Performance of detectors on GRBAlpha and VZLUSAT-2 nanosatellite missions

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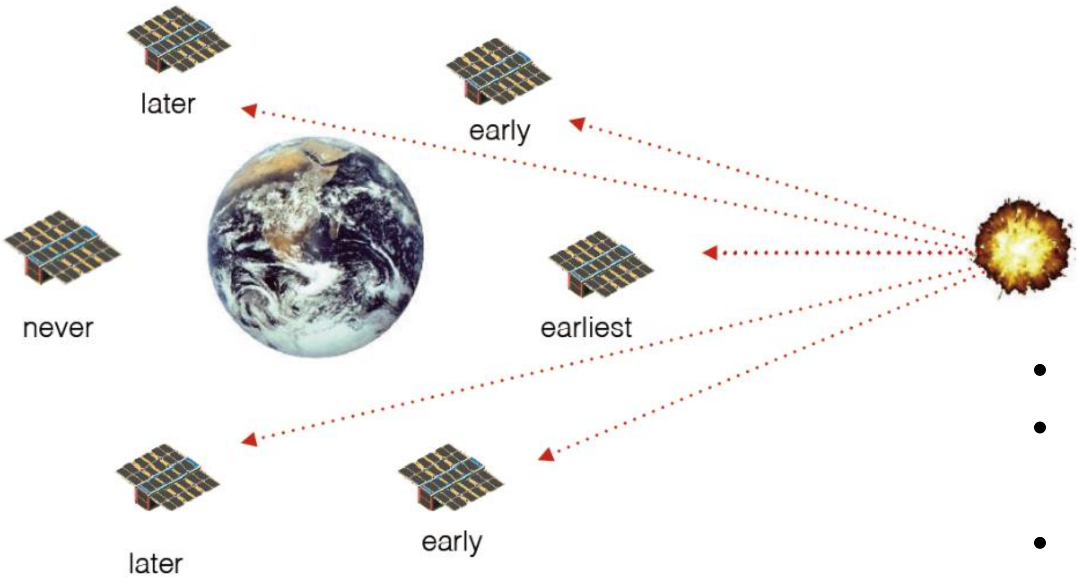
AXRO 2023

Prague 7/12

All-sky GRB coverage



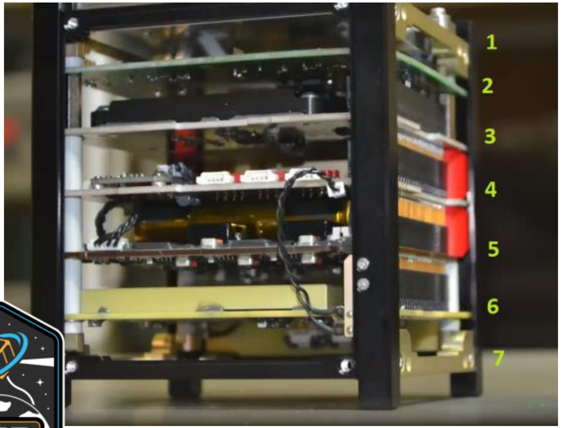
- IPN-like triangulation principle
- at LEO needing **sub-ms** timing precision to reach 1˚ localization
- constellation of 9+ satellites
- many projects in progress (BurstCube, Hermes)

In-orbit demonstration

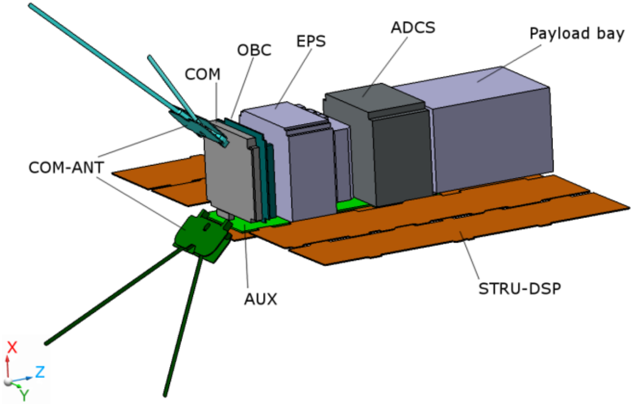
Two missions on polar orbits

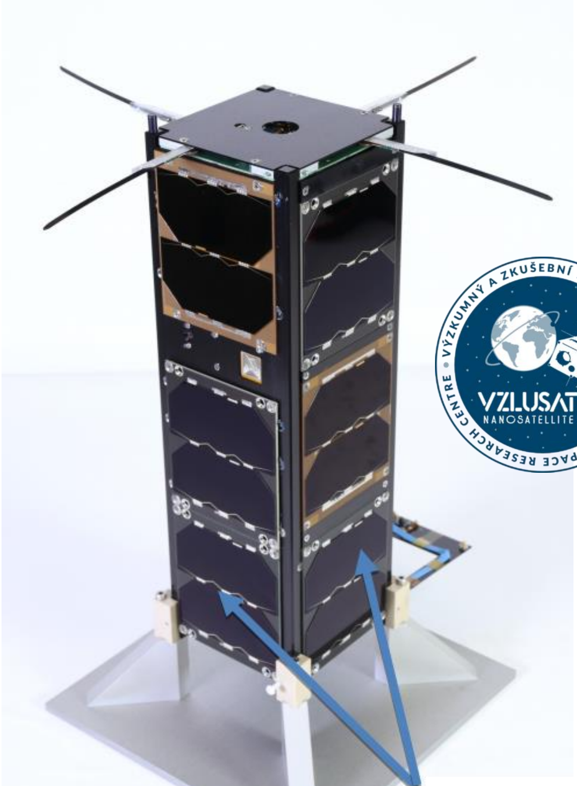
GRBAlpha – 1U – from 03/2021 (very NewSpace devs :)

VZLUSAT2 – 3U – from 01/2022 (secondary payload)



towards CAMELOT constellation

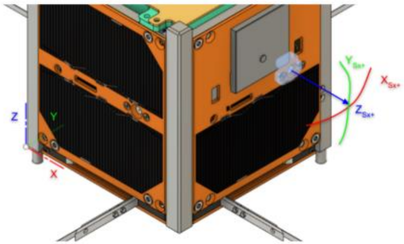


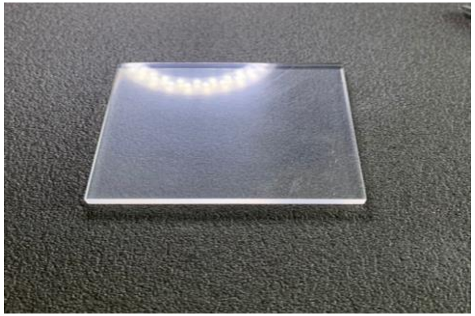


look under solar panels

Detector design & assembly

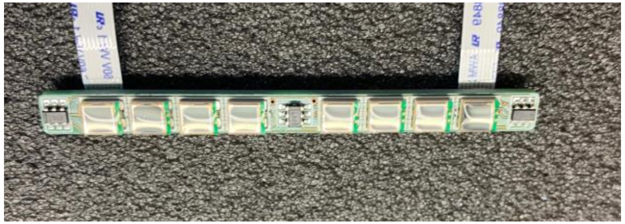
simplest hard X/gamma-ray detector

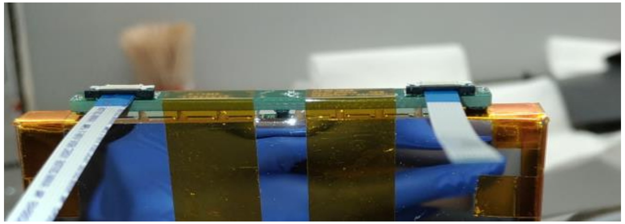




CsI (Tl) scintillator – 5x higher yield than BGO (lower energy threshold)
75× 75×5mm, covered with ESR reflecting foil
open on single side

