Cosmic Ray Measurements
A Proposed, Collaborative, Balloon Based Experiment

Gordon McIntosh
University of Minnesota, Morris

Ionizing radiation is commonly measured on balloon flights using Geiger Mueller (GM) tubes. More sophisticated measurements have also been made using multiple GM tubes and coincidence circuits. Such a measuring apparatus is sometimes known as a cosmic ray (CR) telescope. I propose a coordinated experiment to use CR telescopes, launched at various locations around the country to measure CR flux during balloon flights. The flights would occur twice a year (fall and spring) within a few days of each other beginning in the fall of 2012 and continuing through the sunspot maximum (early 2013) to the next sunspot minimum (2018). The experimenters will share the results and examine the data for the effects of altitude, geomagnetic latitude, and sunspot number on CR flux. The telescopes will be calibrated at the local institution before and after the launch in order to normalize count rates.

This paper reviews available observational information. The theoretical background will be developed and presented in the future as expertise is developed.

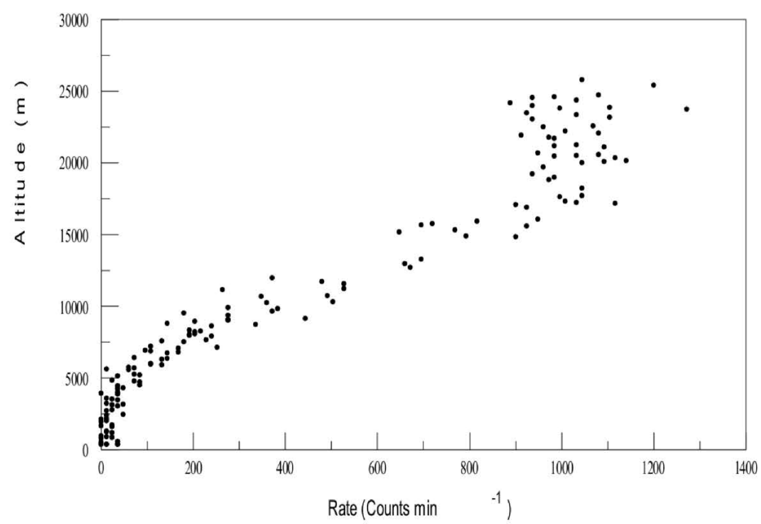

Figure 1. Altitude versus the omnidirectional count rate from an RM-60 GM tube for a balloon flight originating from Morris, MN, on 14 November 2009.

Figure 1 shows a measurement of the altitude dependence of omnidirectional CR counts. As shown the counts occur at a fairly low rate near the surface and increase by a factor of several hundred to a maximum known as the Pfotzer maximum. The Pfotzer maximum occurs at an altitude of ~ 20 km to 25 km. Near the surface the measured rate includes counts from radioactive decays in the Earth's material. At altitudes above those reached during this flight the rate decreases due to the lack of secondary CRs. CR telescope counts versus altitude from the surface to over 27 km measured by the Depauw University group were presented in the 2011 AHAC proceedings (Adams, Brauer, and Stroman 2011).

Cosmic Rays (CRs)

Primary CRs (outside of the Earth's atmosphere) are ~79% protons, ~15% helium nuclei, and 6% heavier nuclei with lifetimes of traveling about the galaxy of 15 Myr. The CR energies range from ~1 GeV to a high energy limit of about 5×10^{19} eV. The upper limit is due to the interaction of CRs with cosmic microwave background photons. These interactions reduce the energy of ultra high energy CRs. For comparison solar wind proton energies are ~1.5 – 10 KeV. These lower energy protons are more easily deflected by the Earth's magnetic field towards the magnetic poles.

Secondary cosmic rays are generated when the primary cosmic rays enter the Earth's atmosphere and interact with atoms or molecules. These interactions typically take place at altitudes of ~15 km.

