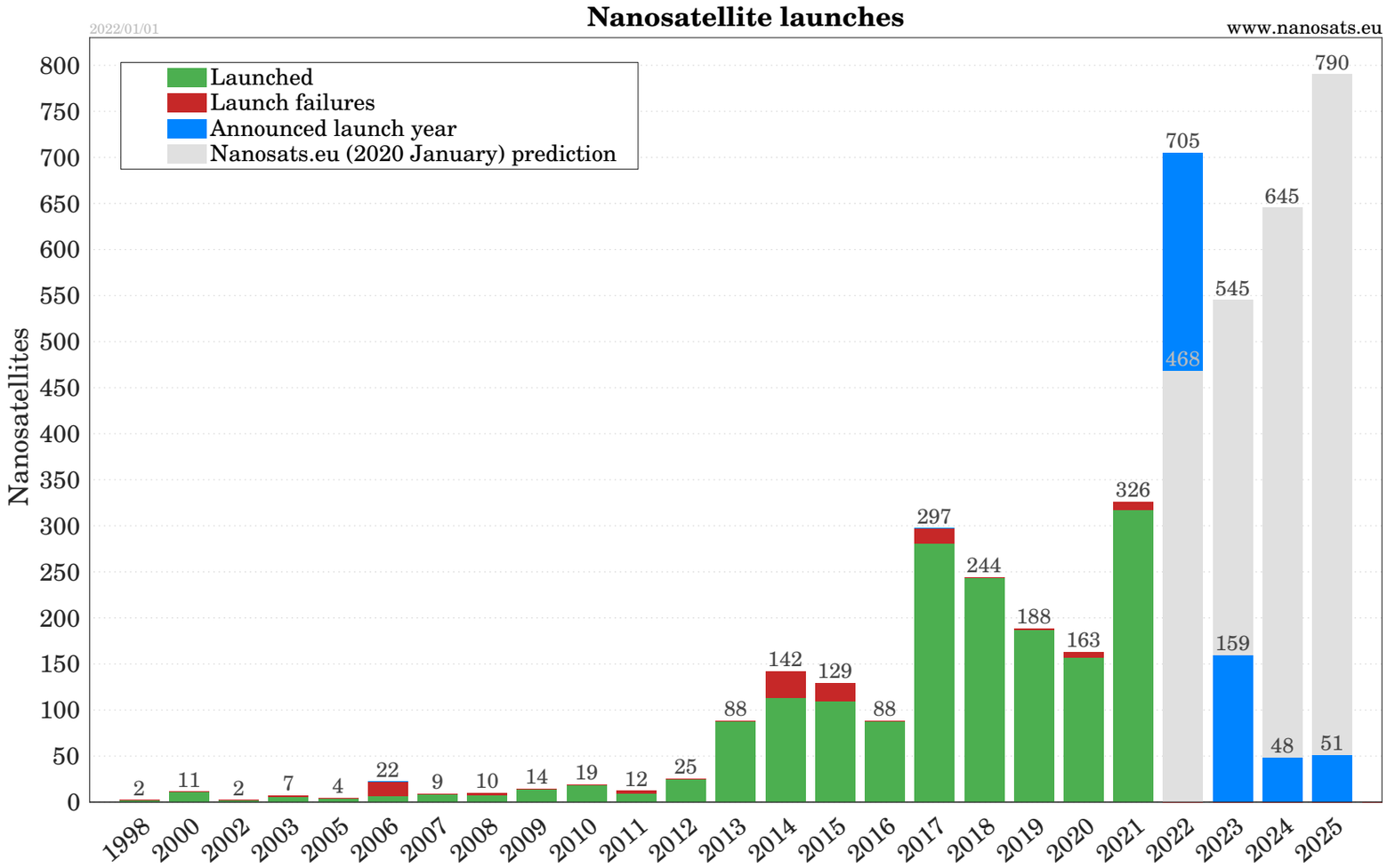
Adriano Di Giovanni on behalf of the LIGHT-1 team

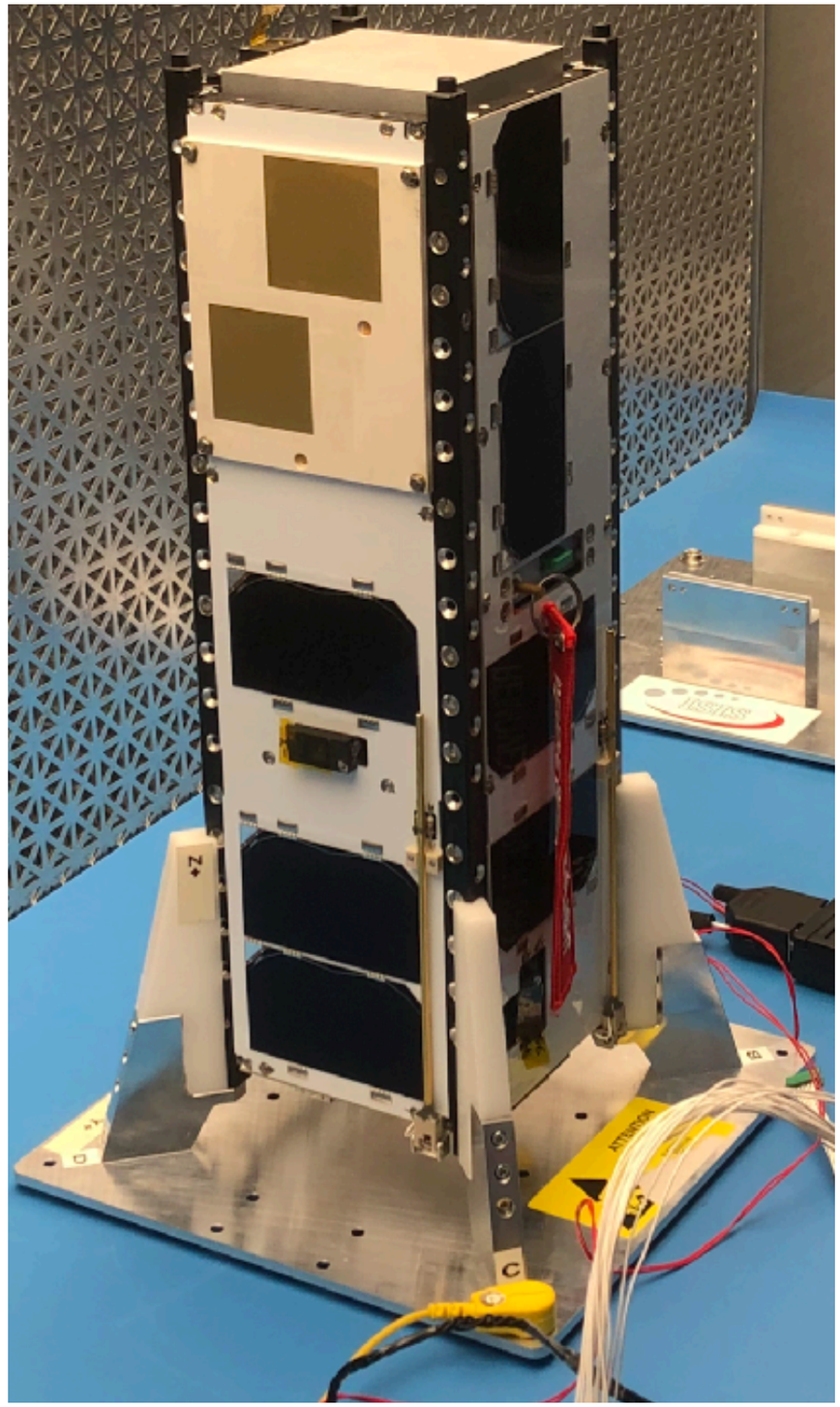
The Scientific Payload of LIGHT-1: A 3U Cubesat Mission for the detection of Terrestrial Gamma-Ray Flashes

الحمولة العلمية لضوء - ١ : قمر صناعي مصغر من ثلاث مكعبات مخصص لكشف ومضات جاما الأرضية

Contents

- Terrestrial Gamma-Ray flashes (TGF) in a nutshell
- The CubeSat standard as a new paradigm to access Space
- The LIGHT-1 Mission
- The Scientific Payload
- First Flight Data and preliminary results





Discovering TGFs

1969 - 1972
Vela 5A/B and 6A/B

Detection of 16 GRBs

1991 - 2000
BATSE-CGRO

Detection of 2704 GRBs + a handful of high energetic short burst from ground (TGFs ?)

