SPS Chapter Research Award Proposal

Project Proposal Title	KUbeSat Primary Cosmic Ray Detector (KUbeSat PCRD)
Name of School	University of Kansas
SPS Chapter Number	3463
Total Amount Requested	[$1994.00]

Abstract

The University of Kansas plans to launch KUbeSat, which will be a part of a NASA CubeSat mission, in a 400 km elevation, circumpolar orbit. KUbeSat will house the Primary Cosmic Ray Detector (PCRD, or "Picard") which will detect primary cosmic rays using a novel technique based on activation of a Boron plate.

Proposal Statement

Overview of Proposed Project

This project is designed to address the following questions:

*) What is the flux of primary cosmic rays in Earth orbit?

*) Does this flux change significantly over time?

*) Can we link measurements of the primary cosmic ray flux above the atmosphere to measurements of secondaries at ground-level to better inform models of cosmic-ray development?

*) Is the method used to detect cosmic rays detailed in this project efficient, scalable and cost-effective?

The University of Kansas will be the beneficiary of a 3U (10 cm x 10 cm x 30 cm) CubeSat donation in January, 2017, equivalent to a multi-hundred-thousand science donation. Provided we can propose a novel and imaginative science project, with an equally impacting educational mission, our chances of NASA flying the CubeSat payload in the next year or so should be very high. Our proposed cosmic-ray detector, originally developed by KU students, should well-match the CubeSat goals. Even if our proposed hardware is not launched, we have sufficient in-house expertise to demonstrate feasibility, riding piggyback on local balloon flights.

Most of our information about cosmic rays is derived, indirectly and using models, from measurements of secondaries, produced during the development of extensive air showers (EAS), at ground-level. The characteristics of the 'primary' that initiated the air shower are best directly measured above the Earth's atmosphere. Herein, we propose a novel approach to cosmic-ray detection, which is well-matched to the goals of the NASA CubeSat program. The state of Kansas (with the 150-year old state motto "Ad Astra per Aspera", which arguably portended the CubeSat program) is one of few remaining states to have not launched a CubeSat. This project has coalesced our local SPS chapter around an original research project with national visibility.

Our chapter of SPS has not yet engaged in a national program or a research project; this proposal represents an original, SPS-initiated effort. In addition to this being a long-term effort (three years, at least, depending on the lifetime of the satellite), we also anticipate that this will provide the basis for many members to present science results at domestic, and possibly international conferences.

Background for Proposed Project

Most of our information about the extra-terrestrial world is derived from either optical observations (via telescopes) or, more recently, detection of cosmic ray particles incident on the Earth. At low energies, the cosmic ray flux incident on Earth is dominated by Solar wind particles. At energies of 10^{15} eV or so, the cosmic ray flux is dominated by protons or heavy nuclei accelerated in supernova explosions, over the entire history of the Universe. The sources of cosmic rays at energies 1000 times higher are not entirely known, although the number of possible cosmic accelerators are limited to objects such as neutron stars, blazar galaxies, and gamma-ray bursts, e.g. Perhaps the biggest goal of current cosmic ray research is to determine whether there are `hot spots' in the sky, such as those recently reported by the Telescope Array experiment in Utah[1], which has observed a source of ultra-high energy cosmic rays somewhere in the vicinity of the constellation Ursa Major. Our goal is to construct a cosmic ray detector that will target the cross-over energy regime between the solar wind and supernovae.

Existing methods of cosmic ray detection by large physics collaborations primarily focus on detecting daughter particles produced in extensive air showers and do so within, or beneath the atmosphere of Earth. PCRD is designed to detect primary particles, such as hydrogen, anti-hydrogen and alpha particles. It will also be flown within a CubeSat, which means that the overall dimensions of the detector have to be low mass and small ($V<30$ cm^3, $M<1$ kg). This detector will be produced by a group of SPS students and will have a much smaller budget than typical of much larger collaborations. Such a detector also serves multiple future applications such as the detection of different forms of ionizing radiation, especially in space, which is important for the future of humanity and electronics in space.

