High Altitude Balloon Operation During 2017 Solar Eclipse

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A total solar eclipse provides an opportunity to observe, quantify, and conduct experiments involving a number of unique meteorological and environmental conditions and phenomena, and the means to develop a more detailed understanding of the atmospheric variables at play during a rarely observed cosmic occurrence. High altitude ballooning is particularly suited for collecting data during an eclipse, although a number of logistical and procedural challenges are associated with launching during totality. The members of the University of Maryland, College Park Balloon Payload Program, funded by the Maryland Space Grant Consortium, traveled to South Carolina to launch a number of experimental and observational payloads during the total eclipse of August 21, 2017. This paper describes the balloon flight, launch procedures, associated challenges, and payload data, thereby providing a window into the variety of valuable engineering design expertise and hands-on skills developed through this student-run initiative.

Keywords: *solar eclipse, high altitude ballooning, undergraduate, student research*

Nomenclature

UMD = University of Maryland - College Park
BPP = Balloon Payload Program
HAB = High Altitude Balloon
APRS = Automated Packet Reporting System
NS-XX = UMDBPP flight number designation
payload string = vertical paracord string of connected research payloads
BLT = Balloon Launch Tube, a plastic tarp designed to contain the balloon during inflation
PARROT = Payload Angled Reasonably Reclined to Observe Totality
SESPA = Solar Eclipse Solar Power Analyzer
IRENE = Ionizing Radiation Exposure Nearspace Experiment
ATOMIC = Atmospheric Thindown Originating Mutagenesis Investigational Capsule
LEOPARD = Lightweight Eclipse-Observing Payload for Ambient Radiance Determination

I. Introduction

Dedicated undergraduate research programs give students practical experience, kindle active interest in research projects, and offer a powerful development platform for smaller and more disposable innovations that, while ultimately making significant contributions to academic research, may not be as appealing to faculty and graduate researchers. When combined with high-altitude ballooning, a research team comprised of undergraduate students can rapidly iterate dramatic development in atmospheric science and aerospace. This paper involves the University of Maryland Balloon Payload Program (UMDBPP), based in College Park, Maryland and funded by the Maryland Space Grant Consortium, and will specifically discuss the flight conducted on August 21st, 2017 from Williamston, South Carolina during the total solar eclipse.

Each flight conducted by the UMDBPP is comprised of a small number of individual research payloads developed and managed by student payload teams. Teams set out to accomplish specific research objectives, and accompany

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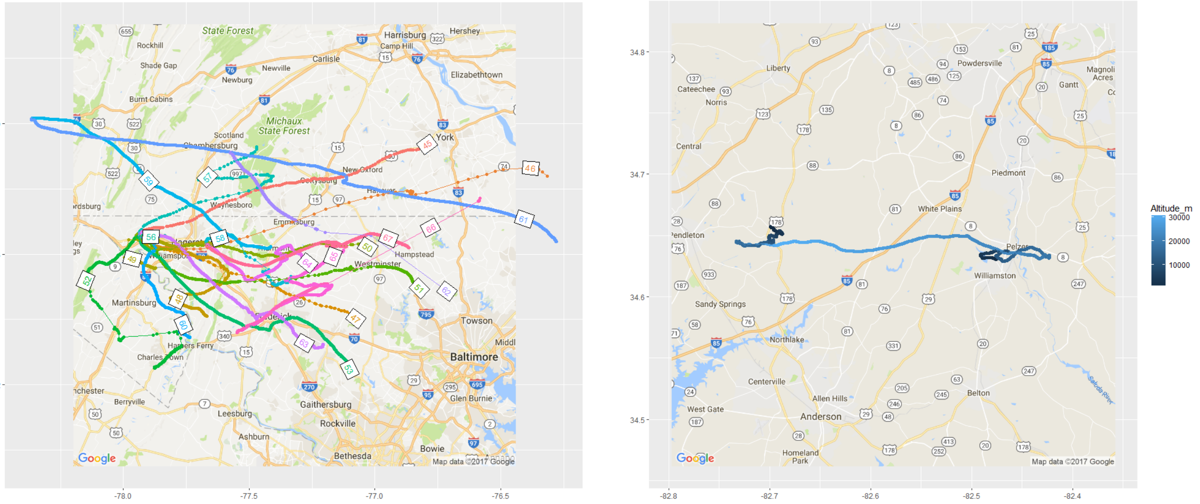
their payloads to balloon launches. A parachute is attached to the neck of the balloon, and beneath the parachute is attached the Command Module, the tracking payload that houses two Uputronics HABduinos, which contain GPS units connected to 2 m band radios set to broadcast location packets over APRS frequencies, a redundant cell tracker for acquiring and broadcasting location over the cellular phone network, and finally, on flights that require packet transfer between the payload string and ground station, a custom built Arduino Mega ("Balloonduino") that transfers CCSDS packets between a long-range 900 MHz ellipsoidal patch antennae and short-range XBee radios. Research payloads are tied together via paracord beneath the Command Module in a single vertical line, typically spaced 0.5 m apart. After the balloon has been inflated and launched, the payload teams chase the payload string in vans, utilizing roof-mounted tracking antennae to receive tracking packets over APRS frequencies and also ensure stable 900 MHz communication on flights that require packet transfer between the payload string and ground station. After several thousand meters of continuous ascent, the balloon bursts and the payload string descends, slowed by the inline parachute. After landing, the cell tracker sends a text containing the landing location over the cell network and the payload teams find and recover their equipment. Typically, UMDBPP balloon flights are designated with the prefix NS (Near Space) followed by the flight number. Of UMDBPP flights between NS-45 and NS-70, average burst altitude of is 22 402.7 m [1], while average downrange distance upon landing is 64 km.



