

THE_PENUMBRA

and The_Umbra

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The atmosphere of the Earth is studied by observing its shadow on the Moon.

Abstract

Software has been developed to compute the topocentric semi-diameter of the penumbra and umbra so that comparison can be made with measurement of eclipse images taken from any known geographic location. These images are calibrated to the semi-diameter of the Moon and the shadow of the Earth's atmosphere is measured either as penumbral or umbral semi-diameters. Measurement of images from two penumbral, two partial and two total lunar eclipses are compared with the computed values resulting in good agreement giving confidence in the theory, computation and measurement.

Introduction – The Penumbra

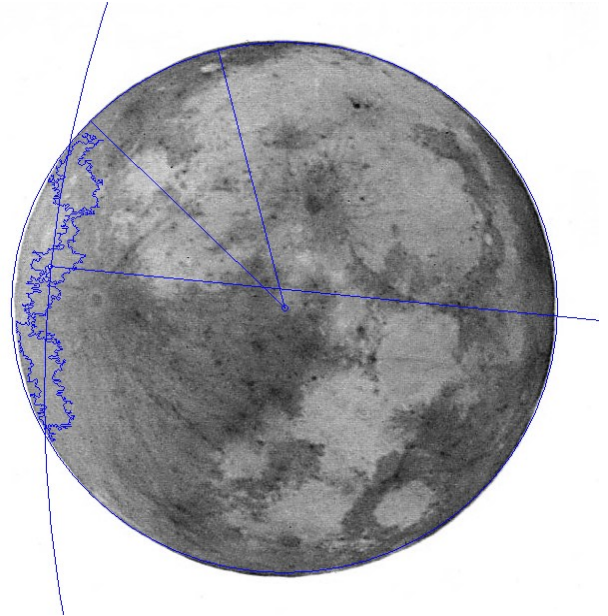
Images of past penumbral lunar eclipses have provided interesting results, where the outer faint shadow of the Earth can be detected on the Moon's surface and then measured for its size or semi-diameter.

A [modified geometry](#) of the topocentric penumbra has been prepared so that estimates of its size can be made and compared with measured images. A computer program, *ViaX8.exe* has been developed to compute the expected topocentric semi-diameter of the penumbra (*Fp*) from any known site. Another program *ILEEP41.exe* is used to generate the required data for the observer's site for the other program.

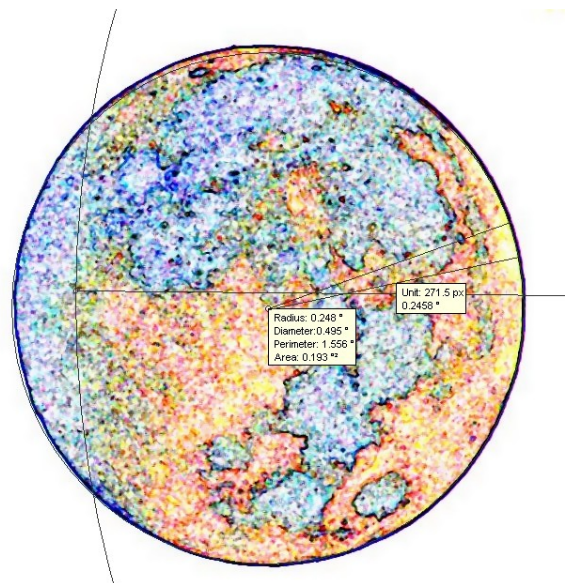
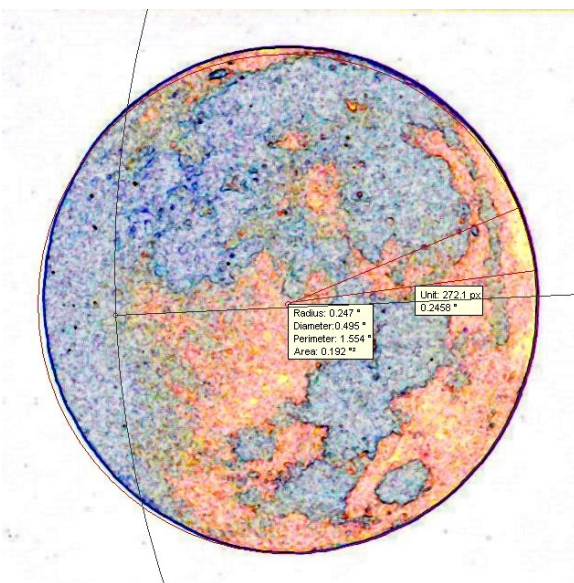
In *1998, 2001 and 2006*, images were obtained of the penumbra which were successfully measured, but until now no comparison with the estimated semi-diameter of the penumbra was possible.¹

