Investigating the Impact of a Solar Eclipse on Atmospheric Radiation

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ABSTRACT

Muons are created when high energy cosmic particles like protons collide with atmospheric molecules, such as diatomic oxygen or nitrogen. These collisions create new molecules and decay products such as muons. It is known that there is a relationship between muon production and altitude.

For this project, we have developed a method for the detection of cosmic ray muons as a function of altitude. The detector is part of a self-contained autonomous payload that is carried up to altitude aboard a weather balloon. The payload contains a plastic scintillator coupled with a silicon photomultiplier and two Geiger counters. All three are connected to a coincidence circuit, making up the muon detection system. This system, along with various other sensors including an internal temperature sensor and altimeter, are controlled by an onboard Arduino Mega microcontroller.

A launch in April will serve as a test flight for the payload and baseline data will be collected. These data will be compared to those collected during a similar flight at the time of the solar eclipse in August.

EXPECTED DATA

The payload will experience a change in radiation flux as it ascends. We expect the muon count to increase with altitude until between 60,000 and 70,000 feet. At altitudes above this, the count will decrease with altitude. This behavior was first reported for the general radiation flux by Erich Regener and Georg Pfotzer in the 1930's. The dip in flux at higher altitude, from which the dip in muon count follows, is caused by less atmosphere being present, and thus fewer radiation scattering events taking place.

Michael Palmer, emeritus professor from West Virginia University, developed a mathematical model to predict the amount of muon flux as a function of altitude. We have adapted his model to fit data collected from previous flights (Fig. 1) in which only the general radiation flux was measured.

A portion of the cosmic particles that generate the showers of muons originate from our Sun. During the eclipse we expect to observe a lower overall count rate.

