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THE JANUARY 21, 2019 LUNAR ECLIPSE

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ABSTRACT

The B- and V-filter brightness values of the eclipsed Moon on January 21, 2019 were measured. The brightness values near mid-eclipse are B = –0.33 (0.15) and V = –2.07 (0.05) magnitudes. Uncertainties are in parentheses. The V-filter brightness near mid-eclipse compares well with a recent lunar eclipse model by Mallama; however, the measured B – V value [1.74 (0.16) magnitudes] is below the predicted value of 3.

Keywords: Moon, Lunar eclipse, Moon's color, Lunar brightness

INTRODUCTION

Scientists have been interested in lunar eclipses for over three centuries (Herald and Sinnott, 2014). Barbier (1961) reviews lunar eclipse work done before 1960. For example, he describes some early work done by Rougier and Dupois. These two report that an eclipsed Moon darkens more in blue than green light. Barbier also points out that the brightness of the eclipsed Moon at the center of Earth's shadow is 2×10^{-5} as bright as a full Moon in green light. Lunar eclipses can give us information about aerosols in our atmosphere, the frequency of objects striking the Moon and how quickly the lunar surface cools off when sunlight is blocked off. Each of these three areas are described.

Lunar eclipses can yield information on how quickly the lunar surface cools off. Saari et al. (1966) reports early mid-infrared images (wavelengths of 10-12 microns) of the Moon during the Dec. 19, 1964 total lunar eclipse. These images show warmer areas as bright. Essentially, they cooled off slower after the Moon passed into Earth's shadow. A similar image by Austin Richards (3–5-micron wavelength) was made during the January 21, 2019 lunar eclipse and once again, show areas that cool off slower on the Moon (Wilson, 2021). This work shows that not all areas on the Moon cool off at the same rate. These results may serve as constraints for the geology of local areas.

Lunar eclipses serve as an excellent opportunity to search for lunar impacts. This is because there is less scattered light in a fully eclipsed Moon than in a crescent lunar phase. For example, a three-day old Moon (waxing crescent phase angle = 140 degrees) has a brightness of –7.6 magnitude (Schmude, 2001). This is over 40 times brighter than a fully eclipsed Moon. Therefore, one may image fainter impacts. Furthermore, an eclipsed Moon will usually have a higher altitude than a crescent phase Moon under dark skies and, hence, there should be less interference from our atmosphere. In one case, two flashes were observed during the January 21, 2000 lunar eclipse that may have been lunar impacts. Unfortunately, these flashes were not confirmed by a second observer (Cudnik, 2002).

The brightness and color of a lunar eclipse may also serve as a probe of Earth's atmosphere. For example, Arnold et al. (2014), Yan et al. (2015), Kawauchi et al. (2018) and Strassmeier et al. (2020) report lunar eclipse spectra which show how gases in the Earth's atmosphere absorb sunlight. One can do this because light is refracted, absorbed and focused by the atmosphere allowing the Moon to be dimly lit during a total lunar eclipse (Mallama, 2022). Changes in the atmosphere may lead to changes in the brightness and color of a totally eclipsed Moon. For example, volcanic aerosol particles in the stratosphere may cause an eclipsed Moon to be darker than expected (Keen, 1983, 2018). Differences in brightness across the lunar disk may be caused by differences in our atmosphere (Ugolnikov et al., 2011).

There have been many visual studies of the Moon's brightness during a total lunar eclipse using the reverse binocular method (Westfall, 1989), (Schmude, 2012). One problem with this technique though is that there is an uncertainty of about 0.5 magnitudes. A more accurate way of measuring the Moon's brightness is to use a photoelectric photometer along with a short focal-length lens.

Whole-disk brightness measurements of the totally eclipsed Moon on Jan. 21, 2019 are presented here. Measurements are reported in filters transformed to the Johnson B and V system. A few other similar measurements were made between 1990 and 2007. All of these are compared to predicted values (Mallama, 2022).

The primary purpose of this study is to report additional B- and V-filter measurements of the eclipsed Moon and compare them to Mallama (2022). Although the V-filter results have usually been consistent with Mallama (2022), there is some difference for the B-filter result in 2000. Furthermore, the B-filter brightness of the fully eclipsed Moon has only been measured once before this study. Therefore, more B-filter measurements of the fully eclipsed Moon are needed.