(a) UMDBPP NS-45 to NS-67: Balloon flights in Maryland, from NS-45 in November 2014 to NS-67 in July 2017.

(b) UMDBPP NS-69: The eclipse flight in South Carolina, designated NS-69, flew westward and landed 23.7 km **from the launch site, an unusually short distance for UMDBPP flights.**

Fig. 1 UMDBPP Flight Tracks: Rendered using ggmap [2] with location data from program archives [3].

On August 21st in 2017, the day of a transcontinental total solar eclipse, the UMDBPP conducted a special flight in Greenville, South Carolina. This flight, designated NS-69, carried sun-facing cameras and instrumentation with the intent of observing and documenting the eclipse from a high altitude. NS-69 launched from Palmetto High School (804 N Hamilton St, Williamston, SC 29697, coordinates 34.6307267,-82.4754667) at 13:56:54 EDT, took 80 min to reach burst altitude, burst at 31 896 m altitude at 15:16:50 EDT, then spent 35 min on the descent, during which it reached maximum speeds of 67.9 m s^{-1}. The balloon experienced totality at 18:38:03 - 18:40:41 UTC, and the payload string subsequently landed at 15:52:27 EDT, 23.7 km away from the launch site [4].

II. Procedural changes associated with an eclipse launch

A. Ground track and weather

One of the unusual challenges posed by launching a HAB during the solar eclipse was that of ensuring the balloon experienced totality at a reasonably high altitude. Due to the location of the University of Maryland campus in College Park in the greater Washington, D.C. area, the program has a considerable amount of experience avoiding restricted airspace. However, ensuring that the balloon remained *in* a specific geographical area instead of *away* from one proved to be an interesting challenge.

The UMDBPP team decided that the easiest way to ensure the balloon experienced totality was to keep the entire predicted track within the eclipse path. The team decided to keep the track to the the center of the path in order to capture a longer period of totality.

The UMDBPP typically begins considering ground tracks and launch site locations five days before a launch, which is at the extreme accuracy limit of the wind models used in the HABhub prediction algorithm [5]. A preliminary launch site decision is usually made by 36 h before launch, though revisions have occurred as late as 12 h before launch.

