SOCIETY OF PHYSICS STUDENTS
An organization of the American Institute of Physics

SPS Chapter Research Award Proposal

Project Proposal Title	Cosmic Ray Induced Bit-Flipping Experiment (CRIBFLEX)
Name of School	Drexel University
SPS Chapter Number	1619
Total Amount Requested	$1,861.00

Abstract

CRIBFLEX is a novel approach to mid-altitude observational particle physics intended to correlate the phenomena of semiconductor bit-flipping with cosmic ray activity. Here a weather balloon carries a Geiger counter and RAM memory to various altitudes; the data collected will contribute to the development of memory device protection.

Proposal Statement

Overview of Proposed Project

The Cosmic Ray Induced Bit-Flipping Experiment is designed to determine the correlation between the particle flux of cosmic rays and soft errors induced in electronic memory storage by them at varying altitudes. This is an important problem because cosmic rays will deposit energy in electronic components as they pass through, generating charge which can alter the state of a memory bit and create soft errors. While there have been studies to examine soft errors in electronics at terrestrial altitudes, there is no existing public data detailing the correlation between particle flux and soft error rates (SER) in electronics at varying altitudes. This has clear implications for the operational limitations of electronics in airplanes and other mid-altitude vessels.

This project entails making use of a weather balloon to carry equipment to mid-altitudes for making measurements of charged particle flux and SER in an electronic component. Specifically, a Geiger counter will be used for measuring the particle flux, and an electronic memory storage device will be set up and monitored to count bit-flips. A Raspberry Pi will be used as the basis of the data acquisition system, handling information about the particle flux and SER as a function of time during the flight. A cell phone will also be carried in weather balloon in order to use a GPS system for tracking the unit and recording its trajectory over time.

Our first research objective is to establish whether our measured data reproduces previously published data on cosmic ray flux as a function of altitude, and identify differences between the them. Following this, our primary objective is to look for a correlation between the particle flux and the SER. We expect to find a strong correlation between the two, which can provide a useful guideline for electronics manufacturing companies to establish operational limitations for their products. We hope to contribute to the public understanding of bit-flipping and soft errors, and to enable manufacturers to create products that are robust enough to handle soft errors at whatever altitude they are created to operate at. Finally, we would like to use this as an example of how simple it is to perform mid-altitude experiments with a weather balloon. Our Chapter is heavily involved in both public outreach and the larger physics community, and we intend to find opportunities to share this work.

As an individual SPS Chapter, it is important to us to expose our members, especially the underclassmen, to what the research process looks like. Through this project students have the opportunity to take part in the entire scientific process, from identifying a focused research question and designing methods to explore that question, to analyzing data and presenting the results. We are quite excited to have had a very committed group of younger students working on this proposal, and are even more excited for the opportunity to guide them through the rest of the experiment. While the research will be engaging, the main objective of this project is to give students the opportunity to gain this research experience. Additionally, having students work toward a common goal strengthens the bonds between members of our Chapter, which is an invaluable network that they will have through their undergraduate careers and beyond.

This project also supports a number of the national organization's objectives. The first constitutional objective - to encourage and assist students interested in physics - is of the highest priority. Within our Chapter this encouragement extends beyond just physics students; we have a number of members in related fields, such as computer science and chemical engineering. Having these students engaged in research under the same banner is arguably the greatest achievement of our small department. Additionally, participating in collaborative research naturally stimulates interest for further study and work in physics. We also intend to give our underclassmen the opportunity to present this work at research conferences, allowing them to participate in professional events and develop relationships within the broader physics community. Lastly, the success of this project will provide us with an avenue to share physics with others beyond our group. By relaying the accessibility of this project, we hope to inspire high school students to pursue their own research projects.

