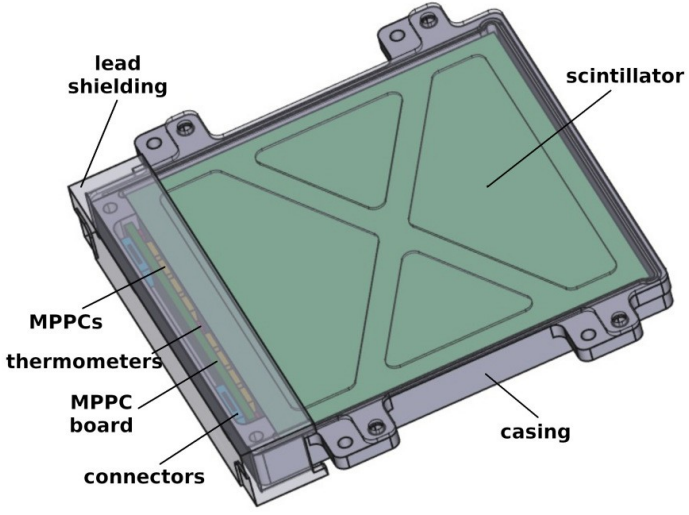


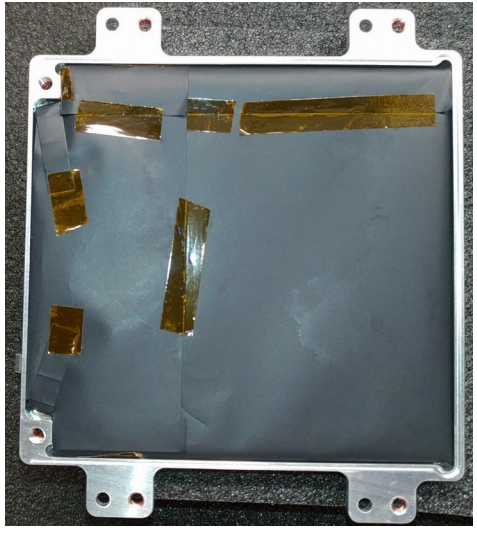
2 readout channels each with 4 MPPCs (S13360-3050 PE) by Hamamatsu

GRBALPHA:
DETECTOR ASSEMBLING

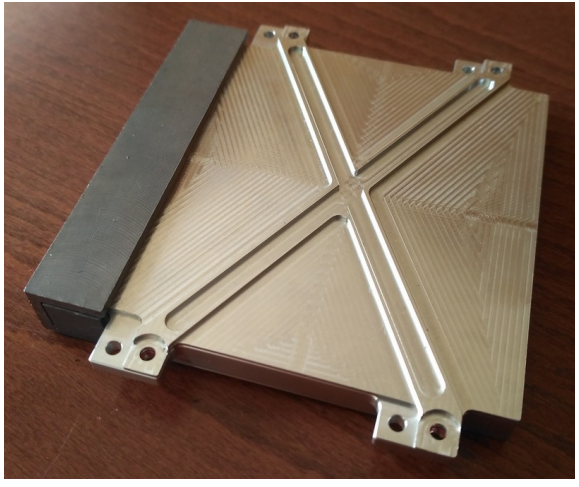
- MPPCs are coupled with crystal by optical glue DOWSIL93-500
- Detector wrapped by optically thick DuPont TCC15BL3 tedlar (PVF) to prevent light leakage from outside





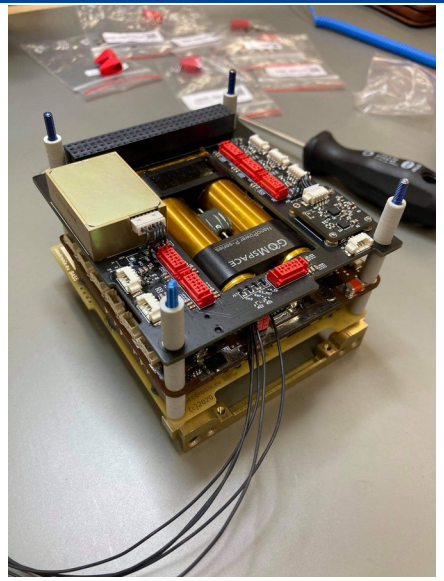


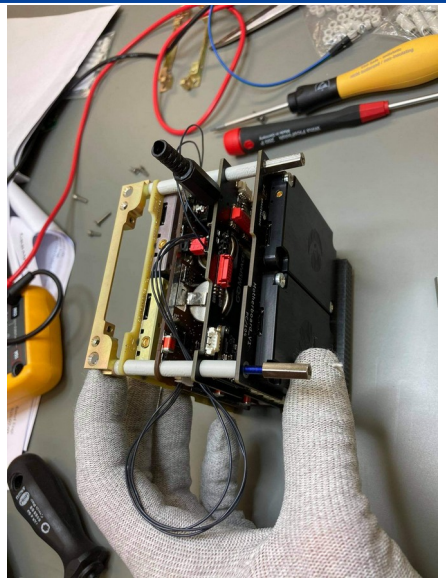
DuPont Tedlar TCC15BL3 wrapping

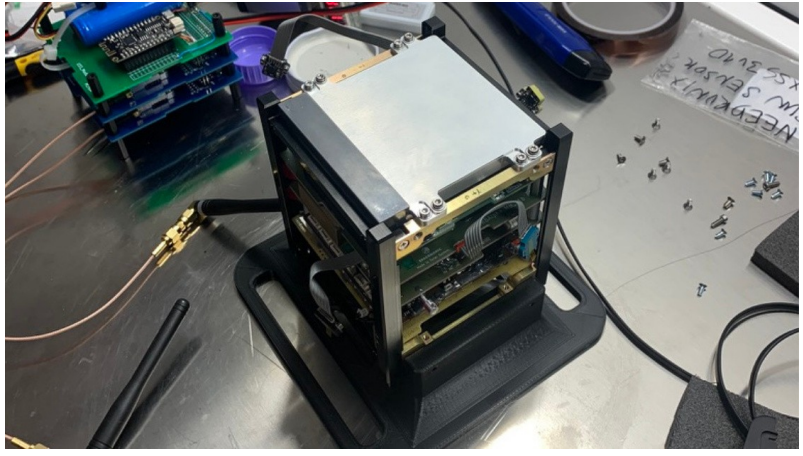


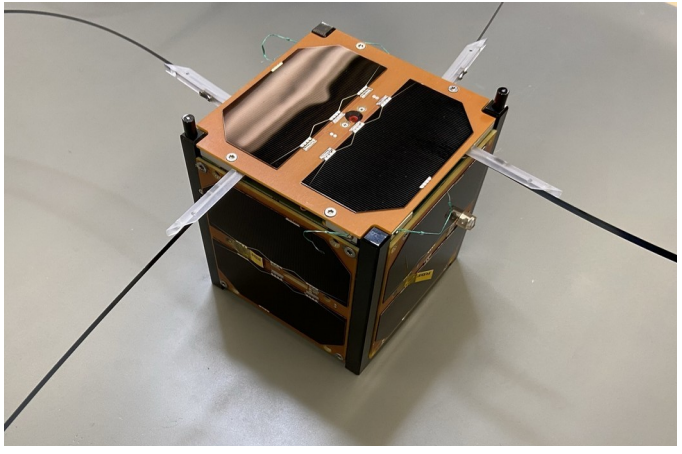
Assembled detector with 2.5mm thick Pb-Sb alloy
To reduce MPPC degradation by protons in SAA

