# THE CAMELOT CONSTELLATION OF NANOSATELLITES FOR GAMMA-RAY BURST OBSERVATIONS

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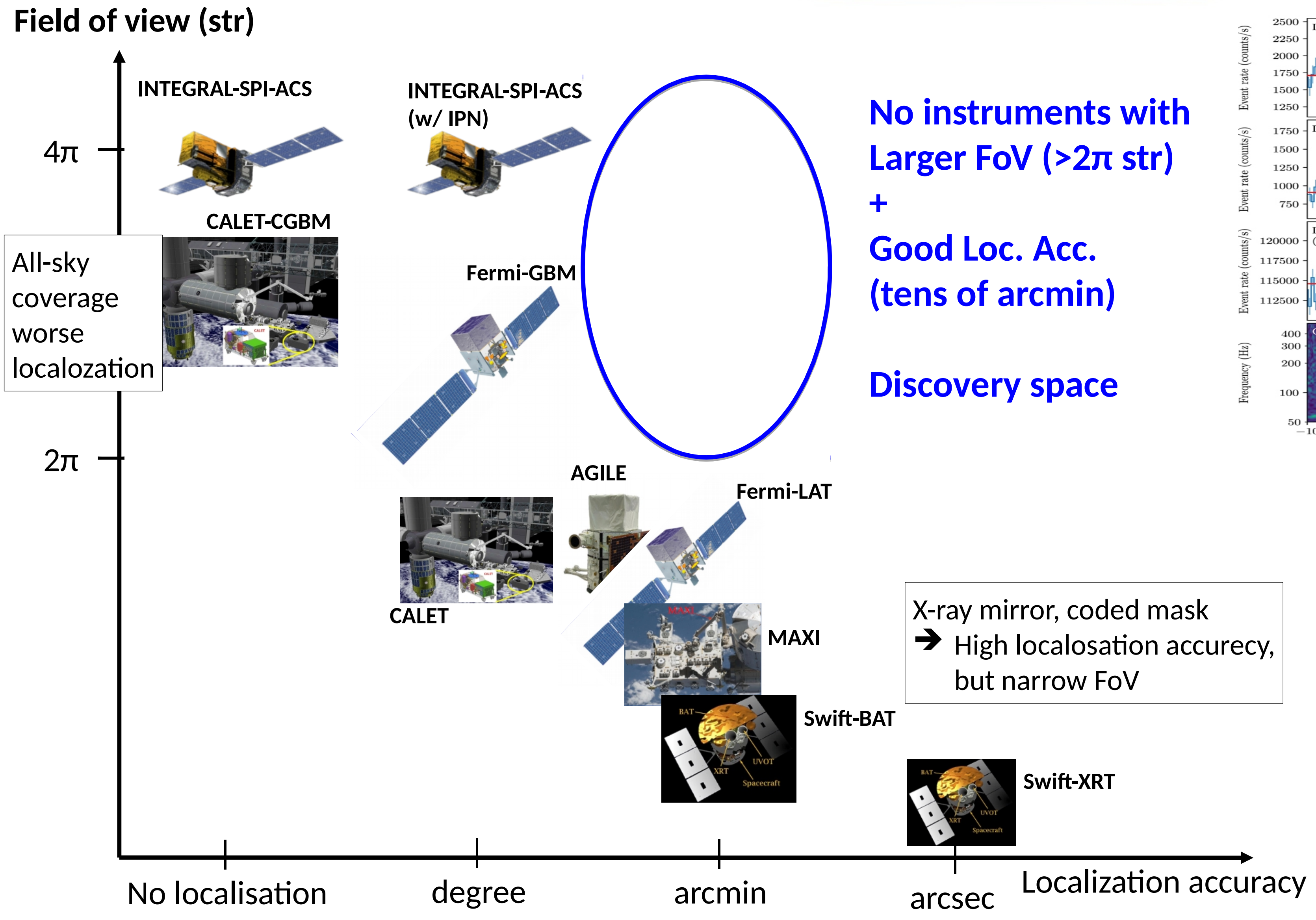
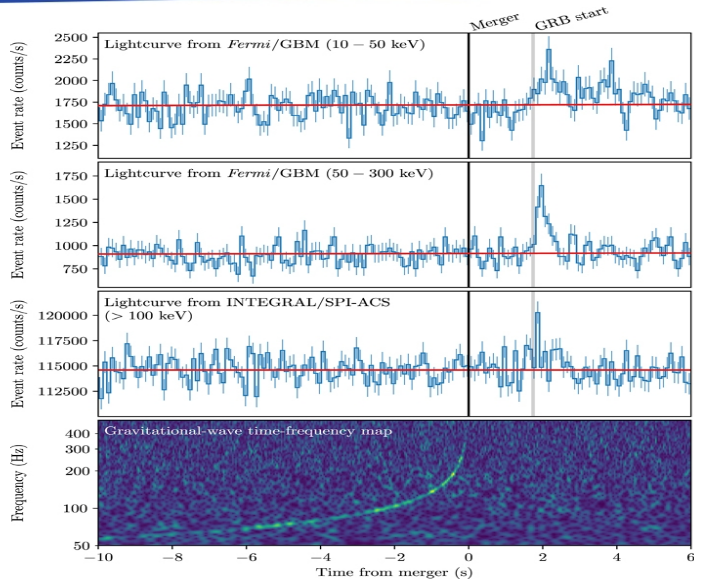
# ALL-SKY COVERAGE + PRECISE GRB LOCALIZATION IS NEEDED FOR EFFICIENT MULTI-MESSENGER ASTRONOMY



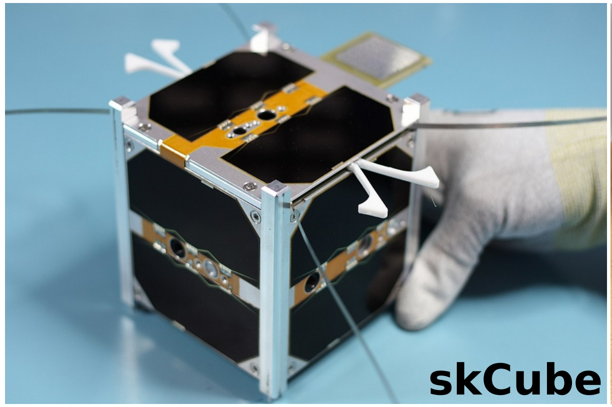



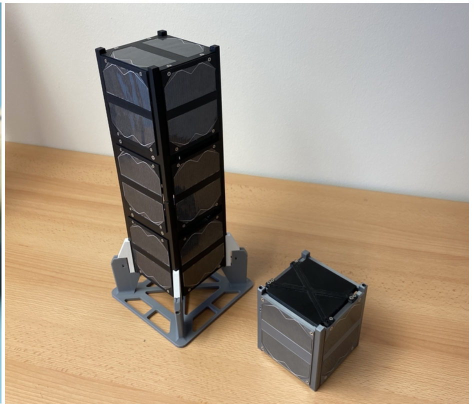


LIGO/Virgo collaboration 18; Abbott+ 17

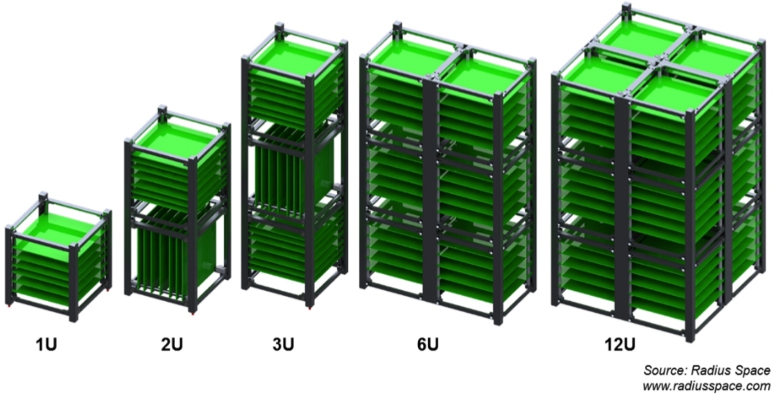
- LIGO/Virgo detected tens of GWs
- counterpart from NS-NS merger event GW170817 / GRB170817A
- Large campaign of follow-up observations identified a kilonova
- **Regular detections/follow-up observations are needed to make progress!**

