Balloon-borne Measurement of Energetic Electron Fluxes Inside Thunderclouds

EGU2014-987

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Abstract

High-energy radiation is routinely produced by thunderclouds and lightning. This radiation is in the form of x-rays and Gamma-rays with timescales ranging from sub-microsecond (x-rays associated with lightning leaders), to sub-millisecond (Terrestrial Gamma-ray Flashes), to minute long glows (Gamma-ray Glows from thunderclouds seen on the ground and in or near the cloud by aircrafts and balloons). It is generally accepted that these emissions originate from bremsstrahlung interactions of relativistic runaway electrons with air, which can be accelerated in the thundercloud/lightning electric fields and gain up to multi-MeV energies. However, the exact physical details of the mechanism that produces these runaway electrons are still unknown.

In order to better understand the source of energetic radiation inside thunderclouds, we have begun a campaign of balloon-borne instruments to directly measure the flux of energetic electrons inside thunderclouds. In the current configuration, each balloon carries Geiger counters to record the energetic particles. Geiger counters are well suited for directly measuring energetic electrons and positrons and have the advantage of being lightweight and dependable. We transmit data at 900MHz, ISM band, with 115.2 kbps transmission rate. This would provide us a high resolution radiation profile over a relatively large distance. Due to the nature of the thunderstorm environment, the campaign has many design, communication, and safety challenges. In this presentation we will report on the status of the campaign and some of the physical insights gained from the data collected by our instruments.

Theory

Cosmic rays are constantly bombarding the atmosphere of the Earth. When ionizing particles produced by cosmic ray particles (e.g., electrons, positrons, and muons) travel through a region of the atmosphere in which the ambient electric field is greater than the runaway electron avalanche threshold, they act as seed particles for relativistic runaway electron avalanches (RREAs) [Gurevich et al.,1992]. Runaway electrons produced by high-energy cosmic ray particles can produce low-energy positive and negative ions, low-energy electrons, and more high-energy electrons through the ionization of air. For an arbitrary electric field, the density of runaway electrons is approximately given by the general transport equation [Dwyer, 2010]:

$$\frac{\partial n_{re}}{\partial t} + \vec{\nabla}\cdot(\vec{v}_{re} n_{re}) - \vec{\nabla}\cdot(\hat{D}\cdot\vec{\nabla} n_{re}) - \frac{n_{re}}{\tau} = n_s,$$

The electrons produced by the avalanche process in the thunderstorm are quickly absorbed by the air particles and cannot be measured using ground based detectors. In this regard we have launched a new balloon-borne campaign at Florida Tech to measure the energetic electron fluxes close to their sources inside thunderclouds. In the current campaign we are mainly interested to detect seconds to minutes long energetic electron emission events, e.g., Gamma-ray glows (Figure 1).