2007 - present
AGILE

Detection of TGFs

2008 - present
FERMI

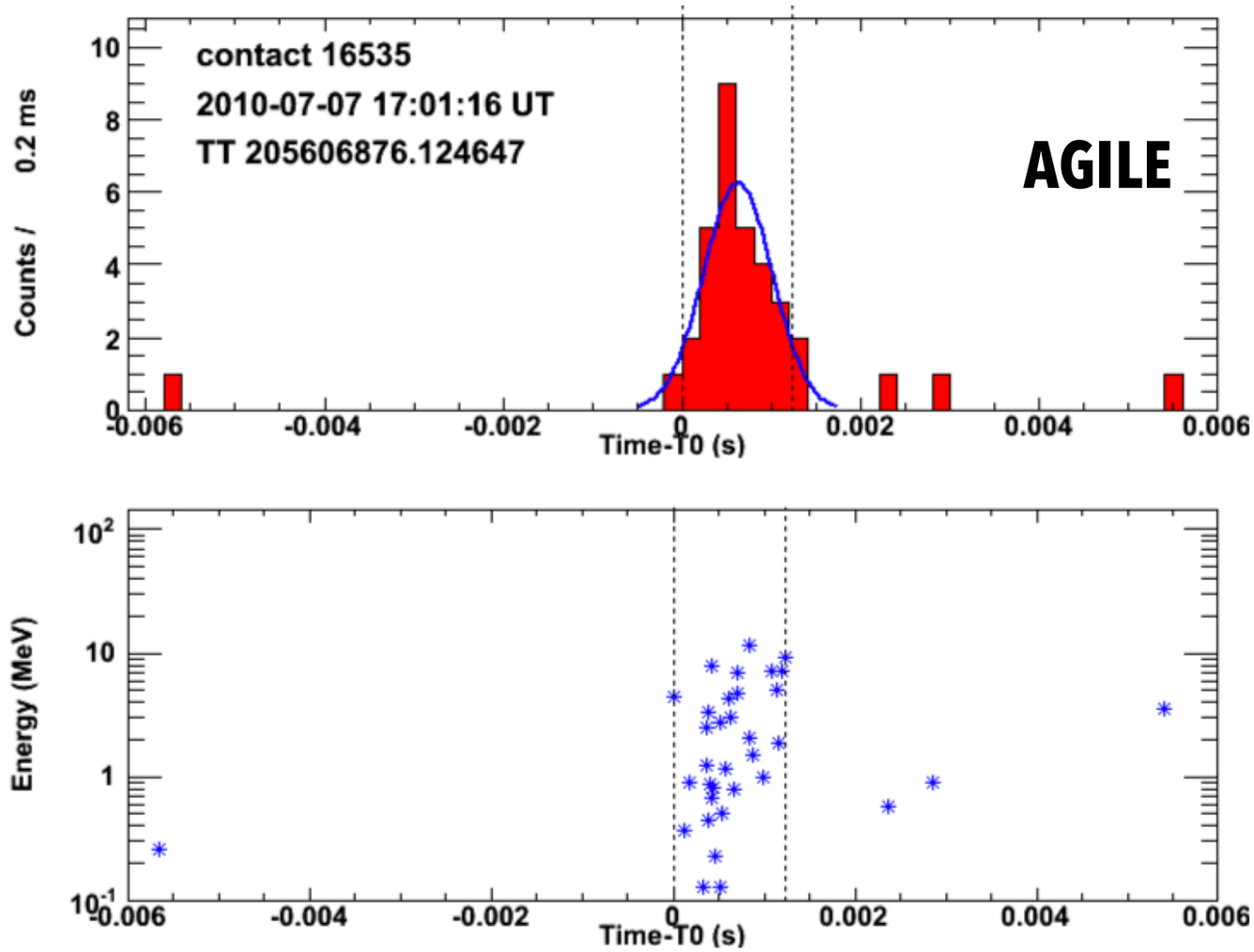
Detection of TGFs

2018 - present
ASIM

Optimised to detect TGFs

2020 - 2020
TARANIS

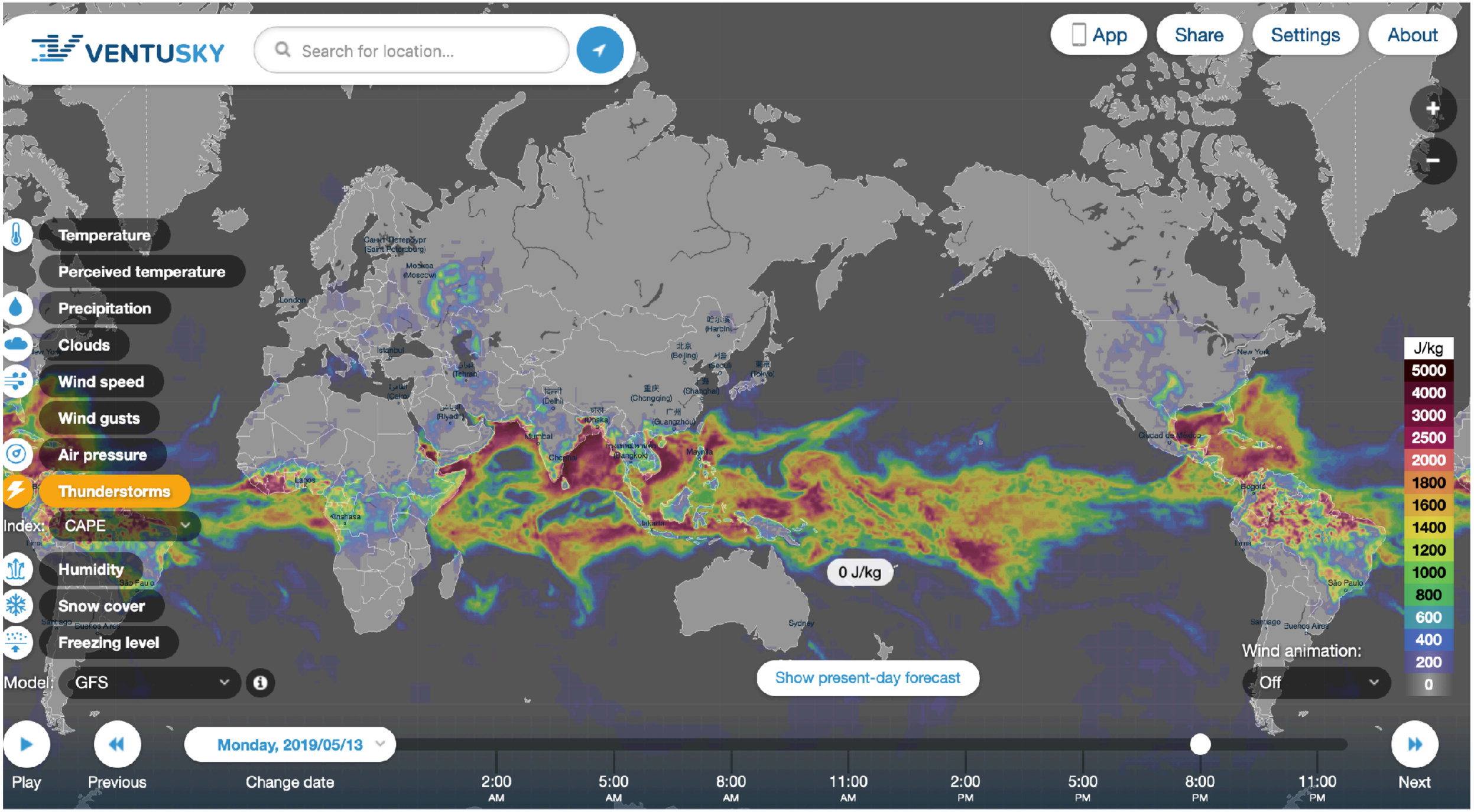
VEGA 17 launch failure



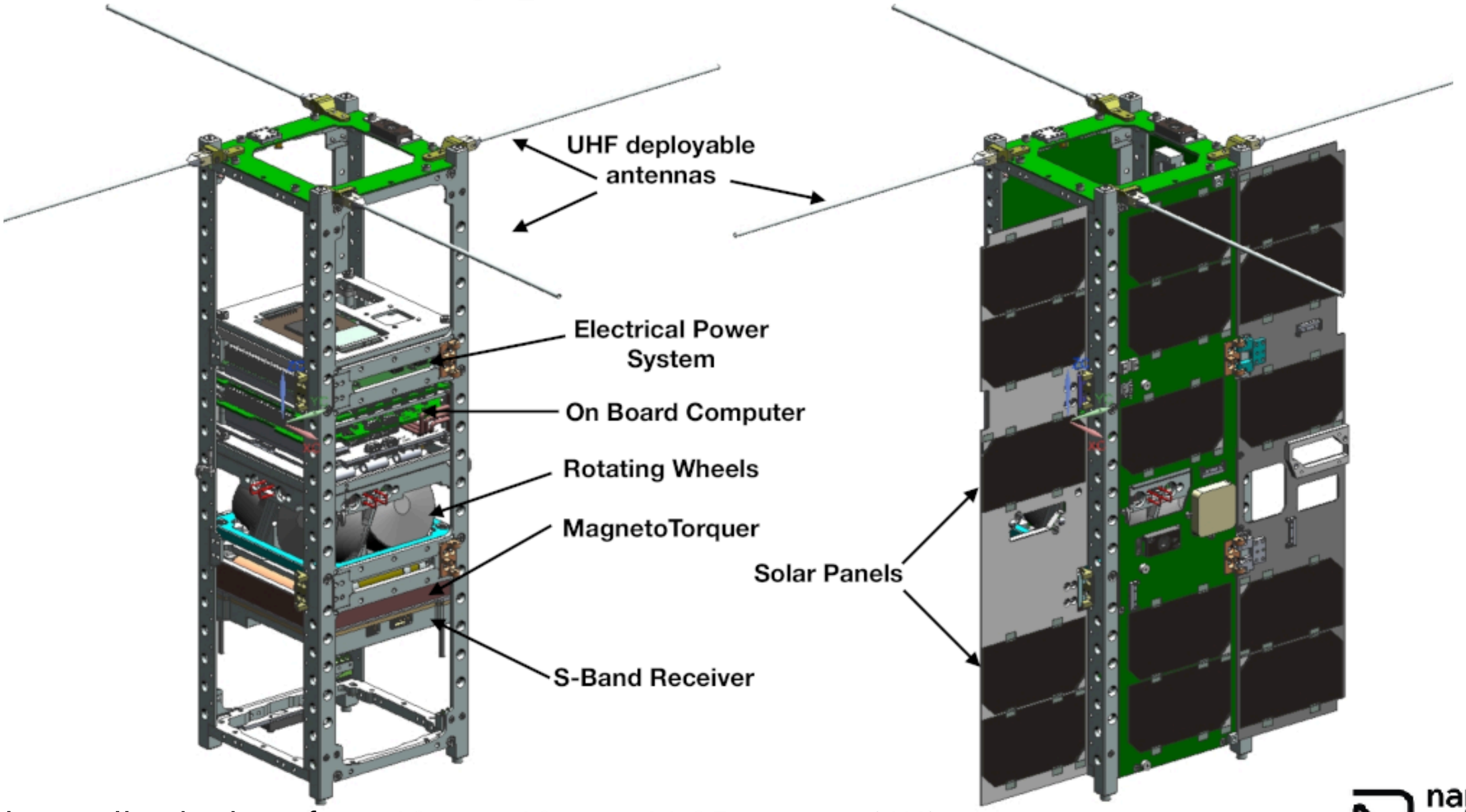
Terrestrial Gamma-Ray Flashes

Origin	Atmospheric Process: Lightning, Thunderstorms, Tropical Storms
Primary particle counterpart	Gamma via bremsstrahlung
Secondary particle counterpart	Electron Beams - Neutrons from photoproduction
Other detectable counterparts	Radio emission (sferics)
Energy Range	10 keV up to ~100 MeV
Event Duration	~ hundreds of μs
Fluence @ 400-500 km	~ 1 gamma/cm^2
Estimated rate (FERMI)	400k events per year
Originating Altitude	(usually) 9 km to 15 km
Generation Mechanism	Not yet fully understood

Daily Thunderstorm Distribution



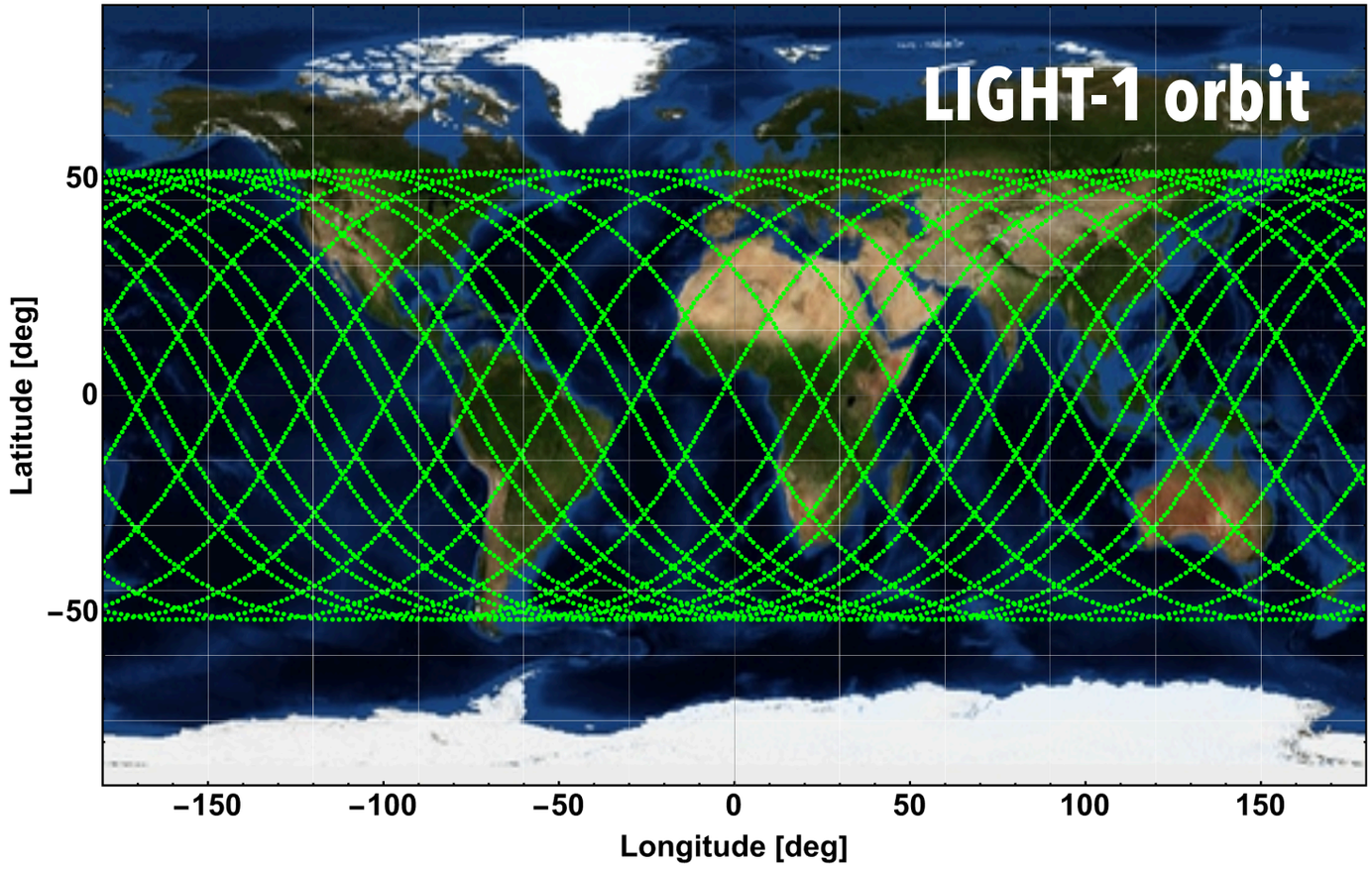
A ~typical 3U CubeSat

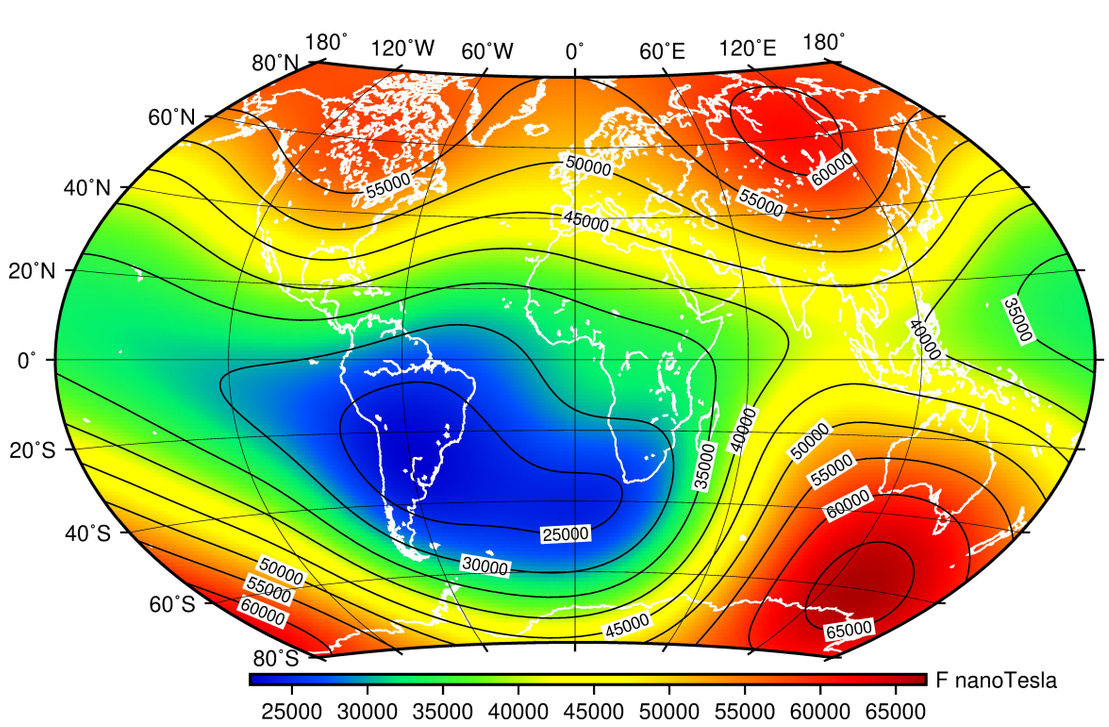


- Modular satellite built up from *10 cm x 10 cm x 11.35 cm* units (1U);
- Relatively low cost to build and launch (typically << $1M);
- Strict size and weight limits (<1.5 kg/U), and very limited power budget (a few W per U)
- Little-to-no propulsion systems.

LIGHT-1 mission requirements

- To survive the extreme stress of a SpaceX Falcon9/Dragon launch;
- To be on time (from PDR to ON-ORBIT operations < 3 y, + COVID19);
- To measure the particle rate (1 sample every 20 s, or every ~160 km) at LEO (ISS polar orbit, 51.6^0);
- To study TGFs at sub-microsecond timescale;
- To space-qualify the technology and prove the detection concept;
- To measure the activity in the South Atlantic Anomaly region.