INTEGRATION OF GRBALPHA





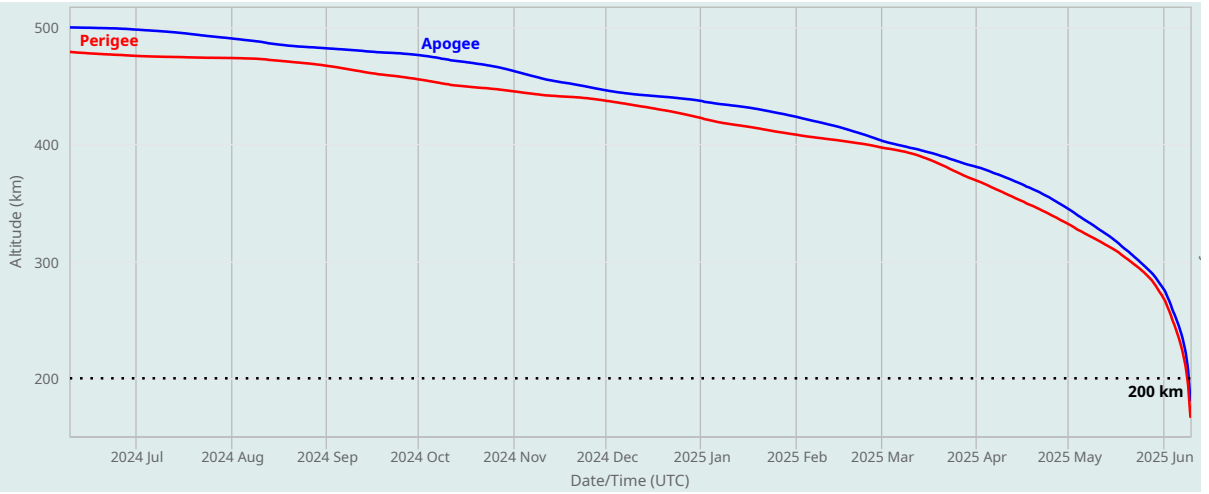




Launched to 550 km SSO on March 22, 2021

GRBALPHA DE-ORBITED ON JUNE 9, 2025

- GRBAlpha de-orbited during this workshop
- It was on orbit observing GRBs over 4 years
- 127 GRBs detected
- 134 GCN circulars published



Credit: celestrak.org

GCN Circular 40663

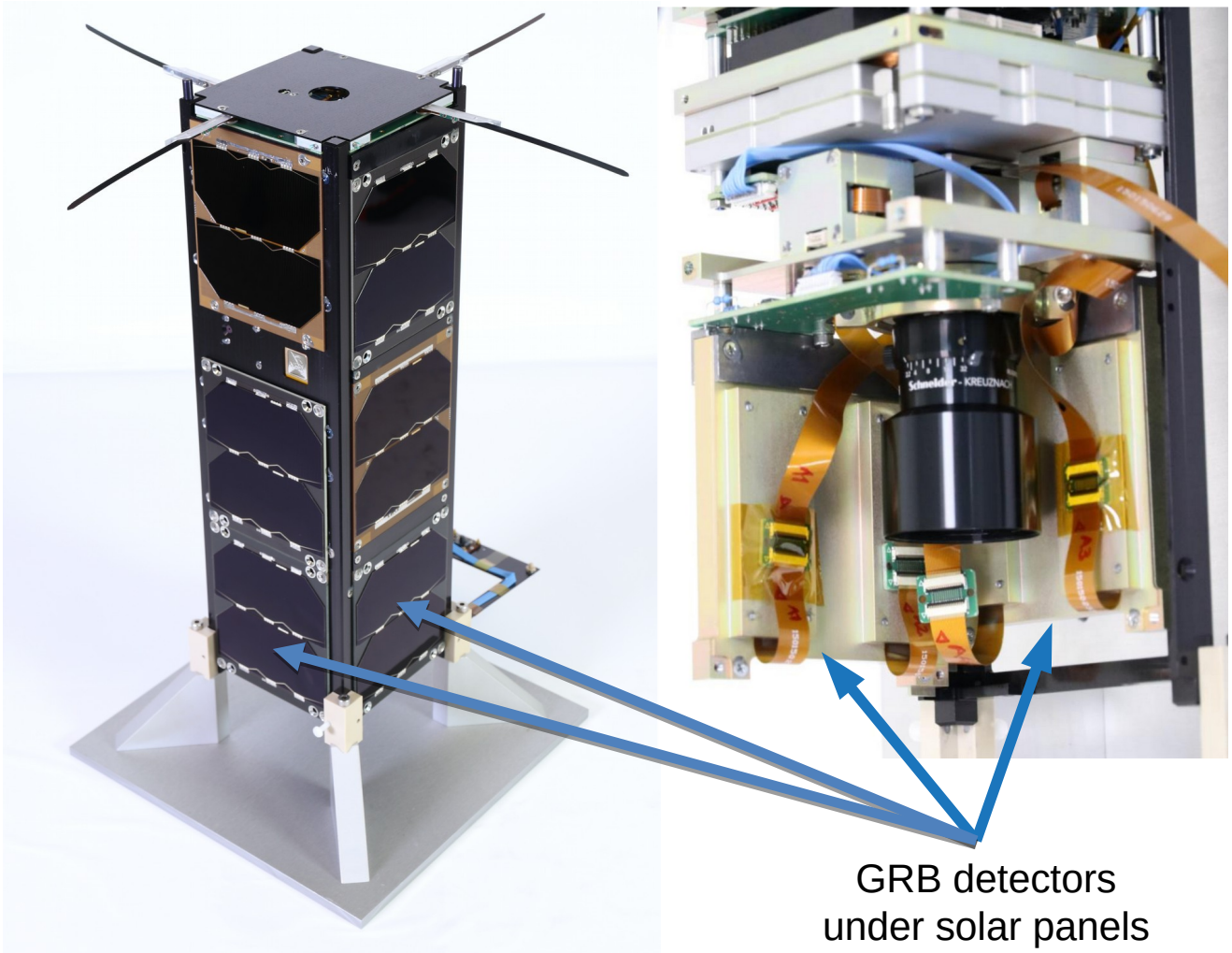
Subject GRBAlpha reentry on June 9, 2025
Date 2025-06-10T09:37:37Z (3 minutes ago)
From Andras Pal at Konkoly Observatory <apal@szofi.net>
Via Web form

A. Pal (Konkoly Observatory), N. Werner (Masaryk U.), L. Meszaros (Konkoly Observatory), J. Ripa (Masaryk U.), M. Ohno (Hiroshima U.), M. Dafcikova (Masaryk U.), H. Takahashi (Hiroshima U.), B. Csak (Konkoly Observatory), N. Husarikova, F. Munz , M. Topinka, M. Duriskova, M. Kolar, L. Szakszonova, J.-P. Breuer, F. Hroch (Masaryk U.), T. Urbanec, M. Kasal, A. Povalac (Brno U. of Technology), J. Hudec, J. Kapus, M. Frajt (Spacemanic s.r.o), R. Laszlo, M. Koleda (Needronix s.r.o), M. Smelko, P. Hanak, P. Lipovsky (Technical U. of Kosice), G. Galgoczi (Wigner Research Center/Eotvos U.), Y. Uchida, H. Poon, H. Matake (Hiroshima U.), N. Uchida (ISAS/JAXA), T. Bozoki (Eotvos U.), G. Dalya (Eotvos U.), T. Enoto (Kyoto U.), Zs. Frei (Eotvos U.), G. Friss (Eotvos U.), Y. Fukazawa, K. Hirose (Hiroshima U.), S. Hisadomi (Nagoya U.), Y. Ichinohe (Rikkyo U.), K. Kapas (Eotvos U.), L. L. Kiss (Konkoly Observatory), T. Mizuno (Hiroshima U.), K. Nakazawa (Nagoya U.), H. Odaka (Univ of Tokyo), J. Takatsy (Eotvos U.), K. Torigoe (Hiroshima U.), N. Kogiso, M. Yoneyama (Osaka Metropolitan U.), M. Moritaki (U. Tokyo), T. Kano (U. Michigan) -- the GRBAlpha collaboration.

