Cosmic Ray Intensity as a Function of Altitude Using a Scintillator Telescope

Allen Bordelon and Jace Boudreaux

Abstract

The purpose of this experiment is to investigate the variation in intensity of ionizing cosmic radiation as a function of altitude up to 100,000 feet. This is accomplished using a dual scintillator and photomultiplier combination where particles hitting both scintillators are counted. The experiment showed that cosmic radiation intensity increased with altitude until around 60,000 feet, where it then decreased with increasing altitude to 99,000 feet.

I. Background

LaACES

The Louisiana Aerospace Catalyst Experiences for Students (LaACES) is a Louisiana State University program designed to interest students in Aerospace and give them hands-on experienced with research, engineering design and construction, project management, and data analysis. All students fly a payload on a 3 kilogram sounding balloon that will ascend to an altitude of 100,000 feet. Students are given a scientific goal to perform on the flight and must design the hardware, software, and structure of the payload that will accomplish the task in the pressures and temperatures that the payload will experience.

The scientific goal of this payload was to measure cosmic radiation intensity with respect to altitude. The payload was launched from the Reese Center in Lubbock, Texas, on May 26, 2010. Instead of payload separation from the balloon occurring at 100,000 feet, the balloon burst at approximately 99,000 feet and wrapped around the parachute decreasing drag effect. The malfunction of the balloon caused the payload to at a faster rate than estimated and the structure of the payload was destroyed at landing. Although the payload was damaged, the data was able to be recovered.

Cosmic Rays

Primary cosmic rays are high-energy particles originating outside of Earth that enter the atmosphere. Before reaching Earth, the cosmic particles are accelerated in space to high energy and can approach the speed of light.

Earth's Magnetic Field

The Earth's magnetic field has a significant effect on cosmic rays. Charged particles are deflected by the magnetic field, which complicates the motion of the cosmic ray in the atmosphere. The path of a particle through the atmosphere depends on the particle's charge, mass, speed, position, and direction with respect to the Earth's magnetic field[1]. Particles must have high enough energy to overcome the magnetic field of the Earth which varies in intensity along geomagnetic latitude. Particles can get trapped in orbit if their due to magnetic field deflection[2].

Solar Activity

Solar activity varies with a cycle in which sunlight reaches an intensity peak approximately every 11 years, switching between high-intensity and low-intensity periods. When solar activity increases, cosmic ray intensity decreases[3]. As seen in Figure 1, the sun is rising from a solar minimum. Solar activity is at a low point allowing more radiation particles reach the Earth.
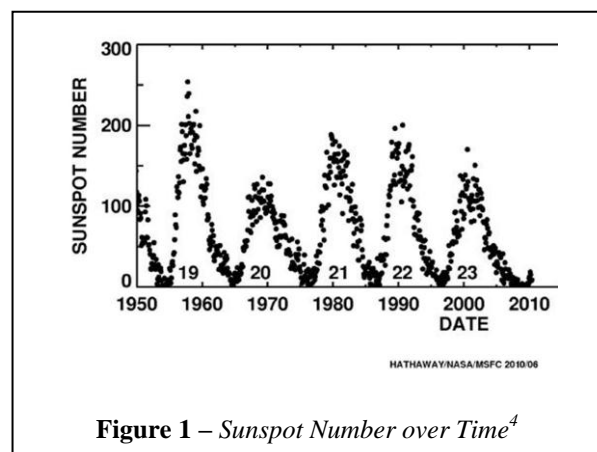

Figure 1 – *Sunspot Number over Time[4]*

When a primary cosmic ray hits the Earth's atmosphere, a reaction occurs between the cosmic particle and an air particle. The primary cosmic particle breaks down into smaller subparticles which either decay or hit another air particle, creating more subparticles. This cascade is called ionization. As the particles altitude decreases, air density starts to rise, resulting in more particle collisions. Particles lose energy in these collisions and eventually lose the energy required to ionize.

II. Measuring Radiation Intensity

Geometrical Factor

A radiation detector will count the amount of particles that pass through it per unit time. This data will vary for detectors of different geometry and needs to be correlated to a radiation intensity reading. Since the amount of counts obtained by a detector depends on the intensity of radiation and the geometry of the detector, intensity can be determined through a geometrical factor. If the intensity of radiation is isotropic, then it can be found by:

$$I = \frac{C}{G}$$

where I is radiation intensity, C is the counting rate of the detector, and G is the geometrical factor of the detector[5]. The geometrical factor relates counts to intensity using the area of the detector and the angle in which a particle could be traveling relative to the detector and still be detected.

