Personal Neutron Dosimeter Analysis of Cosmic Rays from Stratospheric Ballooning Missions

ST. CATHERINE UNIVERSITY

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Abstract

Helium-filled High Altitude Balloons (HABs) have been used by St. Catherine University's all-women research team to investigate the near-space environment. Cosmic ray showers colliding with atmospheric particles are significant in the lower stratosphere, where the neutrons form as part of a collision cascade. A personal neutron dosimeter (PND) can be used to quantify neutrons through the appearance of bubbles as a result of neutron interaction with a liquid substrate Freon-12. Over the years, flights have been flown consisting of a PND, heater circuit, Geiger – Müller (GM) tubes, GPS, and a GoPro® camera. By overlaying the GoPro® time with real-time, the team determined the altitude at which the bubbles occur. Data analysis shows a correlation between the neutron events' altitude and other shower-generated particles measured by the GM detector. The particle peak occurs between 15-25 km – correlating to the charged particle maximum known as the Regener-Pfotzer (R-P max) maximum.

Particle Detection

Galactic Cosmic Rays (GCRs) are constantly colliding with Earth's atmosphere, typically in the form of high-energy protons, resulting in a cascade of high-energy secondary particles called a cosmic ray shower. A cosmic ray shower occurs when protons collide with an atmospheric molecule splitting it into subatomic particles (Figure 1). The R-P max (ranges from 15-25 km) and is the main area of focus when measuring counts from GCR showers. The R-P Max is the altitude at which cosmic radiation intensity reaches its maximum. GM detectors measure the charged particles produced in ionization interactions (Figure 2). The PND detects fast neutrons during high altitude balloon flights (Figure 3). This type of neutron either undergoes elastic scattering and/or inelastic scattering which is mapped out on Figure 4 for further analysis.

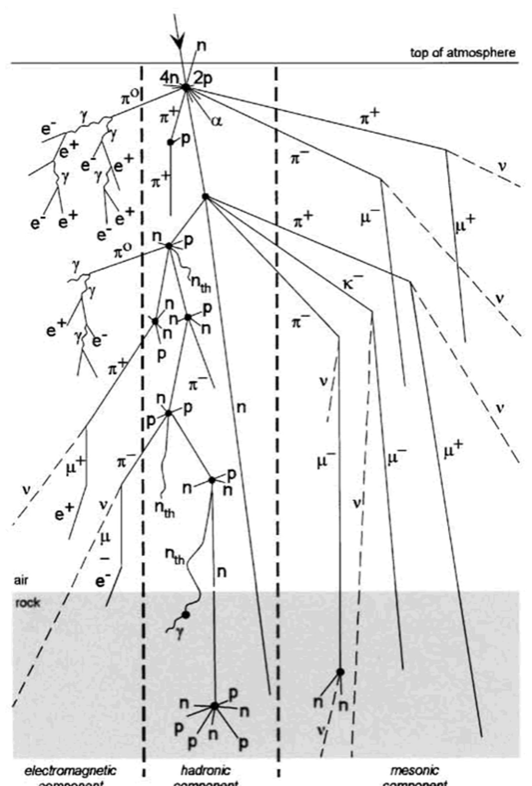

Figure 1. Cosmic Ray Shower diagram.

Link to video of PNDs from flight on 6/8/2022.

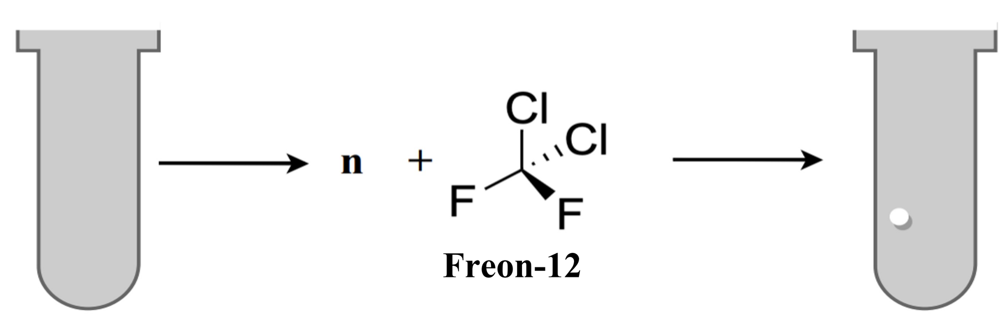

Figure 2. Diagram of PND reaction, the white circle represents a bubble formed after a neutron (n) has collided with the dosimeter.

