Use of a Nikon DSLR Camera to Evaluate the Effect of Moonlight on Nighttime Visibility

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A Nikon DSLR camera and a UDT Instruments Handheld Optometer were used to analyze various parameters of nighttime visibility under varying moonlight conditions. A stuffed Build-A-Bear was used as a model for image analysis. The bear was photographed wearing everyday clothes including jeans and a t-shirt as well as wearing a neon worker's vest with reflective strips. The resulting images indicated that neon clothes are effective in aiding visibility at night. The images also resulted in a greater understanding of how impactful clouds are in altering nighttime visibility. While the abundance of clouds skewed the data associated with the percent illumination of the moon, a separate series of images comparing the new moon and full moon on clear nights indicated that there is a significant difference in brightness as the moon phases change. Analysis also indicated that objects become less visible as they recede in the distance under the full moon and more visible under the new moon. The DSLR images were lastly compared to the brightness data from the optometer and it was concluded that DSLR cameras are able to output good data, but may not always be the best tool for certain research.

I. INTRODUCTION

The lunar cycle is a 29.5 day period marking the time required for the moon to orbit around the earth. This cycle is the cause for many different environmental phenomenon including illumination levels, tides, and geomagnetic fields [1]. As a result, the amount of visible light at night varies by about three orders of magnitude during a one-month period [1]. This can have an immense effect on plants and animals. Many animals, for example, amphibians, fish, birds, and bats all base their reproduction and migration habits on the lunar cycle. Even a plant's growth cycle is effected by visible levels of moonlight [2].

An abundance of technology has been created to enhance our understanding of how the universe works. Unfortunately though, this technology can be very expensive. Professional astronomy cameras have special components such as thermoelectric cooling which enable them to perform exceptionally well [3]. These cameras can cost more then $1,000. As a result, astronomers have been exploring digital single-lens reflex (DSLR) cameras for use in astrophotography [3]. Even astronomers onboard the international space station have used Nikon DSLR cameras to capture side-view images of aurora and air glow [4].

The first successful imaging technology using a digital sensor was invented in 1969 by Willard S. Boyle and George E. Smith, two physicists who worked together at Bell Laboratories in Murray Hill, New Jersey. This technology, called a Charge-Coupled Device (CCD), initiated the rapid development of digital photography. Boyle and Smith were eventually awarded the Nobel Prize for Physics in 2009 for their invention [5]. Seventeen years after the CCD was invented, Nikon developed a prototype for the first DSLR camera, with the first commercial DSLR camera being realeased in 1988 [6]. Since then, DSLR cameras have improved dramatically and are considerably cheaper than the aforementioned CCD cameras. However, even in 2022, they still do not have the special cooling systems that are found in professional astronomy cameras, and they often generate electrical noise [3]. As a result, it remains unclear whether the DSLR camera is a sufficient replacement for high-end cameras in the astrophotography field of research, but their popularity is widely growing.

II. THEORY

This theory section is primarily based on the information provided by Timothy J. Jensen's book, *An Introduction to the Modern DSLR Camera* [3].

Stars, like the sun, emit light from nuclear reactions that occur in the star's core. These reactions produce gamma rays (high energy photons) which are then absorbed by other atoms and molecules within the star. This absorption energizes those atoms, sending their electrons to a higher energy state. Eventually, the electrons reach an unstable energy state and are forced to decay back to their lowest energy level. This process releases photons of different energies which each have distinct wavelengths associated with them. As this process occurs on a continuous loop, the star's surface covers a large percentage of the electromagnetic spectrum with a small fraction of those emissions being visible light.

Based on the Earth's orbit, the sun's light is visible for approximately 12 hours per day. In the next 12 hours, the moon reflects light from the sun, offering a new light source to aid visibility at night. When the photons from this light interact with the detector chip of a DSLR camera, the energy from the photons allows electrons to move across the chip. The detector chip is composed of individual grains called pixels. The number of electrons within each pixel is directly proportional to the amount of light that is incident on it. These electrons are then counted by the camera's analog to digital converter (ADC), and a value for the voltage of the pixel is measured. This value is finally used to determine the brightness of the pixel within the final image.