Expected Results

The Picard KUbeSat will count ionization events produced from the bombardment of the Boron plate by primary cosmic rays. Given the long-duration anticipated for this mission, the change in primary ray flux over time can be observed. In particular, there are some outside events which could contribute to changes in the flux: changes in solar wind flux (ejection events, for which the fluence depends on the orientation of the sun relative to the Earth, etc.), changes in the Van Allen belt, supernovae, changes with the Earth's magnetic field or ionosphere, and changes in flux based on changes in the position of the detector above earth and its altitude. All these environmental parameters will be measured by monitoring hardware provided by NASA, allowing us to check for correlations. Our calculations (below) indicate an expected initial event rate of 35 Hz.

Description of Proposed Research - Methods, Design, and Procedures

The detector is based on activation of ^{10}B by bombardment of protons with energy exceeding 0.675 MeV[3]. The targeted operation of our device in the context of CubeSat leads to constraints in overall size (<30 cm^3) and mass(< 1 kg). We have calculated the mass to be <0.65kg (0.3 kg for the housing and the boron, and the remaining 0.35 kg allocated to electronics). The volume of the PCRD is approximately conical with base 6 cm, height 6 cm, corresponding to about 7% of the total CubeSat volume, leaving considerable room for additional science payloads.

Picard will measure ionization events by two separate methods, one by an ionization event counter, such as a Geiger Counter, and one by a particle detector, such as a scintillator. All of this will be constructed within the CubeSat frame and subtend a solid angle of 1 steradian. The events detected by these two methods will be sent via a transceiver, which is to be supplied by the CubeSat provider, to a receiver on the ground. While KUbeSat is in space the accumulated cosmic ray data will be GPS time-stamped and can therefore be checked and cross-correlated against data from ground detectors in order to provide further insight into how some processes related to cosmic rays, such as Solar ejection events and Van Allen Belt changes, appear in space. The projected flight time is two years, with a 400 km altitude, circumpolar orbit, which will allow correlations with measurements by cosmic ray experiments at the South Pole (IceTop, in particular).

The detector will be tested as a Weather Balloon payload and the radiation shielding of the KUbeSat and its electrical components be tested in the lab prior to launch. The University of Kansas has allocated a clean room for this pre-flight testing.

Using data for hydrogen atoms from the normalized differential flux spectrum, the number density can be estimated, using d□~1 sr, by integration of the differential flux value for the activation energies, which are between 0.675 MeV and ~10 MeV. [1]. The Energy bandwidth was found from the reaction energies for various Boron-10, Boron-11 reactions from two sources [2][3]. The most probable reaction is that with the greatest cross-section, namely B10 + p $\rightarrow$ Be7 + α with a peak cross section of 6.3 millibarns at 4610 MeV. The cosmic ray number density used in flux calculations was $8x10^{-5}$ H/m^3, which was close to Tomaschitz's total value of 10^{-4} (all particles)/m^{3}.The number of activations can then be found by multiplying the number density by the area of the Boron plate, ~$12cm^2$, and the average velocity of primary CR, implying ~35 activations per second. Assuming a canonical efficiency of 50% for detection of the activated Boron still yields a very high detection rate. Figure 1 schematically illustrates the proposed detection strategy. The detector itself will be contained within a conical housing structure, shown in Figure 2.

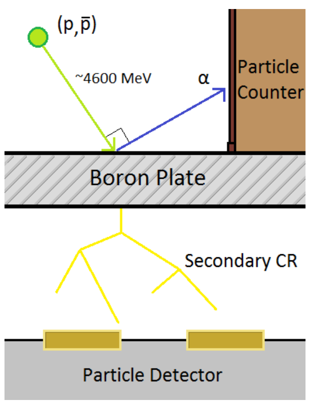

Figure 1: The cosmic rays will activate the boron plate. The alpha particles will be counted by the particle counter while the secondary cosmic rays pass through the particle detector.