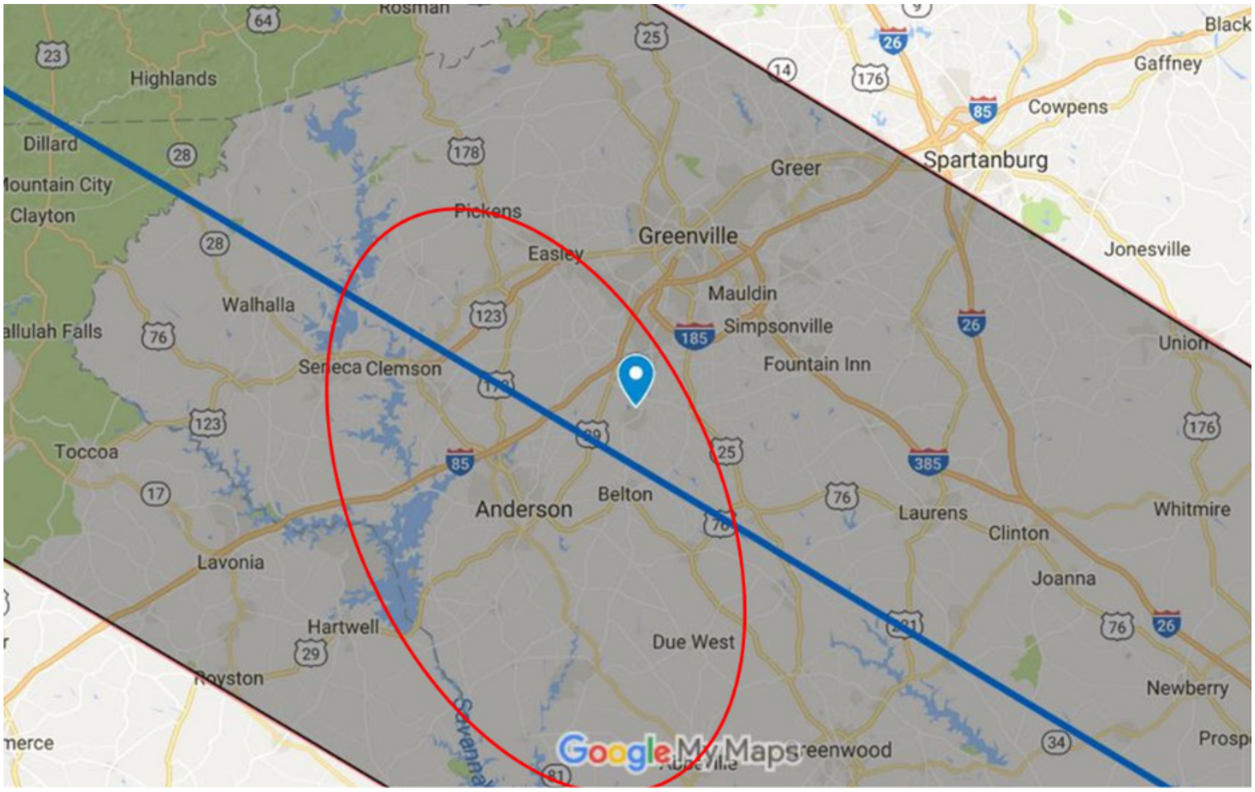


Fig. 2 Candidate NS-69 Launch Sites: The greater Greenville, SC area, with the path of totality calculated by Xavier Jubier in gray [6]. The red ellipse depicts the general area considered for launch sites, while the blue maker shows the actual launch site.

In the case of NS-69, because the launch took place well outside of UMDBPP normal operational area and involved unusual trajectory design requirements, initial launch site considerations began two weeks in before the launch date. Trajectory predictions run at this time suggested the balloon would follow a generally east-west path. These preliminary estimates provided enough information to begin considering launch sites. The designated base of operations, a hotel in Greenville, SC, was on the northeast side of the totality path. Figure 2 depicts the area evaluated for potential launch sites.

The UMDBPP usually prefers public schools as launch sites, and preliminary candidates for this launch were selected on the basis of accessibility from Greenville and proximity to food venues. Given predicted heavy traffic on the day of the eclipse, accessibility from Greenville precluded sites across the Savannah River, crossings of which are limited.

On Thursday, August 17th, four days before the eclipse, five public schools were contacted as potential launch sites. Of those, two gave permission to use their facilities. The eventual launch site, Palmetto High School (804 N Hamilton St, Williamston, SC 29697), was selected on the evening before the launch, since predictions from the other candidate site in Anderson, SC placed the landing location too close to Lake Hartwell. From this site airspace was not a concern, as the only restricted airspace in the area was around Greenville, several miles to the northeast, and the balloon was predicted to travel west.

B. Launch procedure changes and challenges

Typical UMDBPP launches occur very early in the morning, with the balloon being filled before and during the sunrise, and launched shortly after. As the helium tanks store under pressure, launching before outside temperature rises lets the program avoid a significant increase in internal tank pressure. Additionally, several payloads contain sensitive electronics which risk malfunction in daytime heat.

Unfortunately, the eclipse took place in the middle of the afternoon on a very sunny and hot day in South Carolina. The launch team also arrived four hours before the set launch time, two hours before the planned arrival time, in order to set up for the launch before the temperature rose.

Once at the launch site, only the payloads were taken out of the vehicles. The team placed a folding canopy over the payloads to keep them out of the sun while the payload teams worked on preflight procedures. The launch team erected a second canopy for themselves. 2 h before launch, the balloon and helium tanks were brought from the vehicles and set up to start inflation, and the canopies were reassigned to provide shade for the helium tanks and inflating balloon. Balloon inflation employs use of the BLT (Balloon Launch Tube), which is designed to contain and stage the balloon during inflation and release. Usually one or two students will sit inside the BLT in order to hold the balloon while inflating. Payloads were moved in the remaining shade, and no one sat inside the BLT due to its interior heat, as its semi-transparent plastic acted as a greenhouse.

The team had decided that NS-69 should be ascending between 60 000 ft (18 288 m) and 80 000 ft (24 384 m) when the eclipse reached totality at 14:37:59 EDT. The main goal for totality was to be before balloon burst, to ensure payloads were in a stable orientation while collecting data. Lower altitude was preferable to bursting early. 1600 g balloons typically reach burst altitude on average 70.4 min after launch, which gave a window of 13:45:00 EDT ± 5 min in which to launch. This was a much smaller tolerance than the nominal ± 30 min of typical UMDBPP launches.

Although inflation started before 1 h before launch, the balloon launched at 13:56:54 EDT, 5 min after end of the original launch window. This resulted in the balloon being slightly below targeted altitudes. During eclipse totality, the balloon ascended between 53 293.0 ft (16 243.7 m) and 56 764.4 ft (17 301.8 m).

Usually, during the flight, the launch team tracks the balloon in ground vehicles, staying near or underneath the balloon to maximize packet reception. Certain radios require Line of Sight (LOS) in order to be received from the ground station, and recovery efforts are faster if the launch team is nearby when the balloon lands. During NS-69, however, while the balloon was being tracked throughout the flight via APRS, the launch team remained stationary to watch the eclipse. The team kept careful watch on two tracking websites (`https://aprs.fi` [7] and `https://tracker.habhub.org` [8]), to ensure the radios remained in range of the sent packets. After totality ended at 14:40:11 EDT, the launch team packed the launch equipment and resumed normal tracking operations.

