Team Lambda Final Report

By Julia Schwarz

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I. Introduction and Purpose

Why is the sky blue? This is one of the first questions we ask ourselves when we look to the heavens. Fortunately, we know the answer. The earth's atmosphere scatters blue light very effectively due to a phenomenon called Rayleigh scattering. Thus when we look to the sky, we see the blue light that is being bounced off of particles in the air. But how does the color of the sky change as we go higher in the atmosphere? Theory suggests that "since molecular density decreases drastically with height, it is anticipated the sky should darken to become black in directions away from the sun." (Liou, 2002) This means that as we climb, less air bounces blue light into our eyes, thus the sky should become less blue and more black. Our team, Lambda, decided to verify this theory, and examine how quickly the sky turns from blue to black.

Hypothesis

Based on the theory of Rayleigh scattering, we predict that when looking out towards the sky, the intensity of blue light will gradually decrease from around 2 W/m^2 (based on our calibration data) to 0 W/m^2 as our experiment rises into the stratosphere. Moreover, we predict that the intensity of red and green light will remain minimal (less than 0.1 W/m^2) throughout our experiment's journey into the stratosphere.

Objective

To test our hypothesis, our experiment would measure the intensity of blue light when looking out towards the sky. It would also measure the intensity of red and green light to provide two measurements of control (since we expected these to be almost zero). Finally, our experiment would take photos of the sky to provide qualitative data to compare our results again. Team Lambda's goal was to design and build such a payload weighing less than one pound and costing less than $50 to build.

II. Design and Construction

Designing and building a payload which would be sent on a weather balloon to execute our experiment was a challenging task. We broke up our experiment into 3 main components: Three identical circuits to convert current generated by photodiodes into a voltage, a camera that would take photos of the sky every 30 seconds, and a power supply along with and encasing for our experiment. Once assembled, our payload would weigh less than one pound, interface with the telemetry system, and be ready to collect data on one of the two class weather balloons.

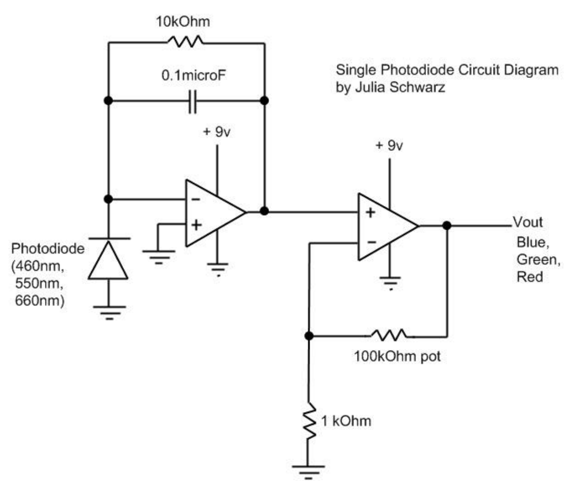


Figure 1 Diagram of the circuit for one photodiode. We had three such circuits in our experiment.

Photodiode Component

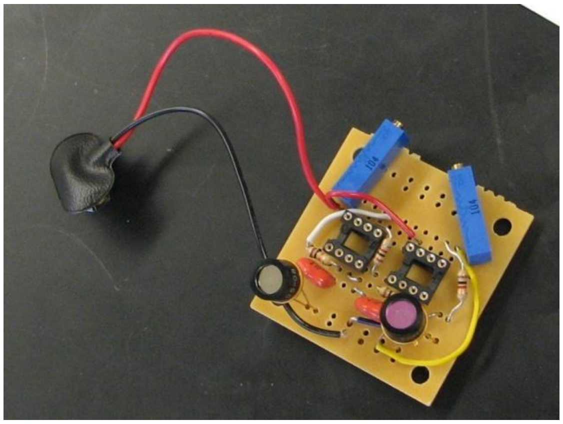


Figure 2 Two of our photodiodes on a CricketSat board

The aim of our photodiode component was to convert current generated by photodiodes sensitive to red, green and blue light into a measurable voltage. There were several constraints we needed to consider when designing our photodiodes. First, the current generated by our photodiodes was very low (around .02 A/W). Second, all of the photodiodes available were sensitive to almost the entire visible spectrum of light, and we wanted our photodiodes to be sensitive to specific wavelengths. Finally, we needed to be able to adjust how much our circuits would amplify voltage to ensure that our instruments weren't outputting too much or too little voltage on launch day. To solve these problems, we designed a dual op-amp circuit with a variable resistor using photodiodes covered by high quality light filters (see Table 1) which would let in very narrow bandwidths of light. See Figure 1 for a diagram of one of the three circuits we built. The first op amp was used to convert the current generated by the photodiode into a small voltage. Then we would be able to adjust the output voltage by adjusting the 100kOhm potentiometer underneath the second op amp. Each Vout lead connected to a wire in the telemetry system which we would then match with the intensity of red, green and blue light as our experiment flew on the balloon.

