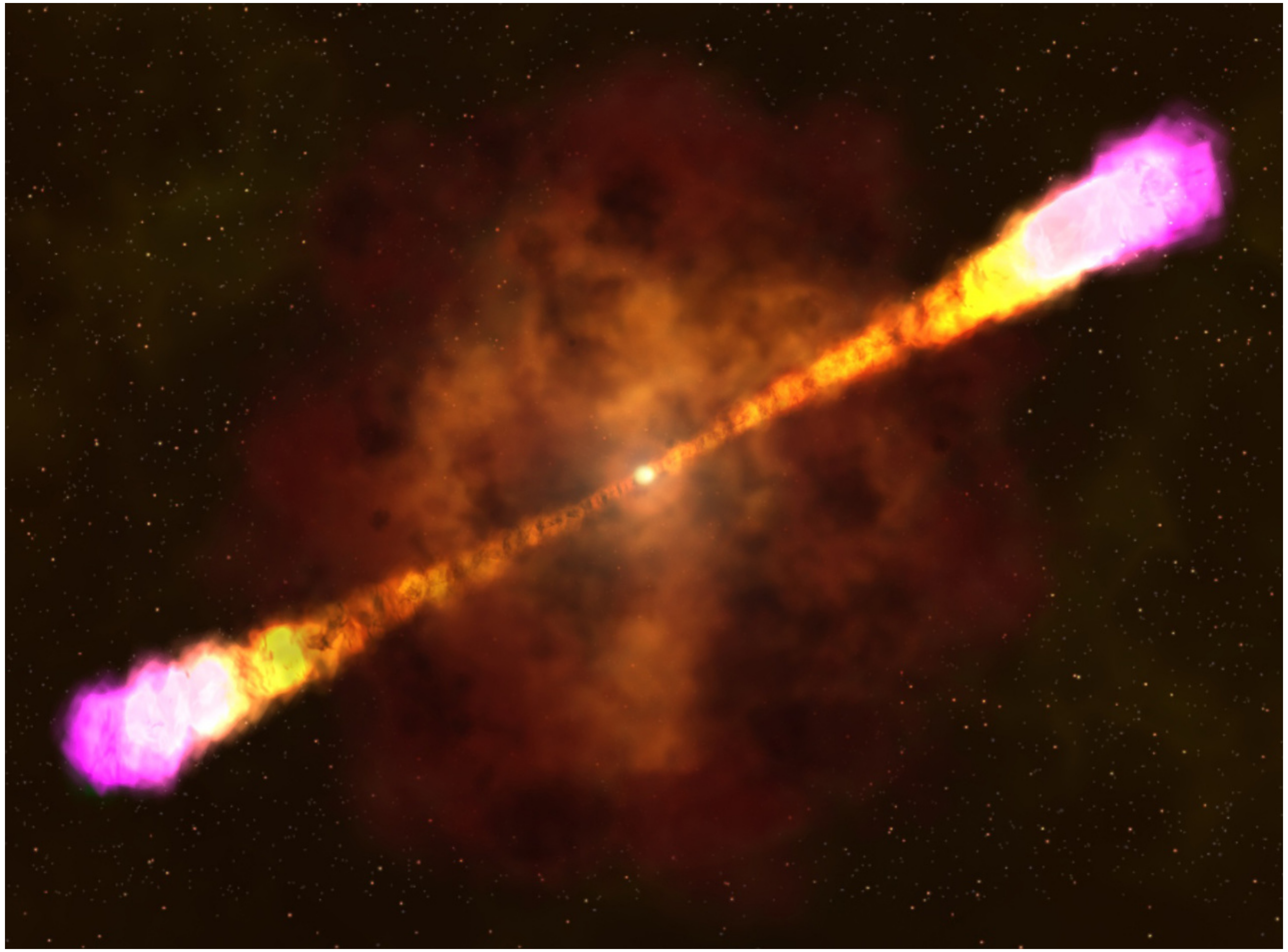
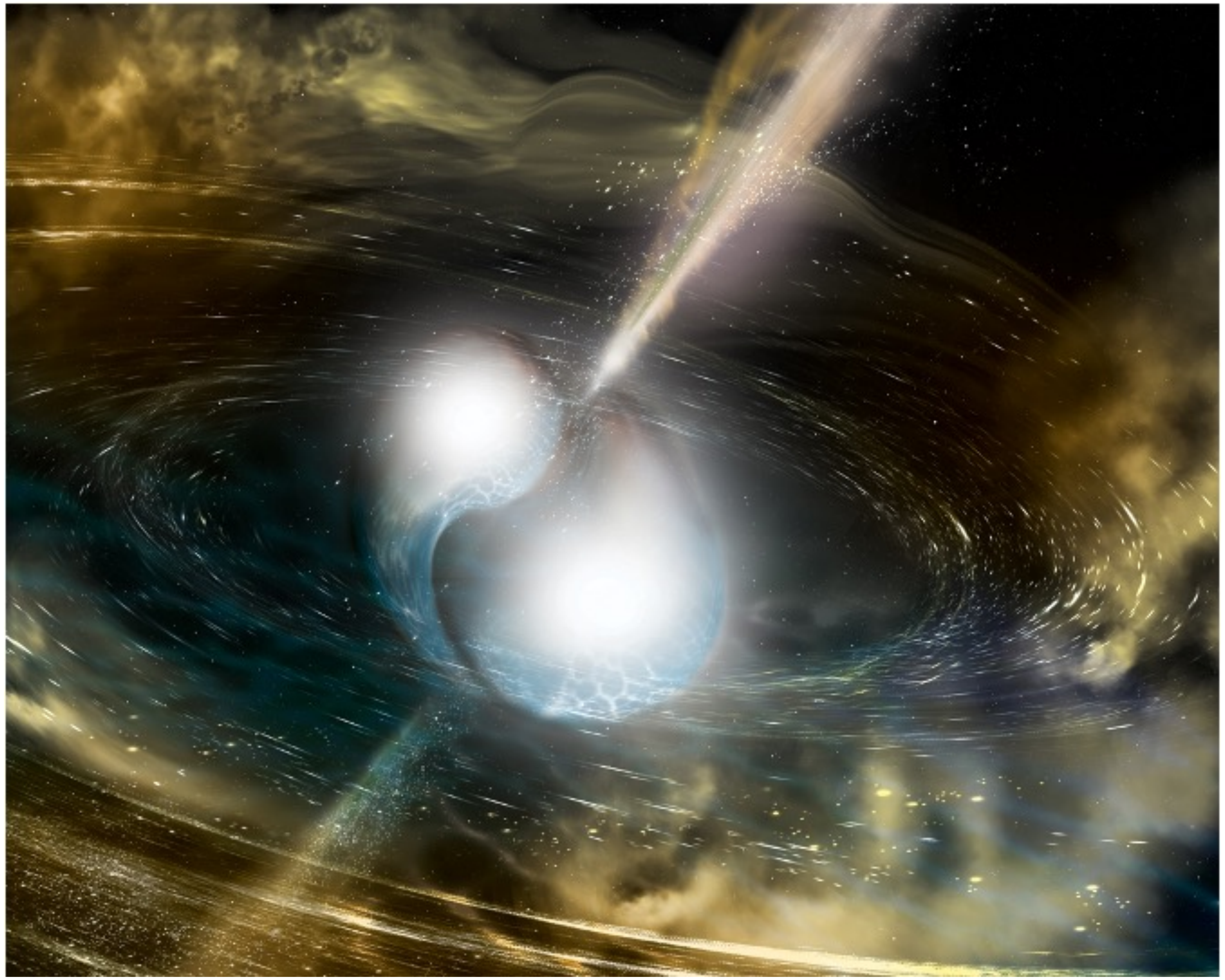
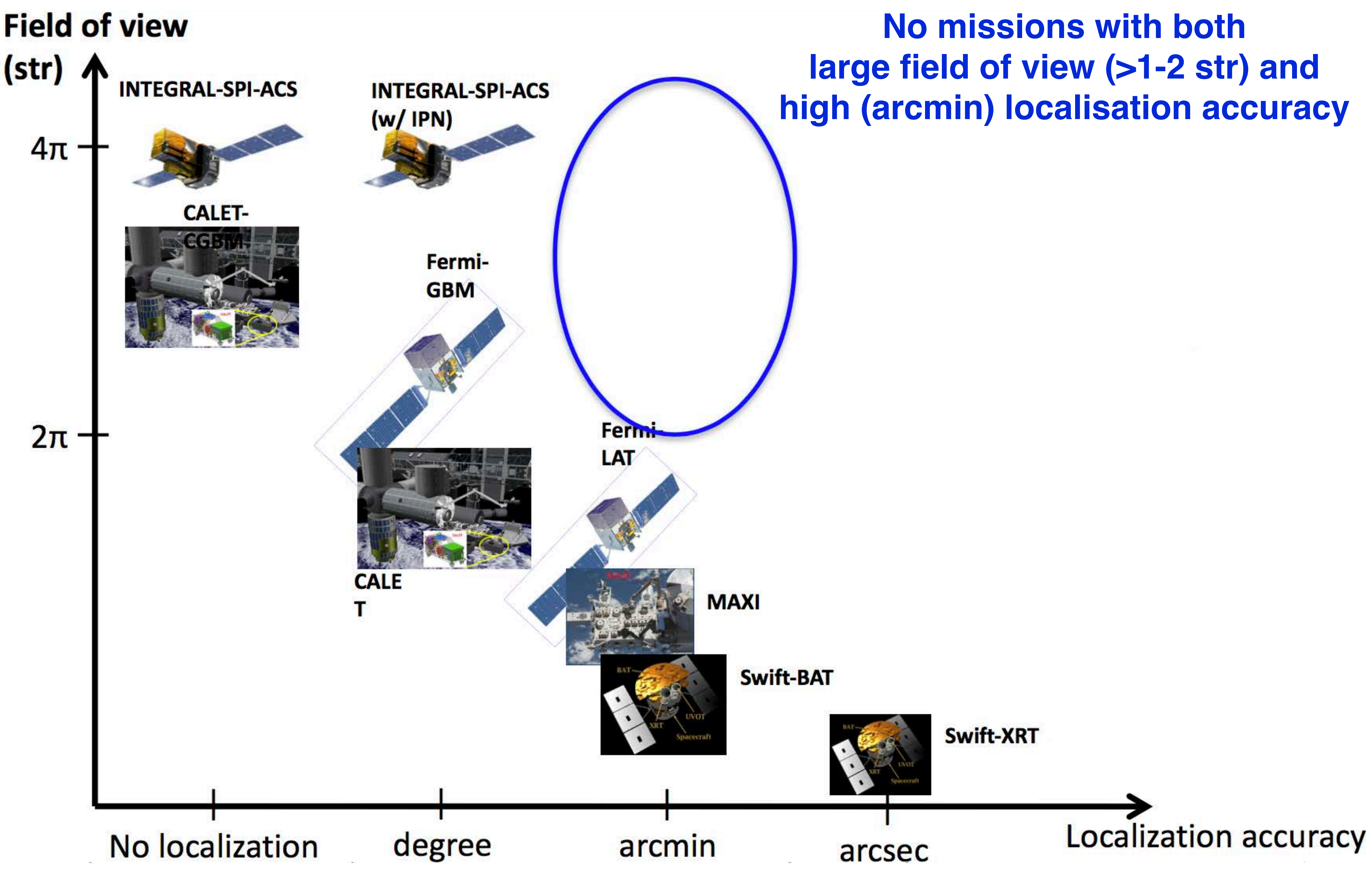
GRBalpha: The Smallest Astrophysical Space Observatory

