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

Adriano Di Giovanni (GSSI & CAP3-NYUAD)
# Terrestrial Gamma-Ray Flashes

<table>
<thead>
<tr>
<th>Origin</th>
<th>Atmospheric Process: Lightning, Thunderstorms, Tropical Storms</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primary particle counterpart</td>
<td>Gamma via bremsstrahlung</td>
</tr>
<tr>
<td>Secondary particle counterpart</td>
<td>Electron Beams - Neutrons from photoproduction</td>
</tr>
<tr>
<td>Other detectable counterparts</td>
<td>Radio emission (sferics)</td>
</tr>
<tr>
<td>Energy Range</td>
<td>10 keV up to ~100 MeV</td>
</tr>
<tr>
<td>Event Duration</td>
<td>~ hundreds of µs</td>
</tr>
<tr>
<td>Fluence @ 400-500 km</td>
<td>~ 1 gamma/cm²</td>
</tr>
<tr>
<td>Estimated rate (FERMI)</td>
<td>400k events per year</td>
</tr>
<tr>
<td>Originating Altitude</td>
<td>(usually) 9 km to 15 km</td>
</tr>
<tr>
<td>Generation Mechanism</td>
<td>Not yet fully understood</td>
</tr>
</tbody>
</table>
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.

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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°);
- 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.
## LIGHT-1 Payload: Design Characteristics

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Detection Energy Range</td>
<td>~ 20 keV - 3 MeV</td>
</tr>
<tr>
<td>Time resolution</td>
<td>~ 100 ns</td>
</tr>
<tr>
<td>Absolute Timing</td>
<td>&lt; 4 μs</td>
</tr>
<tr>
<td>Spectral Resolution</td>
<td>15% @ 20 keV, &lt; 5%@ 511 keV</td>
</tr>
<tr>
<td>Effective Area</td>
<td>40 cm² @ 50 keV, 20 cm²@ 511 keV</td>
</tr>
<tr>
<td>PMT Payload Size (Fits in 1U)</td>
<td>74 x 74 x 86 mm</td>
</tr>
<tr>
<td>SiPM Payload Size (Fits in 0.75U)</td>
<td>74 x 74 x 68 mm</td>
</tr>
<tr>
<td>PMT Payload Weight</td>
<td>1,085 g</td>
</tr>
<tr>
<td>SiPM Payload Weight</td>
<td>966 g</td>
</tr>
<tr>
<td>Power Consumption</td>
<td>&lt; 5.9 W average</td>
</tr>
<tr>
<td>Data Budget</td>
<td>50 MB/day</td>
</tr>
<tr>
<td>Operational Temperature Range</td>
<td>Between -30° C to 55° C</td>
</tr>
<tr>
<td>Survival Temperature range</td>
<td>Between -40° C to 60° C</td>
</tr>
</tbody>
</table>
The bus of LIGHT-1 satellite

- PMT payload
- On Board Computer
- Rotating wheels
- Magneto-Torquer
- SiPM payload
- Electrical Power System
- S-Band receiver

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3D model of the LIGHT-1 payload

PMT payload

SiPM payload

M = 1,185 g

M = 966 g

Aluminum 6061-T6
3D model of the LIGHT-1 payload

M = 1,185 g

M = 966 g

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The LIGHT-1 PMT and SiPM payloads

Veto System

PMT
Electronics

Veto System

Electronics
SiPM/MPPC

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The LIGHT-1 VETO to reject charged particle induced events

STYRON+POPOP+PPO

KURARAY WLSF Y11

SiPM
ASD-NUV1C-P-40

48 mm

STYRON+POPOP+PPO
The LIGHT-1 detection targets

Optical Separator

Crystals  PMT  Electronics

Crystals  SiPM/MPPC  Electronics
## The Hamamatsu Photosensors

### Characteristics

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>R11265-200</th>
<th>S13361-6050AE-04</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type of photosensors</td>
<td>PMT</td>
<td>MPPC (aka SiPM)</td>
</tr>
<tr>
<td>Dimensions (LxDxH) [mm³]</td>
<td>26x26x19</td>
<td>25x25x1.4</td>
</tr>
<tr>
<td>Weight [g]</td>
<td>24</td>
<td>2</td>
</tr>
<tr>
<td>Peak Sensitivity [nm]</td>
<td>~400</td>
<td>~450</td>
</tr>
<tr>
<td>Q.E. [%]</td>
<td>43</td>
<td>-</td>
</tr>
<tr>
<td>P.D.E. [%]</td>
<td>-</td>
<td>40</td>
</tr>
<tr>
<td>Typical Operating Voltage [V]</td>
<td>900</td>
<td>55</td>
</tr>
<tr>
<td>Typical Gain at working point</td>
<td>~10⁶</td>
<td>~10⁶</td>
</tr>
<tr>
<td>Dark Count at working point, room temperature [Hz]</td>
<td>Negligible</td>
<td>&gt;10 M</td>
</tr>
<tr>
<td>Operating Temperature [°C]</td>
<td>-30 to +60</td>
<td>-20 to +60</td>
</tr>
<tr>
<td># of photosensors in LIGHT-1</td>
<td>4</td>
<td>4</td>
</tr>
</tbody>
</table>

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CeBr₃(LB) and LBC scintillating crystals by Scionix

### Characteristics

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>CeBr₃(LB)</th>
<th>LBC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density [g/cm³]</td>
<td>5.1</td>
<td>4.9</td>
</tr>
<tr>
<td>Hygroscopic</td>
<td>YES</td>
<td>YES</td>
</tr>
<tr>
<td>Emission Peak [nm]</td>
<td>~370</td>
<td>~380</td>
</tr>
<tr>
<td>Typical Resolution @122 keV (⁵⁷Co) [%]</td>
<td>10</td>
<td>7</td>
</tr>
<tr>
<td>Typical Resolution @662 keV (¹³⁷Cs)</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>Typical Decay Time [ns]</td>
<td>~20</td>
<td>~35</td>
</tr>
<tr>
<td>Activity [Bq/cm³]</td>
<td>&lt;0.01</td>
<td>~1</td>
</tr>
</tbody>
</table>

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](https://doi.org/10.1088/1748-0221/14/09/P09017)
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.

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The photosensor Arrays

PMT Array

MPPC/SiPM Array

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The PMT payload (Inner View)

- Controller Electronics
- Photomultiplier tube
- VETO system
- Power Supply Electronics
- Electronics
- VETO Electronics

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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

Light-1 Payload Commissioning

Light-1 Science Data

Light-1 End of Life

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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%

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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)

1 Sample/20 s (1 Sample/~160 km)

Transits nearby SAA region

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

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

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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.