MATERIALS AND METHODS

An SSP-3 Photometer along with filters transformed to the Johnson B and V system were used in making brightness measurements (Optec Inc., 2012). The photometer has a 2.0 mm aperture and when it is combined with a 0.030 m aperture f/4 lens, gives a 55.6 arc-minute field of view (Schmude, 2013). This is sufficient to include the entire lunar disk. All brightness measurements were carried out in Barnesville, Georgia at an elevation near 0.25 km.

The Moon's brightness was measured using the comparison star Alpha-Auriga (Capella). Both the Moon and Capella were within 30 degrees of the zenith and, hence, atmospheric extinction corrections were small. Brightness measurements were corrected for extinction. Secondary extinction coefficients of –0.03 and 0.00 were used for the B- and V-filter calculations, respectively (Hall and Genet, 1988). Transformation coefficients of 0.0461 (V-filter) and – 0.196 (B-filter) were measured using the two-star method (Hall and Genet, 1988). Since the B – V value of the eclipsed Moon is unknown, an iterative approach was used in computing the B and V filter magnitudes.

It is believed that this iterative approach gives B – V values to an accuracy of 0.16 magnitudes. There are two reasons for this. Firstly, each B-filter measurement was between two V-filter measurements that were within one to two minutes. This means changes to the measured magnitudes were minimal. Secondly, the B-filter values in Figure 1 show internal consistency. Thirdly, a next generation SSP-3 photometer was used in recording measurements, which performed well.

There are several sources of uncertainty in the reported measurements here. These include those from color transformation, atmospheric extinction, and brightness values of the comparison star. The largest source of uncertainty is probably color transformation. The stars Alpha-Aries and Beta-Aries were used in measuring the transformation coefficients. The B – V value for the red star (Alpha-Aries) is 1.15. This is lower than the B – V value of the eclipsed Moon and, hence, extrapolation is needed to make color corrections. The estimated uncertainties are 0.15 and 0.05 magnitudes for the B- and V-filter magnitudes, respectively. The color correction is larger for the B-filter than for the V-filter and this is why the uncertainty is higher for B.

Measurements were made in the sequence of V, B, V, B, V and so on. Because of this, the B-filter brightness was bracketed by the preceding and following V-filter measurements. As a result, the reported times are for the B-filter measurements and the mean of the preceding and following V-filter measurements. The sky brightness reading was subtracted from each of the B and V filter readings in the normal manner (Hall and Genet, 1988).

RESULTS

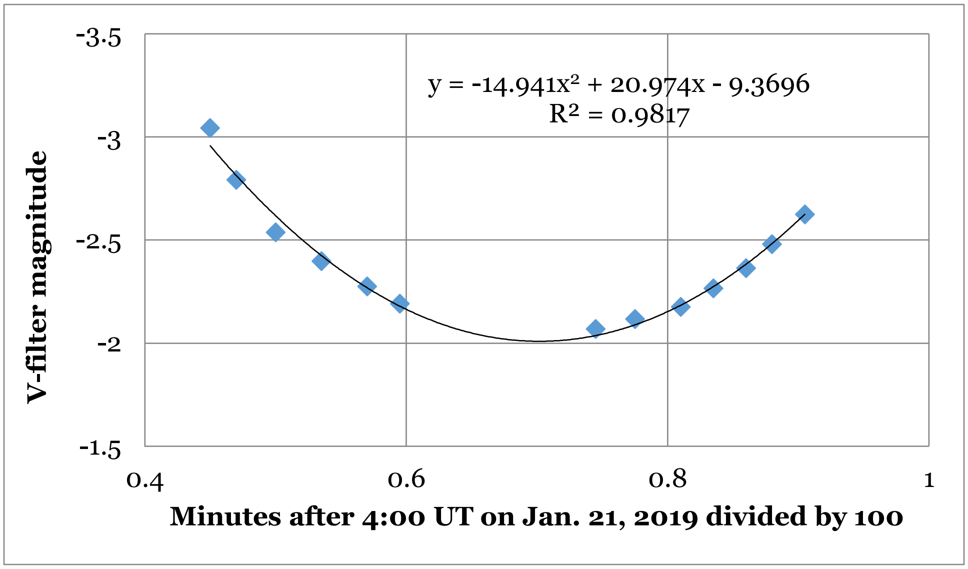
Measured magnitudes of the fully eclipsed Moon are given in Table I. The total eclipse phase was predicted to start at 4:41:17 UT (Harvey, 2018) and measurements commenced shortly afterwards. The eclipsed Moon grew dimmer as it moved deeper into Earth's umbra. The V-filter reading dropped from 1542 at 4:43 UT to 549 at 5:13:30 UT, which was near mid-eclipse. The B-filter reading dropped from 215 at 4:45 UT to 55.3 at 5:14:30 UT. Measured magnitudes of the fully eclipsed Moon are shown in Figure 1. The gradual darkening of the Moon, as it moves deeper into Earth's umbra, is evident. This is consistent with previous results (Schmude et al., 2000); (Schmude, 2004); (Hernitschek et al., 2008) and with a recent eclipse model (Mallama, 2022). More B-filter results in Table 1 are needed to confirm the model of Mallama (2022). This data may be used to prepare a better model of how blue light is refracted by our atmosphere.