# CAN NANOSATELLITES (CUBESATS) ACHIVE IT?



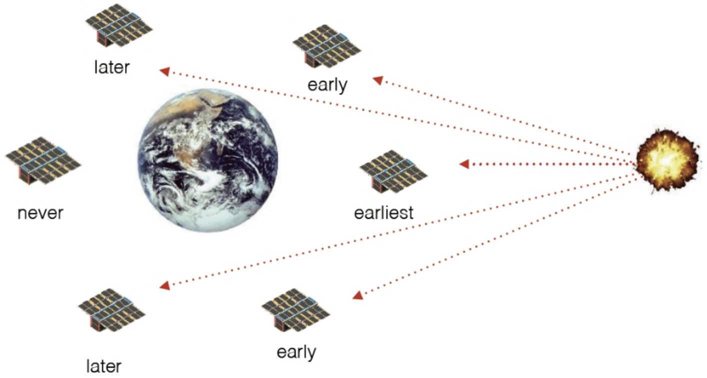



**Standard CubeSat sizes**




**Advantages:**

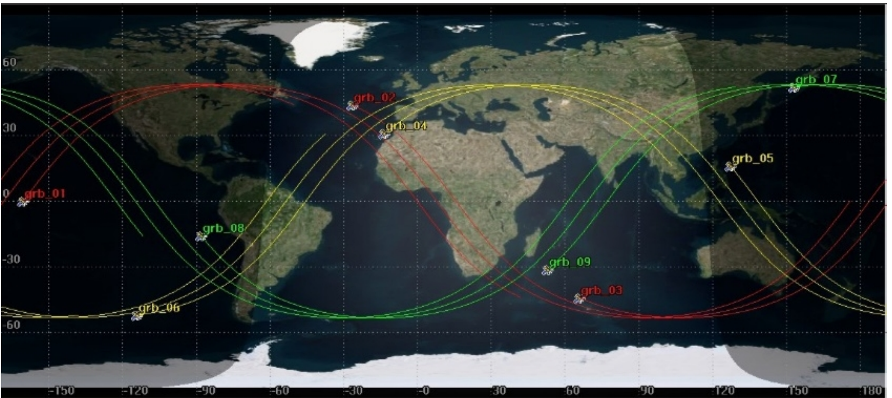
- Affordable by single single university or company
- Fast development time (~year)
- Many launch opportunities as a piggyback payload with larger missions



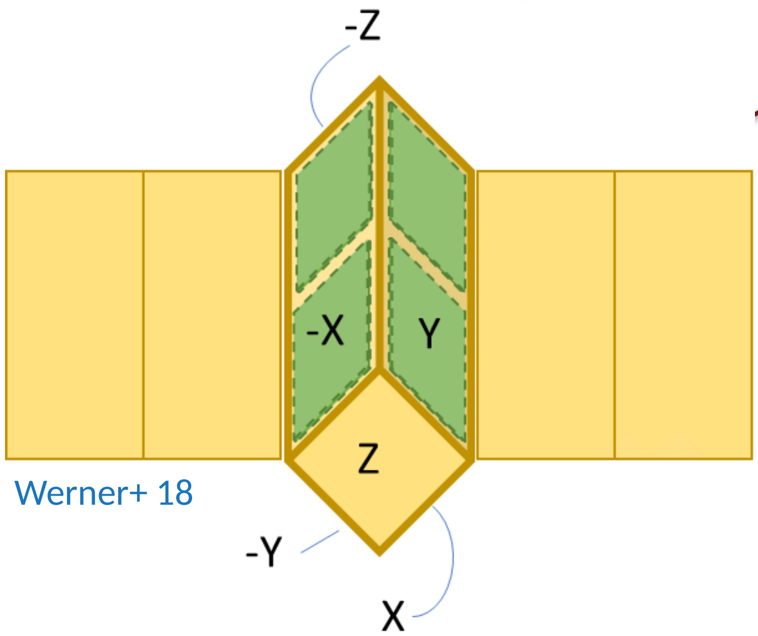

**Cubesats Applied for MEasuring and LOcalising Transients (CAMELOT) mission concept**

| | |
|---|---|
| **Satellite platform** | 3U CubeSat |
| **Target orbit** | 9 satellites constellation in LEO in three orbital planes |
| **Payload** | Four 150x75x5 $mm^3$ CsI scintillators read out by Multi-Pixel Photon Counters (MPPCs) |
| **Goal** | Degree-scale timing-based localization with a similar sensitivity to the Fermi-GBM |

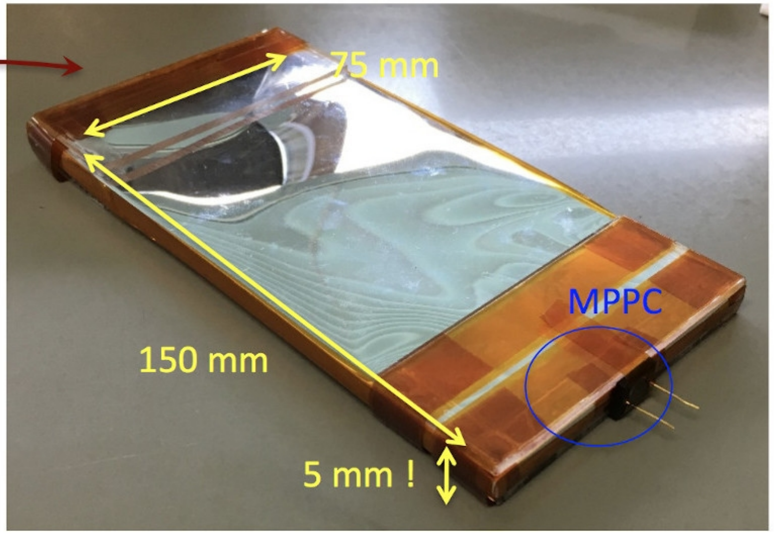
- Equipped with GPS for precise time synchronisation
- Inter-satellite (Iridium NEXT) communication equipment for rapid data download
- All sky coverage with a large effective area