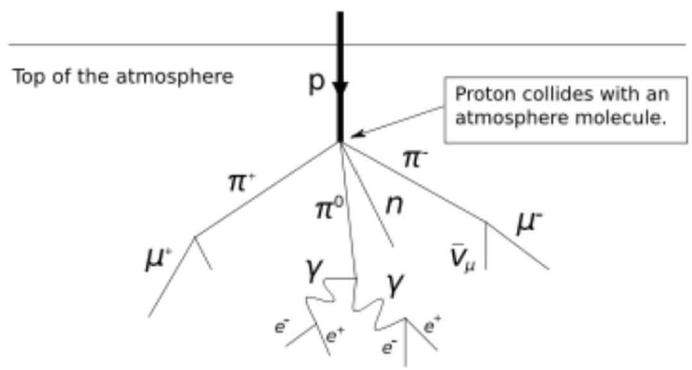

Figure 2. An example of the interactions that generate multiple secondary CRs from a single, incident CR proton. (Image from Wikipedia: Cosmic ray)

The composition of CRs varies with altitude or atmospheric depth as indicated in Figure 3. High in the atmosphere primary CRs dominate the flux. Low in the atmosphere charged muons dominate the flux readily detectible by GM tubes. These muons are produced by the decay of charged pions generated by nuclear interactions with primary CRs. The other particles produced in these interactions lose energy more effectively with the surrounding materials and do not reach the surface with as high fluxes. Neutrinos are also produced in these nuclear interactions.

The average energy of muons reaching the Earth's surface is ~3 - 4 GeV with an approximately $\cos^2(\theta)$ dependence where θ is the zenith angle. A number of laboratory measurements can be carried out with CR telescopes to study the directional flux and coincidence of these muons.

