Sky Brightness at Zenith During the January 2019 Total Lunar Eclipse

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Abstract Lunar eclipses occur during the full moon phase when the moon is obscured by Earth's shadow. During these events, the night sky brightness changes as the full moon rises and then passes first into the penumbral and then the umbral shadow. We acquired sky brightness data at zenith using a Unihedron Sky Quality Meter during the 20–21 January 2019 total lunar eclipse as seen from Morehead, Kentucky. The resulting sky brightness curve shows an obvious signature when the moon enters the umbral (partial) eclipse phases and the total eclipse phase. During the total eclipse phase, the brightness curve is flat and measures 19.1 ± 0.1 mag / arcsec^2. The observed brightness at totality is close to typical new moon in January night at our location, which measures 19.3 ± 0.1 mag / arcsec^2. The partial eclipse phase is symmetric on either side of totality. The penumbral phase is more difficult to identify in the plot, without comparison to a typical full moon night. There is a clear asymmetry in the curve just before and just after the umbral phase. This asymmetry is probably due to changes in terrestrial atmospheric conditions, such as high altitude clouds.

1. Introduction

Photometric studies of sky brightness during solar eclipses are common (e.g. Pramudya and Arkanuddin 2016 and references therein), while those examining the evolution of sky brightness during a lunar eclipse are extremely rare. During the 6 July 1982 lunar eclipse, Morton (1983) monitored changes in the brightness and color of the night sky using the 31-inch reflector at Lowell Observatory in Arizona. He positioned the telescope 20 degrees due north of the moon and tracked at lunar speed. Two decades later, Dvorak (2005) serendipitously obtained eclipse sky brightness data while making CCD observations of the eclipsing binary QQ Cas during the 24–25 October 2004 lunar eclipse. He produced a plot the sky brightness in ADU versus time. We will compare our results to those of Morton's and Dvorak's.

The entire total lunar eclipse of January 2019 was visible across all of North and South America, most of Europe, and western Africa (e.g. https://www.timeanddate.com/eclipse/lunar/2019-january-21) . On the East Coast of the United States, the eclipse began around 9:30 p.m. while on the West Coast the eclipse began around 6:30 p.m. All across the zone of totality, the duration of the eclipse was 5 hours, 11 minutes, and 33 seconds with totality lasting 61 minutes and 58 seconds.

2. Instrumentation and observations

Night sky photometry can be performed quite easily using Unihedron Sky Quality Meters (Unihedron 2019; Cinzano 2005). There are several models of this device but all contain the same photodiode sensor (the TAOS TSL237S) and the same infrared blocking filter (a HOYA CM-500). Each SQM model is designed to measure visible light at zenith. SQMs contain an onboard temperature sensor and provide temperature corrected sky brightness readings in magnitudes per square arcsecond (mpsas). The measurement uncertainty of each device is ±0.1 mpsas.

Our device is a Sky Quality Meter fitted with a lens and enabled with Ethernet connectivity, hereafter, SQM-LE. The lens reduces the field of view of the SQM-LE to a 20-degree cone centered at zenith. Our device is located in weatherproof housing on the roof of a four-story building on the campus of Morehead State University in Morehead, Kentucky. The geographic coordinates of our location are 38° 11' 2.23" N and 83° 25' 57.67" W, 225 meters above sea level. The SQM-LE is controlled by a personal computer with SQM READER PRO software by KnightWare (http://www.knightware.biz/sqm/).

On the night of the eclipse, the temperature started at 15 degrees Fahrenheit and dropped steadily to 7 degrees near the end of the eclipse. In the early part of the night there were some passing clouds and winds averaged 7 miles per hour. Reported visibility was 10 miles the entire night. Astronomical seeing was good to very good and transparency between 4 and 5 (Astronomical League 2019). After midnight, winds dropped to zero and skies remained mainly clear throughout the remainder of the eclipse. Weather conditions on the night of the eclipse were obtained from timeanddate.com and are provided by CustomWeather, Inc. (2019). The SQM-LE took readings every two minutes beginning at sunset and ending at sunrise with all data logged to a text file. The predicted times for eclipse stages and lunar altitude at our location are provided in Table 1.

