

Measuring solar angular diameter, refractive flattening and visual magnitude during sunsets

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Abstract

The refractive flattening of the Sun is due to the differential refraction in the Earth's atmosphere, while the visual magnitude is related to the humidity stratification. The angular diameter is proportional to the length of the sunset, the difference between the first and the last contact with the sea surface. Some problems with respect to these principles are described, along with a method to obtain photo and video using binoculars and smartphone.

Sommario

Lo schiacciamento rifrattivo del Sole è dovuto alla rifrazione differenziale nell'atmosfera terrestre, mentre la magnitudine visuale alla presenza di umidità negli strati più bassi della stessa. Il diametro angolare del Sole è proporzionale alla durata del tramonto, ossia alla differenza tra il primo e l'ultimo contatto con la superficie del mare. Alcuni problemi rispetto a questi principi base sono descritti, insieme ad un metodo per ottenere foto mediante uno smartphone collegato al binocolo.

Introduction: solar diameter at almucantar at zero

It has been already presented the idea to realize measurements of the solar diameter at the sea horizon. The basic assumptions are that :

1) the sea horizon is the best reference for having a definite almucantar, at zero degrees 2) the atmospheric conditions are stable along the line of sight during the sunset event 3) the differential refraction, even if heavy, is constant at the same height above the horizon, in the azimuthal area of the sunset.

To these assumptions we have to add some warnings, like:

a) the difficulty to have a precise timing of the two contacts with the sea b) the difficulty to have the sunset exactly over the sea, without mirages effects c) the luminosity of the Sun at the final stages, coping

with the autoseettings of the camera. To these difficulties we recommend a) the extrapolation to zero of the chord intersection of solar limb and sea horizon; b) using a line parallel to the sea horizon and a little higher where the assumptions 1-2-3 remain valid; 3) using filters or smaller optics when the atmosphere is clear.

The video made with binoculars 12x30 or monocolo 7x21 and smartphone are of didactic interest, and are tests for measuring by timing the solar diameter at the geometrical horizon, exploiting the same principle of the solar astrolabes used from 1970s to 2010s on in Sao Paulo, Rio de Janeiro, Calern, Tubitak and San Fernando. The rarity of perfect conditions at sunset allows very few good measurements, but it is worth to exploit this method.

Refractive flattening of the Sun

In the standard atmosphere US1976 the computation of the relative flattening is part of the ephemerides, but the refraction is strongly affected by the lower layers, which along the line of sight can attain an optical thickness of 30 magnitudes. The case of August 25, 2019 is examined as example: at 19:30 the solar center was at 4° and the Sun entered the haze zone, losing rapidly luminosity. With sunglasses it was possible to look at it without problem, even with binoculars.



Fig. 1 On Aug 25 at 19:48:40 it was at altitude 0.853° (0.4292° airless case) with a theoretical flattening (calsky.com) of 12.22%. The observed one is 503 vs 560 pixels, vertical over horizontal $v/h=89.8\%$.

The percentual flattening is: $[h-v]/h\%=57/560=10.18\%$

Van der Werf gives a formula for the flattening of the setting Sun taking into account the ratio between vertical and horizontal diameters at standard atmospheric conditions (15°C , $P=101325\text{ Pa}$):

$$v/h=0.79-6.13[dT/dh]$$

with the temperature gradient measured in $^\circ\text{C}/\text{m}$.

Normally $dT/dh=6.5\cdot 10^{-3}\text{ }^\circ\text{C}/\text{m}$, and the $v/h=0.75$.

The relative flattening results as 25%.

To obtain the flattening at sunset it is necessary an extrapolation of the values before as in Fig. 2.

Comparison of observed timing with ephemerides

The vertical/horizontal ratio of the solar image diminishes toward the horizon. The value measured in Aug-Sept 2019 in Ostia is always different then STP conditions.

The sunset time for a given location is obtained by calsky ephemerides (STP) when the upper limb has an height of $0^{\circ}.00$. The resolution of this algorithm is 1 s.

The observed end of light is timed with a precision of 1/30s-1/60s depending of video resolution VGA or HD.

The sunset may occur at some height above the sea horizon. As an example on Aug 25 it was 2.55' above the sea horizon, on a "mirage horizon" and about 20 seconds before the ephemerides one, even if the point of observation was 2 m above sea level, which delays the last light for the horizon depression effect, included in the computations of the delay.