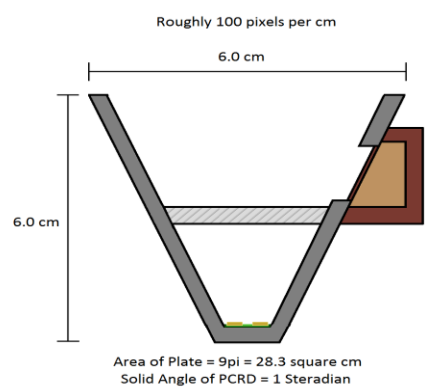

Figure 2: The object is conical, so this 3-D representation is a revolution of the main cone shape with a side chamber for the particle counter. The wall of the housing is designed to be ~0.5 cm wide.

Plan for Carrying Out Proposed Project

Our team consists of 10 students, half of which are SPS members, with the remainder primarily drawn from the KU Physics Department. Dr. Dave Besson will be the advisor. This effort is an entirely original, SPS-initiated effort. Design of the payload and calculations were done by KU SPS members. Dr. Besson is the KU SPS advisor, and has also been the PI for the NASA-sponsored, and KU-led Antarctic balloon project "HiCal", scheduled to fly on December 2, 2016 in Antarctica (https://www.csbf.nasa.gov/antarctica/ice.htm). Undergraduate Josh Macy has directed three weather balloon launches at KU, most recently in September 2016 and will play a key role in testing. Among the KU faculty, Dr. Jerry Manweiler and Dr. Tom Cravens have extensive experience in space physics and will be relied on for consultation input. The University of Kansas will provide a clean room for the CubeSat, and Dr. Besson will provide space in his Astroparticle Physics laboratory for design and development of the PCRD hardware. We expect that some construction (housing, e.g.) will be done by the in-Department machine shop, which is heavily subsidized by the University.

Project Timeline

- December 2016 → January 2017 – Finalize project layout
- February, 2017 – CubeSat acquisition, Material purchase
- February, 2017 → April, 2017 – Assemble CubeSat and perform environmental testing (Pressure, Temperature, Radiation testing)
- April, 2017 → May, 2017 – Test flight on a weather balloon
- May, 2017 → Submit Interim report with weather balloon results and pre-launch specs
- November, 2017 → Submit final CubeSat proposal to NASA, specifying proposed launch date and showing proof of principle results from weather balloon.
- December 31, 2017 → Submit summary report.
- 2018: CubeSat Launch and initial data collection

Budget Justification

The SPS chapter research reward grant is the proposed amount of $1994.00 in order to purchase a particle detector & counter, electronics and data transmission apparatus, weather balloon test expenses and, to machine/create the housing for the electronics + detector & counter. The Boron raw material cost is estimated~$332; the remainder is allocated to remaining expenses of various kinds. The launch expenses for CubeSat will be covered by NASA. The CubeSat frame is being provided by Dr. Marco Villa (KU alumni and President/COO of Tyvak Nano-Satellites). The department will provide for the weather balloon testing. We will investigate the possibility that the Boron plate could be machined from a Boron rod provided by Wolf-Creek Power station or Kansas State U.

Bibliography

[1] R. U. Abbasi et al., “Indications of Intermediate-Scale Anisotropy of Cosmic Rays with Energy Greater Than 57 EeV in the Northern Sky Measured with the Surface Detector of the Telescope Array Experiment”, Ap. J. 790(2014), L21
[2] A. G. Ruggiero, “Nuclear Fusion of Protons with Boron” (1992)
[3] J.G. Jenkin, L.G. Earwaker, and E.W. Tinterton, Nucl. Phys., 50(1964), 517.
Boron-10:
http://www.sandia.gov/pcnsc/departments/iba/ibsphys/sigmabase/data/b10.html
Boron-11:
http://www.sandia.gov/pcnsc/departments/iba/ibsphys/sigmabase/data/b11.html
Other Elements:
http://www.sandia.gov/pcnsc/departments/iba/ibsphys/sigmabase/data/target.html
[4] R. Tomaschitz, “Partition function and thermodynamic parameters of the all-particle cosmic-ray flux” (2016).