After more than 4 years of scientific operations, on June 9, 2025, GRBAlpha, an 1U CubeSat reentered the Earth's atmosphere. GRBAlpha was the first GRB detecting CubeSat of this size and the smallest astrophysical space observatory (Pál et al. 2023, A&A, 677, A40). With 127 GRBs and a similar number of solar flare detections it successfully demonstrated that monitoring of gamma-ray transients can be effectively performed by CubeSats. We thank for the support of the radio amateur community, especially the maintainers and the station owners of the SatNOGS network. We look forward to more successful nanosatellite missions!

VZLUSAT-2: WITH TWO GRB DETECTORS

https://www.vzlusat2.cz

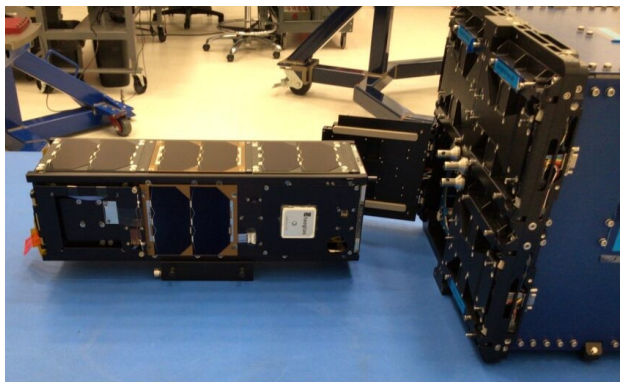


GRB detectors
under solar panels

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

VZLUSAT-2 IN SPACE SINCE 2022

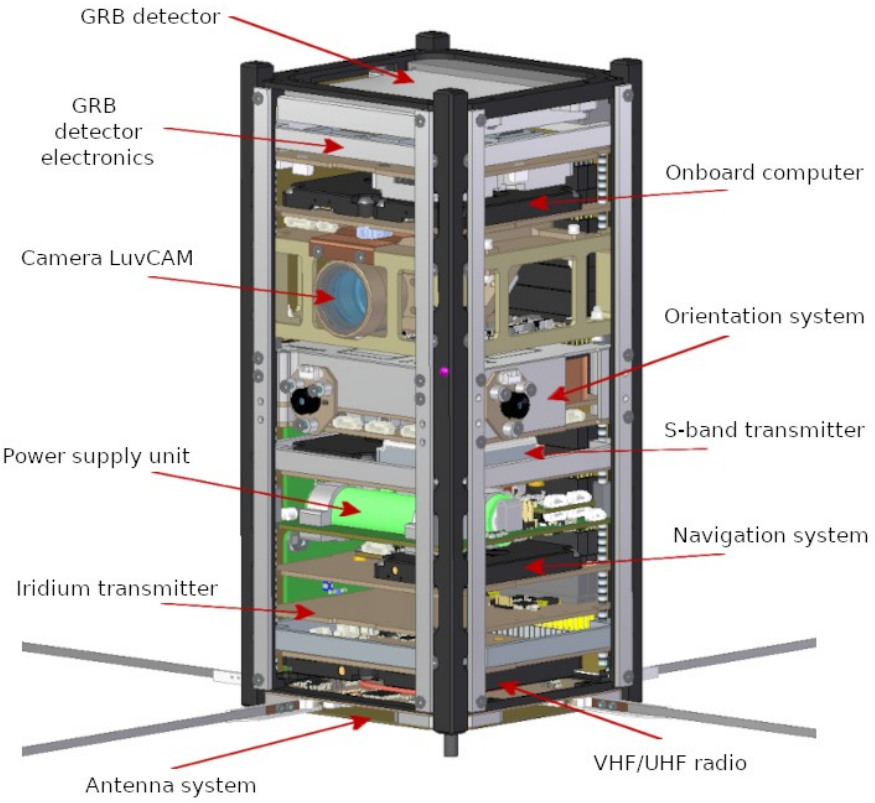
- Satellite was assembled, went through environmental tests and was shipped to USA in Sep 2020
- It was launched to 540 km SSO by Falcon 9 is on Jan 13, 2022



SAGA CONTINUES: GRBBETA (2U)

https://grbbeta.tuke.sk

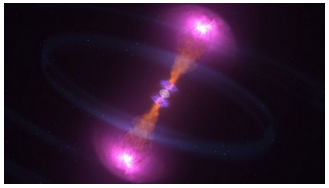
- Gamma detector unchanged
- Testing several technologies
  – inter-satellite transmitter module
  – S-band communication
  – IR position Sun sensors
  – attitude control
  – NUV sensor to test at LEO for QUVIK, including optics (LUVS team, Toronto, CA)
- Launched on July 9, 2024 by the European's new rocket Ariane 6
- Satellite passed commissioning phase
- All sub-systems works well.



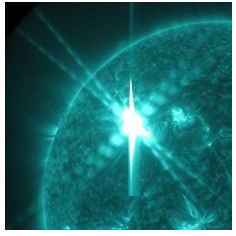
LIST OF TRANSIENTS OBSERVED BY GRBALPHA

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

234 gamma ray transients so far



127 Gamma-Ray Bursts
(24 short / 103 long)



104 Solar Flares

2 Soft Gamma Repeaters
SGR 1935+2154 (magnetar)

1 X-ray binary

List of transients observed by the GRBAlpha nanosatelite

The list contains gamma-ray transients observed by GRBAlpha

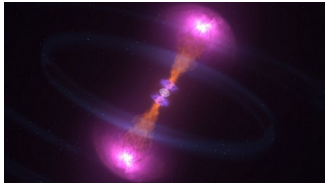
- **Event type/name** denotes the type of the detected event like GRB, Solar flare etc.
- **Peak time** denotes the time when the detected count rate from the event was maximal
- **T90** is the time interval, in which 90 per cent of all counts in the given energy band from the event are observed
- **Count 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	

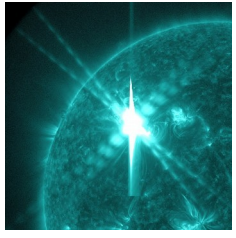
LIST OF TRANSIENTS OBSERVED BY VZLUSAT-2

