Stratospheric Eclipse Ballooning in 2023 and 2024: The U of MN – Twin Cities Experience Continues

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Abstract

The stratospheric ballooning team at the U of MN – Twin Cities served as the "Central" Engineering pod-lead team for the Nationwide Eclipse Ballooning Project (NEBP). Besides helping train other teams in our pod, over several years our team helped work on a variety of projects in support of NEBP, most notably (A) the development of an autonomous vent (ultimately not selected, in favor of Montana's Iridium-commandable vent), (B) the HERMES GUI for the video-streaming ground station, and (C) the PTERODACTYL flight computer / sensor suite. Eight students and a faculty adviser, plus several former ballooning students, made eclipse trips to New Mexico in October 2023 and to Indiana in April 2024. This article gives an overview of our successes and challenges with NEBP payloads (and other payloads) flown during the two eclipses. Video-streaming turned out to be our biggest challenge and ultimately we lost the hardware altogether while driving to the second eclipse (ouch!), so we were unable to even attempt video-streaming during the total solar eclipse. Our PTERODACTYL flight computer worked well and generated valuable data for many NEBP teams, including ours. Venting worked well and allowed us to improve stability for photography on both eclipse dates, though venting failed on some practice flights. We were particularly-pleased with the 360-video footage we collected during both eclipses. This paper will also discuss other payloads that we flew on eclipse missions but still need work, including one designed to actively point cameras at the Sun using a Pixy-camera-pointed pan/tilt mechanism.

1. Introduction

The early 2020s were an exciting time for the Minnesota Space Grant Consortium's (MnSGC) University of Minnesota - Twin Cities (UMTC) Stratospheric Ballooning Team. The team is advised by Professor James Flaten and has conducted over 200 weather balloon launches, starting in 2007. The team has participated in many ballooning-related extra-curricular and outreach events, freshmen seminars, and ballooning workshops. Our team was first involved in eclipse ballooning in 2017 (see Ref. [1]). This paper discusses our more-recent experiences as a "pod lead" in the "engineering side" (AKA the "video-streaming side") of NASA's Nationwide Eclipse Ballooning Project (NEBP).[2] In collaboration with Montana State University, and many other

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ballooning teams around the country, our team has been focusing on preparations for the 2023 and 2024 solar eclipses since 2021. Here we highlight some of our ballooning team's experiences, payload development, and data gathered in preparation for and during the 2023 and 2024 solar eclipses.

2. Eclipse Hardware and Software Development

Development of the Autonomous Eclipse Vent (AKA "e-vent") - ultimately not selected for NEBP implementation Early in the NEBP program, our team put in significant effort working on an autonomous vent that we called the "eclipse vent," or "e-vent" for short. The product of that effort is described in Reference 3. Although the e-vent was not ultimately selected for widespread NEBP use, working on it had a lasting impact on our team's ballooning capabilities. We may eventually return to that concept and try to combine it with an Iridium-commanded vent design for a venting device that is both commandable but also has sensors and is smart enough to make reasonable decisions on its own if ground-commanding happens to be unreliable on any given flight.

Modifications made to the MT 3D-printed vent The vent ultimately used by the UMTC team went through multiple iterations before the 2023 and 2024 eclipses. In early 2023, the UMTC team adopted the 3D-printed vent design developed by Montana State University (MSU). Early on we started to use a vent with a bolted-on top. A switch to hydrogen as a lift gas for our balloon flights required adding a hydrogen fill nozzle to the vent, so now we have both a helium and a hydrogen nozzle next to each other on the same vent for lift-gas flexibility. We have even occasionally done flights with a mixture of hydrogen and helium. After snapping off several 3D printed attachment points during one flight (and losing our NEBP-provided parachute), we incorporated steel turnbuckles into the vent design so there is a continuous metal connection between where the parachute attaches, above the vent, to where the payloads attach, below the vent. Difficulty in getting balloons to stay on the neck insert during inflation and ascent, but then to slip off the neck insert reliably when a string is cut, led us to adopt the 'Marman band' balloon release mechanism promoted by the University of Maryland.[4] The Marman clamp released the balloon more consistently than a traditional wrapping technique, but significantly increased complexity. After failure to achieve a clear release during the 2023 eclipse flight, we added a spring to force the Marman clamp open. This approach was successful in later test flights, and also during the 2024 eclipse.