Background for Proposed Project

As electronics become more advanced, their decreased size and power lead to a greater susceptibility to effects from cosmic ray interaction [1]. When any ionizing radiation passes through electronic components it deposits energy and creates a charge separation, as electrons are knocked from their stable locations within the components. If the charge disturbance is large enough, it will result in soft errors within the electronics. These errors can range from flipping the data state of an individual bit to full product failure, depending on where the disturbance occurs. soft error rates (SERs) from cosmic rays can only be reduced by modifying the device's sensitivity, and in this pursuit it is important to characterize SERs to put operational limitations on the electronics. The scientific literature in this area focuses on terrestrial SERs [2,3], but measurements of these rates at varying altitudes is important for the development of electronics for airplanes and other mid-altitude technologies. The present study aims to make such measurements of cosmic ray soft error rates at varying altitudes up to about 30 km.

The creation of soft errors from cosmic rays depends on a myriad of factors. The first significant factor is the Linear Energy Transfer (LET), which describes the energy that an ion (cosmic ray) deposits as it passes through another material (semiconductor). The LET is a function of the ion's energy, and is generally different for every combination of ion and target material. Most energy deposited is the result of electronic stopping, which is the interaction between the ion and atomic electrons within the target. The amount of energy deposited then directly relates to the charge disturbance created. For example, silicon, a typical component of semiconductors, opens an electron-hole pair for every 3.6 eV of deposited energy from an incident ion. After this charge separation is created, it is subsequently collected as the system seeks equilibrium, and this process is what would result in the creation of a soft error. A minimum, critical charge is required to induce a soft error, and this amount is a function of physical parameters of the electronic component. We will be measuring and comparing cosmic ray activity, which may be of very high and thus sufficient energies, and soft error rates with respect to the specific electronics chosen for this experiment, which can then be extrapolated to a variety of electronics in conjunction with results from ground-based experiments.

Expected Results

CRIBFLEX will be capable of measuring radiation counts per unit time, soft error counts in the target memory and the altitude of the device as a function of time. The first step in our analysis will be to check that our data reproduces the well-established activity curve of radiation flux as a function of altitude [4]. We will then identify and characterize any discrepancies between our measured data and data found in the literature to use as a foundation for further analysis. This is a necessary first step, in order to accurately constrain any correlation determined between the particle flux and soft error rate (SER).

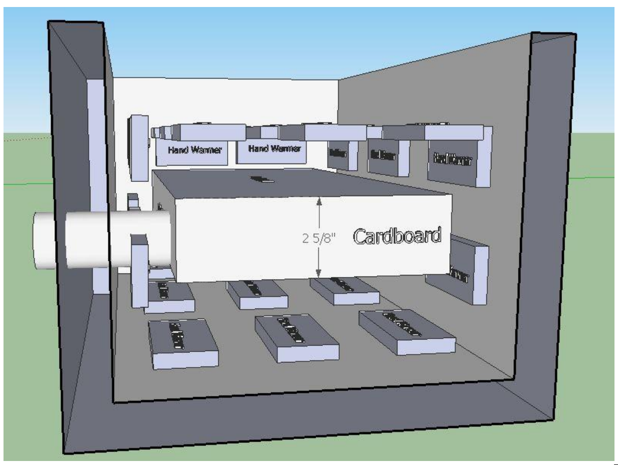
The primary analysis is determine a correlation between the cosmic particle flux and SER. Between the two altitude-dependent variables, we expect to the correlation to be rather strong. There is no significant public database of existing data to suggest what the exact relationship will look like, so we will have to choose our regression fits after viewing the data. However, it is feasible to expect a relationship of an order greater than linear, since at higher altitudes the proportion of high-energy to low-energy particle flux should increase, accordingly increasing the SER faster. Additionally, there are a number of other factors than can be explored in correlating the cosmic ray activity and SER, ranging from local magnetic field variation to the sun's activity, and can be used to more accurately describe the found correlation between particle flux and soft errors.

The final consideration to make in the correlation analysis is the characteristics of the specific electronic storage device used. Based on information about the Linear Energy Transfer rates and geometry of the device, it may be possible to extrapolate the correlation to describe other common electronic components based on published SER data for terrestrial devices.

