Development of a Light, Fast, and Inexpensive TGF Detector

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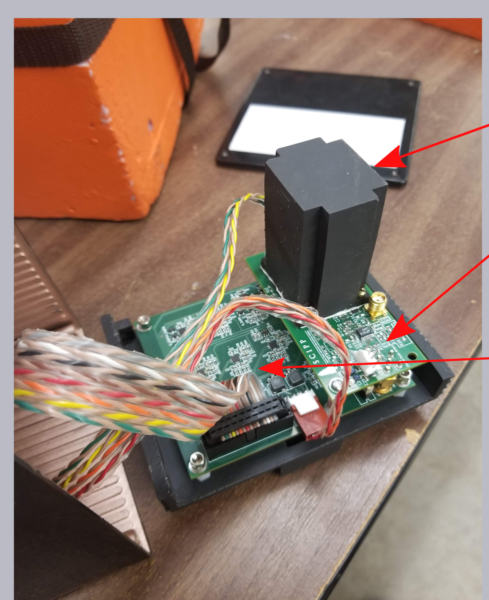
Abstract

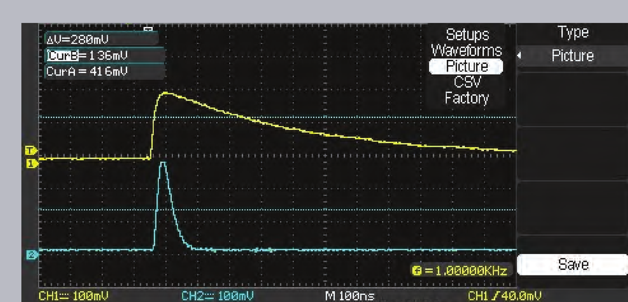
Montana State University (MSU) in collaboration with the University of California, Santa Cruz (UCSC) has developed the **Light and Fast TGF Recorder (LAFTR)**, a NASA-University Student Instrumentation Project, capable of detecting high energy gamma rays at a maximum count rate of >5MCounts/s and time-tagging photons to a few tens of nanoseconds. LAFTR is light enough (<2.5 kg) to be deployed for **balloon born** observations inside thunderstorms, and fast enough to record unsaturated observations near TGF generation regions. In addition to balloon flights, the low-cost nature of LAFTR allows for many units to be **deployed via ground** for multi-point measurements and arrays of ground and tower-based TGF observations. Here an overview of the instrumentation is presented, including a detailed description of the instrument as well as initial results.

In addition to an overview of the LAFTR instrument, an initial analysis of lightning flash period characteristics in TGF-producing thunderstorms is presented from Fermi and associated lightning data. The flash periods immediately prior to and after the TGF are compared to the general flash period in TGF-producing storms. We find that the **pre-TGF flash interval is typically 31% longer** than other flash intervals in the same storm while the **post-TGF flash interval is generally 4% shorter** than other flashes.

Instrument Design

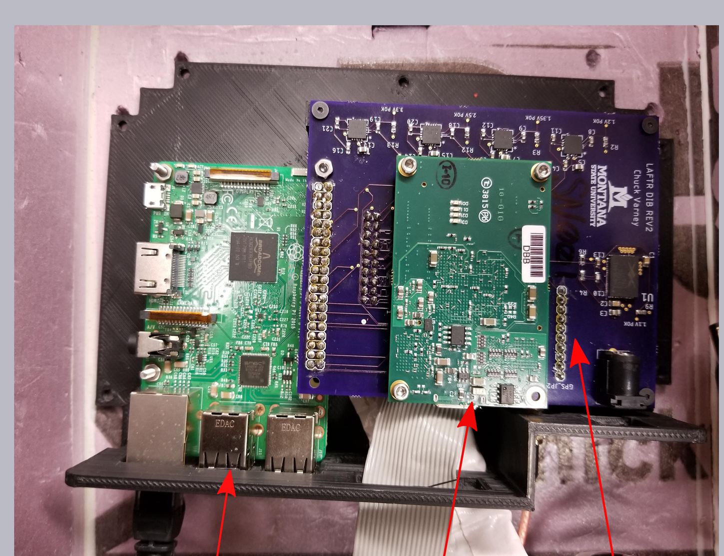
Analog





Shaper Creates a ~40ns pulse from slower SiPM decay

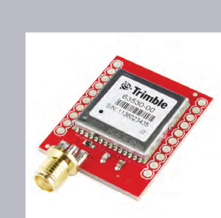
Digital



FPGA:
- Inexpensive Altera Cyclone V E FPGA and Opal Kelly Development board.
- 100MHz clock speed (10 ns)
- Time tags events as a 48 bit word:
  - (5 ID + Energy, 11 second, 27 subsecond)
  - time standard comes from GPS PPS
- On FPGA buffer of 16k events