Gamma-ray bursts accompany the birth of stellar black holes

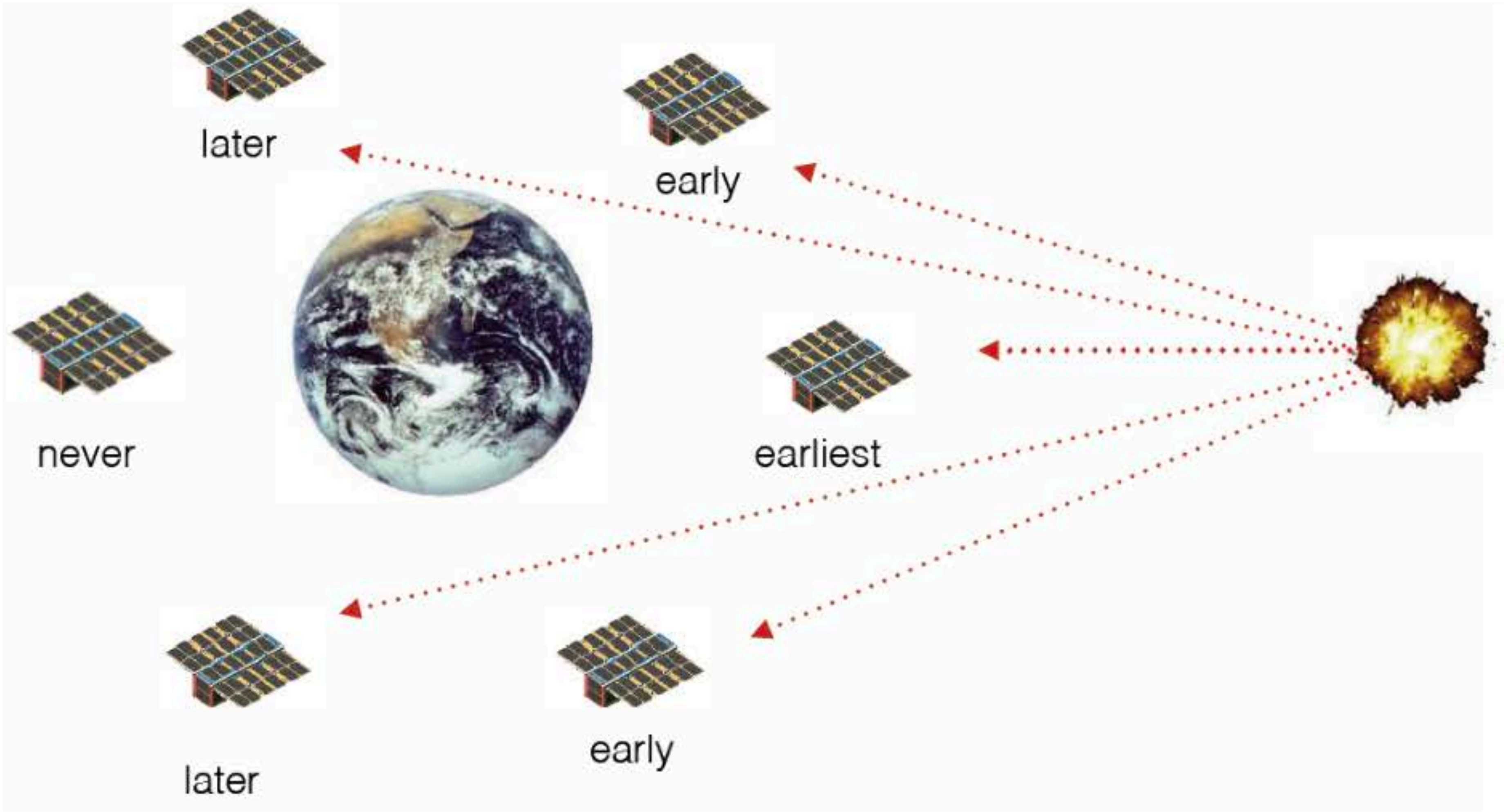




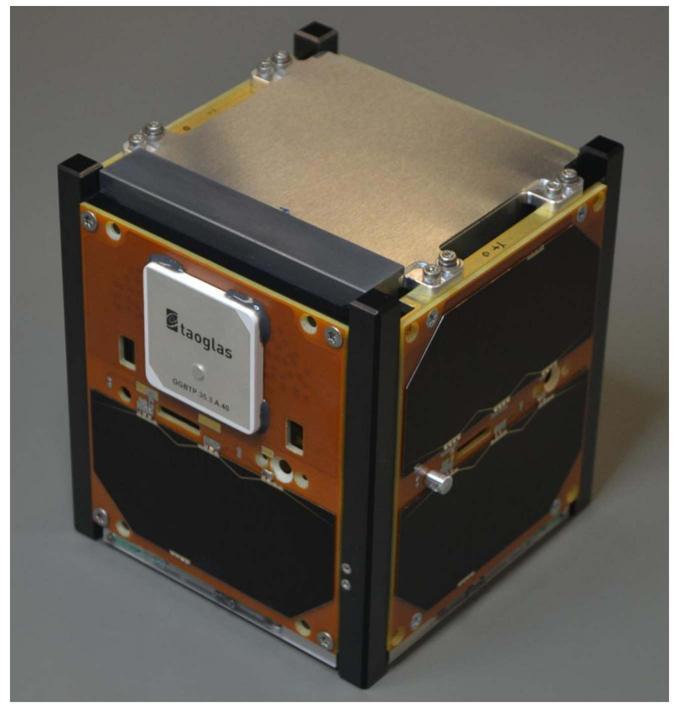
No missions with both large field of view (>1-2 str) and high (arcmin) localisation accuracy



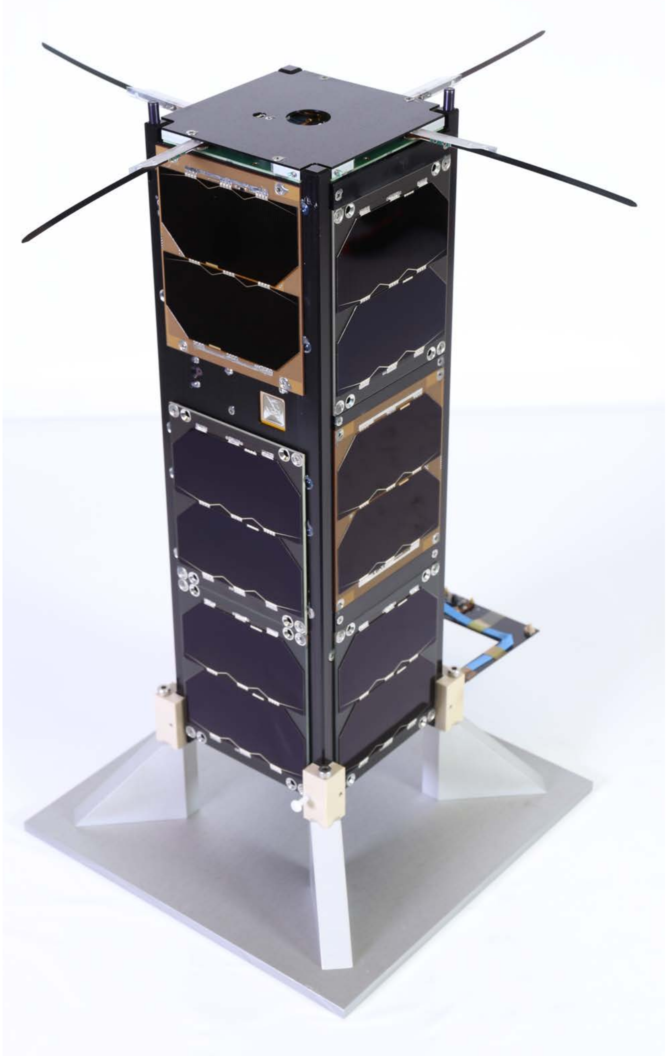
CAMELOT: Cubesat **A**rray for **ME**asuring and **LO**calising **T**ransients



A constellation of at least 9 (18) satellites can provide:
- all sky coverage with a large effective area
- Better than 0.1 millisecond timing accuracy
- ~1 deg^2 localisation accuracy using triangulation