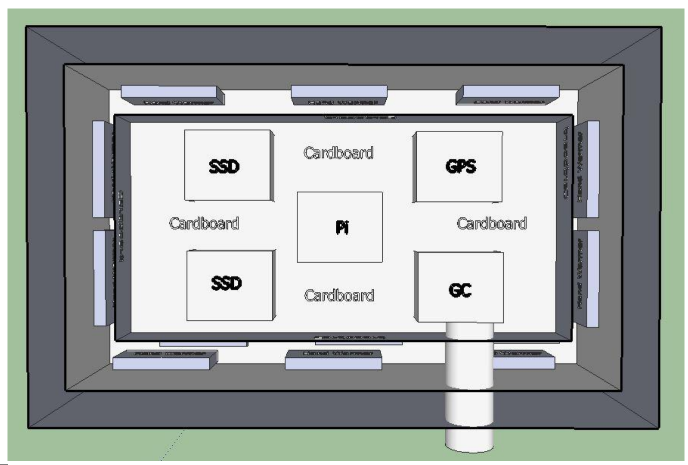
Description of Proposed Research - Methods, Design, and Procedures

The project entails a collection of devices to measure electronic bit-flipping and cosmic ray flux. Our team will launch a weather balloon of a large-diameter (approximately thirty feet) capable of climbing approximately thirty kilometers in the sky. A container housing the data collection equipment will be tethered to the balloon using temperature-resistant Caristrap.

The crux of the setup is the data collection box, designed to withstand a low-temperature environment. The operating temperature of the payload will be maintained using a series of long-lasting hand-warmers, the simplicity and effectiveness of which is attractive for our purposes [5]. The collection box consists of a Styrofoam-lined cooler large enough to house a Raspberry-Pi, Geiger counter, cell-phone and additional power, and target memory and data drives. A port will be cut through the wall of the box and the Müller tube extended outside, optimizing the collection region. The figures below illustrate the planned design for this unit.



Side view without cover*



Internal view of the components*

*Empty space within the box will be filled with sponges; smaller boxes represent hand warmers; the larger, central box houses all on-board electronics; SSD - solid state drive; GC - Geiger counter; Pi - Raspberry Pi

After launch and ascent, CRIBFLEX will enter the official data acquisition stage, where the bits of the target-memory are monitored and the Geiger-counter measures cosmic ray activity. Cosmic ray flux will vary during the flight, and the probability of a soft error in target memory occurring will vary accordingly. The number and time of these errors, and recent counts from the counter, will be recorded to the data drive. Current altitude and location will be monitored from ground via a cellular signal and compatible AccuTracking software, and will be written to a separate drive. If cellular signal is ever lost, the on-board cell phone will cache GPS locations and transmit this data to ground when service is restored.

All bits of target memory will be uniformly set to 1 and monitored for flips using a program written in C++ and compiled on the Pi. A continuous scan will be performed to detect changes in the bit values, storing the data containing a flipped bit's address and time of detection. A flipped bit will be reset to a value of 1 upon detection. The balloon is designed to burst at an altitude of about thirty kilometers. Upon doing so, an on-board parachute will deploy and initiate the landing procedure. Landing protection components - a strategic array of sponges verified sufficient to endure landing impact - will ensure the integrity of the experiment during landing. Data analysis will include correlation between cosmic-ray activity, soft error rates and altitude, and soft errors and altitude. The CERN-born ROOT libraries will be invoked to write C++ and python scripts for this analysis.