Parachute Wrapping We adopted the parachute wrapping inside a "swaddle" cloth technique for vented flights, as promoted by Montana State University. In our case, we run a rigging line through the grommets in the swaddle cloth, not a rubber band, and we loop that line over a post on the side of the vent, with the bundled parachute sitting on a small platform beside the post. We consider the parachute swaddle a work in progress. We still experience occasional premature parachute releases during launch, especially in windy conditions when the act of releasing the stack can jerk the parachute enough to knock the string loop off the post, opening the parachute (upside down) and thereby slowing ascent and increasing the risk of tangling.

PTERODACTYL We designed, tested, flew, distributed kits, and supported the use of the PTERODACTYL flight computer [5] by all NEBP "engineering" teams. The biggest change to PTERODACTYL since the kits were originally distributed to NEBP teams is to the GPS system. The latest flight code includes North East Down (NED) velocities, horizontal and vertical accuracy measurements, and increased polling frequency and stability from a rough 5Hz to a stable 25Hz. On the hardware side of the GPS, an off-board configuration on I2C line 1 (Wire1) on a custom ground plate was shown to improve GPS signal. This is because the on-board chip antenna experienced a lot of interference from the pins on the Teensy 4.1, since it was physically so close to the Teensy 4.1 when mounted on the PTERODACTYL PCB. The PCB has since been updated to version 3.8, on which the GPS module is facing the opposite direction, to be as far as possible from any interference. Another addition to the PTERODACTYL PCB is the ZED-F9P RTK GPS module and the NEO-D9S corrections receiver. The F9P seems to be more accurate than the M9N, and is even more accurate when combined with the D9S. However, the update frequency drops to 10Hz with just the F9P and to 1Hz with the D9S.

One post-2024-eclipse code change corrected a bug with handling of leading and trailing zeros on logged latitude and longitude values. ECEF logged values were not affected by this change. For the most-current PTERODACTYL flight code, go to the PTERODACTYL Google Drive Folder https://drive.google.com/drive/folders/1AHkEVTcYGjr29ESmD6pJE1bOII95peQj?usp=sharing. If incorrectly-logged latitude and longitude values are interfering with data analysis, logged ECEF values can be converted to latitude, longitude, and altitude after-the-fact as need be.

RFD900 Payload and Its Ground Station The team had spotty success with the RFD900 payload onboard logging, and even less success with RFD900 data telemetry at altitude. The team found that the GPS on the RFD900 was sometimes inconsistent, and often struggled to obtain and maintain a GPS lock. In the summer leading up to the 2023 eclipse, telemetry was successful using the RFD900 ground station - the team was able to get telemetry data during ascent for two separate test flights. However, during the 2023 annual eclipse flight the RFD900 payload was set up incorrectly and hence failed to record data. The ground station software being used at the time - a version of HERMES (see below) - did not log the RFD900 telemetry data it received. During test flights between eclipses, the team was unable to successfully receive RFD900 telemetry from balloons at altitude. Unfortunately, during the trip to Indiana for the 2024 eclipse the RFD900 payload was lost so the team was not even able to fly the RFD900 system during the 2024 eclipse.

Raspberry Pi Video Streaming Payload Our team struggled with the video-streaming hardware and software for the duration of the NEBP. Even when the ground station seemed to be pointing appropriately, which was not the case on every test flight, often little or no video was successfully received from balloons once they were at altitude. Our best result was intermittent video on one flight at a line-of-sight distance of just over 30 miles, but that would have been on the short range side for most flights, even if it had been reliable. During the annular eclipse in 2023 the ground station sub-team was only able to get a few minutes of rather uninteresting mid-ascent streamed video to the ground and passed through to YouTube. Between the eclipses we attempted to switch to a Raspberry Pi 5 system, but that proved finicky as well. One last attempt to establish a video link during a ground test at a distance of just over one mile failed a few days before the 2024 eclipse trip. And, to add insult to injury, the tote with the video-streaming payload (and the RFD900 payload) vanished from the back of our pickup truck during our drive to Indiana for the 2024 total solar eclipse, so we did not even have a chance to try live-streaming on the total eclipse day.