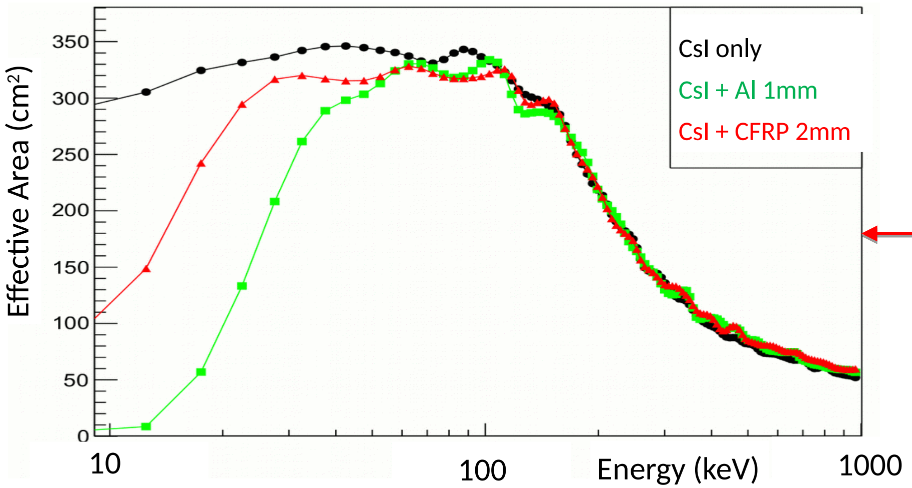
# CAMELOT: DETECTOR DESIGN

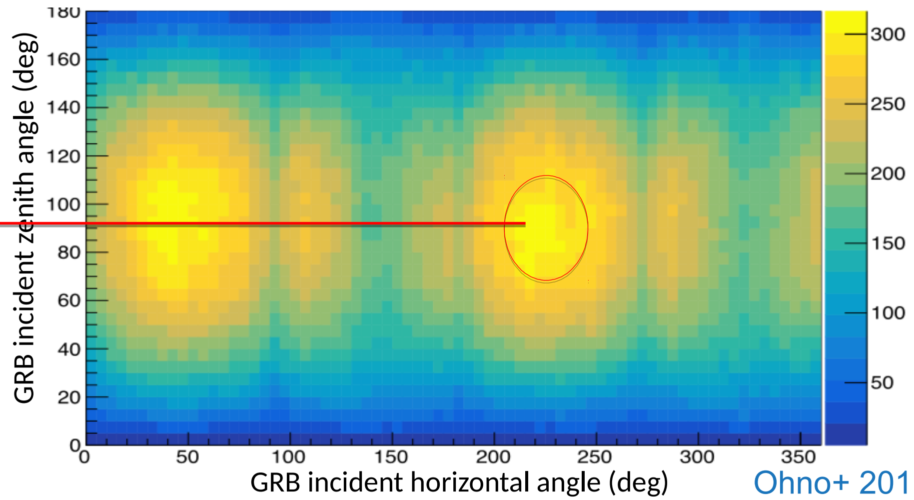



Werner+ 18




- To maximize effective area the CsI scintillator detectors read out by Multi-Pixel Photon Counters (MPPC) will occupy two lateral extensions (8.3 cm x 15 cm x 0.9 cm x 4)
- The large and thin detectors with small readout area are challenging
- The system provides a large light yield, compact readout area and relatively low operational voltage.



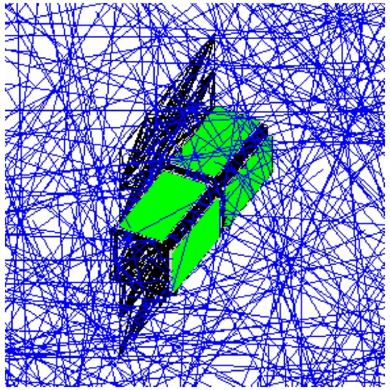




Ohno+ 2018

- Effective area for best incident angle is estimated by MC simulations: ~300 $cm^2$ (100 keV)
- Energy range: 10-600 keV (20 - 600 keV for Al casing)
- **Effective area of one satellite is comparable to two NaI Fermi-GBM detector modules**

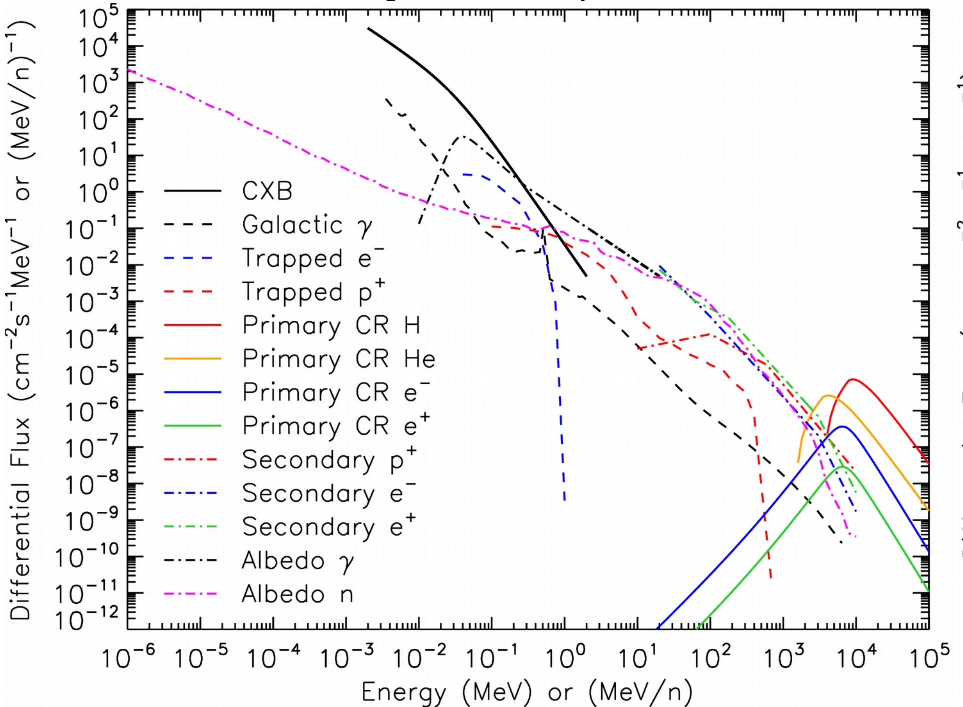
# CAMELOT: BACKGROUND AND SNR STUDY

- Full Monte Carlo simulation in Geant4 including optical photon tracking, satellite structure and expected X-ray/particle background (Galgóczi+ 2021, arXiv:2102.08104).
- Code available at GitHub (github.com/ggalgoczi/szimulacio/tree/master/Bck_4.10.6)
- Outside SAA and for latitude < 50°, i.e. in regions favorable for detection of gamma-ray transients
- Typical sGRB, lGRB, TGF, SGR spectra used based on Fermi/GBM, AGILE, and Konus measurements
- If we have a polar orbit at 500 km then study of trapped particle models (Řípa+ 2020) and measurements by Lomonosov/BDRG detectors suggest ~60% duty cycle