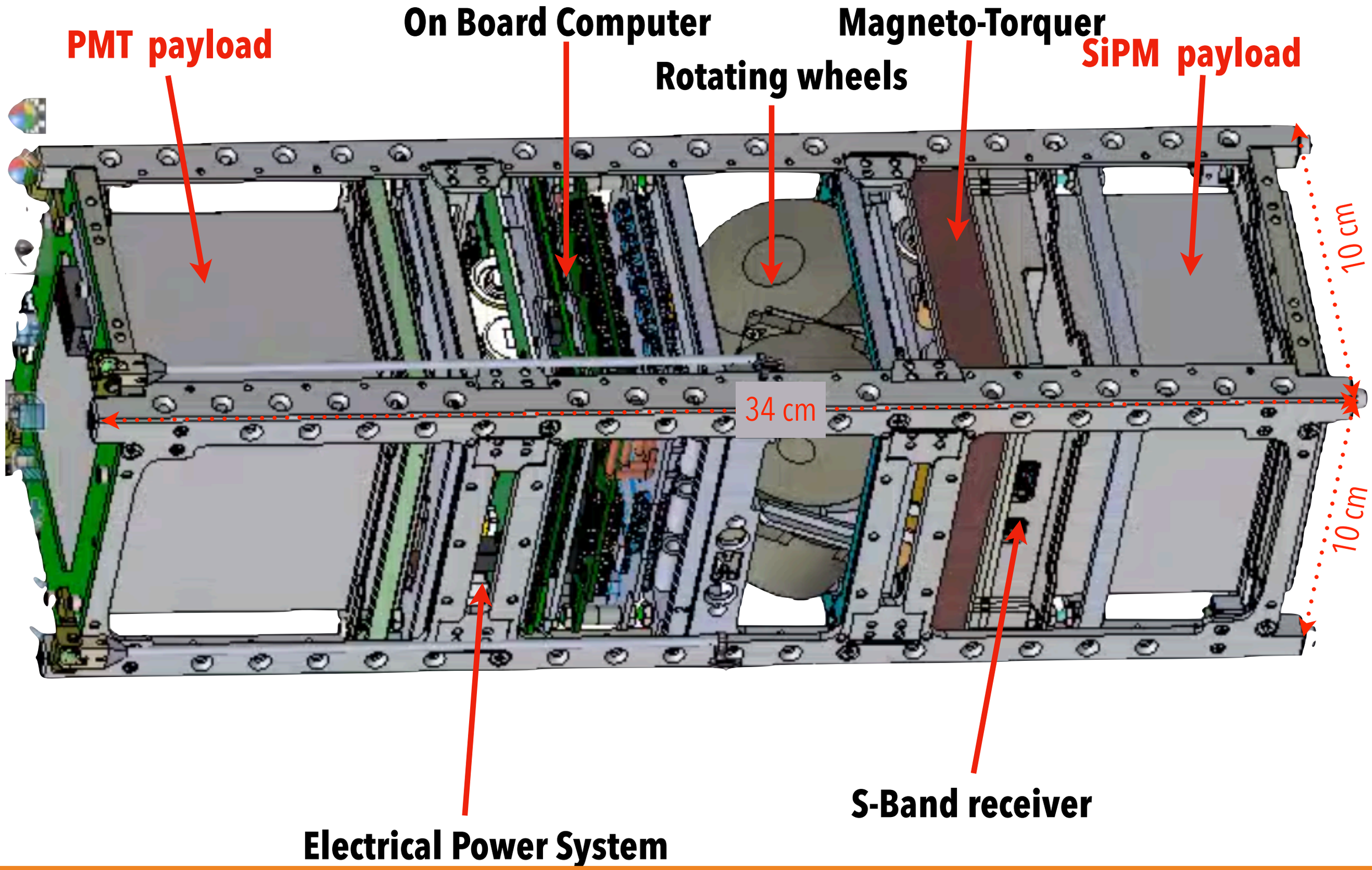


IGRF: total field Intensity

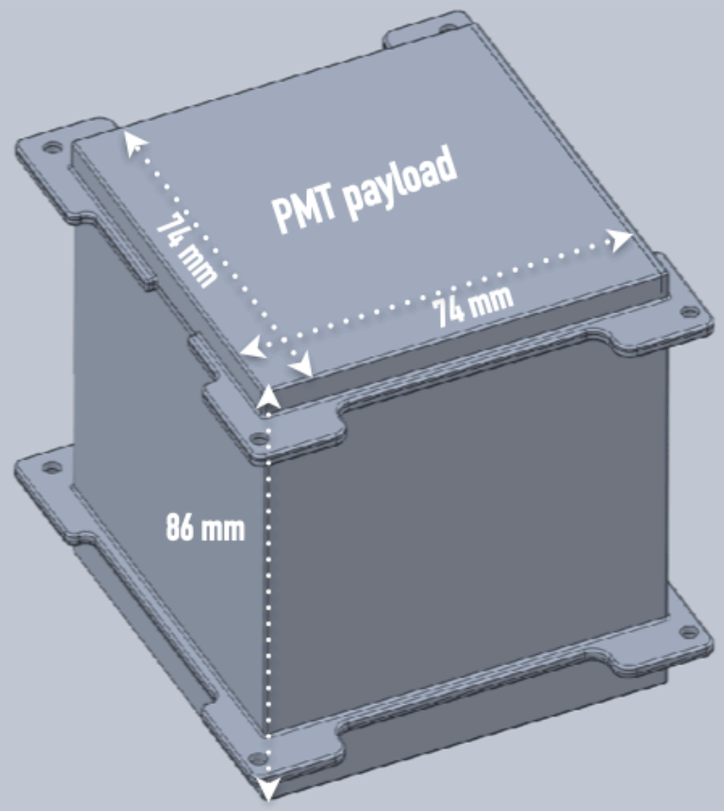
LIGHT-1 Payload: Design Characteristics

Parameter	Value
Detection Energy Range	~ 20 keV - 3 MeV
Time resolution	~ 100 ns
Absolute Timing	< 4 μs
Spectral Resolution	15% @ 20 keV, < 5%@ 511 keV
Effective Area	40 cm^2 @ 50 keV, 20 cm^2@ 511 keV
PMT Payload Size (Fits in 1U)	74 x 74 x 86 mm
SiPM Payload Size (Fits in 0.75U)	74 x 74 x 68 mm
PMT Payload Weight	1,085 g
SiPM Payload Weight	966 g
Power Consumption	< 5.9 W average
Data Budget	50 MB/day
Operational Temperature Range	Between -30° C to 55° C
Survival Temperature range	Between -40° C to 60° C

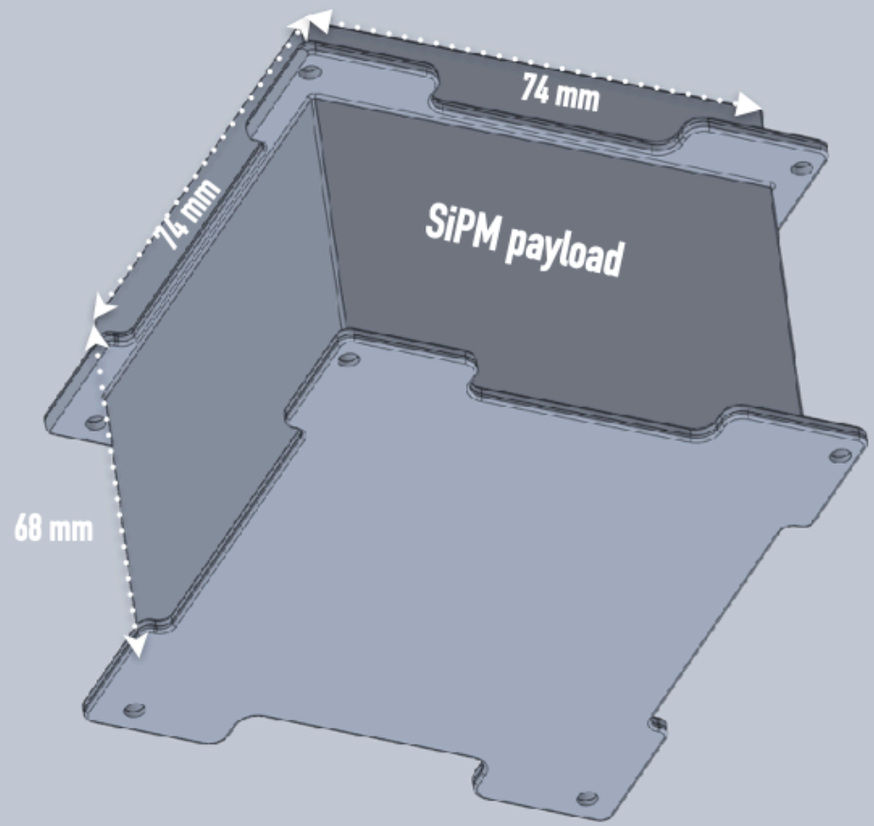
The bus of LIGHT-1 satellite



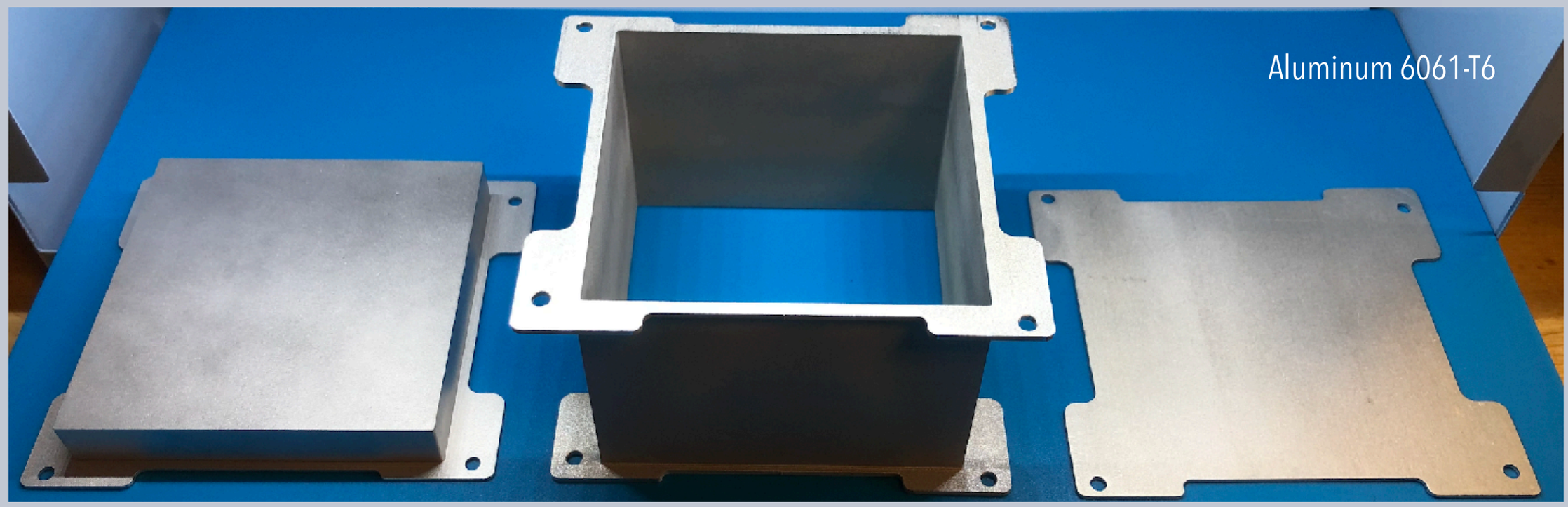
3D model of the LIGHT-1 payload



M = 1,185 g



M = 966 g



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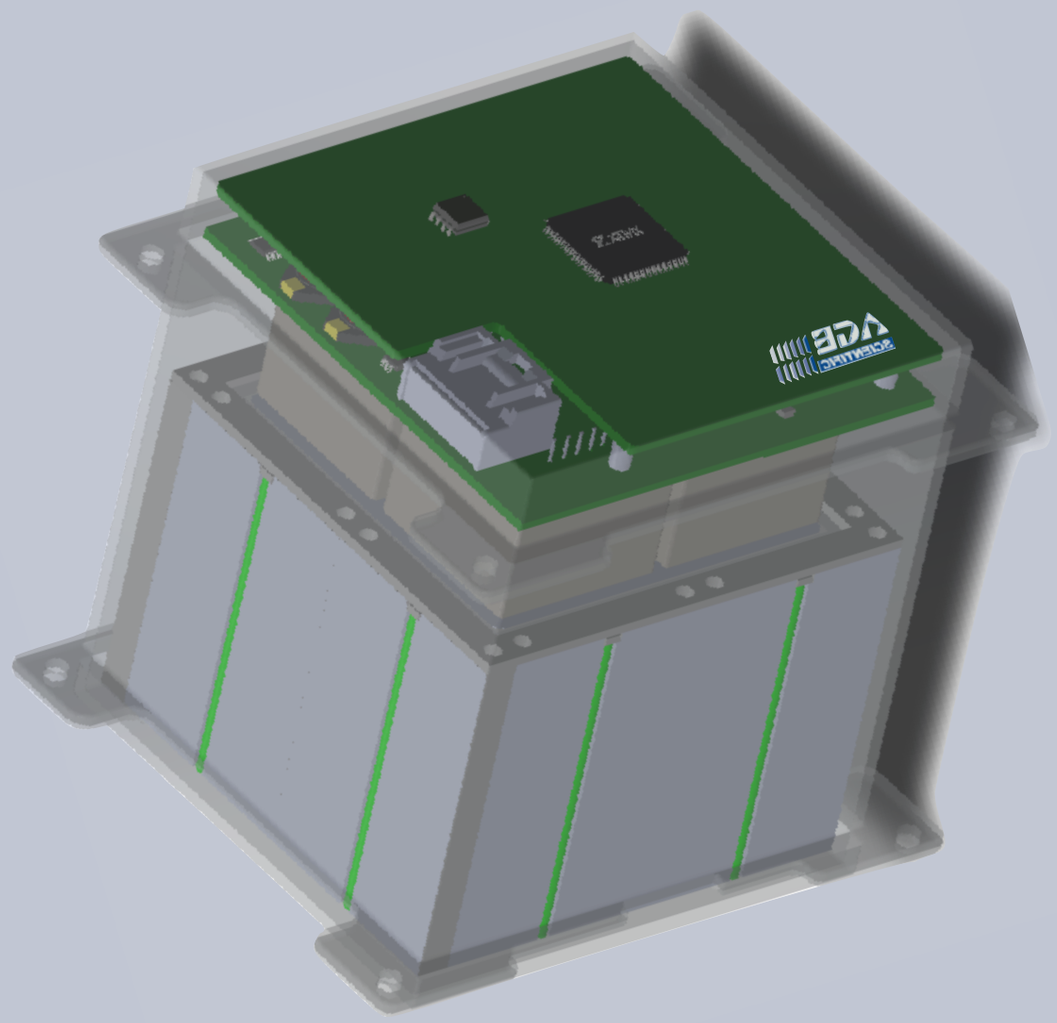