Measurements

A calibrated and measured image of the penumbra is shown below, taken from a series of images by Bengt Ask observing in Svalov, Sweden (latitude 13°06'27.9" E, longitude 55°54'47.5" N, elevation 59m) during the **19980313** penumbral lunar eclipse. When measured with *Digimizer* (after calibration to the Moon's semi-diameter of 0.2458°, converted to greyscale, sharpened and then rotated left for measurement) this image gives a topocentric semi-diameter of 1.041° for the penumbra, lower than the geocentric value of 1.1949° given by Fred Espenak.



Further images by Bengt Ask for this eclipse have been measured in a similar manner to the above and then compared with the computed values of F_p . Here, the image processing was by *ImageJ* to highlight the penumbra which was then measured with *Digimizer*. Two of the images measured are shown below, the first taken at 4h10m (where $F_p = 1.022^\circ$) and the other at 4h 05m ($F_p = 1.041^\circ$): ²

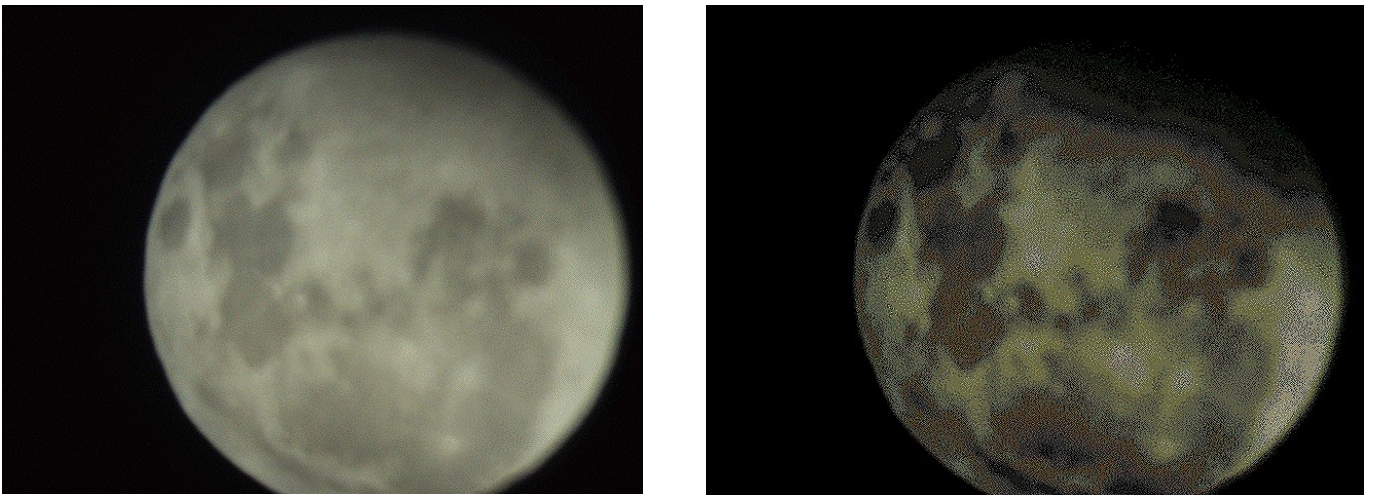


Computed F_p

I have used my original theory and software to compute the expected [topocentric](#) semi-diameter for any location. The pdf file [here](#) shows the computed F_p values compared with the [measures](#) for Bengt's observing site at Svalov, Sweden.