Voltage values have no color information, so in order to convert the image from black and white to color, a Bayer matrix must be used. As shown in Fig. 1, Bayer matrices are composed of a set of colored filters which are placed over the detector chip, thus forcing light to be filtered through the matrix before analyzing it within the pixel. The 2×2 grid of filter colors is composed of the three primary colors of additive light: red, green, and blue [7]. The human eye has a greater sensitivity to green, thus green is used twice in the matrix. After the photons have filtered through the Bayer matrix, the camera measures the pixel intensities and adds them together to produce a color. One way this conversion can be explained is by the equation,

$$Y = 0.2125R + 0.7154G + 0.0721B \ , \tag{1}$$

where Y is the relative luminance, R is the red component, G is the green component, and B is the blue component [8]. As luminance from a DSLR image increases, its gray value also increases.

If an image of an object under the moonlight is captured using a DSLR camera, it's RGB values can be measured. Using Eq. (1) we can find its average brightness value as a black and white image. If this process is followed for an object under several different moonlight conditions, the average brightness values may be compared to determine how significantly the moon affects nighttime visibility. While these results in gray value are unitless, an optometer can also be used to understand the moon's brightness by means of nanowatts.

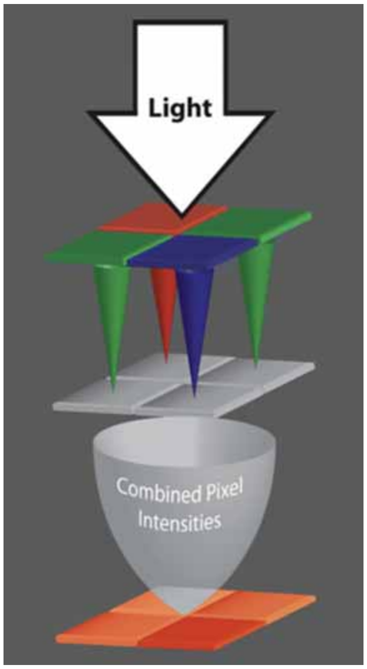

FIG. 1: Schematic of the Bayer matrix which the DSLR camera's detector chip uses to assign a color to each pixel that light is incident on (from [3]).

III. PROCEDURE

This experiment was performed in two different locations due to timing conflicts with spring break. The first five trials were performed in a fenced-in backyard in LaGrange, Ohio. The remaining trials were performed on the College of Wooster's golf course in Wooster, Ohio. Each day, a light brown Build-A-Bear with a blue t-shirt, jeans, and white tennis shoes was set up outside. This model was used to represent the different curves, shadows, and colors that are commonly visible on humans. The bear was placed on top of a (27.31 ± 0.03) cm high blue box, (55.9 ± 2) cm away from a Nikon D3500 DSLR camera. The camera used an $18 - 55$ mm lens and was mounted on top of a (29 ± 2) cm tripod. This experimental setup is shown in Fig. 2.

FIG. 2: Experimental set up of the self design moonlight experiment. The Nikon D3500 camera is shown in the center of the image on a tripod with the stuffed bear positioned directly across from it. The towel was laid out to allow the experimenter to avoid kneeling in mud that resulted from rainy weather.

After the equipment was arranged, auto mode was used on the camera to find the best settings for quality nighttime pictures. These settings were found to be: shutter speed = 1/5 s, focal ratio (f-stop) = $f/3.5$, ISO

= 12800, focal length = 18.00 mm, resolution = 300.00 pixels per inch (ppi), and flash = off. These settings were used for the duration of the experiment with a time stamp being placed on the bottom right corner of every image.

A vast majority of the pictures were taken around 9:45 pm, however some accommodations were made for weather patterns and phases of the lunar cycle. For example, if it was storming at 9:45 pm, but the sky was supposed to be clear around 10:30 pm, pictures may have been taken later. Also, as the lunar cycle approaches the waning phase, the moon begins to rise later in the night, thus some pictures were taken earlier or later to accommodate for the moon's position in the sky. This general time was also chosen because it would still be reasonable for people to be active outside, and the purpose of this experiment is to gain a better understanding of how the moon affects an individual's ability to see. With that in mind, images were also taken of the bear wearing a neon yellow worker's vest with large reflective strips not only to test the impact of wearing neon at night, but also to see if the light reflected off of the moon is strong enough to activate reflective strips. A general idea behind this is if two runners are moving towards each other at night with no street lights and no nearby vehicles, will they be able to see each other, and will different phases of the moon have a significant impact on that visibility?