Wavelength range(nm)	Color	Responsivity (A/W)	Temperature (Celsius)	Area of Diode (mm^2)
655 – 665 nm	Red	0.4	20°	55.42
545 – 555 nm	Green	0.12	20°	55.42
455 – 465 nm	Blue	0.12	20°	55.42

Table 1 photodiode specifications from Intor, Inc. In our calibration, we found that the responsivity was 10 times smaller than specified.

Camera Component

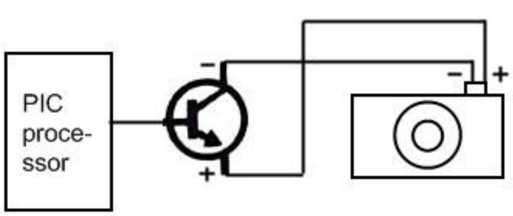


Figure 3 Circuit diagram for camera timing circuit

The goal of our camera was simply to take photos every 30 seconds. To accomplish this, we took apart a Nikon Coolpix 7.1 Megapixel camera and found the two leads near the shutter button which, when bridged, would force the camera to take a photo. We then connected these two leads to a transistor, and connected a timing circuit which would send a pulse every 30 seconds to the controlling lead of the transistor, connecting the two camera leads and taking a picture (see Figure 3). With the help of Bob

Frost, I programmed a PIC microprocessor for our timing circuit which would send a pulse every 30 seconds to an output pin on the PIC. We then used this pulse to control the camera.

Obstacles

Building our payload came with plenty of challenges. First, photodiodes with light filters already on them were hard to find. When I found some, they turned out to be $30 per photodiode. Since we needed 3 photodiodes, the price would put us far over our $50 budget. So I talked the manager at one company, (Intor, Inc.), and told him our story. The manager was kind enough to send us 6 photodiodes free of charge. Second, the two leads on our camera were absolutely tiny, and impossible to solder with a normal soldering iron. Fortunately, Mike McCarthy was kind enough to lend us his micro-soldering iron, which we used to solder wires to the camera leads. Unfortunately, because we didn't secure the wires more firmly to the leads this micro-soldering proved fatal on launch day. One final problem we had was that the PIC chip I programmed took five volts as input, but our battery gave out 9 volts of power. To solve this, we built a small voltage converter which output the 5 volts we needed to power our timer chip.

III. Calibration and Testing

Our photodiodes required quite a bit of calibration testing because we were not sure that our photodiodes output the current as defined by the specification. Also, we needed to adjust our potentiometer to ensure that it would not read a maximum voltage of 9 volts while looking directly at the sun, because we anticipated that the sun would get brighter as we went into the stratosphere. We also took some data measurements after the experiment because we wanted to know whether our data readings before the flight were similar to those after the flight. These measurements would give us an idea of whether or not the photodiodes were functioning after their trip to the stratosphere.

Calibration Procedure

To calibrate our photodiodes, we first needed to know how many Amperes/Watt our photodiodes were generating. To calculate this, we took our photodiodes outside on a sunny day and recorded voltage from our experiment while the photodiodes were pointing straight at the sun. We then calculated the current our photodiodes were generating by using the following formula derived from our circuit:

Equation 1:

$$I_{photodiode} = \frac{V_{out} * 10^7}{10^3 + R_{pot}}$$

Then, using the *American Society for Testing and Materials (ASTM) Terrestrial Reference Spectra for Photovoltaic Performance Evaluation* (ASTM, 1999) we calculated how many Watts our photodiodes were receiving using the following formula:

Equation 2:

$$Watts_{photodiode} = \sum_{\lambda \in wavelength\ range} Watts_{\lambda}$$

From this, we were able to get the A/W generated by our photodiodes:

Equation 3:

$$A/W_{photodiode} = \frac{I_{photodiode}}{Watts_{photodiode}}$$

Using this data, we were able to then check to see whether our calibrations gave reasonable readings.

Calculating A/W Generated by Photodiodes

Table 2 illustrates the results of our calculations. After comparing our results to the specifications, we noticed that our calculations were far different from the specifications.

Wavelength (nm)	Current at Sun (mA)	Watts / m^2 Into Photodiode	Watts into Photodiode (mW)	A/W Calibrated	A/W Spec
655 -665	0.018	13.515	0.749	0.018	0.4
545 - 555	0.015	15.042	0.834	0.009	0.12
455 -465	0.007	14.361	0.796	0.023	0.12

Table 2 Calculations made to calculate the A/W generated by our photodiodes.

Calibration Data and Analysis

Figure 4 illustrates calibration data before our launch. This data shows that the optical filters do a superb job of filtering out unwanted wavelengths. For example, notice how only the 660 nm (red) photodiode captures any of the red light. Also, notice that the blue 460 nm (blue) photodiode captures far more light than the other photodiodes because it is pointing at the sky (which is blue). It is also interesting to note how much brighter the outside is from the inside (more than a factor of 10!). It's amazing what our eyes can adjust to!