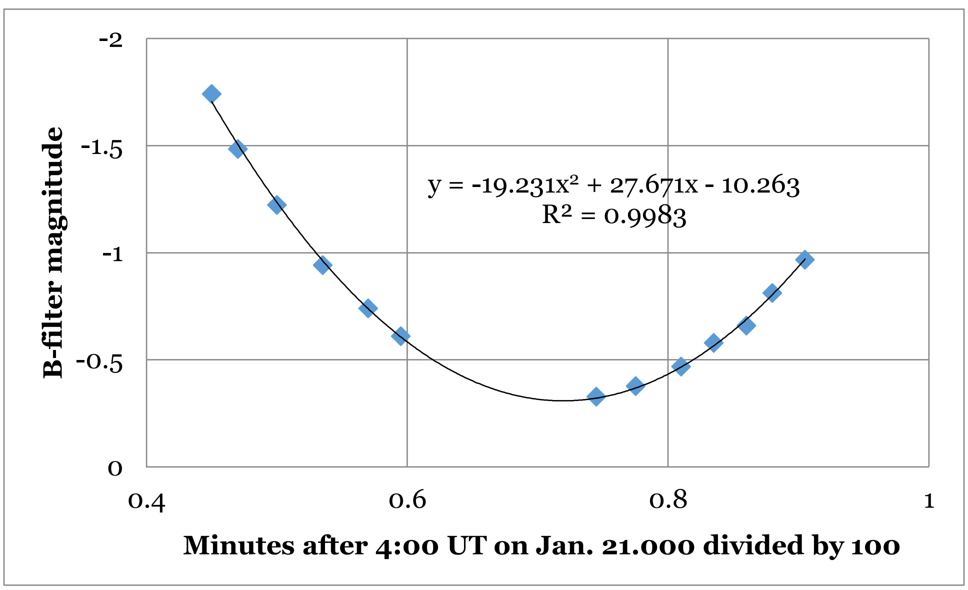
It is difficult to compare the sky brightness with those measured by Birriel and Adkins (2019). Since they are for a small part of the sky next to the Moon, whereas those of Birriel and Adkins (2019) are for the Zenith.

Table I: Measured brightness values of the fully eclipsed Moon on January 21, 2019. All times are in Universal Time (UT). Uncertainties of 0.05, 0.15 and 0.16 magnitudes are assigned to the V-filter, B-filter and the B – V values, respectively.

Time on Jan. 21	V-filter (magnitudes)	B-filter (magnitudes)	B – V (magnitudes)
4:45	– 3.04	– 1.74	1.30
4:47	– 2.79	– 1.48	1.31
4:50	– 2.54	– 1.22	1.31
4;53	– 2.40	– 0.94	1.46
4:57	– 2.28	– 0.74	1.54
4:59:30	– 2.19	– 0.61	1.58
5:14:30	– 2.07	– 0.33	1.74
5:17:30	– 2.12	– 0.38	1.74
5:21	– 2.18	– 0.47	1.71
5:23:30	– 2.27	– 0.58	1.69
5:26	– 2.36	– 0.66	1.70
5:28	– 2.48	– 0.81	1.67
5:30:30	– 2.63	– 0.97	1.66

Figure 1: Graphs of the V- and B-filter magnitudes of the fully eclipsed Moon on January 21, 2019.