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

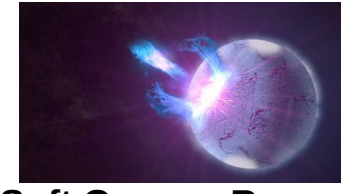
143 gamma ray transients so far



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



71 Solar Flares



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

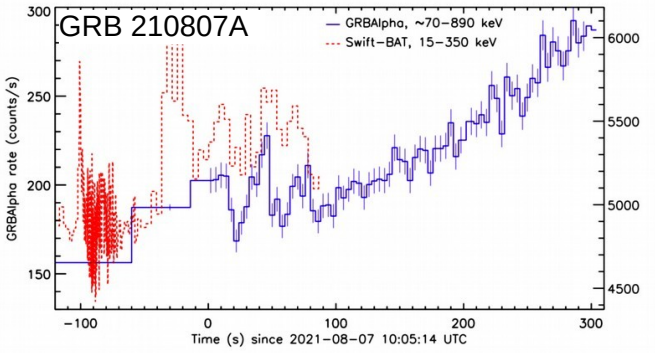
List of transients observed by the GRB detectors on the VZLUSAT-2 nanosatelite

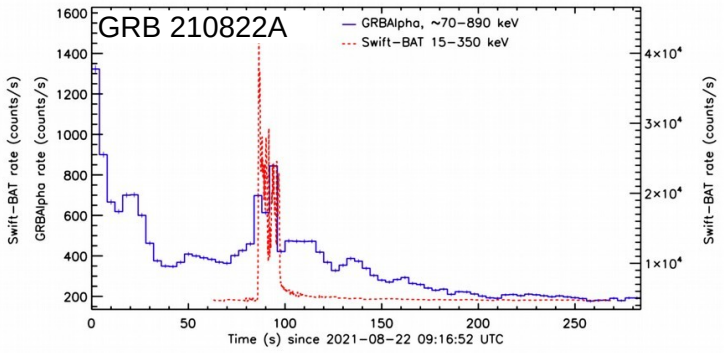
The list contains gamma-ray transients observed by the GRB detectors on VZLUSAT-2

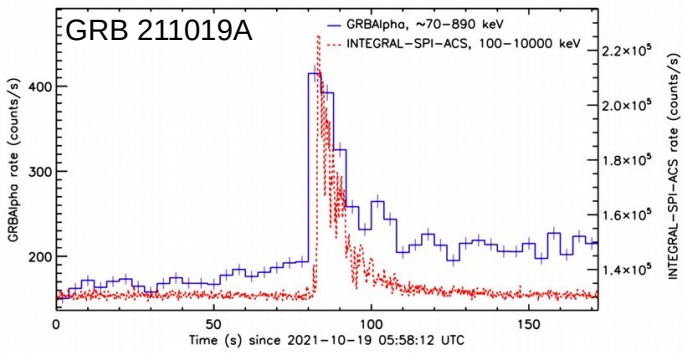
- **Event type/name** denotes the type of the detected event like GRB, Solar flare etc.
- **Det. unit** is the number of the detector unit (no. 0 or no. 1).
- **Peak time** denotes the time when the detected count rate from the event was maximal
- **T90** is the time interval, in which 90 per cent of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

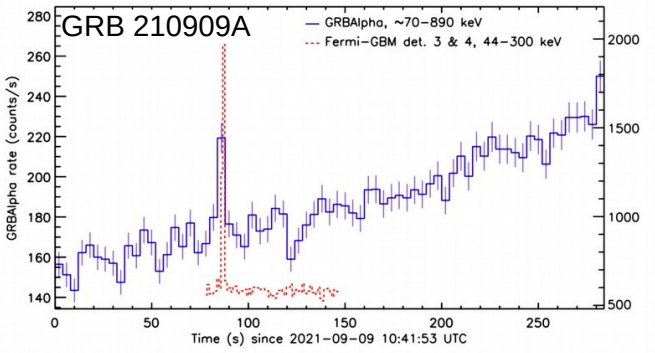
Event type/name	Det. unit	Peak time (UTC)	T90 [s]	Count rate [cnt/s]	Band [keV]	S/N [σ]	Raw LC	Bkg-sub LC	LC res. [s]	GCN circ.	References	Comment
Solar flare	no. 1	2023-02-24 17:13:51	35	48.5	~40-890	9.2	PNG, EPS	PNG, EPS	1		Fermi/GBM Solar Orbiter/STIX GOES	
Solar flare	no. 1	2023-02-20 14:55:26	121	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	X1.1 class

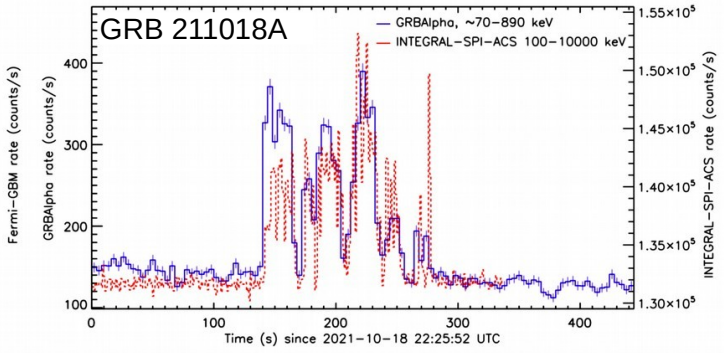
GRBALPHA & VZLUSAT-2: EXAMPLE GRB DETECTIONS









