Hobart and William Smith Colleges

The purpose of our experiment is to detect muon flux at various levels in the atmosphere. Our original intention for this project was to utilize a solid-state scintillator muon detector. However, due to the fact that we had trouble processing our signal electronically from the solid state scintillator muon detector we resorted to using our detector which used dual Geiger Mueller tubes in order to detect muon flux.

Fig. 1: L to R Turksonmez, Nutter, Oplinger, St. Peter, Dumitriu, Hooper, Spacher missing Hanzlik

Students: Frank Oplinger, Rousseau Nutter, Robert Hooper, Lauren St. Peter, Kemal Turksonmez, Tyler Hanzlik

Advisors: Ileana Dumitriu, Ph.D., Peter Spacher, Ph.D.

Hobart and William Smith Colleges

July 20, 2016
1.0 Mission Statement

The goal of our experiment is to learn how to detect muons and to detect muon flux at various altitudes in Earth’s atmosphere. Based on literature review muons are created by the interaction of cosmic radiation with the Earth’s atmosphere and increase in intensity closer to the Earth’s surface. It was our expectation that if we designed a system to detect only muons then we would detect a higher flux of muons at the Earth’s surface and a decreasing flux of muons as the detector increased in altitude above the Earth’s surface. Literature also indicates that muon flux should have a cutoff altitude of between 60,000 feet to 100,000 feet above sea level and at sea level Muon rate can be estimated as slightly less than one muon per square centimeter, per minute, per steradian.

Our original intention for this project was to utilize a solid-state scintillator muon detector that utilized two separate plastic scintillator plates, each coupled to a silicon photomultiplier detector that were fed into a coincidence circuit and then into an Arduino used to record events. However, due to the fact that we had trouble processing our signal electronically from the solid-state scintillator muon detector we resorted to using our backup detector, which used dual Geiger Mueller tubes connected to a coincidence circuit in order to register muon flux on an Arduino computer.
2.0 Mission Requirements and Description (1-2 page(s))

Muons, like electrons, possess a negative charge and a spin of $\frac{1}{2}$, but are 207 times more massive. They are generated when cosmic rays from space enter the atmosphere and interact with atomic nuclei. When cosmic rays impact atomic nuclei, pions are generated. As the pions move towards the Earth’s surface, they decay into muon neutrinos and muons, which continue traveling towards the surface. Muon flux has been detected on Earth’s surface since 1936, but little data exists on muon flux in the upper atmosphere, near their sight of generation.\textsuperscript{iv}

Muon Detectors can come in many forms and each form has characteristics making them useful for particular applications. This experiment required that the detector was lightweight (6.62lbs), robust, low power consumption and fit within the confines of half a canister (4.5” diameter x 4.9” high”).

We decided on a plastic scintillator detector coupled to silicon photomultiplier (SiPM) detectors all encased in aluminum and connected to an Arduino via a coincidence circuit. Such a detector could maximize detection area, increase detection efficiency, fit within dimensions given and still be lightweight enough for payload characteristics. The aluminum skin would also act as a filter to filter out stray alpha, beta and gamma radiation – as the experiment progressed a thought of putting in pulse height analysis could be used to filter out other cosmic radiations.
A backup payload was also developed using Geiger Mueller detectors – again this was designed to meet all of the payload requirements given above but it was not a first choice as the detector area is much smaller than that of the plastic scintillator – having approximately 1/50 of the detection volume due to the size of the tubes used to detect radiation.

As much of the planning phase for this project as well as development of basic skills, such as soldering, circuit design, mechanical design and manufacturing techniques were carried out during the fall semester, and funding did not come through until after semester break – the detector had to be simple enough in design to build across the spring semester.

Finally we wanted a payload that could be used to confirm our previous experiments muon data that we collected on a previous RockSat-C mission (2015) and which could provide additional information about the radiation encountered and the environment through which the payload traveled.

3.0 **Payload Design**

Our primary payload was a solid-state scintillation muon detector, however due to some last minute errors in what we suspect was an impedance issue, we were
unable to launch our primary payload and had to default into launching our backup payload.