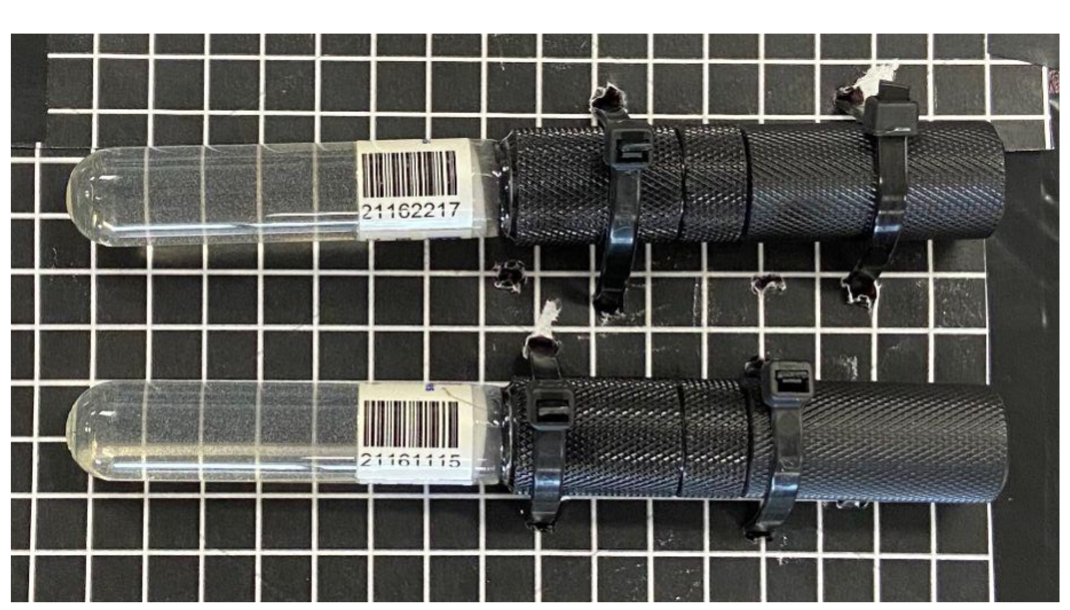

Figure 3. PND's before flight mounted on lid of box in view of the GoPro®. Black grid paper has been placed behind to split the PND tubes into sections for easier bubble detection.