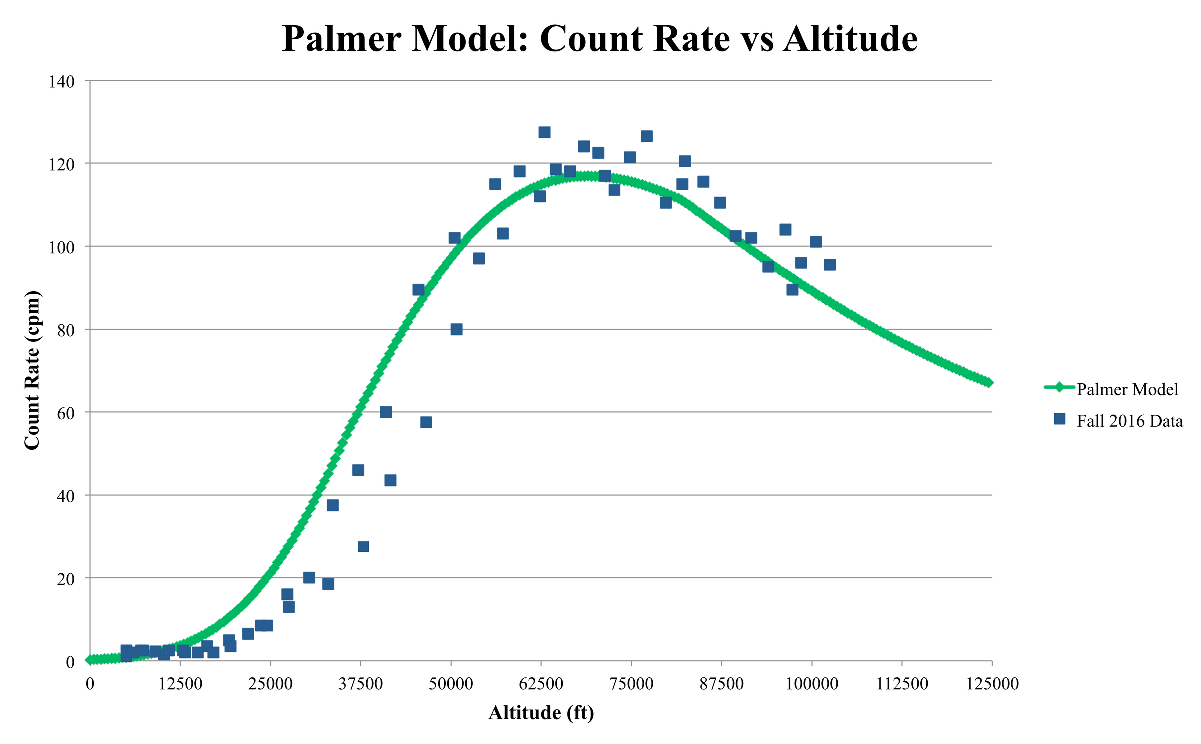


Figure 1. Muon count versus altitude. The blue data points were collected during a balloon flight in the fall of 2016. The green line is a mathematical model developed by Michael Palmer.

IDENTIFICATION OF MUONS

The current experiment is built upon previous attempts to measure muon flux as it varies with altitude using Geiger–Müller tubes. A downfall of the use of a single Geiger–Müller tube is that any charged particle will trigger a "count" in the device. In an earlier experiment, three tubes were wired to a coincidence circuit to help identify just the muons that passed through the payload . Given their high energy (relative to other forms of cosmic radiation), there is a nominal probability that muons will not be stopped by a single device. Only when at least two of the tubes were triggered "simultaneously" would the count be increased. Stacking the Geiger–Müller tubes vertically allowed us to determine the direction from which particles were detected. Only particles that came from a small arc directly above the tubes would be detected. To increase the detection angle, three Geiger–Müller tubes were used (Fig. 2).

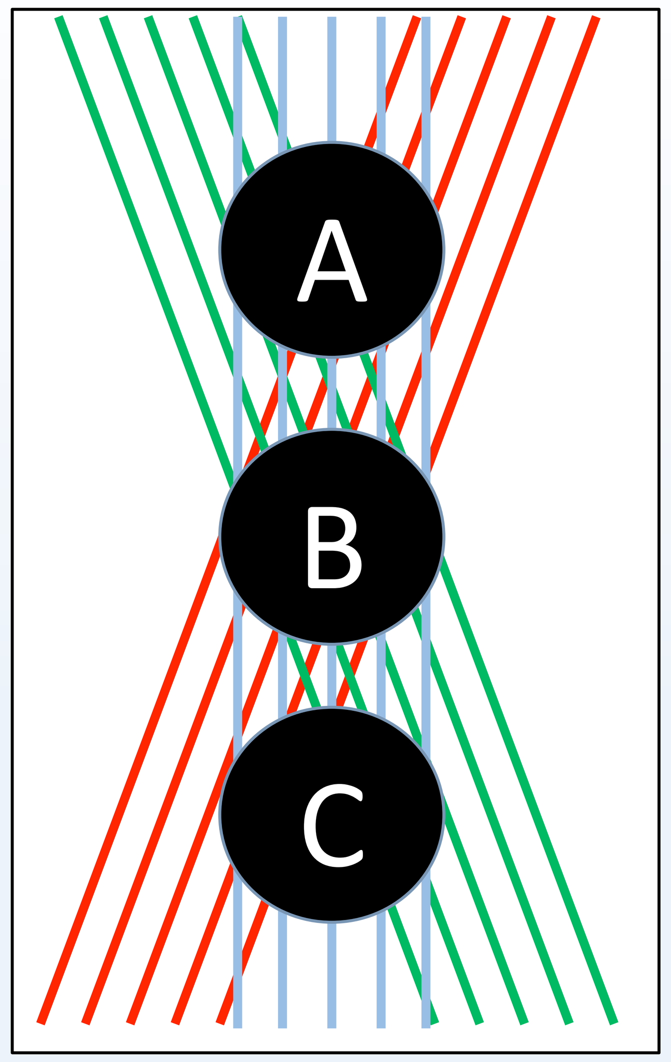
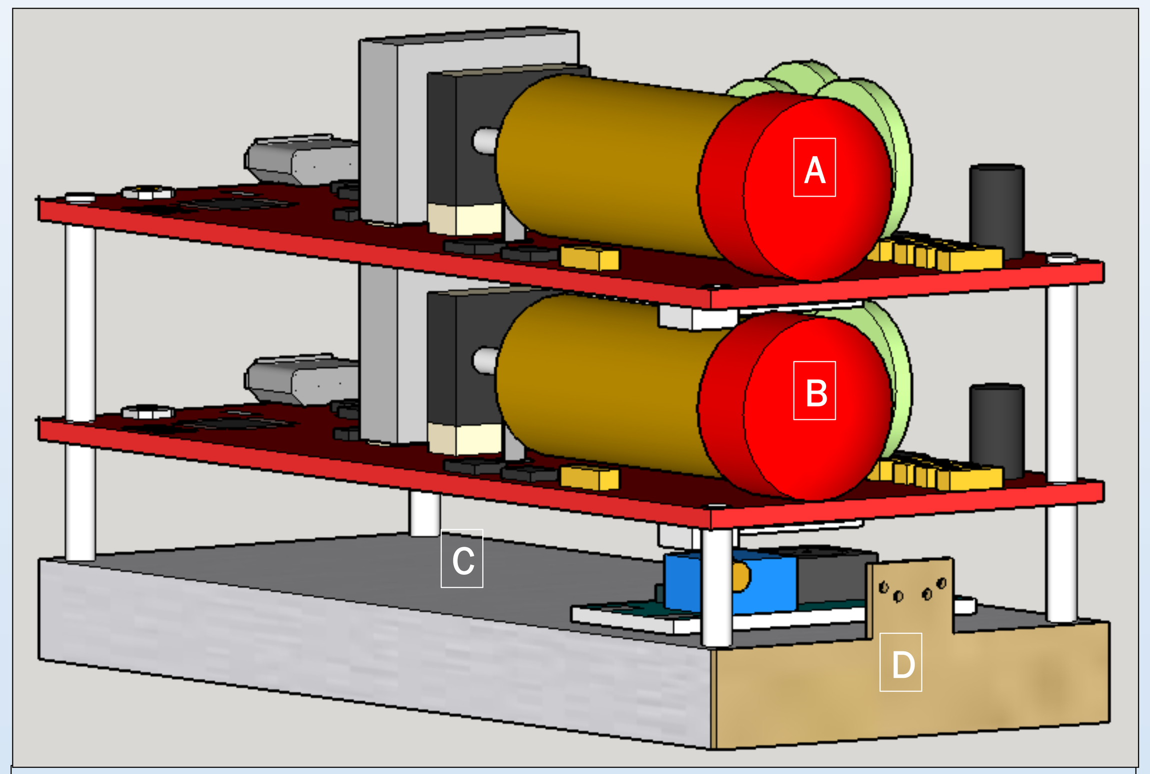


