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Monitering and Addressing Light Pollution at Utah State University

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MONITERING AND ADDRESSING LIGHT POLLUTION AT UTAH STATE UNIVERSITY

by

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ABSTRACT

Many outdoor light fixtures illuminate in all directions, meaning that a large portion of light is emitted upwards. This excess light – light pollution – represents wasted energy and money, decreases public safety, is a health hazard for humans as well as wildlife, and inhibits the view of the night sky. In order to quantify the anthropogenic contribution of local light pollution, I studied detection methods at the National Optical Astronomy Observatory though a summer REU in 2013. Upon my return to USU, I monitored the night sky brightness from September 2013 to April 2015 at Utah State University. Due to its popularity in citizen science, I used a Sky Quality Meter and a Pocket Lux Meter. Seasonal variations were found in Logan, Utah, due to presence of snow. Through this research, I was also able to obtain a Blue Goes Green grant to replace several outdoor fixtures with night-sky friendly alternatives.

ACKNOWLECDGEMENTS

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Special thanks to Dr. David Peak, who pushed and terrified me into working hard and doing well during my undergraduate career. Thanks for believing in me even when I didn't.

1. INTRODUCTION

Though the view of city lights can be considered a modern beauty, it is the cause of an assortment of negative effects (Navarra and Nelson (2007)). When outdoor lighting is not focused downwards by shielding, the excess light in the sky – light pollution – damages the environment, wastes energy and money, and impedes ground-based astronomy. Light pollution impacts the fragile ecosystems of frogs, songbirds, insects, and various other organisms. Excessive lighting is not only harmful to animals by altering migration paths and hunting grounds, but it is also detrimental to human health. Ambient light disturbs the circadian rhythm and has been linked to insomnia, depression, obesity, and several forms of cancer. Proper shielding of lamp posts increases safety. In addition, to medical and ecological concerns, anthropogenic nightglow is a source of financial concern. The International Dark-Sky Association estimates that one-third of street lighting is wasted due to poorly shielded street lights (International Dark-Sky Association (2015)). With an average light cost of $0.10 per kilowatt-hour, this amounts to $2.2 billion wasted annually in the United States. Focusing light downwards also allows for the use of a lower wattage, which reduces costs and carbon footprints.

Over the past decade, amateur and profession scientists have been recruited to help characterize light pollution and identify trends across the globe. A lot of this research is done through citizen science projects, such as Globe at Night. In order to keep costs low, the most common tool used in these efforts in an SQM-DL, which has not been subjected to the same level of scrutiny as most instruments in the scientific community. In order to best interpret the results these SQM-DL provide, I first needed to know how well they performed under lab conditions.

All Sky Quality meters manufactured by Unihedron (the manufacturer and vendor of SQM-DLs) measure the brightness per area in terms of magnitudes per square arcsecond (mag/arcsec^2). Magnitudes are inversely related to brightness on a logarithmic scale, meaning that high numbers correspond to darker skies. An arcsecond is 1/3600 of a degree. A sky quality reading of 22 mag/arsec^2 corresponds to dark skies, whereas a reading of 18.5 mag/arcsec^2 would imply that most stars are not visible which is typical for the USU astronomical observatory.

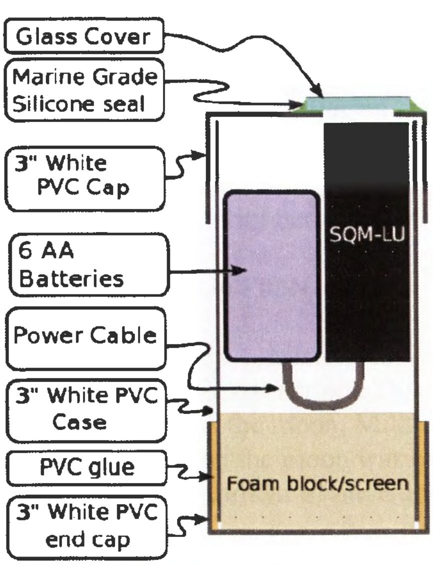


Figure 1 DQM-DL diagram

2. OVERVIEW

In spring 2013, to determine the severity of light pollution at Utah State University (USU), I applied for an Undergraduate Research and Creative Opportunities (URCO) grant. With the funding from this grant and the Honors Research Fund, I purchased two Sky Quality Meters with remote data-logging capabilities (SQM-DLs) and one Pocket Lux Meter. The SQM-DLs measured sky brightness and the Pocket Lux Meter provided a method of measuring the efficiency of existing light-covers on the university campus. Because some of the equipment was damaged, data collection would be postponed until January 2014.