Figure 5 illustrates that our photodiodes behaved unexpectedly after visiting the cold stratosphere. Although the dark current is consistently smaller than the visible current, the photodiodes are inconsistent with prior observations. While the red photodiodes give less W/m^2 than before the launch, both blue and green photodiodes give significantly larger outputs. This seems to be an indicator that our photodiodes became unreliable during launch because of temperature (although we did temperature test our photodiodes and seemed to get expected results).

Figure 4 Photodiode Calibration Before launch. Indoor measurements were taken in room 127 of Johnson Hall with the light on.

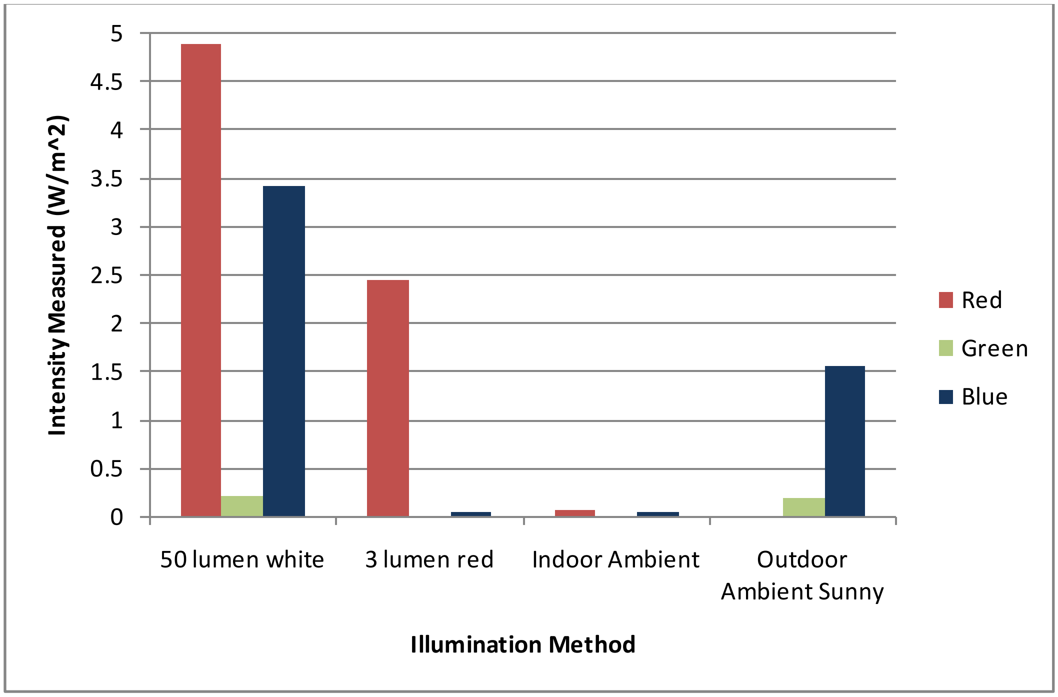
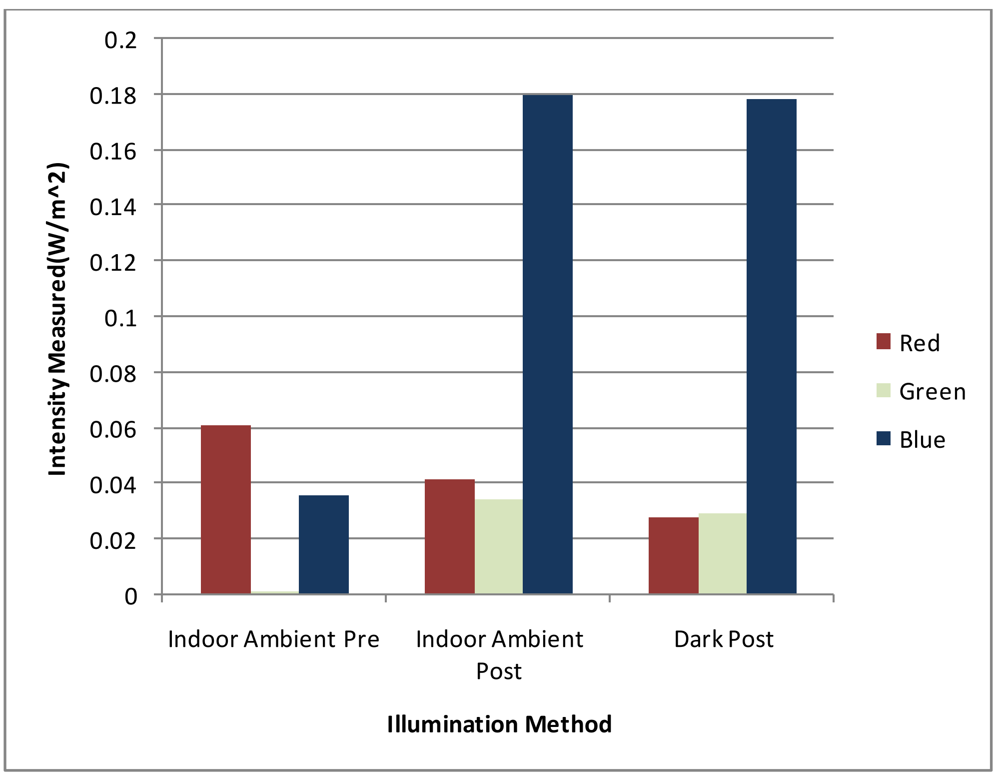


Figure 5 Comparison of readings before and after the launch. "Pre" indicates measurement made before launch, "Post" indicates measurement made after launch. Indoor measurements were taken in room 127 of Johnson Hall with the lab lights on, and the dark measurements were taken by covering photodiodes with our hands.