Table 1. Predicted times for eclipse stage.

Eclipse Stage	*Time (EST)*	*Lunar Altitude (°)*
Moon Enters Penumbra	9:26 p.m.	45.7
Moon Enters Umbra	10:33 p.m.	56.2
Moon Enters Totality	11:41 p.m.	66.8
Middle of Eclipse	12:12 a.m.	70.2
Moon Exits Totality	12:43 a.m.	71.9
Moon Exits Umbra	1:50 a.m.	67.9
Moon Exits Penumbra	2:48 a.m.	59.3

Note: Data from Thorsen (1995–2019), copyright © Time and Date AS 1995–2019. All rights reserved. Used by permission.

3. Results and analysis

The sky brightness during the night of the eclipse (20 January to 21 January 2019) are displayed in Figure 1. The plot displays mpsas versus local (Eastern Standard) time. Recall that magnitude is an inverse scale, with brighter values indicated by smaller numerical values.

How does the night of the eclipse compare to a new moon night or a full moon night? We have historical plots that serve as a good comparison of sky brightness. These data are measurements of night sky brightness at zenith taken with the same SQM-LE at the same location. Note that a clear new moon night, Figure 2, displays a constant night sky brightness after astronomical twilight. On the other hand, a clear full moon night, Figure 3, displays a steady increase in brightness until the moon reaches maximum altitude in the sky and then decreases as the full moon sets.

On the night of 20 January 2019, astronomical twilight began at 6:43 p.m. The full moon rose in the East and the sky began to brighten at zenith as it would on a normal full moon night. In Figure 1, it is difficult to see when the Moon enters the penumbral shadow; we will examine this later. The signature of the umbral phase of the eclipse is clear around 10:33 p.m., as indicated by the steady increase in mpsas, indicating a darkening of the sky. This corresponds to the first partial eclipse phase. Between roughly 11:43 p.m. and 12:43 a.m., the sky brightness reached a constant value of 19.1 ± 0.1 mpsas at totality. From just after 12:43 a.m. until about 1:43 a.m., the sky steadily brightened as the moon entered the second partial phase. There is a flattening in the brightness curve between 1:43 and 2:43 a.m., when the moon was in the penumbral shadow. The jagged feature just after 2:43 a.m. is a passing cloud; clouds have been shown to amplify night sky brightness (Kyba *et al.* 2011). After 2:43 a.m., the moon exited Earth's shadow. The night sky brightness following this decreased as it would on a clear, full moon night.

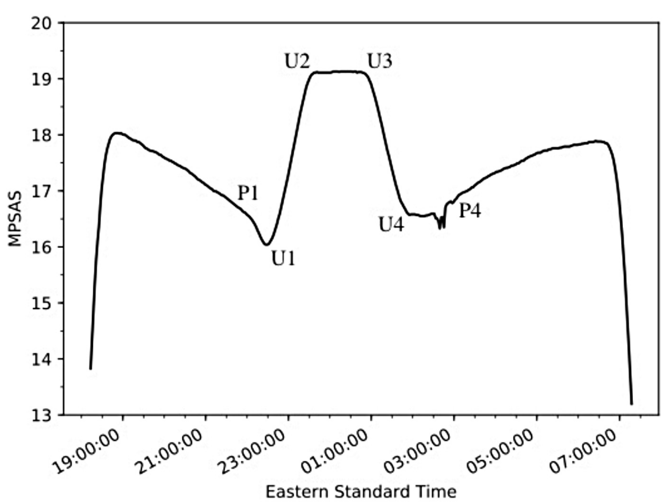

Figure 1. Measured night sky brightness in magnitudes per square arcsecond (mpsas) versus local (Eastern Standard) time during the January 2019 total lunar eclipse as observed from Morehead, Kentucky. This plot was created with the Matplotlib library in PYTHON (Hunter 2007).