The backup payload is a Geiger Müller detector. This detector utilizes two Geiger Müller tubes stacked vertically with lead and aluminum shielding in between. The shielding is composed of two pieces of aluminum stacked on top and on bottom of three pieces of lead. The 1/8” aluminum sheet on either side of the lead is used to provide mechanical support for the lead plates and provide a less malleable surface.

![Component assembly of detector](image)

**Fig. 2: Component assembly of detector**

The shielding attenuates approximately 75% of the high-energy gamma rays. Muons are able to pass through the Geiger tube, pass through the shielding (unlike other radiation such as alpha, beta and most gamma rays) and then pass through
the bottom tube. We can assume if both tubes are triggered then the particle has passed through all of the shielding and is likely to be a muon. Muons travel close to the speed of light and are able to pass through both tubes nearly simultaneously. Thus we are able to record them with the use of a coincidence circuit.

The coincidence circuit only sends a signal to the Arduino Uno if each tube produces a signal within a period of time. The signals are received as sin waves and are converted into square waves to be read by the Arduino and stored as a count on the SD card. The count is also stamped with a date and time as well as the time elapsed since the start of the system.

Our primary payload utilized two scintillation plates to create pulses of energy that would be picked up on two photomultipliers supplied by Ketek. The plates and photomultipliers were incased in aluminum, each plate is also separated by aluminum so that each photomultiplier picks up the energy from a muon once. The aluminum is opaque as to keep the inside light tight but also reflective so no counts were missed due to absorption. We used the same coincidence circuit in this detector as with our Geiger Müller detector. Once both photomultipliers pick up an energy signature, they send a signal through the coincidence circuit that turns the signal from a sin wave into a square wave to be read by the Arduino Uno and stored with a time stamp on the SD card.
System Functional Block Diagram:

Mass/Monetary for Backup payload Budget:

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<th>MASS (G)</th>
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<tr>
<td>STANDOFFS</td>
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Full break down of primary payload/travel expenses as originally budgeted:
The team consisted of students from each class year at the Colleges and from a diversity of backgrounds of study. Frank Oplinger, Hobart ’18, is a co-lead for the HWS RockSat-C team and he is a declared physics major with interest in pursuing engineering as a career in the future. Frank took a large bulk of the
project on and handled almost all aspects of the project. Frank particularly spent a
great deal of time working on attempting to produce the signal from the Silicon
Photomultipliers. Rousse Nutter, Hobart ’16, who is now a recent graduate of
Hobart College, graduated as an architecture major and plans to attend graduate school in the upcoming years. With his experience in design and project building,
Roue was assigned with the task of creating the mechanical designs and
optimizing the usage of space in the canister. Robert Hooper, Hobart ’18, is
another physics major on the team and has special interest in electrical engineering. Bobby was the most experienced member of the team with electrical
schematics and creating circuit systems, and therefore made the most major contributions in this area. Bobby created the coincidence circuit for the payload
and worked with the Eagle Cad program, for the first time, in order to make schematics for the coincidence circuit. Tyler Hanzlik, Hobart ’17, is also physics
major with interest and experience in electronics and helped created the electrical schematics. Kemal Turksomez, Hobart ’19, is an undeclared physics major but
has special interest in computer science and plans to attend graduate school for engineering. Kemal took responsibility for the software design and writing the
counting code so that signals from detector output could be processed by Arduino
and stored on the SD cards. The final member is Lauren St. Peter, William Smith ’18. She is a chemistry major and plans on going to medical school after her
undergraduate studies at the Colleges. Lauren’s main focus was the logistics of the project, such as funding, but also assisted each member of the team with their respected areas of specialty.
5.0 Testing Results

We first tested the accuracy of our counting code using an Arduino, a data logger shield, a pulse generator, and an oscilloscope. To test the code, we used a pulse generator to generate sinusoidal waves at a certain frequency and amplitude. We then ran the code for 30 seconds and calculated how many hits the Arduino should have received by multiplying the total time the code ran for by the frequency of the pulse generator. We also used an oscilloscope to check if we were getting the right frequencies from the pulse generator. In each case, the actual values were less than 1% off of the expected values.

