Building Gamma-Ray Detectors for Two CubeSats

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ABSTRACT

Terrestrial RaYs Analysis and Detection (TRYAD) is a collaborative project between The University of Alabama in Huntsville, Auburn University, and NASA Goddard Space Flight Center that focuses on the development of two CubeSats to detect and measure Terrestrial Gamma-ray Flashes (TGFs). TGFs are short bursts of gamma-radiation in the upper atmosphere thought to be associated with Bremsstrahlung radiation originating from electrons accelerated in thunderstorms. The two CubeSats will be deployed in low-Earth orbit, flying in tandem, and taking multipoint measurements of the TGF beams to shed insight into their production mechanisms. The primary roles of UAH in the TRYAD mission include creating the Science Instrument Package (SIP) which will act as the gamma-ray detector of the CubeSats and to design the Data Acquisition (DAQ) board that powers and reads data from the SIP. Recent work has been focused on testing and assembling the first SIP to prepare for a launch planned for 2023.

TERRESTRIAL GAMMA–RAY FLASHES

Terrestrial gamma-ray flashes are brief, sub-millisecond intense pulses (up to 40 MeV) of gamma rays believed to be produced when a relativistic electron or cosmic ray enters a strong electric field associated with thunderstorms.

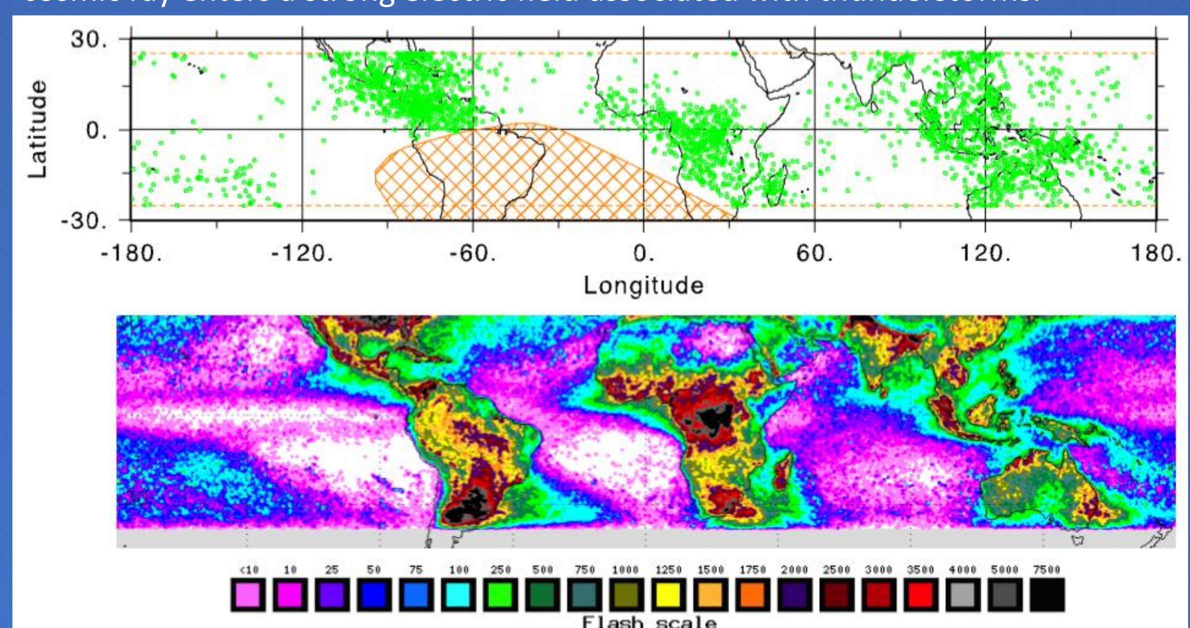
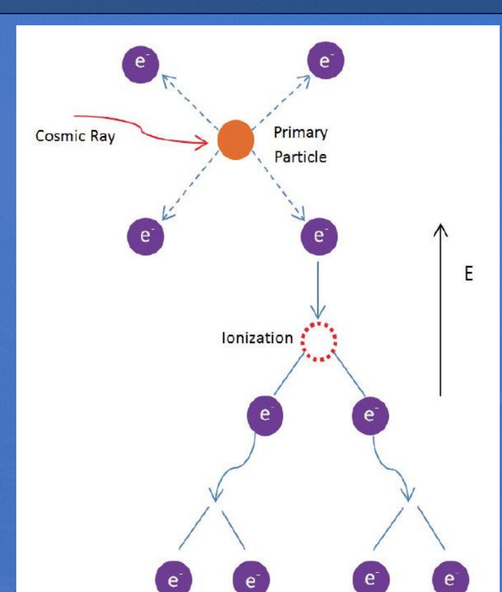