Calibration results

From our calibration we were able to:

1. Calculate the A/W generated by our photodiodes, and observe that they were very different from our specification.
2. Observe that before the launch the photodiodes and filters seemed to be working correctly.
3. Observe that after the launch, the photodiodes were not working as they were before.

IV. Mission Operations

Preparation

Our group had finished testing our experiment the day before launch, and had confirmed that both the camera and photodiodes were working. On launch day, our group needed to put a fresh battery on our experiment, tape it up, and send it off.

I was in charge of GPS for the recovery team, so after arriving on the tarmac of the Grant County airport, I talked to Robert Winglee to make sure I understood how to operate the GPS system. Afterwards, I checked up on my team members to see if they needed any help. Taping didn't require five people, however, so I set off to document as much of the launch as possible. I would periodically check on our two builders to make sure our team was on track. At every point, they were fine.

Our Payload

Figure 6 Lambda payload just before launch.

Our payload ended up weighing in just under 1 pound (our camera was unexpectedly heavy), and we had three wires feeding a voltage to the telemetry system: one for each photodiode in our experiment. Our payload was located in the middle of a string of payloads from groups in the class.

Balloon Launch

Our payload was scheduled to fly on balloon B, which was the first of the two to be flown. Just before launch, our team put fresh batteries into our power supply and camera. We tested our photodiodes and camera one more time with the telemetry, and all systems were go. As we walked down the tarmac I couldn't help but think that our experiment couldn't be in any better shape.

But then, disaster struck. Right as we were about to hook up our experiment, Jeff asked if our camera was working. So we turned on our experiment, and listened. Thirty seconds went by. A minute, nothing. Taking it apart, we noticed that the micro-solder on our camera had broken. We quickly pulled the experiment away in an attempt to fix it, but were unable to re-solder the connection to the camera switch and force the camera to take photos every 30 seconds. Instead, we decided to just leave the camera switch on, so that it would take photos continuously until its memory filled up. With 2GB of memory in our camera, we thought we could get photos for at least half an hour. We quickly hurried to tape our experiment together and ran back to the launch platform to get our payload onto the balloon minutes before launch. We thought we had made it. Unfortunately, when we got back to the telemetry station to listen for our photodiode voltages, all we heard were zeros.

The Chase

Figure 7 Recovering Balloon B's payload.

Despite Team Lambda's unfortunate launch disaster, the recovery of our payload went remarkably smoothly. We followed our balloon, Balloon B, as it flew first 20 miles north, then about 10 miles south before settling in a lush pea field in the middle of the desert. We had been incredibly lucky. Somebody in our car even spotted the payload as we were driving by, so we didn't even need to use our antennas to track our payload.

After recovering our payload we took a look at our experiment and realized that in our hurry to tape our experiment back together, the two wires which powered our device had somehow slipped off of each other, thus disconnecting our circuit. Even though our camera had taken a couple of photos, it stopped minutes after launch, and we never got any photos of the edge of space. Our careless last-minute attempts to get photos didn't work, and our experiment failed because of this. Seeing those photos provided a disappointing end to an exciting but unfortunate day for team Lambda. We headed back home disappointed, but a little wiser about the experimentation process.

V.Data

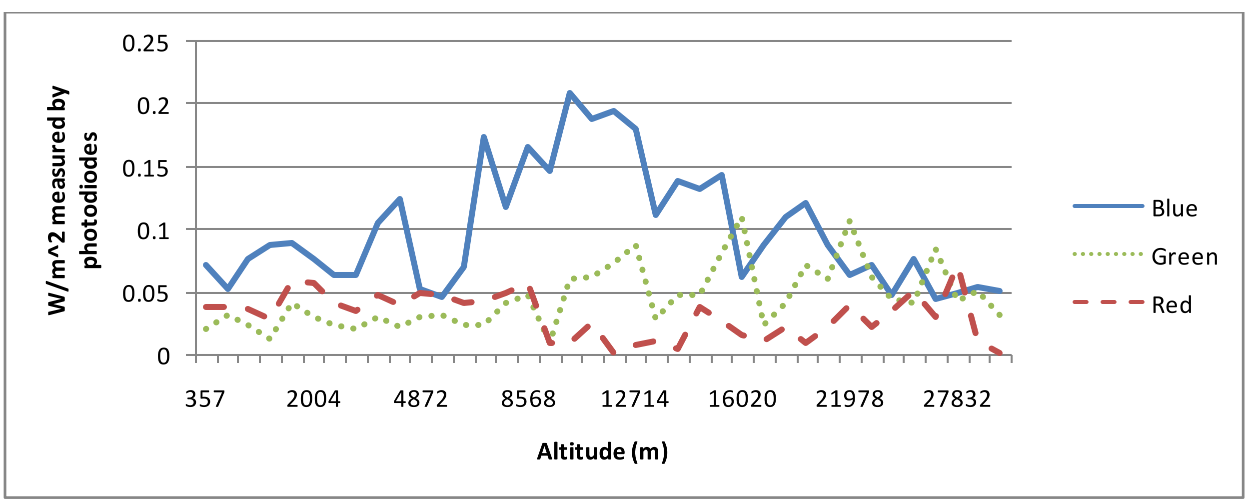


Figure 8 Light intensity versus altitude as measured by our photodiodes, represented in power over area.