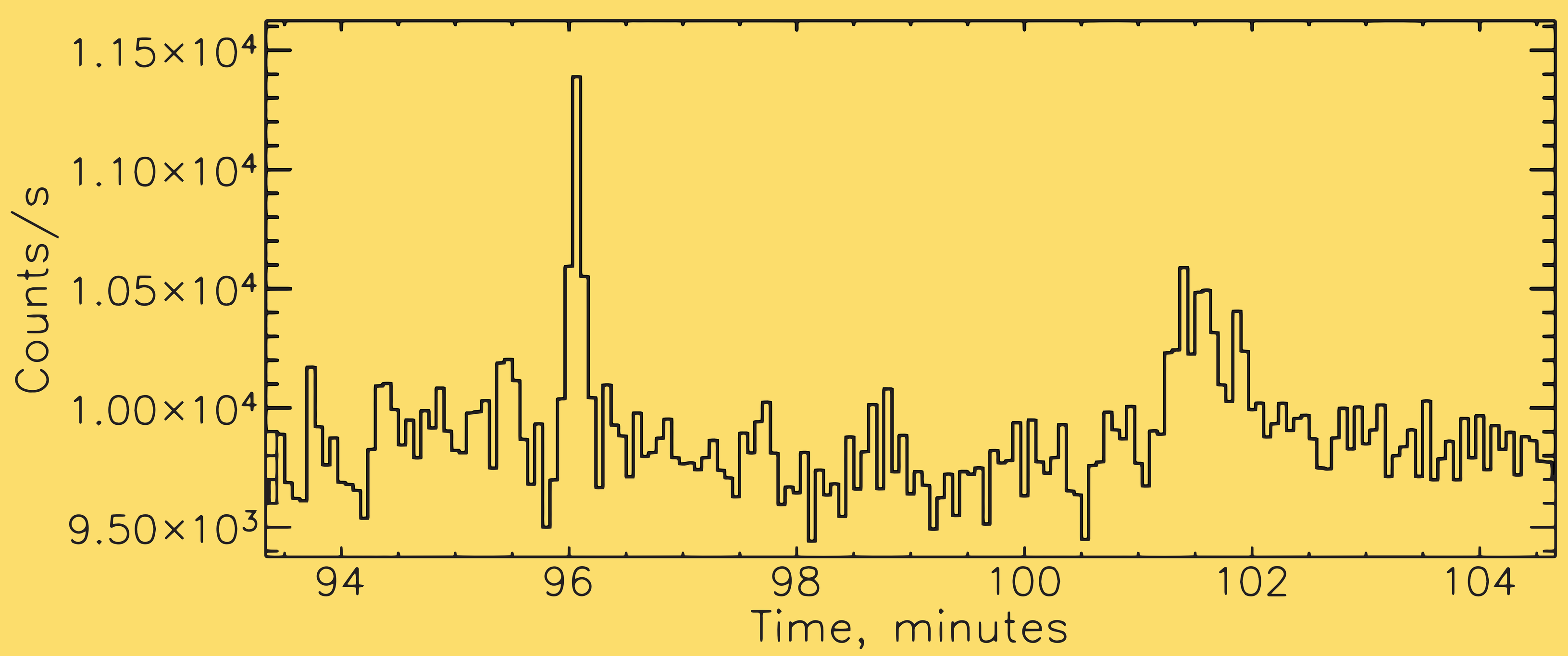

Figure 1. Gamma-ray count rate for two glows observed by the ADELE instrument flying above two different active cells. The longer duration of the second event implies a greater spatial extent of the source

Instrumentation

Since Florida Tech is next to the ocean, the balloons' payloads are usually not recovered. Therefore, the data must be transmitted during the flight. Telecommunication has been one of the biggest challenges of this campaign. Thunderclouds are very electromagnetically noisy environments. Great care has been taken into account in order to have uncorrupted data for the radiation count rate, at 1ms intervals.
The count rate of energetic electrons, detected by the Geiger counter, is measured and primary analyzed by the on-board microcontroller. Then, the count rate data, the GPS location of the payload, and all the payload health monitoring information is transmitted to our ground station. Figure 2 shows all the components of the instrument.

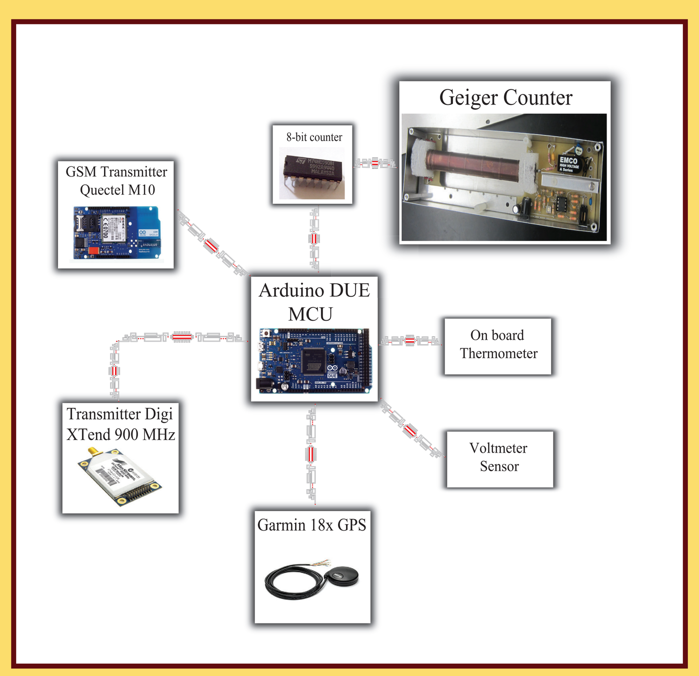

Figure 2. Components of the balloon-borne detectors.

Data Analysis

Property	Value
Balloon Burst Altitude	30,000-50,000 ft
DAQ Transmitter Frequency Band	902-928 MHz (ISM)
Data Transfer Rate	115.200 kbps
Payload Weight	2.1 lbs
Detector Efficiency	80% for muon, 0.6% for 1GeV gamma

Table 1. Main parameters used for data analysis.