In summer 2013, I participated in an undergraduate research experience and the National Optical Astronomy Observatory (NOAO). While there, I tested the detection of SQM-DL devices and worked to create an automated computer process to isolate the anthropogenic contributions of sky brightness. This research provided a baseline for data analysis for my research in Logan.

Data collection began in January of 2014 with the installation of an SQM-DL atop the Science and Engineering Research (SER) building. While in the early stages of the project, I further tested the SQM, and found that the infrared filter was not properly functioning; this skews results from the device.

While using the Pocket Lux Meter to find the more night-sky friendly fixtures, I discovered that the newer instillations were held to a higher light pollution prevention standard, and the older nights needed renovations. Using the findings from my previous research, I applied for Blue Goes Green grant to replace four parking lot lights by the Industrial Science Building on Logan campus.

3. RESEARCH AT THE NATIONAL OPTICAL ASTRONOMY OBSERVATORY

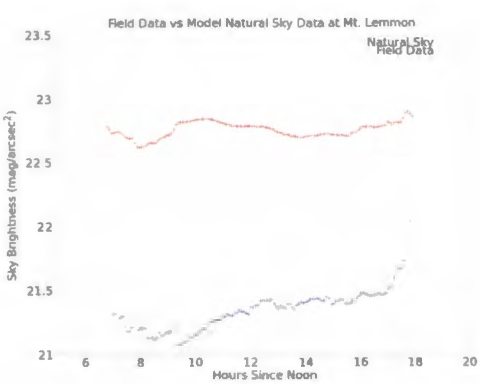


Figure 2 Comparison of natural and artificial sky brightness

Astronomy is a big industry in Tucson, Arizona, and therefore the city has taken various measures to keep anthropogenic light pollution at a minimum. My research dealt with interpreting the data collected by eight SQM-DLs, placed in the city and at various observatories. These data quantified the temporal and spatial light pollution trends in the region. The SQM-DLs were programmed to take brightness readings every 5 minutes once the sky was darker than 12 magnitudes per arcsecond squared (mag/arcsec^2), and can detect sky glow as dark as 24 mag/arcsec^2. The data I analyzed spanned over a year – that's over 26000 readings for each of eight recording sites.

These devices have a 20° FWHM, and use this area to measure sky brightness in mag/arcsec^2. HOYA-CM500 filters inside the devices should have no transmission between 730 nm and 1020 nm (Hoya-Optics (2008)), an infrared filter that should not transmit wavelengths between 1000 nm and 4000 nm (Hoya-Optics (2008)), and a TSL237 detector (TAOS (2007)) that has a responsivity between 300 nm and 1100 nm.

3.1 DATA REDUCTION

To ensure a consistent analysis process of in ever-growing data bank, I created several Python and MATLAB scripts. This also provided a system to remove natural sources of sky brightness such as the moon, Milky Way, and twilight. To find when astronomical twilight occurred and when the moon was overhead, I referenced tables produced by the Astronomical Application Department of the United States Navy. To remove the Milky Way, I created a reference time that the Milky Way was up in 2012, and used an algorithm that would calculate the position of the Milky Way based on that reference for any night. By removing these sources, it is easier to quantify the anthropogenic contributions made.

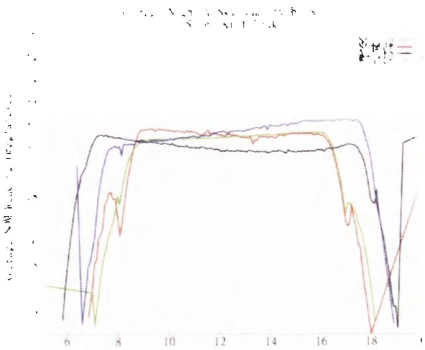
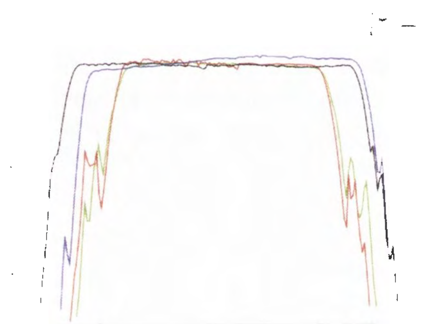