HERMES Ground Station Software Streaming video footage from onboard cameras in real time requires constant line-of-sight communication between the payload and a ground station with a parabolic antenna. To automate the pointing of such an antenna for the duration of the eclipse flights, the team developed a program called “HERMES,” an all-in-one telemetry GUI designed to continuously receive GPS data from multiple radio channels, calculate pointing angles for the ground station, and display a live video stream plus housekeeping data on a single screen. For an in-depth discussion on the development of HERMES, its core functionality, and its extra features, see the manuscript published separately at AHAC 2024 entitled “Development of the HERMES Ground Station GUI for Antenna Pointing by NEBP Engineering Teams.” [6]

Pixy-Pointing Payload Project During a weather balloon flight, accurately pointing cameras and other sensors at the Sun while the payloads are swinging and swaying is challenging and requires some mechanism to sense the direction of the sun and some mechanism to pan and tilt the camera(s)/sensor(s) in the correct direction. The goal of the “Pixy” project is to address this problem by setting up a Sun-tracking system based on a machine-vision Pixy camera to record footage that mostly focuses on the Sun. This would be particularly-useful during a solar eclipse.

In order to track the sun, the Pixy-camera - a camera for hobbyists learning computer vision - was mounted on a setup involving a sort of “clamshell” platform and a rotating base, all under a Plexiglas dome. The clamshell upon which the Pixy-camera was mounted provided the ability to tilt the platform up and down, with the rotating base giving the platform the ability to yaw. The platform was tilted by a pair of linear actuators and was almost entirely 3D printed using low-infill PLA. The rotating base was controlled by a stepper motor and consisted of a flat, ball-bearing turntable which connected the 3D printed base of the clamshell to a mounting plate firmly attached to the payload box itself. All the batteries and circuitry of the entire setup were mounted on the clamshell platform, to avoid the potential of tangled wires caused by the rotation of the motor.

The Pixy-camera came with a pre-programmed ability to recognize colors, so it was trained to track the color orange, which is what the Sun looks like through a solar filter placed over the Pixy-camera lens. The Pixy camera code ran on an Arduino Uno which also controlled the linear actuators and the stepper motor. Every time the Pixy-camera detected a shift in the position of the Sun, it would adjust the linear actuators and the stepper motor to attempt to re-center the Sun in its view. Two other cameras were mounted on the same platform, next to the Pixy-camera, so when the Pixy-camera panned and tilted the platform those cameras also had the Sun in the center of their views.

During the 2024 eclipse, the Sun-tracking payload was sent up with a Pixy-camera, a wide-angle GoPro camera, and a Raspberry Pi telephoto camera. Unfortunately, both of the cameras failed to record. On previous test flights, the GoPro was having issues with recording full videos. We assumed it was due to low temperature, so we placed a heater to keep the GoPro warm, which caused it to overheat and shut off. The Raspberry camera failed due to a subtle Python coding error. Python is not friendly with unnecessary white space, and a space was accidentally added to a line of the code that prevented the code from compiling.

After analyzing footage from the Insta360 camera mounted on the same stack above the Pixy payload, we noticed that the Sun-tracking system seemed to work during the first half of the flight but stopped tracking the Sun during the second half of the flight (including during totality). Our assumption is that the stepper motor, which is used to handle the horizontal movement of the system, ran out of battery. In the future we will try to improve the system so that it can handle a wider variety of temperatures, has more consistent tracking, and is more power efficient. The Pixy payload is already quite heavy, so we will try to avoid adding additional batteries.

Noé and Seyon's Neulog Payload Another custom payload box built for the 2024 total solar eclipse was intended to study the changes in light intensity of various wavelengths during the course of the entire balloon flight, with an emphasis on studying light levels during totality. This box was shaped to point all its light sensors towards the Sun, at least when the payload rotates (upon occasion) to face the Sun.

Noé and Seyon's Neulog payload was an extension or the previous solar-powered payload experiment SONIA [7], which focused on testing solar panel efficiency during ascent through the atmosphere. Although similar in concept, this new payload also implemented the use of Neulog "visible light", UV-A, and UV-B modules, which would help understand the light intensity for each range at different altitudes as the eclipse progressed. As seen in Figure 9, the peak light intensity in all ranges decreased as totality approached, with regular variation due to the payload rotating so the sensors were not always pointing directly toward the Sun. However, venting was so successful in quashing rotation that during totality the light sensors and nearby GoPro camera were not pointing toward the Sun, which prevented them from documenting the most interesting part of the light intensity change.

The Neulog payload also contained a Geiger counter, which was used to monitor cosmic radiation. This instrument did require a specific orientation with respect to the Sun to measure data. As observed in Figure 10, there is little to no variation in the radiation levels when the Moon covers the Sun, in agreement with the suggestion that most cosmic radiation comes from deep space rather than from the Sun

The Neulog payload also included a solar panel, with current and voltage sensors to monitor the solar panel output during the flight. However, those sensors only presented an initial spike during the first 10 minutes then reported constant values through the remainder of the flight – incorrect - so that experiment apparently failed.