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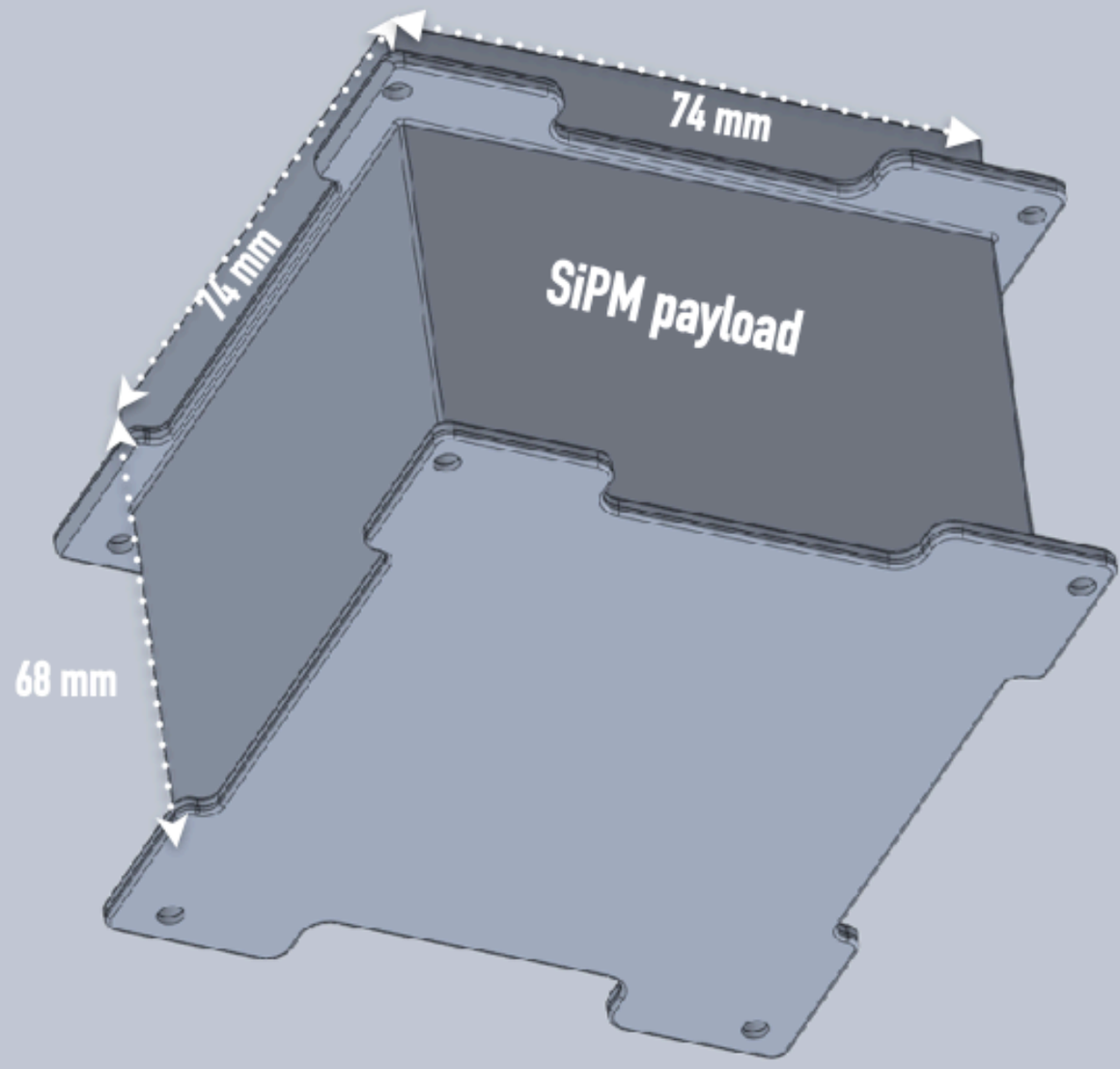
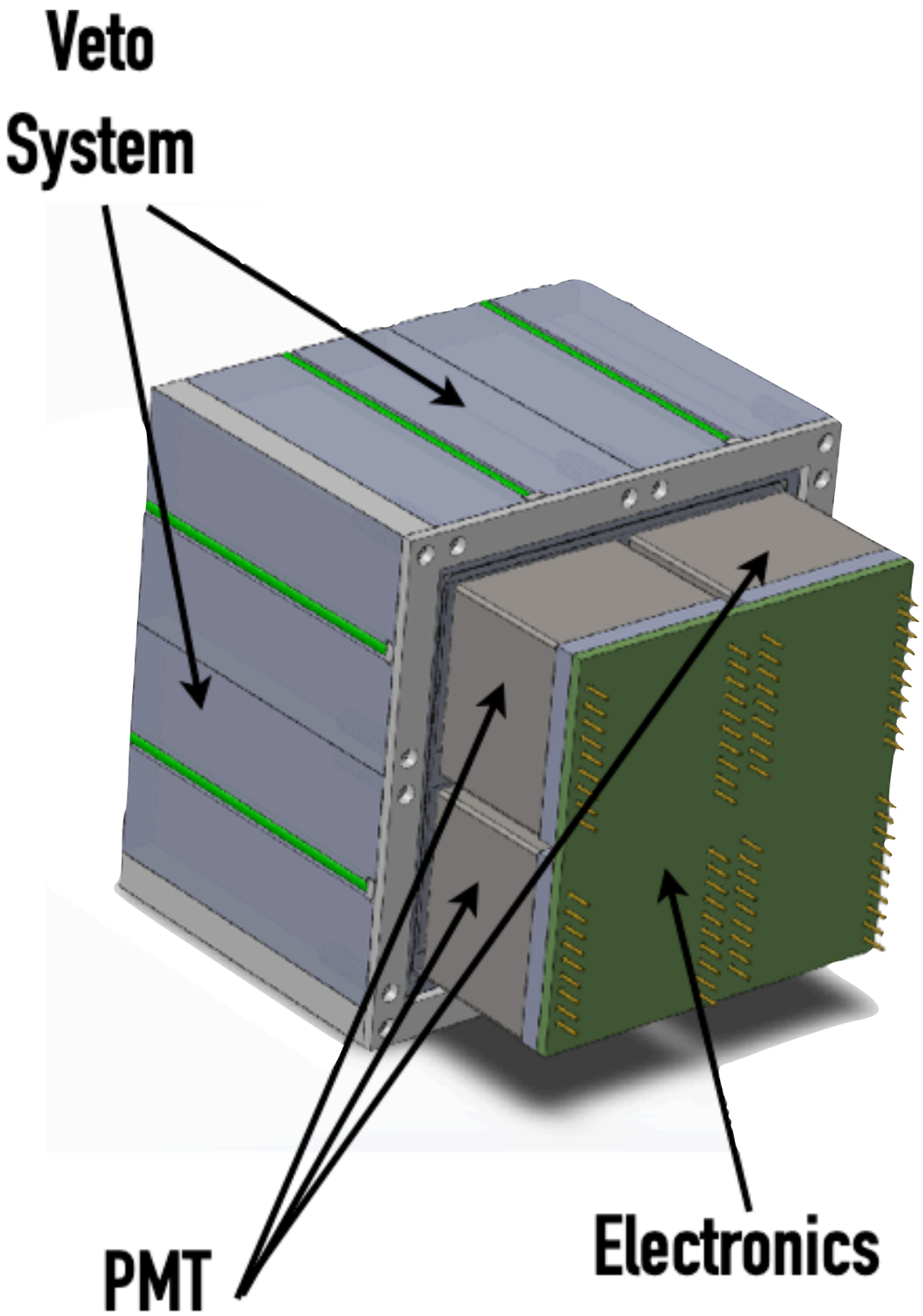
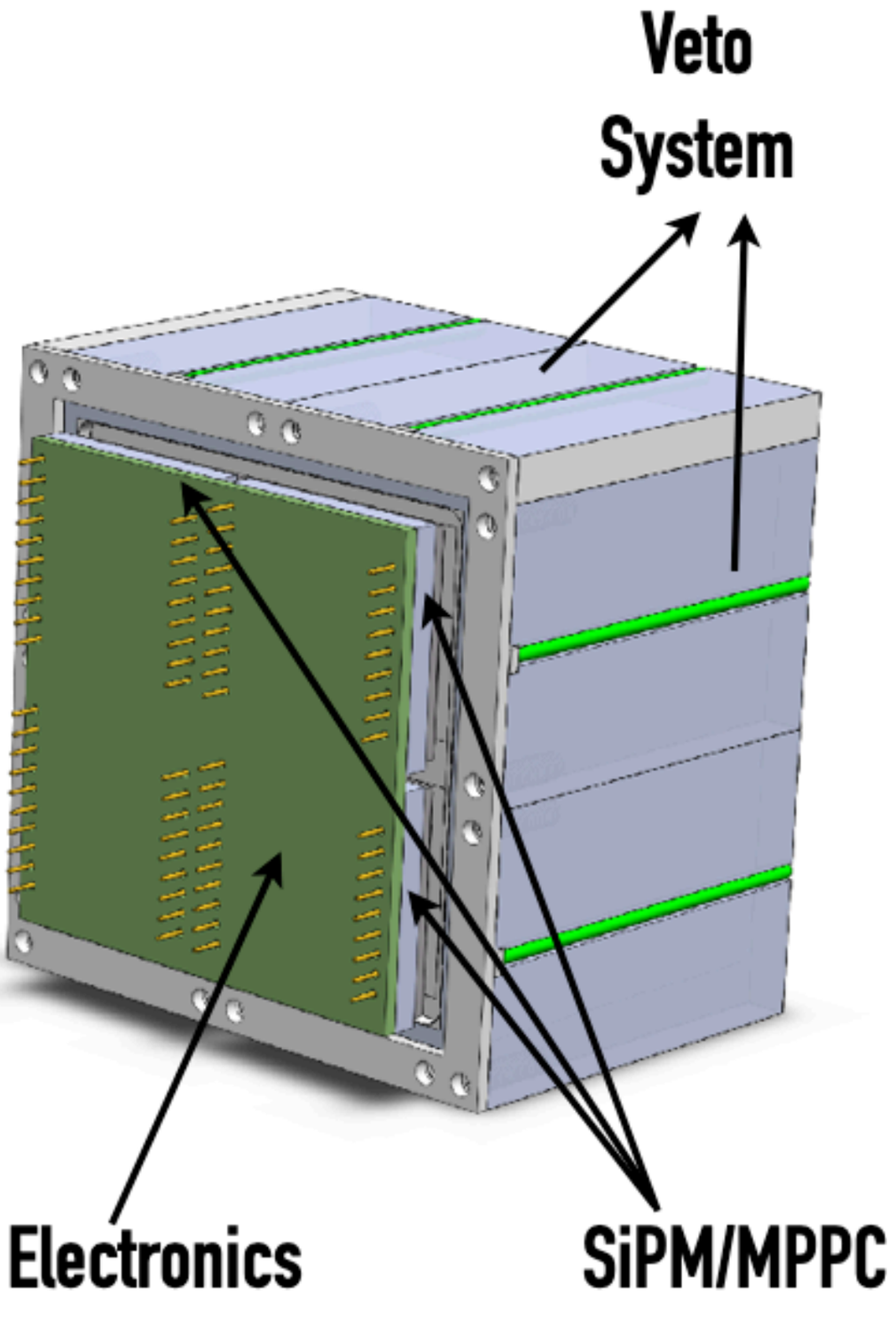