Figure 1: A comparison highlighting that TGFs occur more commonly where there is increased lightening activity. [TOP] Fermi locations at the times of 2700 GBM TGFs. [BOTTOM] Lightening activity observed with the Lightening Imaging Sensor (LIS).

TGF PRODUCTION

The electron is then accelerated, and interacts with atoms in the atmosphere, knocking off electrons on those atoms. This process continues and produces a cascade of electrons which interact with the electric field in atoms, causing Bremsstrahlung emission. The cascading of electrons that produces this is called Relativistic Runaway Electron Avalanche (RREA).



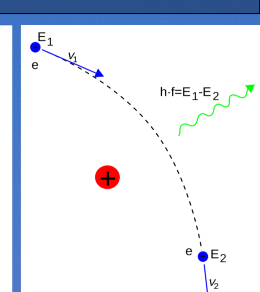


Figure 2: [LEFT] A depiction of the cascading electrons. [RIGHT] Bremsstrahlung emission.

TGF PRODUCTION MECHANISMS

Though TGFs are thought to be produced as a result of Bremsstrahlung emission caused by RREA, the production mechanism of the accelerating electrons is not known. TRYAD will be investigating two competing theories that explain the TGF production mechanism: the Lightning Leader model (Celestin 2012) and the Relativistic Feedback Discharge (RFD) model (Dwyer 2012). The Lightning leader model predicts that the electric field which triggers a TGF is generated by lightning step leaders creating a wide beam profile, while the RFD model hypothesizes that the electric field of the thunderstorm itself accelerates the electrons, thus producing a narrow beam profile. Therefore, TRYAD will take multipoint measurements of the beam profiles.

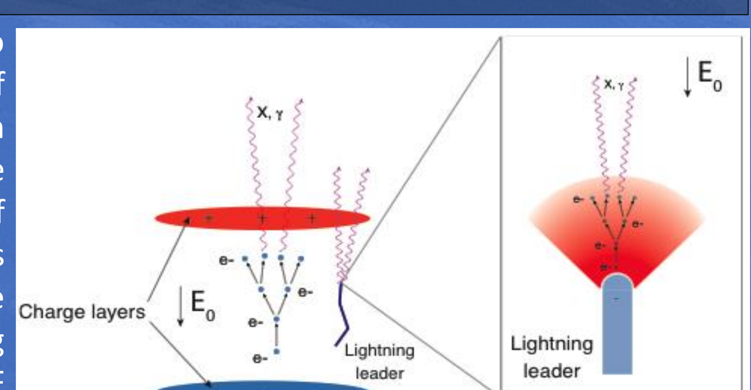


Figure 3: [LEFT] RFD model, Dwyer 2012. [RIGHT] Lightning Leader model, Celestin 2012.

We are building and testing a gamma-ray detector for two CubeSats that will take multipoint measurements of the beam profile of terrestrial gamma-ray flashes.