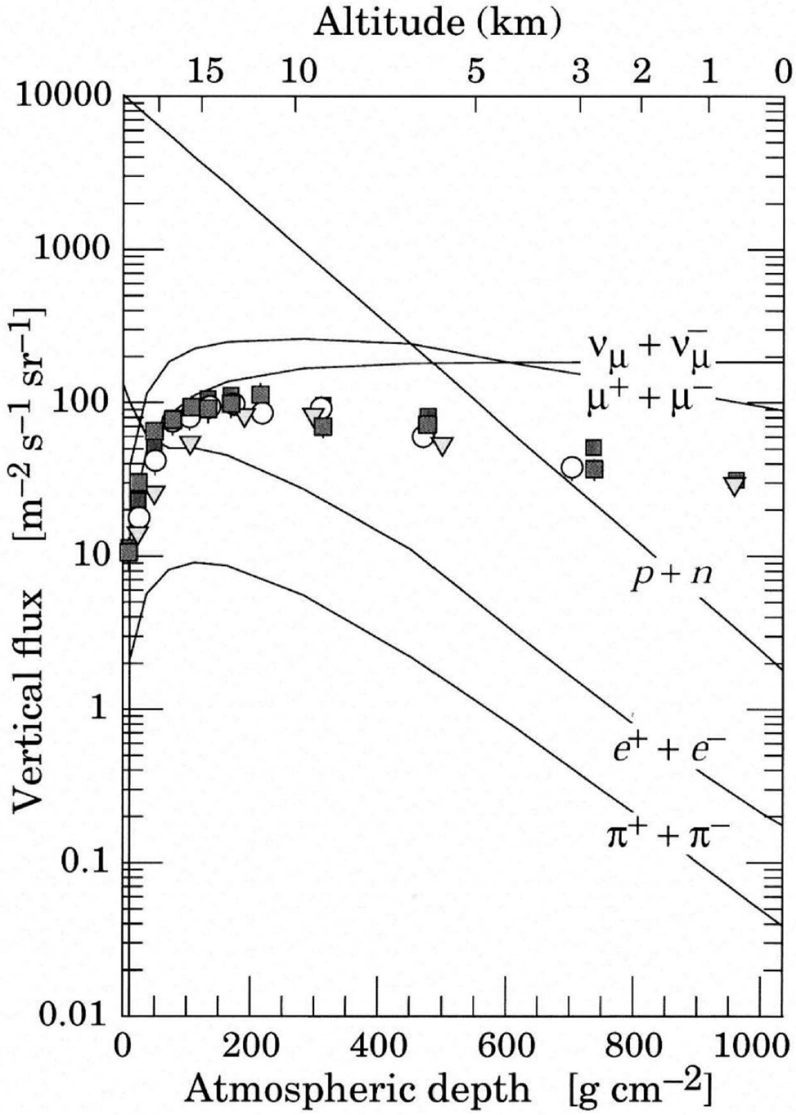

Figure 3. The vertical flux of CRs energies greater than 1 GeV versus atmospheric depth and altitude. The points show measurements of negative muons (Amsler et al. 2008 Chapter 24 p. 5).

The Earth's Magnetic Field

Since the CR flux around the Earth is largely made up of charged particles, the particles' trajectories are affected by the Earth's magnetic field. The major effect is to direct particles toward higher geomagnetic latitudes. The Earth's magnetic field can be modeled as a dipole field not quite aligned with the rotation axis of the planet. The "south" magnetic pole is located at geographic coordinates of 80.18^{o} N 72.38^{o} W (http://www.geomag.bgs.ac.uk/education/poles.html) The Earth's magnetic dipole axis does not pass through the center of the Earth but is offset by several hundred miles toward the Indian Ocean. Figure 4 shows a map of geographic coordinates and geomagnetic latitudes.

Geomagnetic Latitude

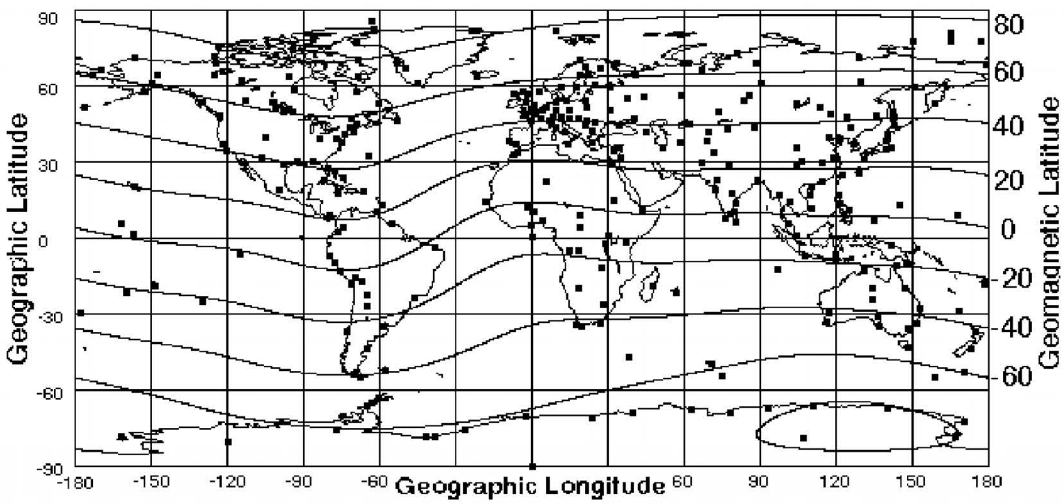

Figure 4. Geographic coordinates and geomagnetic latitudes
Image from NOAA http://www.ngdc.noaa.gov/stp/cdrom/ionocd.html

Most of the United States is between 40^{o} and 55^{o} of geomagnetic latitude. This variation in geomagnetic latitude produces a variation in the CR flux at the surface and in the atmosphere. Table 1 gives the geographic and geomagnetic coordinates of several locations in the US for 2012. Since both of these coordinates slowly vary with time it is useful to specify the date for the coordinate values.