2 x 4 Si PM arrays – Hamammatsu S13360-3050PE
glued with optical rubber

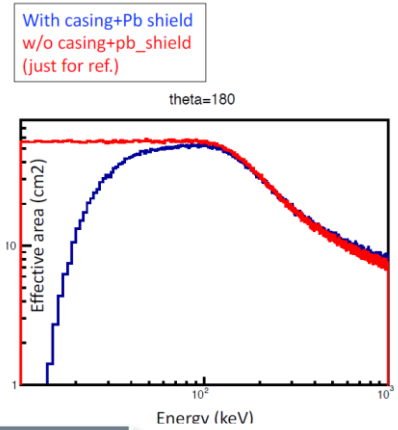


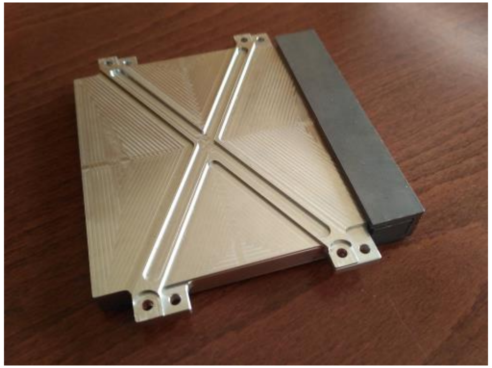


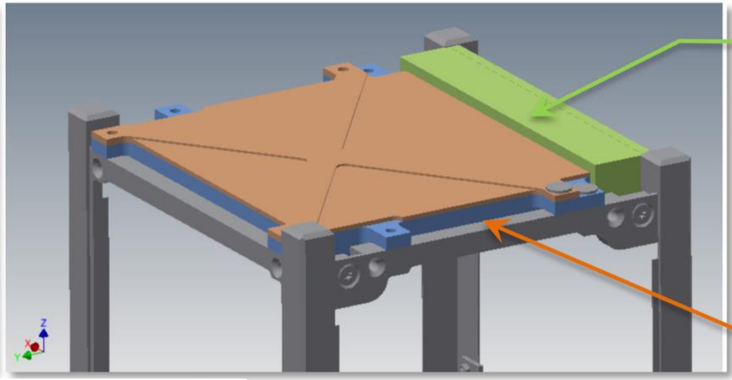
Detector design

right amount of shielding
(for VZLUSAT including outer solar panels)
→ background level higher but acceptable in polar regions

detectors sensitive from both sides
(1U not an obstacle above 200 keV)



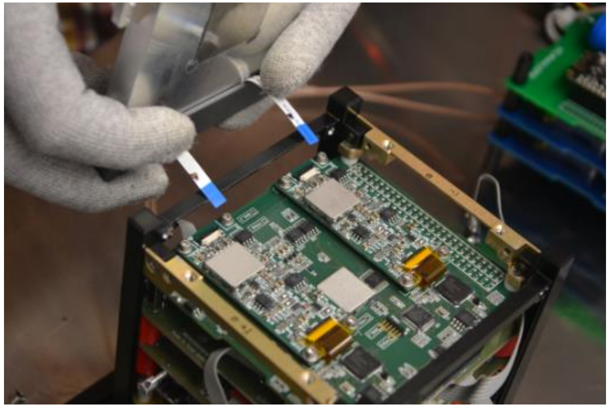




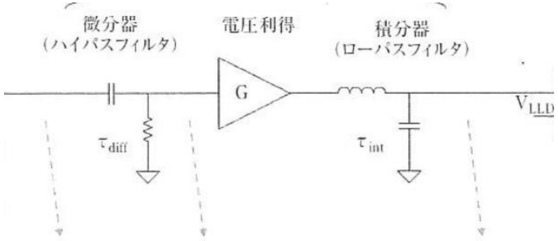
2.5mmt Pb shield only around the MPPC to reduce the radiation dose

75x75x5mm^3 CsI scintillator
Enclosed by 1mmt Al casing

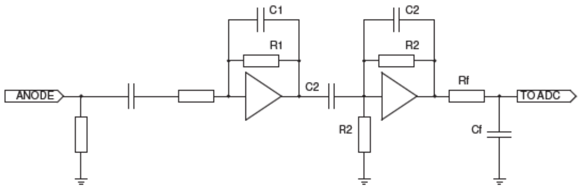
Detector design – signal shaping



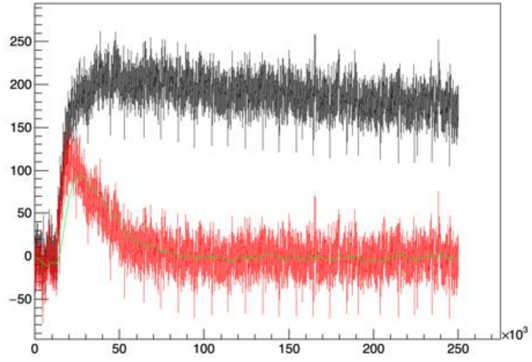
electronics / analog part (*no ASIC*)
concept CR (differ.) – RC (integ.) combined filter



final 2-stage amplifier (R_1C_1=3.3 ms decay,
next shaping defining 15 μs eff. pulse duration: C_2R_2= 3 μs, R_fC_f=1 μs)

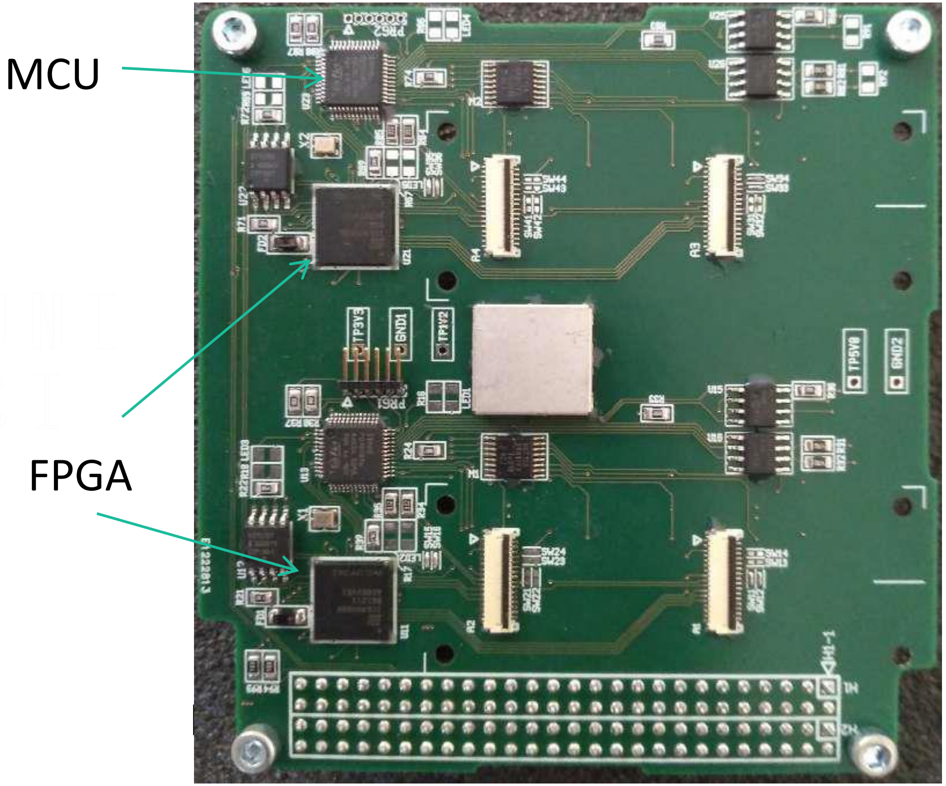


careful design and fabrication
M. Ohno, A. Pál, L. Mészáros



Digital processing

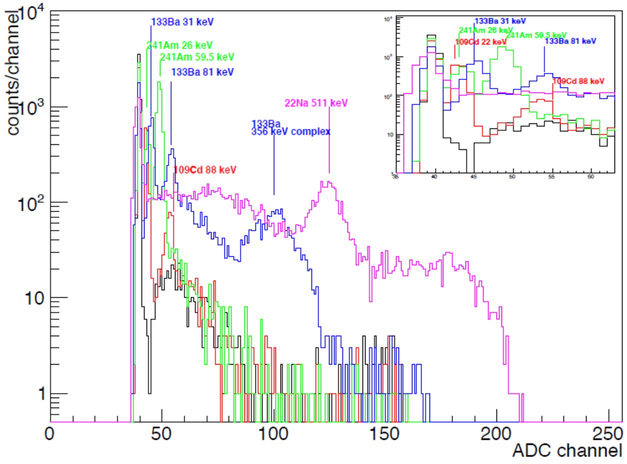
- AD conversion to 128 channels
  stored in histogram (currently 1s integration)
- 2 channels for redundancy (no failure fo far)
- software upgrades possible even with very limited uplink bandwidth
- storage/downlink improved significantly with variable-length compression (Pal et al 2023)

