Proceedings of the Iowa Academy of Science

Volume 71 | Annual Issue Article 60

1964

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Abstract. A three-color photometry of the eclipsed moon was carired out with a 12-inch reflector during the total eclipse on December 30, 1963. In order to examine the intensity and color distribution of refracted light in the umbral region, the observation was centered at Mare Crisium during the course of the eclipse. The decrease in brightness was found to be about 16 magnitudes for each of the three colors, and no significant reddening effect was observed during the totality. The magnitude differences between different colors appear to be nearly the same on the uneclipsed and the totally eclipsed moon.

A three-color photometric observation was made on the total eclipse of the moon, December 30, 1963, with a 12-inch Cassegrain reflector at the Country Observatory of the State University of Iowa, located about 22 miles west of Iowa City. The photometer used for the observation consists of the 1P21 photomultiplier and the filters for the standard UVB system [Johnson, 1955]. A Weitbrecht [1957] current integrator was used to make intensity measurements possible over a wide range of magnitudes. The integrator provides nearly full-scale readings over a range of ten magnitudes for any given integration time and diaphragm. In order to avoid a possible error due to the automatic timer setting, the integration time was fixed at approximately 3 seconds throughout the observation. A series of calibrated diaphragms was used to extend the magnitude range beyond the normal integration range. The diaphragms covered the fields ranging from about 6.7″ to nearly 150″ in angular diameter.

The original plan of this program was to determine brightness variations of several regions of the moon's surface during the course of the eclipse in order to map the intensity and color distributions of the umbral region as widely as possible. Due to the extreme cold (about −10° F) at the time of observation, however, various instrumental difficulties delayed observations until the moon was well within the penumbra and a much longer time was required to locate a specific area of the moon in the diaphragm of the photometer. It was therefore decided to follow only one area through the Earth's shadow. Mare Crisium was selected since it was one of the easily located areas of relatively

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uniform brightness and it was still most distant from the center of the umbra.

The position of the diaphragm with respect to the image of Mare Crisium had to be adjusted before each reading so that two consecutive observations were separated by intervals of at least 20 seconds. During the progress of the observed point through the shadow, appreciable intensity changes occurred in these intervals, making it impossible to compare directly the intensities obtained through different filters. Instead of the common technique of establishing a single magnitude scale and two color-indices, it was necessary to treat observations in different colors independently. For this purpose, observations of the next full moon were carried out on January 29, 1964. In this way three independent and arbitrary magnitude scales were established after making corrections for extinction and background. Subsequent observations of standard stars permitted the adjustment of three magnitude scales into a single arbitrary scale. The zero point of the magnitude scale thus obtained was fixed by converting the actual size of the diaphragm into the apparent area of the moon at the time of observation.

Since it was not possible to determine the extinction coefficients on the night of the eclipse, we used the mean extinction coefficients for relatively good photometric nights in winter. They are 0.23, 0.32, and 0.62 for V, B, and U colors, respectively. The extinction coefficients determined independently during the following full moon nights were found to be the same as the above mean values. Since the phase angle on January 29, when the full moon was observed, was much less favorable than that during the eclipse, a correction was made following the rule given by Tschunko [1949]. It is based on an empirical relationship between radiance, phase angle, and the angle of incidence and reflection. From this, it was found that the moon just prior to the eclipse would be 0.58 magnitudes brighter than it was during the following full moon night.

The brightness and color variations during the eclipse are shown in Figure 1. The relative magnitudes adjusted for the whole disc as discussed in the above are taken in the ordinate, and the times of observation in the U.T. are given in abscissa. The observation covered a period of approximately 25 minutes before Mare Crisium entered the umbra and another period of slightly more than half an hour during the middle of totality. Mare Chrisium reached the nearest point to the center *of the* umbra at a distance of 13 minutes of arc at 11^{h} 32^{m} U.T., which is indicated by a vertical broken line in Figure 1. The differences