Figure 3 Above: Kitt Peak Raw data
Below: Kitt Peak reduced data



Though collaboration with Dan Duriscoe of the National Park Service, I was able to further validate my data reduction pipeline. Duriscoe created a model that addresses the distinction between natural and artificial light pollution. In addition to using information about celestial objects to determine which data is most representative of anthropogenic light pollution, his model uses this information to estimate what the natural sky glow should be in terms of nanolamberts and mag/arcsec^2 (Dursicoe (2013)).

As shown in Figure 2, the sky glow increases by as much and 2 mag/arcsec^2, even though this location is Mt. Lemmon, an observatory that is over 61 km away from Tucson.

While isolating the man-made sky glow is vital to this project, creating a code that could repair mislogged data was much more pressing. For reasons unknown, data is occasionally saved with unrealistic years, days, hours, SQM-DL readings, etc. These erroneous data can be seen by comparing to the line of data about and below in the list, and consequently fixed. Others, specifically SQM-DL measurements, must be removed from the data set.

To assess the validity of the reduction, comparisons can be made between pre and post faulty measurement reduction. Figure 3 shows average nights for each season, where high magnitudes correspond to darker skies. Given that Kitt Peak is an observatory on the Tohono O'odham Reservation, hourly variance in the data is unlikely. By comparing the same type of graph for several sites, I found that the nearby observatories we up 4 mag/arcsec^2 darker than Tucson.

To better analyze the periodic features of ambient sky brightness, a Fourier analysis is undertaken. First, the reduced SQM-DL data are used to generate a times series. The average of this time series is then subtracted and a Hann window function is applied with zero padding. The discrete Fourier transform is computed, and resulting data are interpolated with a cubic spline method. Then the data are converted from the frequency domain to the period domain.

This process was applied to both raw and reduced data sets. The most notable difference was the 28 day period in the raw data that is attributable to the moon, which illustrates the effect of natural celestial objects on sky glow. Within Tucson, this trend was less noticeable and the artificial light was more powerful.

I analyzed these data and found several long-term trends, including a weekly period, a 10 day trend in Tucson, and a 15 day trend in Tucson. The most interesting trend was a very strong correlation between light pollution measurements and OI 557.7 nm airglow, suggesting that non-anthropogenic sources have a significant impact on our measurements of air quality. This research has now been incorporated into a project spearheaded by Dan Duriscoe of the National Park Service to model light pollution and its various sources. This reduction pipeline was also created to provide a standard analysis for the Globe at Night graphical user interface online.

3.2 NOAO LABORATORY FINDINGS

Aside from my work on the data processing automation, I analyzed the devices to determine their wavelength sensitivity as well as identified some sources of error. The climates that each of the eight SQM-DL were stationed at varied greatly, as the altitude changed by as much as 1985 m between sites. This altitude difference translates to a significant temperature difference; the devices were exposed to temperature between -12°C and 44°C. Population sizes also differ greatly between sites, changing the amount of anthropogenic light pollution and perhaps the wavelengths emitted. Therefore, knowing how the meter responds to specific wavelengths of light and temperature assists in the interpretation of light pollution data.

Figure 4: Wavelength sensitivity testing

The devices were placed within an integrating sphere to ensure uniform exposure from sources of several wavelengths. I exposed each of the meters to light-emitting diodes of wavelengths 365 nm, 470 nm, 655 nm, 770 nm, 850 nm, and 950 nm to represent the visible spectrum. The source outputs were kept constant voltages that corresponded to SQM-DL readings of approximately 20 mag/arcsec^2. Once the output voltage was stabilized, 25 readings were taken with each meter with and without the weatherproof housing, the cover, and the glass filter (see Figure1). Unihedron, the manufacturer of these devices, reports that the first reading is often erroneous due to temperature (Unihedron (2015)), and so the first five readings were removed for the sake of validity.