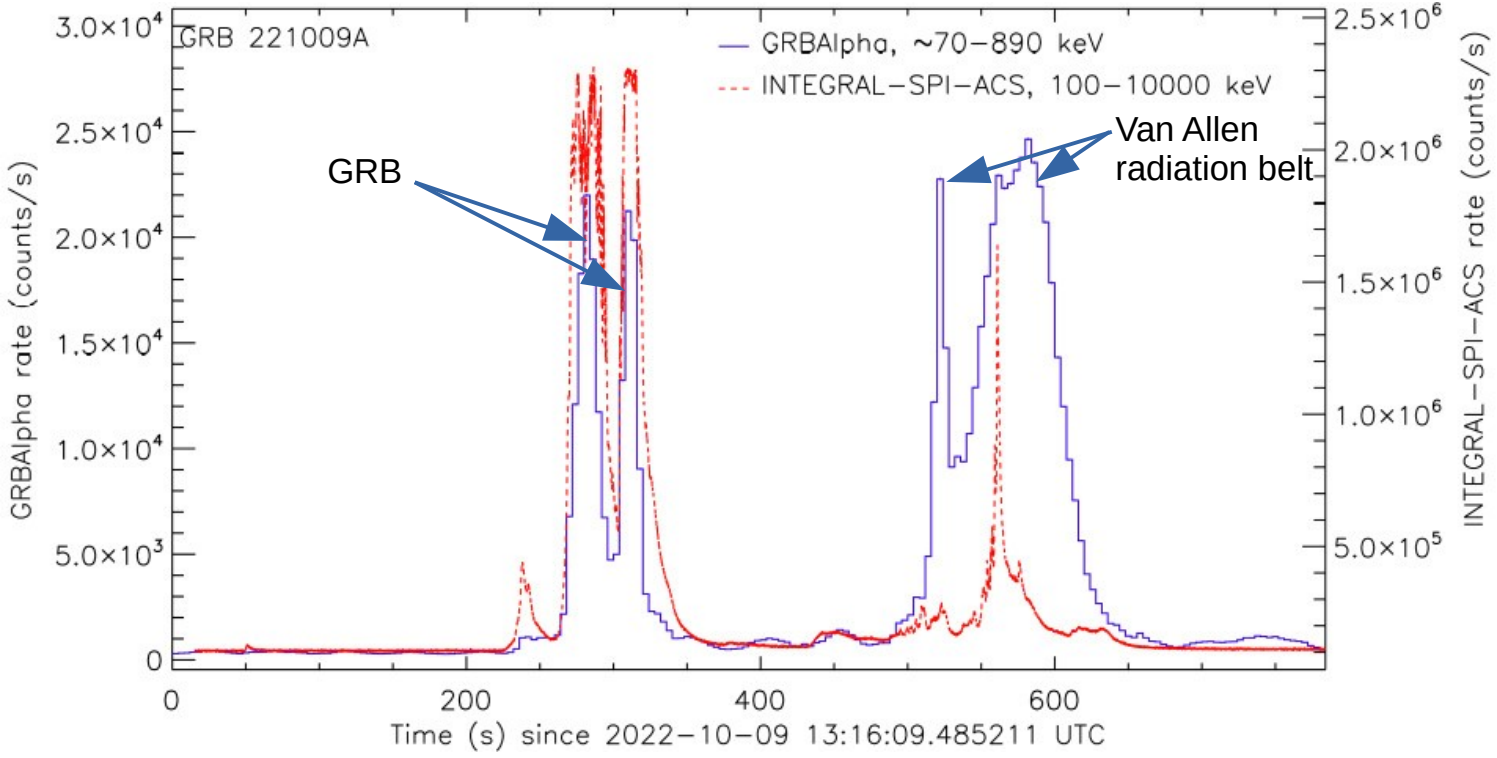


- GRB detections by GRBAlpha confirmed by other missions: Swift/BAT, Fermi/GBM, INTEGRAL/SPI-ACS **...**

- GRBAlpha's GRB 241026A at z=2.8, light travel time 11.4 Gyr
- VZLUSAT-2's GRB 241025A at z=4.2, light travel time 12.3 Gyr
- Demonstration that nano-satellites can host payloads sensitive enough to routinely detect GRBs!

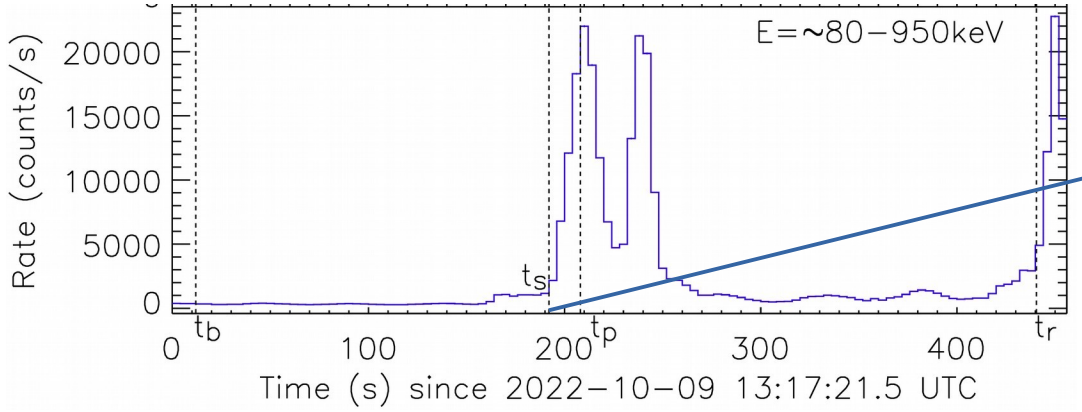
GRB 221009A
BRIGHTEST OF ALL TIME (BOAT)!

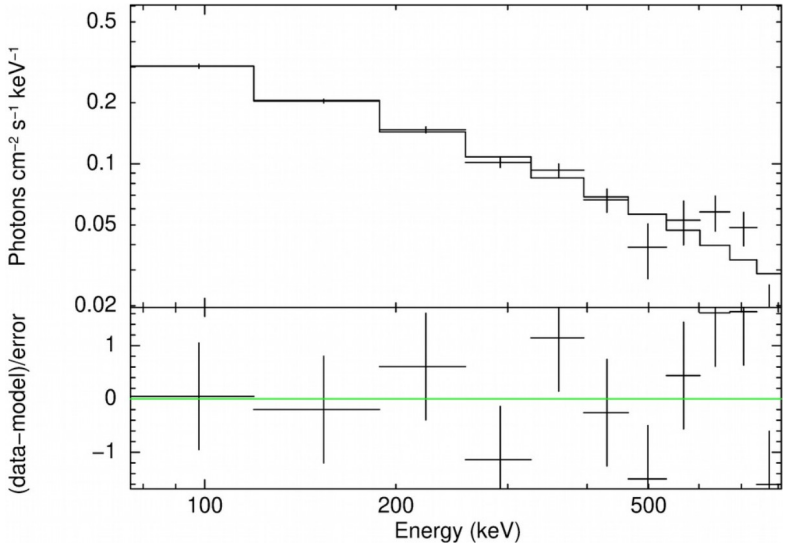
- **The most intense GRB ever recorded in the 55 years history of GRB science**
- Claimed to be once-in-10,000-year event
- Detected by several instruments: Fermi/GBM+LAT, Swift, INTEGRAL, Wind-KONUS, AGILE etc.
- So bright that it saturated larger detectors and effected Earth ionosphere. Redshift z = 0.151 (740 Mpc).
- LHAASO and Carpet 2 observed very high energy photons reaching 18 TeV



GRB 221009A
BRIGHTEST OF ALL TIME (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
- $L_{iso} > 8.4 \times 10^{52}$ erg/s (4 s scale) in the 1 − 10 000 keV
- **$E_{iso} > 1.5 \times 10^{54}$ erg in 1 - 10 000 keV (> 2.5 solar rest-mass energy)**
- Details in Řípa et al. 2023, A&A, 677, L2