3. The 2023 Annular Solar Eclipse - Road Trip to New Mexico

The team drove to Soccoro, New Mexico, for the 2023 annular eclipse - a 20-hour drive each way! On the day of the eclipse, the ground station sub-team set up in Vaughn, New Mexico, and the launch sub-team set up Willard, New Mexico. The launch team flew two stacks, one vented NEBP stack and a second stack with other UMTC custom payloads. A pack of stray puppies kept the launch sub-team company (see Fig. 1). We did not take any puppies home with us, though we were encouraged to do so. The UMTC stack landed in a pasture with cattle, making for an interesting recovery. The vented NEBP stack failed to cut properly, so it was commanded to "vent-vent-vent" and ultimately it came down slowly and landed, with its balloon still intact, over 150 miles from the launch site and nearly across the border into Texas.

Fig. 1. A puppy greeting Ethan Thompson-Jewell (left), Ashton Posey (center), and Seyon Wallo (right), while filling two balloons to fly during the 2023 annular solar eclipse

In addition to eclipse glasses, our team used Sunspotter solar telescopes for easy and safe viewing of the eclipse. Fig. 2 and 3 show how the Sunspotter projects an image of the Sun onto a piece of paper. Multiple people can view the projection of the Sun simultaneously, making the Sunspotter a particularly-useful tool for outreach and solar viewing (not just eclipse viewing).

Fig. 2. A Sunspotter solar telescope projecting an image of the beginning of the annular eclipse in 2023.

Fig. 3. A closeup of the annual eclipse near annularity, as viewed with a Sunspotter solar telescope.

Despite the vented stack's slow descent, the recovery of both stacks went smoothly (see Fig. 4). The team agreed that recovery is easier in the farmland of Minnesota, compared to the mountains and deserts and barbed wire of New Mexico.

Fig. 4. Part of the UMTC team recovering the NEBP stack in New Mexico. Left to right: Jasmine Thayer, Yoel Mekbeb, Ethan Thompson-Jewell, Ashton Posey, and Seyon Wallo.

4. The 2024 Total Solar Eclipse - Road Trip to Indiana

The team traveled to Muncie, Indiana, for the 2024 total solar eclipse. Unfortunately, along the way one tote vanished out of the back of our pickup which contained the RFD900 payload and the Raspberry Pi video-streaming payload. Despite this setback, the team launched 3 stacks on the day of the eclipse from Lizton, Indiana, with the assistance of high school students who joined us from Hutchinson, Minnesota. The ground station sub-team monitored the flights from the campus of

Ball State University in Muncie, but did not have any streaming video nor RFD900 transmissions to try to pick up. Fig. 5 below shows the inflated balloons, ready for timed release. The vented NEBP balloon is in the foreground. Vent commanding went well, and the team was able to achieve a floated stack at 79,000 feet ASL prior to totality - see altitude vs time graph (see Fig. 7). Both of the other balloons were higher, but still ascending, as totality occurred. About 20 minutes after the end of totality, as we were considering sending a cut command, the vented stack unexpectedly began to descend at a high rate of speed. We thought it might have been due to the timed cut going off one hour earlier than expected, but video footage examined later shows the balloon actually bursting - unexpected, since we did not let the balloon go to burst altitude. We were fortunate that happened after the eclipse shadow had already passed. All 3 stacks were recovered without incident, after which the team went out for a celebratory meal (see Fig. 6).

Fig. 5. Inflating 3 balloons to fly into the path of totality during the 2024 total solar eclipse.

Fig. 6. Post-recovery photo of “eclipse travel team” plus alums (3) and other guests (2).

5. Notable Results

A: Figures 7 and 8 show altitude vs time graphs for our two vented NEBP eclipse flights, based on aprs tracking records, with times for annularity and totality indicated. On both flights we were able to achieve float just before maximum obscuration. Like some other NEBP teams that vented balloons to float, on both flights we saw a decrease then recovery of altitude which we ascribe to eclipse-induced cooling then re-warming of the balloon at altitude based on solar exposure. However, this effect was not as strong during the total solar eclipse than during the annular solar eclipse, which is odd. The commanded cut-down failed to release the balloon on the annular eclipse flight – the string was cut, but the Marman band failed to come off. This issue has since been resolved by making the Marman band spring-loaded.