Immediately after the pictures were taken, a UDT Instruments S471 Handheld Optometer was used to find an exact brightness value of the experimental atmosphere. The optometer was connected to a model 260 Silicon Optical Sensor which had a thick black plastic cap screwed on to in. Before removing the cap, the ambient zero command was initiated on the optometer. This instructed the machine to register the darkness as absolute zero. As soon as this command was processed, the cap was unscrewed and the sensor was held next to the bear pointing directly at the moon. This device is very sensitive and one specific brightness is not given, so a video of the numerical output on the device was recorded for future analysis.

For further exploration of the moon's impact on nighttime visibility, additional pictures were taken under the full moon and new moon. With this, the bear was not only observed at its (55.9 ± 2) cm distance from the camera, but also at eight other distances, each (51 ± 2) cm further than the previous location. This was done in order to see if the bear would eventually disappear into the darkness. Thus, relating to the previous example of the runners, would the two individuals have to be extremely close in order to see each other, and does this change depending on the illumination level of the moon?

All of the images were compiled into Photoshop and cropped to (28.58 ± 0.03) cm in length and (22.86 ± 0.03) cm in width. This helped eliminate the inconsistency in backgrounds throughout the experiment before analyzing the brightness values. From here, the Record Measurements feature was used in Photoshop to convert the images to gray scale and analyze their mean gray value data. Then, the optometer videos were played, and the average brightness in nW was recorded for each night. The *Time and Date* website [9] was also used to find the moon position and percent illumination at the time that each of the images were taken. All of the results were then transferred to Igor and plotted for further analysis.

IV. RESULTS & ANALYSIS

Conditions for this experiment were less than ideal, leading to skewed results and poor data. However, a few of these poor conditions gave rise to information that was not considered in the experimental design. The first obstacle that arose was a series of timing conflicts. The experiment was intended to begin a month in advance. However, the battery within the optometer died, setting this back a week. After collecting five days worth of data, the moon shifted into its waning phase. As a result, the moon did not rise until times ranging from the middle of the night to early in the morning. Thus, between the small likelihood that two individuals would be outside running at times like 2:00 am and the overlap of the sunrise at times after 6:30 am, collecting data from the waning phases of the moon became impractical. This put a pause on all data collection for the next two weeks until the moon cycled back to the waxing phase. Then, after about another week of data collection, a travel conflict prevented data from being collected for three additional days. Unfortunately, these three days occurred during the same moon phases that were missed due to the optometer issue, thus, a sizable range of results are missing from the data collection as visible in Fig. 3.

The purpose for beginning this experiment a month in advance was to avoid cloudy nights by having time to retake pictures when the sky was clear. However, with the loss of all data collection during the waning phases as well as all of the other timing issues, cloudy skies could not be avoided. The months of March and April are on average 56 % and 54 % cloudy [10] respectively, making for even fewer opportunities to take pictures under a clear sky. Although these conditions do skew the results of the initial question (How influential is the moon on nighttime visibility?), they also shed light on a question that was not previously considered (How influential are clouds on nighttime visibility?). It turns out that clouds are extremely influential. Figure 3 shows that the results were extremely scattered, giving no apparent correlation. This is impart to cloudy nights and the various conditions of those clouds. Some nights were partly cloudy, some completely cloudy, some with thick or thin clouds, and some with stagnant or