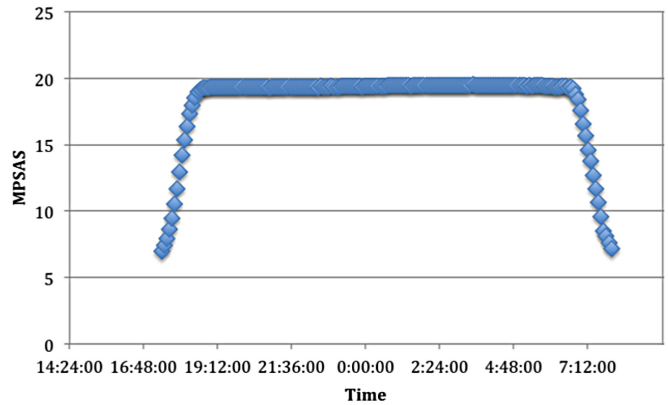

Figure 2. A clear new moon night occurring 7–8 January 2013 taken with the same SQM-LE at the same location.

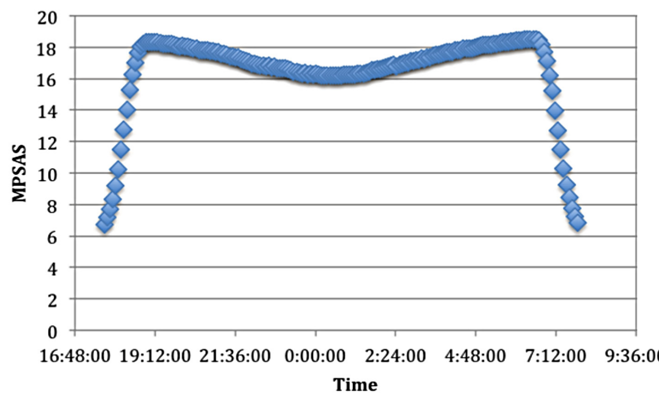

Figure 3. A clear full moon night occurring 26–27 January 2013 taken with the same SQM-LE at the same location.

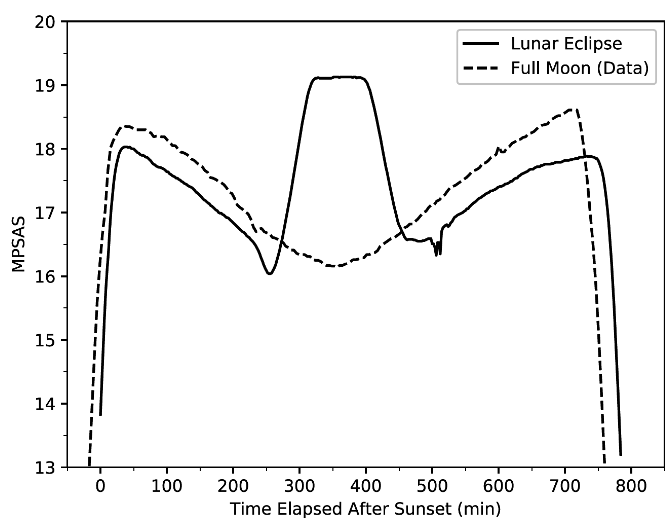

Figure 4. A plot comparing the night sky brightness in mpsas during the January 2019 lunar eclipse to a January 2013 full moon night with no lunar eclipse versus the time elapsed after sunset. The systematic difference of about 0.5 mpsas is attributed to recent construction on campus as noted in the text. This plot was created with the Matplotlib library in PYTHON (Hunter 2007).

To help identify when the Moon enters Earth's penumbral shadow, in Figure 4 we plot the data presented in Figure 3 collected on a full moon night in January 2013, without an eclipse, on top of the lunar eclipse data. Unfortunately, a hard drive failure resulted in the loss of the majority of our historical data, leaving only plots from previous talks and analyses. The full moon data presented in Figure 4 were extracted from Figure 3 with the WebPlotDigitizer (Rohatgi 2019) automatic extraction feature. In Figure 4, it is clear that the full moon night was on average about 0.5 mpsas darker than the lunar eclipse night. Because of the large lapse in time between datasets, we at first attributed this offset to the recent grand opening of a newly constructed student union directly adjacent to the building where our SQM-LE collects data. However, a colleague (Cool 2019) pointed out that the lunar altitude at our location on January 26, 2013 was 4.77 degrees higher than on the night of the eclipse. Further investigation revealed that the moon was 11% closer on the night of the eclipse as compared to January 26, 2013 (timeanddate.com): as a result, the moon was 23% brighter on the night of the lunar eclipse. These two astronomical factors would far outweigh the effects of local construction. In Figure 4, it is easy to see the concave-up shape of the full moon sky brightness curve. The brightness asymmetry before entering umbral phase (towards U1) and the exiting penumbral phase (towards P2) most likely results from changes in atmospheric conditions (Dvorak 2005). Interestingly, just before entering the umbral phase, there is a small increase in brightness, for which we have no explanation.