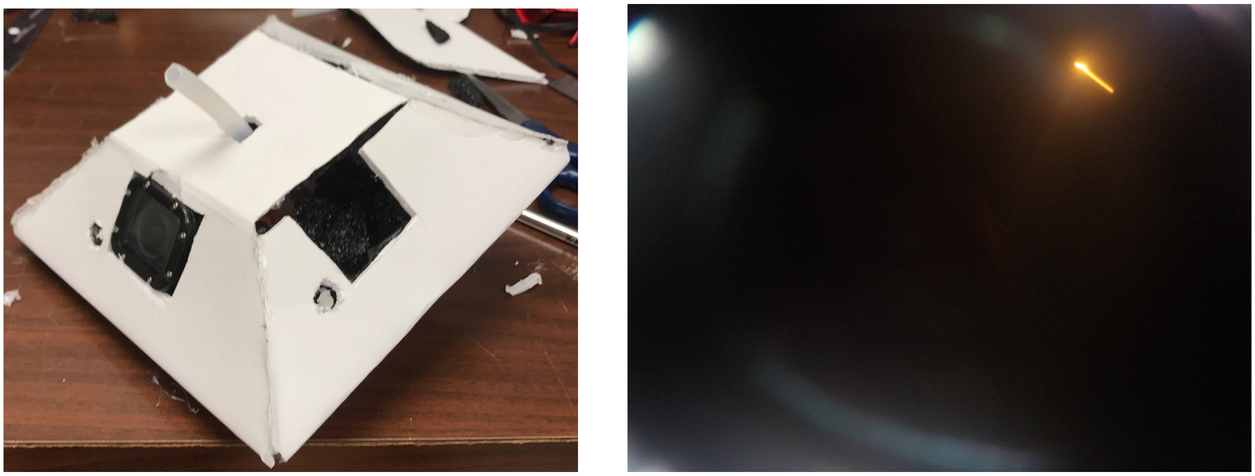
Depending on the particular ground track for a launch, recovery operations can take anywhere from one to five hours. This includes recovery operations such as finding and reaching the payload string in a tree, attempting to knock the payload string from the tree using a rope and slingshot, and waiting for a professional tree climber to recover the payloads from the tree. It is for this reason that team members are expected to allocate an entire day to a launch operation, even on flights launched in the morning.

The amount of time typical for recovery efforts could prove problematic for NS-69, as the balloon landed at 15:52:27 EDT. If recovery took more than a few hours, the sun might set before successful recovery. The ground track for the balloon predicted return a relatively short distance from the launch site. However, an unrecoverable landing location remained a likely enough possibility that the team by delegating a contingent recovery team of members willing to stay an extra day in South Carolina. Fortunately, this contingency was not necessary. The payload string landed in an open field, and was successfully recovered within fifteen minutes of visual sighting.

III. Key payloads and data

A. PARROT

PARROT (Payload Angled Reasonably Reclined to Observe Totality) is a structure of four GoPro Hero3 cameras angled at 62.9° elevation from horizon (Figure 3a) with solar filter fitted to observe the eclipse during totality. Unfortunately, the high exposure times of the cameras meant the Sun was not defined in the resulting images and instead ended up as orange streaks.



(a) PARROT during construction. **(b) Image from a GoPro Hero4 camera aboard PARROT.**

Fig. 3 PARROT overview

B. SESPA

SESPA (Solar Eclipse Solar Power Analyzer) was designed to analyze net coronal power output in visible light, assess the amount of sunlight refracted around the moon during totality, and measure eclipse progress by tracking voltages. The payload comprised of eight 3 V 200 mA photovoltaic cells purchased from Sundance Solar [9], eight 100 Ω resistors connected in parallel, an Arduino MEGA board, and an Adafruit MicroSD breakout board. Solar panel mounting surfaces on SESPA were oriented at 60° elevation (Figure 4a) to align with the sun and attain maximum solar power during totality.

Solar power values were calculated using the following formula:

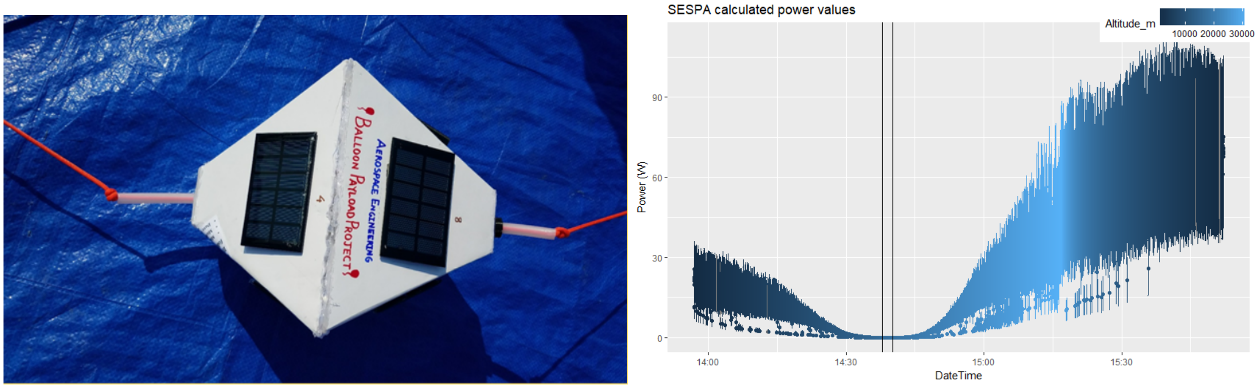
$$P = \frac{(V_{net})^2}{R_{net}} \tag{1}$$