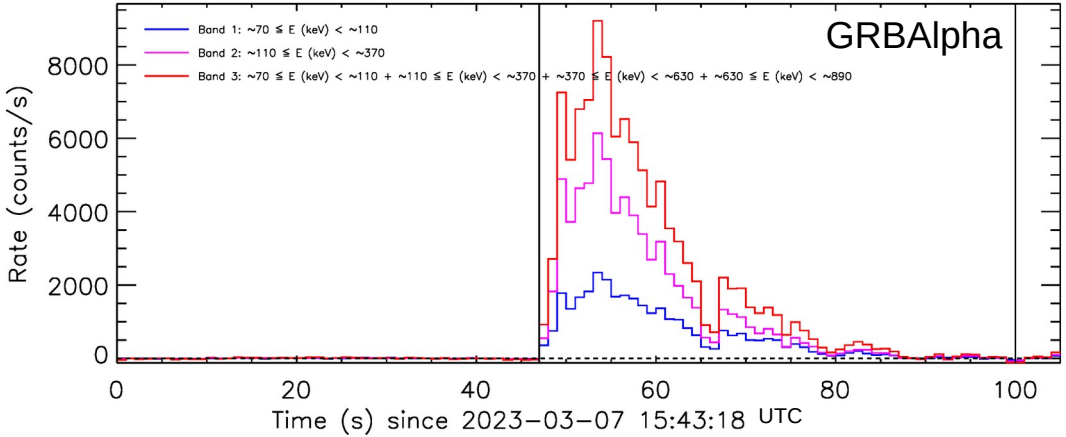


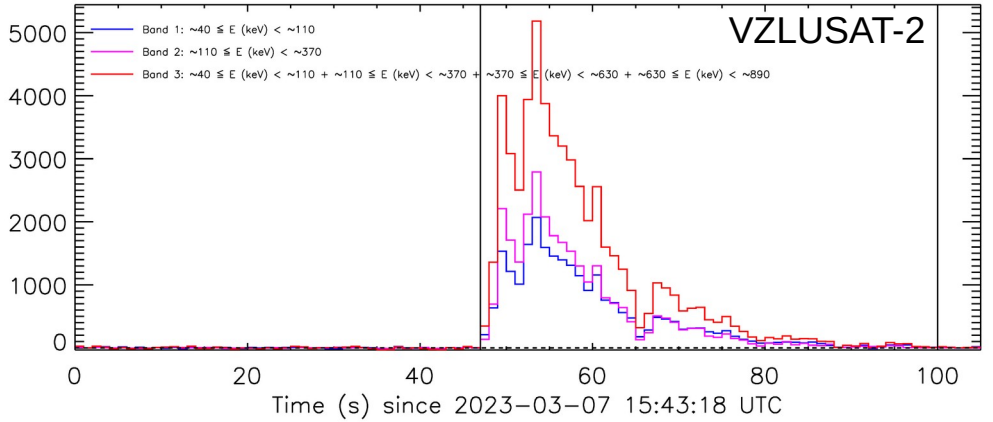
Cutoff power law
α = 0.7 ± 0.1
E_0 = 750 (+410,-200) keV
A = 8 (+6,-4) ph keV/cm²/s

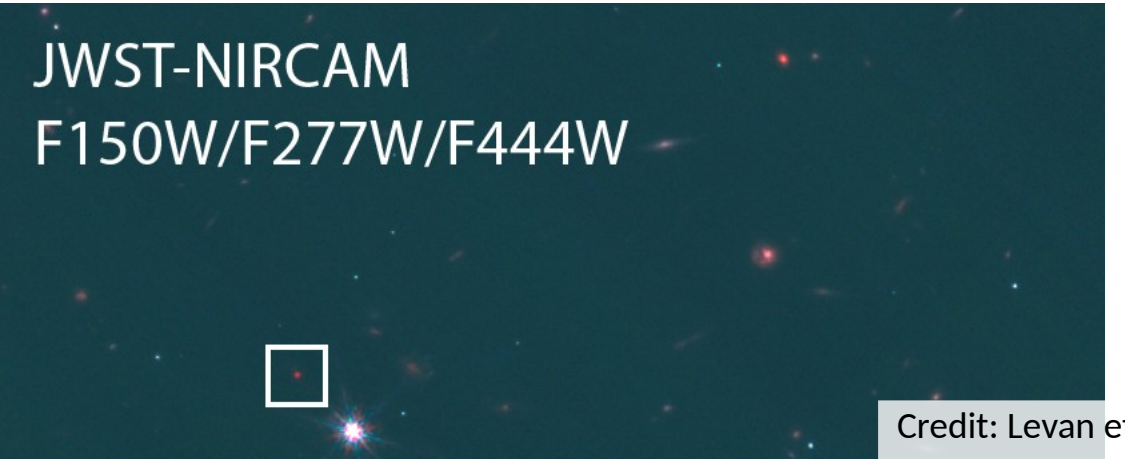
$$N(E) = A\left(\frac{E}{1\text{keV}}\right)^{-\alpha} \exp\left(-\frac{E}{E_0}\right)$$

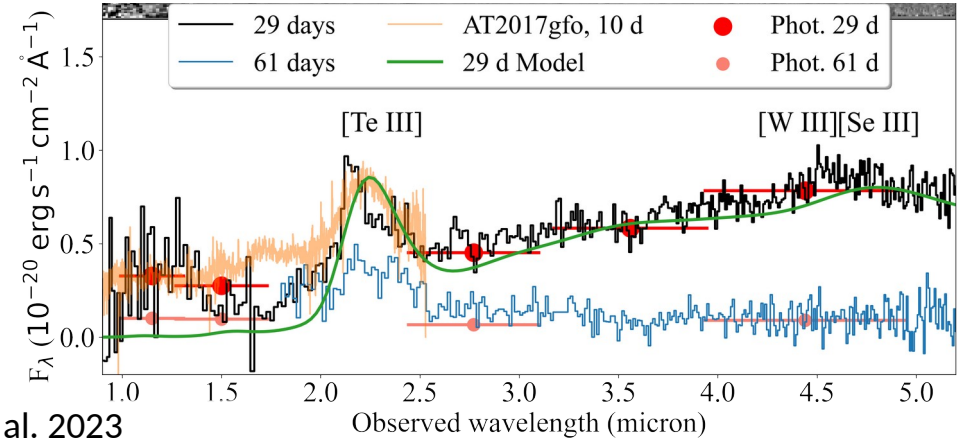
VZLUSAT-2 AND GRBALPHA JOINT DETECTIONS: GRB 230307A

- **2nd brightest GRB ever detected**
- Long GRB (T_{90} = 30 s) with identified kilonova pointing the merger involving a NS !
- JWST provided the infrared spectrum of a kilonova identifying elements heavier than iron