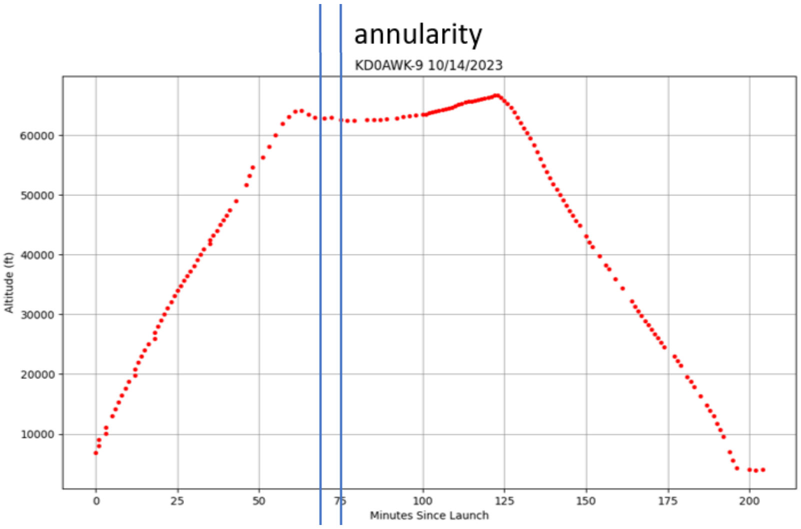

Fig. 7. Altitude vs time graph for flight during the annular eclipse on 10/14/2023. The dip then recovery in altitude, which was also noted by other NEBP teams, is thought to be eclipse-induced. The cut-down failed on this flight, so the descent was slow - "under balloon," rather than "under parachute".

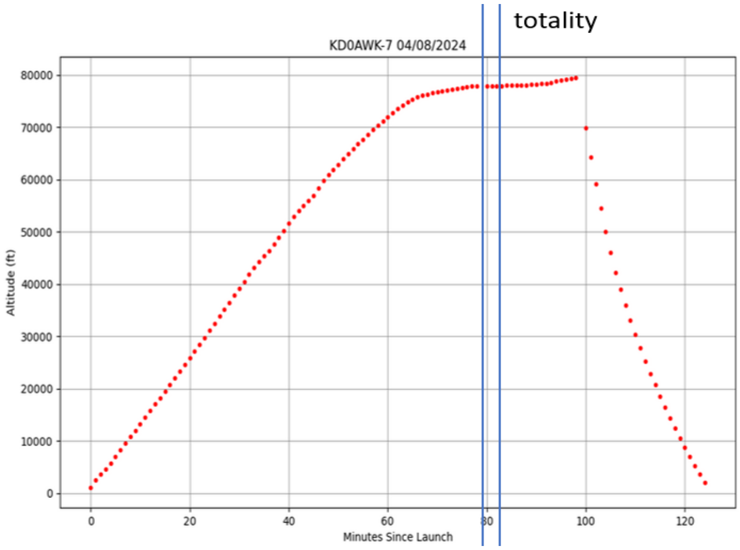

Fig. 8. Altitude vs time graph for flight during the total eclipse on 4/8/2024. Despite the fact that this was a total eclipse, not just annular, the dip then recovery feature was much less pronounced during this flight. The cut-down worked, so descent was fast - "under parachute."

B: In the absence of the video-streaming payload and the RFD900 payload during the total eclipse flight, we elected to add a payload with Neulog light sensors, pressure sensors, and a Geiger counter on the NEBP stack. The camera and light sensors failed to capture the total eclipse because venting made it so calm that the sensors were literally looking away from the Sun for the duration of totality (see Fig. 9). Geiger counter data was collected until just past burst - during and well beyond totality - and did not dip during the eclipse (see Fig. 10). This is consistent with Victor Hess' work in the early 1900's, for which he was awarded the 1936 Nobel Prize for discovering cosmic radiation. [8]