λ (nm)	Voltage (eV)
365	.0400
470	.0435
570	0810
655	.1030
770	1160
850	.1190
950	.1470

Table 1 Source output was kept constant for valid data comparison at each wavelength. Output varied to avoid saturation of the SQM-DL detectors

Intensity readings in the integration sphere depended on which SQM-DL I used, leading to the discovery that the reflectivity of the SQM caps varied. The weatherproof housing of each device was stationed at a different altitude, and thus each had yellowed differently due to varying ultraviolet exposure. This currently means that data from each site cannot be compared to one another. To address this issue, the manufacturer had agreed to coat the SQM-DL housing in a glossy white paint to prevent ultraviolet yellowing and to maintain a cooler temperature with the case. To further reduce light scattering, the inside of the housing may be coated in a matte black.

The HOYA-CM500 filter with each device should have no transmission between 730 and 1020 nm, but readings of roughly 20 mag/arcsec^2 were detected in this range. These readings required a high output to achieve, but prompted further testing on the filter. When a device was opened up, I noticed that the filter is encased in plastic. Results showed that the index of refraction of the plastic caused light-piping (i.e. leaking) of light around the filter, leading to transmission, which skews the integrated readings of the devices as they include low infrared wavelengths.

Prior testing results showed that the glass cover on the weatherproof housing lead to a a slightly bright reading. The transmission curve found for this glass filter illustrates a loss of roughly 10% around 400 nm for all devices. The transmission steadily drops down to about 83% around 900 nm. Data gathered with and without the glass produced a trend that is in agreement with the transmission curve. In order to interpret results, this needs to be taken into account. The transmission curve for the glass was the same for each device, meaning that they can still be compared in that regard, once the weatherproof housing is properly protected from ultraviolet damage.

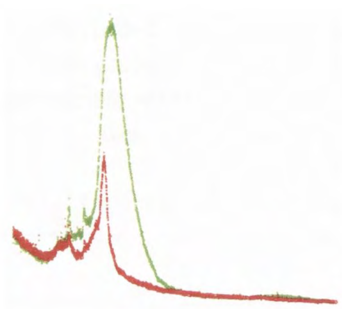


Figure 5 Spectral output with and without the external IR filter

4. FINDINGS IN LOGAN

Though I returned to Logan in the fall of 2013, I was not able to install the two SQM-DLs I purchased through my URCO grant at that time. One device was damaged upon arrival, and was lost in transit when it was sent back to Unihedron. Before getting the second SQM-DL back to Logan, I collaborated with Jordan Rozum to further test the HOYA-CM500 filter that is installed in the SQM-DL devices. This is important to analyzing the validity of the SQM-DL readings because we are attempting to isolate visible contributions to light pollution and must take care not to allow contamination by infrared sources. The atmospheric airglow in particular is a bright light source in the night sky beyond the visible region of the spectrum that could contaminate the data with its own natural variation (Nydegger & Rozum (2014)).

For comparison, we measured SQM-DL readings of a 60 W bulb behind a 3.0D neutral density filter (so as to not saturate the device) with and without an external infrared filter. The difference was compared to the difference we could expect from measuring the spectral output of the bulb. By integrating between 300 nm and 700 nm, we obtained the expected difference. Assuming the internal infrared filter is functional, we expected a factor of 1.1962 in intensity, corresponding to a sky brightness measurement of 0.19451 mag/arcsec^2.

Figure 6 Light pollution map

The observed intensity ratios were much larger than expected, with 2.6792 being the minimum and 5.5463 the maximum ratio found. This means that there is significant sensitivity to the wavelengths outside of the 300–700nm range, which agrees with the findings I made at NOAO. To expand upon the data reduction pipeline created at NOAO, we also used weather data from Weather Underground to reduce data. Overcast weather generates artificially low SQM-DL readings because the clouds reflect much more light than the clear sky. Thus, readings taken during these times to not accurately reflect the extent of the light pollution. In addition, if the weather causes the SQM-DL to turn on before the evening, or alters measurements at night, the weather data reduction routine will remove those readings.

One research goal at Utah State University was to map the sky brightness (and thus the light pollution severity) across campus. This was done using a hand-held Sky Quality Meter and a GPS. The framework for this may is made from readings taken every 50 steps. I then took three readings to account for errors in detection. The data was then overlaid onto satellite images through Google Earth using the average of these three readings. While the outdated fixtures by the Mountain and Valley View Towers emit a large amount of light, new buildings are scheduled to be built there, and with that the lights will be updated.