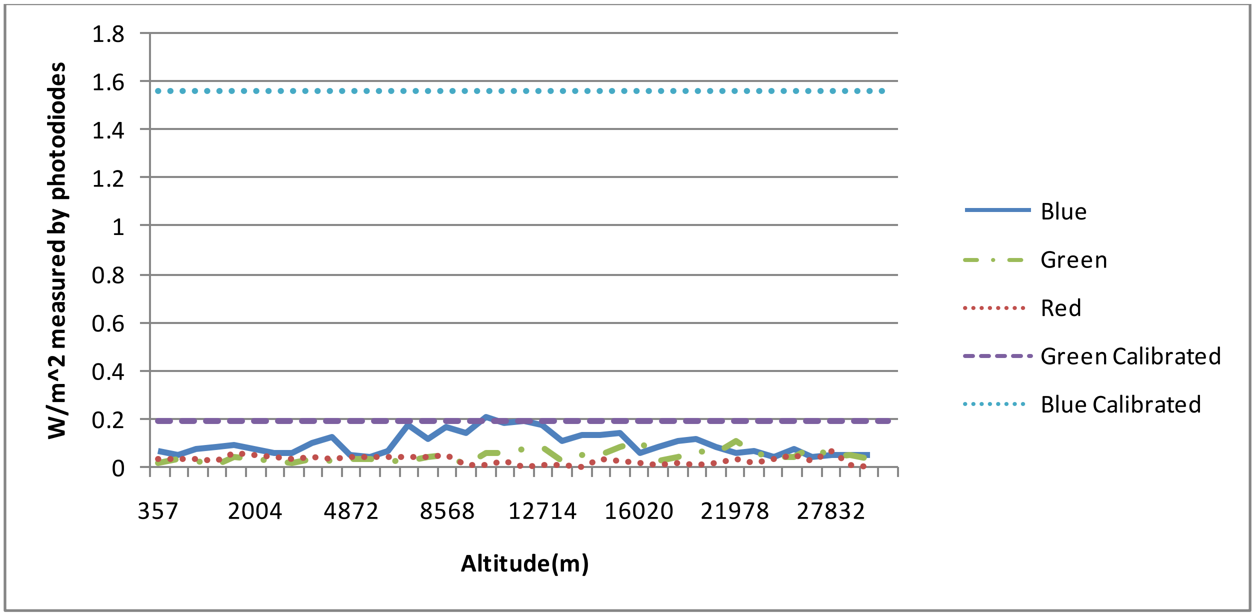


Figure 9 Measurements made by our photodiodes during launch compared to measurements made during calibration. The Green and blue calibrated lines refer to the intensity measured while pointing towards the sky (but not the sun) on a sunny day similar to launch day.

VI. Analysis

Camera Data

Instead of taking photos every 30 seconds, our camera ended up taking photos every 1.5 seconds, and instead of taking photos for the entire flight, our camera took photos for 6 minutes of the flight before stopping. This was far from what we expected, and was largely due to the last minute micro-solder failure and our decision to have the camera take continuous photos from the time of launch.

Figure 10 The last shot our onboard camera took of the atmosphere, 6 minutes into the flight.

Launch Data Calculations

The data we received from telemetry came in the form of voltage readings for each photodiode where the independent variable was the time since startup of the telemetry system. We used the same methods described in Equations 1-3 to calculate the intensity measured by each photodiode during flight. To convert time since startup to altitude, I took the altitude data from the same balloon flight and matched it up by hand as best I could so that the time of an altitude reading was as close in time as possible to a given voltage reading.

Launch Data

At first glance, this data seems to indicate that while the intensity of red and green light remained low as expected, the intensity of blue light rose until about 10km, before dropping to about the same levels as red and green intensity. Even though the readings seem unusually low, there seems to be very little noise in our data, and the photodiodes behave as expected after 10 km. However, it seems extremely unusual that the intensity of light at 30 km was similar to that at 300 m. Even if the photodiode was in the shade for most of our experiment, the photodiodes should have given a much higher reading at ground level than at 30 km. One final suspicious observation is that the blue photodiodes did not measure a significantly larger light intensity than red or blue light until about 5km altitude. This is not what we expected our photodiodes to read, however it is possible that the photodiodes were not pointing at the sky until the balloon reached 5km in the air.