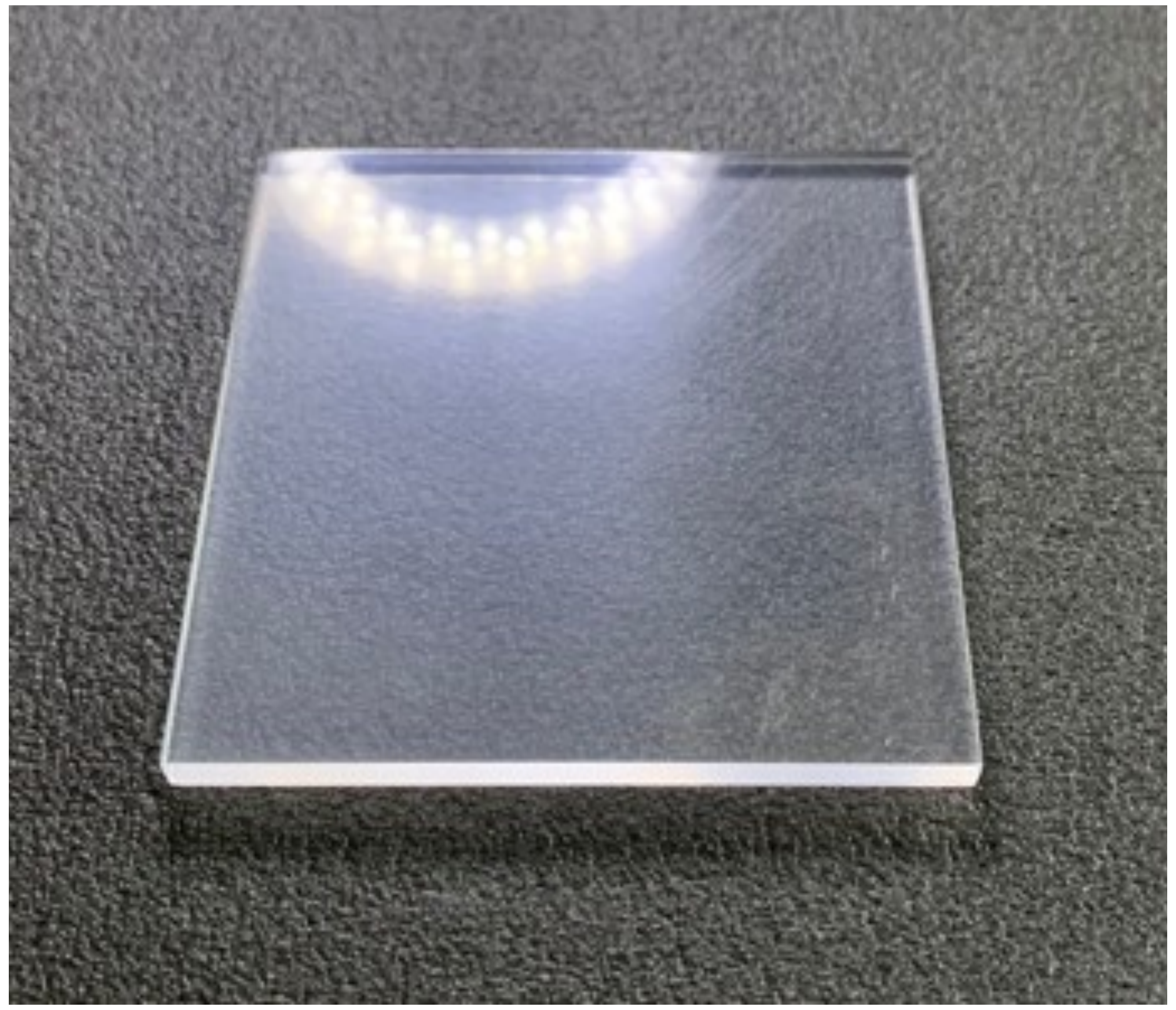
GRBAlpha
Launched: 22. 3. 2021



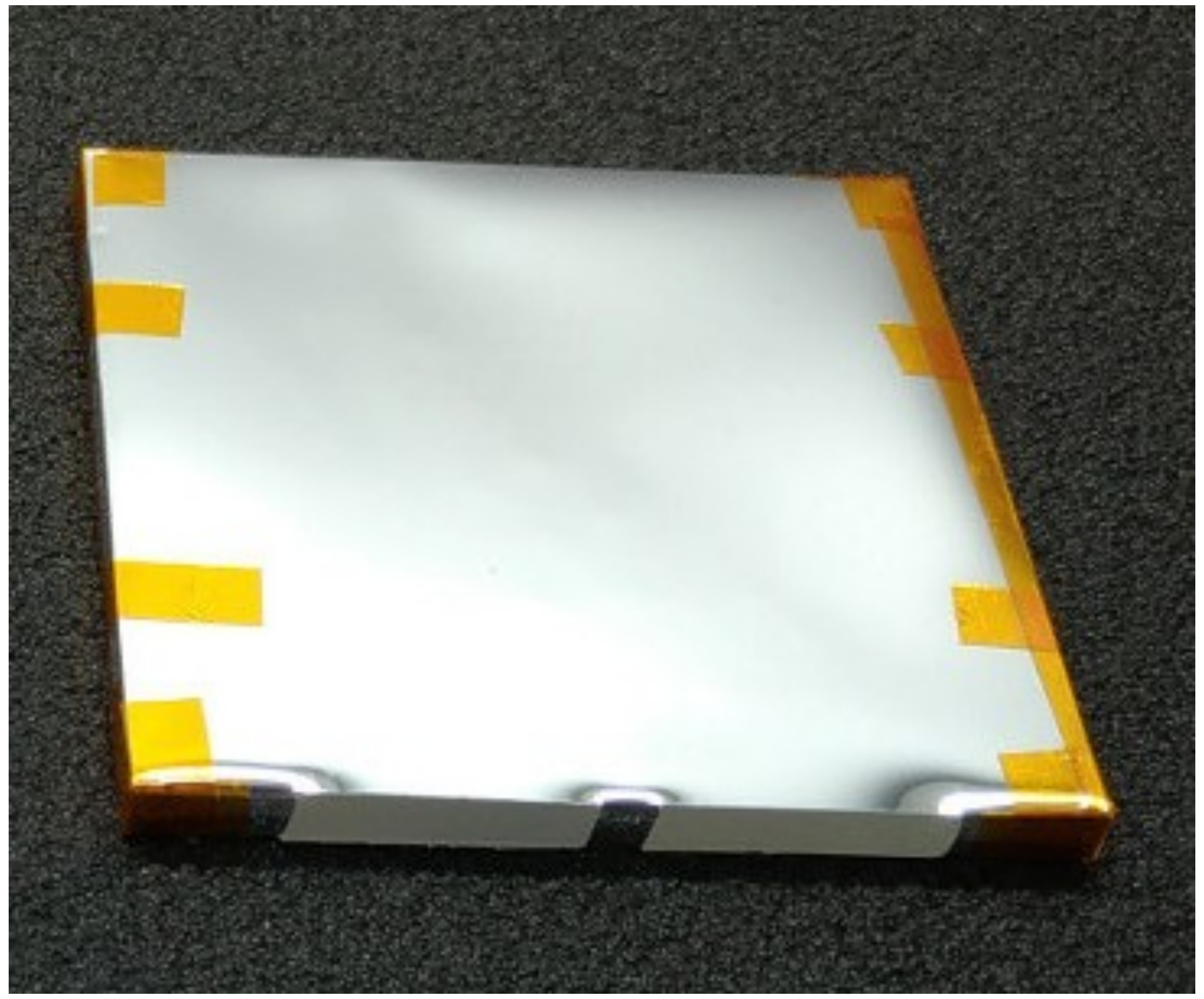
VZLUSAT-2
Launched: 13. 1. 2022

GRBAlpha detector

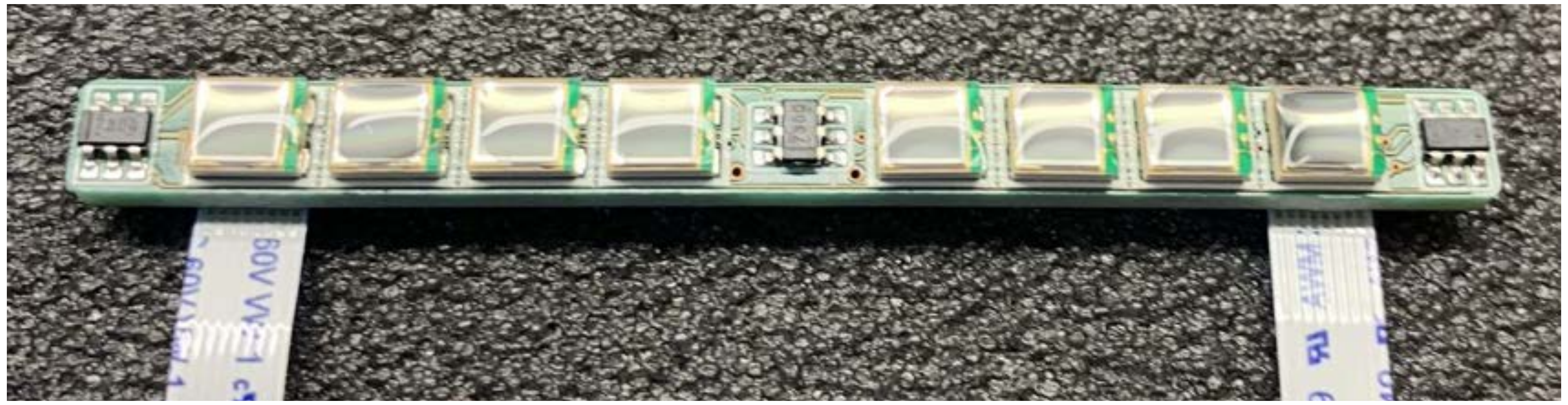
Pál+ 2020



CsI(Tl) scintillator

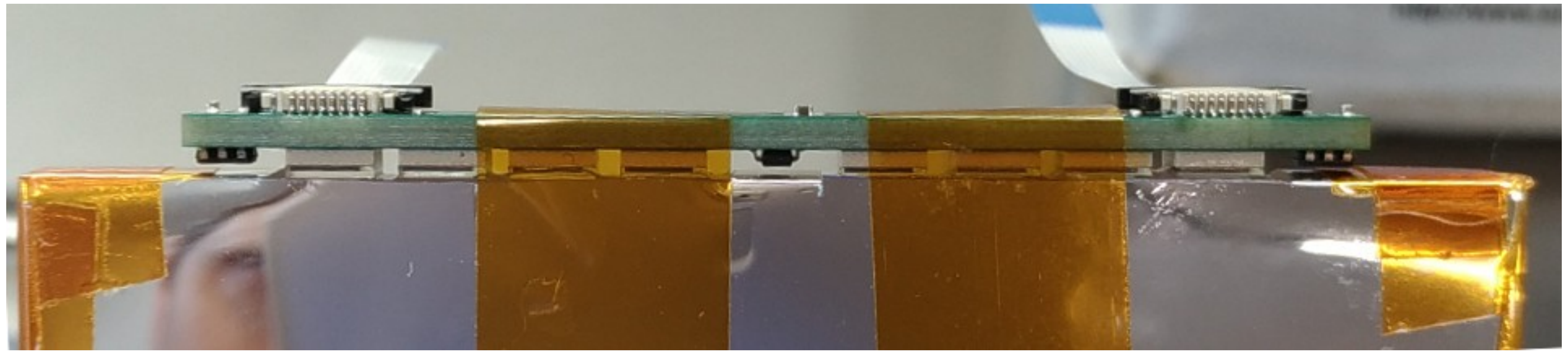


Wrapped in Enhanced
Specular Reflector (ESR)