M = 966 g

The LIGHT-1 PMT and SiPM payloads

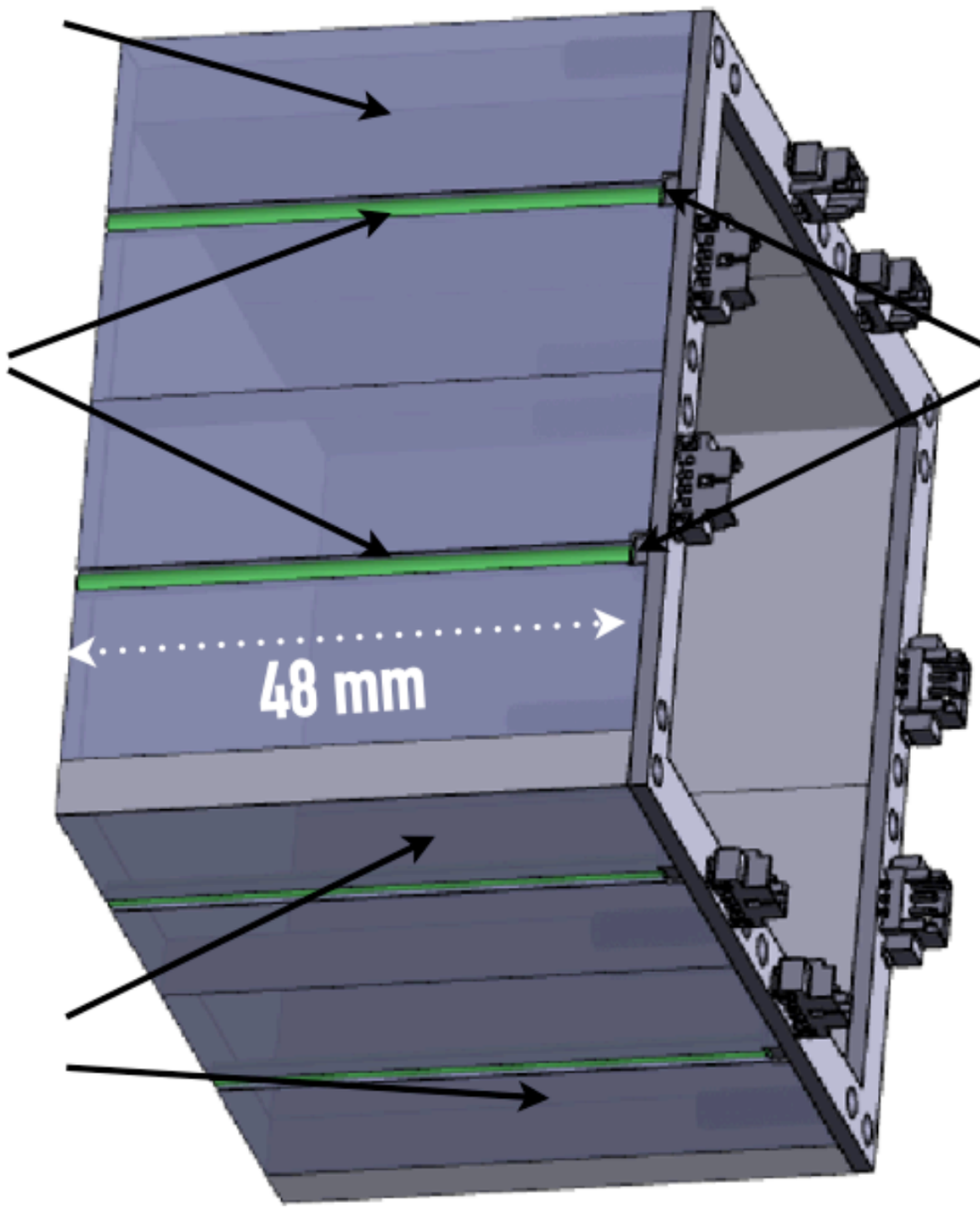




The LIGHT-1 VETO to reject charged particle induced events

STYRON+POPOP+PPO

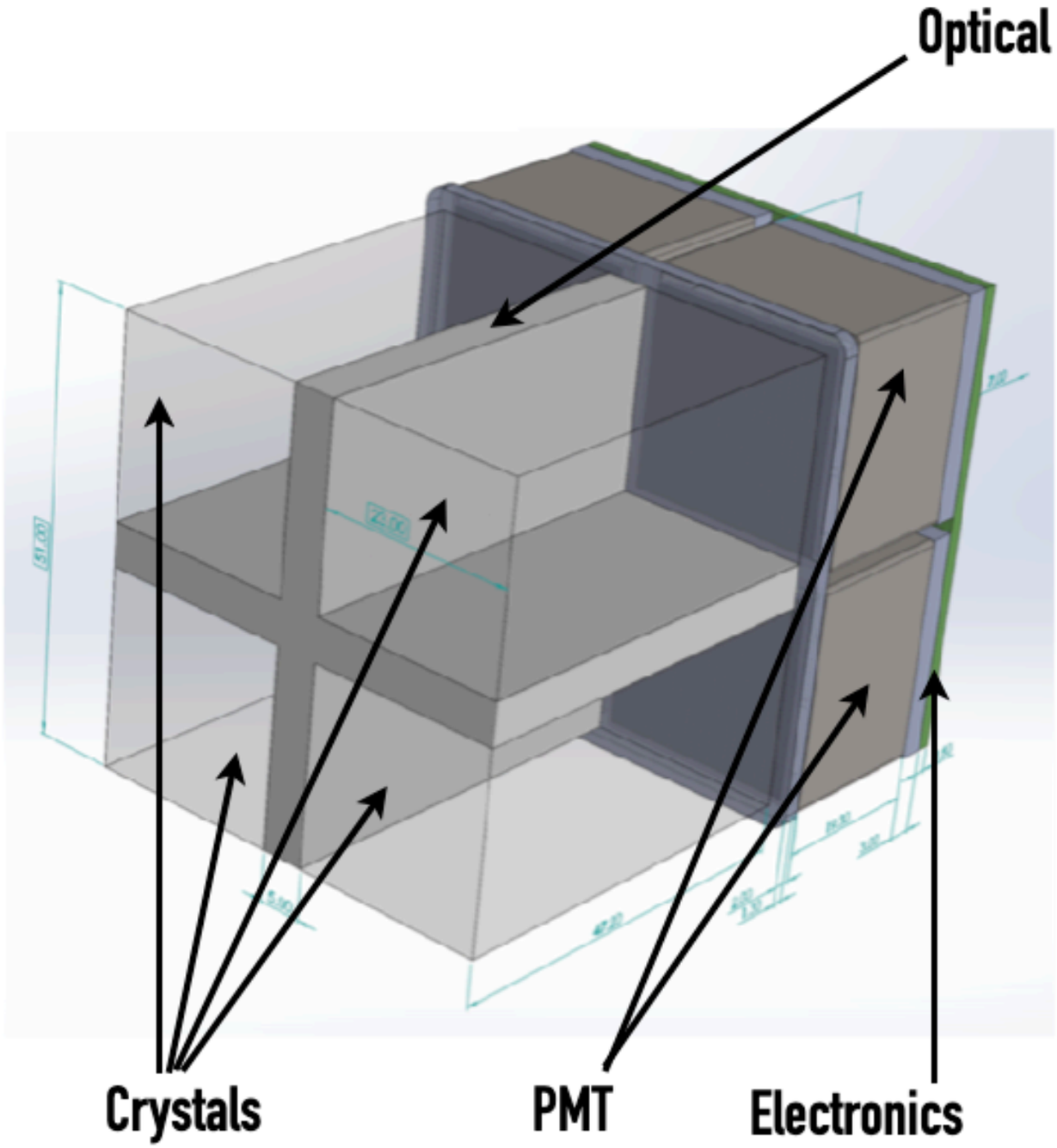
KURARAY WLSF Y11

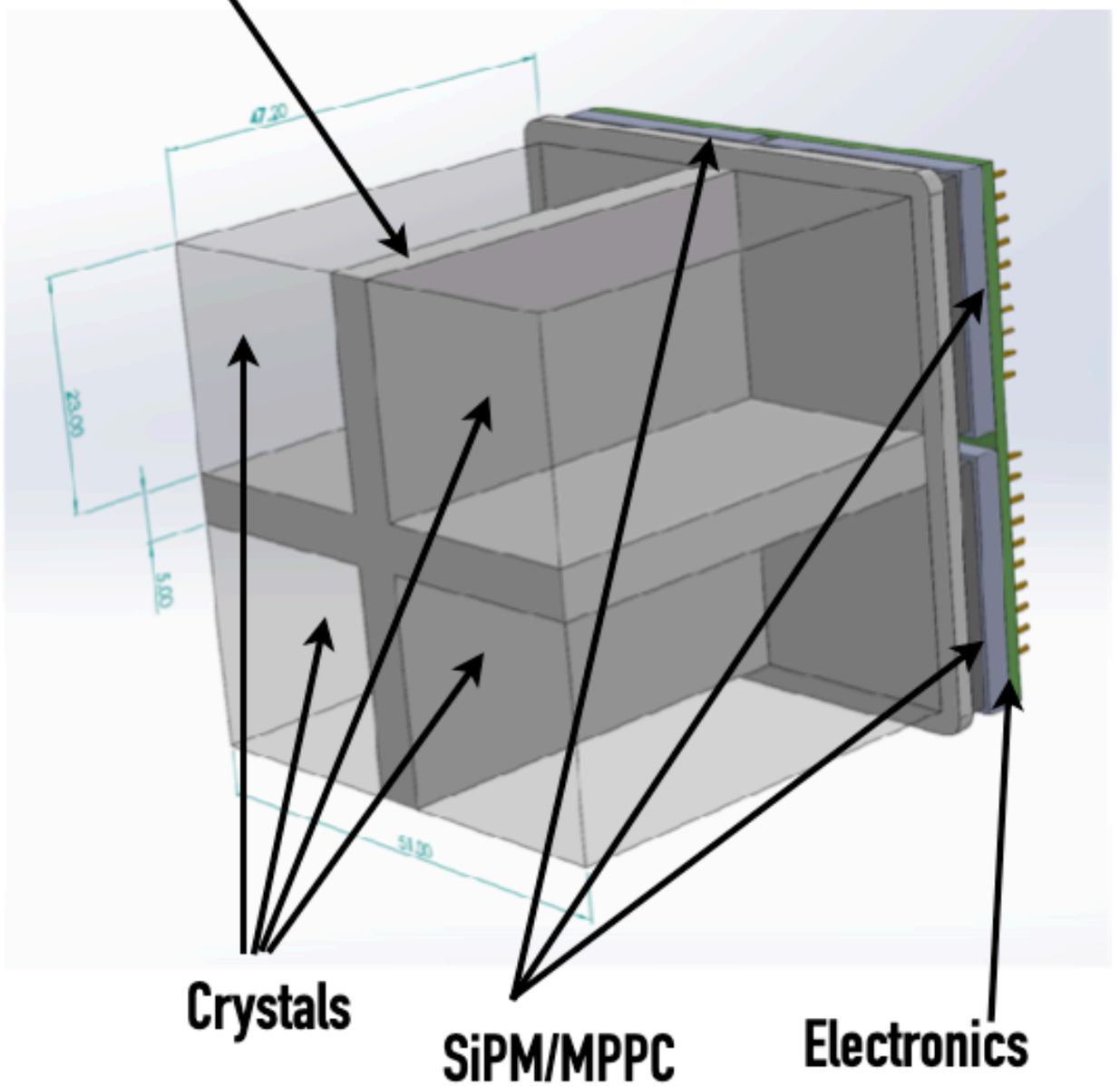


SiPM
ASD-NUV1C-P-40

STYRON+POPOP+PPO

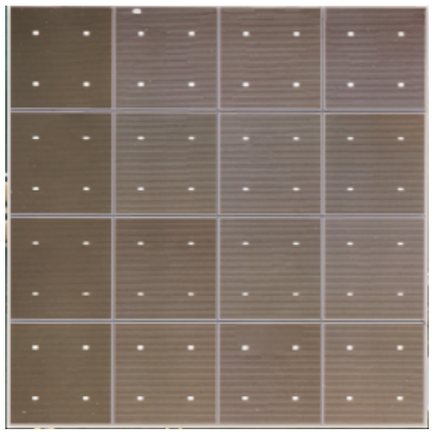
The LIGHT-1 detection targets





The Hamamatsu Photosensors

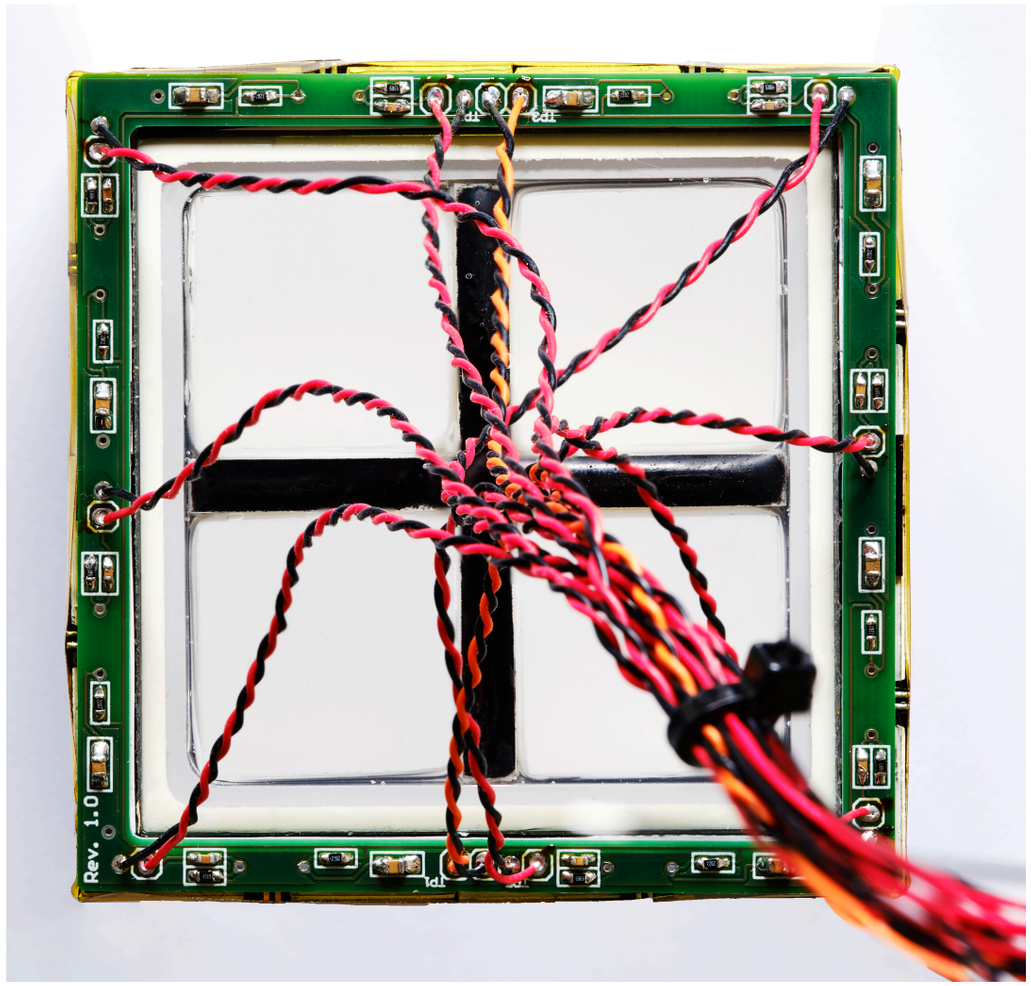
Photomultiplier Tubes
R11265-200



Multi-Pixel Photon Counters
S13361-6050AE-04

Characteristics	R11265-200	S13361-6050AE-04
Type of photosensors	PMT	MPPC (aka SiPM)
Dimensions(LXDXH) [mm^3]	26X26X19	25X25X1.4
Weight [g]	24	2
Peak Sensitivity [nm]	~ 400	~ 450
Q.E. [%]	43	-
P.D.E. [%]	-	40
Typical Operating Voltage [V]	900	55
Typical Gain at working point	$\sim 10^6$	$\sim 10^6$
Dark Count at working point, room temperature [Hz]	Negligible	> 10 M
Operating Temperature [^oC]	-30 to +60	-20 to +60
# of photosensors in LIGHT-1	4	4