Comparison to Calibration Data

After comparing our launch data to our calibration data, I began to realize how strange our data really was. First of all, although the intensity of blue light changed, it barely rose above the amount of green light measured at the ground during calibration, and the photodiode measured a ground level light intensity about 10 times smaller than what we measured during calibration. Given the lighting conditions that day (sunny, and very bright), I find it hard to believe that the photodiode measured such a low light intensity. If anything the light intensity should have been larger that day.

Comparison to Post-Flight Data

Finally, the blue photodiode almost always measured a light intensity which was lower than the intensity measured when we covered the photodiodes with our hands after launch (0.18 w/m^2, see Figure 5 Comparison of readings before and after the launch. “Pre” indicates measurement made before launch, “Post” indicates measurement made after launch.). Since the photos from our camera indicate that the photodiodes were clearly not in darkness for at least the first 300 meters of the flight, I feel that it is safe to say that our photodiodes were not behaving as they were either before or after the flight.

VII. Conclusion

The blue, red and green photodiodes gave readings that were far below what we had expected or calibrated, forcing us to conclude that based on our analysis of our data the photodiodes were not functioning properly during launch, and that our data is invalid. This is most likely because the power to our photodiodes was disconnected just before launch (as we verified upon retrieval of our payload), and thus that all of our data was simply noise from the telemetry system.

Pre and Post-Flight Data

Based on our pre and post-flight data, our photodiodes did not behave in the same way before and after the flight. While the green and blue photodiodes read a much higher intensity after the flight, the red photodiode read a similar (perhaps slightly lower) intensity than before. Although our photodiodes were reading higher values when brighter lights shone on them, their responsivity had changed. It seems like the cold atmosphere had an effect on the blue and green photodiodes, however we need to take more measurements before making any quantitative conclusions. It would have been interesting to compare the voltage readings of the photodiodes when pointing directly at the sun after the flight, however the weather after the launch was consistently cloudy, and we were unable to make this measurement before the report was due.

Reasons For Failure

Photodiode Failure

The most likely reason our photodiodes failed was that the power connection to our photodiodes broke when we were taping our experiment together after fixing our camera last minute. Instead of just wrapping our power wires together, we should have soldered them together to ensure a better connection. Additionally, we should not have taken the payload off of the balloon when we realized our camera was not working, since it was not critical to our mission.

Camera Failure

We know that our camera did not fail because of a power failure, because we were able to turn it on upon recovery. However, when recovering the camera we noticed its lens was half-retracted, indicated that it tried to shut down automatically. The most likely thing that happened was the camera attempted to turn off after having its shutter switch on for a very long time, but was unable to retract its lens to the cold temperature. Although we had tested our camera's time lapse photography with the timer chip I had made and confirmed that it continuously took photos for an hour, we had not tested the camera when it was taking continuous photos, and so I am not surprised that its behavior was so unexpected.

Lessons Learned

Because of our experimental failures, we learned more than we would have if our experiment had worked. Since we were merely confirming an existing fact (Rayleigh scattering), the lessons we learned about how to conduct an experiment were more valuable than the scientific goal our experiment aimed to achieve. Here are a couple of lessons we learned:

- Things never go as you expect, so plan for the worst.
- If bad things happen, don't rush to fix them, take your time.
- Always secure micro-solder joints.
- We could have gotten good data if we had just decided not to fix the camera. Never sacrifice science for some pretty pictures.

What we would have done differently

The main thing I would have done differently was I would not try to make changes to our payload in such a hurry. People make more mistakes when in a hurry, and this was no more apparent than with our experiment, which after so much good fortune and preparation failed because of a careless mistake.

To make our camera more secure, I would have also super-glued the micro-solder joints to the camera. Finally, I would have tried to take more calibration data before and after our launch (specifically, I would have liked to measure the voltage output when the photodiodes were pointed at the sun after launch, and would have liked to measure the dark output of photodiodes before launch) so that we could have had more data to compare our flight data to.

Future Work

To be honest, I would really like to simply repeat this experiment and see it work. Our team had very high quality photodiode filters suitable for getting accurate measurements of light intensity of specific wavelengths, and I'd be curious to see how the amount of blue light changes as we climb in the atmosphere. Who knows, perhaps I will have a chance to this experiment again next year.