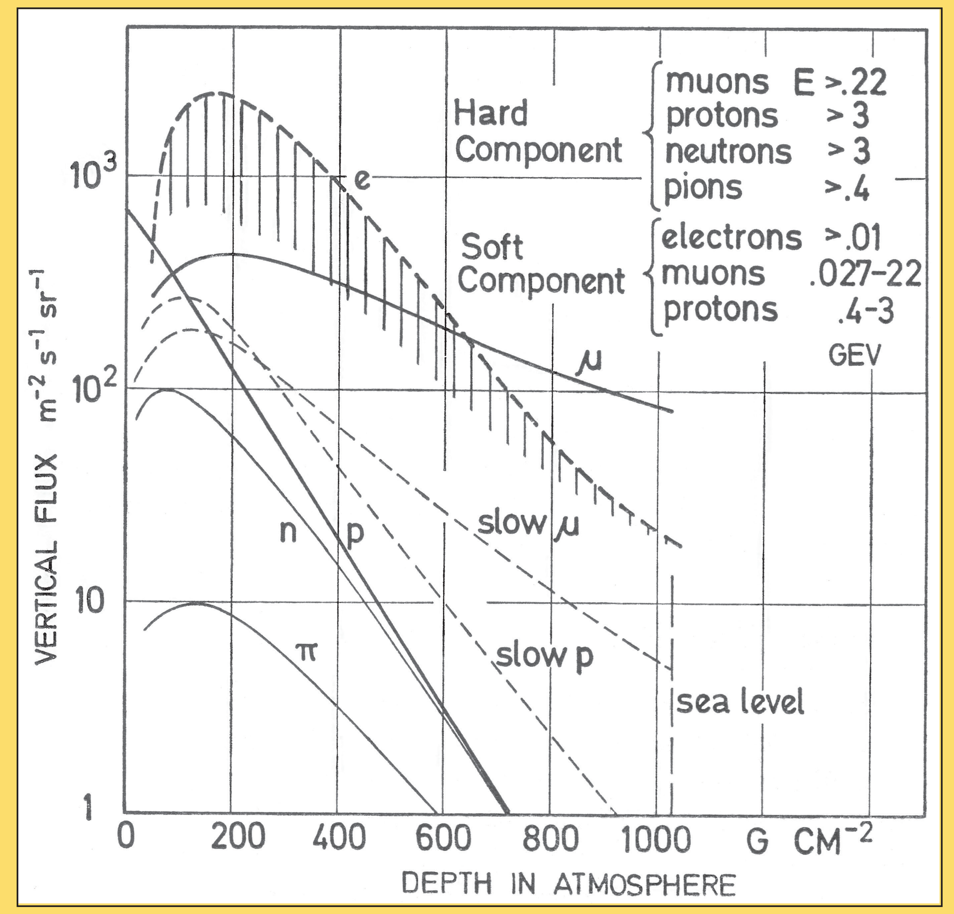

Figure 3. Vertical flux of radiation components inside the atmosphere [Hillas, 1972].

During the Fall of 2013, we designed and tested detector units to measure energetic electron's rate in the atmosphere. The units collect and transmit data to our ground station in real time. After multiple revisions of both the software and hardware, we successfully measured the background radiation profile as a function of height.
We have had 4 balloon launches so far. The data retrieved during our balloon launches agrees well with theoretical predictions [Hillas, 1972]. Figure 5 shows the background radiation rate profile for the data recorded during our launches on November 21st and December 2nd. The shaded area corresponds to the theoretical predictions based on the vertical flux profile of cosmic ray components shown in Figure 3.3 [Hillas, 1972].