CeBr3(LB) and LBC scintillating crystals by Scionix



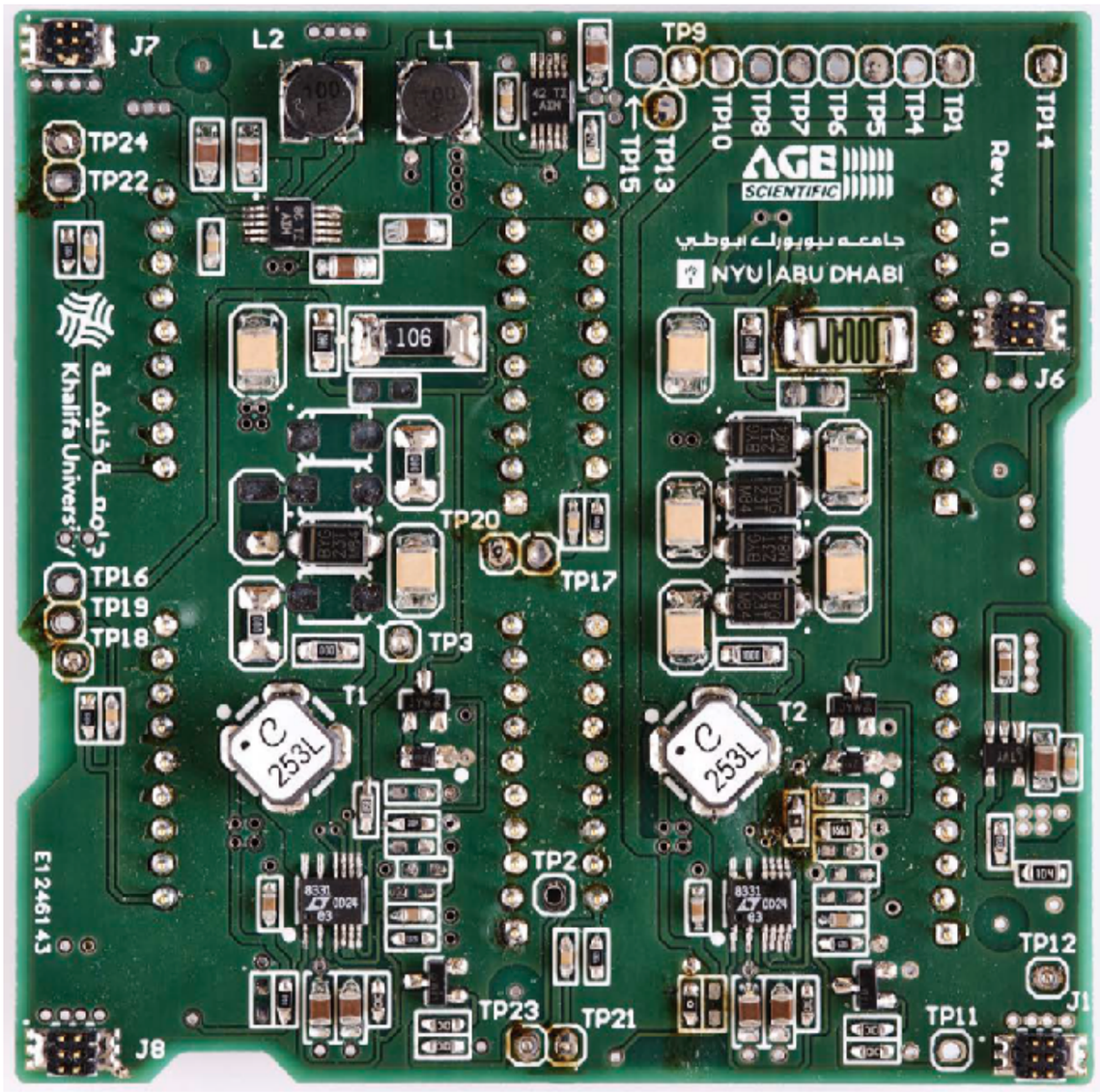
Characteristics	$CeBr_3$(LB)	LBC
Density [g/cm^3]	5.1	4.9
Hygroscopic	YES	YES
Emission Peak [nm]	~370	~ 380
Typical Resolution @122 keV (^{57}Co) [%]	10	7
Typical Resolution @662 keV (^{137}Cs)	4	3
Typical Decay Time [ns]	~ 20	~ 35
Activity [Bq/cm^3]	< 0.01	~ 1

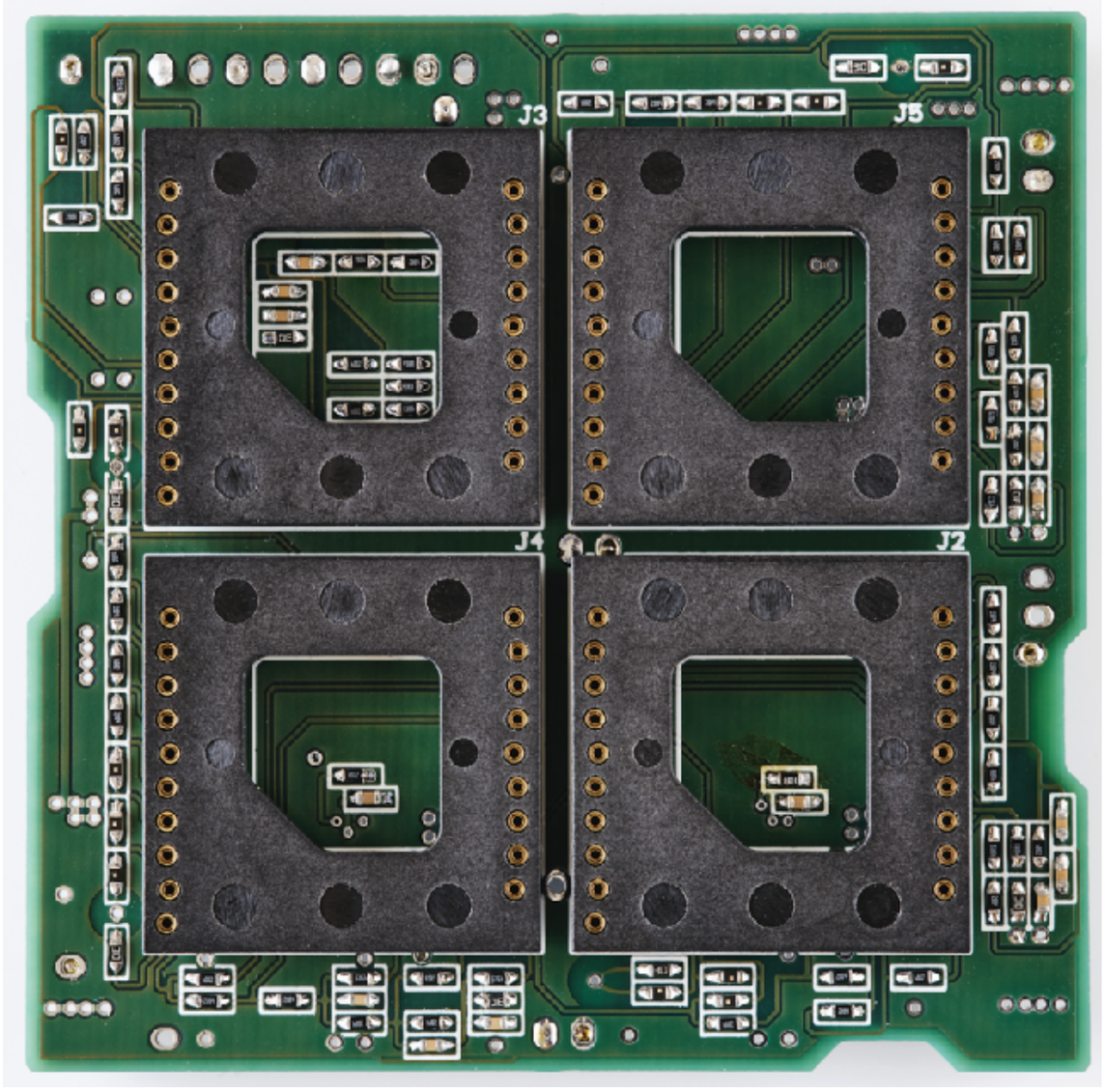
The LIGHT-1 detection target consists of:

- ***6X*** *(23 mm X 23 mm X 45 mm) Low Background Cerium Bromide (CeBr3(LB))*
- ***2X*** *(23 mm X 23 mm X 45 mm) Lanthanum Bromo Chlorine (LBC)*

For Basic Unit characterization see here: https://doi.org/10.1088/1748-0221/14/09/P09017

Proximity Electronics (Power Supply)

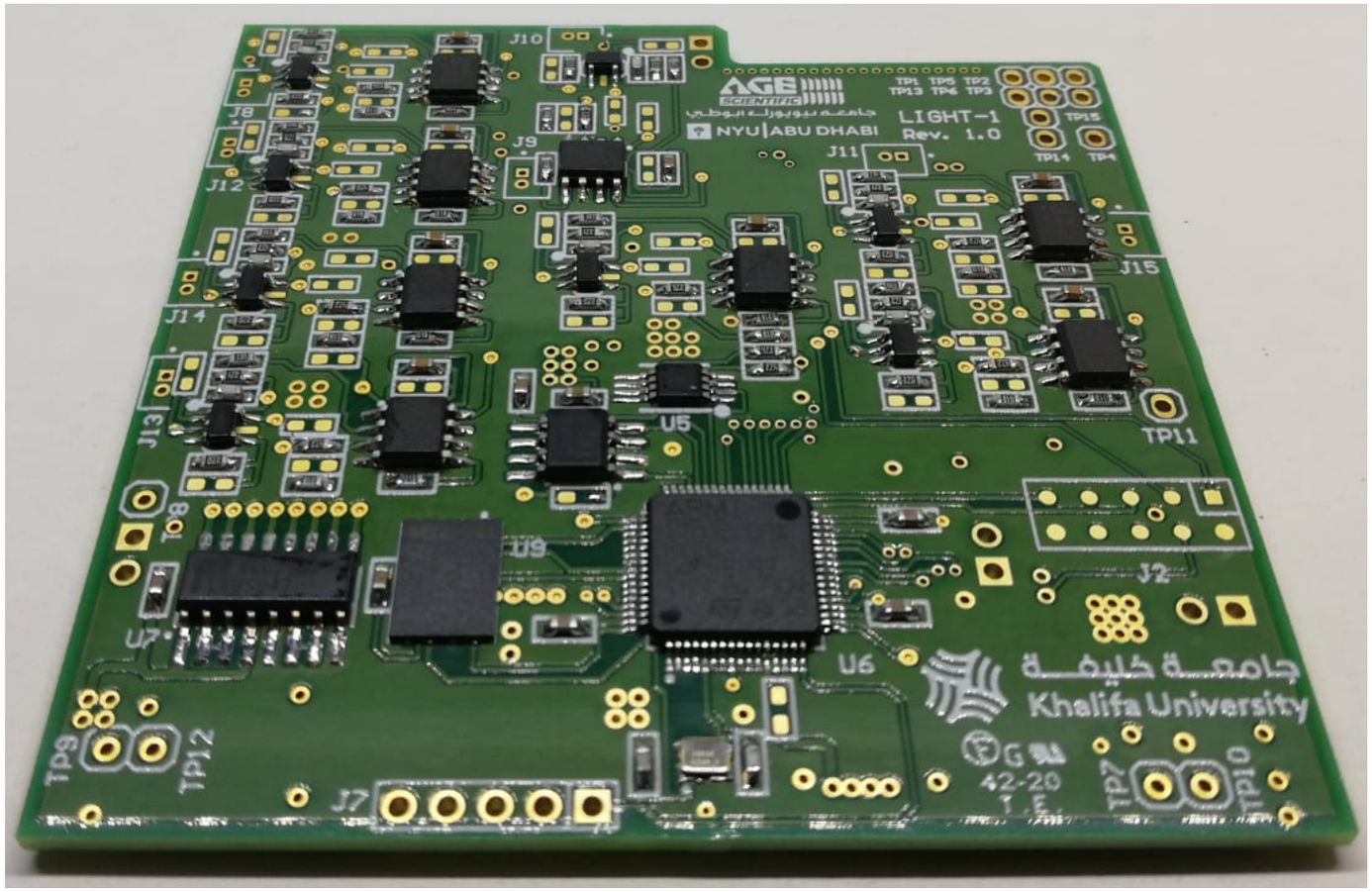


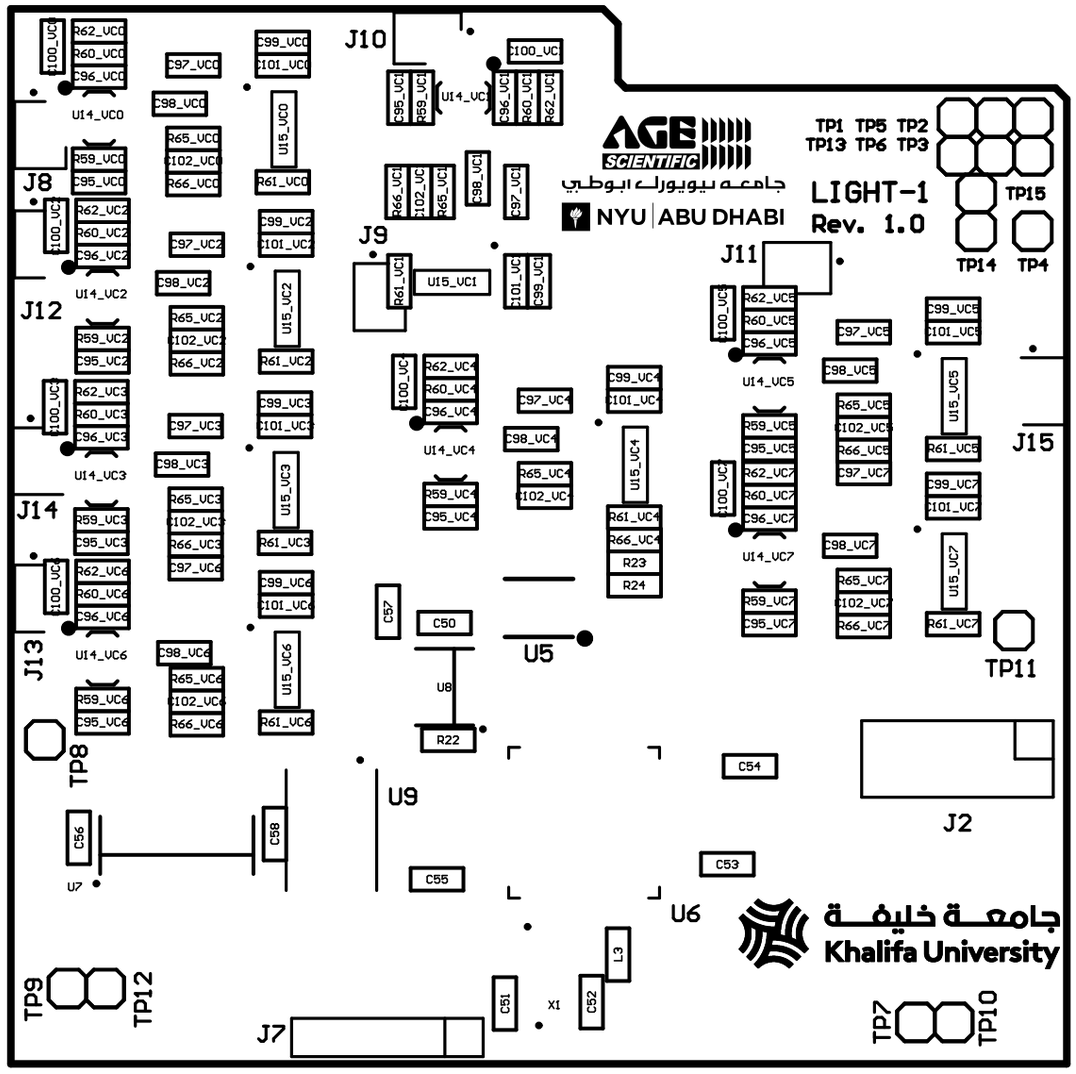


Main Characteristics:

- Operation and Readout of 4 photosensors (each) + VETO SiPMs (8)
- Based on C.O.T.S. (Components off-the-shelf);
- Detector Voltage Biasing (PMT/SiPM and VETO). PMT: -600 V to -750 V; SiPM: 25 V to 62 V; VETO: 25 V to 38 V;
- Voltage Inputs: +3.3 V, -3.3 V, +5 V;
- Weight: 27 g (SiPM) - 35 g (PMT)

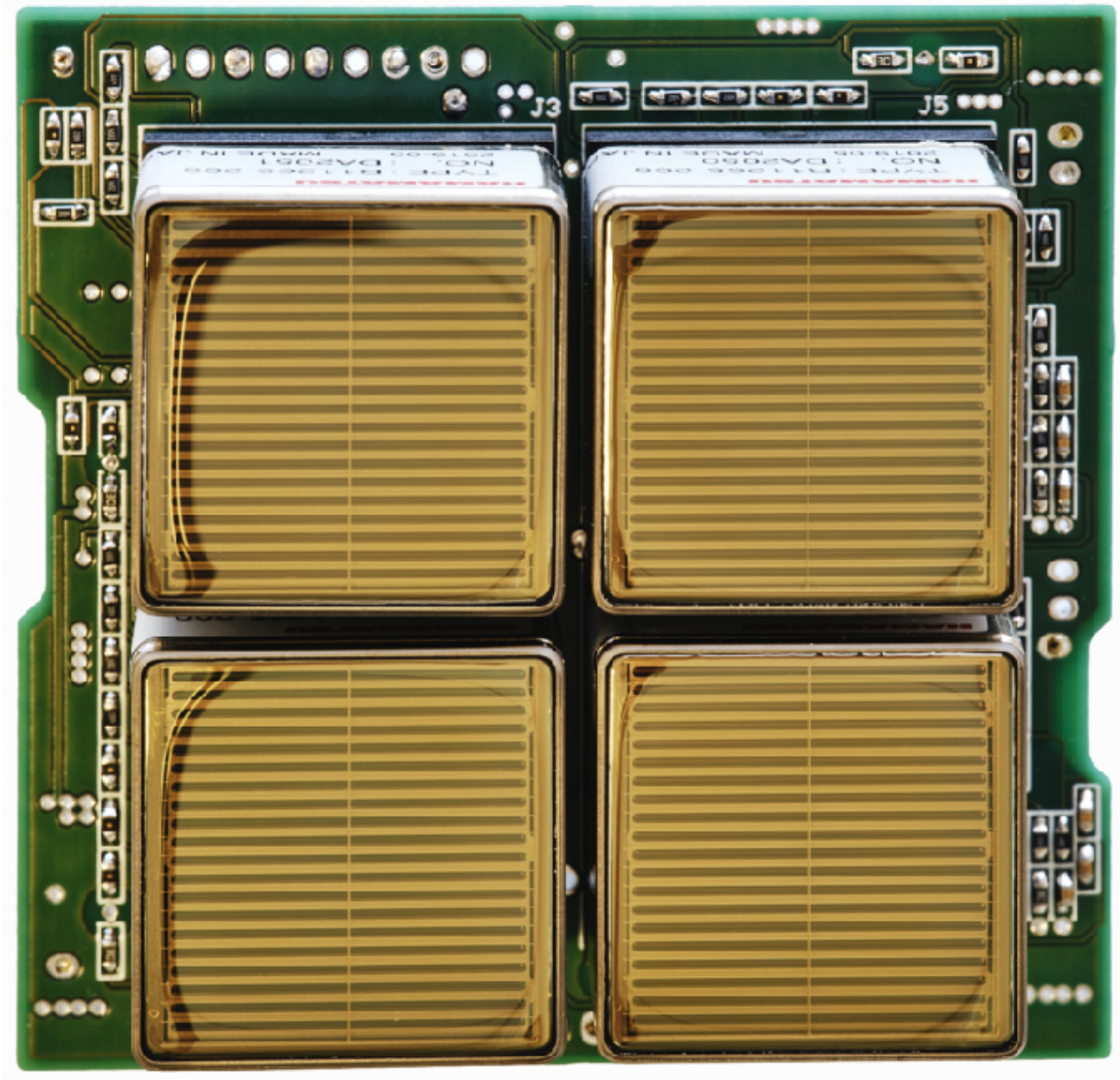
Proximity Electronics (CTRL & FE board)



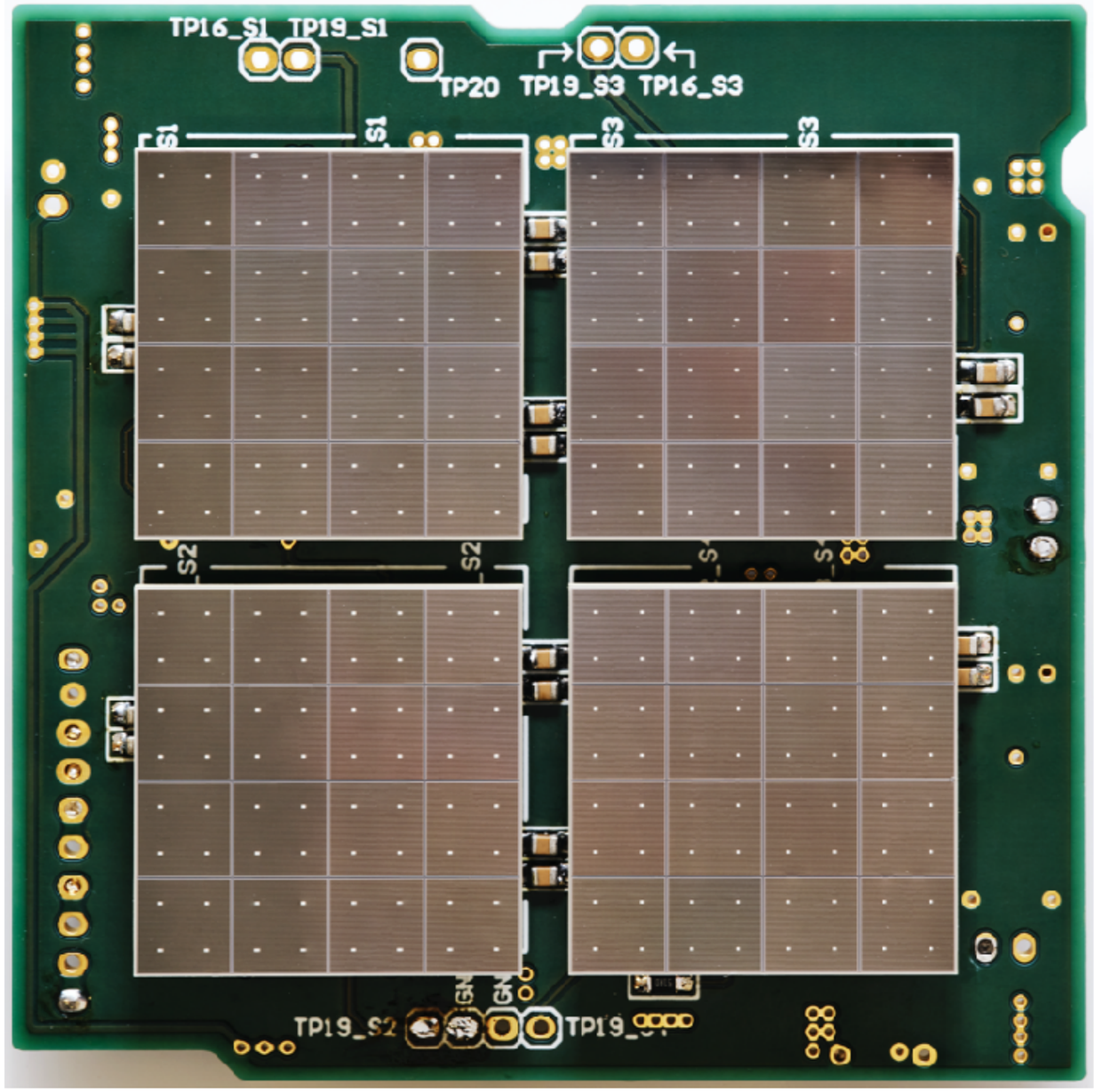


- Payload operations;
- Signal conditioning;
- Signal Charge extraction (ADC+FPGA);
- CubeSat Software Protocol (CSP) compliant ;
- Event builder;
- Time stamping;
- Preprocessing and data priority assignment;
- Temperature monitoring;
- Voltage Input: +3.3 V;
- Weight: 27 g .

The photosensor Arrays

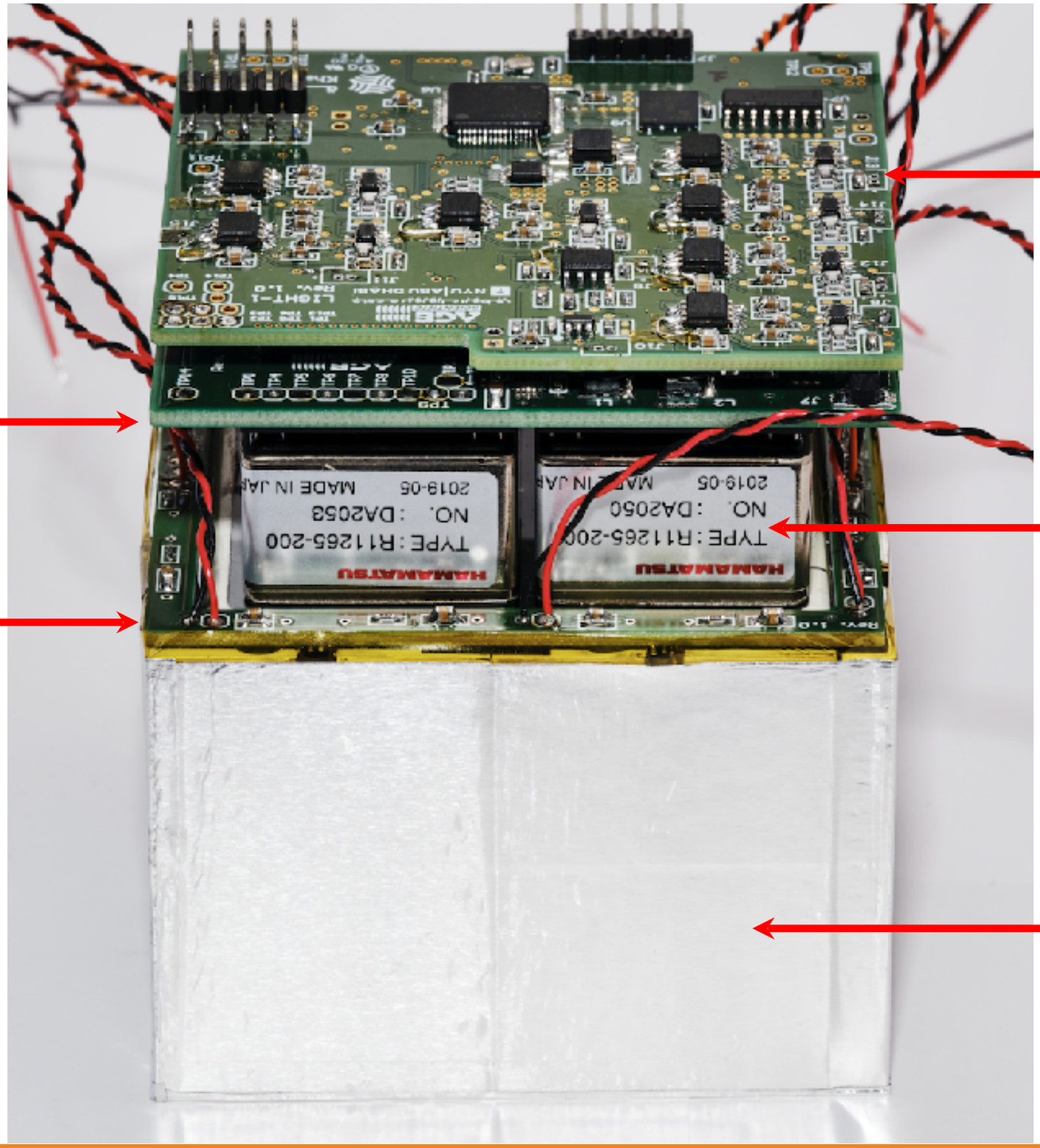


PMT Array



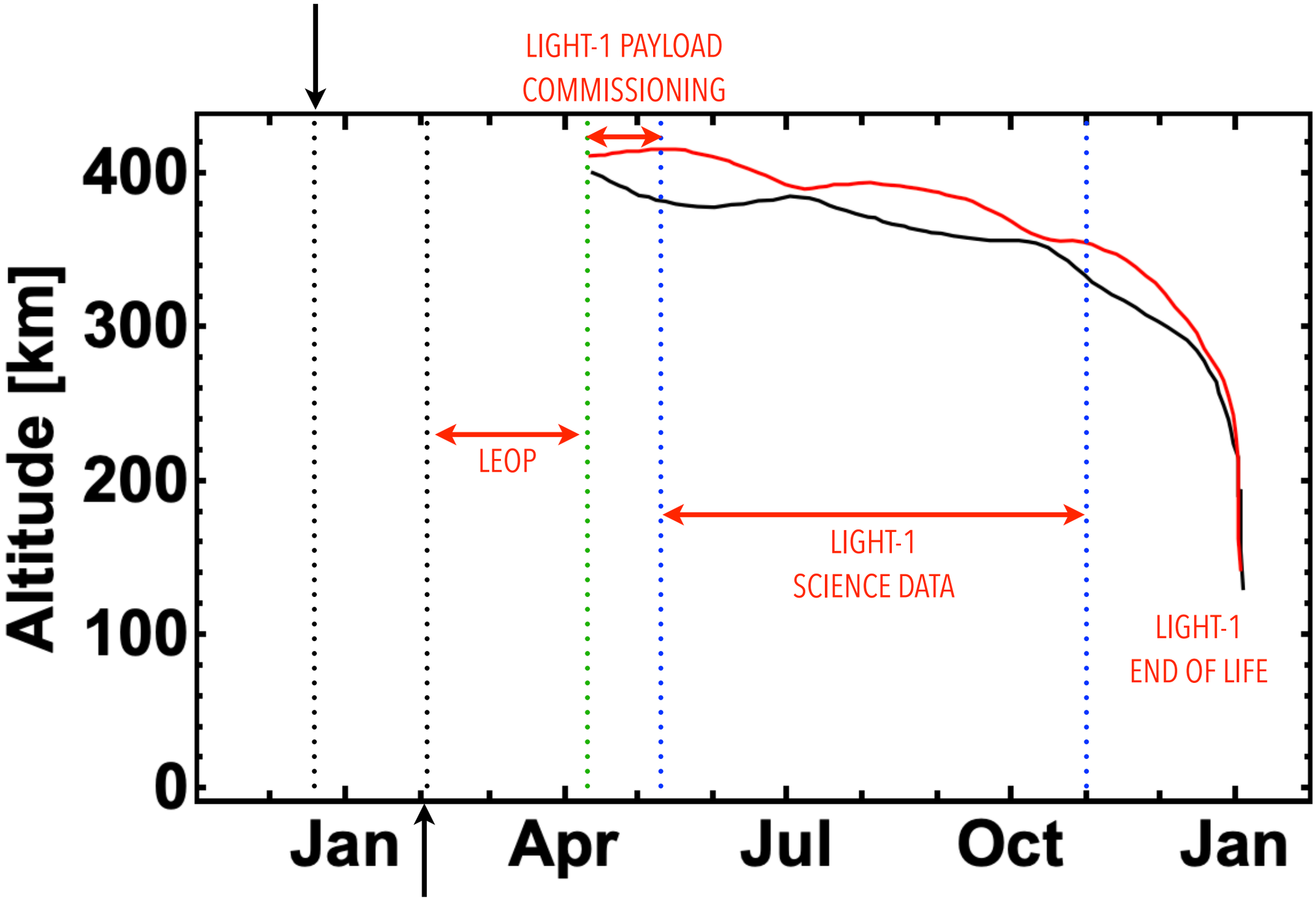
MPPC/SiPM Array

The PMT payload (Inner View)