where V_{net} is the sum of voltages output by the solar cells, and $R_{net} = (12.5 \pm 5.0)\,\Omega$, the sum of eight $100\,\Omega$ resistors in parallel. This resistance was used to calculate the power generated. A baseline of 80 W at 100 % sunlight was determined prior to launch. Recorded voltage measurements are accurate to 4.89×10^{-3} V.

At the time of launch, (13:56:54 EDT) net power was found to be about $(26.200\,00 \pm 0.009\,78)$ W. This implies that the amount of sunlight emitted would have been at 32.75 %. At launch, the eclipse factor was 43.1475 %, according to Stellarium [10]. During totality maximum coronal power output was found to be $(9.374 \pm 4.608) \times 10^{-5}$ W.

Figure 4b depicts recorded power in the time between balloon launch (13:56:54 EDT) and landing (15:52:27 EDT). From this data, it is estimated that $(1.1720 \pm 0.5760) \times 10^{-4}$ % of available sunlight reached the sensor. Final sunlight percentage values have an average propagated uncertainty of 13.72 %.

The angle of incidence of sunlight on the solar cells changed constantly during flight as winds swayed the payload string and rotated the payload. As efficiency of solar cells is directly proportional to incident sunlight [11], consecutive recorded values did not act according to predicted behavior. These outliers which showed voltage much lower than expected were omitted from the graph. Considering that the solar cells have an efficiency rating of nearly 15 % [9], we estimate the maximum coronal output reaching the sensor during totality to be $(6.249 \pm 3.072) \times 10^{-4}$ W.



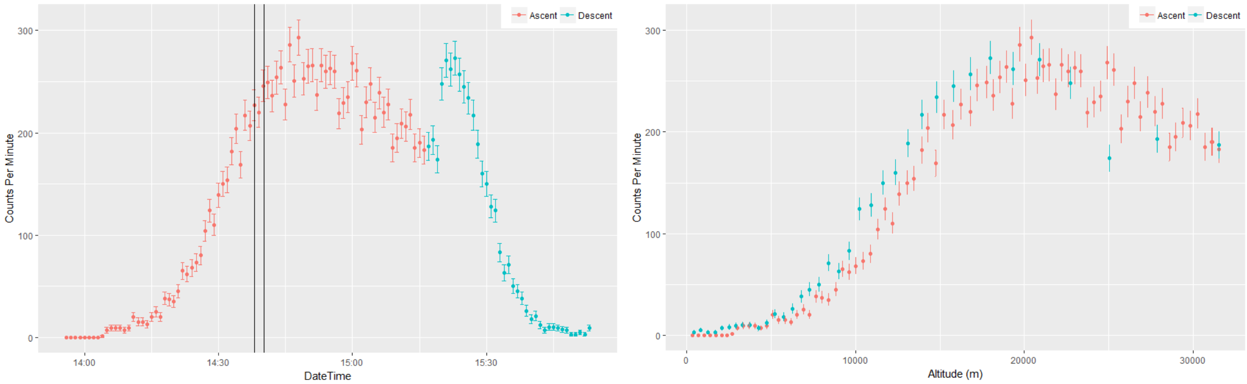
(a) SESPA, attached to payload string at the launch site. **(b) SESPA received wattage. Vertical lines indicate start and end of totality.**

Fig. 4 SESPA overview

C. IRENE

IRENE (Ionizing Radiation Exposure Nearspace Experiment) is small Geiger-Muller Tube detector intended to measure the Pfotzer maximum in the upper atmosphere. The detector uses a small cylindrical full metal Geiger-Muller tube and is sensitive to Gamma and Beta radiation. Being a Geiger Tube, the detector only records ionization events and not the individual energies of the particles. At one minute intervals the detector stores the time and number of counts that occurred during the previous minute.

The Pfotzer Maximum, or Pfotzer curve, is named after Georg Pfotzer who did experiments with Geiger Counters on high altitude balloons in the 1950's and 1960's. Ionization events increase quickly with altitude to a certain point in the atmosphere, and then decrease in a more leisurely fashion until reaching a relatively stable level in space (neglecting the influence of the Van Allen Radiation Belts). This is due to secondary ionizing particles being created by incident radiation interacting with the low density air in the upper atmosphere, where there is enough air to cause such secondary scattering, but not enough to have significantly blocked said incident radiation from reaching the detector.