Data Analysis

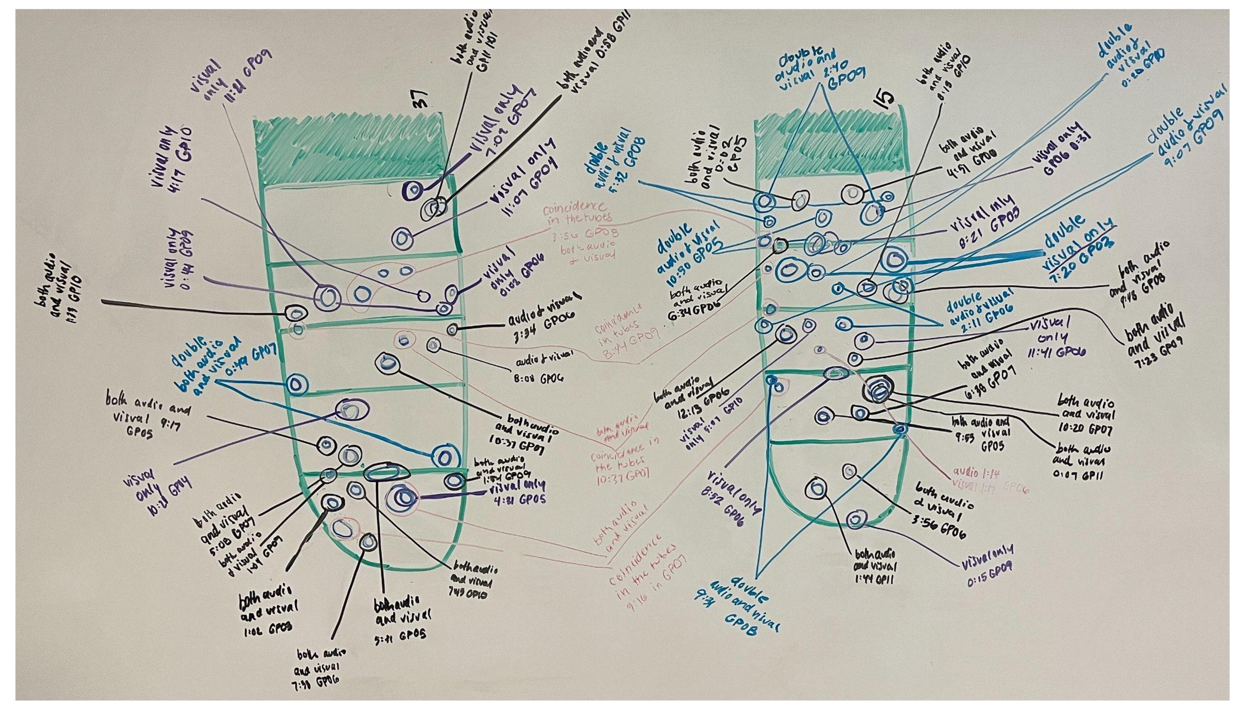

Figure 4. Bubble mapping from GoPro® videos of neutron tubes to document altitudes at which bubbles appear.

Alignment of GoPro® with Real Time

The GoPro® footage is stored on a SD card in automatically named video files (ex. GP02) of varying length. When the balloon is launched, the team yells "launch" which the GoPro® audibly captures. This marks launch (ex. 2:46 in GP01 in Flight 64) as time zero for flight duration. The real time was determined from the Arduino (12:46.15 PM CST). With 2:46 of GP01 marked as launch at real time of 12:46 CST, the remaining time in GP01 was added to the real time to get the time real time range for GP01 (12:49:01). The same was done for the remaining video segments by adding the duration of the video to the real time of the previous segment.

Bubbles (37) Reg B	Real time	Altitude at time (ft)	Altitude at time (m)
GP03 1:02 (single)	13:02:29 PM	18575.85	5661.92
GP04 10:20 (single)	13:24:16 PM	38847.20	11840.63
GP04 11:01 (single)	13:24:57 PM	39282.67	11973.36
GP05 4:31 (single)	13:28:48 PM	42856.00	13062.51
GP05 5:30 (single)	13:31:57 PM	45299.33	13807.24
GP 05 9:17 (single)	13:35:44 PM	48291.27	14719.18
GP 06 0:02 (single)	13:39:01 PM	50657.00	15440.25
GP 06 3:34 (single)	13:42:33 PM	53405.08	16277.87
GP 06 7:38 (single)	13:46:37 PM	56535.50	17232.02
GP 06 8:08 (single)	13:47:07 PM	56913.75	17347.31
GP 07 0:49 (double)	13:52:18 PM	60894.53	18560.65
GP 07 5:08 (single)	13:56:37 PM	64384.00	19624.24
GP 07 7:09 (single)	13:58:38 PM	66002.43	20117.54
GP 07 9:16 (double - COI)	14:00:45 PM	67559.77	20592.22
GP 07 10:37 (double - COI	14:02:06 PM	68630.9	20918.70
GP 08 3:55 (triple - COI)	14:07:54 PM	73407.66667	22374.66
GP09 1:04 (single)	14:16:34 PM	80535	24547.07
GP09 1:54 (single)	14:17:24 PM	81209.8	24752.75
GP09 8:44 (single - COI)	14:24:14 PM	86936.2	26498.15
GP09 11:21 (single)	14:26:51 PM	89241.7	27200.87
GP10 1:33 (single)	14:29:42 PM	91812.66667	27984.50
GP10 4:17 (single)	14:32:26 PM	94244.26667	28725.65
GP10 7:45 (single)	14:35:54 PM	97120.96667	29602.47
GP11 0:58 (single)	14:41:46 PM	101894.2	31057.35
GP11 1:01 (single)	14:41:49 PM	101932.1	31068.90

Figure 6. Correlation of GoPro® bubble time with APRS times and altitudes.

