



# SOCIETY OF PHYSICS STUDENTS

An organization of the American Institute of Physics

## SPS Chapter Research Award Proposal

<b>Project Proposal Title</b>	Polarimetric measurements of the X-ray and gamma-ray background noise in the stratosphere
<b>Name of School</b>	American River College
<b>SPS Chapter Number</b>	0169
<b>Total Amount Requested</b>	\$2000.00

### Abstract

Our goal is to obtain, for the first time, fine measurements of all background components that deteriorate X-ray and  $\gamma$ -ray polarimeter responses in space. American River College students plan to develop a CdTe detector payload to fly in a stratospheric balloon, characterizing background radiation in the 20-1000 keV energy range.

### Proposal Statement

#### **Overview of Proposed Project**

Among the frontiers of astronomy are the polarization measurements of X- and  $\gamma$ -rays, emitted from phenomena such as  $\gamma$ -ray bursts, pulsars, and active galactic nuclei. Polarimetric sensitivity has a strong dependence on background noise and the fluxes of X- and  $\gamma$ -rays detected throughout Earth's atmosphere essentially result from galactic cosmic rays (GCR), solar flares, and even phenomena such as lightning and terrestrial  $\gamma$ -ray flashes.

As explained better further below in the scientific background section, thus far data are available exclusively for single events' background. By measuring the double events' background (see figure 1), as well as that of multiple events (photons undergoing more than two interactions in different pixels) and incorporating these data with data for known single events, we would then be able to estimate all possible background components. Therefore, obtaining a far more precise background flux will allow for optimizations in future space instruments' design with respect to the minimization of the expected space background.

Figure 1, taken from [10], shows a specific simulation example of the theoretical distribution of double events in a CdTe pixel matrix. The generated model demonstrates a Compton scattering event in the central pixel, followed by a photoelectric absorption of the scattered photon in a peripheric pixel. In Figure 1a, the distribution exhibits an oblong shape produced from the simulation of a 100% linearly polarized beam at 200 keV, normal to the detector surface with a polarization angle of  $30^\circ$ . Figure 1b represents the same simulation,

however with an unpolarized incident beam shown without a preferred scattering direction visible on the simulation map.

This relatively modest experiment **has never been done before** in the stratosphere and is crucial for developing reliable calibration data for future instrumentation. Further, this project provides international collaboration between American River College (ARC) undergraduates and research partners in Portugal and Italy.

The grant offered by the Society of Physics Students will greatly benefit our efforts in building and assembling a high-energy radiation payload qualified to fly in near space conditions. Students will need to develop software to communicate with the detector and manage data storage and analysis, while at the same time doing housekeeping/telemetry of voltages, currents and external stratospheric conditions, like temperature and pressure. We already acquired the semiconductor detector, but still need to purchase and develop the Printed Circuit Board (PCB) incorporating an Analog to Digital Converter (ADC), a Field Programmable Gate Array (FPGA), temperature sensors and SD data cards. We also need to buy software licenses to program the FPGA in low-level languages – in principle we will use LabView instead of Verilog.

A stage two goal will be earning a payload slot in the NASA financed and Louisiana State University operated High Altitude Student Platform (HASP) balloon. We already have experience in the launch and retrieval of our own stratospheric balloons from a previous smaller experiment in the Mojave Desert.

This activity meets the SPS program objectives in getting undergraduate students actively involved in research projects. We hope to get more students interested in such projects and have our SPS chapter grow accordingly. In the future our college is even planning to offer lab. courses about near space/stratospheric projects, all going well with these initial projects.