(a) IRENE counts as a function of time. Vertical lines indicate start and end of totality. **(b) IRENE counts as a function of recorded altitude.**

Fig. 5 IRENE measurements

The results from this flight indicate a slight difference between data points closer in time to totality (which occurred during ascent) and events at similar altitudes taken during descent, after totality. In previous non-eclipse flights, the descent curve shows a slightly higher count rate for such points, an artifact of the fact that during decent the one minute recording intervals are timestamped at the endpoint and cover a larger altitude range. Additionally, such points error bars are usually overlapping, indicating they are within statistical noise. Data from this flight shows a clear difference as opposed to previous flights, evidenced by a portion of point's error bars not overlapping for similar altitudes as seen in

5b. This suggests that the eclipse did have a momentary effect on the intensity of the ionizing radiation in the high upper atmosphere, albeit small.

D. ATOMIC

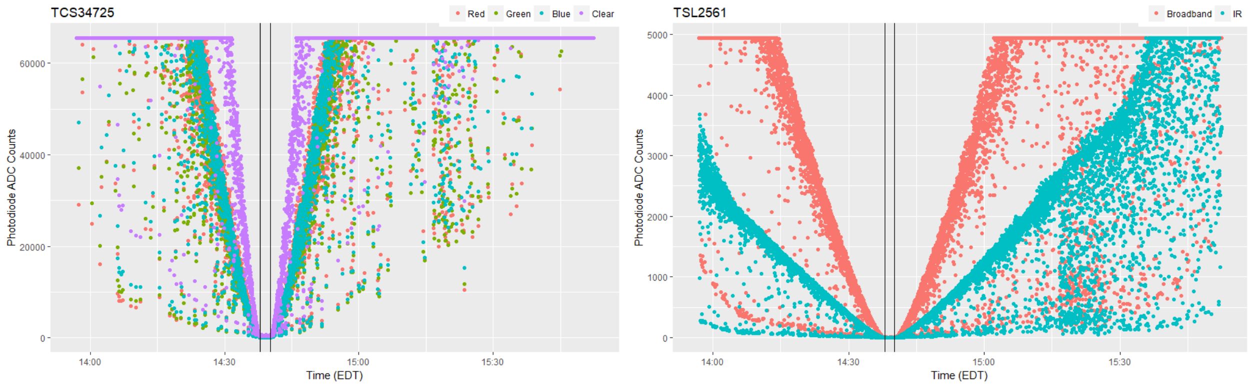
ATOMIC (Atmospheric Thindown Originating Mutagenesis Investigational Capsule) is designed to analyze the effect of atmospheric ionizing radiation on the development of mutations in micro-organisms. Prior research has established both the presence of populations of micro-organisms at high altitudes [12], and the efficacy of high-energy ionizing radiation in damaging DNA and causing mutations in organisms. However, for the most part the literature does not delve into the implications of combining these two sets of findings, specifically the possibility that fluctuations in the levels of ionizing radiation that are experienced in the atmosphere might cause notable changes in mutation rates. A total solar eclipse was a particularly suitable stage for testing this hypothesis, as it would be associated with a decrease in the altitude of the ionosphere and would thus cause any airborne micro-organisms to experience a larger than average dose of ionizing radiation.

In order to test this phenomenon, ATOMIC carried sealed agar-plate cultures of two species of bacteria – *Bacillus subtilis* and *E. coli*. Both species were chosen for their resilience and ubiquity in the environment, and the cultures purchased were specifically non-pathogenic classroom-grade strains. They were grown on agar containing the nutrient media lysogeny broth, along with 40 % glycerol. The glycerol was discovered during pre-flight testing as a means of preventing syneresis of the agar and thereby preserving sample integrity.

After a successful launch, ATOMIC was recovered without issue. Cryogenic stocks were prepared from the agar plates that were flown, and were kept in storage until they could be processed for sequencing.