Altitude Data and Time Stamps from APRS

APRS takes altitude measurements every minute. The raw data is stored in a file on the APRS website which is then exported and converted to an Excel file. The APRS time is then overlaid with the real time using the Arduino data. APRS altitude data with the real time stamps is then overlaid with the time stamps from the GoPro®. This allows for matching up the time of bubble formation with the correct altitude in real time. APRS is used for altitude measurements because multiple APRS units are on the payload to ensure consistency.

$$\text{Altitude} = (\text{Upper Altitude} - \text{Lower Altitude}) \times (\text{Fraction of time}) + \text{Lower Altitude}$$

Equation 1. Altitude calculation from flight generated data.

Bubble Mapping from GoPro® footage

A blank version of a tube is drawn and labeled on the board. It is then filled in as footage is reviewed. It is split into sections based on the black grid paper from the payload to match how the tube appears in the GoPro® footage. The top of each tube is filled in with green to mimic the appearance of the wrapper on the actual tube. Black indicates a bubble with audio and visual. Purple indicates visual bubbles only. Pink indicates audio first, visual second. Blue indicates double bubbles with audio and visual. Orange indicates coincidences between the tubes with both audio and visual.

Box 1		Time	Real Time
Setup	G0P0025	12:20	
Setup	GP01	9:44	
Flight	GP01	2:46	12:46:15 PM-12:49:01
Fliight 2	GP02	12:24	12:49:02 PM-13:01:26
Flight 3	GP03	12:29	13:01:27PM-13:13:55
Flight 4	GP04	12:30	13:13:56 PM-13:26:26
Flight 5	GP05	12:31	13:26:27PM-13:38:58
Flight 6	GP 06	12:29	13:38:59PM-13:51:28
Flight 7	GP 07	12:29	13:51:29PM-14:03:58
Flight 8	GP08	12:30	14:03:59PM-14:15:29
Flight 9	GP 09	12:38	14:15:30PM-14:28:08
Flight 10	GP 10	12:38	14:28:09PM-14:40:47
Flight 11	GP 11	7:05	14:40:48PM-14:47:53
Total time		121:29:00	
Launch 12:46:15			
Burst 2:47:52 = 14:47:52			

Figure 5. The alignment of GoPro® footage with real time

Correlating GoPro® Bubbles with APRS Time and Altitude

The GoPro® footage was examined to determine where bubbles that were only visual or had both audio and visual occured. The GoPro® time was converted into real time which was then compared to the APRS time. Those bubbles were then overlaid with APRS time to determine the altitude they formed at. To find the correct altitude the bubbles appeared at, the team used equation 1. The altitude was in feet (ft) so the team then converted the altitude to meters (m) and placing it into a graph (Figure 8). The boxes highlighted in purple show bubble events at the same time point across multiple tubes. These are classified as coincidences (COI) followed by the number of bubbles in the coincident event.

Time	Altitude in ft	Altitude in m
12:46:55	1945	592.836
12:47:55	3422	1043.0256
12:48:52	4468	1361.8464
12:49:52	5456	1662.9888
12:50:52	6358	1937.9184
12:51:52	7588	2312.8224
12:52:52	8658	2638.9584
12:53:52	9564	2915.1072
12:54:52	10745	3275.076
12:55:52	11772	3588.1056
12:56:52	12841	3913.9368
12:57:52	13904	4237.9392
12:58:52	15069	4593.0312
12:59:52	16172	4929.2256
13:00:52	17231	5252.0088
13:01:52	18186	5543.0928
13:02:52	19203	5853.0744
13:03:52	20247	6171.2856