Scintillator and PMT Counter System

A scintillator is a transparent crystal or plastic material that emits light when struck by ionizing radiation. The scintillator can be made to reflect the light to one side of the scintillator where the light can be detected by a light-sensitive device, in this case a photomultiplier tube (PMT). The PMT transforms the light pulse entering into a proportional current pulse. The current pulses can then be counted using a counter system. The geometrical factor for a single detector can be found by:

$$G = \pi A$$

where A is the area of the detector where particles will pass through[5]. In this case, the area is 12 cm^2, so the geometrical factor is 37.68 cm^2 sr.

Telescopes

Telescopes are multiple radiation detectors used together that gather more accurate readings than a single detector. The measurements from a single detector can be inaccurate alone due to noise effects, but if two detectors are placed on top of each other and only the particles that hit both detectors are counted, noise effects can be significantly reduced. The coincidences over time can then be correlated to a radiation-intensity reading based on the geometry of the telescope. The detector in this experiment is a telescope of two scintillators paired with two PMTs. The scintillators used are BC-408 and the PMTs used were R5611-01. As shown in Figure 2, the detectors have the same size, with a length of a and a width of b. The detectors are placed on top of each other with all sides aligning with a distance of l between them.
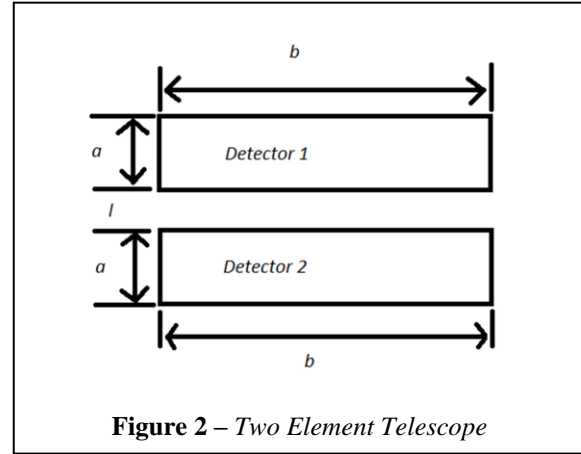

Figure 2 – *Two Element Telescope*

The geometrical factor for a rectangular telescope with two elements that are equivalent is[5]:

$$
\begin{aligned}
G = l^2 \ln &\frac{l^2 + a^2}{l^2 + a^2 + b^2} \frac{l^2 + b^2}{l^2} \\
&+ 2a(l^2 + b^2)^{\frac{1}{2}} \tan^{-1} \frac{a}{(l^2 + b^2)^{\frac{1}{2}}} \\
&+ 2b(l^2 + a^2)^{\frac{1}{2}} \tan^{-1} \frac{b}{(l^2 + a^2)^{\frac{1}{2}}} \\
&- 2al \tan^{-1} \frac{a}{l} - 2bl \tan^{-1} \frac{b}{l}
\end{aligned}
$$

In this experiment, a = 2 cm, b = 6 cm, and l = 12. These yield a geometrical factor of .9193 cm^2 sr.
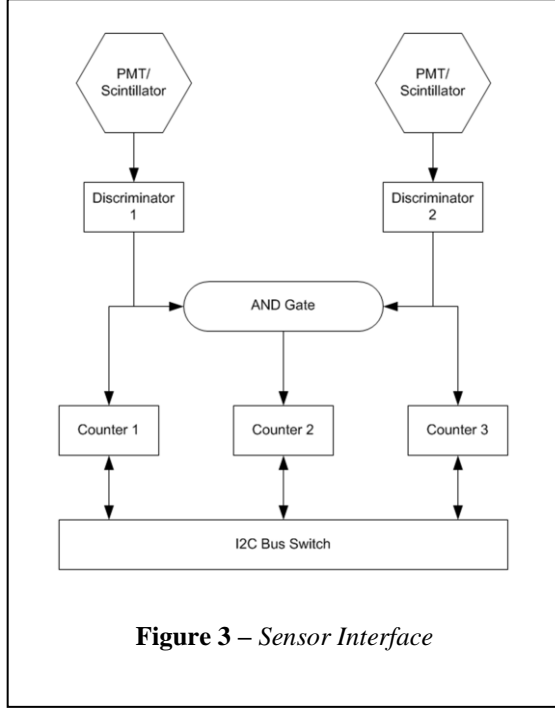
Signal System

Figure 3 – *Sensor Interface*

Figure 3 shows the sensor interface used to condition the PMT output signal. The PMTs are powered by a regulated 1kV divider network, and they produce a current pulse when an ionizing radiation particle passes through the scintillator. The current signal from each PMT is turned into a voltage using resistance. The voltage signal is compared to a reference voltage using a discriminator. If the voltage exceeds the reference voltage a digital high is produced by the discriminator. Both discriminators use the same reference voltage and the digital output of the discriminator was extended to 1μs. The reference voltage was calibrated to 100 mV, because at that voltage no coincidences were lost. The outputs are then counted individually and an AND gate is used to count pulses that occur at the same time. Through an I2C line, data is sent to a microcontroller which stores the information to a data-storage device. The counts were stored every 20 seconds and the counter was reset each sample.