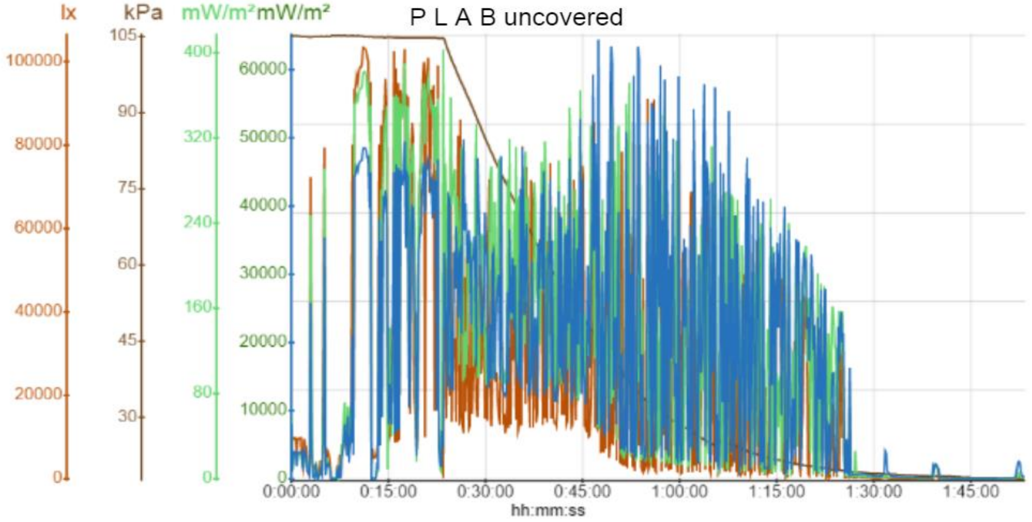

Fig. 9. Pressure, visible light, UVA, and UVB intensity, all versus time from the Neulog payload. The battery failed shortly before the balloon burst (unexpectely), but data was collected through and beyond totality. Intensity variation is due to payload rotation. Once vented, the payload ended up pointing away from the Sun and was so still that the light sensors (and the camera) missed seeing the eclipse altogether!

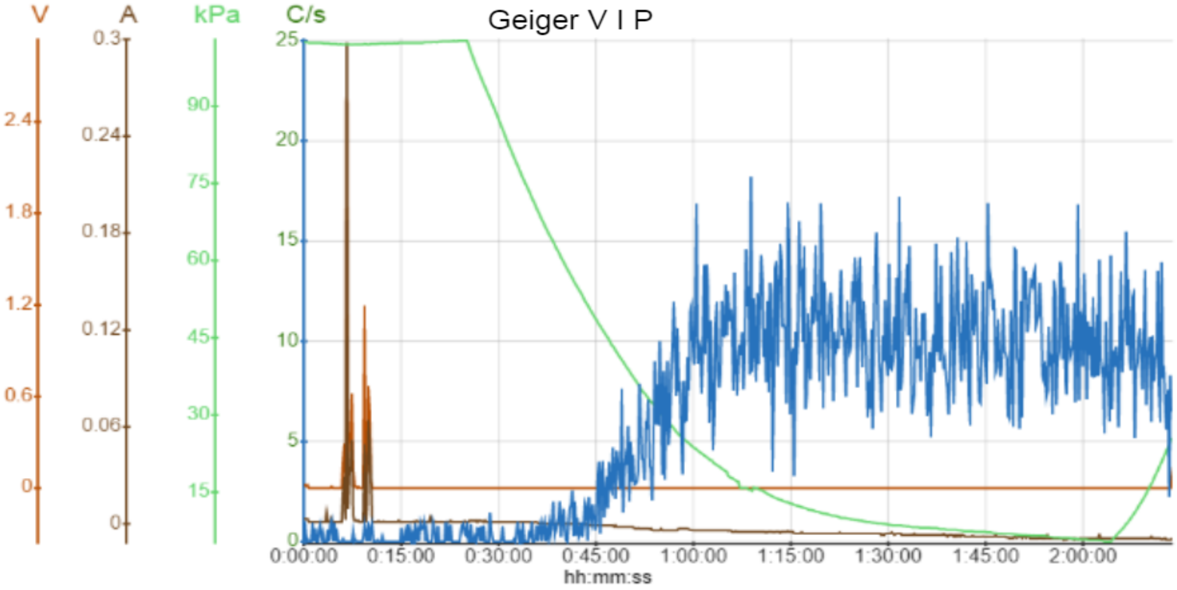

Fig. 10. Pressure, solar panel voltage and current, and Geiger counts, all versus time from the Neulog payload. The battery failed shortly after the balloon burst (evident by the increasing pressure), which was well after totality. The passing eclipse shadow had no noticeable effect on the Geiger counts (AKA the cosmic radiation level).