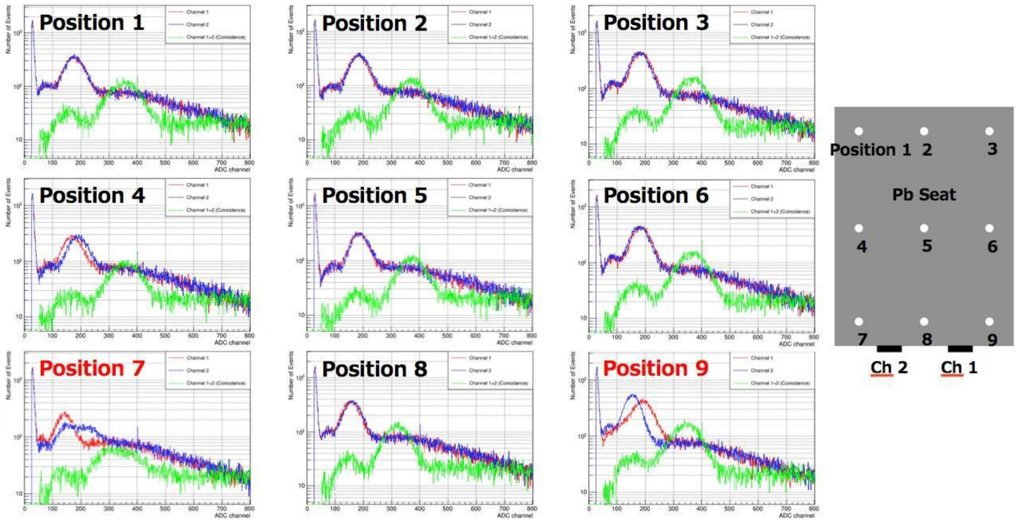


Pathfinders needed

- lot of testing on ground (shape of scintillators, coupling, electronic design)
- flight verification needed for further expansion (in size and numbers)

calibration spectra





variation of detector response for gamma source at different positions
(from CAMELOT feasibility study)

Communication limits

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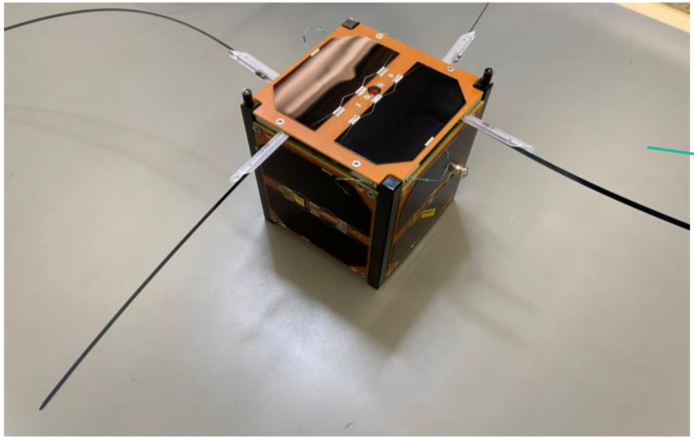
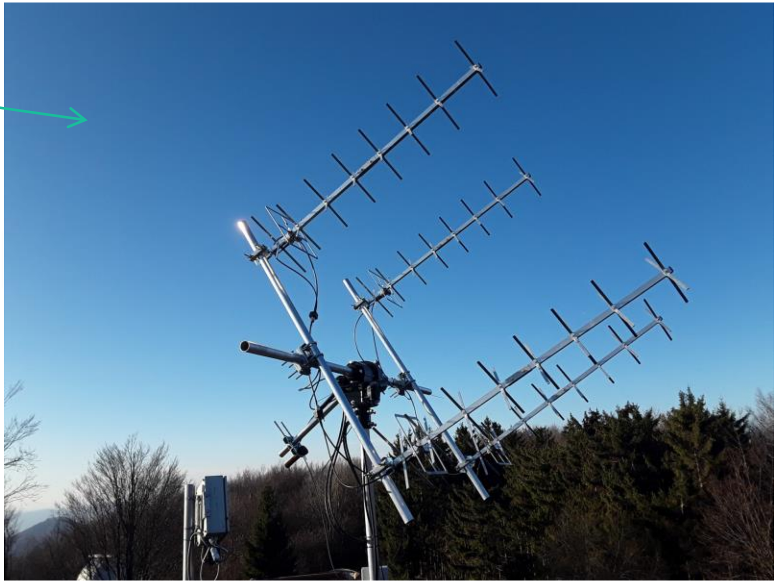
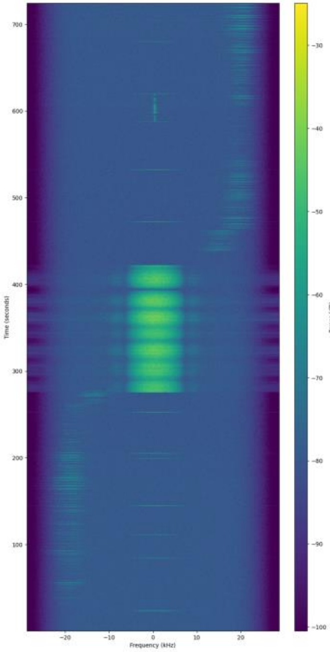


only VHF/UHF (almost omnidirectional) transmission

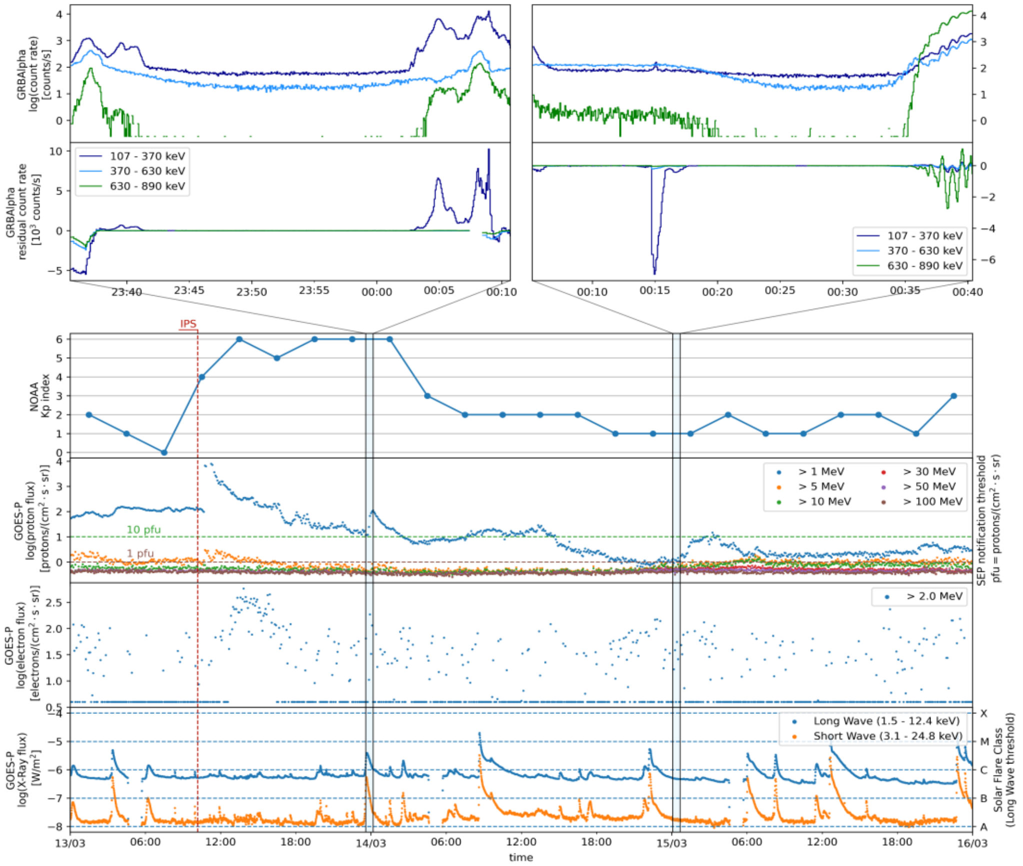




using storage of digital board
(direct transfer to radio)
– day of 1Hz sampling in 4 bands