Digital Interconnect Board (DIB):
- Provides low voltage power lines to FPGA
- Connects and powers GPS and Raspberry Pi

GPS:
- SparkFun Copernicus II DIP (12 Channel)

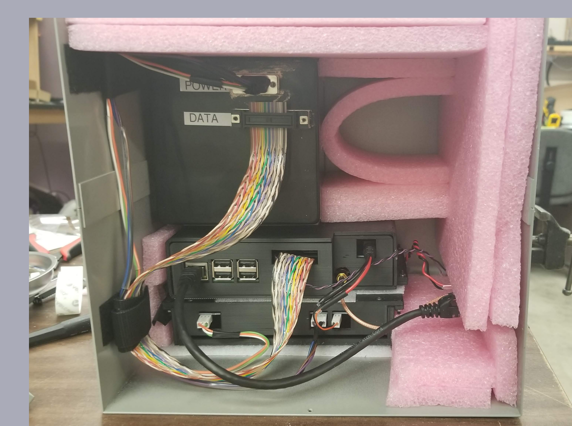


Raspberry Pi:
- Continuous readout of FPGA buffer at 10k events/second (Peak 50k events/second)
- ~8GB memory storage (SD Card)
- Flight Computer also reads GPS NEMA sentences as well as split GPS PPS.
- For ground units, ethernet and Teamviewer allow remote access to data

Flight and Ground Units

LAFTR is capable of being deployed for both ground and balloon born observations. For deployment, the digital and power systems are mounted to 3D printed housing structures, while the analog system is self contained within a plastic, light-tight box. The three enclosures are then secured to a protective metal (for the ground unit) or foam (for the flight unit) box. A GPS antenna is attached to the outside of both units via SMA connector.

At present, a ground unit has been deployed to the base of a lightning protection tower in Uchinada, Japan. A nearby (~50m away) wind turbine was struck by a TGF producing lightning stike, as described in Bowers (2017). This unit requires an external 12V power supply and an internet connection for data access. The internet connection is supplied by a WIMAX modem.



Inside of the LAFTR ground unit prior to deployment

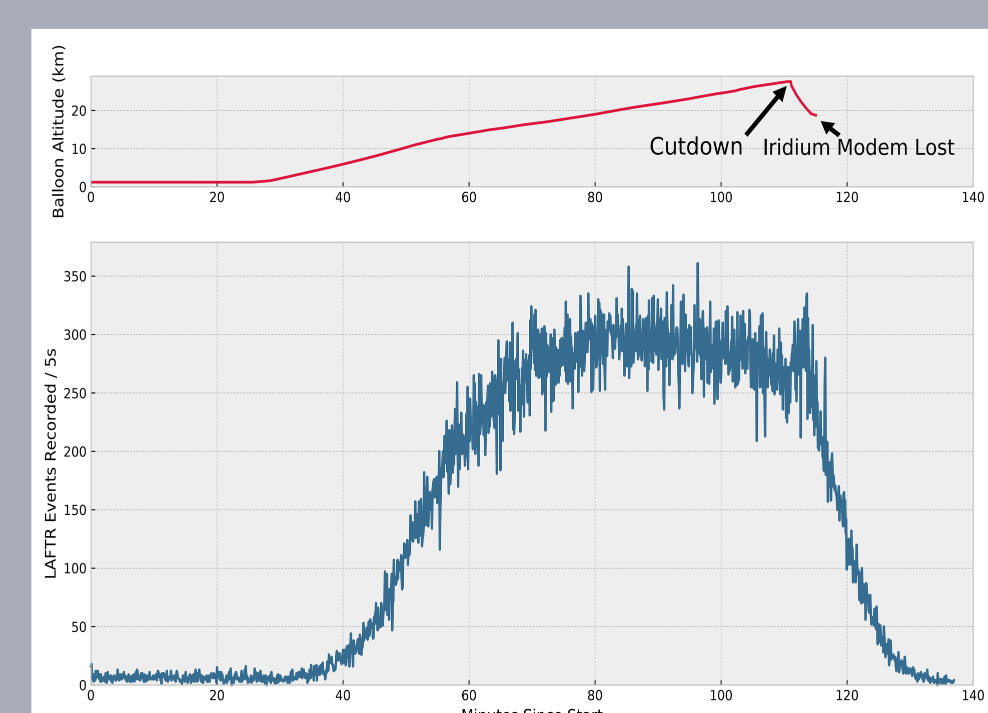
Enclosure of LAFTR unit as currently deployed. Ethernet provided by WIMAX modem (red)

View of the enclosure at the base of the lightning protection tower in Uchinada, Japan

(Left) inside of LAFTR flight unit prior to deployment. (Right) Side-by-side image of LAFTR ground (gray) and flight (orange) units.