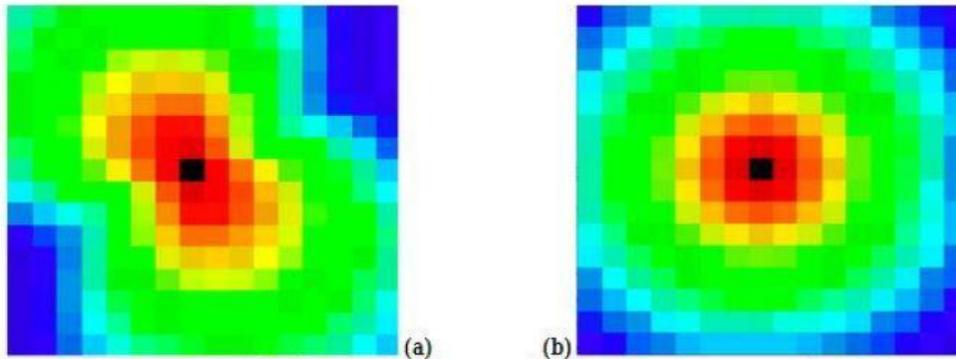


Fig. 1 (a) – Simulations for an 100% linearly polarized beam with an angle of polarization of 30°.

Fig. 1 (b) – Simulations for an unpolarized photon beam.

## Background for Proposed Project

Since celestial-source polarimetric measurements are not likely achievable during a balloon flight due to very low  $\gamma$ -ray flux at balloon altitude combined with detector sensitivity limitations within a balloon payload, measuring the double events' background would be notably useful in determining the expected sensitivity of future instrument's space configuration.

As mentioned above, polarimetric sensitivity has a strong dependence on background noise, therefore measuring the double events produced by background radiation should provide critical information for further polarimeter development. Thus far, data are available exclusively for single events' background.

Double events are generated by a celestial background of randomly polarized photons and the polarimetric performance of a focal plane detector is determined by the fundamental concepts associated with polarized Compton interactions. The Compton scattering of polarized photons generates non-uniformity in the

azimuthal angular distribution. After undergoing Compton scattering, the polarized photon's new direction depends on the orientation of its polarization before the interaction. If the polarized photon undergoes a new interaction inside the detector, the statistical distribution of the relative positions of the two interactions (double event) allows for inference of the degree and polarization direction of the incident radiation. The Klein-Nishina cross-section for linearly polarized photons gives us an azimuthal dependency for the scattered photons, as figure 2, taken from [11], below helps to clarify further.

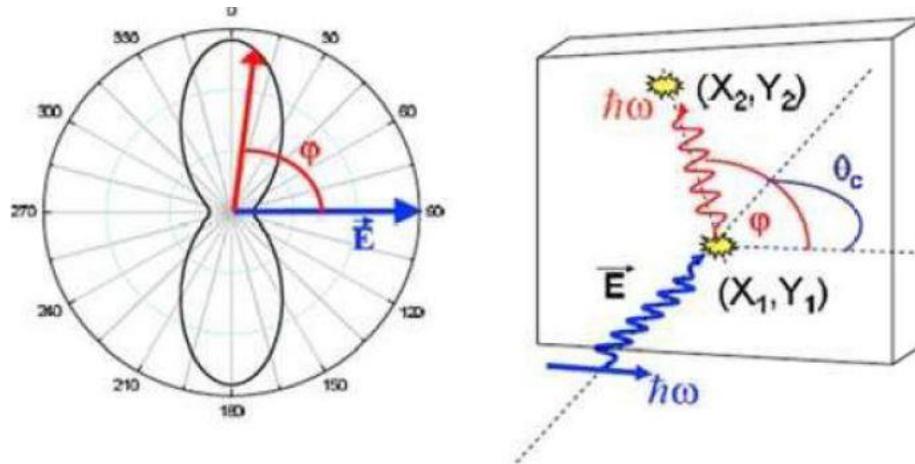


Fig. 2 - On the left, shows the scattering probability diagram from the Klein-Nishina equation as a function of the azimuthal angle,  $\varphi$ . The electrical field vector  $E$  indicates the direction of the photons' polarization plane. The right panel shows a generic Compton scattering event, with a scattering angle (labeled  $\theta_c$ ) of  $90^\circ$ . The incoming photon is represented in blue and the scattered photon is represented in red.

## Expected Results

Our main goal is to obtain, for the first time, a fine measurement of all background components capable of deteriorating an X-ray and  $\gamma$ -ray polarimeter response in space.

We propose to explore the implementation of coincidence logic for the characterization of double and multiple events. Double events (two hits within different pixels, the first interaction being a Compton) are essential in determining Compton photons' new direction and therefore the polarization direction.

We will develop and test a stratospheric instrumentation payload, with semiconductor detectors, to make these measurements.