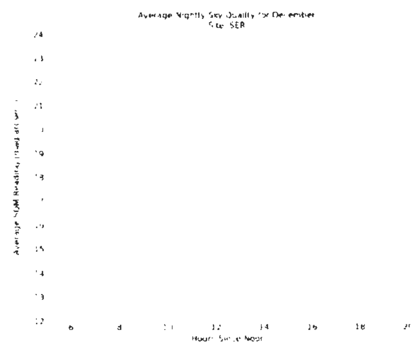
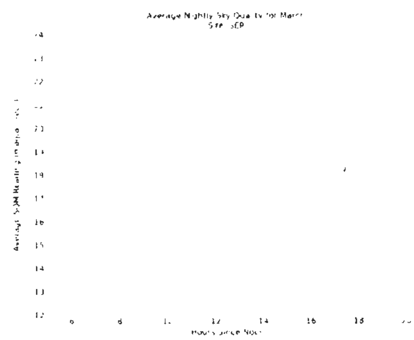


Figure 7 Average December nights are 1 magnitude darker than March nights



Though I eventually received the second SQM-DL, the weatherproof housing was not sent with it. This limited my data collection to only one device. While this was an unfortunate setback that limited my analysis of spatial sky glow trends, I was still able to analyze temporal trends after gathering data for little over a year. I placed a SQM-DL atop the SER roof near the astronomy observatory to assess how much light the observatory is detecting.

After removing natural sources of sky glow (e.g the moon) from the data, average measurements hovered between 18 mag/arcsec^2 and 19.5 mag/arcsec^2. Measurements far from the center of Logan are approximately 21 mag/arcsec^2, implying that an anthropogenic contribution of approximately 2 mag/arcsec^2 exists closer to the University. However, measurements with the hand-held Sky Quality Meter had much brighter measurements of 16 mag/arcsec^2 on the ground by the Merrill-Cazier Library. The difference between the bright readings on the ground and the darker readings on the nearby rooftop of the Science and Engineering Research building leads me to believe that the lights near the library are well-shielded.

Comparing average nights for each season illustrated that fall and winter nights are on average 1 mag/arcsec^2 brighter than the summer and spring nights. Further investigation lead to the discovery that the light reflected off of snow is responsible for this. Snowfall for the winter of 2014 and early 2015 was sparse, and that is reflected in the data. By March, the sky had already darkened by 1 magnitude in comparison to December. This is due to a scarcity of snow this past winter, where a majority of snowfall occurred in December, and sporadically for the rest of the season.

Over the course of several months, we found that the average sky brightness at the measurement site was 17.5 mag/arcsec^2 with a standard deviation of 1.3 mag/arcsec^2. However, individual nights varied in brightness by as much as 4 mag/arcsec^2. This relatively large variation points to light sources of anthropogenic origin, as no known natural phenomena have such wide variation. Some of the variation may be attributed to sporting events; the Legacy field stadium-type lighting often shines on the roof of the Science and Engineering Research building. Also, the USU football stadium is not far from the data collection sight.

5. BLUE GOES GREEN GRANT

Through analyzing various lamp posts on Logan campus with the Pocket Lux Meter, I discovered that the newer street lamps on campus are more dark-sky friendly than the old fixtures. While USU Facilities does have a program in place to retrofit light fixtures, and newly installed fixtures are chosen with light pollution taken into consideration, concerns regarding too little lighting take priority over those with too much.

USU has been taking strides towards becoming a more eco-friendly university, and offers Blue Goes Green grants to students who want to contribute to a more sustainable campus. These grants are funded through student fees, and have been used to address conservation issues through installing water-filling stations, organic farms, and composting on campus.

With help from Matt Rogers from USU facilities, I selected four parking lot lights to renovate to the east of the Industrial Science Building. These fixtures were poorly shielded, and are close to the astronomy observatory – used for classes as well as public outreach, the LIDAR observatory, the Kent Concert Hall, and the Manon Russell Caine and Kathryn Caine Wanlass Performance Hall. This area has a lot of nighttime traffic on campus, and is a prime candidate for renovation. The fixtures are also quite old, and replacement parts are expensive.

Matt Rogers and I determined that the best replacement lights would be shielded Lithonia LED fixtures. A contour plot of the output from the new fixtures shows that less than one footcandle of light will leave the parking lot (see Figure 6). Each new light uses only 213 W, resulting in an annual savings of $570/year. With an initial installation cost of $8200, the costs would be recovered in twelve to fifteen years.