Table 1. Geographic and Geomagnetic Coordinates 2012 from the World Data Center for Geomagnetism (http://wdc.kugi.kyoto-u.ac.jp/igrf/gggm/index.html)

Location	Latitude (^{o}) North	Longitude (^{o}) West	Geomagnetic Latitude (^{o})	Geomagnetic Longitude (^{o})
South Geomagnetic Pole	80.18	72.38	90	_
Morris, MN	45.58	95.90	54.27	28.68
Nashville, TN	36.16	86.78	45.49	16.69
Palestine, TX	31.76	95.63	40.32	29.61

Longitudinal effects

The magnetic field of the Earth provides a way to determine the charge of the CRs. The charges are deflected according to the charge to the east (positive charges) or west (negative charges). This asymmetry produces a slight difference in the flux at a zenith angle of 45^o east compared to 45^o west. Since most CRs are positively charged the flux from the west exceeds the flux from the east. This flux difference, first measured in 1933 in Mexico City, is larger at lower geomagnetic latitudes and higher altitudes.

Atmospheric Depth

As indicated in Figure 3 the atmosphere affects the flux of CRs. As the charged particles traverse the atmosphere they lose energy and the unstable particles decay. The atmospheric depth characterizes the mass per unit area above the altitude specified. The units are usually g cm^{-2}. Figure 4 presents the atmospheric depth as a function of altitude. At the surface the atmospheric depth is about 1000 g cm^{-2}. At an altitude of 25 km the atmospheric depth is about 24 g cm^{-2}.

Based on the specificatiions for the Aware RM-60 GM tube, it should be possible to construct CR telescopes with mass depths ≤ 1 g cm^{-2}. High altitude balloons should be able to carry the CR telescopes to altitudes of 25 km or more achieving a total mass depth of ≤ 30 g cm^{-2}. This depth is above the Pfotzer maximum which occurs at ~100 g cm^{-2}. At this depth the telescopes can sample the flux of primary CRs.