C: We were particularly pleased with the 360-video footage we were able to acquire from 2 balloons during the annular eclipse, and another 3 balloons during the total eclipse, using an Insta360 ONE RS camera, an Insta360 X2 camera, and a Garmin VIRB camera. Some of our footage, and ways we view it including using VR goggles, were presented in a poster/exhibit at AHAC 2024.[9] Of particular note is the 360-video from our vented NEBP flight during the total solar eclipse which was so still that post-flight digital stabilization of the footage was not even necessary. Figure 11 shows a series of photos from the well-stabilized video, showing that the eclipse shadow literally followed a straight line as it crossed the field of view. That stunning 360-footage, with some logos added, can be viewed at https://www.youtube.com/watch?v=flIrnfth9Rg.

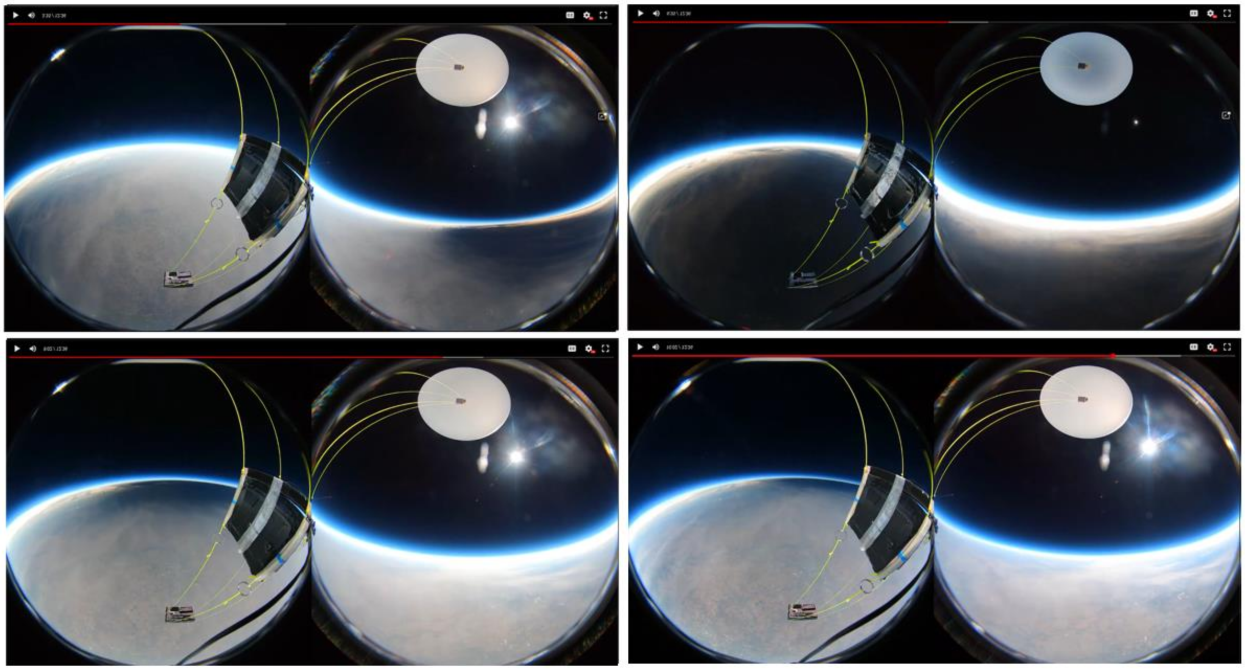

Fig. 11. Still images from Insta360 ONE RS camera showing shadow 1 minute before start of totality (upper left), mid-totality (upper right), 1 minute after end of totality (lower left), and 2 minutes after end of totality (lower right) taken from 79,000 feet ASL. The payload was so well-stabilized that the shadow moves in a straight line and the camera on the payload hanging below was pointing in the wrong direction and missed seeing the Sun get eclipsed!

D: In addition to Sunspotter telescopes (mentioned earlier), we purchased a Seestar S50 telescope to observe the total eclipse from the ground. Ballooning team alum Noé Bazan unilaterally learned to use the S50 and was able to make a great video of the Sun during totality. Here is a direct link: https://drive.google.com/file/d/1DGALTAvQC9JrQm2ZXOLPNT859RcTv9OL/view. The two still images from his video, show in Figure 12, show dramatic evolution even during the short duration of totality of several features extending out from the limb of the Sun, far enough out to be seen from Earth despite the Moon covering the Sun's photosphere.