Plan for Carrying Out Proposed Project

Active members of this chapter who contributed to this proposal and will participate in this work include:

- Maureen Burnside, Sarah Coccia, Eesha Das Gupta, Keziah Sheldon and Zara Zahimi

Students with experience relevant to this work include:

- Ed Callaghan (Observational particle physics, experience with cosmogenic particle detectors), Samuel Ciocys (Experimental solid-state physicist), Matthew Parsons (Computational physicist, experience with ion/matter interactions), Andrew Pellegrino (Electronics and embedded systems developer), Ge Pu (Experience in engineering and product design) and Alex Weber (Computational physicist, experience with data analysis)

Research space:

- Physics undergraduate lounge for device assembly and testing; Physics student computer lab for data analysis; Road trip west of Harrisburg for launch

University faculty who have offered assistance in this work include:

- Dr. Brian L Stuart, Department of Computer Science: Guidance with electronics and algorithms for monitoring memory

Project Timeline

March: Award notification; Purchasing of supplies
April: Setup/testing of equipment on the ground; Writing up initial results
May: Field trip to launch/retrieve balloon; Initial data analysis; Completion and submission of Interim Report
June/July/August: Possibility of additional flights; Further analysis
September/October: Completion of analysis; Submission of final report before November

Budget Justification

Geiger counters are the most economic option to electronically monitor and record particle activity, in contrast to traditional scintillation detectors which require photomultiplier technology, and bubble chambers, which utilize sophisticated pressure-control systems.

Weather balloons are the simplest available method to reach our laboratory - the sky. Landing parachutes are necessary to ensure the integrity of this experiment and recorded data. A standard balloon launch kit ensures the intended construction and launch of the unit.

Raspberry Pi computers, in addition to their low cost and advantageous size, allow for installation of additional RAM memory, execution of C++ code, and additional device connection through USB. Their compact size and ease-of-interface make them the ideal candidate for the central DAQ unit.

The Motorola i290 cellular phone is a small, long-battery device which, in conjunction with commercial AccuTracking service, may operate as both a GPS and altimeter. The GPS service allows for flight data, including position, time, altitude, and speed relative to ground, to be exported in CSV format. If cellular signal is lost, the phone automatically caches the data, to be transmitted when service is restored. Real-time alerts may also be received via e-mail or text message - further eliminating the possibility of lost data.

To keep the central unit from disassembling during the intense phases of rising and falling, commercially available Caristrap binding is the best option. It is used ubiquitously in professional construction and science environments that require strong, reliable tethering. Cheaper options such as common ropes may fail under tearing-stress, or freeze and break when exposed to the frigid environment of the stratosphere, compromising the experiment.

The strong mid-altitude winds in the Philadelphia region require the experiment to be launched from no farther east than central Pennsylvania to ensure that the balloon does not land in the Atlantic Ocean. The expected travel cost is for two economic cars to travel west of Harrisburg, and return to Philadelphia.

Because bit-flipping is, like many phenomena under current investigation, probabilistic in its nature, it is advantageous to experiment with as large a sample size as is reasonable. In this case, the most cost-effective standard memory unit is the single terabyte, although a smaller target memory, of a design which is more prone to flipping but more expensive, may be used. Very little memory is required for actual data storage. A back-of-the-envelope calculation shows that at the flip-rate expected for this experiment, binary messages of length approximately one byte will consume far less than sixty-four gigabytes of storage. The default formatting of information from the Geiger-counter, ASCII, is less efficient, but this should still remain under a sixty-four gigabyte limit. This information can be preprocessed to reduce its capacity if necessary to meet our limits.

Bibliography

[1] Robert C. Baumann. “Radiation-induced soft errors in advanced semiconductor technologies”. *IEEE T. Device Mat. Re.* **5**(3). (2005).
[2] G. Hubert, R. Velazco, *et. al*. “Continuous high-altitude measurements of cosmic ray...”. *IEEE T. Nucl. Sci.* **60**(4). (2013).
[3] G. Hubert, D. Regis, *et. al. Radiat.* “Multi-physics modelling contributions to investigate atmospheric cosmic rays...”. *Prot. Dosim*. Feb. (2014).
[4] Y.I. Ztozhkov, N.S. Svirzhevsky and V.S. Makhmutov. “Cosmic ray measurements in the atmosphere”. *CERN*. (2001).
[5] See Google Search Results for “MIT weather balloon” and “weather balloon hand warmers”