Figure 7. Altitude data and time stamps from the APRS unit

Results

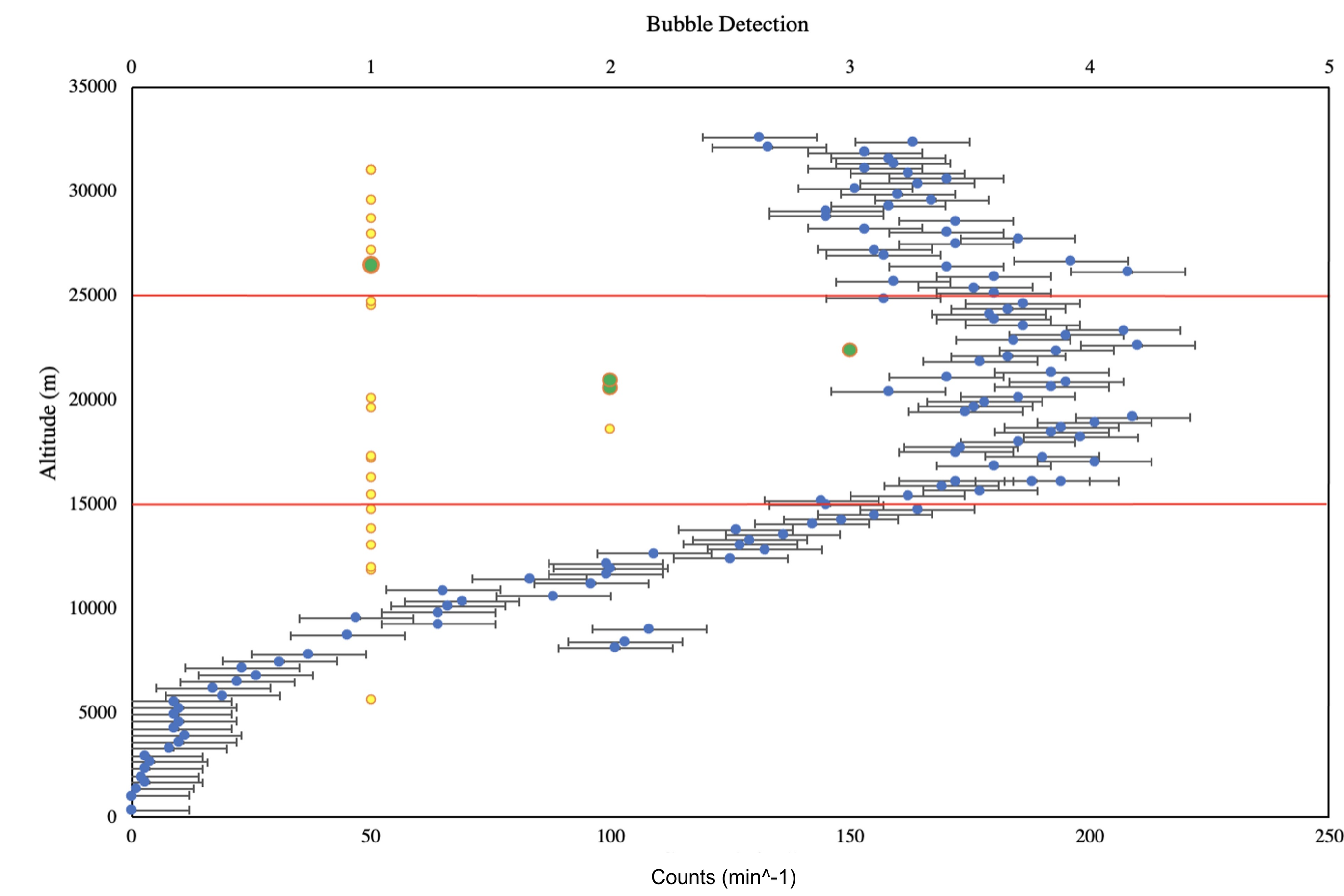

Figure 8. Plot of bubble detection/counts versus altitude from flight on 6/8/2022. Neutron occurrences in yellow, neutron coincidences (detection of bubbles in two PND's simultaneously) in green, GM detector data in blue. The red lines at 15 km and 25 km are the borders of the R-P max region.

Major Takeaways

The highest incident of charged particle detection occurred at approximately 22 km. This maximum falls within the R-P max range of 15-25 km. Neutron bubble detection was also at its peak between the RP-max range which supports that the apex of atmospheric neutral particle interaction which follows a similar pattern to that of charged particle interaction. The flight conducted on 6/8/2022 was the second time we had flown multiple PNDs in the same flight; however, this was first time we captured video footage of all four tubes. Results showed coincidences between bubble events across multiple tubes. Future flights will focus on these coincidences to characterize the difference between bubbles formed by a single neutron trajectory and bubbles formed by multiple neutrons. Improvements on the GoPro® set-up are being explored for clearer video footage. The focus of these improvements are mainly on minimizing the glare on the PNDs from the light source which will allow for more accurate bubble detection and counts.

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