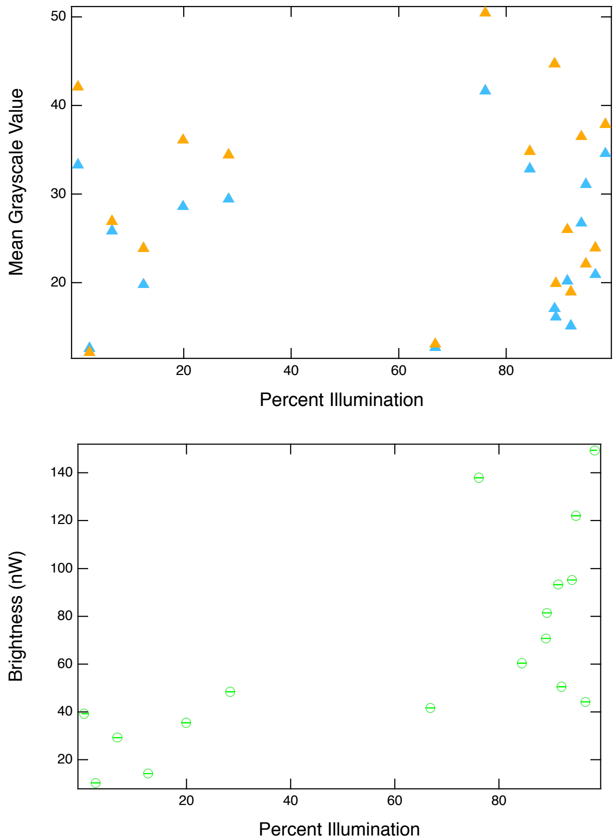

FIG. 3: Brightness data under different levels of moon illumination. Top: brightness data from the Nikon DSLR camera (blue triangles) for images of the bear wearing a t-shirt and jeans, as well as (orange triangles) the bear wearing a neon vest. Bottom: data collected from the optometer as the moon illumination increased. Each data point has vertical error bars of ±0.01 %.

rapidly moving clouds. All of these conditions had an impact on the visibility levels, thus obscuring any potential correlation between moon phases and night sky brightness. Some examples of the different clouds that were present during the experiment are shown in the Appendix (Figs. 6 to 9).

The brightest night that was observed according to the data recorded from the DSLR camera was when the moon was only at about 3/4 illumination capacity. This night occurred at the end of a very rainy day. While taking pictures, the sky was completely covered in thick clouds, and there was a heavy mist in the air. The golf course where data was collected is located at the top of a hill where city lights can be seen in the surrounding distance (see Fig. 10 in the Appendix). Presumably on this night, the city lights were refracted not only off of the clouds in the sky, but also throughout the mist in the air, making the surrounding area significantly brighter. Because it was so bright outside, the camera processed images at a shutter speed of 1/8 s instead of 1/5 s. This makes the resulting images 1.6 times darker than the standard setting that the rest of the images were captured with. Even though these images do not fit within the parameters of the rest of the data, they were still included in the results to show how impactful atmospheric conditions are on nighttime visibility as well as how they impact the use of DSLR cameras. According to the optometer, there was only one night that was brighter than this and that was with a full moon and minimal scattered clouds.

Similar to this abnormally bright night, there were also some nights that were much darker than expected. For instance, on March 15, 2022, the moon was at 92 % illumination, and the sky was very cloudy. These clouds blocked nearly all of the moonlight, making the night sky brightness only (50.517 ± 0.005) nW. This then constitutes the question, how do the various types of cloud formations interact with light? One night was very cloudy, causing the city lights to be reflected back to Earth, while another night was very cloudy and minimal ambient light was reflected. There are numerous different cloud properties that could affect this including cloud optical thickness, ice distribution, relative position to the moon, number of cloud layers, cloud type, ice water content, cloud coverage, etc. [11]. Since there are so many factors to consider, cloud properties will not be further analyzed in this report, however it should be noted that clouds can have a major impact on atmospheric brightness in many ways.

In addition to analyzing a bear wearing a t-shirt and jeans under different moonlight conditions, this object was also analyzed wearing a neon vest with reflective strips. Images of both of these subjects are shown in Fig. 11 in the Appendix. Figure 3 gives a comparison of these results, indicating that neon clothes are consistently more visible than standard clothes. In many situations there was a significant increase in brightness between these two outfits such as the 27.6 value increase at 89 % moon illumination. However, on some nights the difference was minimal like the 0.44 value increase at 2.5 % moon illumination. With this being noted, the difference in visibility levels did seem to increase as the overall brightness increased. This indicated that the reflective strip could have been activated under brighter conditions, although there is not enough consistency in the data to form this conclusion.