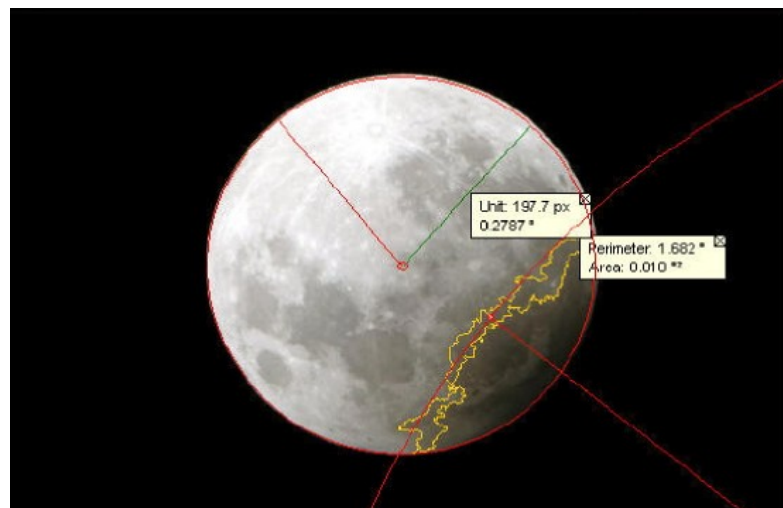
Bengt Ask also observed and took images of the **20010109** total lunar eclipse where a few measurements were obtained, one for the penumbra and two for the umbra. These results are shown [here](#).

Another image captured at 9h43m03s (UT) of the penumbral lunar eclipse of **20011230** at the **Calwell Lunar Observatory** (35°26'25.6"S, 149°05'16.6"E, 586m) is shown below on the left. The image was processed by Gamma correction under [Preview](#) and clearly reveals the penumbra at upper right as shown below:



The image was measured by [Digimizer](#) and compared with the computed topocentric penumbra as can be seen [here](#).

The above measurements are supplemented by a further set of images by [Sabahattin Bilsel](#), who observed the partial lunar eclipse of **20060907** from his site (37°06'09.1" N, 27°20'54.8" E, 70m) in Istanbul Turkey. One of his images is shown below where the semi-diameter of the penumbra has been measured at 1.314° , very near the geoid value of 1.3139° .



Additional observations of this eclipse by David Herald from Kambah Australia (35°23'49.3" S, 149°03'48.8" E, 583m) were by high definition movie to confirm my predicted early first contact time of the umbra due to its oblateness. Images from the movie were measured by *Digimizer* providing excellent agreement with the computed umbra (*Fi*). The results for **20060907** from the two observers can be seen [here](#).

Comments

It is interesting to note the comparison in the data sets produced for each eclipse. Due to the curvature of the Moon, it is logical to expect the projected shadow from the Earth to be initially at zero at first penumbral contact (*P1*) increasing rapidly to near the Geoid value given in the classical ephemeris. Similarly, the curvature causes the penumbra size to drop from a steady value to zero at the final penumbral contact (*P4*) at the end of the eclipse. It is important that the topocentric penumbra size is computed only while its **edge** is on the Moon's surface. This is allowed for in the software.

Conclusions

The measured penumbra taken from the sets of high quality images provided especially by Bengt Ask and Sabahattin Bilsel, have enabled conclusive proof of my topocentric **penumbra** theory and computation. For the first time these measurements have provided data points for the increase in the penumbra size correlating closely to that computed.

It has also been shown that the observed penumbra increases in size from zero at first contact rising rapidly to the expected ephemeris value and then falling towards zero as the penumbra **edge** leaves the surface of the Moon.

Introduction – The Umbra

The measurement of 31 images of the umbra for the total lunar eclipse of **20080221** provided by Bernard Durand observing in France, has enabled a comparison to be made with the computed topocentric umbral semi-diameter for his site.

Good agreement between the data sets was obtained and it has been conclusively shown that the umbra increases in size from primary contact to a value near the geocentric umbral semi-diameter.

Measurements

The image below illustrates a typical measurement of one image where the umbral semi-diameter (*Fi*) has been measured with a calibrated image of the eclipsed Moon (red circle) with the best fit circle set to coincide with the edge of the umbra. The value of *Fi* was 0.646°. The software used for measurement is [Digimizer](#).⁴