During a total lunar eclipse the surface of the moon is not completely dark: sunlight is refracted and transmitted by the terrestrial atmosphere onto the lunar surface (Keenan 1929; Danjon 1985). Full disk lunar photometry observations during lunar eclipses are numerous (e.g. Di Giovanni 2018, references therein) and such studies are used to probe the structure of the terrestrial atmosphere. The sky brightness at totality was 19.1 ± 0.1, which is consistent with a typical clear, new moon night in Morehead, Kentucky, which averages 19.3 ± 0.1 mpsas. The small difference is insignificant given that even on a clear night atmospheric extinction varies with season, dust, and air pollution (Krisciunas *et al.* 1987). Our measurements indicate that night sky brightness during totality is similar to that of a new moon night, in agreement with the results of Morton (1983).

Our SQM-LE sky brightness at zenith qualitatively agrees with those of Morton (1983) and Dvorak (2005) despite the use of distinctly different measurement methods. In all three observations, the umbral and totality phases are qualitatively similar in shape. During totality, we observed a nearly constant slope of zero, consistent with the observations of Dvorak. The eclipse data of Morton (1983) exhibit a zero slope during totality with the exception of a small positive "bump" in the second half of totality. This bump might be due to atmospheric conditions or the result of volcanic dust as mentioned by Morton.

The penumbral phases of our data are clearly asymmetric. The 1982 eclipse observed by Morton exhibits no asymmetry in the first and second penumbral phases. However, the October 2004 eclipse reported on by Dvorak exhibits penumbral phase asymmetry. In our data, the first penumbral phase exhibits an increase in brightness just before entering the first umbral phase, in qualitative agreement with the observations of Dvorak. On the other hand, Dvorak recorded an immediate, gradual increase in brightness as the moon exited the umbral phase. During the 1982 eclipse, the moon traversed through the middle of Earth's shadow. The 2019 and 2004 eclipses had similar geometry, with the moon traversing the upper third of the Earth's shadow. However, it is difficult to see how the lunar path would result in the observed asymmetries, especially given how closely the concave upward shape of our eclipse data matches that of a full moon, non-eclipse night. We posit that the asymmetry is due to atmospheric changes. Neither Morton nor Dvorak reported atmospheric conditions or weather. However, full disk photometry of the lunar surface during eclipses indicate that atmospheric conditions such as high altitude clouds, aerosols, and volcanic dust affect lunar brightness during eclipses (e.g. Muñoz and Pallé 2011). It is reasonable to assume that this might also affect night sky brightness. It is of note that Schaude (1999) observed unexplained increases in brightness just before and after the start of penumbral eclipses, just as we observe in our data.

4. Conclusions

The observed times for the phases of the lunar eclipse are consistent with predictions to within ±2 minutes, which is not surprising given the time resolution of our observations. The partial and total phases of the lunar eclipse can be identified by visual inspection. The measured brightness at totality is consistent with that of a new moon night. On the other hand, determination of the penumbral phases is more difficult and requires additional data from a full moon clear night for comparison. We posit that the origin of the brightness asymmetry in the two penumbral phases is due to atmospheric effects.

This study represents a tentative step towards filling a gap in sky brightness photometry during lunar eclipses. It is also the first study of night sky brightness during a lunar eclipse using inexpensive equipment, the meter, housing, and computer costing just under $900 US. This study is complementary to a daytime study recently done during the 2016 total solar eclipse (Pramudya and Arkanuddin 2016) using the same device. We suggest that coordinated observing campaigns of future lunar eclipses using a network of SQM devices might prove useful to further examine the origin of the observed asymmetry in the penumbral phase, particularly if paired with simultaneous observations of full disk lunar eclipse photometry.

5. Acknowledgements

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