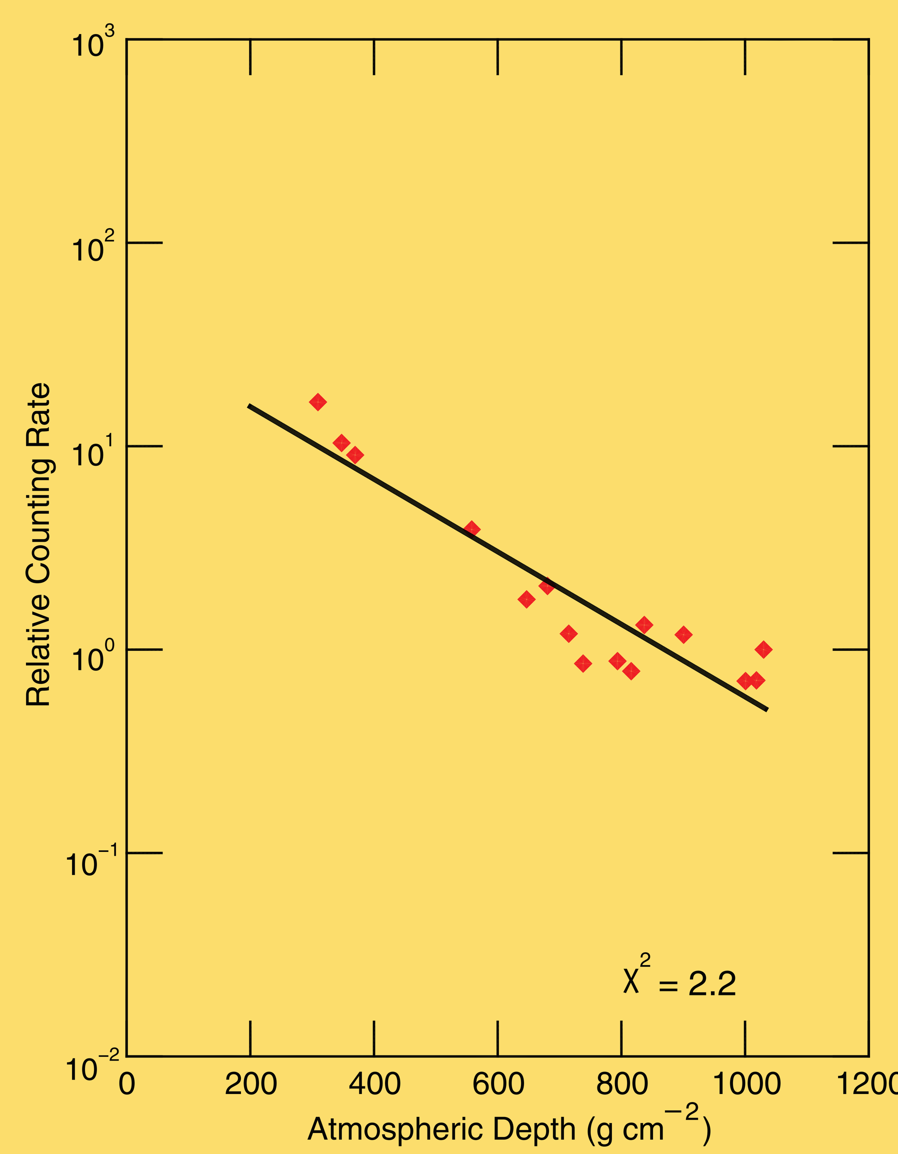

Figure 4. Relative count rate of the charged particles from data recorded on Nov. 21 and Dec. 2 in fair weather. The rate has been normalized to its value on ground.