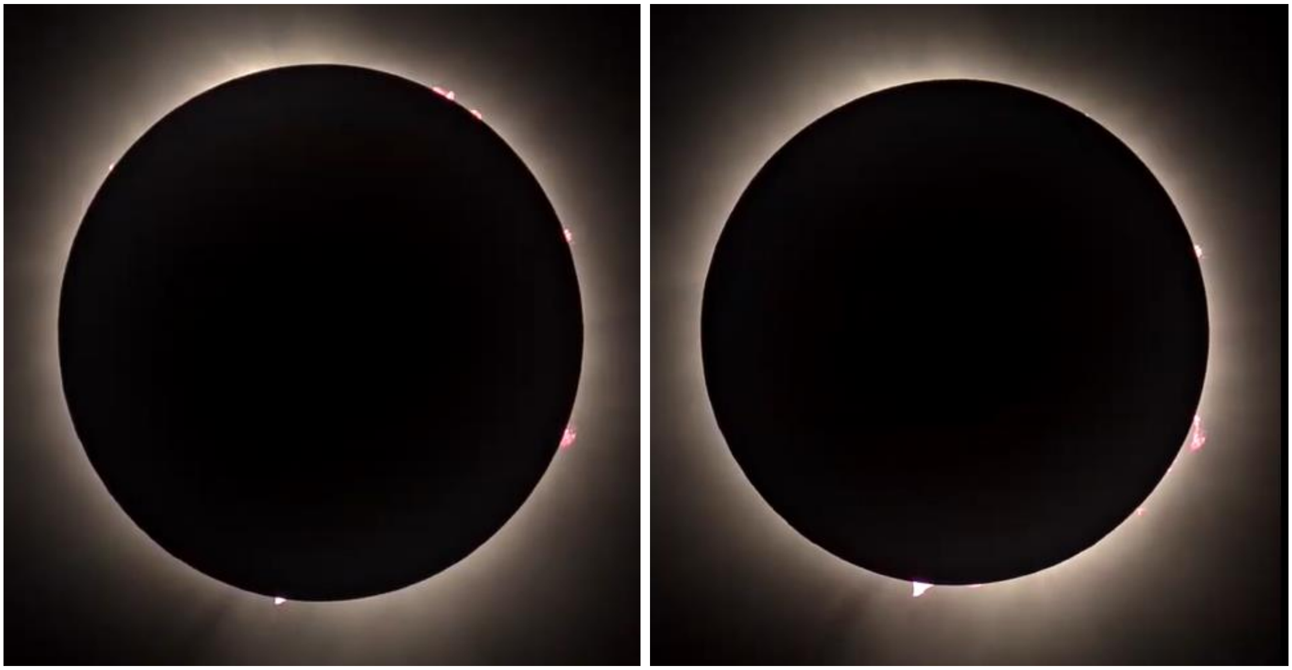

Fig. 12. Two stills from Seestar S50 (ground telescope) footage show significant evolution of limb features of the Sun over the course of less than 2 minutes. The solar prominence extending downward in these views was clearly visible to the naked eye during totality.

6. Concluding Remarks and Future Plans

All our team members benefited enormously from our participation in the NEBP. Although not all of our NEBP payloads worked on every flight, we made significant progress and are proud that we were able to contribute the PTERODACTYL flight computer [5] to the NEBP "common hardware" collection and that we were able to effectively command our vent to float balloons during both eclipses and were able to capture stunning 360-photography. We were honored to be able to serve as a pod lead team and we believe that we learned as much, if not more, from the other teams in our pod, and from the other pod leads, than we taught others.

Despite more than half the students on the "eclipse travel team" graduating in the spring of 2024, the ballooning team at the U of MN - Twin Cities is going strong, with new members inspired by stories of eclipse trips and challenged to help with ongoing data analysis and to continue to improve upon payloads flown during the two solar eclipses. Of particular interest is further development of the Sun-pointing Pixy payload. On vented flights, we anticipate that we may be able to achieve long-duration, precise Sun-pointing from floated balloons, allowing us to pursue additional solar photography including taking telephoto images, doing solar spectroscopy from above the bulk of the atmosphere, and building a solar coronograph using an occultation disk between a camera and the Sun to allow us to observe a "synthetic" eclipse during any balloon flight, and not be limited to natural eclipses which are few and far between, both in space and in time. Indeed, we need to wait until 2099 for a total solar eclipse to pass over Minnesota - too long!

We look forward to continuing to share our eclipse stories and results with others, both formally and informally. We also will keep in touch with, and possibly do future projects with, balloonists we have come to know through the Nationwide Eclipse Ballooning Project.

Acknowledgments

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