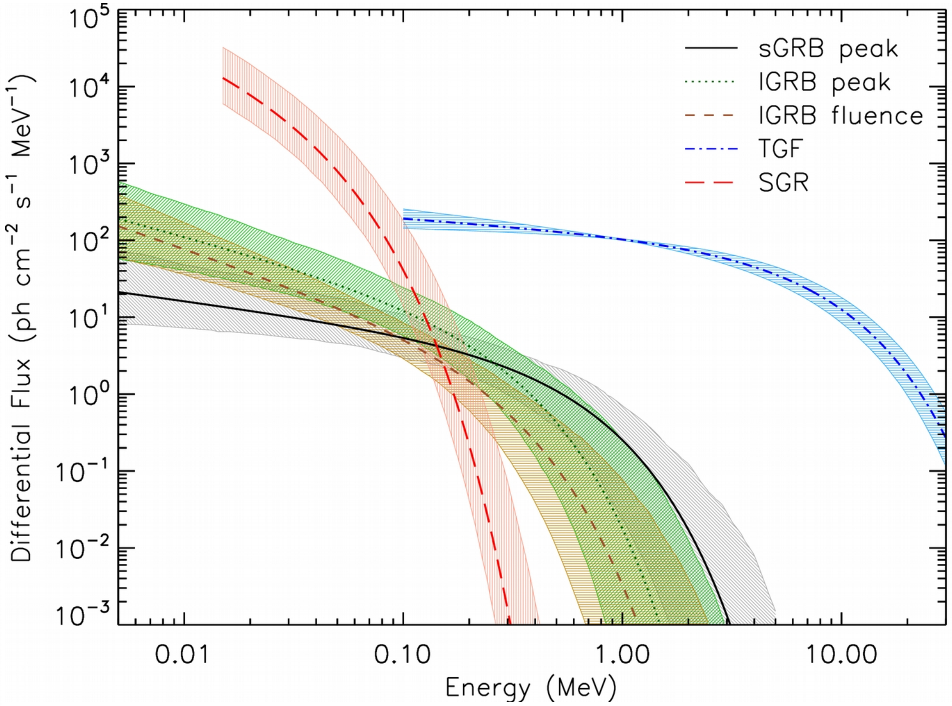


particles/X-ray background
optical photons in detectors

Different background components at 500 km



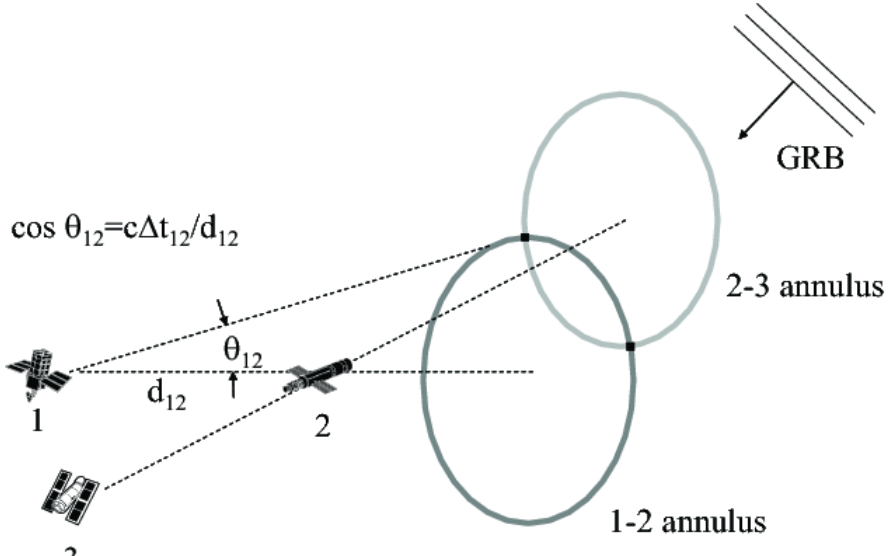

Different transient sources



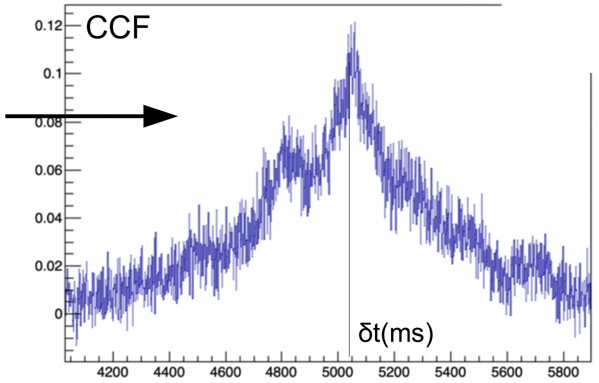

- For direction with highest eff. area the detection SNR by a single satellite are:
  - **sGRB SNR = 9-13** (64, 256, 1024 ms)
  - **lGRB SNR = 8-20** (64, 256, 1024, 4096 ms)
  - **SGR SNR = 140** (200 ms)
  - **TGFs also detectable**
- Detection rate by a single satellite:
  **~20 sGRB/year**
  **~120 lGRB/year**

# TIMING BASED LOCALIZATION OF TRANSIENTS

- Localization by photon arrival time (triangulation)
- Photon arrival time is estimated by cross correlation

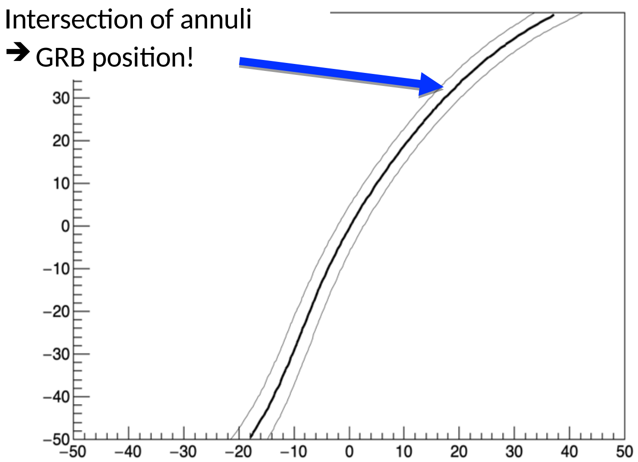


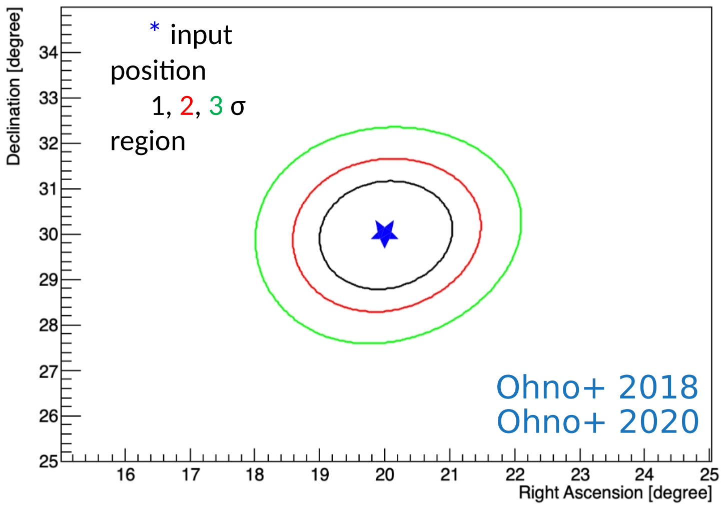
Hurley+13




- Cross-correlation analysis for every combinations of GRB detected satellites
- GRB position and error estimated by $\chi^2$ minimization

$$\chi^2 \equiv \sum_{i=0}^{N} \frac{\left\{\delta t_{\mathrm{sim,i}} - \mathrm{Norm} \times \cos\theta_{\mathrm{model,i}}(\mathrm{R.A.}, \mathrm{Dec.}) \times \mathrm{D/c}\right\}^2}{\sigma^2_{\mathrm{sim,i}}},$$



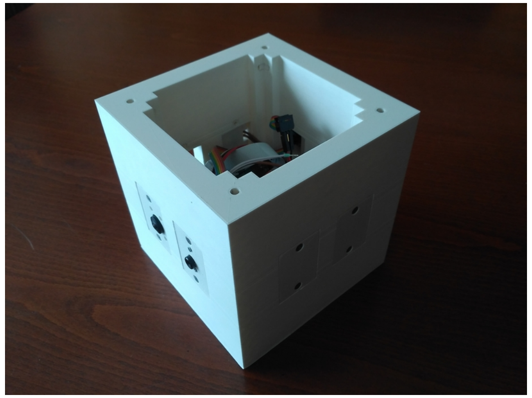

- <u>IPN deals with:</u>
  - Different clock accuracy from one s/c to another
  - Various time resolutions
  - Uncertainty in s/c positions for far-Earth s/c
  - Different energy responses of various detectors

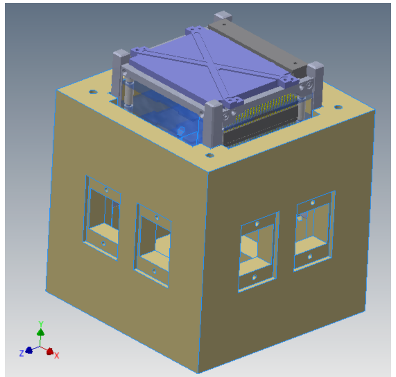
Fleet of the same detectors at LEO can overcome these problems, but baseline is shorter

- **~1 deg (1σ) accuracy for bright sGRB**
- **~30 sGRB/year localized < 1 deg**

# WHERE DO WE STAND?

- We performed a feasibility study and developed the detector concept.
- We developed a GRB detector for CubeSats, which we intended to test on a **high-altitude balloon**.