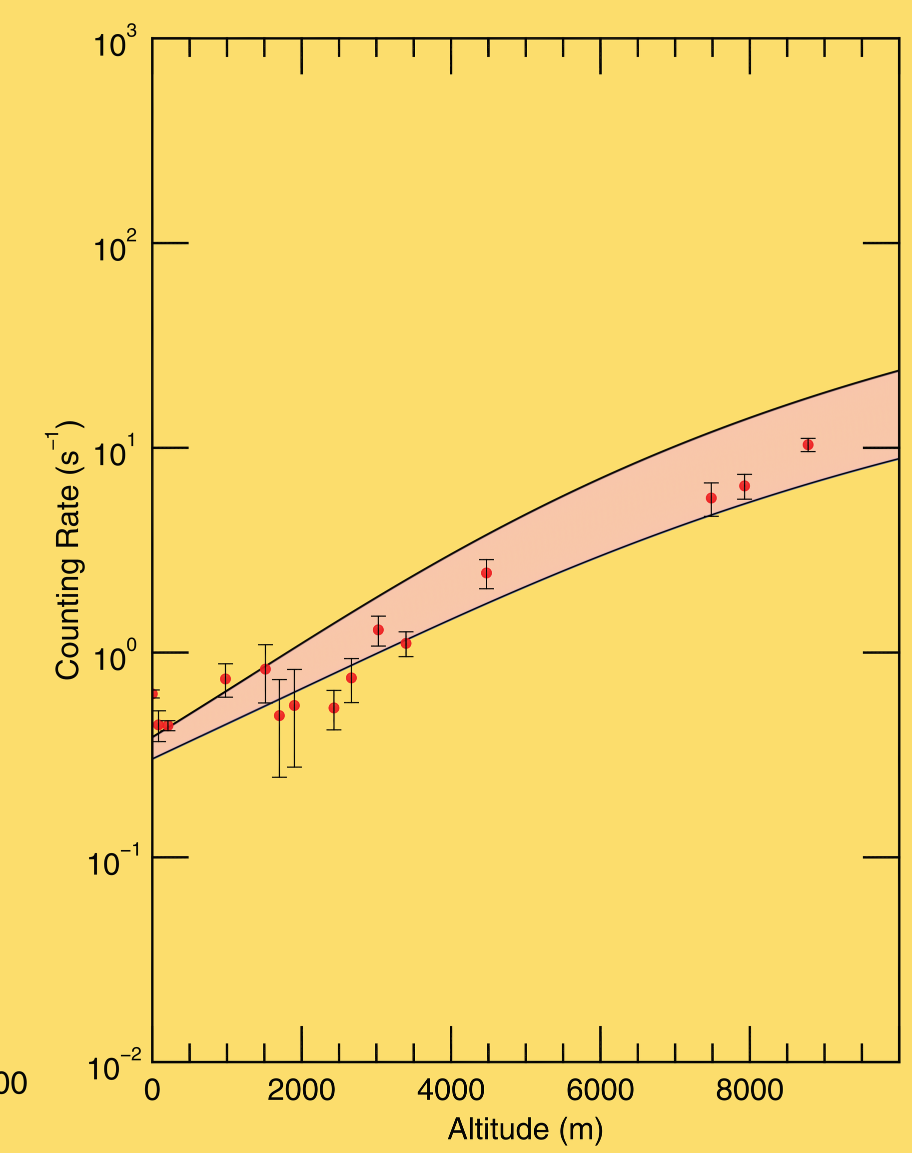

Figure 5. Comparison of data recorded on Nov. 21 and Dec. 2 in fair weather, to the theoretical predictions. These predictions are based on the vertical flux of cosmic ray components at different atmospheric depths shown in the figure above by Hillas [1972].

Summary and Conclusions

We have successfully measured the fair weather background radiation profile as a function of height. The data retrieved agrees well with theoretical predictions [Hillas, 1972]. The second phase of the campaign is scheduled for the Summer of 2014 and until then we will incorporate the following components in order to have comprehensive measurements of energetic electrons spectra inside thunderclouds:

- **Addition of an electric field sensor.** This sensor is a necessary component in order to find the energetic electron spectrum from the count rate.
- Addition of two more Geiger counters with different thicknesses of lead shielding. By doing so we will have directional information of the incoming electrons flux.
- Addition of more environmental sensors to the payload (e.g., barometer, accelerometer, etc).
- Addition of a lower frequency transmitter dedicated to the environmental data and to send commands to the payload.
- Increasing the communication range by incorporating Bandpass filters and amplifiers with higher efficiency.
- **Launching multiple balloons at the same time into a single thundercloud to increase the probability of detecting fast and short-scale events.**