A fully functional flight unit has also been developed and tested. A test flight of this unit took place on 11-12-2018. LAFTR was launched with a latex sounding balloon from Eddie's Corner, MT and reached a height of roughly 90,000 feet before it was cutdown and recovered near Columbus, MT. The entire flight lasted roughly 2.5 hours, however, LAFTR is capable of extended flights which are achieved using Montana Space Grant developed latex valved balloons. Flights of this type are planned for Summer, 2019.

Map showing the balloon's flight path.



Count rate data from November, 12th test flight. Also shown is the balloon's altitude.

Shortly after cutdown, the Iridium modem (onboard an accompanying payload) was abruptly lost. As such, no altitude data is available for the remainder of the flight.

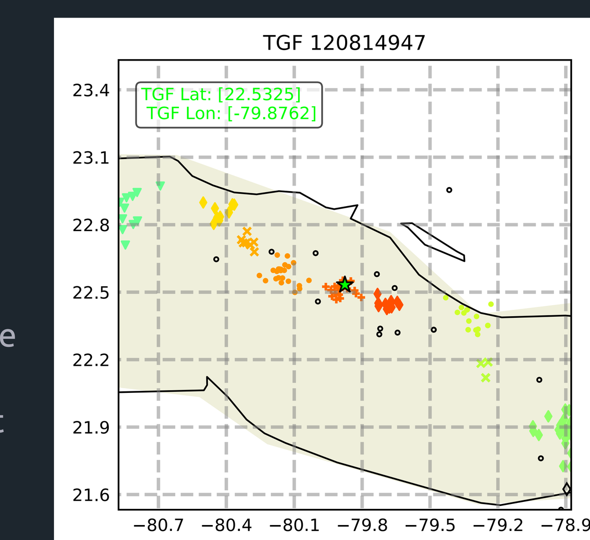
Flash Period Characteristics in TGF Producing Storms

Here we present the initial results of an analysis of lightning flash period characteristics in TGF producing thunderstorms. Lightning data is provided by both the World Wide Lightning Location Network (WWLLN) and the Earth Networks Total Lightning Network (ENTLN), for TGFs identified in the Fermi GBM TGF Catalog. Only TGFs with close WWLLN radio signal associations (1342 out of 4144 TGFs in the catalog) and only those TGFs for which associated ENTLN data was available have been considered in this study (1169 TGFs in total). The ENTLN data was time corrected, as described in Briggs (2010), and the WWLLN and ENTLN datasets were merged.

Clustering and Flash Grouping

The merged lightning data is clustered using the Hierarchical Density-Based Spatial Clustering of Applications with Noise (HDBSCAN) clustering algorithm.
- Probability scores (0-1.0) are assigned to each point in a cluster.
- We set a threshold at p = 0.2 for inclusion.

After spatial clustering, the time series of individual clusters are grouped into flashes using Kernel Density Estimation (KDE)
- This ensures we calculate time differences between distinct flashes and not parts of the same flash
- Eliminates any "double counting" from merging the ENTLN and WWLLN datasets



Example of HDBSCAN clustering. Different colors/markers indicate cluster assignments.