Tables for Reference

Wavelength	Voltage (v)	Illumination Method	Current	A/W	Watts In	Area of photodiode (m)	W/m^2
660 nm	2.8	50 lumen white	6.23608E-06	0.023	0.000271134	5.54177E-05	4.892551
660 nm	1.4	3 lumen red	3.11804E-06	0.023	0.000135567	5.54177E-05	2.446276
660 nm	0.035	Indoor Ambient	7.7951E-08	0.023	3.38917E-06	5.54177E-05	0.061157
660 nm	5	Outdoor Ambient Sunny	1.11359E-05	0.023	0.000484168	5.54177E-05	8.736699
660 nm	1.93	Directly at Sun	1.75455E-05	0.023	0.000762846	5.54177E-05	13.76538
660 nm	0.0058	Ambient Indoor 2	5.27273E-08	0.023	2.29249E-06	5.54177E-05	0.041367
660 nm	0.0039	Covered by Hand (dark)	3.54545E-08	0.023	1.5415E-06	5.54177E-05	0.027816
550 nm	0.085	50 lumen white	0.0000002	0.018	1.11111E-05	5.54177E-05	0.200498
550 nm	0.0005	3 lumen red	1.17647E-09	0.018	6.53595E-08	5.54177E-05	0.001179
550 nm	0.0005	Indoor Ambient	1.17647E-09	0.018	6.53595E-08	5.54177E-05	0.001179
550 nm	0.081	Outdoor Ambient Sunny	1.90588E-07	0.018	1.05882E-05	5.54177E-05	0.191062
550 nm	1.65	Directly at Sun	0.000015	0.018	0.000833333	5.54177E-05	15.03732
550 nm	0.0038	Ambient Indoor 2	3.45455E-08	0.018	1.91919E-06	5.54177E-05	0.034631
550 nm	0.0032	Covered by Hand (dark)	2.90909E-08	0.018	1.61616E-06	5.54177E-05	0.029163
460 nm	0.7	50 lumen white	1.70732E-06	0.009	0.000189702	5.54177E-05	3.423129
460 nm	0.0073	3 lumen red	1.78049E-08	0.009	1.97832E-06	5.54177E-05	0.035698
460 nm	0.0073	Indoor Ambient	1.78049E-08	0.009	1.97832E-06	5.54177E-05	0.035698
460 nm	0.319	Outdoor Ambient Sunny	7.78049E-07	0.009	8.64499E-05	5.54177E-05	1.559969
460 nm	2.4	Directly at Sun	7.43034E-06	0.009	0.000825593	5.54177E-05	14.89765
460 nm	0.029	Ambient Indoor 2	8.97833E-08	0.009	9.97592E-06	5.54177E-05	0.180013
460 nm	0.0287	Covered by Hand (dark)	8.88545E-08	0.009	9.87272E-06	5.54177E-05	0.178151