## Description of Proposed Research - Methods, Design, and Procedures

The research experiment will revolve around the 16-channel eV-MultiPIX semiconductor detector (recently purchased to Kromek), and the calibration tests to be done using radioisotopes and a nuclear spectrometer multi-channel analyzer, that we just purchased.

The PCB needs to be capable of treating the analog-to-digital signals of the ADC and record its data in a parallel sequential way, controlled by the FPGA. The ADC provides for internal coincidence clocks and the data stored in the SD card will be downlinked periodically during the balloon flight to access the good functionality of the detector. Regular telemetry will help us making sure that the temperature parameters are within the electronics' functional limits.

Students will write LabView code to have the PCB fully functional, specially the ADC-FPGA-SD card interactions.

Before flying in a high-altitude balloon, we plan to do qualifying mandatory 2 days long Thermal and Vacuum tests (TVAC) at NASA's Columbia Scientific Balloon Facility (CSBF), Palestine, Texas.

After the payload returns to ground level, the collected data will be retrieved and processed. The data spectropolarimetry will be compared with computer simulations based on GEANT4 for such cosmic rays' cascade stratospheric environments. Following this analysis, the information gathered will be disseminated through a formal report and college seminars. Most importantly – all going well, we also expect to publish a scientific paper with our results.

## Plan for Carrying Out Proposed Project

- ❖ **Personnel** - Although only a handful of our team members are Physics majors, our team consist of a core of 10 students who share a great passion for the Physics field. Our team is divided into specific groups based on area of expertise, interest, and needs of the group. A couple students are individual members of the SPS.
- ❖ **Expertise** - Our current club president has significant knowledge and background in programming. Professor Paulo Afonso has background in astronomical properties of high energy particles in deep space. Prof. Jordan Meyer is our senior partner from our college Electronics Dpt. We also have senior experts in instrumentation and computer simulations assisting us in Portuguese and Italian academic institutions/experimental labs.
- ❖ **Research Space** - The HASP balloon will launch from the Columbia Scientific Balloon Facility (CSBF) base in Fort Sumner, New Mexico. Integration and tests will be done at CSBF - Palestine, Texas. We also have the Physics, Chemistry and Electronics dpts. facilities and the Design Hub available at our college (ARC).
- ❖ **Contributions of Faculty advisors or the department** - Professors Paulo Afonso (currently serving as our faculty advisor) and Prof. Jordan Meyer (Electronics Dpt. – senior faculty project member) have their academic and industrial areas of expertise in astronomy, particle, and nuclear physics, programming and electronics.

## Project Timeline

- ❖ **December 2, 2019:** Submit a detailed proposal and budget to SPS
- ❖ **January 2020:** Calibrate detector response with radioisotopes and MCA analyzer.
- ❖ **February 2020:** Develop LabView software for FPGA and ADC
- ❖ **March 2020:** Finish software development
- ❖ **April 2020:** Test detector's hardware and software together with radioisotopes.
- ❖ **May 2020:** Design payload housing and 3D drawings for balloon gondola
- ❖ **May 31, 2020:** Submit an interim report to SPS
- ❖ **June 2020:** end of Spring semester, Summer vacations
- ❖ **July 2020:** develop GEANT simulations
- ❖ **August 2020:** Start writing an application for the NASA-HASP balloon
- ❖ **September 2020:** Start writing an application for the European Space Agency (ESA) BEXUS balloon
- ❖ **October-November 2020:** submit proposals to NASA and ESA
- ❖ **December 31, 2020:** Submit the final report to SPS
- ❖ **January 2021:** Know selection results for stratospheric flights

## Budget Justification

The cost for the PCB sbRIO-9651 System on Module, Processor, FPGA (Zynq-7020), Dev Kit is \$3,335.92

The cost for the programming LabView license: LabVIEW Full Development System, All Languages, Download (Includes Standard Service for Software) is \$787.25.

We received additional \$7000 in American River College funds so far – with much of it already spent in buying the detector and multi-channel analyzer. So at the moment we do not have enough funds left to buy the missing equipment mentioned here – thus this SPS grant would be of tremendous help.

## Bibliography

### References

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