E. LEOPARD

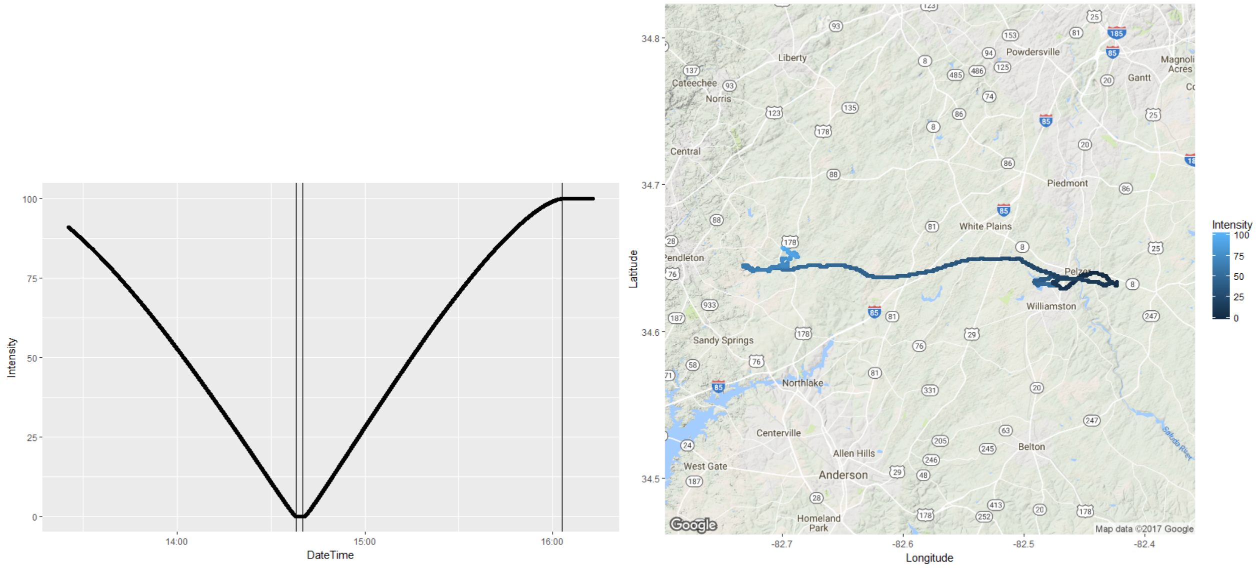
LEOPARD (Lightweight Eclipse-Observing Payload for Ambient Radiance Determination) was designed to measure ambient light intensity during flight. It is equipped with a TAOS (Texas Advanced Optoelectronic Solutions) TSL2561 lux sensor (Figure 6b) and TCS34725 color sensor (Figure 6a), along with a SiLabs SI1145 UV index and light sensor, although the SI1145 failed to function properly. All of these sensors operate by using one or more photodiodes to generate a current proportional to the available light and measuring it with an analog-to-digital converter (ADC). Figure 6 shows the data from these sensors, in ADC counts; there is a marked decrease in available light in throughout the visible and infrared bands near totality. Unfortunately, both the TSL and TCS saturated before the eclipse ended, so it is not meaningful to quantify the rates at which the available light changed. Figure 7 shows the expected sunlight intensity along the balloon's track, expressed as a percent of full exposure, calculated using AGI's Systems Tool Kit (STK) software. The change in sunlight intensity occurred over a significantly longer period of time than is evident from the LEOPARD data, consistent with saturation of the LEOPARD sensors.



(a) TAOS TCS34725 color sensor. Vertical lines indicate start and end of totality.

(b) TAOS TSL2561 lux sensor. Vertical lines indicate start and end of totality.

Fig. 6 LEOPARD Measurements



(a) LEOPARD calculated intensity values. Vertical lines indicate start and end of totality, as well as end of eclipse duration.

(b) LEOPARD calculated intensity [2].

Fig. 7 LEOPARD Calculated Intensity

F. Panoramic

Panoramic (not an acronym) is comprised of two Samsung Gear 360 v1 cameras housed in insulating foam. The payload captured panoramic video of launch, ascent, totality, and balloon burst. The recording stopped shortly after burst, which is typically when the UMDBPP records the coldest temperatures of balloon flights. We suspect this made the camera equipment inoperable until landing.

Fig. 8 Still frame from Panoramic payload video [13], showing approaching umbral shadow 97 s **before totality.**

IV. Discussion

A. Recommended changes

Although NS-69 was generally successful in terms of acquiring eclipse-related data, the UMDBPP team identified a number of areas which, in retrospect, could have been improved upon. Operationally, a major of area of improvement the team identified was in contacting the school that hosted the launch site. This contact was made only a few days before the launch, which limited the team's ability to engage in outreach. While uncertainties in the balloon's ground track precluded picking a definitive launch site too far ahead of time, it would have been beneficial to contact a few schools that were good candidates far enough in advance to allow for the possibility of a stronger outreach program.

Another improvement in launch site selection was identified during post-launch discussions with Xavier Jubier, an astronomer who publishes eclipse maps. He observed that location of the umbra is not the same at ground level as at altitude, and can in fact vary by more than 10 km (figure 9). The UMDBPP team failed to consider this during launch site selection, which was major oversight. The launch site in Williamston was selected because it was near the center of the umbral path, so any deviations from the predicted trajectory were expected to keep the balloon within the umbral path. This conservative launch site selection ensured that the team's miscalculation did not prevent the balloon from experiencing totality, but a launch site closer to the edge of the umbral path might have. It is therefore strongly recommended that future eclipse flights use tools that consider the variation in the umbral path with altitude when selecting a launch site.

A final area of improvement the team identified was the need for better payload testing. Most of the payloads on NS-69 collected useful data, but the quality of some of the data was significantly degraded due to issues that would have been identified during testing in an operational environment. For example, the camera settings on the PARROT payload were suboptimal for capturing clear images of the sun, and some of the sensors on LEOPARD suffered from saturation effects. Given the rarity of solar eclipses, it would have beneficial to test the payloads more thoroughly prior to the eclipse, ideally on a balloon flight, in order to ensure the eclipse launch collected the most useful data possible.