Minimum brightness values of – 2.07 and – 0.33 were made for the V and B filters. Unfortunately, the battery had to be replaced at about 5:00 UT and that is why measurements were not made then. The brightness values are fitted to the best fit quadratic equations. These predict minimum brightness values of – 2.01 and –0.31 for the V and B filters, respectively. The predicted time of minimum brightness for the V and B filter equations are 5:12:07 UT and 5:11:57 UT, respectively. These compare well with the time of greatest eclipse which is 5:12:16 UT (Harvey, 2018). The small-time discrepancy may be caused by differences between the two limbs of Earth as seen from the Moon. Ugolnikov and co-workers (2011) report that their measurements are consistent with greater atmospheric clarity over the western limb of Earth (Atlantic Ocean) than on the eastern limb (near China).

The minimum brightness value of an eclipsed Moon depends on how deep it moves into Earth's umbra. As the eclipsed Moon approaches the Umbra center, it should darken. Mallama (2022) states that the fully eclipsed Moon drops to magnitude −3.5 at U2 (just after all of the Moon enters Earth's umbra and at U3 (just before the leading edge of the Moon exits the umbra). He also states the Moon's brightness continues to drop as it approaches the umbra center.

What was the drop in the Moon's brightness as a result of the eclipse? In order to answer this question, one must compare the Moon's brightness with and without Earth's shadow. The Moon-Sun and Moon-Earth distances were 0.9864 and 0.00235 au at mid-eclipse, respectively (JPL Horizons Ephemeris). These distances are between the centers of the Sun, Earth and Moon. The observer-Moon distance is closer to 0.00231 au since the eclipsed Moon was near the observer's zenith. Furthermore, the Moon's phase angle was 0.22°. When these values are combined with a V(1, 0)* value of 0.19 magnitudes (Schmude, 2001), and an opposition surge of 0.4 magnitudes (Buratti et al., 1996), the moon's brightness would have been at magnitude – 13.42 without the effect of Earth's shadow. [The V(1, 0)* value is corrected for distance and is extrapolated to a phase angle of 0° but does not include a brightness from the opposition surge (Schmude, 2022).] The minimum V-filter brightness of the Moon was measured as magnitude – 2.07. Therefore, the Moon's brightness dropped by 11.35 magnitudes or by a factor of 34,700, which is consistent with an attenuation of 10.45 (Keen, 1983).

DISCUSSION

Mallama (2022) presents a model of how light is refracted, absorbed and focused by our atmosphere. He also predicts the whole-disk V-filter magnitude at mid-eclipse along with the B – V color index for total, partial and penumbral eclipses. His model includes all lunar eclipses between 2000 and 2050. It does not take into account other factors like volcanic eruptions and extensive wildfires. Table II summarizes measured and predicted values for several recent lunar eclipses.

The quality of the 2019 results surpasses those of previous studies for two reasons. Firstly, B-filter measurements were made in 2019 which allowed color corrections to be made to the B and V filter results. This is an improvement because the color of the eclipsed Moon changes as it moves into different parts of Earth's umbra (Karkoschka, 1996), (Mallama, 2022). The changing color means the color correction term changes. A second reason why the 2019 data is better than in previous studies is that they are internally consistent. The B and V filter magnitudes in Table I show gradual changes which should be expected during a total lunar eclipse.

Most of the other studies only report V-filter measurements. The uncertainties in the B- and V-filter measurements in the current study are believed to be 0.1 magnitudes while those in 2000, 2003 and 2004 are believed to be a bit higher (Schmude, 2004), (Schmude et al., 2000). Hernitschek et al. (2008) report uncertainties of 0.1 and 0.35 magnitudes for their 1990 and 2007 magnitude drops. Therefore, definite conclusions of the measured brightness drop of the Moon during total eclipse may be made.