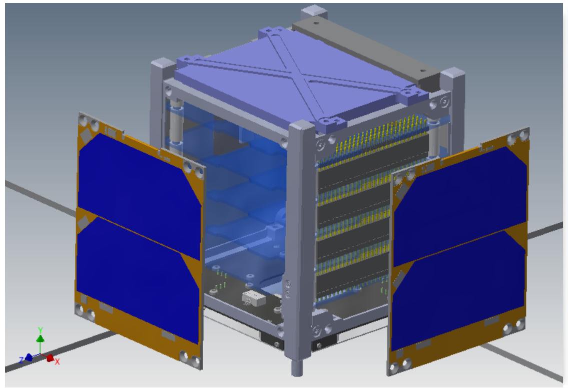


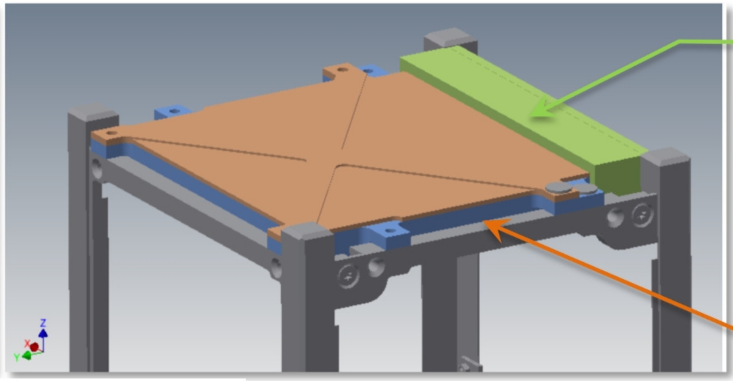
- Up to 30-38 km
- 6-7 hours of flight
- Relatively easy to launch
- Possible launch site in Slovakia
- 3D printed gondola
- Spin-off: new IR sensor based attitude determination

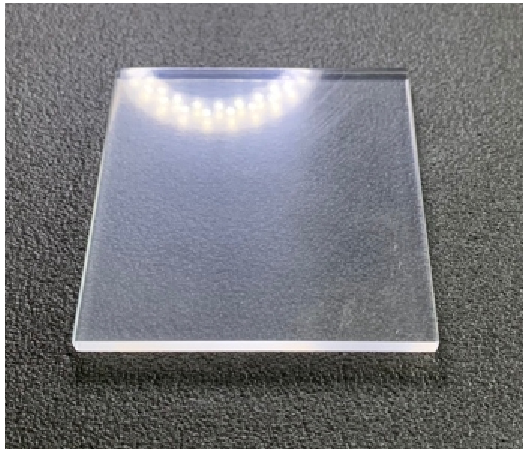
- Demonstration mission with a smaller sized detector on 1U CubeSat - **GRBAlpha** - was **launched this Monday!**
- Demonstration mission with two smaller sized detectors as secondary payload on 3U CubeSat - ***VZLUSAT-2*** - will be launched in summer 2021.

# GRBALPHA
# 1ST DEMO MISSION

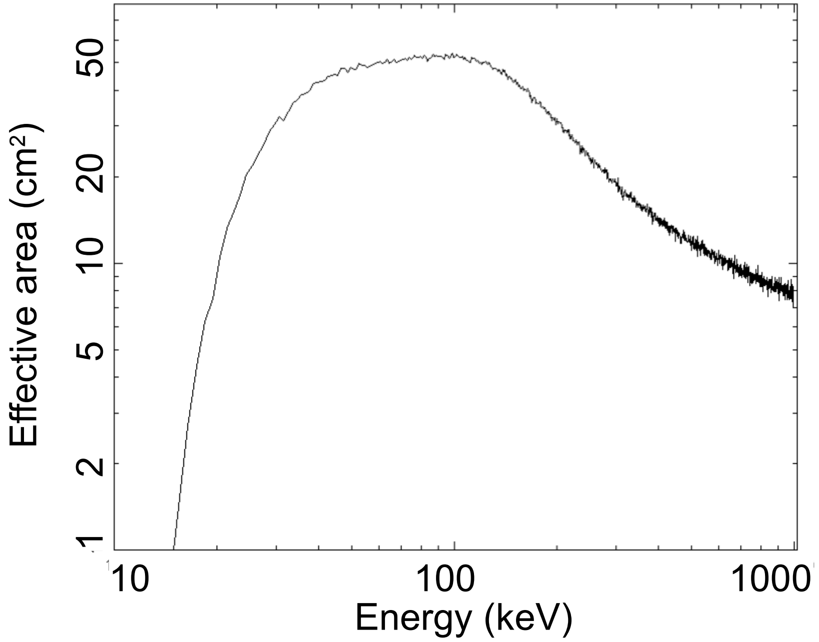
- Small size of scintillator (75x75x5mm$^3$ ), readout by 8 MPPCs, for 1-U platform but the same basic concept to CAMELOT



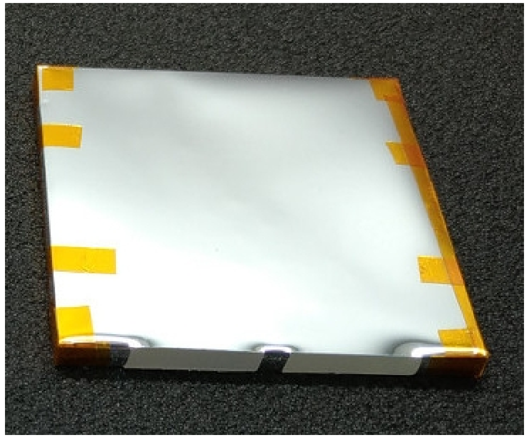


CsI(Tl) scintillator




- We estimate the photon numbers based on the detector response of GRBAlpha and the flux distribution of Fermi-GBM GRBs
- 10 % of Fermi-GBM GRBs (both long and short) can be detected by GRBAlpha (~10-20 GRBs/year)

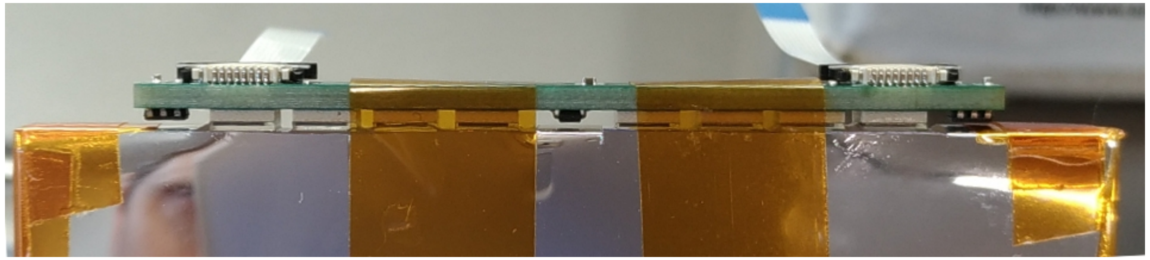


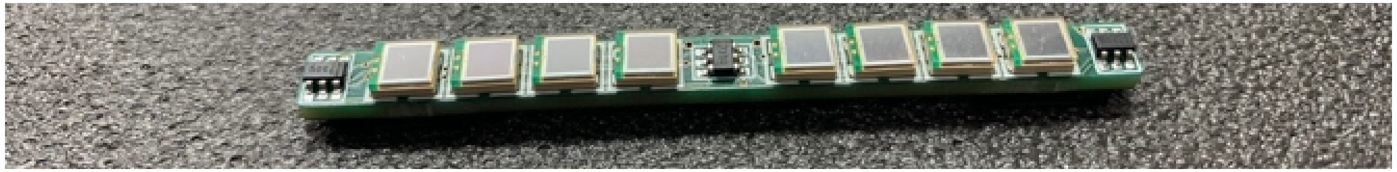
Wrapped in Enhanced Specular Reflector (ESR)