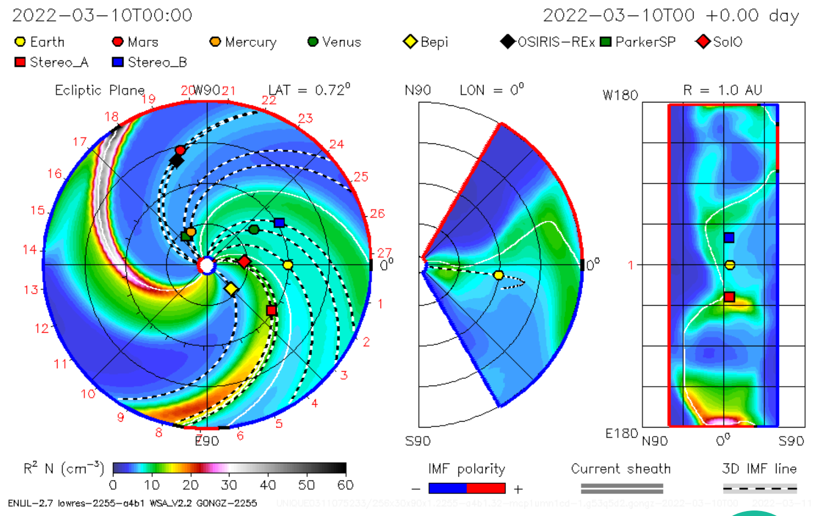
selecting chunks of data around GCN events (no autonomous trigger)
dropping scrambled packets on chosen (amateur) stations (up to 1 MB per day, power limited)

Space weather correlations

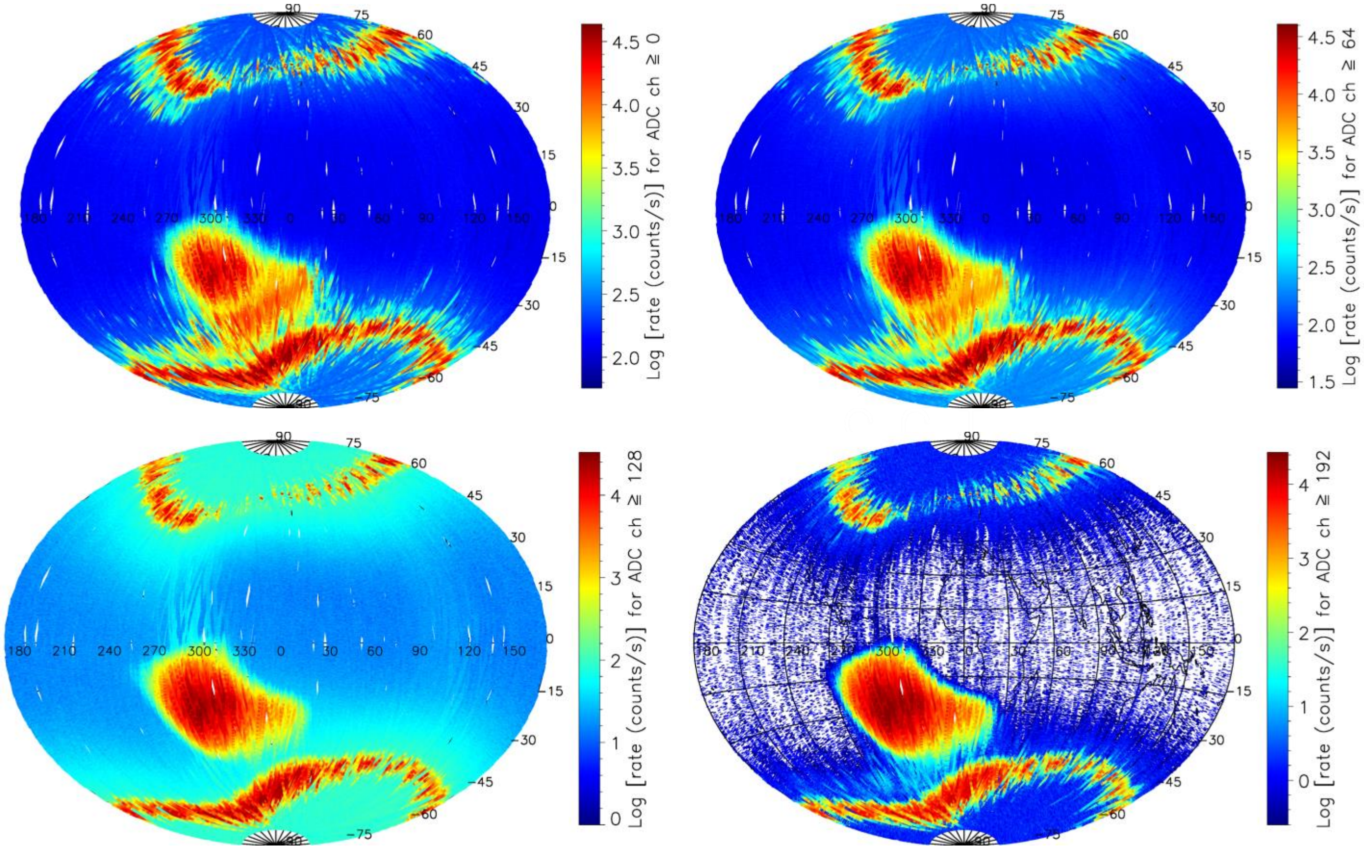


‘22 March 10

M. Dafčíková Bc thesis



Background maps



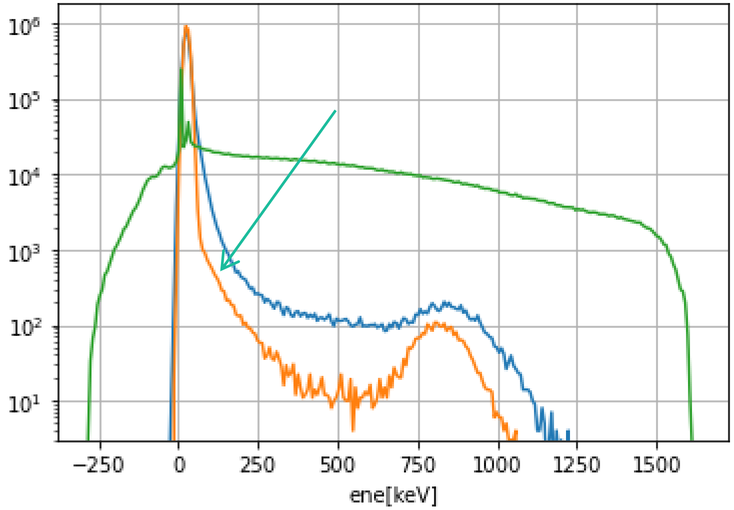
processing of J. Řípa
maps for 8/2022-3/2023