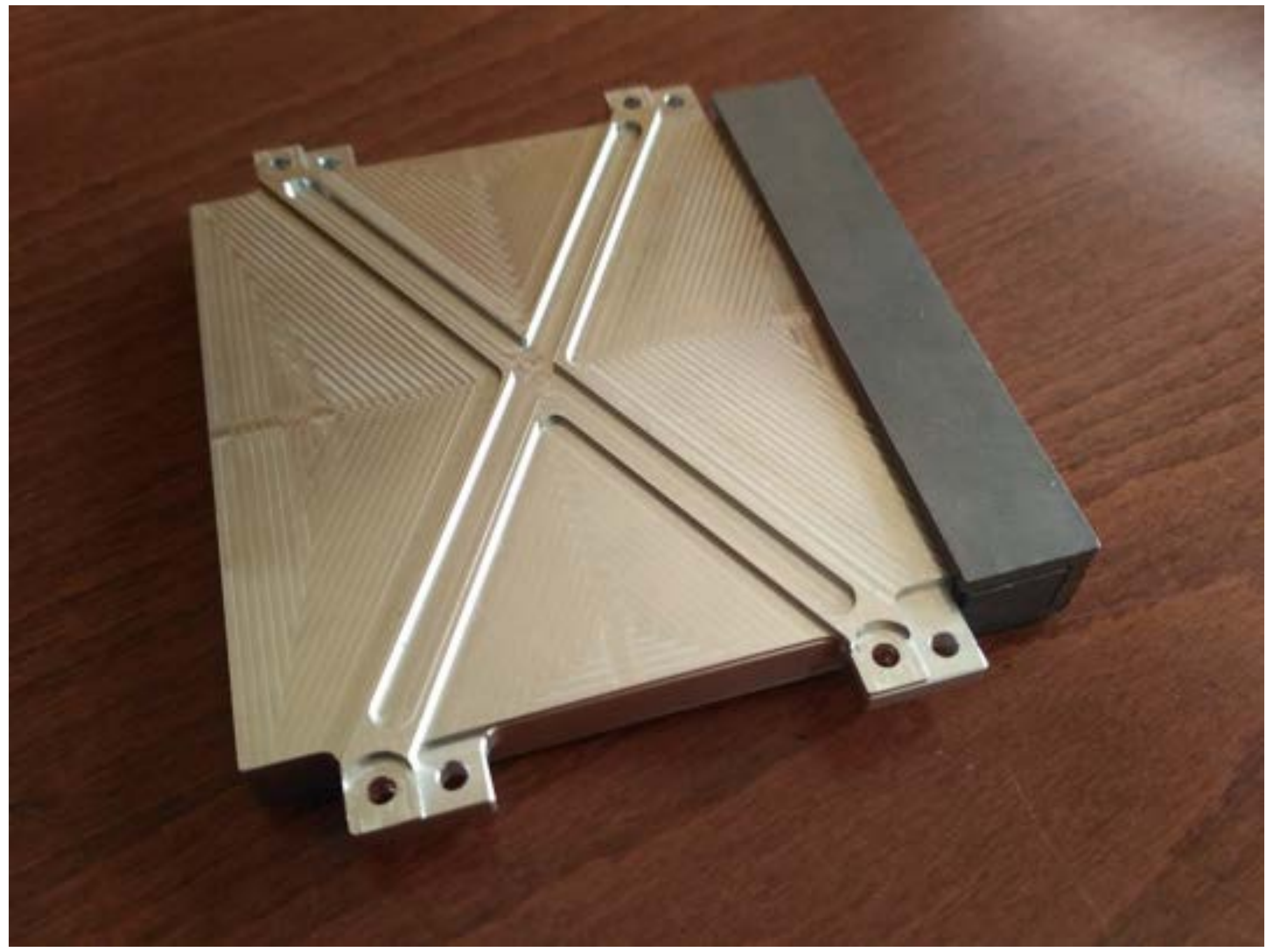


2 readout channels of 4 MPPCs (S13360-3050 PE) by Hamamatsu

GRBAlpha detector

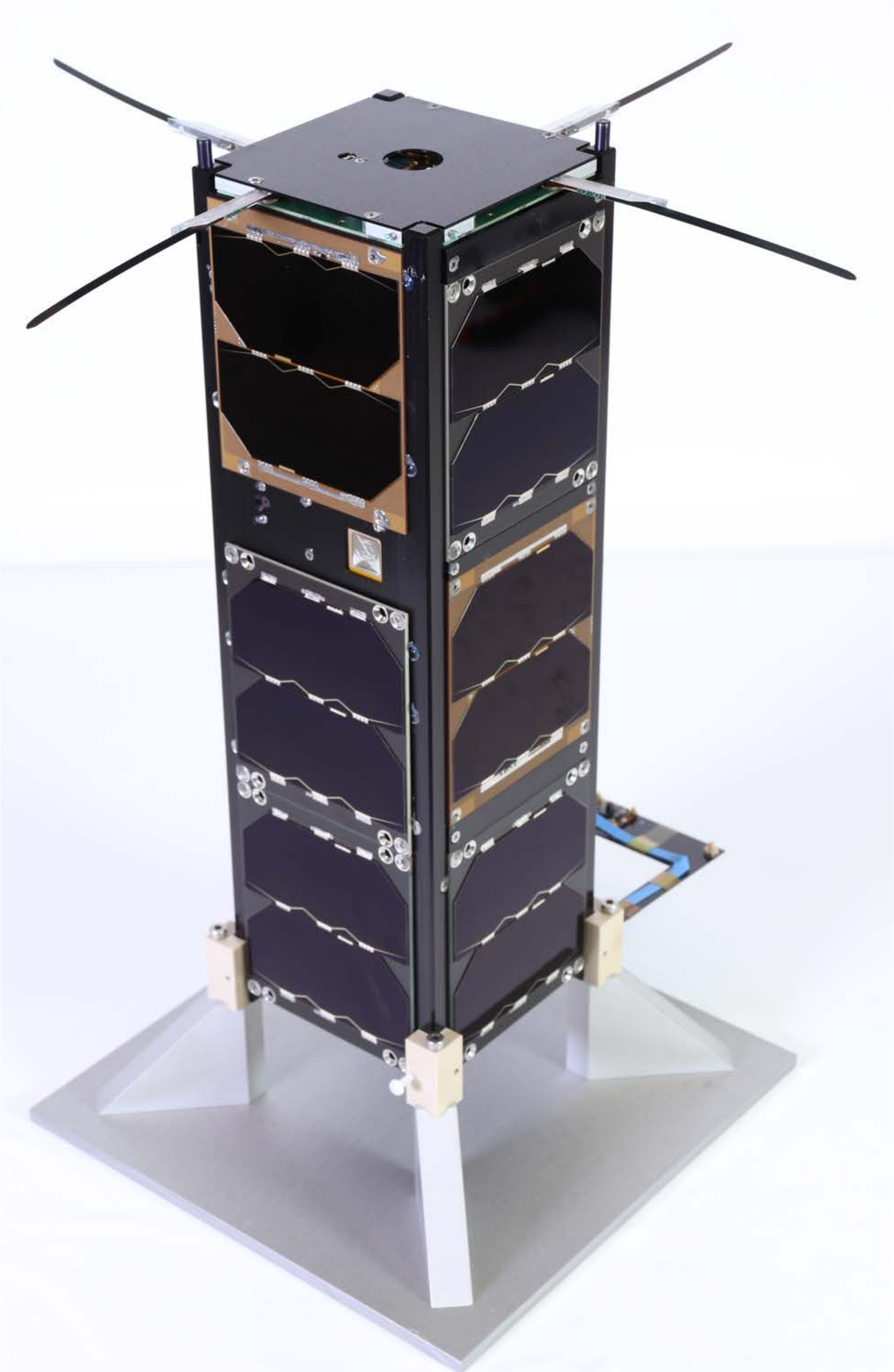


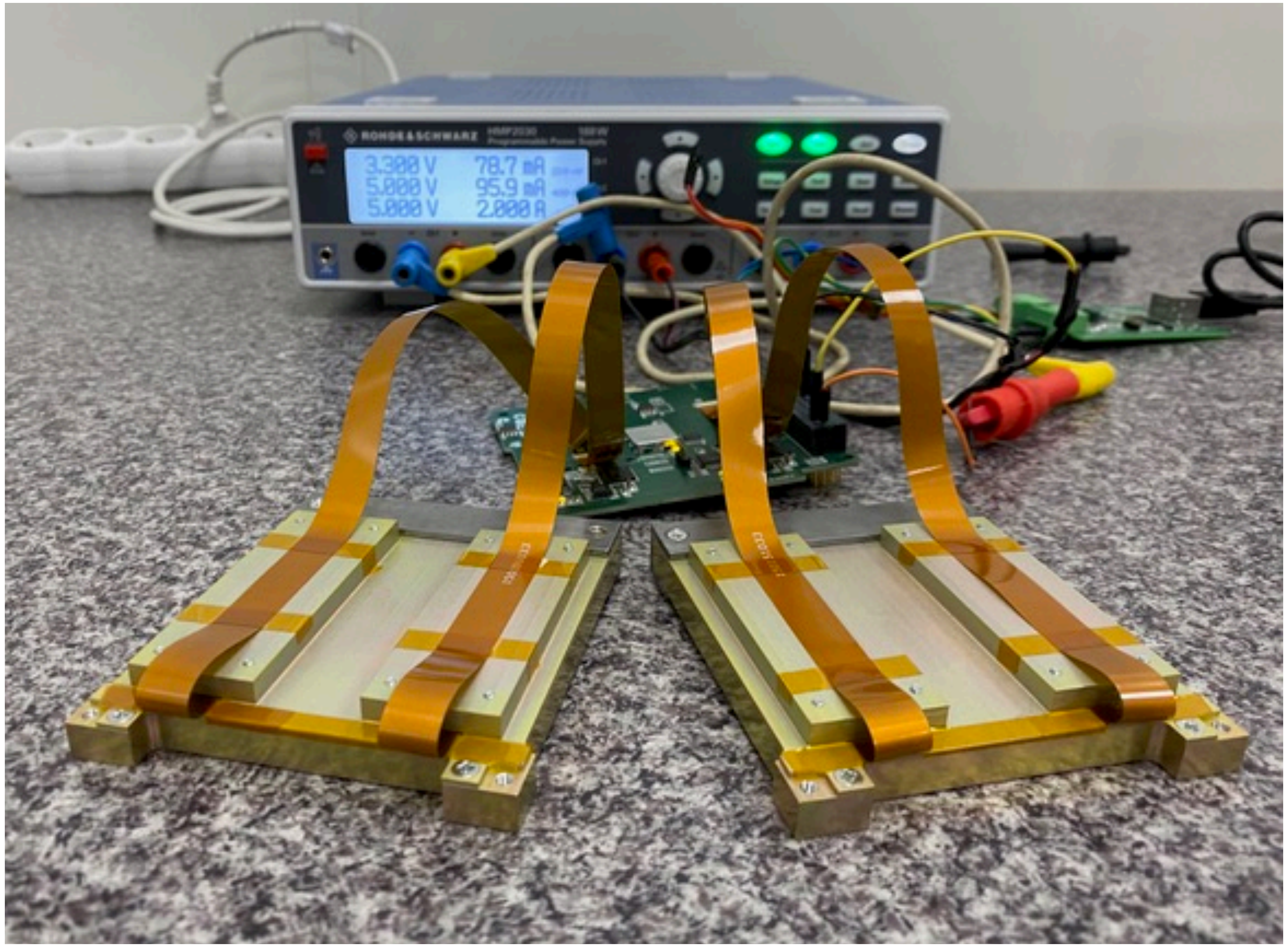
DuPont Tedlar TCC15BL3 wrapping



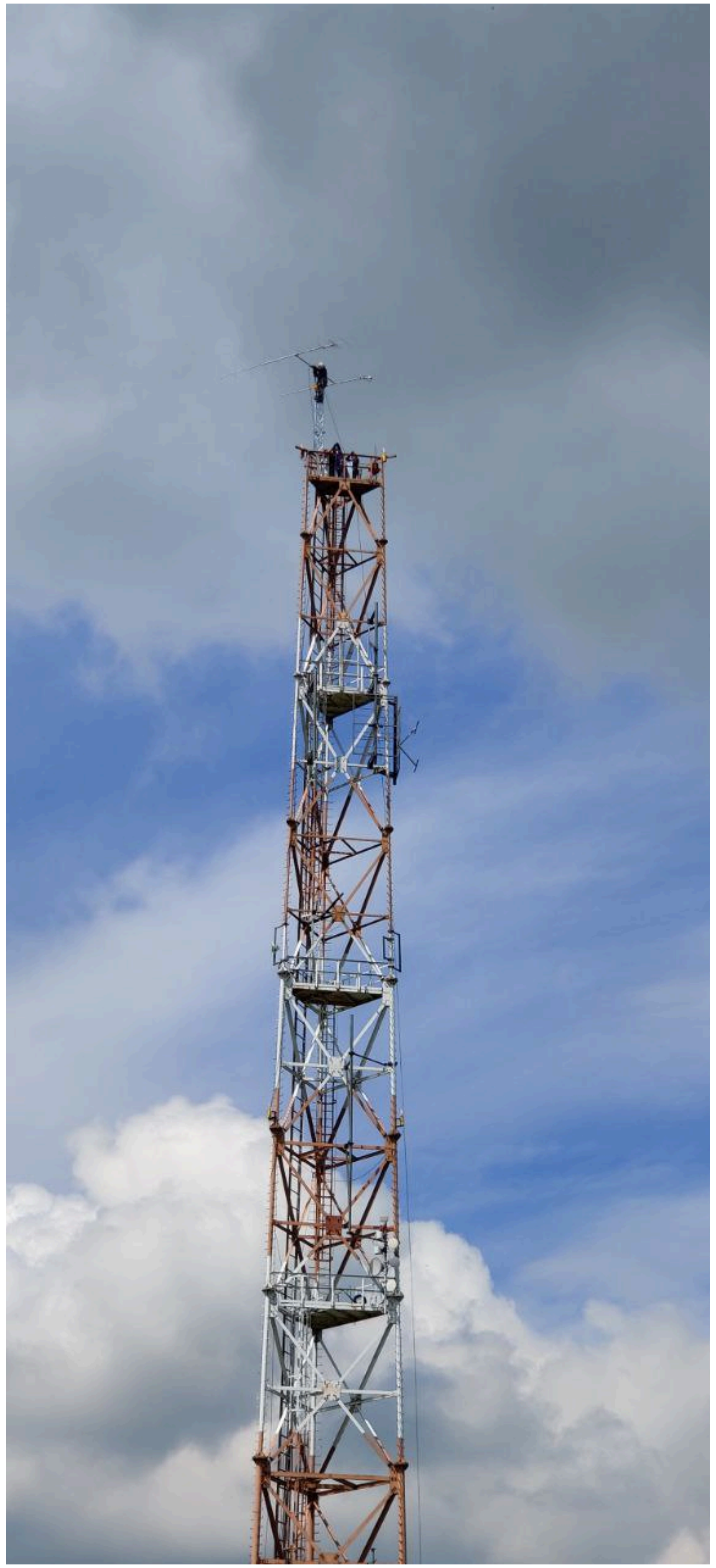
Assembled detector with Pb-Sb alloy to reduce MPPC degradation by protons