# GRBALPHA
# 1ST DEMO MISSION

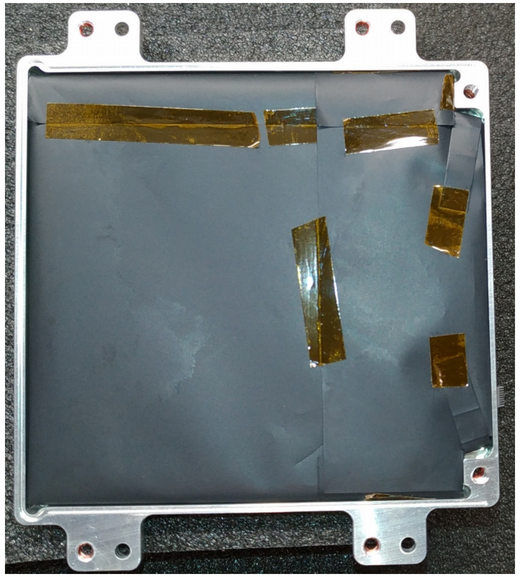
- 8 MPPCs on a board are attached to the crystal by optical glue DOWSIL93-500
- Detector is wrapped by optically thick DuPont Tedlar TCC15BL3 to prevent light leakage

Pál+ 2020

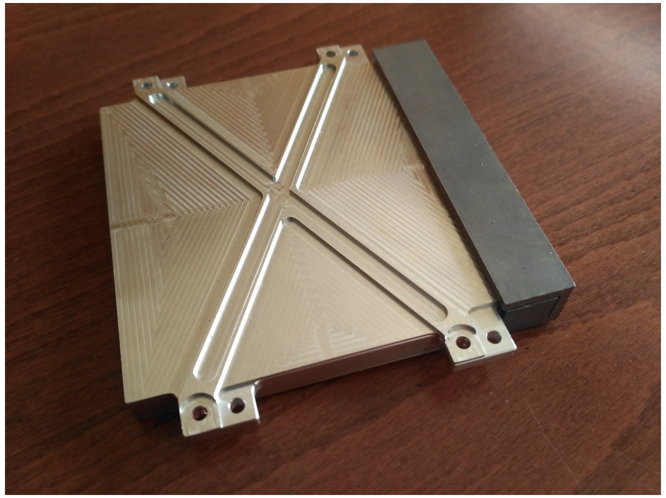




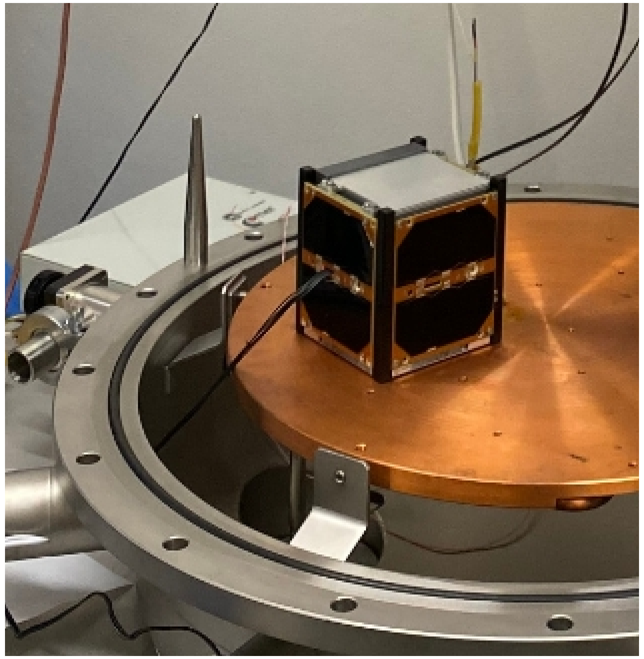
2 channels of 4 MPPCs (S13360-3050 PE)