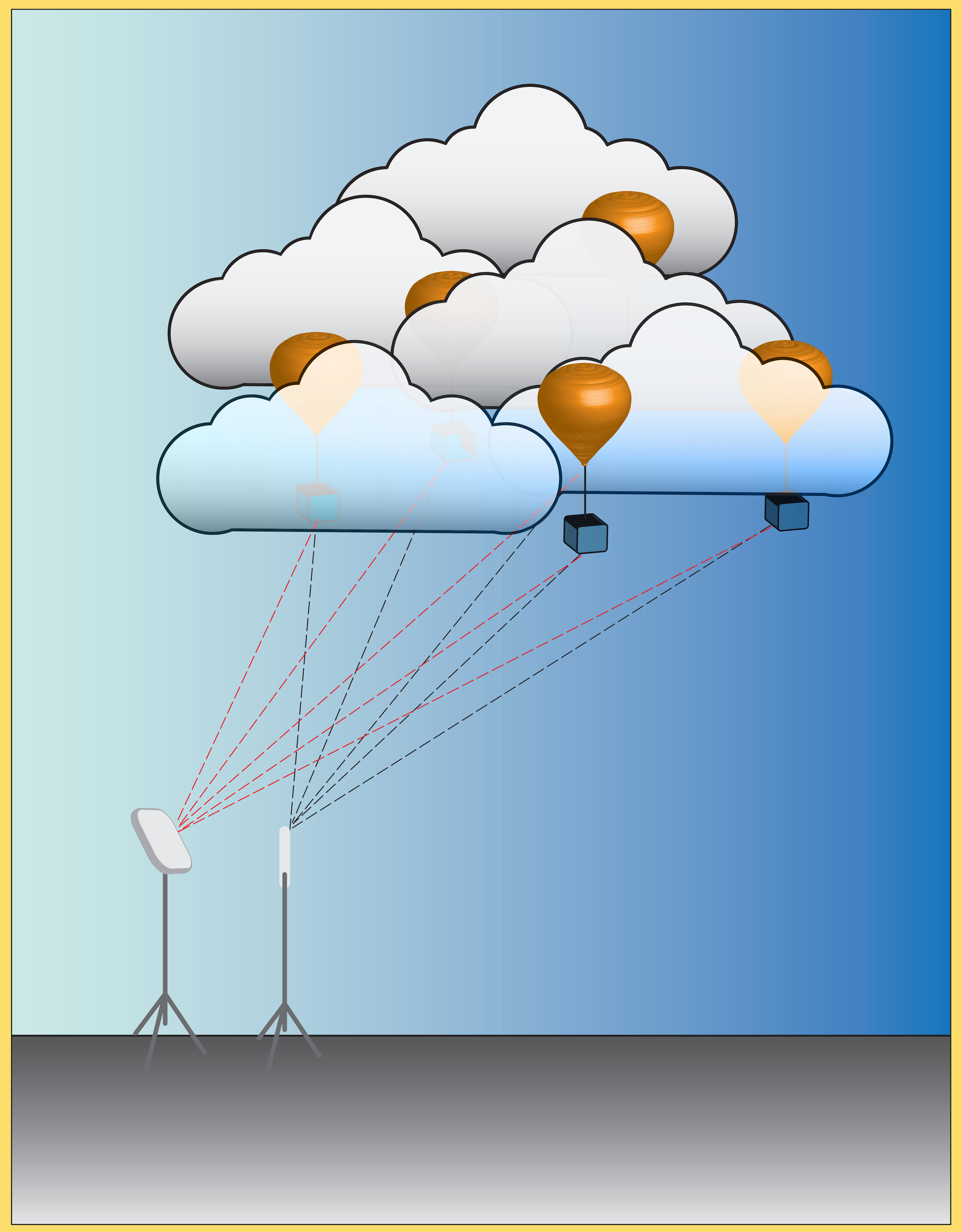

Figure 6. Visual representation of the planned campaign for the Summer of 2014.

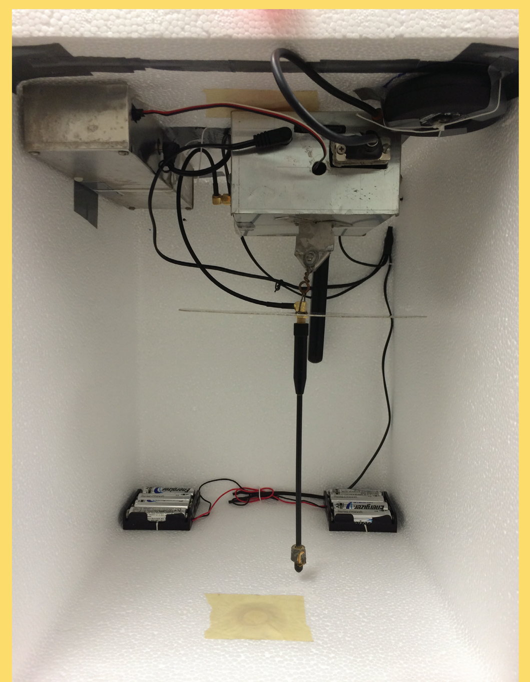

Figure 7. Balloon's payload; Inside view of the payload box.

Figure 8. Ground Station; Data acquisition (DAQ) and tracking units

Acknowledgments

This research was supported in part by NASA grant NNX12A002H and by DARPA Nimbus grant HR0011-1-10-1-0061 to Florida Institute of Technology.

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