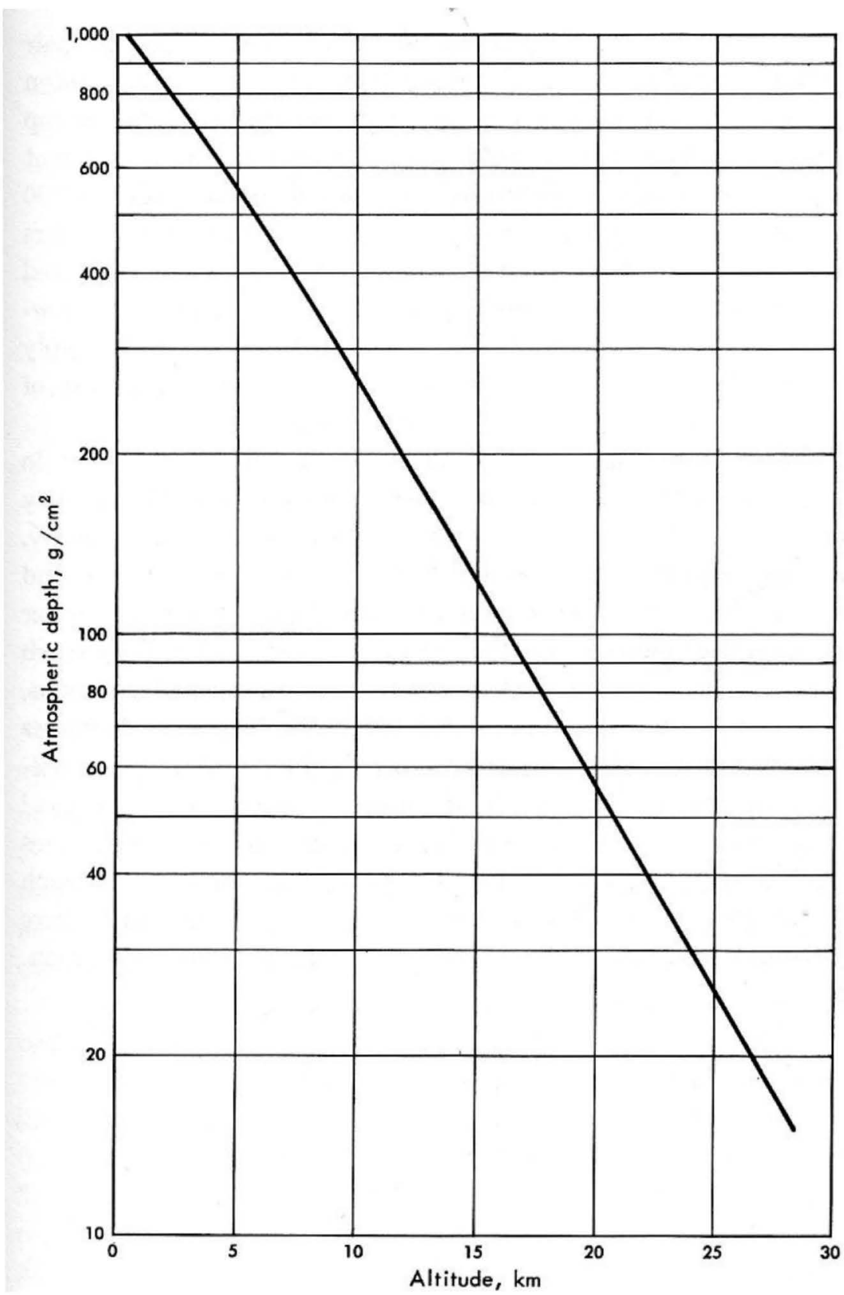

Figure 4. Atmospheric depth versus altitude (Rossi 1964, p. 177)

Sunspots and CRs

Figure 5 shows the variation of CR flux versus time along with the variation in sunspot number with time. The anticorrelation is obvious. Along with the increase in sunspot numbe, the solar magnetic field expands and lower energy CRs cannot penetrate into the inner solar system so the observed CR flux decreases.

The next sunspot maximum is predicted to occur during the spring of 2013. If the coordinated balloon flights suggested in this paper begin in the fall of 2012, the sunspot and solar magnetic field cycle, from maximum to minimum, can be observed over the next five or six years.