The next comparison that was observed in this experiment was how the full moon and the new moon impact the visibility of objects as they recede into the distance (see Fig. 4). For this experiment, the DSLR camera was kept in a constant position to take pictures as the bear was moved backward from (0.56 ± 0.02) m to (4.62 ± 0.02) m with $\Delta x = (0.51 \pm 0.03)$ m. These images were then imported into Photoshop and just the

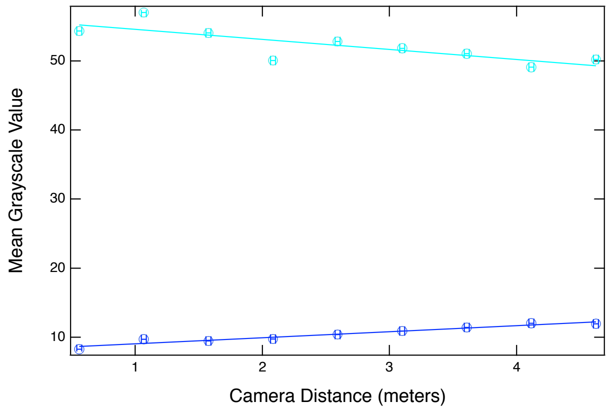

FIG. 4: Gray value as the stuffed bear was moved incrementally further away from the camera. The light blue data at the top of the graph represents images captured under the full moon on a clear night in LaGrange, Ohio. This data was compiled with a linear fit, giving a slope of (-1.46 ± 0.41) 1/m and a y-intercept of (56.079 ± 1.19). The dark blue data on the bottom represents images captured under the new moon on a clear night in Wooster, Ohio. This data was also compiled with a linear fit, giving a slope of (0.88 ± 0.08) 1/m and a y-intercept of (8.1592 ± 0.242). Both sets of data have horizontal error bars of 0.02 m.

bear was cutout to measure the mean grayscale value. Unexpectedly, as the bear receded under the new moon, it appeared to become brighter at a rate of (0.88 ± 0.08) 1/m, but as it receded under the full moon, it became slightly darker at a rate of (-1.46 ± 0.41) 1/m. When performing this experiment, there were dark nights in which I could hear but not see individuals until they were directly in front of me, and bright nights in which I could see individuals who were as far as 200 m away. Thus, these results are likely inaccurate. This could possibly be due to the location that the images were taken in. The full moon data was collected in LaGrange, Ohio with a flat white fence in the background while the new moon data was collected in Wooster, Ohio with the sky and distant city lights in the background. What this experiment was successful in showing though, was the significance in difference between nighttime visibility under the new moon compared to the full moon as both of these sets of data were recorded under clear night skies.

The final major observation that was made in this experiment was comparing DSLR camera results to optometer results in order to determine how accurate DSLR cameras are for future experimental use. This comparison is shown in Fig. 5. The optometer results seem to follow a similar pattern to the camera results, but they are not quite the same. These two devices recorded data in different units, so it was not expected for the results to line up perfectly, however the optometer output should at least be consistently above or consistently below the DSLR output. Unfortunately this is not always the case.

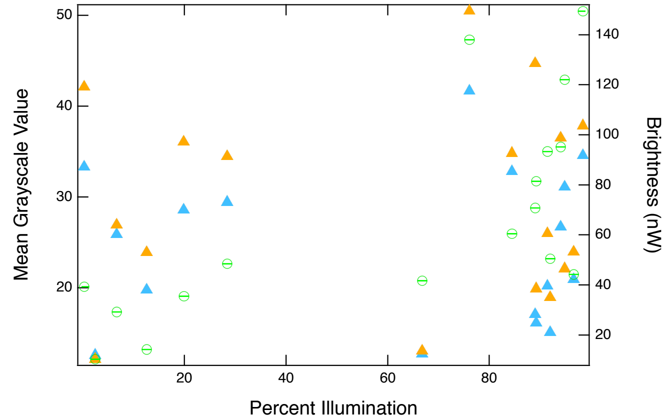

FIG. 5: Combination of plots in Fig. 3.

The greatest difference in using these two devices was that on cloudy nights when pointing the optometer sensor towards the moon, it was possible to wait to record data for the few seconds that the moon was not covered. When focusing the camera on the stuffed bear though, watching the moon became a little more difficult. Because the camera results still have very similar tendencies to the optometer, it may be concluded that DSLR cameras are good tools for experimentation, however, depending on what they are being used for, there may be better options. Note that the Appendix depicts three additional images in Figs. 12 to 14 which show observations that were made during the experiment.