A very intense and (eventually) sad story

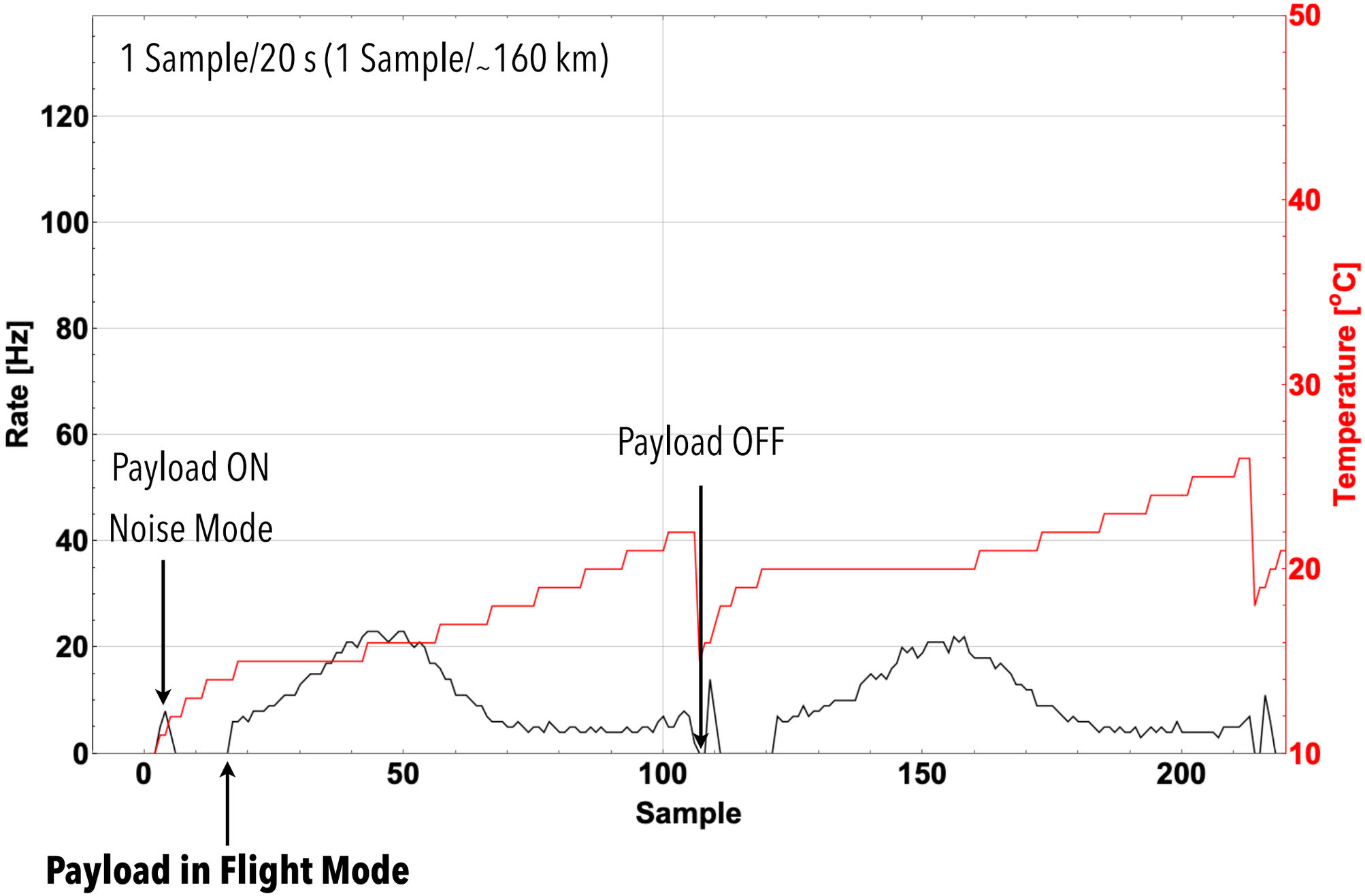
SpaceX Launch from Kennedy Space Center
on 2021-12-21 (Falcon9/Dragon docked ISS the day after)



Deployment from ISS on 2022-02-03

LEOP = LAUNCH and EARLY ORBIT PHASE

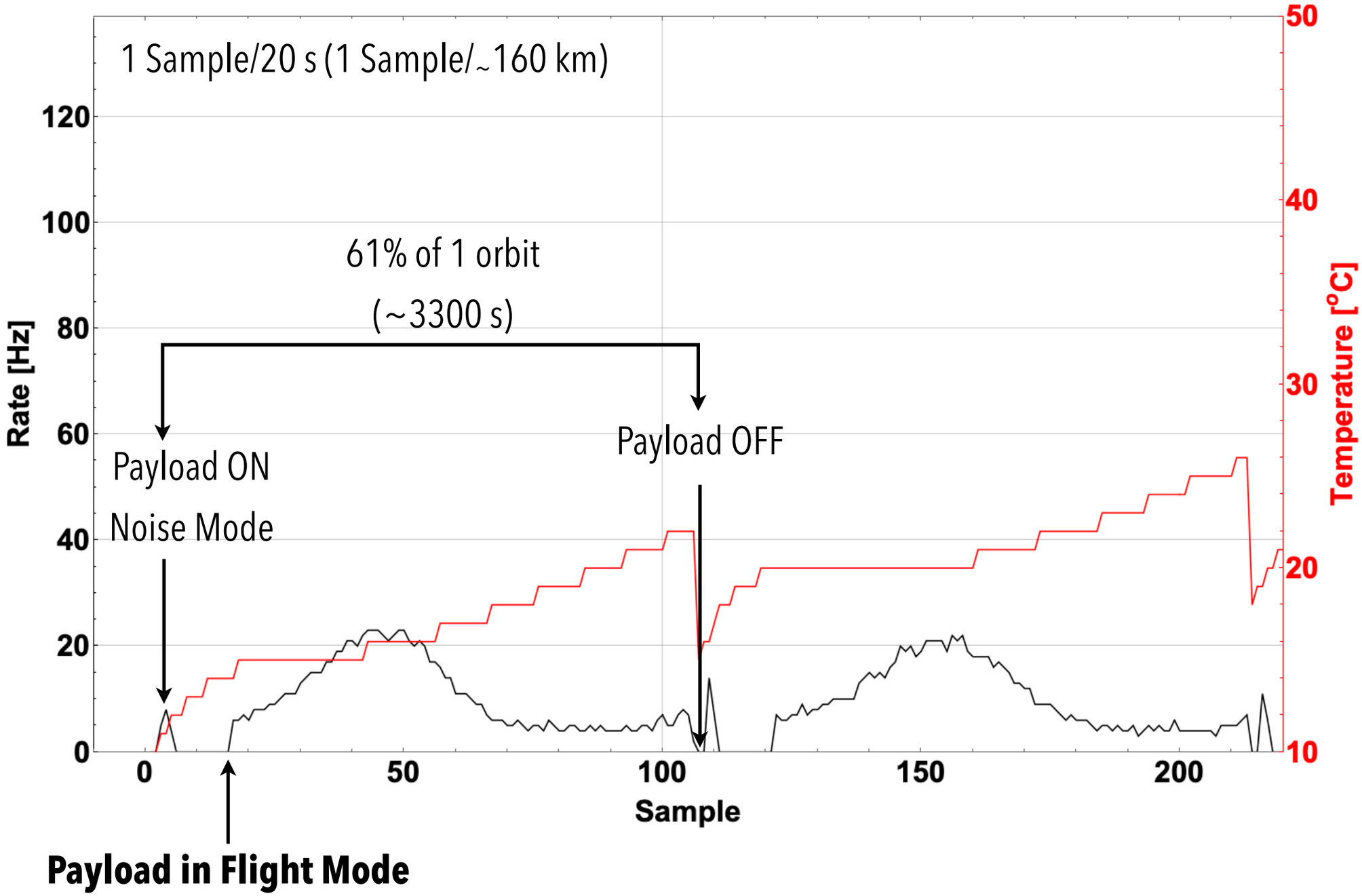
Measured particle rate (SiPM CH2)



SiPM CH2 detection THR set to 1800 ADC CH / 64k ADC CH

LIGHT-1 Operational DutyCycle (DC): 61%, Effective DC (checks, reboot, SAA): 48%

Measured particle rate (SiPM CH2)



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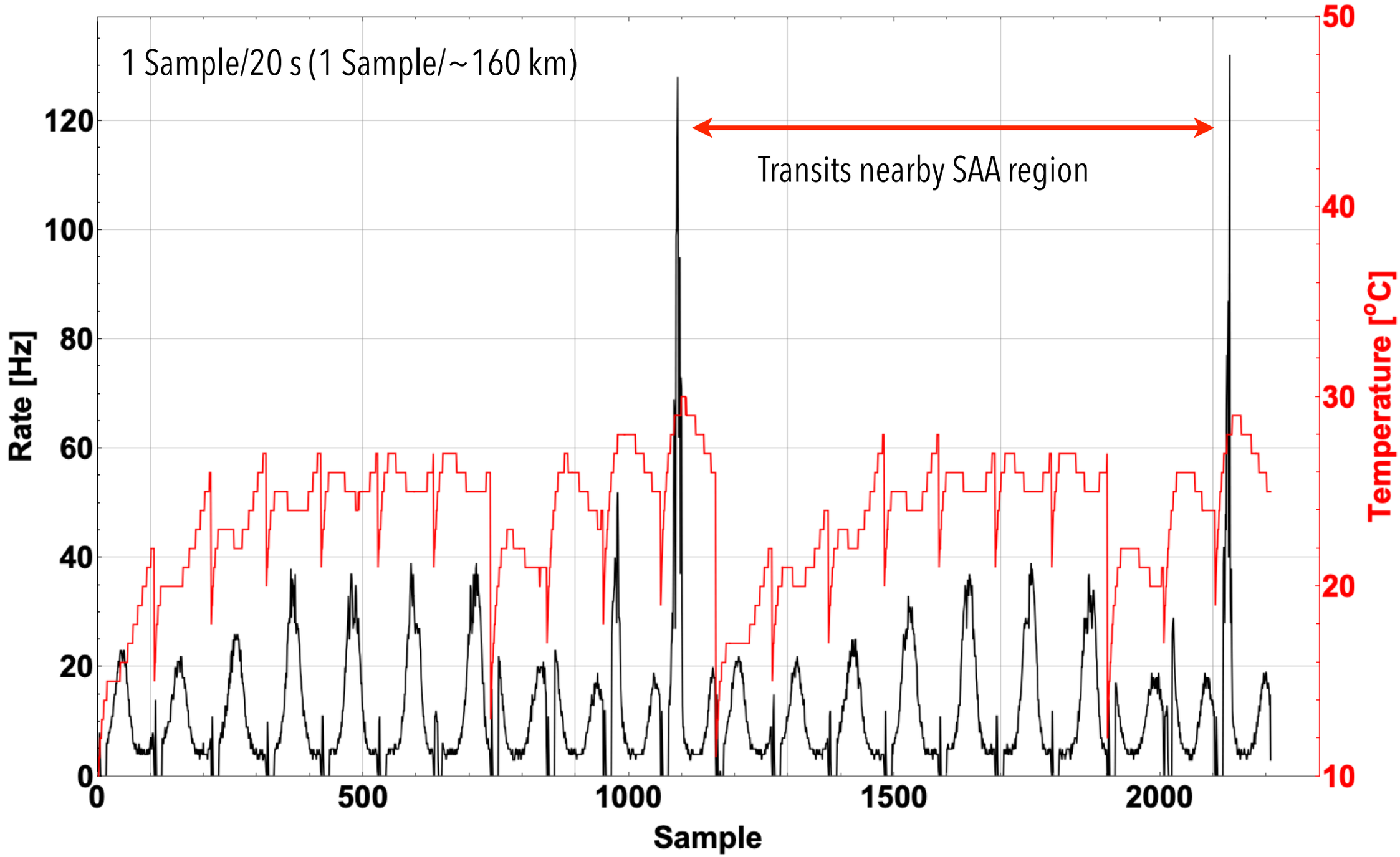

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Summary and present status

- LIGHT-1 was launched on December 21st, 2021 SpaceX Falcon9/Dragon;
- LIGHT-1 was set into orbit (LEO, from ISS) on February 3rd, 2022;
- LEOP completed, LIGHT-1 payload commissioning completed;
- LIGHT-1 entered in the operating phase on May 10th, 2022;
- It has been a tremendous opportunity to teach students on instrumentation and detector operations;
- working fast toward the identification of TGF candidates.