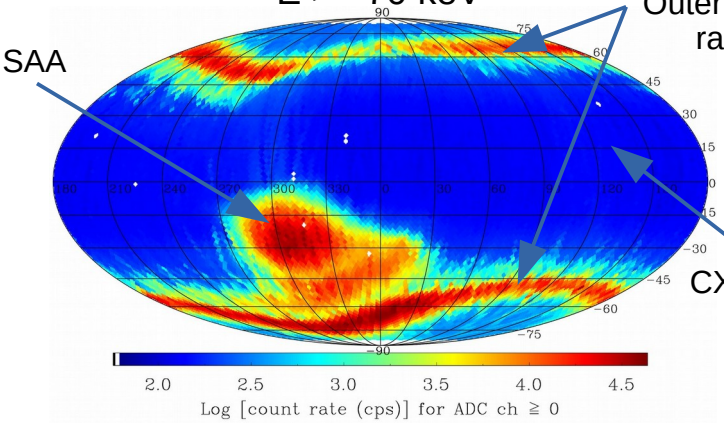


Credit: Levan et al. 2023

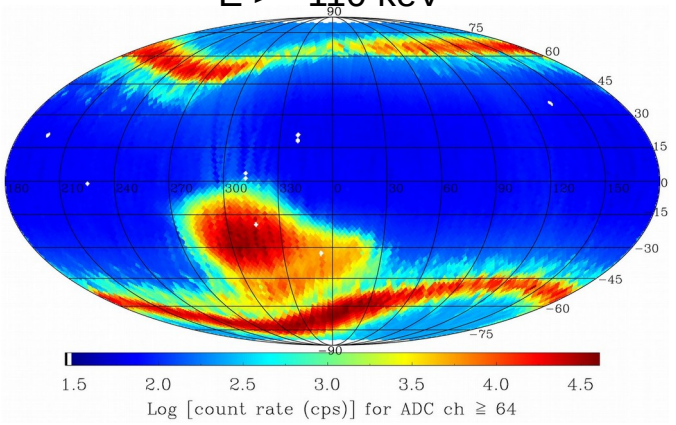
GRBALPHA: HALF-YEAR BACKGROUND MAP

- 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

E > ~70 keV

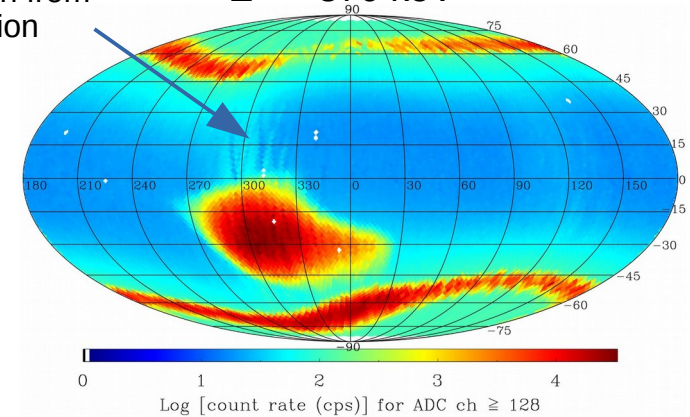


E > ~110 keV

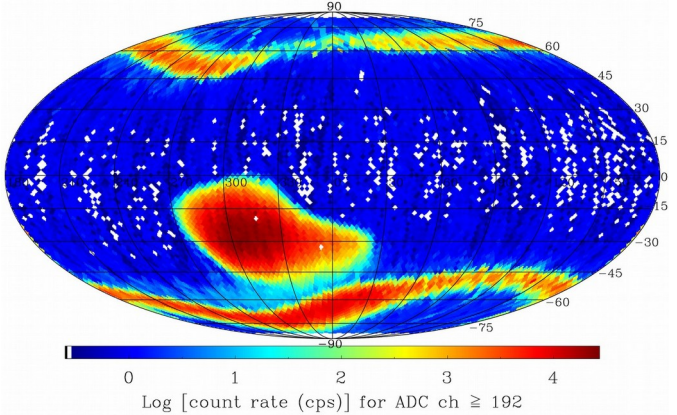


contribution from activation

E > ~370 keV

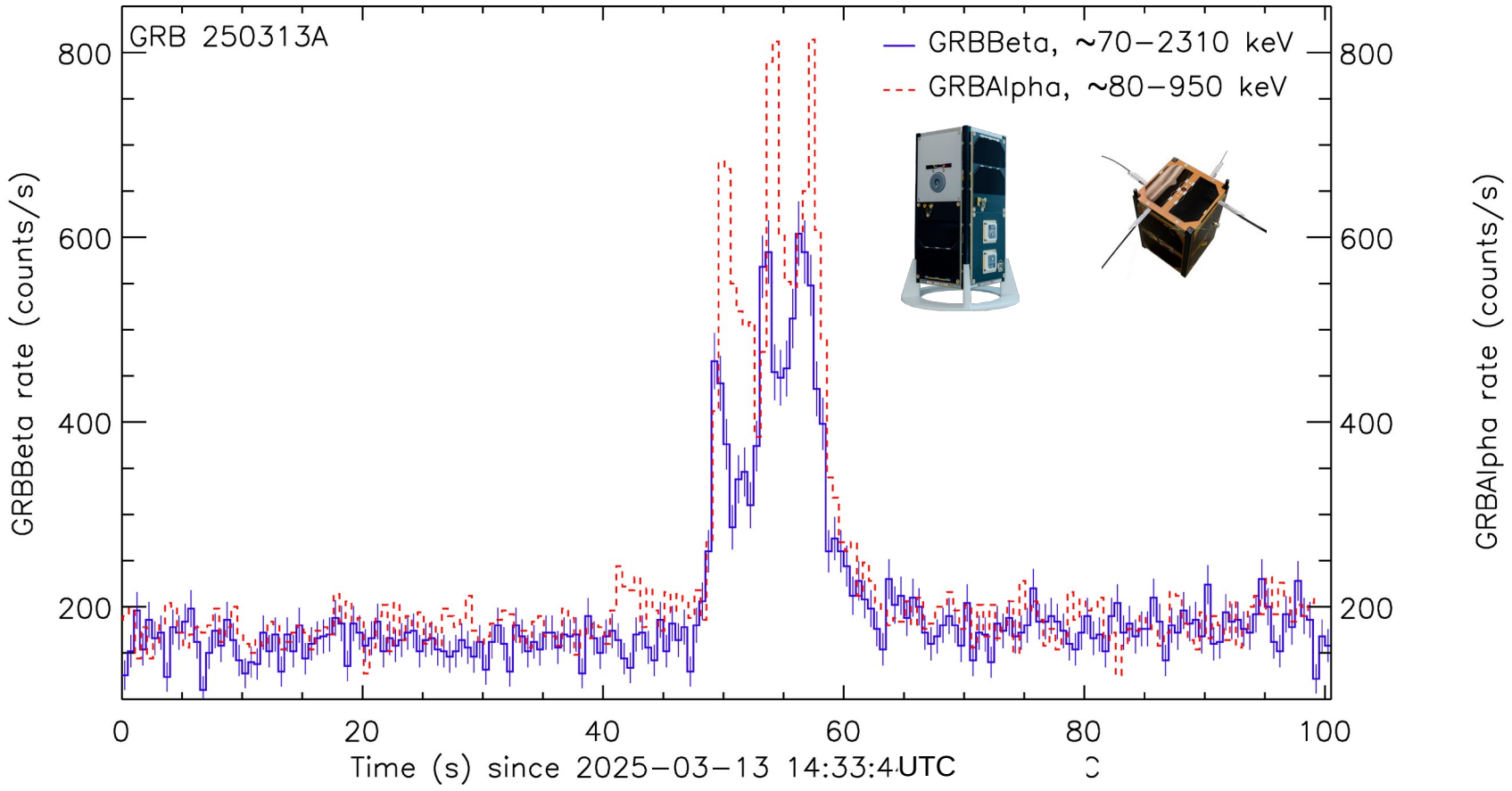


E > ~630 keV

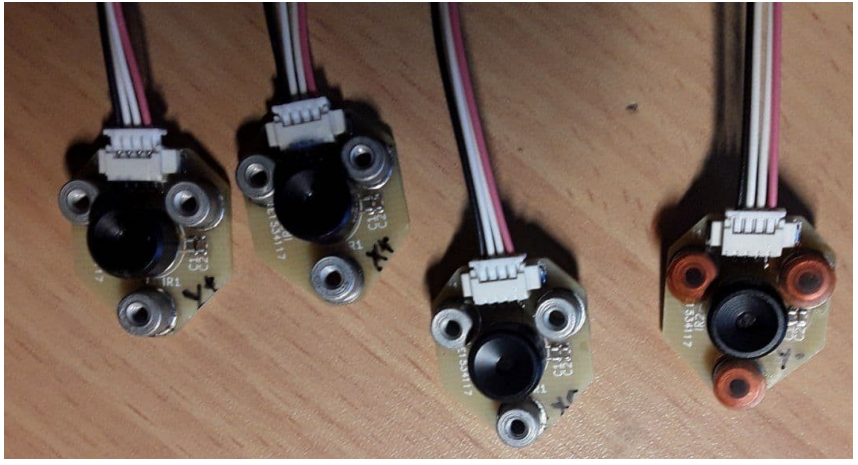


TRANSIENTS OBSERVED BY GRBBETA

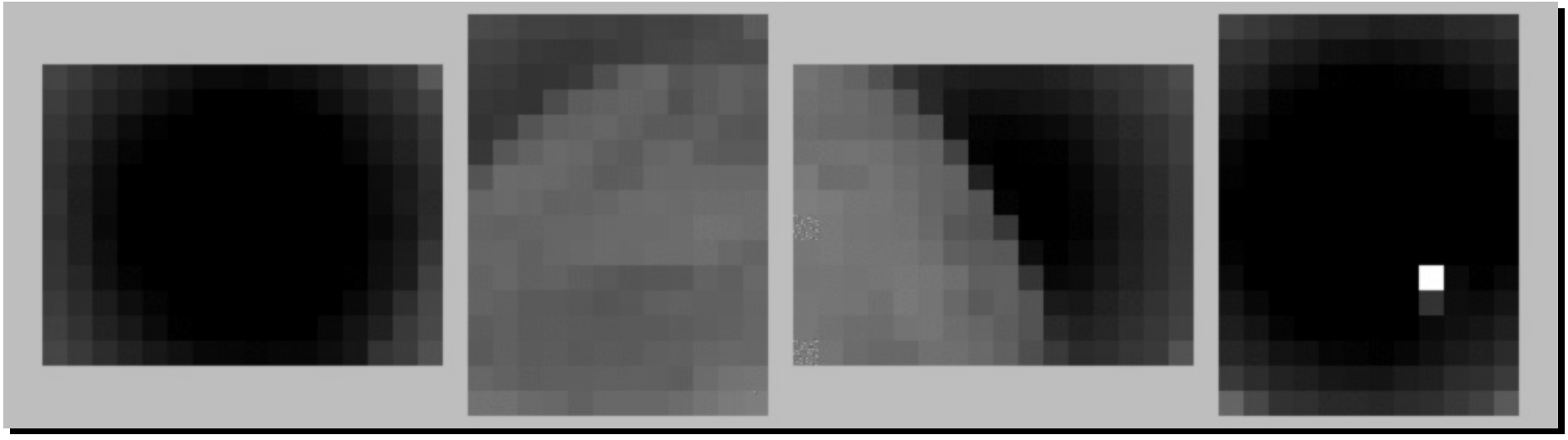
- **2 solar flare and 11 gamma-ray bursts so far**



GRBBETA: ATTITUDE DETERMINATION BY IR SENSORS



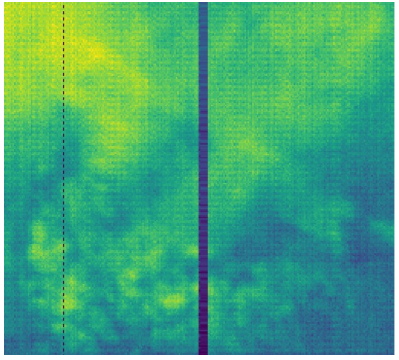
Credit: András Pál



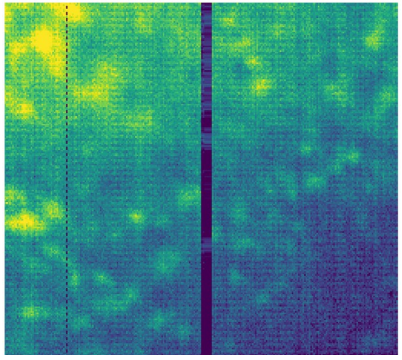
NUV CAMERA LUVCAM @ GRBBETA

- LUVCam @ GRBBeta covers near-UV band 240-310 nm
- Dunlap Institute - University of Toronto: S. Sivanandam, A. Tohuvavohu for LUVCam team
- Operations of satellite by Marianna Dafčíková