V. CONCLUSION

A DSLR camera was used to study the relationship between moon phases and nighttime visibility. Within this experiment, several different topics were analyzed in order to gain a better understanding of how the moon interacts with Earth's surface as well as how efficient a DSLR camera is for research purposes. The first relationship analyzed was how nighttime visibility levels change relative to moon illumination. No direct correlation was found for this part of the experiment because there were too many sources of error affecting the data. However, results from a later comparison did show that there is a significant increase in brightness between clear nights with 0 % illumination and clear nights with 100 % illumination.

Some of the error that was inhibiting the research was extremely noteworthy. By analyzing the scattered results that are found in Fig. 5, it became evident that different types of clouds can have a much greater impact on nighttime illumination levels than the moon. In certain situations, the clouds refracted so much light that the night became unexpectedly bright, while in other situations, the clouds inhibited any light from dissipating throughout the atmosphere, causing the night sky to be unusually dark.

These results were compared to the brightness levels of images when the stuffed bear being photographed wore a neon yellow workers vest with reflective strips. These results were consistently brighter, forming the conclusion that neon colors are easier to see at night than other colors. The differences in these two results also appeared to increase as the overall brightness levels increased, leading to the possibility that the reflective strips were activated under brighter conditions, although, the data was not consistent enough to fully support this conclusion.

The data from those two analyses were plotted alongside brightness measurements from an optometer in order to understand how accurate the DSLR camera was in this experiment. Overall, the data appeared to follow the same trends, however there was a lack of consistency in this relationship, showing substantial error in the DSLR. This may be impart to the fact that while recording data with the optometer, it is easy to watch the sky and only collect measurements when the moon is visible, however, it is difficult to monitor cloud positions while taking pictures with your back to the moon. This indicated that DSLR cameras can be very useful for future experiments, but may not always be the best choice of technology for certain research.

The final set of images that were analyzed in this experiment were those taken at various distances under the new moon and full moon. These results indicated that objects get brighter as they recede with no moon illumination and darker as they recede with 100 % moon illumination. Personal experience disproves this result though. The best assumption for why new moon images got brighter is because the bear was receding into a night sky background illuminated by distant city lights whereas the full moon data was collected while the bear approached a tall, plain white fence.

There were many sources of error that could have been fixed to improve this experiment. One issue was that the neon vest was much to big for the bear, so sometimes more or less of it showed up in the image depending on how it was draped over the bear. The reflective strips also changed depending on where the vest folded over. Future experiments could use a neon outfit that fits the model, or find a way to hang the clothes so that their shape is always consistent. Experimenters could also be careful to perform the entire project in the same location with a consistent background, avoiding any city lights that may be on or off in different nights. With this, the experiment should also be performed over a longer period in order to avoid nights with air pollution. Another inconsistency was the direction in which the bear was leaning because this effected the area of the bear in the final image. Overall though, a lot of information was gained from this experiment showing that many factors other than the moon can have a strong impact on nighttime visibility.

VI. ACKNOWLEDGMENT

I would like to thank Dr. Manz for helping me plan this experiment as well as for allowing me to borrow his optometer to record measurements in the field.

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Appendix A: Experiment Images

FIG. 6: Cloud conditions: minimal clouds.

FIG. 7: Cloud conditions: several thick layers of clouds.

FIG. 8: Cloud conditions: complete cloud coverage with lots of moisture in the air.

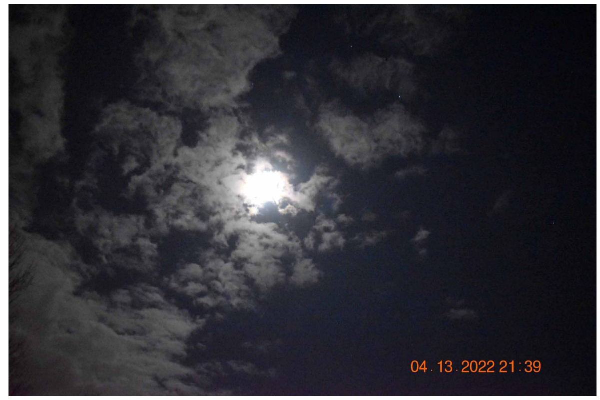

FIG. 9: Cloud conditions: scattered thick clouds.

FIG. 10: Experimental environment in Wooster, Ohio.

FIG. 11: Experimental environment in LaGrange, Ohio.

FIG. 12: Other images: Big Dipper.

FIG. 13: Other images: nice picture of the moon.

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FIG. 14: Other images: bear gazing at the moon.