correct modelling needed for
tuning trigger algorithm

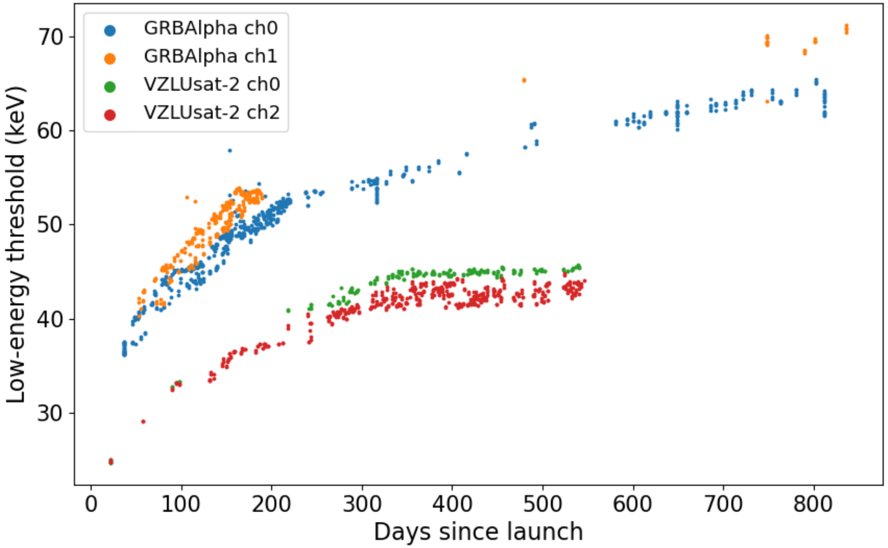
Detector degradation

- threshold settings

position right above the noise peak

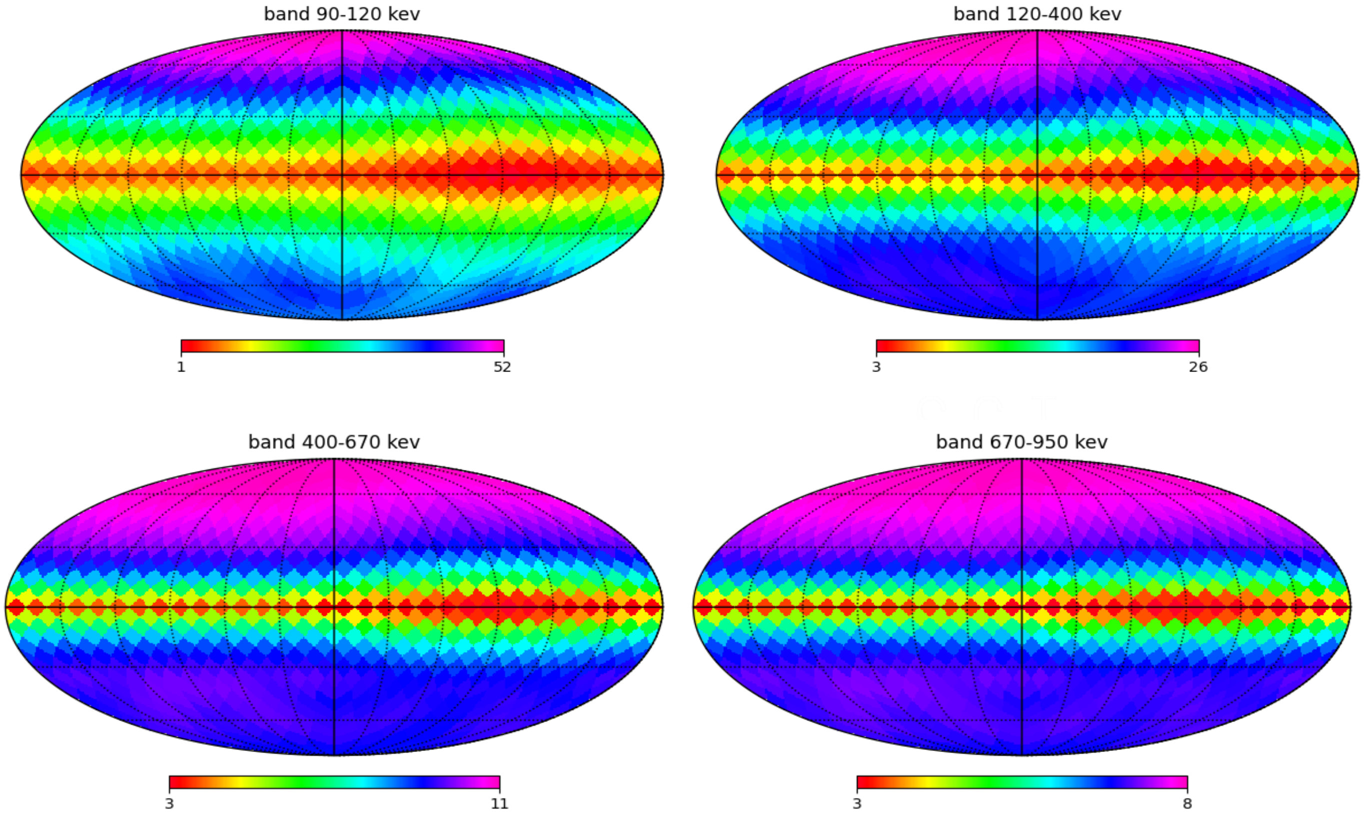


preliminary analysis (P. Kosík, J. Řípa)



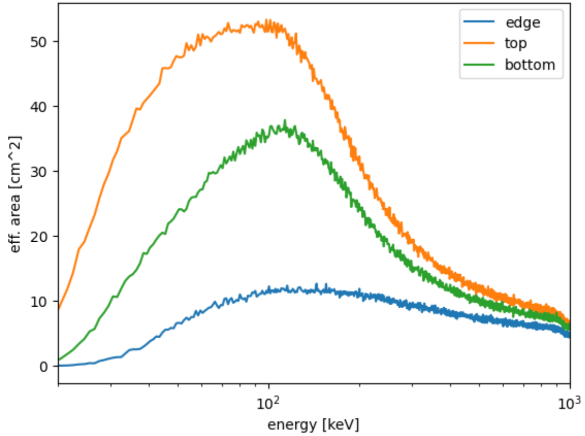
VZLUSAT-2 at 30km lower orbit, extra shielding

Calibrating response



average eff. area (in cm2)
for GRBAlpha (simple model)

based on GEANT4 simulations
by H. Takahashi & Y. Fukazawa



Transient tables

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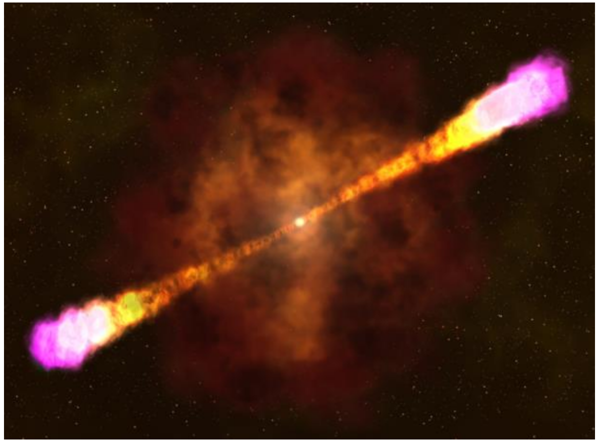
GRBAlpha – 54 GRBs (7 in november 23)
27 solar flares

VZLUSAT2 – 34 GRBs (4 in november 23)
26 solar flares + 2 SGRs (repeated)
lower threshold (and sorbit)



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

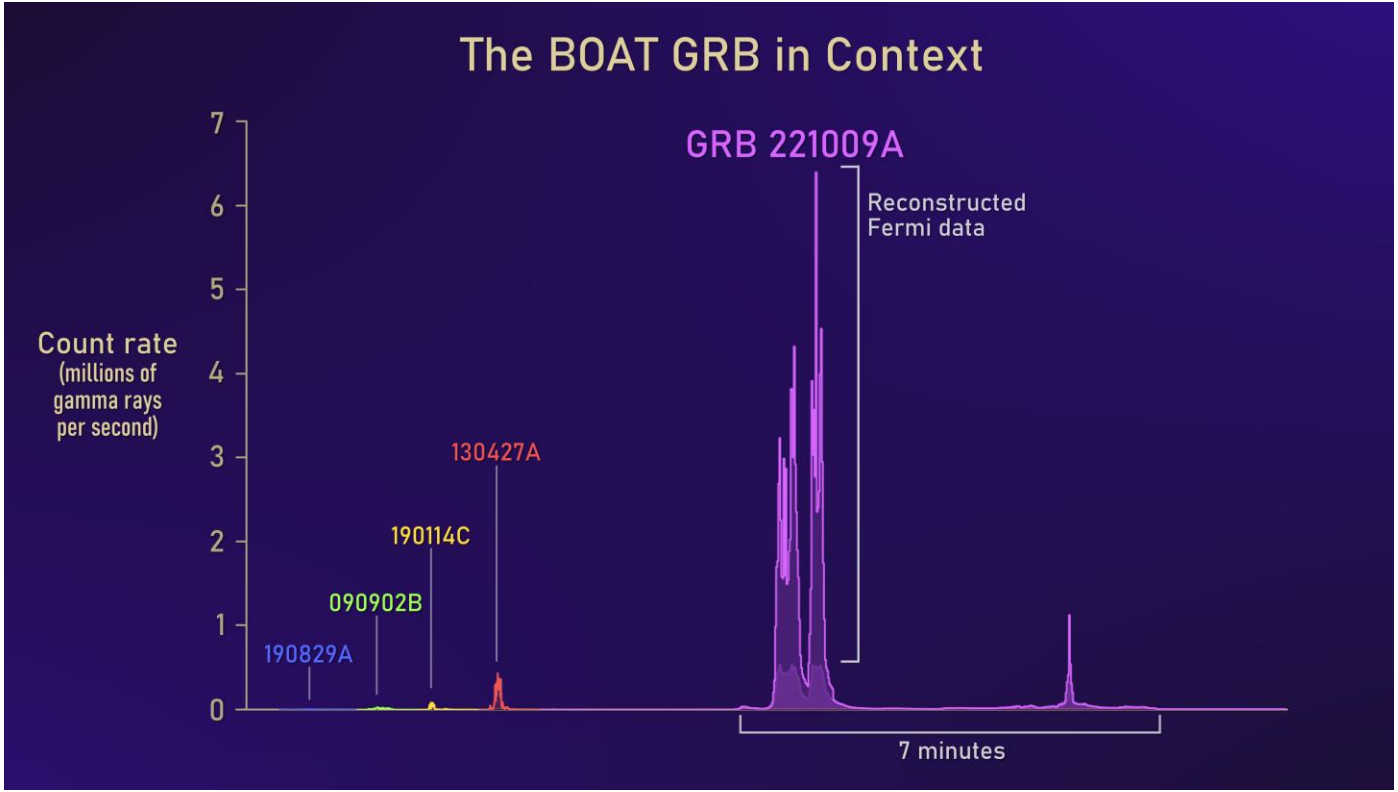
The list contains gamma-ray transients observed by the GRB detectors on VZLUSAT-2