III. Data Analysis Methods

Data Bins

The counts were sampled every 20 seconds during the experiment. To make the findings of the experiment more readable, the counts were grouped into 3 minute bins.

Error Due to Accidentals

Rate of accidentals caused by noise or separate particles being counted as a coincidence is found by:

$$R_{acc} = 2S_1 S_2 \tau$$

where S_1 is the singles rate for detector 1, S_2 is the singles rate for detector 2, τ is the width of the pulse entering the coincidence circuitry, and R_{acc} is the rate of accidental coincidences[6].

Error Due to Altitude

GPS was used to determine the altitude and correlated to the data using a time. GPS is accurate to within 50 feet, so that is the error on the altitude.

Statistics

Poisson statistics were performed on the data to a confidence level of 84.13%. The upper limit was found using the equation

$$\lambda_u = n + (n + \frac{3}{4})^{\frac{1}{2}} + 1$$

where λ_u is the upper limit and n is the number of counts detecter[7]. The lower limit was found using the equation

$$\lambda_l = n\left(1 - \frac{1}{9n} - \frac{1}{3n^{\frac{1}{2}}}\right)^3$$

where λ_l is the lower limit and n is the number of counts detected[7]. These equations are approximations and are within 2% of the exact solution.
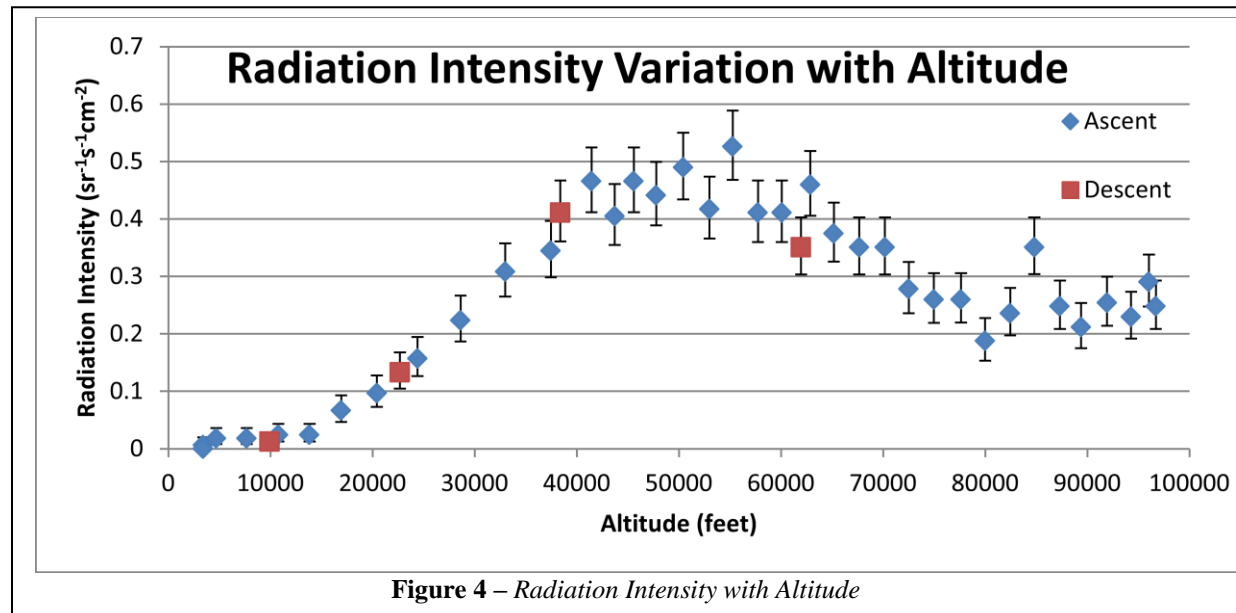
IV. Results