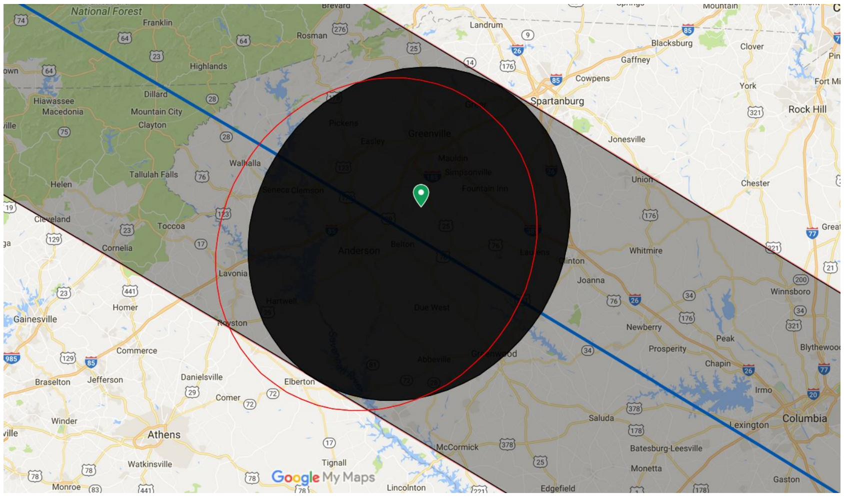


Fig. 9 A map, based on data provided by Xavier Jubier, showing the eclipse umbral extent at ground level (dark ellipse) and 55000 feet (red line). The balloon's position at this time (at altitude 56000 feet) is indicated by the green marker.

B. Significance

1. Scientific merit

Total solar eclipses provide a rare opportunity to study the manner in which various environmental parameters vary in relation to solar radiation changes, as well as the chance to verify the accuracy of relevant models and theories. Given the significance of solar irradiance in the dynamics and composition of the atmosphere, radio communications, and terrestrially-based biological and biochemical processes, increasing understanding of the manner in which the environment responds to rapid decreases in solar radiation is of interest to the scientific community as a whole. High altitude ballooning is a testing bed that is well suited to measuring such changes, as it provides the ability to measure atmospheric variables at altitudes that are less subject to localized weather patterns capable of skewing data.

2. Value as an outreach/educational tool

For NS-69, students and staff of the school that hosted the launch were invited to observe launch proceedings, an opportunity that helped foster interest in science and engineering in general and increase awareness of high altitude ballooning as an accessible means of conducting scientific research. The launched payloads also included a number of cameras that were dedicated to taking photographs and video during the eclipse, thereby allowing visitors and other members of the public to have a better understanding of the unique perspective and environment involved in high altitude ballooning.

In general, the solar eclipse launch helped highlight high altitude ballooning as a research platform that combines aspects of aerospace and atmospheric science with a selection of scientific disciplines as diverse as electrical engineering and biology. Its accessibility, by virtue of its relatively low cost and the availability of open-source plans for high altitude ballooning equipment and software, along with the flexibility ballooning offers in terms of launch locations makes it an ideal platform to use to encourage and empower student involvement in the sciences. The very premise of sending items into the near-space environment, beyond the domain of most human travel, and of having the capacity to vicariously interact with the inaccessible, is an exciting premise that high altitude ballooning provides a means of introducing students to the wide range of possibilities in scientific research.

V. Acknowledgments

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References

[1] Burnett, Z., “Flight Statistics,” , 2017. URL `http://nearspace.umd.edu/archives/Launch_Data/Overall/flight_statistics.nb.html`.

[2] Kahle, D., and Wickham, H., “ggmap: Spatial Visualization with ggplot2,” *The R Journal*, Vol. 5, No. 1, 2013, pp. 144–161. URL `http://journal.r-project.org/archive/2013-1/kahle-wickham.pdf`.

[3] Burnett, Z., “Flight Summary,” , 2017. URL `http://nearspace.umd.edu/archives/Launch_Data/Overall/flight_summary.nb.html`.

[4] UMDBPP, “NS-69 Archive,” , 2017. URL `http://nearspace.umd.edu/archives/Launch_Data/NS-69_2017-08-21/`.

[5] HABhub, “HABhub Predict,” , 2017. URL `http://predict.habhub.org`.

[6] Jubier, X., “Eclipse Maps,” , 2017. URL `http://xjubier.free.fr/en/site_pages/solar_eclipses/`.

[7] aprs.fi, “APRS.fi,” , 2017. URL `https://aprs.fi`.

[8] HABhub, “HABhub Tracker,” , 2017. URL `https://tracker.habhub.org`.

[9] Solar, S., “3 V 200 mA Solar Cells,” , 2017. URL `http://store.sundancesolar.com/3-0v-200ma-solar-cell-with-wires-10-pack/`.

[10] stellarium.org, “Stellarium,” , 2017. URL `http://stellarium.org`, v0.16.0.

[11] classroom.synonym.com, “The Effects of the Angle of Sunlight on a Solar Panel,” , 2017. URL `http://classroom.synonym.com/effects-angle-sunlight-solar-panel-33180.html`.

[12] Burrows, S. M., Elbert, W., Lawrence, M., and Pöschl, U., “Bacteria in the global atmosphere–Part 1: Review and synthesis of literature data for different ecosystems,” *Atmospheric Chemistry and Physics*, Vol. 9, No. 23, 2009, pp. 9263–9280.

[13] Burnett, Z., “Panoramic Video Playlist,” , 2017. URL `https://www.youtube.com/playlist?list=PLtrPXwuRkAaXe04zCuh9IQdeuGx4gVABI`.

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