The mean discrepancy (O – P) in Table II for the V-filter magnitude is near – 0.4 magnitudes. Therefore, the measured value is a little brighter than what is predicted. Since the predicted brightness values are reported to the nearest 0.5 magnitudes, this discrepancy is believed to be acceptable.

The measured B – V value is 1.26 magnitudes lower than the predicted value (Mallama, 2022). This represents a factor of 3.2 and means the eclipsed Moon was about 3.2 times brighter in blue light than what was predicted. This discrepancy cannot be caused by the meteor imaged on the Moon at 4:41:38.09 UT (Madiedo et al., 2019) since it occurred just before measurements commenced. Kawauchi et al. point out that their results are consistent with the lowest altitude at which light passed through and reached the Moon was 10 km. Karkoschka (1996) points out that the Ozone concentration has a large impact on the amount of blue light passing through our atmosphere and, hence, seasonal ozone changes in the stratosphere may be the reason for the B-filter discrepancy.

More whole-disk brightness measurements of the eclipsed Moon are needed to confirm model predictions. This is because our atmosphere is undergoing several changes. The impact of wildfires and volcanoes varies from year to year, which may contribute to a variable concentration of aerosols. Secondly, the amount of carbon dioxide is rising at a rate of about 0.4 % per year (Bennett et al., 2020). This may lead to additional changes. Thirdly, changes in the amount of stratospheric ozone may change and this could lead to additional changes in the amount of light our atmosphere refracts. Therefore, the B – V value is also unknown and, hence, one should measure both the V- and B-filter brightness of the eclipsed Moon so that proper color corrections may be made and as a check on our atmosphere.

Table II: Measured and predicted V-filter and B – V values for a few recent total lunar eclipses near mid-eclipse. The observed – Predicted (O – P) brightness values, in magnitudes, are also given. All brightness measurements were made with photometers.

Eclipse Date	**V – filter magnitude**			**B – V magnitude**		
	Obs.	**Pred.**	**O – P**	**Obs.**	**Pred.**	**O – P**
Feb. 9, 1990	−3.3[a]	−3[b]	−0.3	---	---	---
Jan. 21, 2000	−2.2[c]	−1	−1.2	2.9	3.5	−0.6
May 16, 2003	−2.77[d]	−2.5	−0.27	---	2.5	---
Oct. 28, 2004	<−2.8[d]	−1	---	---	---	---
Mar. 3, 2007	−1.7[a]	−1.5	−0.2	---	3.0	---
Jan. 21, 2019	−2.07[e]	−2.0	−0.07	1.74	3.0	−1.26

[a]Hernitschek et al. (2008) [b]Mallama (1996) [c]Schmude et al. (2000)
[d]Schmude (2004) [e]Current work

Table III lists whole-disk brightness values of the Moon near U2 and U3. (The U2 and U3 points are when the entire Moon just enters and is about to leave the Earth's umbra, respectively.) Since the brightness of the Moon changes rapidly at these times, linear interpolation from experimental data was used in determining the brightness values at these times. The changing Moon-Earth distance and phase angle are two reasons for the scatter in magnitude values for the eclipsed Moon. The mean brightness value near U2 and U3 is −3.5 magnitude. This is consistent with the predicted value (Mallama, 2022).

Table III: Whole-disk V-filter brightness values of the Moon near U2 and U3.

Eclipse date	V-filter brightness Magnitude
Feb. 9, 1990	−3.8 (U2)
Feb. 9, 1990	−3.7 (U3)
May 16, 2003	−3.7 (U2)
Oct. 28, 2004	−4.2 (U2)
Mar. 3, 2007	−2.6 (U2)
Jan. 21, 2019	−3.2 (U2)

In conclusion, the Moon's V-filter brightness dropped to magnitude −2.07 at mid-eclipse. This is consistent with a nearly clear atmosphere (Mallama, 2022). This agreement along with the four measurements made between 1990 and 2007 show that the model in Mallama (2022) is consistent with experimental V-filter results. The B – V value, 1.74 magnitude near mid-eclipse is lower than the predicted value of 3.0 magnitude (Mallama, 2022). Only two B – V measurements of the eclipse Moon have been made (2000 and 2019). Both measurements are consistent with the eclipsed Moon being brighter than predicted. There is a chance that seasonal changes in stratospheric ozone concentration may be responsible.

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