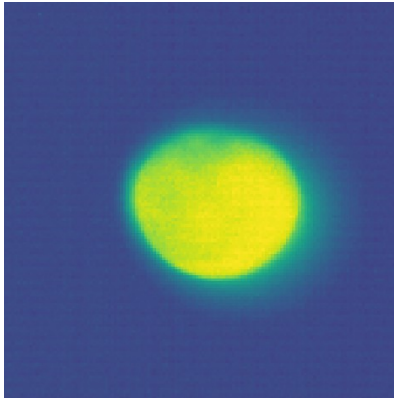
Clouds: 2025-04-15



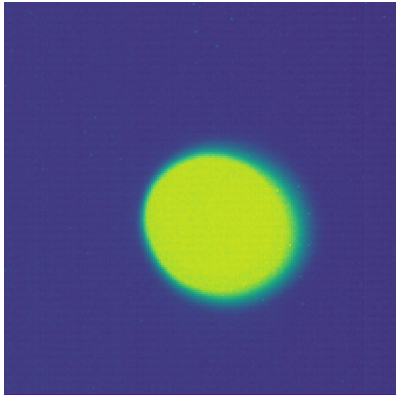
Clouds: 2025-04-30



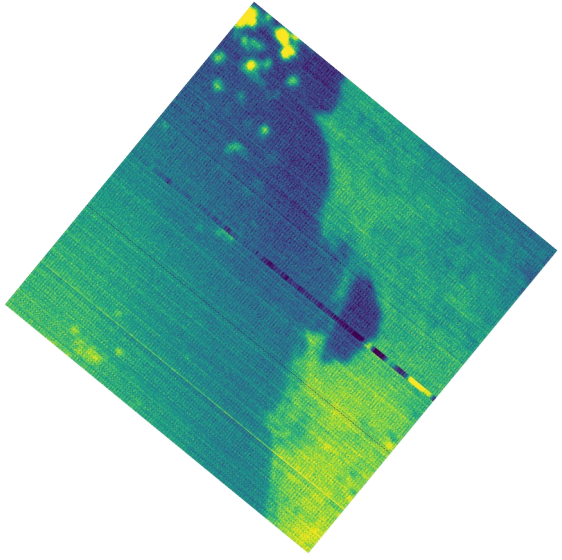
Moon: 2025-06-13

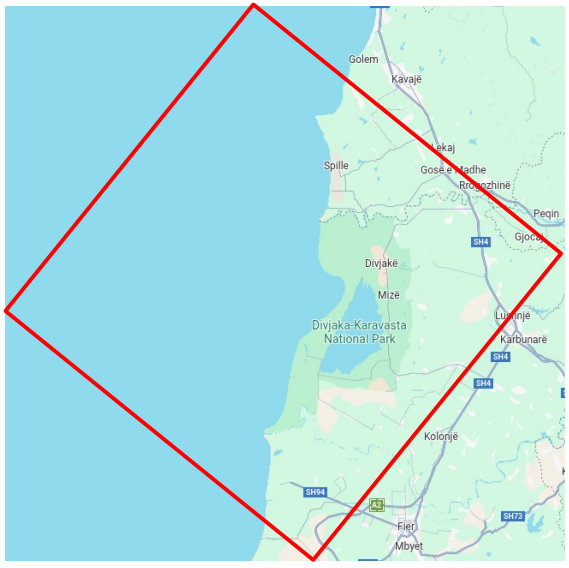


Moon: 2025-09-08



Divjaka-Karavasta National Park, Albania
2025-07-09





SUMMARY

- **GRBAlpha:**
  - worked at LEO >4 years, de-orbited this June
  - detected ~230 transients up to now (GRBs, solar flares, SGRs)
  - detector concept proven
- **VZLUSAT-2:**
  - at LEO >3 years
  - detected ~140 transients up to now
  - both CubeSats map background at LEO
  - characterized aging of MPPCs over 3 years at LEO
- **GRBBeta:**
  - launched >1 year ago, all systems works well
- **Details in publications:**
  - Řípa et al. 2025, NIM-A, 1076, 170513
  - 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
  - Mészaros et al. 2022, Proc. of SPIE, 12181, 121811L
  - Pál et al. 2020, Proc. of SPIE, 11444, 114444V
  - Werner et al. 2018, Proc. of SPIE, 10699, 106992P