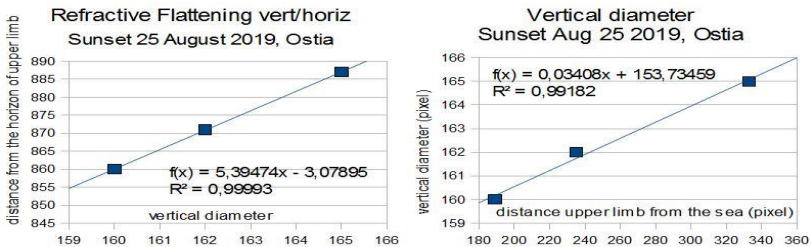


Fig. 2 The refractive flattening at sunset on 25 August 2019.

In the last stages before the contact on the sea the deformation of the solar image does not allow to recover a correct flattening, because of the formation of mirages, then it has been inferred from the phases immediately before, by extrapolation of vertical diameter at zero distance.

The mean vertical gradient can be obtained from the temperature of the water as zero level, and the zero

temperature quote, e.g.: Jan 13, 2019 (14° C and 1400 m) Aug 25 and 26, 2019 (26°C and 4000 m). But the local atmospheric gradient in the lower troposphere (<4 km) is the most relevant for the refractive flattening. For an observation site of 2 m above sea level, the distance of the horizon $d=5$ km, the depression of the horizon is 82"; conversely a diameter of 1900" corresponds to 46.5 m of atmosphere at the distance of the horizon, where the higher temperature gradient is manifesting. The line of sight toward the Sun, through the Earth's atmosphere, encompasses up to 3.5 km of vertical troposphere 350 km beyond the horizon distance, and the "bad layers" effects (where shear turbulence act) are visible as discontinuities on the solar figure

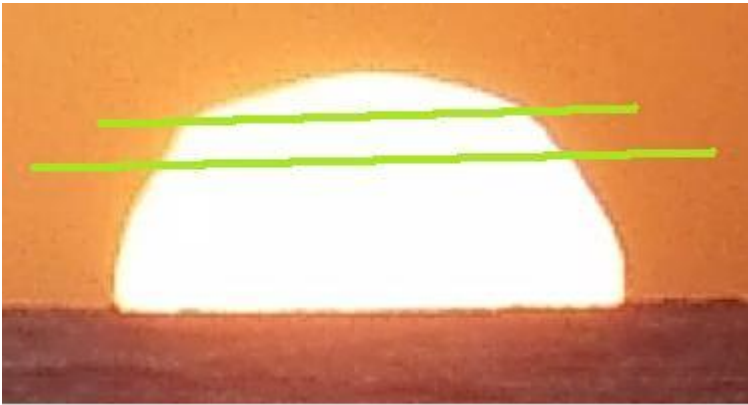


Fig. 3 Discontinuities around the solar limb on 9 Sept 2019, Ostia, Pontile.

Velocity of the sunset, delay or anticipation

The time interval from the first contact with the horizon to the last one is proportional to the angular solar diameter of the epoch of the observation. The actual solar diameter is

$\theta_{\text{sun}} = \Delta t \cdot 15''/s \cdot \cos(\delta) \cdot \sin(\alpha)$, α is the angle formed by the solar trajectory with respect to the horizon, δ =Sun declination.

If the sunset occurs higher than the real horizon the duration is almost the same, but the first and last contacts are both anticipated with respect to the ephemerides calculated with standard atmosphere (STP). The following table shows the variability of observed conditions from Ostia in different days.

Date	Flattening %	Delay [s]
13 January 2019	87.21	2
15 August 2019	81	35
16 August 2019	NA	23
18 August 2019	87	13
19 August 2019	82	23
20 August 2019	68.68	33
24 August 2019	86.84	-12
25 August 2019	85.53	20
26 August 2019	88.96	10
3 September 2019	91.33	11
4 September 2019	92.45	-10
5 September 2019	84.05	-16.5
7 September 2019	88.57	-14
9 September 2019	84.51	-12

The delay is different each day, and no evident correlation appears with the flattening. In the first decade of September we had anticipations with respect to the Standard Atmosphere model: the real average refraction index near the horizon is lower than the one of the model. A larger flattening corresponds to a larger refraction index, which delays the apparition of the last light.

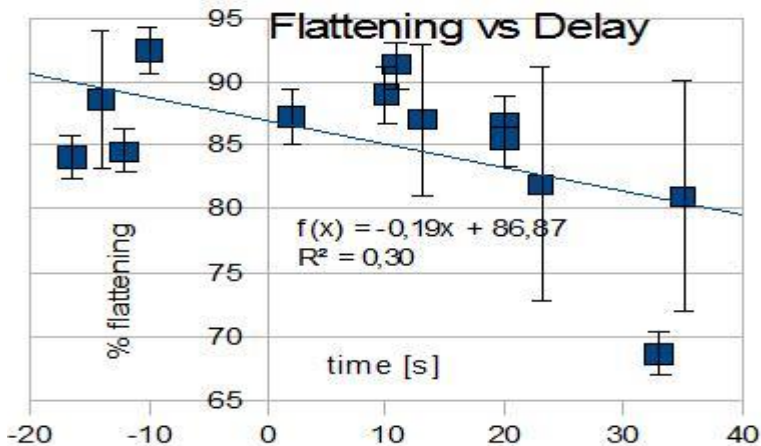


Fig. 3 the relationship between flattening and delay.