Figure 3. These tables show two measured values of wave frequencies tested in the “ideal” scenario (waves generated directly from the function generator being fed into the arduino).

Examining our testing results, we concluded that our code was both accurate and precise.

To test the coincidence circuit we utilized the coincidence circuit on a circuit board, two pulse generators, and an oscilloscope. The setup of the testing
consisted of the two pulse generators individually connected to the two separate inputs of the coincidence circuit. The output of the circuit, the AND gate, was connected to the oscilloscope. To ensure our coincidence circuit was outputting a signal, we had both of pulse generators generate a sinusoidal wave with a certain frequency and amplitude so the waves would always be in coincidence with each other. A properly working circuit would display on the oscilloscope a square wave output that had same frequency of the generated waves with an amplitude of approximately 5 Volts. After the oscilloscope displayed the correct wave, we ran a test where the waves generated by the pulse generators had different frequencies. This test would prove that our circuit didn’t generate every signal it received but was able to discriminate between signals that were in coincidence and signals that were not; also ensuring that our coincidence circuit was fully functional.
Figure 4: The following results show the accuracy of the coincidence circuit running at a single frequency from two signal generators as inputs. Four out of five trials resulted in counts in agreement with the error of our expected values.

Our results showed that our counts, with two varying signals running into the coincidence circuit, were consistently within our accepted error. We were pleasantly surprised by the accuracy of our coincidence circuit, as this ensured that we would not be losing many counts during the actual flight.

We tested the output of our Solid State Scintillator detectors by placing a radioactive source on each unit and observing the output signal through a preamplifier circuit. The output was consistent with expectations. However when we connect the output of the preamplifier with the coincidence circuit we observed no output pulses. We then checked the amplitude, shape and time of the output pulses of the amplifier circuit and found them to be consistent with expectations and consistent with what input to the coincidence circuit should be – we however still could not match the circuits after multiple tries and
It is our conclusion that there is an impedance issue which at the moment we cannot rectify. This led us to utilizing our backup payload.

Our backup payload as mentioned previously consist of two GM detectors coupled to the coincidence circuit which is the fed into an Arduino for recording counts. The GM detectors were assembled and then tested using a radioactive source. Response to the radioactive source was recorded and a plateau was determined for each detector by adjusting the detector voltage. The detectors were then connected to the coincidence circuit which in turn was fed into the Arduino used to collect count data. We let the detector run through multiple trials and recorded a count rate of 8±3 counts per hour at our facility ground level. We recognized this to be less sensitive than our previous year’s data of 533±23 counts per hour. We were not been able to resolve this discrepancy of reduced sensitivity though all parts appeared to be functioning as designed.

6.0 Mission Results

While our launch successfully collected data, we did not collect the volume of muon counts that was expected based on our 2015 launch. Using almost the exact same design and build for the Geiger muon detector as this current year’s team, the HWS 2015 RockSat-C team was able to collect over 140 individual muon hits during rocket flight. Figure 5 & 6 displays their data mapped underneath of the
flight telemetry. In comparison, this year’s team was only able to collect 41 total muon counts throughout the entire duration of the flight/pickup (Figure 7). At this time we are unsure of the exact cause of the extreme decrease in data collection. However, we believe there are a few distinct possibilities that may have caused the lack of data collected.

It is possible that one (or both) of the Geiger Mueller tubes was not as sensitive as in the previous year (despite using the same model). This could have been a result of different gas density in the tube itself or perhaps a difference in the operating voltage of the GM tube. The change in the configuration of the lead divider plates may have also caused a change in sensitivity. This is likely not the source of such a large discrepancy though, as the configuration was different by only a few millimeters. Another possible explanation is the possible saturation of our circuit. It is possible that high frequencies of pulses caused the Arduino to read the pulses as a single pulse rather than an individual collection of pulses.