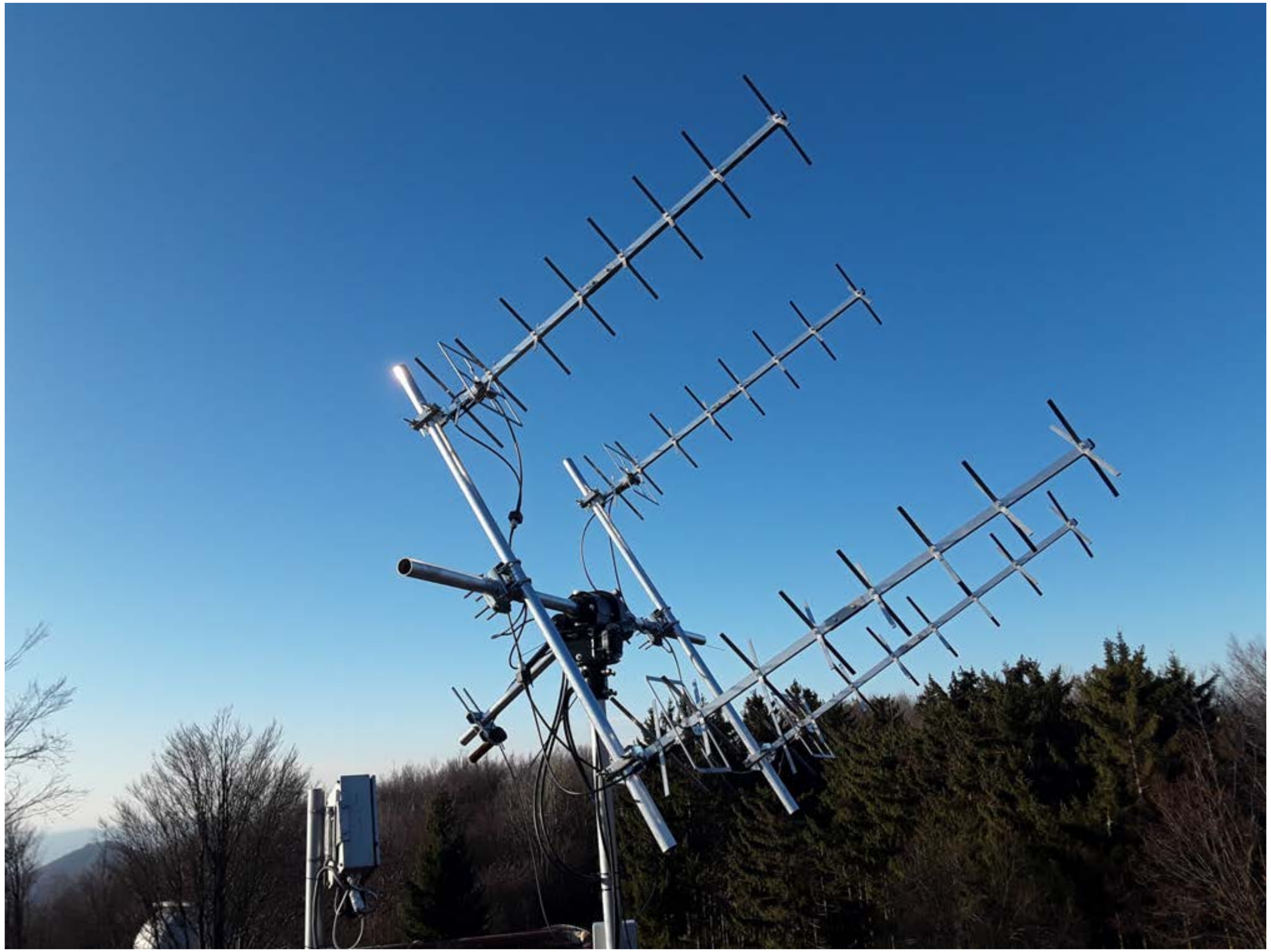

taoglas
GGBTP.35.3.A.40




ROHDE&SCHWARZ
3.300 V
78.7 mA
5.000 V
95.9 mA
5.000 V
2.000 A

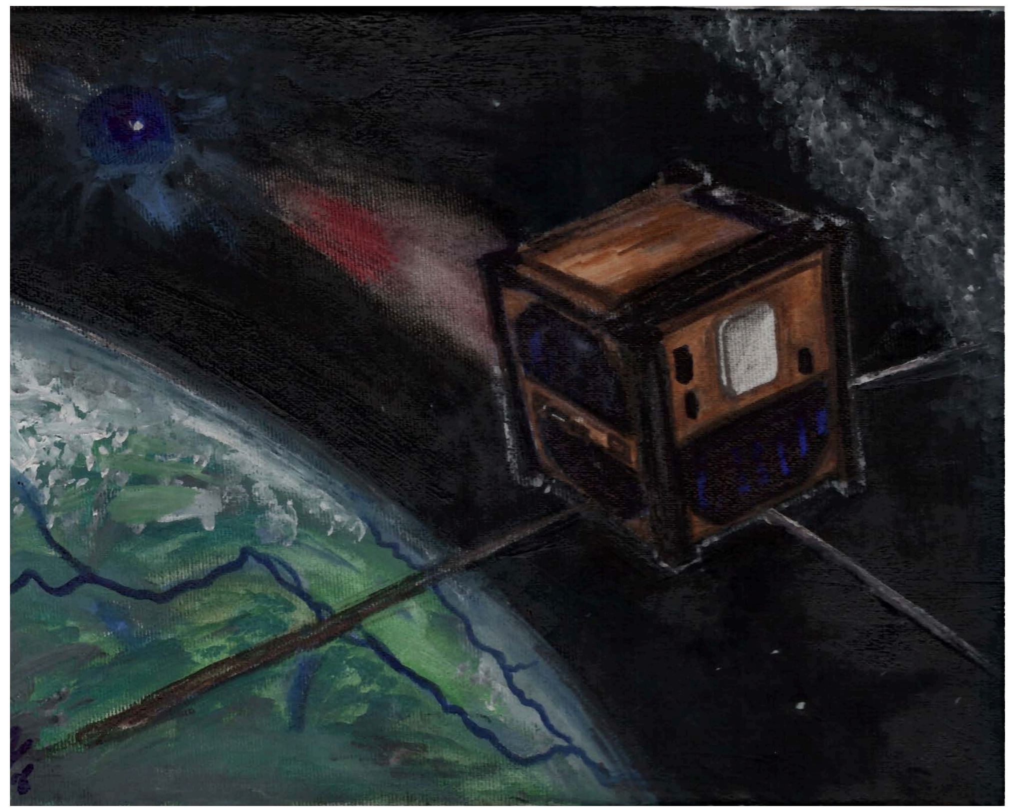
Communication





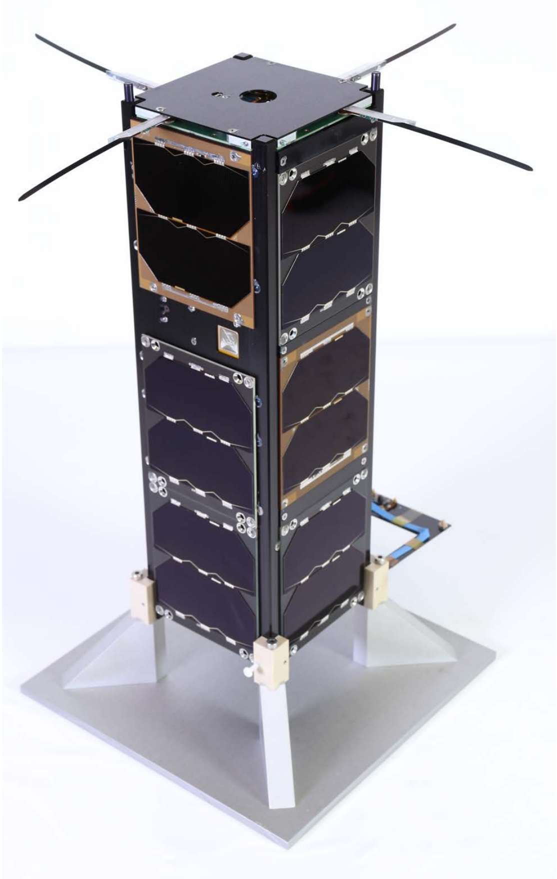
Receiving: Piszkés Tető Observatory
+ the SATNOGS network

Transmition: Bankov (LF TUKE)



GRBAlpha and *VZLUSAT-2*

CURRENT STATE



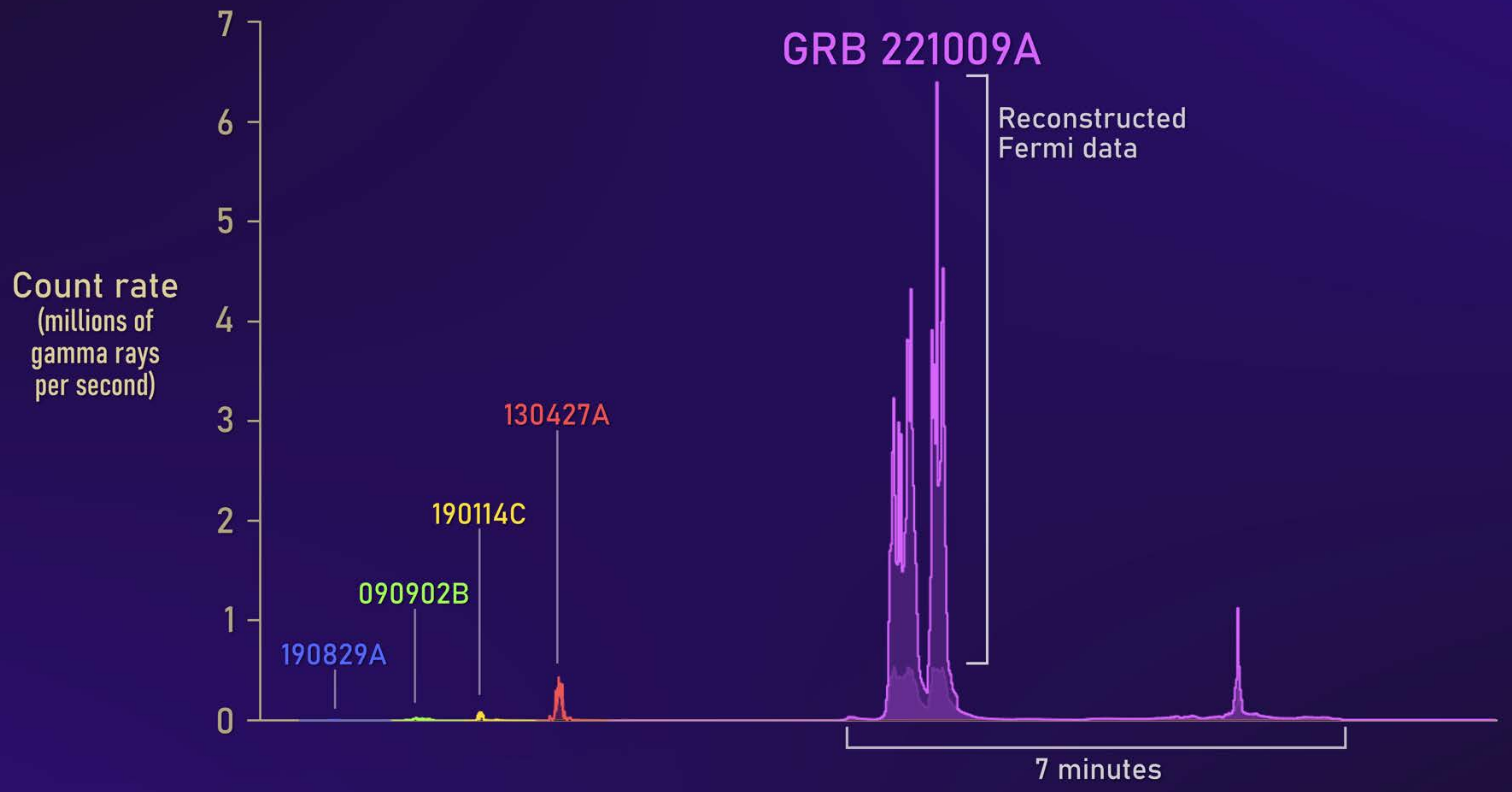
- **83 transients detected by GRBAlpha:** 53 GRBs, 27 Solar flares, 2 SGR flares, 1 X-ray binary flare
- **63 transients detected by VZLUSAT2** 32 GRBs, 25 Solar flares, 6 SGR flares

Enabled by in-orbit firmware updates and the possibility of data drops over various ground stations.

Both satellites continue to monitor the particle environment ("space weather") at the low Earth 550km polar orbit.

Both satellites and their GRB detectors are in good health. The SiPM detector degradation and the low energy threshold of the detectors remain acceptable.

The BOAT GRB in Context




Mars
Swift
GRB Alpha
Fermi

First two papers in *Astronomy and Astrophysics*

Astronomy & Astrophysics manuscript no. aanda
March 14, 2023

Letter to the Editor

The peak-flux of GRB 221009A measured with *GRBAlpha*

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(Affiliations can be found after the references)

Received date / Accepted date

ABSTRACT

Context. On 2022 October 9 the brightest gamma-ray burst (GRB) ever observed lit up the high-energy sky. It was detected by a multitude of instruments, attracting the close attention of the GRB community, and saturated many detectors.
Aims. *GRBAlpha*, a nano-satellite with a form factor of a 1U CubeSat, has detected this extraordinarily bright long-duration GRB 221009A without saturation, but affected by pile-up. We present light curves of the prompt emission in 13 energy bands, from 80 keV to 950 keV, and perform a spectral analysis to calculate the peak flux and peak isotropic-equivalent luminosity.