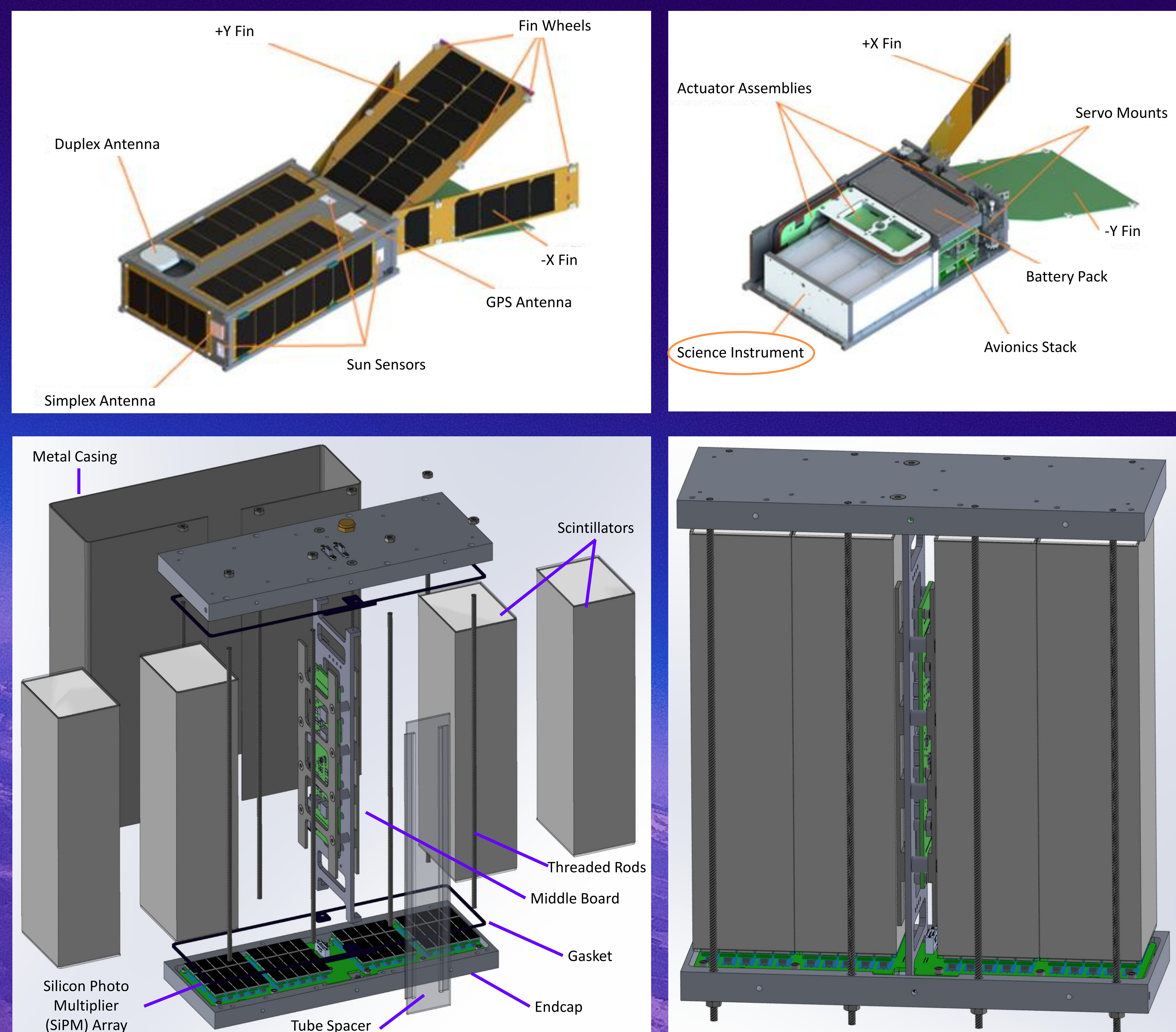
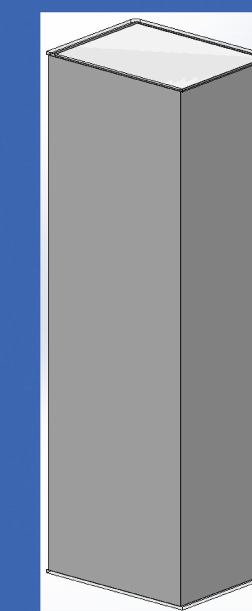


Figure 4: [TOP LEFT] CAD Diagram of the exterior of the CubeSat with parts labeled. [TOP RIGHT] A cutaway view of the CubeSat with parts labeled. Circled in orange is the Science Instrument UAH is developing. [BOTTOM LEFT] An exploded view of the Science Instrument, with parts labeled. [BOTTOM RIGHT] A cutaway view of the Science Instrument. The electronics boards supplied by NASA Goddard Space Flight Center are depicted in green.