- **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 c
- **Peak time** denotes the time when the detected cou
- **T90** is the time interval, in which 90 per cent of all
- **Peak count rate** is the detected count rate of the ev
- **Band** is the energy range for which the T90 duratic
- **S/N** is the maximal significance of the signal detec
- **Raw LC** is the raw light curve without the backgrc
- **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

http://physics.muni.cz/hea/GRBAlpha /
/VZLUSAT-2/

Event type/name	Det. unit	Peak time (UTC)	T90 [s]	Peak count rate [cnt/s]	Band [keV]	S/N [σ]	Raw LC	Bkg-sub LC	LC res. [s]	GCN circ.	References
GRB 231129A	no. 1	2023-11-29 05:06:01	157	74.0	~40-890	20.9	PNG, EPS, TXT, FITS	PNG, EPS	1	35248/PDF	Swift/BAT INTEGRAL/IBIS
GRB 231128A	no. 1	2023-11-28 11:44:15	24	51.3	~40-890	9.7	PNG, EPS, TXT, FITS	PNG, EPS	1	35246/PDF	Fermi/GBM
Solar flare	no. 1	2023-11-20 03:10:11	20	52.5	~40-890	8.3	PNG, EPS, TXT, FITS	PNG, EPS	1		Fermi/GBM GOES
GRB 231118A	no. 1	2023-11-18 17:16:34	8	5.6	~40-890	73.0	PNG, EPS, TXT, FITS	PNG, EPS	1	35143/PDF	Fermi/GBM INTEGRAL/SPI-ACS Swift/BAT Wind/KONUS GRBAlpha Astrosat/CZTI
GRB 231104A	no. 1	2023-11-04 01:47:39	26	444.5	~40-890	21.2	PNG, EPS, TXT, FITS	PNG, EPS	1	35008/PDF	Fermi/GBM INTEGRAL/SPI-ACS Swift/BAT

Brightest of all times



22 000 counts/s peak
for GRBAlpha (>80 keV)
pile-up (cca 20%)
far enough from saturation

allows to reconstruct
peak flux
(if we know the attitude)

Brightest of all times

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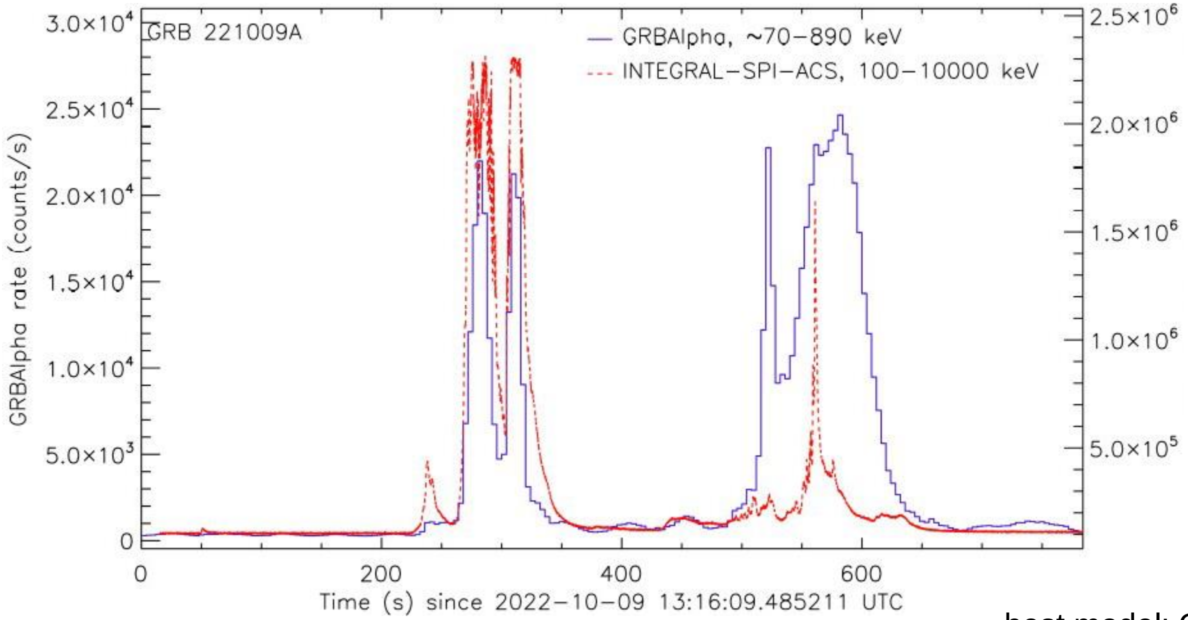
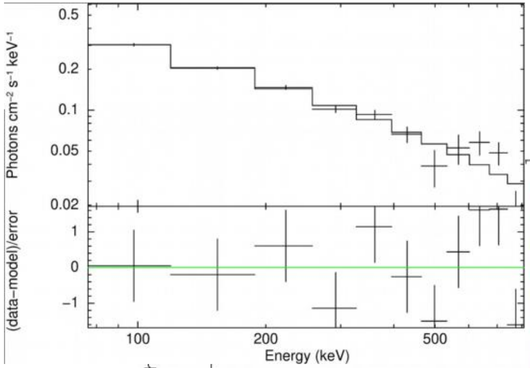
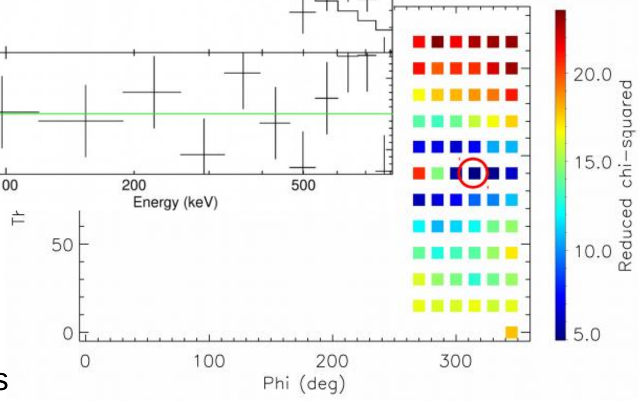
+ : measured in 16 channels (3 empty)
– : caught during north polar passage



reconstruction from responses for all possible directions
Řípa et al 2023





best model: CPL
$\alpha = 0.7 \pm 0.1$
E0 = 750 (+410,-200) keV
A = 8 (+6,-4) ph keV/cm2/s

Brightest of all times

GRBAlpha mentioned along the greatest GRB observatories

Deciphering the ~18 TeV Photons from GRB 221009A

Sarira Sahu[1], B. Medina-
[1] Instituto de Ciencias Nucleares, Universidad Naciona
rtamento de Física Aplicada, Centro de Investigación y d
[3] Department of Physics and Astronomy, Cal
Received 2022 November 8; revised