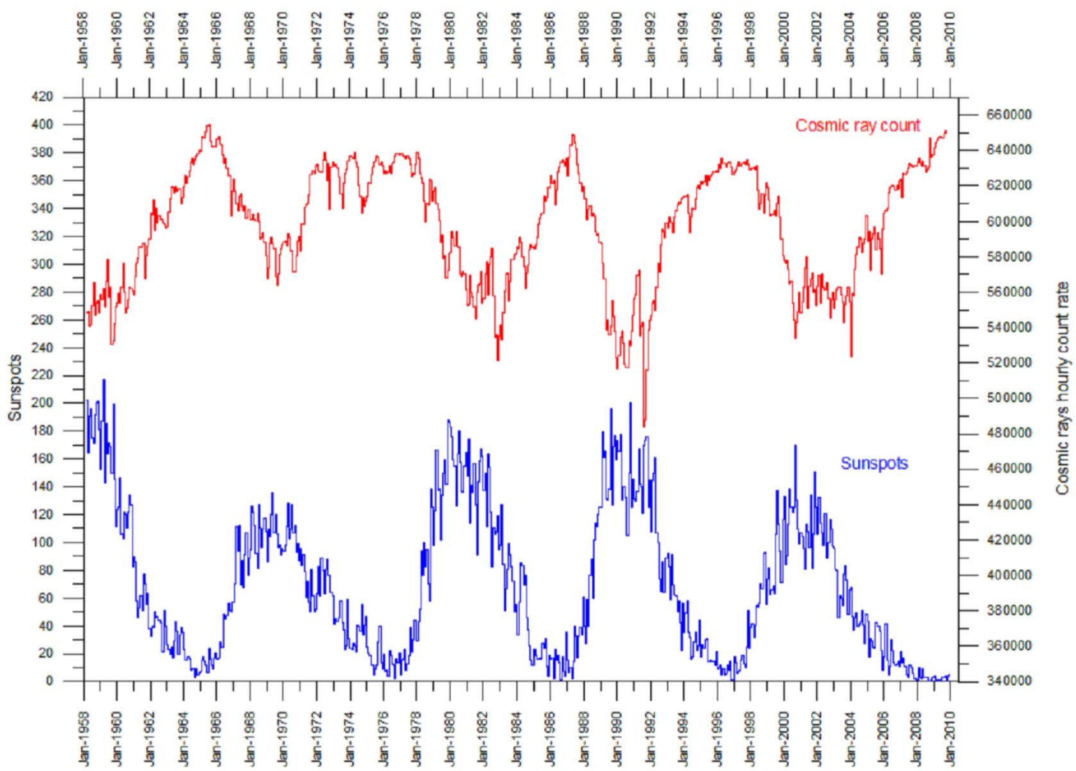

Figure 5. Sunspot number and CR counts from 1958 until 2010.
(http://www.climate4you.com/Sun.htm#Cosmic ray intensity and sunspot activity)

Atmospheric Depth Variations

Van Allen (1994) reported the results of a series of measurements of omnidirectional CR fluxes at various atmospheric depths and geomagnetic latitudes.

The results are shown in Figure 6. The omnidirectional flux was observed to increase with altitude at all latitudes. The flux levels out as a function of altitude and latitude. This leveling occurs at lower latitudes as the altitude increases. The analysis of these observations indicate a factor of ~1.26 between fluxes measured at geomagnetic latitudes of 40° and 54° at an atmospheric depth of 58 g cm^{-2} or an altitude of 20 km.

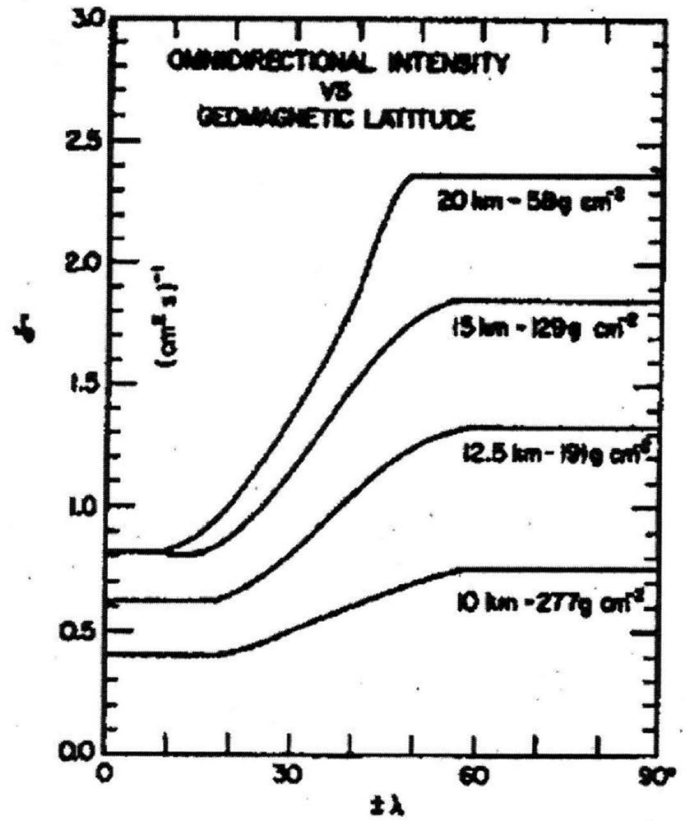

Figure 6. Omnidirectional CR flux versus geomagnetic latitude at various atmospheric depths (Van Allen 1994, p. 17,634)

Winkler and Anderson (1957) used CR telescopes to measure the vertical flux of CRs as a function of atmospheric depth and latitude. The analysis of these observations indicates the flux at 54° geomagnetic latitude to be ~2 times greater than the flux at 40° at an atmospheric depth of 10 g cm^{-2}, but no data are indicated below 51° geomagnetic latitude.