The linear correlation is low, the value of the fitting line at zero delay is 86.9%, different from the Van der Werf equation of 83%. A quadratic fit has a better R^2 , but the zero-delay flattening is even larger. A complete and predictive approach would consider the local atmospheric temperature, its gradient, the regional lower troposphere conditions, available for astronomical seeing predictions.

Solar diameter at almucantar at zero: azimuthal hypothesis

The goal of this study is to assess the reliability of measuring the solar diameter by accurately timing a sea sunset. In

principle an accuracy of 1/30s and also 1/60s is possible, as already said, this corresponds to 0.5"-0.25" of angular accuracy, which is already interesting and competitive for ground measurements.

The basic hypothesis is that in the $\Delta t \approx 180$ s of sunset duration the layers of the atmosphere remain at the same quote and have same optical properties along all azimuths of the sunset. The angle of inclination with the Ostia horizon on 9 Sept 2019 was 48° , then the azimuthal difference between first contact point and last one was $\Delta \text{az} = R_{\text{sun}} / \tan(48^\circ) = 28.6'$

For the above reasons this angle encompasses nearly 4 km of atmosphere up to 400 km in the line of sight, where the conditions may not be the same at the same quote.

As an example a sequence of the last lights of 4 sept 19 sunset, with a green flash, is shown in fig. 4 with a scale of $1'' \approx 2.22$ m at 400 km. The irregular form of the Sun in the left images reflects the conditions along 720 m in azimuthal direction toward the edges of the atmosphere at almucantar at 0° .

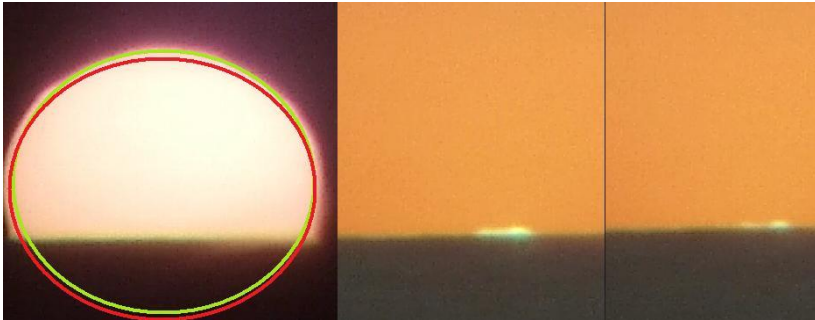


Fig. 4 Sequence of 4 Sept 19 sunset, the last green rim is 324" wide. The green Sun and the red Sun are superimposed to the real image to explain the differential refraction with λ .

Even in a very good sunset, the lower troposphere may present small azimuthal inhomogeneities, which affect the final result on the solar diameter.

Solar diameter at almucantar at zero: vertical hypothesis

The renowned phenomenon of the green flash/rim/ray arises from the differential refraction of the atmosphere as function of the light wavelength λ . This can be imagined as the combination of two Suns : the upper green and the lower one red (fig. 4). If the observations are made in white light the value of the angular solar diameter recovered with this method is larger than the actual value.

This remains also after extrapolation of the zero chord (sun disk-horizon) at the first contact.

The value of this λ differential effect has been 30" on 4 and 9 Sept 19. Further studies should assess it as systematic, also filtering the sunlight in bandwidths ≤ 100 nm.

Conclusions

This approach to sunsets science is innovative from the point of view of the accurate relative and absolute timing approach (relative through video inspection with quicktime 7.1 by including in the same video a radiocontrolled watch). This is the approach of IOTA observations for celestial mechanics (lunar and asteroidal occultations). The values of the solar diameter obtained after subtraction of the λ splitting in white light are within 1" from the actual angular solar diameter. Further observation will improve the statistics of λ effect, also reducing it with appropriate colour filters.

The time delay between ephemerides and observed sunset is dependent also on the quote of the observer, differences as small as 1 m can determine different timing and absolute

refraction's evaluation. This approach is followed in the paper about réfraction index at -47' in Ostia, this volume.

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