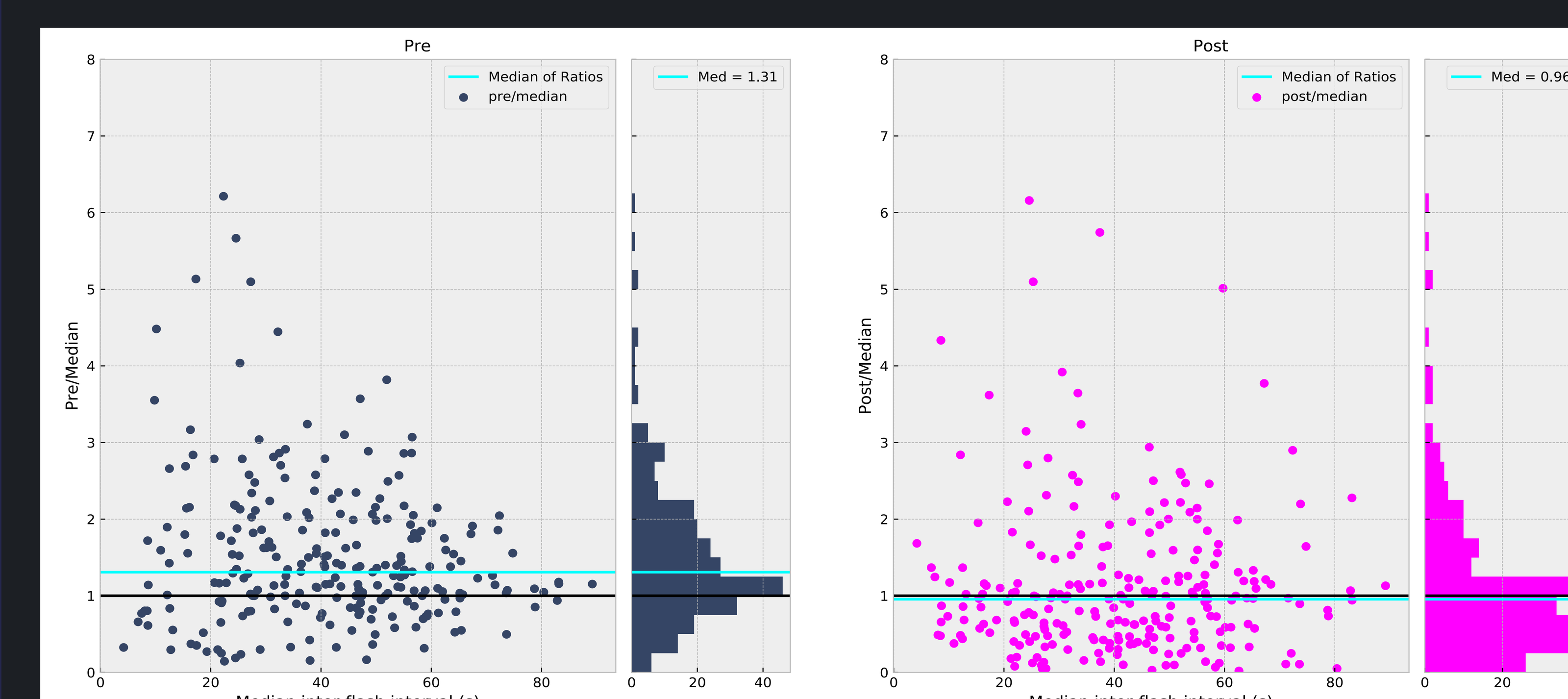
Latitude	Longitude	Time Sep. (s)	Cluster ID	Probability	Flash ID
22.4937	-79.8272	-575.585433	32	0.364429	0
22.507212	-79.832906	-575.505836	32	0.48209	0
22.4766	-79.8038	-575.505156	32	0.311464	0
22.4891	-79.9015	-510.161332	32	0.860828	1
22.4668	-79.9141	-509.578022	32	0.776583	1
22.4943	-79.9191	-401.776577	32	0.858407	2
22.5156	-79.8661	-401.737909	32	0.725014	2
22.4818	-79.9329	-401.185001	32	0.723843	2
22.5288	-79.8993	-99.149232	32	1	3
22.5102	-79.8979	-98.963344	32	0.951735	3
22.5189	-79.9077	-98.814485	32	1	3
22.5245	-79.9603	-0.000124	32	0.442758	4
22.5325	-79.8762	-9.3E-05	32	1	4
22.5325	-79.8762	-9.3E-05	32	1	4
22.5527	-79.8855	26.442814	32	0.799495	5
22.5324	-79.8925	26.517859	32	1	5
22.5493	-79.8499	26.729835	32	0.655163	5
22.5493	-79.8499	26.73052	32	0.655163	5
22.5252	-79.9216	94.539551	32	0.815986	6
22.5091	-79.9375	145.811625	32	0.783794	7
22.4721	-79.8968	583.020847	32	0.623366	8

dt_{typ}, dt_{pre}, dt_{post}

Example data showing the latitude, longitude, time (from TGF), cluster ID, probability score, and flash ID for a set of sferics. Different colors represent identified flashes. The TGF flash is boxed, and pre, post, and typical flashes are marked as well.

A total of 247 TGFs were manually selcted based on the accuracy of assigned clusters, number of flashes in the TGF cluster, and compactness of the TGF cluster.

Time differences between all sucessive flashes in a cluster are calculated as well as the time separation between the flash immediately prior (pre) and immediately following (post) the TGF flash. These are then compared to the median flash interval of their respective storm.



(Left) Scatter plot of the median inter-flash interval (cluster median) versus the pre-TGF interval, normalized by the cluster median, for each of the 247 considered TGFs. A Histogram of these ratios is also included. (Right) Scatter plot and histogram of post-TGF intervals, as compared to individual cluster medians. We note that the pre-TGF interval is (typically) 31% longer than other intervals in the TGF producing storm. Conversely, the post-TGF interval is typically 4% shorter than other intervals. This implies that at least some TGFs are the result of extended charge-up periods.