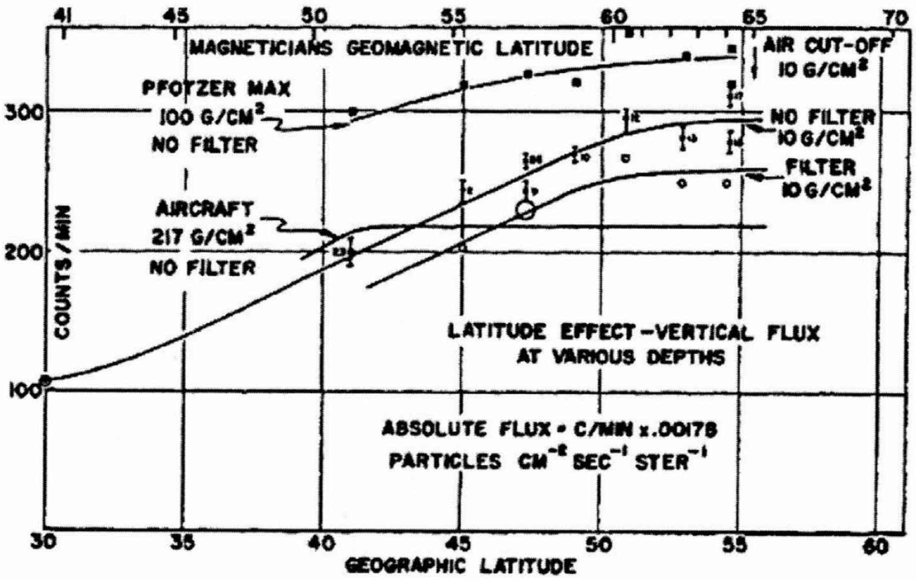

Figure 7. Vertical CR flux versus geomagnetic latitude at various atmospheric depths (Winckler and Anderson 1957, p. 152).

So the CR flux has been observed to vary in geomagnetic latitude, atmospheric depth, and time. These variations provide an opportunity for continuing balloon based measurements at various atmospheric depths and latitudes over the next solar cycle to further measure the effects and analyze the results.

The Experiment

The coordinated CR telescope measurements proposed will provide all participants with data from resources that would not be available at a single location or institution. If successful, the experiment will provide a rich source of information to motivate study in various areas of physics - high energy physics, astrophysics, relativity, magnetodynamics, solar physics, experimental techniques and circuitry, computational techniques and display, and data analysis. Participants can approach all of these various areas of physics or specialize in a few areas.

In order to carry out the experiment and acquire comparable data from the various locations as similar CR telescopes as possible will have to be flown. The flights should occur within as short a time span as possible to minimize any time variation. Van Allen (1994) and Winckler and Anderson (1957) compared data collected over three months and six weeks, respectively. Fall and spring flights over the next few years should be carried out to measure the variation of CR flux during the sunspot cycle.

Acquiring comparable data will require a set of equipment, calibration, and observing conventions to be established.

It appears that the Aware Electronics RM-60 GM tube is a fairly inexpensive, robust, readily available piece of equipment to be the CR detector for the CR telescope. The coincidence circuit can either be purchased from Aware Electronics with a coincidence time of 20 ns, developed based on the Depauw University approach (Adams et al. 2011), or based on another design. The omnidirectional and vertical fluxes can be recorded using StratoSTAR or BASIC Stamp technologies.

The design of the CR telescope environments should be as similar as possible to maintain similar physical parameters during flights.

References

Adams, Brauer, and Stroman 2011, in Academic High-Altitude Conference proceedings (Ames, IA), 1

C. Amsler et al. (Particle Data Group), Physics Letters B667, 1 (2008)

Rossi, B. 1964, Cosmic Rays (New York: McGraw-Hill Book Company)

Van Allen, J.A. 1994, JGeophysRes, 99, 17, 631

Winckler, J.R. & Anderson, K.A. 1957, PhysRev, 108, 148