Methods. Since the satellite's attitude information is not available for the time of this GRB, more than 200 incident directions were probed in order to find the median luminosity and its systematic uncertainty.
Results. We found that the peak flux in the 80–800 keV range (observer frame) was $F^{\rm p}_{\rm ph} = 1300^{+1200}_{-200}$ ph cm^{-2}s^{-1} or $F^{\rm p}_{\rm erg} = 5.7^{+3.7}_{-0.7}\times10^{-4}$ erg cm^{-2}s^{-1} and the fluence in the same energy range of the first GRB episode lasting 300 s, which was observable by *GRBAlpha*, was $S = 2.2^{+1.4}_{-0.3}\times10^{-2}$ erg cm^{-2} or $S^{\rm bol} = 4.9^{+0.8}_{-0.5}\times10^{-2}$ erg cm^{-2} for the extrapolated range of $0.9 - 8,690$ keV. We infer the isotropic-equivalent released energy of the first GRB episode to be $E^{\rm bol}_{\rm iso} = 2.8^{+0.8}_{-0.5}\times10^{54}$ erg in the $1 - 10,000$ keV band (rest frame at $z = 0.15$). The peak isotropic-equivalent luminosity in the $92 - 920$ keV range (rest frame) was $L^{\rm p}_{\rm iso} = 3.7^{+2.5}_{-0.5}\times10^{52}$ erg s^{-1} and the bolometric peak isotropic-equivalent luminosity was $L^{\rm p,bol}_{\rm iso} = 8.4^{+2.5}_{-1.5}\times10^{52}$ erg s^{-1} (4 s scale) in the $1 - 10,000$ keV range (rest frame). The peak emitted energy is $E^{*}_{p} = E_p(1+z) = 1120 \pm 470$ keV. Our measurement of $L^{\rm p,bol}_{\rm iso}$ is consistent with the Yonetoku relation. It is possible that, due to the spectral evolution of this GRB and orientation of *GRBAlpha* at the peak time, the true values of peak flux, fluence, $L_{\rm iso}$, and $E_{\rm iso}$ are even higher.