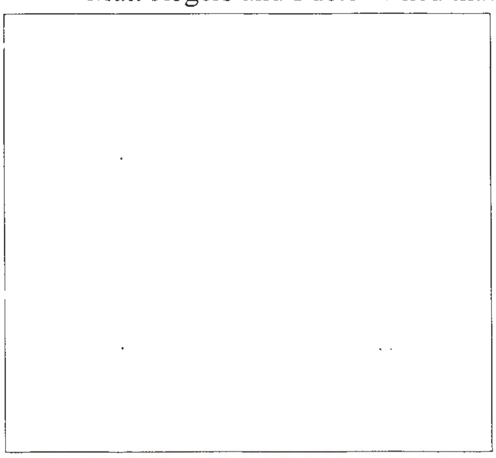


Figure 8 Contour plot of light output, where pink is 5 footcandles, blue is 4 footcandles, red is 1 footcandle

The Student Sustainability Committee granted $7100, and Facilities donated $200 and labor. The excess funds were to be used for outreach events, such as Science Unwrapped and conferences. I applied for this grant in the fall of 2014, and the lights were installed in March 2015. An educational sign will be posted by the parking lot during the summer of 2015 to help raise awareness about light pollution issues.

7. OUTREACH

While updating light fixtures makes an impact, changes on an individual level can make a much more substantial impact. Simple, effective ways to reduce light pollution are to close the window blinds at night or to turn off the porch light once it is no longer needed. Citizens can purchase bulbs only emit wavelengths that humans can see that do not disturb melatonin production in the brain or interfere with migratory patterns. Awareness of light pollution and the plethora of negative effects associated with it is relatively low. To address this, an important part of my work with light pollution is outreach. In addition, much of the research in this field is conducted by citizen-scientists, making outreach with the public all the more crucial.

To increase awareness on a local scale, I participated in several interviews to educate the public about light pollution. I have been interviewed by Aggie Radio, ATV News, FOX 13, and others. Regional conferences such as Research on Capitol Hill, the Utah Conference for Undergraduate Research, Student Showcase, and Research Week at USU have all be excellent venues to increase awareness. I have consequently been contacted by several citizens to consult on light pollution matters, showing the effectiveness of this outreach.

I also presented my research at several Science Unwrapped events. Science Unwrapped is a series of lectures at USU geared towards to general public, and especially children. Following the lecture, activities are held to engage the public in education on topics related to the lecture of the day. The most recent series, in spring semester of 2015, was an ecology-centered series, and I created a poster for passersby to read and brought out birds that use stellar compasses and are therefore greatly affected by light pollution. I also used this opportunity to educate the public about the Blue Goes Green Grant program and how I have taken advantage of it to make a difference on campus. Many of the people who came to see the poster and the birds were very interested to know what they could do to help reduce light pollution in their communities, leading to many productive conversations.

On a national and international level, I presented my research at the first annual International Artificial Light at Night conference in Berlin, Germany, and at the American Astronomical Society in Washington, D.C. These conferences have offered me an excellent opportunity to increase awareness in the scientific community regarding light pollution. My research has been recognized by the International Dark Sky Association, who awarded me the Dark Sky Defender award in 2013, and by the Barry M. Goldwater scholarship in 2013. These awards have made me more visible on the international level and have given me a platform for spreading awareness about these issues. For example, in fall of 2014, I was contacted for an interview in Radiations Magazine, the national magazine for the Sigma Pi Sigma, a national honor society for physicists. While I was contacted to discuss my academic career, it served as an excellent vehicle for my message to reach physicists across the country.

8. FUTURE WORK

Much of the data collected from the Logan site has yet to be fully analyzed. These data are expected to reduce the uncertainties in the measured quantities regarding light pollution, such as average brightness and durations of periodic trends. While the Logan site is no longer actively collecting data, the Tucson project remains active and might benefit from the insights gained in Logan. For example, analyzing the data in relation to weather is not currently part of the processing pipeline in the NOAO project.

When Unihedron releases its new SQM-DL devices with improved filters and ultraviolet protection, data collection can begin again in earnest. Comparison of the new data with the old may provide further insights into the effect of the environment on the measurement devices. The new data will also be used to examine the validity of the conclusions drawn from the old devices, since the newer devices will function more reliably and predictably.