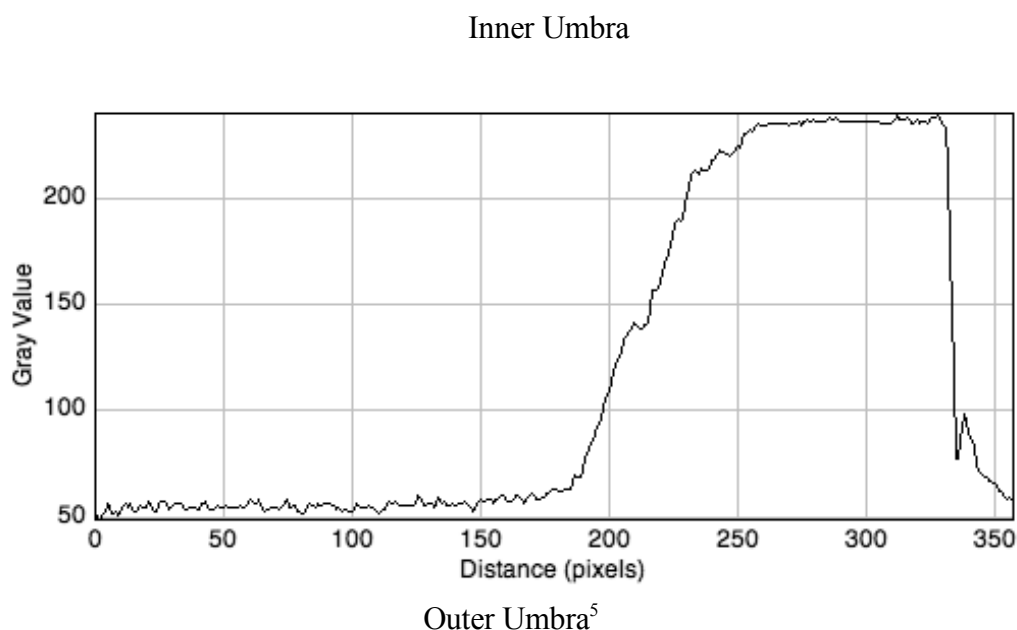


Computed Fi

I have developed an original theory and software to compute the expected [topocentric](#) umbral semi-diameter for any location. Bernard provided his observing site co-ordinates at "Le Sauze du Lac", France (44°28'39"N, 6°18'48"E, 1050m) and the pdf file [here](#) shows the computed Fi values for **20080221** compared with the [image measurements](#). These images are supplemented by a further set by Jay Pasachoff (42°42.7'N, 73°12.1'W, 215m) and these result can be seen [here](#).

Bernard also provided another set of images for the total lunar eclipse of **20080816** observed from "La Roche des Arnauds" (44°33'43"N, 5°59'32"E, 1169m), which have been similarly analysed along with my images of this eclipse observed from Isabella Plains (35°25'52.2"S, 149°05'16.6"E, 586m) and those images by Gerhard Dangl from Nonndorf, Austria (48.79°N, 15.24°E, 542m). The charts have been prepared for the actual location of each of the three observers, and good comparison has been found for all measured values. The overall results are shown [here](#).

It is possible to measure the inner and outer umbra where the transition from dark to light in an **ImageJ** contour trace across the umbra edge is pronounced, as shown below for one of my images 1065:



Comments

It is interesting to note the comparison of computed and measured values in the two data sets. Due to the curvature of the Moon, it is logical to expect the projected shadow from the Earth to be initially at zero at first primary contact (*IC*) and then increasing rapidly to a value very near the Geoid value given in the classical ephemeris (for the eclipse of **20080221** the Geoid value is 0.6983° at *IC* to 0.6969° at *4C* and for **20080816** around 0.6901°). It can also be seen that the Moon's curvature causes the umbra size to drop to zero at totality, rise from zero at third contact to the maximum and again decrease toward zero at fourth contact at the end of the eclipse.

Conclusions

The measured umbra taken from two sets of high quality images provided by Bernard Durand has enabled conclusive proof of my topocentric umbra theory and [computation](#). For the first time measurements of eclipse images have provided data points for the increase in the umbra size correlating closely to that computed.

It has also been conclusively shown that the observed umbra increases in size from zero at first contact rising rapidly to the expected ephemeris value and falls towards zero when the umbra **edge** is not traversing the surface of the Moon.

I believe this is the first time the characteristics of the penumbra and umbra have been adequately examined.

Acknowledgments

I am indebted to Bengt Ask, Sabahattin Bilsel and David Herald, for the excellent images provided of the **19980313**, **20010109** and **20060907** eclipses and for their early interest in this project.

I am also most grateful for the many excellent images made available by Gerhard Dengl and Bernard Durand for use in this project.

References

The [web pages](#) for the Soulsby series of lunar eclipses.

My [geometry for the computer program](#) for the determination of the topocentric penumbral size.

A summary of observers and images measured can be seen [here](#).

Produced by the *Isabella Plains Lunar Observatory Australia* 20081230.⁶