Key words. stars: gamma-ray burst: individual: GRB 221009A

Astronomy & Astrophysics manuscript no. ms
February 21, 2023

GRBAlpha: the smallest astrophysical space observatory

Part 1 – Detector design, system description and satellite operations

András Pál[1], Masanori Ohno[2], László Mészáros[1], Norbert Werner[3], Jakub Řípa[3], Balázs Csák[1], Marianna Dafčíková[3], Marcel Frajt[4], Yasushi Fukazawa[2], Peter Hanák[5], Ján Hudec[4], Nikola Husáriková[3], Jakub Kapuš[4], Miroslav Kasal[6], Martin Kolář[3], Martin Koleda[7], Robert Laszlo[7], Pavol Lipovský[5], Tsunefumi Mizuno[2], Filip Münz[3], Kazuhiro Nakazawa[8], Maksim Rezenov[4], Miroslav Šmelko[9], Hiromitsu Takahashi[2], Martin Topinka[10], Tomáš Urbanec[6], Jean-Paul Breuer[3], Tamás Bozóki[11], Gergely Dálya[12], Teruaki Enoto[13], Zsolt Frei[14], Gergely Friss[14], Gábor Galgóczi[14,15], Filip Hroch[1], Yuto Ichinohe[16], Kornél Kapás[17,18,15], László L. Kiss[1], Hiroto Matake[2], Hirokazu Odaka[19], Helen Poon[2], Aleš Povalač[6], János Takátsy[14,15], Kento Torigoe[2], Nagomi Uchida[20], and Yuusuke Uchida[21]

GRBAlpha mentioned along big famous observatories

2. OBSERVATIONS

GRB 221009A was identified by a large number of space-based γ-ray observatories. These ir (Veres et al. 2022), *Fermi*-LAT (Bissaldi et al. 2022), *AGILE*/MCAL (Ursi et al. 2022), *AGILE*, 2022), *INTEGRAL* (Gotz et al. 2022), Konus-*Wind* (Frederiks et al. 2022) *Insight*-HMXT (Tan e *6*/SIRI-2 (Mitchell et al. 2022), *SATech-01/GECAM-C* HEBS (Liu et al. 2022), *SRG*/ART-XC (l *Solar Orbiter*/STIX (Xiao et al. 2022), and *GRBalpha* (Ripa et al. 2022). The initial brightness was sufficiently extreme (and also considering its location on the sky in the plane of the Milk proposed to be a new Galactic transient rather than a GRB, despite the fact that *Swift* actua afterglow emission (Dichiara et al. 2022)

Following the identification of the source as a GRB (Kennea et al. 2022), ground-based observat a redshift measurement of $z = 0.151$ (de Ugarte Postigo et al. 2022b; Malesani & Stargate 2023) observations continued until the source entered Sun-block and found a typical GRB afterglow dec also showed evidence for emission from an accompanying supernova Fulton et al. (2023), althoug in Section 3.3.1, isolation of such a supernova component is challenging.

2.1. *James Webb Space Telescope*

On 22 October 2022 we obtained observations of the afterglow of GRB 221009A with JWST (p PI Levan). A single, uninterrupted set of observations were obtained with NIRSPEC and MIRI. NI began at 17:13 UT and MIRI at 18:12, corresponding to time since burst of 13.16 and 13.20 d image of the field at the time is shown in Figure 1, and the resulting spectra in Figure 2.

For NIRSPEC we utilized the prism, spanning a spectral range from 0.5-5.5 microns at a low (a resolution. MIRI observations were undertaken in low resolution mode, and span the range fro both NIRSPEC and MIRI observations we re-process the data with the most up to date calibrat 2022, and obtain our own 1D extractions. We compare these with products obtained with the a

(64-ms scale), making GRB 221009A the most energetic and or since the beginning of the GRB cosmological era in 1997. Th nicely both 'Amati' and 'Yonetoku' hardness-intensity correlatio that GRB 221009A is most likely a very hard, super-energetic v

Keywords: Gamma-ray bursts (629); Transient sources (1851); I

1. INTRODUCTION

Cosmological gamma-ray bursts (GRBs) are thought to be produced by events: mergers of binary compact objects, such as two neutron stars or produce short, $\lesssim 2$ s, so called Type I GRBs; the core collapse of massive sta see, e.g., Zhang et al. (2009) for more information on the Type I/II classifi

The measured GRB isotropic-equivalent energy release $E_{\rm iso}$ and isotropic with the most intense GRBs reaching close to $E_{\rm iso} \sim 10^{55}$ erg and $L_{\rm iso}$ as h of Konus-*WIND* and *Fermi*-GBM samples of GRBs with known redshifts has a cutoff at $E_{\rm iso} \sim 1$–3×10^{54} erg (Atteia et al. 2017; Tsvetkova et al. 2 extremely energetic GRBs. Bright nearby gamma-ray bursts provide a uniq physics, prompt emission and afterglow emission mechanisms, as well as C such bursts have been observed.

On 2022 October 9 at T_0 =13:17:00 UTC an extremely intense GRB 22 missions: *Fermi* (GBM and LAT; Veres et al. 2022; Lesage et al. 2022; Biss *Wind* (Svinkin et al. 2022; Frederiks et al. 2022), *AGILE* (MCAL and G *INTEGRAL* (SPI-ACS; Gotz et al. 2022), *Insight*-HXMT (Tan et al. 2022 *Spektr-RG* (ART-XC; Lapshov et al. 2022), *GRBAlpha* (Ripa et al. 2022) *C* (Liu et al. 2022), and *BepiColombo* (MGNS; Kozyrev et al. 2022). The initial analysis of the burst showed that the prompt emission was so intense that it saturated almost all instruments.

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.).

(Lapshov et al. 2022), *Solar Orbiter*/STIX (Xiao et al. 2022), and *GRBalpha* (Ripa et al. 2022). However, the event was first reported by a *Swift* detection of the afterglow over 50 minutes later (Dichiara et al. 2022b). The location of the burst within the Galactic plane (l = 52.96°, b = 4.32°), combined with its brightness, led to confusion over the nature of the outburst: initially it was suspected to be due to a new Galactic X-ray transient (Dichiara et al. 2022b,a), but its subsequent behaviour appeared more like that of an extragalactic GRB (Kennea et al. 2022).

Despite high foreground extinction (Section 3.2), an optical afterglow was seen by various telescopes (e.g. Dichiara et al. 2022b; Lipunov et al. 2022; Fulton et al. 2023 and many more). The counterpart was localised at coordinates (J2000): RA = 19ʰ13ᵐ03ˢ.500792(2), dec = 19°46′24″.22891(7) by the VLBA at 15.2 GHz (Atri et al. 2022).

Detection with several high energy instruments have also been reported, including GeV emission with *Fermi*-LAT (potentially up to 400 GeV; Xia et al. 2022), TeV emission extending to 18 TeV from LHAASO (Huang et al. 2022), and even a suggestion of a possible association with a 250 TeV photon (Dzhappuev et al. 2022).

tometric set (de Ugarte Postigo et al. 2023, in preparati nally, we have applied a telluric correction using mod mated using the line-by-line radiative transfer model (LB Clough et al. 1992) and atmospheric properties, such as ity, temperature, pressure and zenith angle, which are s the header of each exposure.

The observations revealed a very bright trace in the infrared, strongly attenuated towards the blue end by t Galactic extinction. Figure 1 shows the overall shape of t trum and zoom-in panels highlighting specific features.

We subsequently obtained further X-shooter observa follow the afterglow evolution. These are discussed in de Ugarte Postigo et al. (2023, in preparation). Among spectra, here we only exploit the 4 × 600 s spectrum tak mid time 2022 Oct 20 00:19:38 UT, which provides the tection of the emission features (Fig. 1 and Sec. 3.3).

The results reported in this paper supersede our nary analysis (de Ugarte Postigo et al. 2022; Izzo et al Our spectroscopic measurement was subsequently confi Castro-Tirado et al. (2022).

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Deciphering the ∼18 TeV Photons from GRB 221009A

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Abstract

On 2022 October 9, an extremely powerful gamma-ray burst, GRB 221009A, was detected by several instruments. Despite being obstructed by the Milky Way galaxy, its afterglow outburst outshone all other GRBs seen before. LHAASO detected several thousand very high energy photons extending up to 18 TeV. Detection of such energetic photons is unexpected due to the large opacity of the universe. It is possible that in the afterglow epoch, the intrinsic very high energy photon flux from the source might have increased manifolds, which could compensate for the attenuation by pair production with the extragalactic background light. We propose such a scenario and show that very high energy photons can be observed on the Earth from the interaction of very high energy protons with the seed synchrotron photons in the external forward shock region of the GRB jet.