On 2022 October 9, an extremely powerfu
Despite being obstructed by the Milky W
LHAASO detected several thousand ve
energetic photons is unexpected due to th
the intrinsic very high energy photon
compensate for the attenuation by pair p
scenario and show that very high energy
energy protons with the seed synchrotron

Unified Astronomy Thesaurus concepts:

1. Introduction

2022 October 9, at T0 = 13:16:59.000 UT
), a long-duration gamma-ray burst (GRB)
221009A (also known as Swift J1913.1-
ted in the direction of the constellation Sa
na-ray Burst Monitor (GBM; Meegan et a
the Fermi Gamma-ray Space Telescope.
ion was also detected by several other spa
, such as the Fermi Large Area Telescope (LAT), Swift
iara et al. 2022; Krimm et al. 2022), AGILE (Piano et al.
; Ursi et al. 2022), INTEGRAL (Gotz et al. 2022), Solar
er (Xiao et al. 2022), SRG (Lapshov et al. 2022), Konus
eriks et al. 2022), GRBAlpha (Ripa et al. 2022), and
Sat-6 (Mitchell et al. 2022). The GRB 221009A is located
coordinate R.A. = 288.282 and decl. = 19.495 (Pillera
2022). Fermi-LAT detected the most energetic photon of
y, 99.3 GeV (at $t_0 + 240$ s). It is the highest-energy
n ever detected by Fermi-LAT from a GRB in the prompt
(Bissaldi et al. 2022; Pillera et al. 2022). The afterglow
ion was also observed at different wavelengths (Das &

(Dzhappuev et al. 2022). Observations of these ul
gamma rays by LHAASO and Carpet-2 from G
are incomprehensible and led to speculation abou
physics explanations of these observed events. H
is a caveat concerning the observation of the 251
ray. The angular resolution of Carpet-2 is severa
the two previously reported Galactic VHE sou
J1928+178 and LHASSO J1929+1745, are loc
the position of GRB 221009A (Fraija & Gonz
remains uncertain whether the observed 251 T
from GRB 221009A or either of these Gala
Nevertheless, the temporal and spatial coincidenc

4

bright transient denoted as *Swift* J1913.1+1946 (triggers 1126853 and 1126854, Dichiara et al. 2022a,b). *Swift* slewed immediately to the position and its narrow-field instruments, the X-ray telescope (XRT, Burrows et al. 2005) and the Ultra-Violet/Optical Telescope (UVOT, Roming et al. 2005) discovered a transient, which was very bright in X-rays (> 800 ct/s) and moderately bright in the optical (unfiltered finding chart, *white* = 16.63 ± 0.14 mag). The optical detection was somewhat remarkable as the transient lies in the Galactic plane and extinction along the line-of-sight is very high, $E_{(B-V)} = 1.32$ mag/$A_V = 4.1$ mag (Schlafly & Finkbeiner 2011, henceforth SF11). It was furthermore reported that the source was also detected over ten minutes earlier by the Gas-Slit Camera (GSC) of the *MAXI* X-ray detector onboard the International Space Station (ISS, Negoro et al. 2022; Kobayashi et al. 2022; Williams et al. 2023). Overall, this is in agreement with a new Galactic transient.

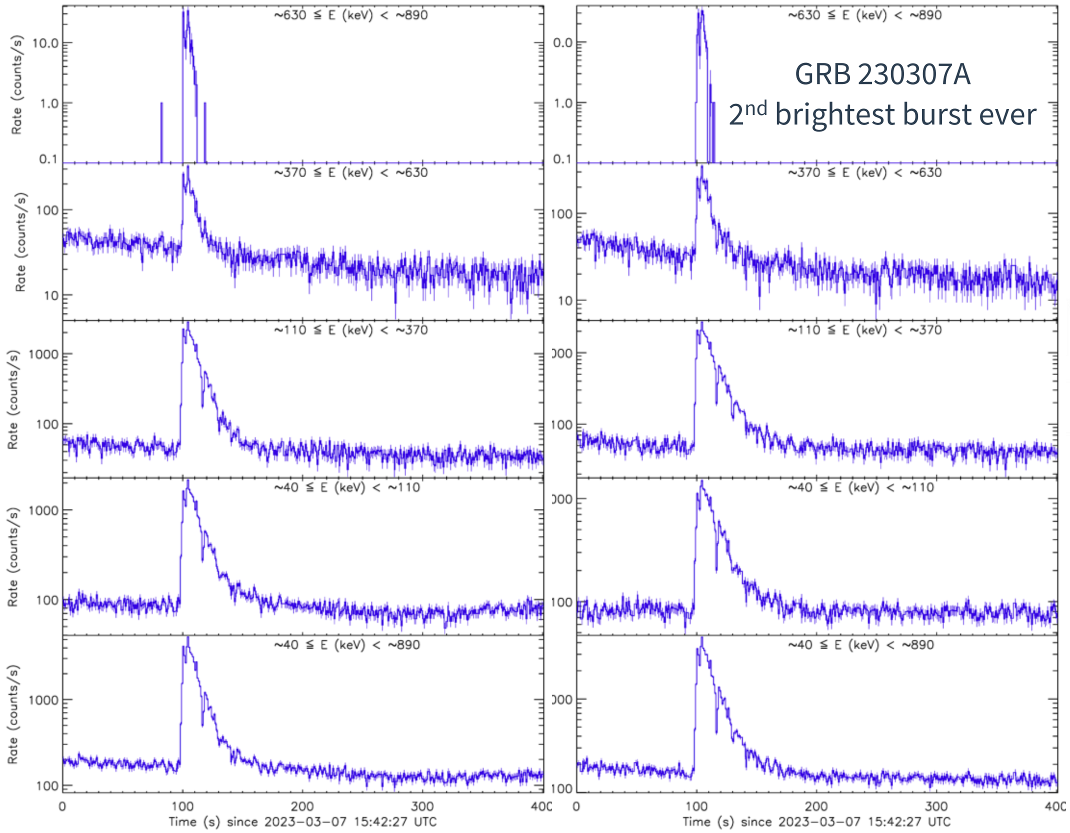
About 6.5 hours after the *Swift* trigger, it was reported by Kennea et al. (2022a) that this source may be a GRB, GRB 221009A, as both the Gamma-Ray Burst Monitor (GBM, Meegan et al. 2009) and the Large Area Telescope (LAT, Atwood et al. 2009) of the *Fermi* ob-

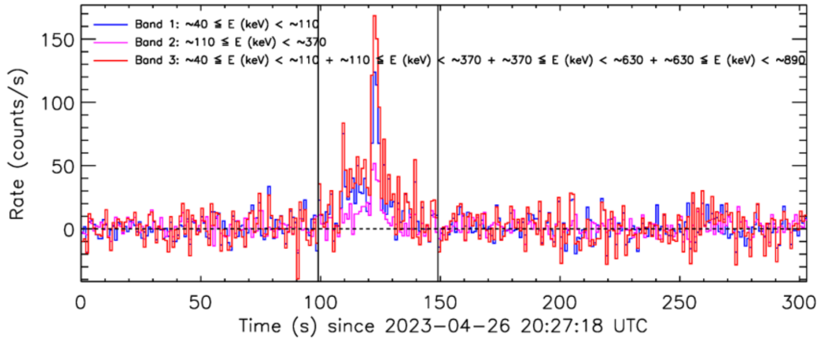
SPI/ACS (Gotz et al. 2022) analysis finds 1.3×10^{-2} erg/cm^2, *Fermi* GBM finds $(2.912 \pm 0.001)\times10^{-2}$ erg/cm^2 and peak flux 2385 ± 3 ph s^{-1} cm^{-2}, Konus-*Wind* report 5.2×10^{-2} erg/cm^2 (Frederiks et al. 2022), and Kann & Agui Fernandez (2022) estimate $\approx 9\times10^{-2}$ erg/cm^2. Even these preliminary estimates show GRB 221009A exceeded GRB 130427A in fluence by a factor of at least 10.