Given the low count rate, it is however important to know that there where similarities and general trends between the two years data. First the lowest count rate was when the rocket (and payload) was at ground level and in our current year data this was essentially no counts. As the payload increased altitude the count rate increased. At apogee there appears to be a dead spot where no counts were registered – this we associate with the directional response of the payload as it changes direction for descent. After reaching Apogee the count rate increases
then finally the counts decrease again as the payload descends. In the ocean there was minimal counts registered.

This in itself is an interesting phenomenon as we expected muon flux to decrease with altitude, where in both cases it appeared to increase with altitude. There might be two possible explanations for this. The first is that there actually are more muons in the upper atmosphere than closer to Earth though all models would dispute this. The second and more likely explanation is that we are not discriminating out all types of radiation and that other cosmic radiation, which we expect to be more intense with higher altitudes, is having an effect on our experiment.

Given the second scenario it would be helpful for us in the future to ensure our solid state plastic scintillator muon detector is not only functional but can also do pulse height analysis to weed out other forms of cosmic radiation – pulse height analysis cannot be accomplished with GM detectors so the backup payload we used this year would not be applicable to this type of analysis.

We are planning on conducting further research and analysis on our 2016 collected data in order to better understand the differences between the data sets. This includes revisiting the calibration of the GM tubes and ensuring that the voltage adjustment is correct to have maximum counting efficiency. In addition we will also look at the coincidence circuit to determine if any changes can be
made to better discriminate types of radiation detected. Finally we will also look at directional dependence of the detector and how that affects muon detection efficiency.
Figure 6: This histogram displays the HWS 2015 Geiger Mueller muon data collected during flight. As shown, the team amassed a large number of muon hits during flight.
Figure 7: This histogram displays the HWS 2016 Geiger Mueller muon data collected during flight. As shown, the team amassed a large number of muon hits during flight.

7.0 Conclusions

Unfortunately, our small amount of data did not allow us to draw many convincing conclusions about the potential correlation between altitude and muon count. We did not amass anywhere near our expected amount of data. The smaller quantity of data makes it more challenging to discern patterns within the two data sets. As mentioned in the results, we did however see some consistent trends in
both the 2015 and 2016 data sets. There was a noticeable increase in muon count as the rocket ascended. When the rocket reached apogee a pause in the muon hits is evident in the data. The trends of the muon fluxation remain similar in both the experiments despite the low data count during the second flight.

Our original hypothesis was that muon count would decrease with the increase of altitude. Despite going against the trends of our data, we still will not rule out this hypothesis as the increase in detection of other types of radiation may have caused a spike in counts. The completion of our solid-state scintillator detector will allow us to better explore this possibility as it gives the ability to monitor pulse height to better differentiate between radiation types (unlike the Geiger Mueller detector).

There are many different questions we, as a team, have been left with after analyzing our data. We plan to revisit both the analysis of why our Geiger Detector recorded so many fewer counts than 2015 and the cause of the problems with our solid-state scintillator detector when we return to campus in the fall. We also plan to discuss improvements of our project to hopefully be implemented by a group of new HWS Rocksat-C students next year.

8.0 Potential Follow-on Work
There are a number of improvements that could be made to this particular research project some of which have been mentioned previously. First and foremost is to understand the impedance issues with the original plastic scintillator solid state detector payload and to make that detector function properly. This would provide a larger detection volume and higher count rate. Second miniaturization of circuity and condensation into all one circuit platform would be helpful to minimize the effects of stray signals. Third would be to add temperature probes to determine the effect temperature has on the detectors and to make corrections for such. And finally fourth would be to add a pulse height discrimination circuit to weed out other types of cosmic radiation that may be encountered that may be interfering with muon counting.