I will continue to be a vocal proponent of good lighting practices through various outreach events. I remain an active speaker on the Aggies Going Green radio show to encourage sustainable practices by students at USU. In addition, I continue to be contacted by concerned citizens asking about what they can do to make a difference in their community's lighting. I hope to encourage and be part of political movements to enact and enforce stricter lighting codes throughout the country.

9. CONCLUSION

A slew of negative side-effects are caused by the excess light due to inefficient light shielding – light pollution. To quantify the amount of anthropogenic sky glow, many citizen-scientists use SQM-DLs, which are lost cost and provide an easy method of measurement. With this field being predominantly citizen driven, these devices are as rigorously evaluated as most scientific instruments.

Through my research at NOAO, I found that while these meters detected wavelength in the visible spectrum, they also picked up wavelengths that the internal CM500 filter was meant to block. Incoming light was being refracted by the plastic in which the filter is encapsulated. Another cause of concern is that the weatherproof housing for these SQM-DLs yellows over time due to ultraviolet radiation, and the amount of radiation depends on wherever the device is stationed, and the readings are affected by the amount of yellowing. This means that data from SQM-DLs that were exposed to different climates cannot be compared. Following discussion with the manufacturer, future housing for these devices will be coated on the outside with a glossy white paint for ultraviolet resistance and a matte black on the interior to decrease light scattering.

Nonetheless, SQM-DLs are the predominant instruments used for detecting ambient sky glow. From a year of data collection at eight sites in and around Tucson, Arizona, I created an analysis pipeline to be implemented in a Globe at Night graphical user interface in order to standardize interpretation. With this pipeline, I found that the Tucson area has a 10 day trend, 15 day trend, and I stumbled upon a correlation between sky brightness and the OI 557.7 nm airglow, prompting further investigation. I also found a spatial trend showing that Tucson is up to 4 mag/arcsec^2 brighter than the remote observatories surrounding the city. This suggests that the difference is purely anthropogenic.

Further experimenting was done to determine how well the infrared filter is functioning. This was done by comparing SQM-DLs readings of a 60 W light bulb through a 3.0D neutral density filter to spectral readings through the same filter. Jordan Rozum and I found that the SQM-DL was up to five times for sensitive to wavelengths between 700 nm and 1000 nm than advertised.

Another year-long data set was amassed in Logan, Utah, through funds provided by an URCO grant. While the data collected atop the SER building at USU showed that the university has relatively well shielded fixtures, there are enough outdated, unshielded street posts that there exists a difference of up to 4 magnitudes between USU campus and the outskirts of Logan. A non-anthropogenic contribution of light pollution in Cache Valley, which brightened the sky by 1 magnitude, was found to be light reflecting off the snow.

To address a source of light pollution, I applied for a Blue Goes Green grant to replace four parking lot lights to the east of the Industrial Science building. The new fixtures are better shielded LEDs, which lead to an annual savings of $570. Depending on maintenance of these fixtures, they will pay of themselves in twelve to fifteen years.

In an attempt to bring awareness to the general public, I participated in several outreach events. On a local level, I have been participating in the Aggies Goes Green radio show for the spring of 2015, and have been interviewed by several USU media outlets and regional news stations to discuss the issue of light pollution. I also have presented my research and provided activities for Science Unwrapped. On the national and international level, I have presented my research at several venues, and my research was recognized by the International Dark-Sky Association as well as the Barry M. Goldwater Foundation. This recognition has brought increased visibility of the issues my research pertains to, which led to an interview with Radiations magazine.

Continued work must be done with outreach to publicize the issue, and I intend to continue my analysis of light pollution once Unihedron updates their instruments, as they have agreed must be done after seeing the results after my research. As more data is amassed in Logan, a better understanding of local light pollution can be made. The improved pipeline also can be shared with NOAO and the National Park Service, to further isolate anthropogenic contributions to sky brightness in Tucson as well as be implemented in the Globe at Night graphical user interface for everyone to use.

REFLECTION

I began this research with an interest in astronomy. I had done research in gravitational waves, and I enjoyed astro-imaging at the observatory atop the SER building. My work in the observatory opened my eyes to the issue of light pollution, and I decided to do something about it. Sustainability and environmentalism are very important to me, so as I explored all the issues surrounding light pollution, I became more and more invested. Light pollution research especially appealed to me because of its obvious applications – in contrast with the astronomy work I had focused on earlier.