Unified Astronomy Thesaurus concepts: Gamma-ray bursts (629); Particle astrophysics (96)

1. Introduction

On 2022 October 9, at T0 = 13:16:59.000 UT (Veres et al. 2022), a long-duration gamma-ray burst (GRB) identified as GRB 221009A (also known as Swift J1913.1+1946) was detected in the direction of the constellation Sagitta by the Gamma-ray Burst Monitor (GBM; Meegan et al. 2009) on board the Fermi Gamma-ray Space Telescope. The prompt emission was also detected by several other space observatories, such as the Fermi Large Area Telescope (LAT), Swift (Dichiara et al. 2022; Krimm et al. 2022), AGILE (Piano et al. 2022; Ursi et al. 2022), INTEGRAL (Gotz et al. 2022), Solar Orbiter (Xiao et al. 2022), SRG (Lapshov et al. 2022), Konus (Frederiks et al. 2022), GRBAlpha (Ripa et al. 2022), and STPSat-6 (Mitchell et al. 2022). The GRB 221009A is located at the coordinate R.A. = 288.282 and decl. = 19.495 (Pillera et al. 2022). Fermi-LAT detected the most energetic photon of energy, 99.3 GeV (at t_0 + 240 s). It is the highest-energy photon ever detected by Fermi-LAT from a GRB in the prompt phase (Bissaldi et al. 2022; Pillera et al. 2022). The afterglow emission was also observed at different wavelengths (Das &

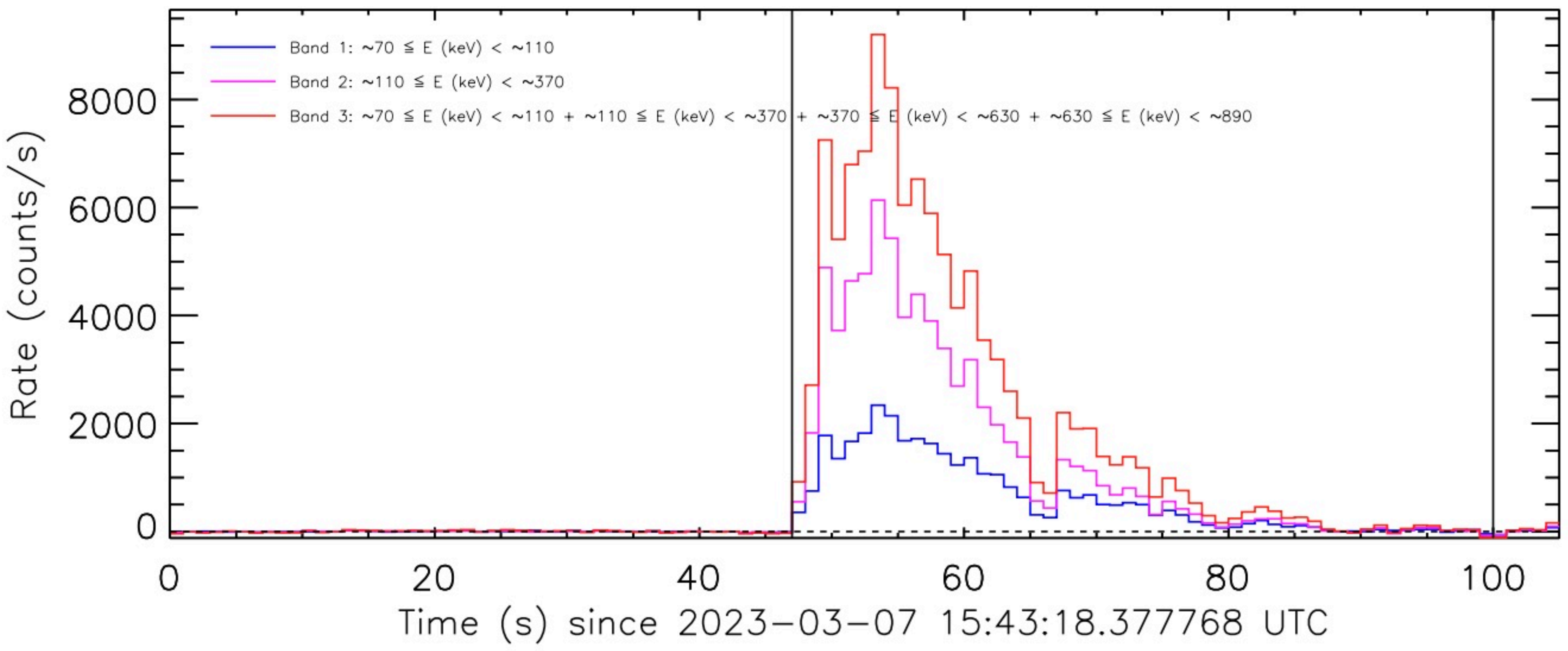
detector observed more than 5000 very high energy (VHE) photons within T_0 + 2000 s in the 500 GeV–18 TeV energy range, making them the most energetic photons ever observed from a GRB (Huang et al. 2022). Surprisingly, the ground-based Cherenkov detector Carpet-2 at Baksan Neutrino Observatory reported the detection of what is undoubtedly a very rare air shower originating from a 251 TeV photon 4536 s after the GBM trigger from the direction of GRB 221009A (Dzhappuev et al. 2022). Observations of these unusually VHE gamma rays by LHAASO and Carpet-2 from GRB 221009A are incomprehensible and led to speculation about nonstandard physics explanations of these observed events. However, there is a caveat concerning the observation of the 251 TeV gamma ray. The angular resolution of Carpet-2 is several degrees, and the two previously reported Galactic VHE sources, 3HWC J1928+178 and LHASSO J1929+1745, are located close to the position of GRB 221009A (Fraija & Gonzalez 2022). It remains uncertain whether the observed 251 TeV photon is from GRB 221009A or either of these Galactic sources. Nevertheless, the temporal and spatial coincidence of this event

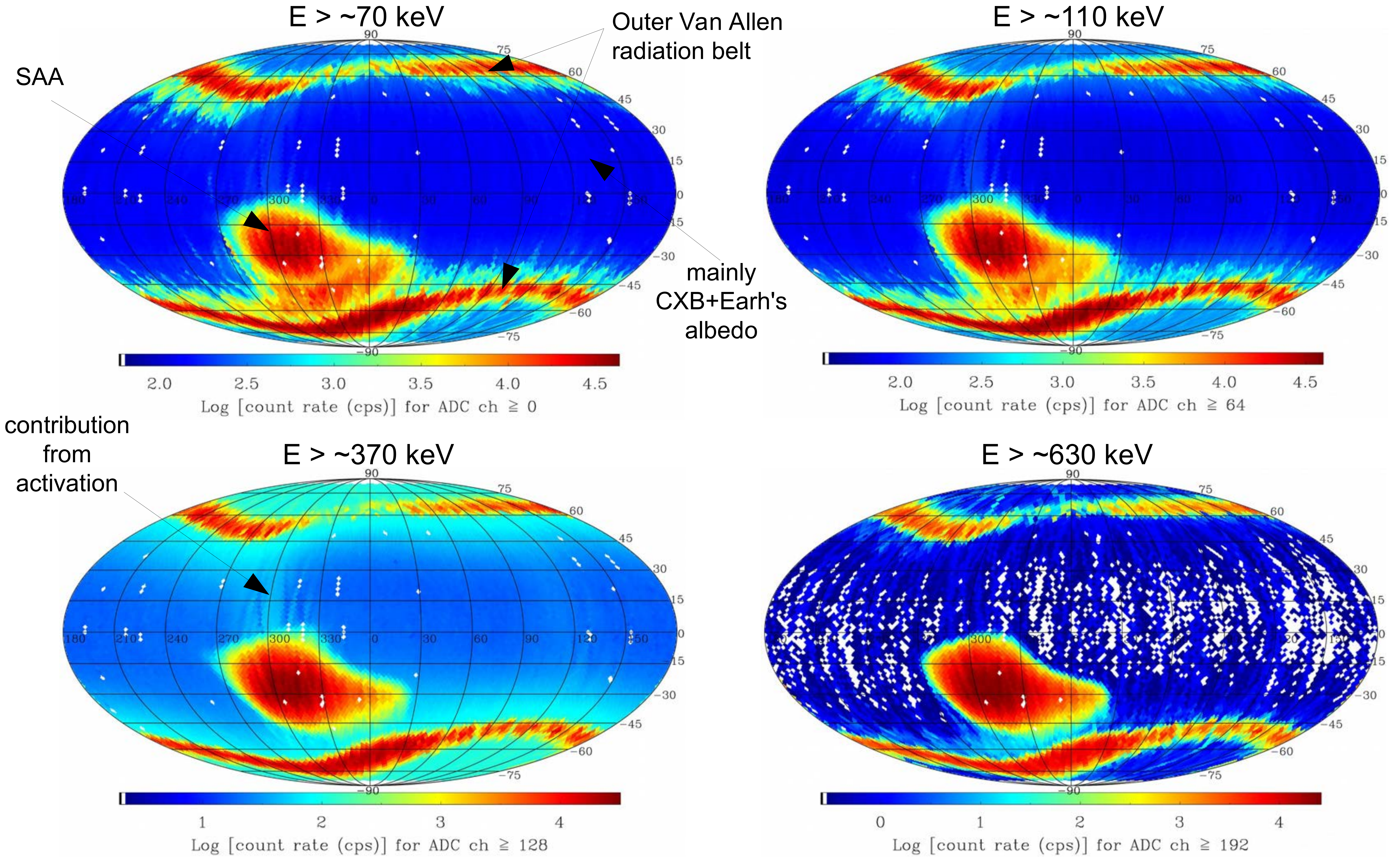
ground light (EBL; (*4, 5*)).

$10^{-7} - 10^{-4}$ erg cm^{-2} (*1*) and spectra up to the MeV or, less frequently, GeV range (*6*).

On October 10, 2022 at 13:16:59 UT (hereafter referred to as T_0), the Gamma-ray Burst Monitor (GBM) aboard *Fermi* (*7, 8*), among many other high-energy satellites (*INTEGRAL, Konus-Wind, AGILE, SRG, GRBAlpha, HEBS*; (*9–13*)), detected an unprecedented, extremely bright burst lasting hundreds of seconds. This burst, dubbed GRB 221009A, is the brightest GRB ever detected in nearly 55 years of operating gamma-ray observatories, with an observed fluence of $\approx 5\times10^{-2}$ erg cm^{-2} in the 20 keV – 10 MeV band, more than an order of magnitude brighter than GRB 840304 and GRB 130427A (*14*), the previous record holders (Fig. 1). Its high-energy radiation was so intense that it disturbed Earth's ionosphere (*15, 16*).

GRB 230307A the second brightest burst ever!





E > ~70 keV
Outer Van Allen radiation belt
SAA
mainly CXB+Earh's albedo
Log [count rate (cps)] for ADC ch ≧ 0
E > ~110 keV
Log [count rate (cps)] for ADC ch ≧ 64
contribution from activation
E > ~370 keV
Log [count rate (cps)] for ADC ch ≧ 128
E > ~630 keV
Log [count rate (cps)] for ADC ch ≧ 192

Summary

- If operated continuously, the detection rate is approximately **1 transients per 5 days**

- The **duty cycle** on a 550 km polar orbit is around **~ 67%** (GRBs detected in the polar regions)

- The **degradation of MPPCs** remains at an **acceptable** level, resulting in a low energy threshold decrease to ~60 keV for *GRBAlpha* and ~40 keV for *VZLUSAT-2*