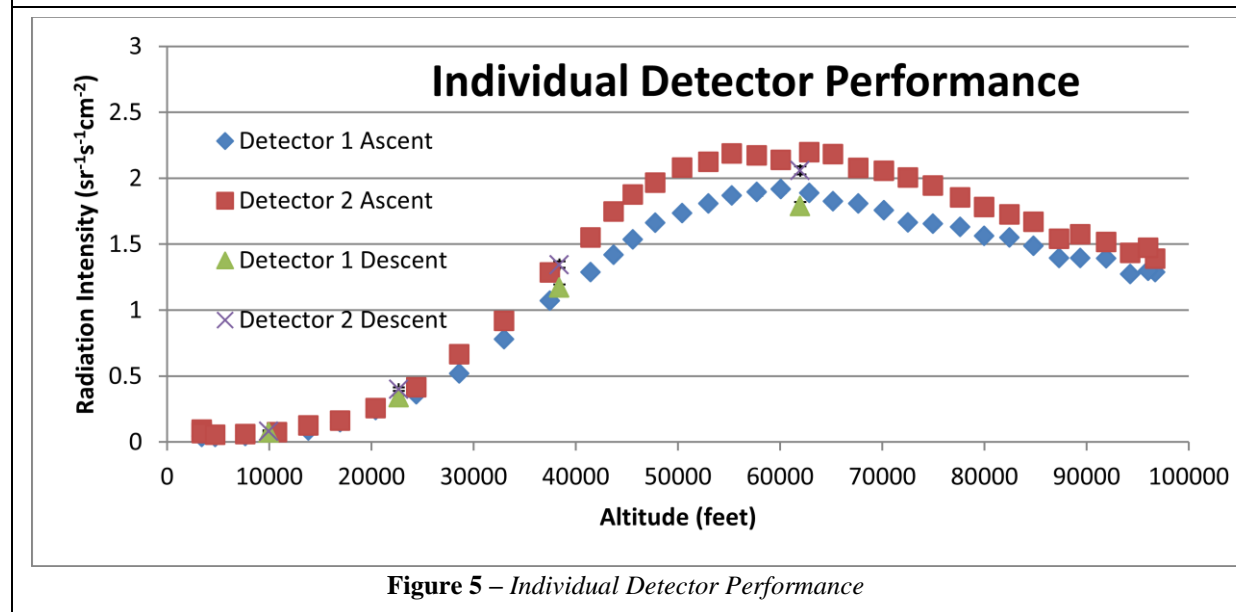**Figure 4** – *Radiation Intensity with Altitude*

Figure 5 – *Individual Detector Performance*

Figure 4 shows that the intensity of cosmic radiation increases with altitude until it almost plateaus between 38,000 and 65,000 feet. Although Figure 5 has inaccurate intensity values due to noise, it holds the correct graphical shape of ionizing radiation intensity with altitude, showing that the peak occurs closer to 60,000 feet. This is explained due to the increased air density around 60,000 feet causing more cosmic particle interactions. Eventually, the cosmic particles lost sufficient energy to ionize, which is why there is a direct correlation between altitude and cosmic radiation below 38,000 feet. When the altitude climbs higher than 65,000 feet, the ionizing radiation intensity decreases until around 80,000 feet, where the intensities increase again peaking at around 85,000 feet. No natural explanation could be found for this peak. The peak at around 85,000 feet is not present in Figure 5, so the peak is not a natural phenomenon. It is due to the same amount of particles hitting the detectors, but an increased amount, by chance, hitting both detectors. Figure 4's point seems to be outside the data curve due to the 84.13% confidence level of the Poisson distribution, but it does signify a valid data point.

V. References

1. Friedlander, Michael W. *Cosmic Rays*.
    Cambridge: Harvard University Press, 1989.

2. Van Allen, James. "Radiation Belts." In
    Encyclopedia of Physics, edited by R.G.
    Lerner and G.L. Trigg, USA: Wiley-VCH,
    1989.

3. Forbush, Scott. *Journal of Geophysical
    Research* 63 (1958): 657.

4. Marshall Space Flight Center. "The Sunspot
    Cycle." NASA.
    http://solarscience.msfc.nasa.gov/SunspotCycl
    e.shtml (accessed June 14, 2010).

5. Sullivan, J.D. "Geometrical Factor and
    Directional Response of Single and Multi-
    Element Particle Telescopes." *Nuclear
    Instruments and Methods* 95 (1971) 5-11.

6. Fernow, Richard C. *Introduction to
    Experimental Particle Physics*. Cambridge:
    Cambridge University Press, 1986.

7. Gehrels, Neil. "Confidence Limits for Small
    Numbers of Events in Astrophysical Data."
    The Astrophysical Journal 303 (1986) 336-
    346.