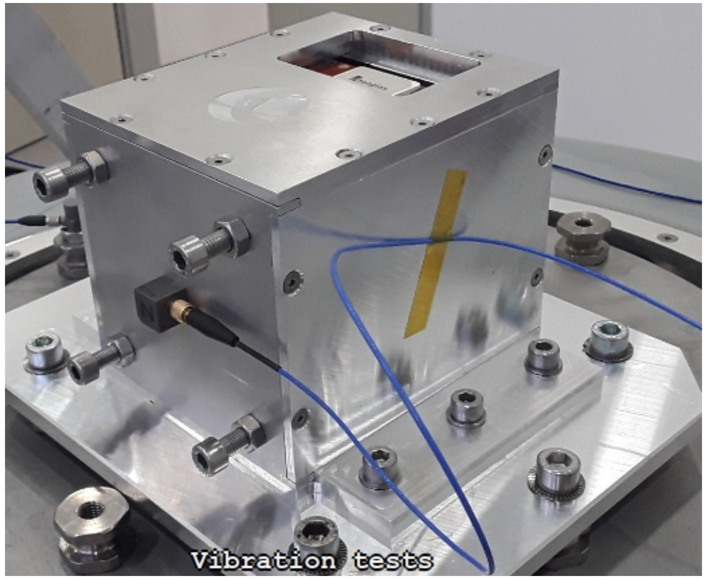
DuPont Tedlar TCC15BL3 wrapping



Assembled detector with PbSb3 allow to reduce MPPC degradation by protons



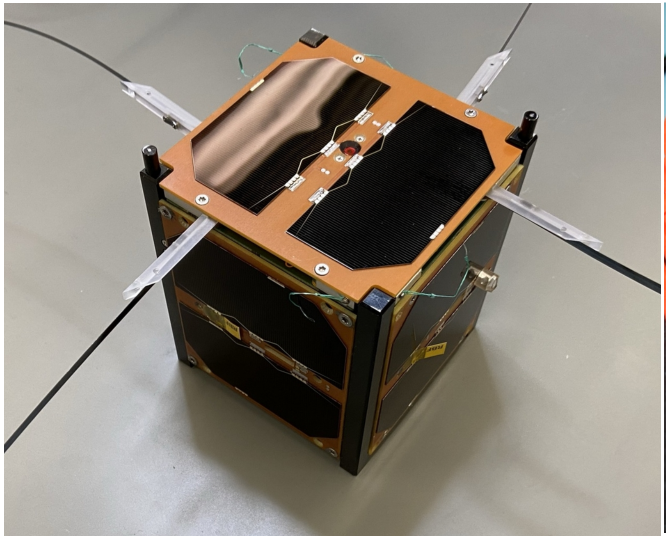
Thermal & vacuum test

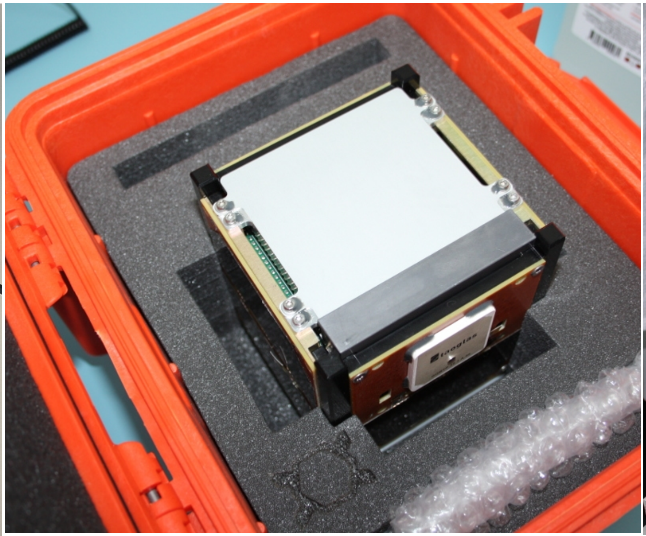


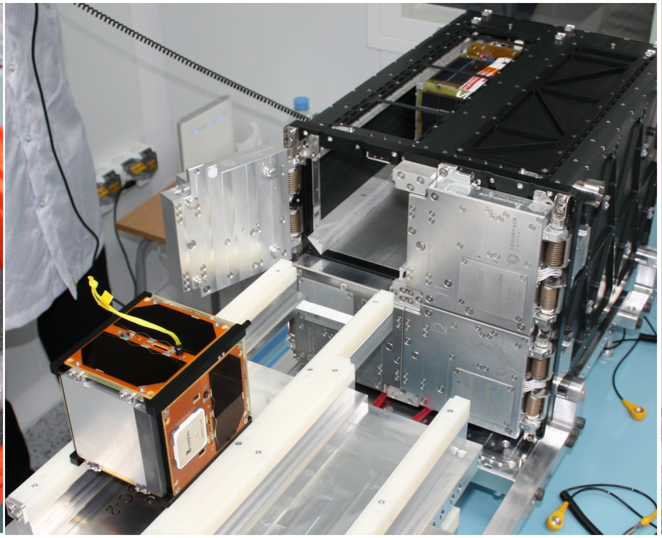
# GRBALPHA LAUNCH

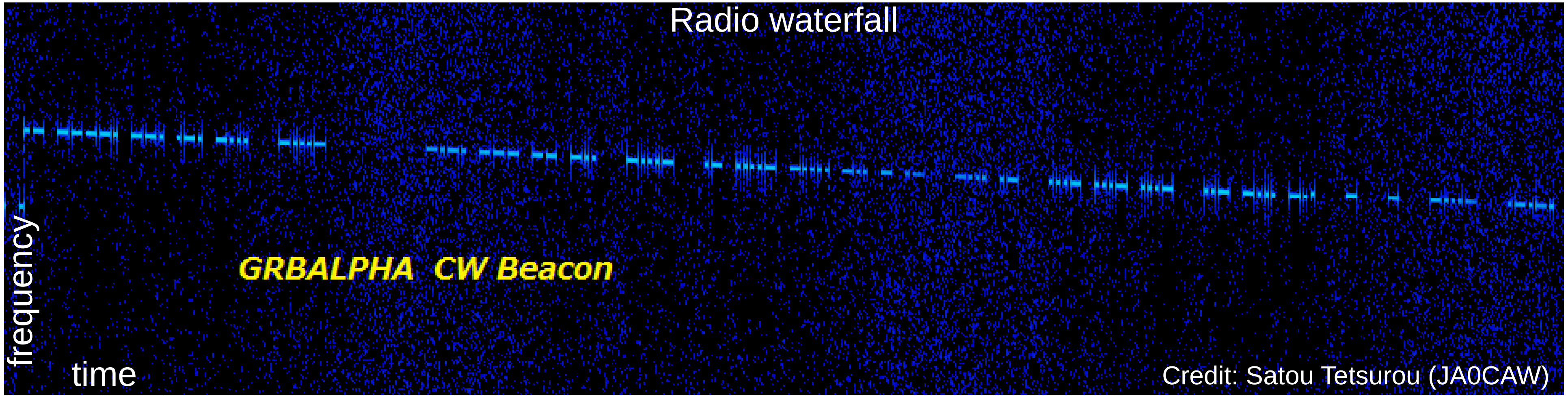
https://grbalpha.konkoly.hu/

- Assembled and shipped to Russia
- **Launched on Monday** from Baikonur by Soyuz-2 to 550 km SSO, March 22, 2021
- Detections by radio amateurs at 437.025 Mhz, see SATNOGS



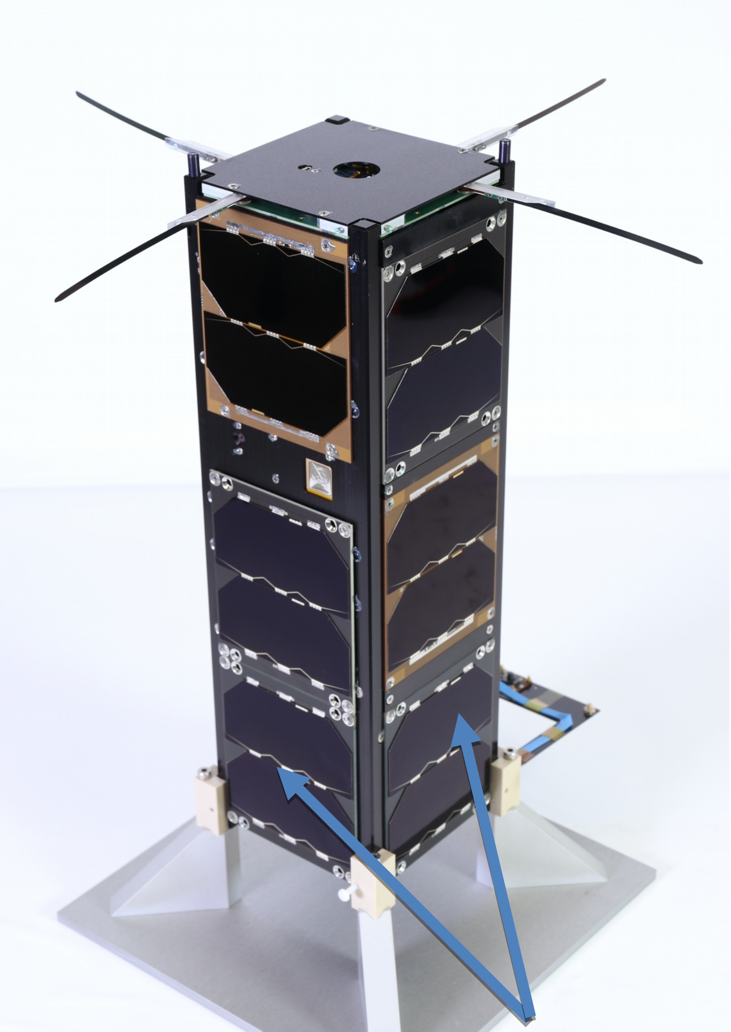







- Contact using GS in CZ, SK
- Sat. and detector respond to ground commands
- 1st packets from sat.
- Sat. and payload HK: detector temp. (16°C); CPU, batt. voltages and currents; info. from sun-sensors etc.