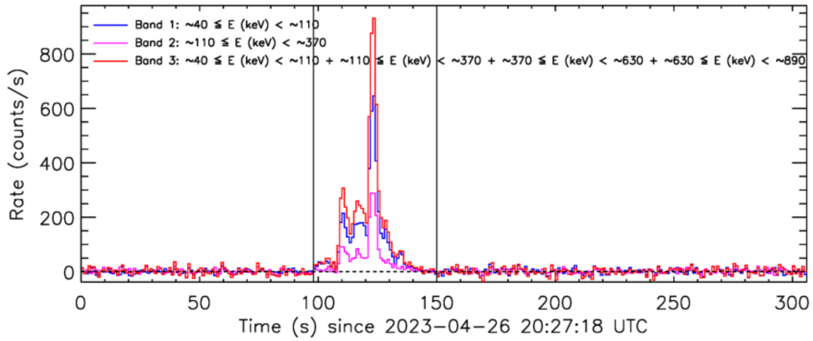
Several smaller orbital detectors were not saturated, stemming from size, environment, or off-axis detection, such as detectors on *Insight* (the Low-Energy (LE) telescope and the Particle Monitors, Ge et al. 2022), *SATech-01/GECAM-C* HEBS (Liu et al. 2022), *GRB-Alpha* (Ripa et al. 2022), *STPSat-6*/SIRI-2 (Mitchell et al. 2022), and *SRG*/ART-XC (Lapshov et al. 2022).

Optical spectroscopy of the transient showed it to indeed be a GRB afterglow, with a redshift $z = 0.151$ measured both in absorption and emission (de Ugarte Postigo et al. 2022; Castro-Tirado et al. 2022; Izzo et al. 2022, Malesani et al., in prep.), making it even closer than GRB 030329. Such an event is ultra-rare, e.g., Atteia (2022) estimate it to occur only once every half-millenium (see also Williams et al. 2023, Burns et al., in prep.).

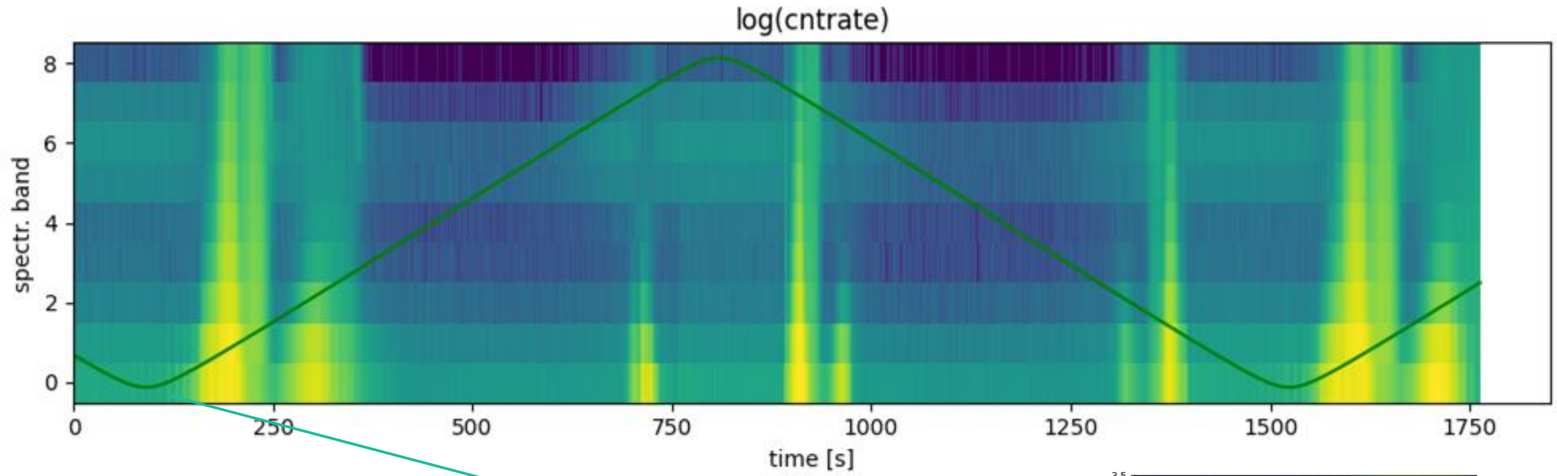
VZLUSAT-2 : similar and different

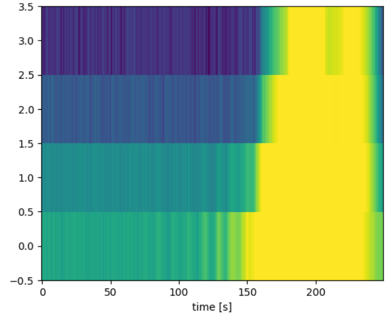






GRBAlpha: Full orbit spectra





VZLUSAT-2: limited operation time (sharing power resources) → might improve in future

attitude knowledge on demand attitude control in special cases only

References

Details in publications

- Pál et al. 2023, Astron.&Astroph. 677 (2023) A40 arXiv:2302.10048
- Řipa et al. 2023, Astron.&Astroph. 677 (2023) L2 arXiv:2302.10047
- Řipa et al. 2022, Proc. of SPIE, 11444, 114444V
- Meszáros et al. 2022, Proc. of SPIE, 12181, 121811L
- Pál et al. 2020, Proc. of SPIE, 12181, 121811K

GRB Beta – the sequel

- gamma detector unchanged (compatibility of data)
- testing several technologies

–Globalstar transmitter module

–S-band communication

–IR position Sun sensors

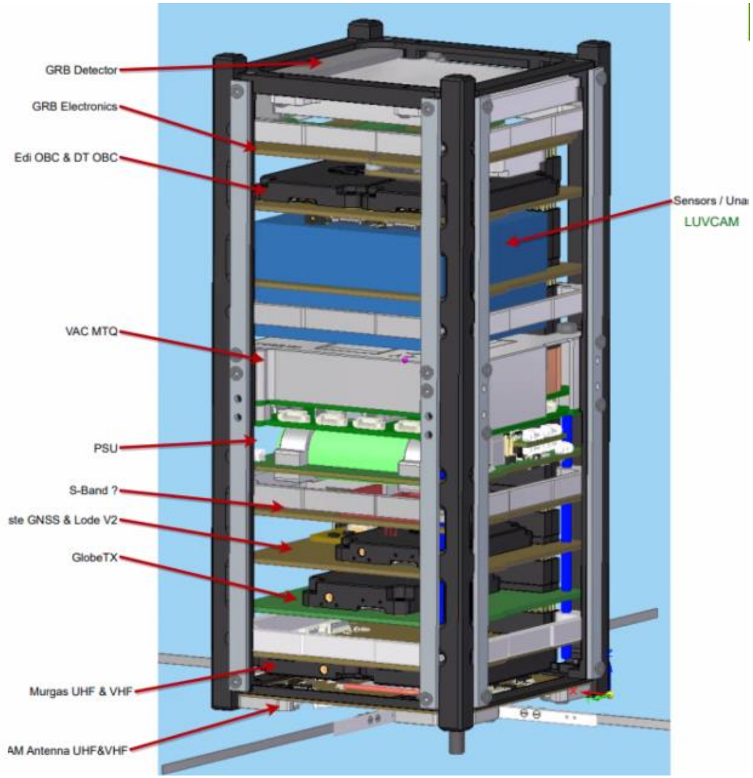
–attitude control – coils only (cubesat module)

–UV camera test board (LUVS team, Toronto CA)

including optics!

SPACEMANIC

SERENUM SPACE



On behalf of..

MUNI SCI

- Consortium of VZLUSAT-2 & GRBAlpha
- communication thanks to Pilsen (West Bohemia University), Technical University Kosice (Slovakia) and many contributors of SatNOGs network
- enthusiastic operators from MU students (M. Dafčíková, M. Kolář, L. Szakszonová, N. Husáriková) with senior support (A. Pál, J. Řípa)

Summary

☑ 1U box capable of detecting GRBs

☑ SiPM degradation under control (choice of orbit)

☑ amateur network used at large scale (citizen science)

TD: on-board trigger will allow for finer timing

TD: interoperation and standardization of timing constellations

(beyond AHEAD2020 WP): **GRBnanosats.net**

AHEAD 2020
HIGH ENERGY ASTROPHYSICS

Funded by the Horizon 2020
Framework Programme
of the European Union
Grant Agreement No. 871158