Table 3 Calibration calculations

Lambda			Amps			Watts			Watts/m^2		
red	green	blue	red	green	blue	red	green	blue	red	green	blue
0.0054	0.0022	0.0113	4.9014E-08	2.01083E-08	3.50962E-08	2.13104E-06	1.11713E-06	3.89957E-06	0.038454211	0.020158333	0.070366935
0.0053	0.0035	0.0084	4.77572E-08	3.14192E-08	2.61081E-08	2.0764E-06	1.74551E-06	2.9009E-06	0.037468205	0.031497395	0.052346135
0.0051	0.0025	0.0122	4.65005E-08	2.26218E-08	3.76642E-08	2.02176E-06	1.25677E-06	4.18491E-06	0.0364822	0.022678124	0.075515735
0.0040	0.0014	0.0140	3.64463E-08	1.25677E-08	4.32282E-08	1.58462E-06	6.98205E-07	4.80313E-06	0.028594157	0.012598958	0.086671469
0.0083	0.0044	0.0144	7.54062E-08	4.02166E-08	4.45122E-08	3.27853E-06	2.23426E-06	4.9458E-06	0.059160324	0.040316665	0.089245869
0.0080	0.0033	0.0123	7.28926E-08	3.01625E-08	3.80922E-08	3.16924E-06	1.67569E-06	4.23246E-06	0.057188313	0.030237499	0.076373868
0.0058	0.0025	0.0101	5.27843E-08	2.26218E-08	3.12441E-08	2.29497E-06	1.25677E-06	3.47157E-06	0.041412227	0.022678124	0.062643735
0.0050	0.0022	0.0101	4.52437E-08	2.01083E-08	3.12441E-08	1.96712E-06	1.11713E-06	3.47157E-06	0.035496194	0.020158333	0.062643735
0.0068	0.0033	0.0167	6.15817E-08	3.01625E-08	5.17882E-08	2.67747E-06	1.67569E-06	5.75425E-06	0.048314264	0.030237499	0.103834136
0.0057	0.0024	0.0200	5.15275E-08	2.13651E-08	6.20603E-08	2.24033E-06	1.18695E-06	6.89559E-06	0.040426221	0.021418228	0.124429336
0.0069	0.0033	0.0083	6.28385E-08	3.01625E-08	2.56801E-08	2.73211E-06	1.67569E-06	2.85335E-06	0.04930027	0.030237499	0.051488001
0.0068	0.0035	0.0073	6.15817E-08	3.14192E-08	2.26841E-08	2.67747E-06	1.74551E-06	2.52046E-06	0.048314264	0.031497395	0.045481068
0.0058	0.0026	0.0112	5.27843E-08	2.38786E-08	3.46682E-08	2.29497E-06	1.32659E-06	3.85202E-06	0.041412227	0.02393802	0.069508802
0.0059	0.0026	0.0279	5.40411E-08	2.38786E-08	8.64564E-08	2.34961E-06	1.32659E-06	9.60627E-06	0.042398232	0.02393802	0.173342937
0.0069	0.0046	0.0189	6.28385E-08	4.14734E-08	5.86363E-08	2.73211E-06	2.30408E-06	6.51514E-06	0.04930027	0.041576561	0.117564269
0.0080	0.0053	0.0267	7.28926E-08	4.77572E-08	8.26044E-08	3.16924E-06	2.65318E-06	9.17826E-06	0.057188313	0.04787604	0.165619737
0.0012	0.0010	0.0235	1.13109E-08	8.79739E-09	7.27603E-08	4.91779E-07	4.88744E-07	8.08448E-06	0.008874049	0.008819271	0.14588267
0.0012	0.0065	0.0336	1.13109E-08	5.90682E-08	1.04004E-07	4.91779E-07	3.28156E-06	1.15561E-05	0.008874049	0.059215102	0.208526405
0.0035	0.0068	0.0301	3.14192E-08	6.15817E-08	9.33044E-08	1.36605E-06	3.42121E-06	1.03672E-05	0.024650135	0.061734894	0.187073071
0.0001	0.0080	0.0314	1.25677E-09	7.28926E-08	9.71564E-08	5.46421E-08	4.04959E-06	1.07952E-05	0.000986005	0.073073956	0.194796271
0.0010	0.0095	0.0289	8.79739E-09	8.67171E-08	8.94524E-08	3.82495E-07	4.81762E-06	9.93916E-06	0.006902038	0.086932809	0.179349871
0.0014	0.0030	0.0180	1.25677E-08	2.76489E-08	5.56403E-08	5.46421E-07	1.53605E-06	6.18225E-06	0.009860054	0.027717707	0.111557336
0.0007	0.0053	0.0223	6.28385E-09	4.77572E-08	6.89083E-08	2.73211E-07	2.65318E-06	7.65648E-06	0.004930027	0.04787604	0.13815947
0.0054	0.0053	0.0212	4.9014E-08	4.77572E-08	6.54843E-08	2.13104E-06	2.65318E-06	7.27603E-06	0.038454211	0.04787604	0.131294403
0.0039	0.0088	0.0229	3.51895E-08	8.04332E-08	7.10483E-08	1.52998E-06	4.46851E-06	7.89426E-06	0.027608151	0.08063333	0.142450137
0.0022	0.0120	0.0100	2.01083E-08	1.09339E-07	3.08161E-08	8.74274E-07	6.07439E-06	3.42402E-06	0.015776086	0.109610933	0.061785601
0.0014	0.0025	0.0140	1.25677E-08	2.26218E-08	4.32282E-08	5.46421E-07	1.25677E-06	4.80313E-06	0.009860054	0.022678124	0.086671469
0.0030	0.0044	0.0176	2.76489E-08	4.02166E-08	5.43562E-08	1.20213E-06	2.23426E-06	6.03958E-06	0.021692119	0.040316665	0.108982936
0.0012	0.0077	0.0194	1.13109E-08	7.03791E-08	5.99203E-08	4.91779E-07	3.90995E-06	6.65781E-06	0.008874049	0.070554164	0.120138669
0.0032	0.0065	0.0140	2.89057E-08	5.90682E-08	4.32282E-08	1.25677E-06	3.28156E-06	4.80313E-06	0.022678124	0.059215102	0.086671469
0.0055	0.0118	0.0102	5.02708E-08	1.06825E-07	3.16721E-08	2.18569E-06	5.93474E-06	3.51913E-06	0.039440216	0.107091142	0.063501868
0.0032	0.0068	0.0115	2.89057E-08	6.15817E-08	3.55242E-08	1.25677E-06	3.42121E-06	3.94713E-06	0.022678124	0.061734894	0.071225068
0.0048	0.0048	0.0076	4.39869E-08	4.39869E-08	2.35401E-08	1.91248E-06	2.44372E-06	2.61557E-06	0.034510189	0.044096353	0.047197334

0.0071	0.0046	0.0123	6.40952E-08	4.14734E-08	3.80922E-08	2.78675E-06	2.30408E-06	4.23246E-06	0.050286275	0.041576561	0.076373868
0.0043	0.0093	0.0071	3.89598E-08	8.42035E-08	2.18281E-08	1.69391E-06	4.67797E-06	2.42534E-06	0.030566167	0.084413018	0.043764801
0.0101	0.0047	0.0077	9.17442E-08	4.27302E-08	2.39681E-08	3.98888E-06	2.3739E-06	2.66312E-06	0.071978394	0.042836457	0.048055468
0.0014	0.0055	0.0086	1.25677E-08	5.02708E-08	2.65361E-08	5.46421E-07	2.79282E-06	2.94846E-06	0.009860054	0.050395831	0.053204268
0.0001	0.0035	0.0082	1.25677E-09	3.14192E-08	2.52521E-08	5.46421E-08	1.74551E-06	2.80579E-06	0.000986005	0.031497395	0.050629868
7.9585	3.9991	6.7986	7.23497E-05	3.63558E-05	2.10483E-05	0.003145639	0.002019768	0.002338698	56.76235873	36.44626529	42.20128201

Table 4 Flight calculations

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