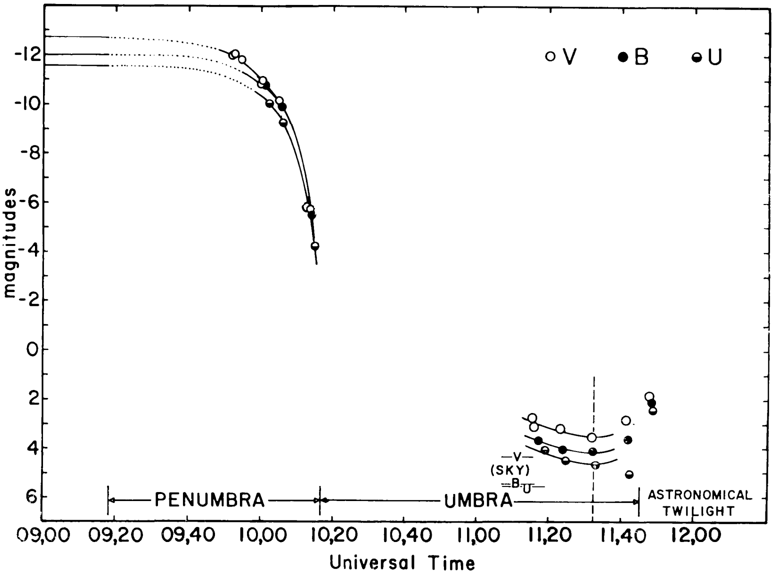

Figure 1. Magnitude-Color Variation of Mare Crisium during the eclipse.

between the B and V and the U and B curves at a given time give the instantaneous values of B – V and U – B, respectively.

We first note that the decrease in brightness of the Mare Crisium area appears to be at least as much as 16.1 magnitudes. The amount of the brightness decrease is the same for all three colors, with no significant differences in colors between the uneclipsed moon and the moon in the mid-totality. As Mare Crisium approached the umbra there was first a decrase in B – V followed shortly by a less distinct decrease in U – B. The observations were interrupted at the time of entry into the umbra itself and the color differences had returned to their normal uneclipsed values by the time observations were recommenced during the totality. The actual changes in B – V and U – B before the totality were very difficult to determine due to the rapid change in magnitude, but are estimated to be about one magnitude for B – V and one-half magnitude for U – B.

A number of observers have reported the minimum visual magnitude of the eclipsed moon to be about 4.1. It will give a crude comparison with our minimum V magnitude of about 3.5, since the adopted magnitude scale was set to correspond roughly to the magnitude of the entire moon. However, great caution has to be used in interpreting the magnitude scale in Figure 1, as the calibration to the full moon scale was made without correction for the albedo difference between Mare Crisium and the mean albedo. There is also a possible error due to the calibration of the diaphragms. Although the relative differences in the diaphragm openings are accurately known, conversion from an actual diaphragm to the hypothetical lunar disk aperture may involve an error of several tenths of a magnitude.

The accuracy of the results is limited by several sources of errors. As was noted before, mean extinction coefficients were used in the analysis. Since actual extinction coefficients are seldom significantly lower than the mean values but may be distinctly higher, it is probable that the magnitude values during the totality were lower than those we obtained. Slight fluctuations in the sky brightness might have introduced some additional errors in the totality observations. The direct intensity readings in V and B colors before correcting for extinction are barely higher than the sky readings and the ultra-violet reading was nearly one magnitude fainter than the sky. The minimum magnitudes of the sky during the eclipse were found to be $V_{sky} = +4.32$, $B_{sky} = +5.43$, and $U_{sky} = +5.50$. The visual sky brightness was therefore about 20.5 magnitude per square seconds of arc, which is typical of our observatory site and somewhat lower than that in many areas. In an eclipse such as this, sky brightness becomes one of the major factors in determining the visibility, contrast, and observed color of the moon during totality. A difficulty due to lack of sufficient darkness adaption by the observer contributed to the interruption of the observations at the beginning of the totality.

Due to the great range in magnitude variation, a diaphragm up to 150″ aperture was used especially for ultraviolet readings near the minimum. Such a large diaphragm necessarily included more than the Mare Crisium area or the areas of probably higher albedo surrounding Mare Crisium. In addition, the moon appeared to show a litlte contrast during totality that it was difficult to perceive the boundaries of Mare Crisium. No correction for these pointing errors has been made; any correction would increase the obtained magnitudes, particularly in the ultraviolet.

The greatest source of error for the penumbral observations may be due to slight errors in determining the time of observations and the centering of the diaphragm within Mare Crisium. This error was serious only during the most rapid changes in brightness, and, in the worst case, the error should not exceed $\pm$ 0.2 magnitudes.

As discussed before, the calibration of the magnitude scale between different colors was made on the basis of the full moon observations a month later. The use of Tschunko's empirical relation for correcting the phase angle, from which a value of

0.58 magnitudes was obtained for the correction, has to be regarded as merely an approximation. It is probable that the true correction would be somewhat larger than the adopted value. The comparison of the observations separated by an interval of one month depends also on the constancy of the radium light source used as a standard. Slight variations in the brightness of the standard source might be expected to occur in a month's time.

We wish to thank James E. Hansen, Andrew A. Lacis, and A. Muriel for their assistance in the observations during the cold night.

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