Figure 2. The orientation of detectors, A, B, and C. The lines indicate the detection window. Only when a particle passes through at least two of the detectors does it trigger a muon count.

This experiment will see the replacement of the third Geiger–Müller tube with a silicon photomultiplier (SiPM) coupled to a Cesium iodide (CsI) scintillation crystal (Fig. 2, Object C, and Fig 3). When incident particles enter the CsI crystal, they excite the atoms in the structure and cause them to eject photons. The energy released due to these photons is directly proportional to the energy of the incident particle as well as the amount of material the particle has penetrated. This means that every particle detected has a characteristic energy. This unique design, utilizing both Geiger–Müller tubes and a scintillation detector, should provide greater certainty in distinguishing muons from other forms of ionizing radiation.

In addition to the replacement of the third Geiger–Müller tube, thin sheets of lead will encase each tube. The lead will act as a filtering agent by attenuating the radiation caused by particles other than muons. The muon has much higher energy than other particles and is not as easily absorbed by lead. In this configuration, a coincidence count will consist of a positive detection signal from at least one of the Geiger–Müller tubes as well as from the scintillation detector.



A. Geiger–Müller tube A
B. Geiger–Müller tube B
C. Scintillation crystal wrapped in Mylar to provide a light barrier
D. Silicon photomultiplier (SiPM)

Figure 3. 3D rendering of the Geiger–Müller tubes and SiPM.