Through this experience, I learned first and foremost that experiments rarely go as planned. When I applied for an URCO to purchase SQM-DLs, I had not realized the extent to which the devices were in need of improvement. It would seem that many researchers in the field were also unaware of these issues; the SQM-DL is a standard instrument in this line of research. My research at NOAO may have led to renovations of the SQM-DLs, but it also meant that the analysis done with these meters required a lot of massaging.

When I first received the equipment from my URCO grant, I was eager to start my project, but one of the devices arrived damaged. My research was delayed. I sent it back to the manufacturer for a replacement. The replacement was lost in transit. My research was delayed. I contacted the company and they sent another device – this time it arrived. It was missing its weatherproof housing. My research was delayed. Eventually, I managed to work around these problems, but I didn't see these setbacks coming, and when I talked with others about their projects, it sounds like that's just how experimentation goes: Expected results are not common.

One huge benefit of this research is that I learned how to program. I struggled with it in the beginning, but I've learned to really enjoy it, and it has made me a very marketable researcher. I find that it has developed into an indispensable skill and I regret not taking the time to learn it sooner.

Over the course of my undergraduate career, I realized that I would be happier as an ecologist than as a physicist, and this research played a big role in that decision. I enjoyed doing work that truly meant something to me on a personal level and as I got father along in my math and physics classes, I didn't enjoy them anymore. I wanted to do something that I felt benefitted the world; something that aligned with my ethics and made me feel morally obligated to continue forward in my work – something that I could really be proud of. This sustainable, moral part of my research ethic is what led me to work in light pollution in the first place. When I presented my research at the 2013 Artificial Light at Night conference in Berlin, Germany (hosting the Pergamon Museum - probably the best museum in the world!), I felt like I had found my drive again. While part of the conference was focused on physics and instrumentation, a very large portion of the meeting included ecology talks. It was here that I realized that I relished the ecological aspect of my research the most; it seemed vastly more important to me than the physics and astronomical roots of the project.

With a new focus in mind, and a drive to make a tangible difference, I decided to look into the Blue Goes Green grant to see if there was any way I could incorporate one of these grants with my research. I used the Pocket Lux Light Meter from my URCO grant to find inefficiently shielded fixtures on campus, and realized that the oldest fixtures are the biggest culprits.

I went to USU Facilities with a plan to change the lights at the Mountain View and Valley View Towers, only to be told that they will be torn down soon and it would be a waste of money. Again, things rarely go as planned. So I instead looked at areas of campus that have a lot of nighttime traffic – like the area around the Kent Concert Hall, Manon Caine Russell and Kathryn Caine Wanlass Performance Hall with the LIDAR and USU astronomy observatory. I found that the fixtures in the Industrial Science building's parking lot contributed the most to light pollution near the observatory, interfering with astronomy done there, which is what first steered me toward this line of work. I received the grant and all went well.

I really enjoyed this research project, but it taught me that a research topic is never really exhausted. My research led to a URCO, which led to Blue Goes Green, and I wish that I could take it further at USU, but I am, alas, graduating. I continue my work through outreach and hope to make a positive change in my community's lighting practices, wherever that community may be.

BIBLIOGRAPHY

Duriscoe, D. M Measuring anthropogenic sky glow using a natural sky brightness model (2013)

Hoya-Optics. Color Compensating Filter (Cyan) CM-500 (2008)

International Dark-Sky Association www.darksky.org, (2014).

Navarra, K. J. and Nelson, R. J. Journal of Pineal Research **43**:215-224 (2007).

TAOS. TSL237 High-Sensitivity Light-to-Frequency Converter (2006)

Unihedron. Sky Quality Meter -Lens USB - Datalogger SQM-LU-DL
User manual ((2015)

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Rachel Nydegger is graduating with a Bachelor's degree in physics with a professional emphasis and a minor in mathematics. She has worked on several research projects including investigating sources and management of light pollution, multi-messenger astronomy, and mathematical modeling of invasive species. Rachel is a Barry M. Goldwater Scholar and an International Dark Sky Association "Dark Sky Defender" awardee. She has worked to improve lighting conditions internationally through conference presentations, nationally through magazine interviews, and locally through public outreach and through her participation in Utah State University's Blue Goes Green initiative. She plans to take a year off from classes to focus on research, and then attend graduate school in ecology.