THE SCIENCE INSTRUMENT DETECTOR

The science instrument detects gamma-rays using Silicon Photomultiplier arrays placed at each end of four scintillators.

SCINTILLATOR CRYSTALS



The scintillators are made of a plastic polymer called Polyvinyltoluene, chosen for its long optical attenuation length and fast timing. This material is useful for time-of-flight systems. Each of the four scintillator crystals are wrapped in three layers of Teflon tape. The Teflon is necessary for the detection of signals as it diffuses and propagates the light, creating a Compton scatter effect. This allows a gamma-ray signal to be detected by the SiPMs as optical light. Then, sheets of silicon will be cut and attached to each end of the scintillator. This is an optical pad that is necessary for optical coupling between the plastic of the scintillator and the SiPMs.

Figure 5: A CAD diagram of a single plastic scintillator crystal, measuring at a height of around 193 mm.

SILICON PHOTOMULTIPLIERS (SiPMs)

SiPMs are sensitive light detectors. When incident gamma-ray particles interact with the science instrument, some energy is transferred to the scintillator and converted into optical light in the process described above. This optical light is then read by the SiPMs, which produce a voltage proportional to the energy absorbed by the scintillators. There are 60 pairs of SiPMs on the Goddard boards in the endcaps, and when a signal is received by the SiPMs, the Goddard boards preprocess the data and send it to TRYAD scientists for further analysis.

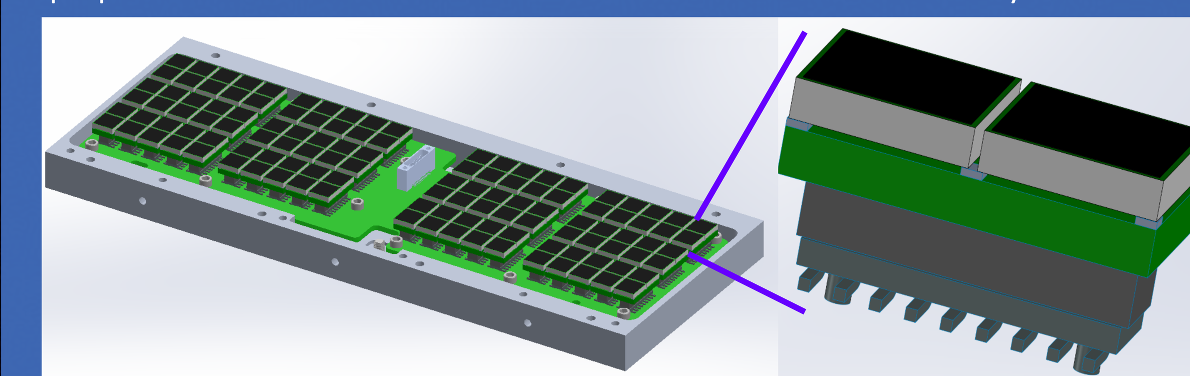


Figure 6: A CAD diagram of the endcaps with the Goddard board (green) and SiPMs installed. Blown up on the right is the SiPM.

PROGRESS

The goal of UAH's TRYAD team for the summer of 2021 was to fully assemble and test the science instrument package (SIP) so that we could have one of two detectors finished for launch. While we do not yet have a finalized SIP, the steps we have taken towards accomplishing this goal are as follows:

- Practiced assembly to develop an updated procedure for building the SIP.
- Took inventory and documented each component needed for flight assembly.
- Developed an updated procedure for fabricating the casing gasket and then successfully created multiple gaskets to help with light-tightness of the SIP.
- Tested bank A of the SiPMs in a dark box and using an LED bulb to verify that they were receiving power and reading light signals.
- Assembled the SIP completely with flight components to test with a radioactive source.

RESULTS & FUTURE WORK

Testing the fully constructed SIP with a radioactive source revealed that only bank A of the SiPMs are working, so further testing of bank B is required. When connected to the oscilloscope, a signal can be shown, but a spectra of the light has not yet been acquired due to difficulties with the CAEN MC^2 software. Future tests will focus on testing if bank B is receiving power and becoming familiar with the CAEN MC^2 software.

ACKNOWLEDGEMENTS

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