CONCEPT OF OPERATION

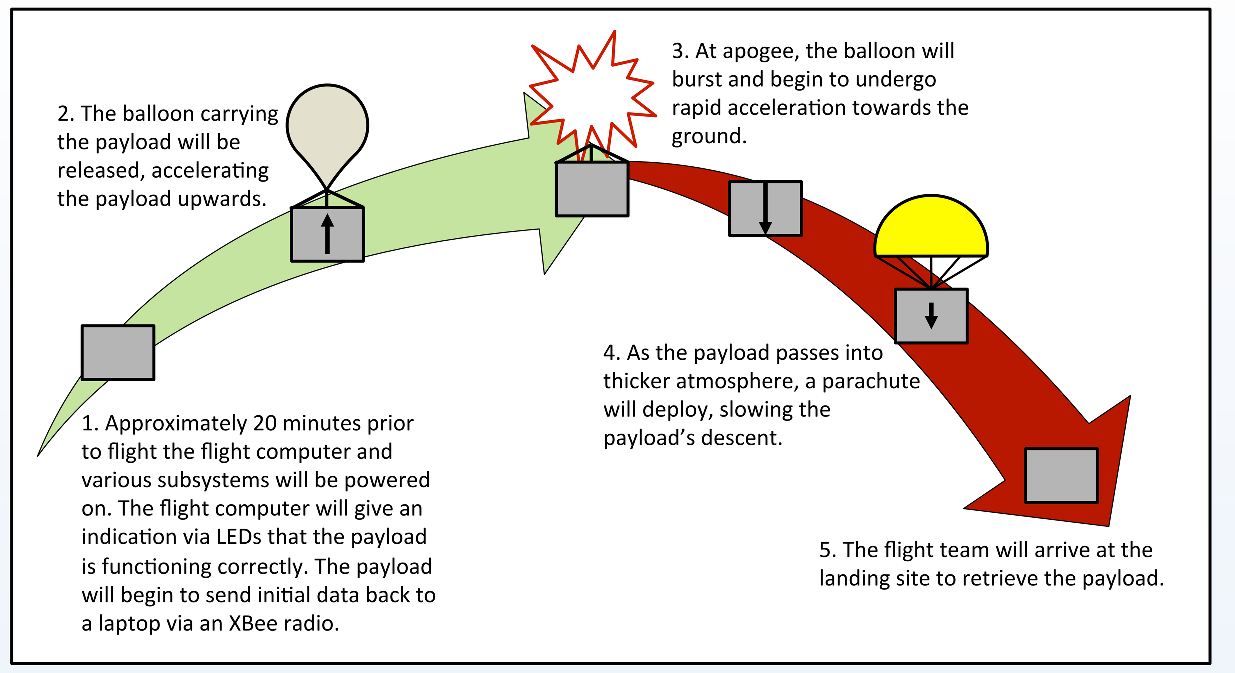


Figure 4. Overview of the expected flight plan.

TESTING

To ensure our payload's readiness, we test the electronic and structural components. The payload will reach an altitude of between 15 and 20 miles and must be able to endure harsh conditions including:

- *Temperatures ranging from -80°C to 25°C.*
- *Accelerations up to 8 G's.*

Electronics Tests

- All sensors and the program code are run for a duration of 4 hours (approximately the length of the launch).
- All data collected during this period are compared with known values to ensure each sensor's accuracy.

Physical Tests

- We drop the payload from a height of approximately 40 feet to test payload survivability during a hard landing.
- The payload is whip tested to determine payload survivability during large accelerations.
- The payload is cold tested to simulate payload functionality in a low-temperature environment, such as found in the upper atmosphere

POST FLIGHT

After recovery of the payload, we will inspect it for damage and retrieve the stored data. We will analyze the data by comparing the new data to the results of past experiments as well as the Palmer model adapted to the parameters of this flight. We will then use this information to improve on our construction techniques and data collection procedures for future flights.

Our intention is to use the results from the flight in April as baseline data for the upcoming flight during the 2017 solar eclipse. By showing that the Palmer model can accurately predict the shape of the count rate vs. altitude curve, we will be able to use it as a tool to analyze any anomalies detected during the eclipse.

Acknowledgments

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