9.0 Benefits to the Scientific Community (0.5 to 1 page)

The radiation environment within the Earth’s atmosphere is complex because it is subject to spatial and temporal variations. This high altitude environment is composed almost entirely of secondary particles. These secondary particles are the result of air showers or particle cascades initiated when primary cosmic rays interact with the constituent nuclei of the atmosphere. The usual scenario, involves the interaction of an incident proton or neutron with a target oxygen or nitrogen nucleus in the atmosphere. The incident nucleon is commonly a primary GCR proton, but a secondary proton or neutron resulting from an earlier nuclear interaction within the atmosphere may also be the case. A target fragmentation
event can result in a number of different scenarios depending on the kinetic energy of the incident nucleon and the proximity of the interaction. An understanding of the radiation environment at high altitudes can be obtained by considering the sources of cosmic radiation and the different physical processes that affect this radiation. For high altitudes one must first consider propagation of this radiation field through the Earth’s magnetosphere before taking into account its propagation in the atmosphere. Herein lies the need for better data and understanding of what is actually happening between the elements and cosmic radiation in the Earth’s atmosphere. Not only is the rudimentary knowledge important but it can also help us understand geophysical processes related to warming of the Earth as a change in concentration of atmospheric elements will lead to changes in particle interactions and muon creation. Hence muon flux may also be an indicator of global warming processes.

10.0 Lessons Learned

RockSat-C provided our team with the opportunity not only to work on cutting edge scientific research, but learn along the way about electronics, programming, 3-D printing, machining, team management, and organization. More than that RockSat-C gave us an opportunity to work alongside peers with diverse academic interests and knowledgeable faculty advisors, and gain insight about teamwork, fundraising, and innovative thinking.
Teamwork was an important aspect to the success of our mission. Unlike many other RockSat-C teams, our team consists of physics, chemistry, and architecture majors (no engineers). At first, this seemed like a disadvantage, but this diverse team dynamic only aided our teamwork and collaboration. In order to be successful, it was necessary to understand each individual’s strengths and delegate tasks accordingly. For this particular project, it was crucial to have people to build the payload, research previous studies, write the necessary coding for the Arduino platform, and design the electronic circuits. Each team member was responsible for specific tasks. We learned that it is important to delegate tasks appropriately and collaborate between members to maximize efficiency and produce the best results possible. This skill is important because it will be carried into future projects and careers. Working with a team can be difficult but due to different skills, abilities, and ideas that people have, it is important to be able to collaborate and utilize everyone’s abilities toward a common goal.

Fundraising was surely one of the most challenging aspects of the project for our team. We were delayed for many weeks attempting to find sponsors and research grants for our project. This process helped to make us more focused and committed to the project. We were ultimately funded by the NY Space Grant Consortium, our HWS Student Government, and the HWS Presidents Office as well as KETEK Corp., and Alcoa. We learned how to overcome difficulties in securing research money and how to persuade sponsors to fund our research.
We also learned about innovative thinking, why it is important to constantly ask questions, and the need for a backup plan. The week before launch, we were trying to connect our amplifier signal to our coincidence circuit with no luck. For many days, we used every strategy possible to try and connect the signal between components with no success. As launch time approached we realized that this was not a problem we were going to overcome in time and we resorted to utilizing the backup payload we had been alternatively working on. This shows the importance of thinking outside of the box, asking questions and having a backup plan. We knew throughout the semester that this outcome was a legitimate possibility, and thus constructed a contingency plan. As of date we believe that the solution for our initial payload was an impedance problem and we are currently working on a fix. Another lesson from this experience was that sometimes the simplest answer is the right answer.

RockSat-C was truly an in depth engineering and physics project, but it also provided us with many experiences that have benefited our growth as researchers, leaders, and inquisitive minds. These lessons are invaluable and will reappear often in future projects and ultimately in our careers. We are extremely grateful as a team for this experience and for all of the people involved (Becca, our teammates, our advisors and many other HWS faculty).

11.0 **Appendices**

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*RockSat-C 2016*
http://www2.fisica.unlp.edu.ar/~veiga/experiments.html
http://physics.okstate.edu/rpl/muons.htm
http://www2.fisica.unlp.edu.ar/~veiga/experiments.html