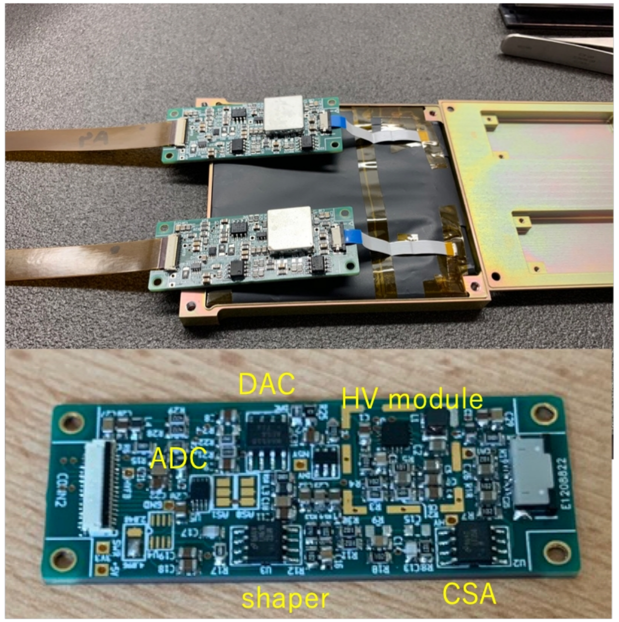
# VZLUSAT-2
# 2ND DEMO MISSION



Here are our detectors under solar panels

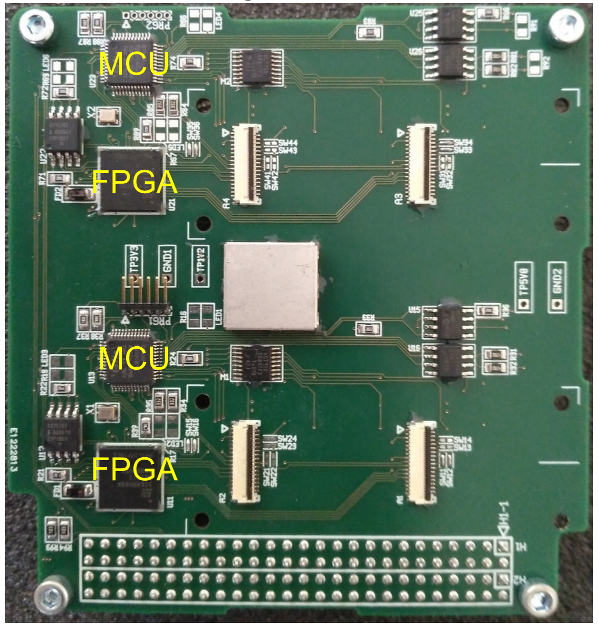
- VZLUSAT-2 is a technology mission with an earth observing camera as a primary payload developed by Czech Aerospace Research Centre
- Two detectors ($75x75x5mm^3$) as a secondary payload

Compact analog electronics



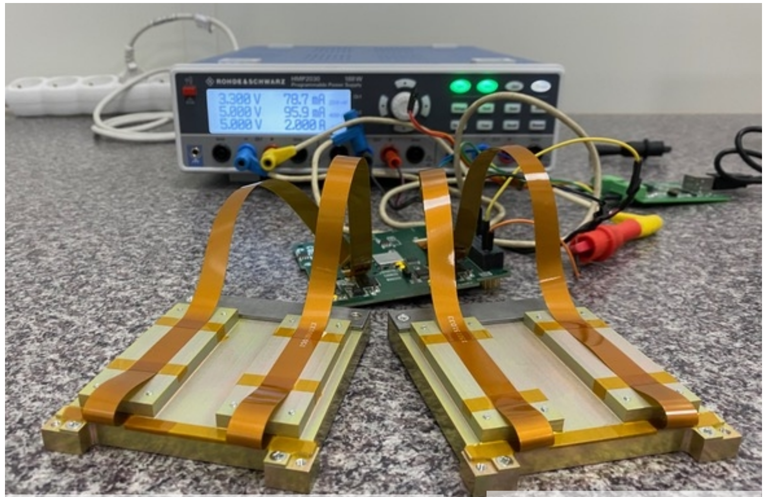

- A simple CSA (LF356)+ shaping amplifier (LM6142)
- 12-bit sampling ADC (LTC2315-12)
- HV supply module (LT3482) controlled by DAC

Digital board



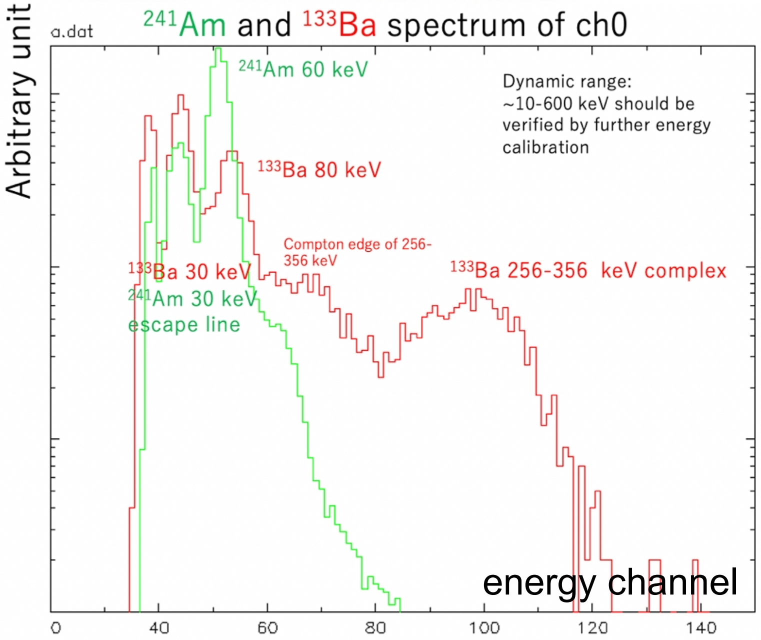

- FPGA - iCE40HX8K-BG121
- MCU - STM32F072CBT7 ARM Cortex-M0

# VZLUSAT-2
# 2ND DEMO MISSION

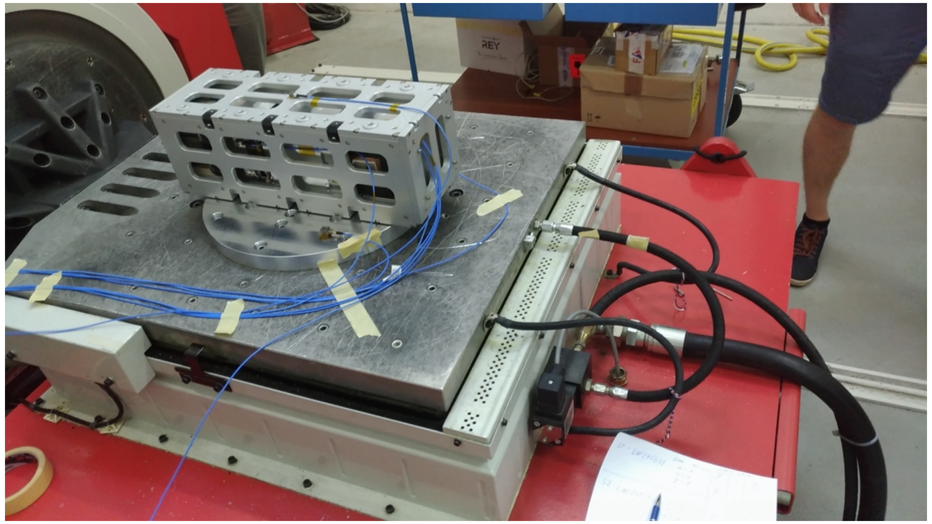



Weight: 2 x 280 + 50 g

Power: 0.7 W

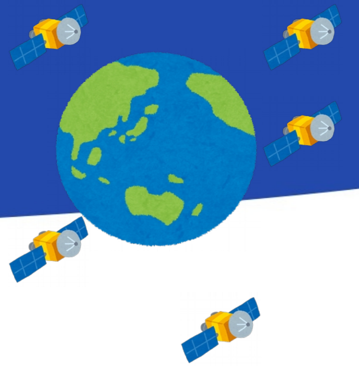



- Test with radioisotopes sources showed lines from 241Am and 133Ba
- Satellite was assembled, went through environmental testing and was shipped to USA **to be launched in summer 2021** by SpaceX



Vibration tests, shock tests, and thermo-vacuum tests

# SUMMARY



- Constellations of CubeSats providing both **all-sky coverage** and **localization capability** will be highly **complementary to large missions** monitoring the high energy sky
- The orbital demonstration mission of our first GRB detecting CubeSat was launch, the second one is expected to be launched in summer this year
- A close collaboration between GRB detecting CubeSats will leverage the advantages of nano-satellites and different detector concepts - *such close collaboration between missions is key for the success of global networks of GRB detecting nanosatellites*

Werner et al., Proc. of SPIE 10699 (2018) id.106992P
Ohno et al., Proc. of SPIE 10699 (2018) id.1069964
Pál et al. arXiv: 180603685
Torigoe et al. NIMPA 924 (2019) 316
Řípa et al. AN 340 (2019) 666