

# SOLAR ECLIPSES

## I. GENESIS OF SOLAR ECLIPSES

The solar eclipses occur if the Moon, by interfering between the Sun and the Earth, covers, either partially or totally, the solar disk, so as the Moon's shadow sweeps the Earth. A total solar eclipse is not a frequent phenomenon at all. It recurs after approximately 350 years for a given place on Earth. The mechanism of solar eclipses' genesis is quite simple: as being an opaque body lighted by the Sun, the Moon sends an umbral cone – where sunlight cannot go through – and a penumbra cone – where sunlight can only partially go through (Fig. 1).

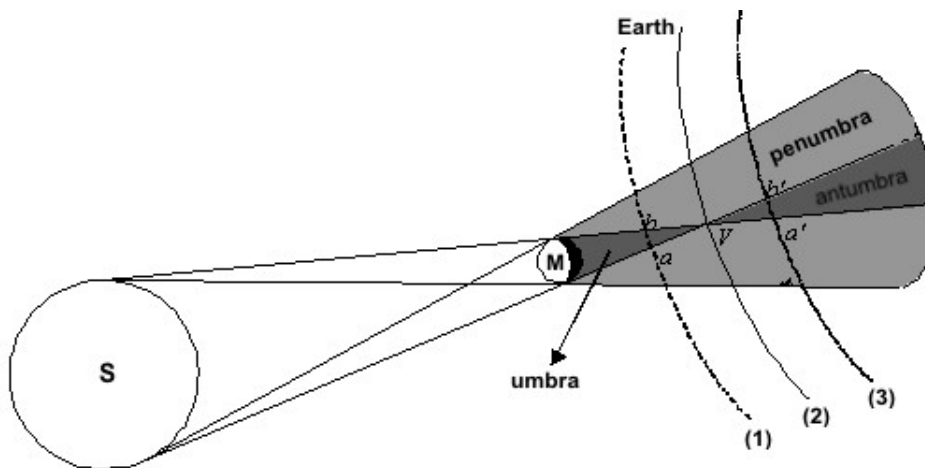


Fig.1 – Solar eclipse types

In the areas where the Moon's umbral cone sweeps the Earth, a total solar eclipse is produced (route (1), arc  $ab$ ), and in the areas where Moon's penumbra sweeps the Earth, a partial solar eclipse is produced (route (2) and the arcs of routes (1) and (3) that are comprised in penumbra). If the Moon is too far from the Earth, its disk cannot entirely cover the Sun's disk; the Moon's umbra will not reach the Earth but its prolongation (antumbra) can, and an annular solar eclipse can be observed in those areas (route (3), arc  $a'b'$ ). Eclipse **magnitude** is expressed by fractions of solar disk covered by Moon's apparent disk or by percentage (0.503 or 50.3%).

Total solar eclipses can be visible only from the Earth, because of certain weird coincidences within the "Sun–Earth–Moon" system. Thus, though the orbits of the Moon and Earth are elliptic, Sun and Moon's apparent dimensions (noticed on the Earth) vary a little with time. The Moon is about 400 times smaller than the Sun in diameter, but it is about 390 times closer. This makes possible that the two astral bodies could be seen on the Earth under approximately the same angular diameter. Providing the Moon was smaller, its disk wouldn't entirely cover the solar disk and a total solar eclipse wouldn't be produced ever! In this case, the eclipse could be only annular or partial. Providing the Moon's disk were significantly larger than it is in reality, it could totally cover both the chromosphere and a great part of solar corona, so that the eclipse could be visible on a larger area of the Earth and its duration would be greater! Table 1 shows certain interesting astronomic data. Solar apparent semi-diameter alters with only 3%, but the 12% variation in Earth–Moon distance results in a tremendous variation in Moon's apparent diameter. It has to be with 7% greater than that of the Sun (in this case a total eclipse occurs) or with about 10% smaller than the solar semi-diameter (in this case annular solar eclipse could occur). There are "central eclipses" if the

axis of the Moon's umbral cone penetrates the Earth (these are annular or total eclipses), or "non-central eclipses" if the axis of the umbral cone does not reach the Earth. As regards total eclipses, the maximum diameter of the umbral cone cannot go beyond 273 km, whereas as regards annular eclipses, the antumbra cone can have a maximum 313 km diameter. The intersection of the shadow with the Earth can produce a wider totality band than the aforementioned values. The duration of a total solar eclipse could vary from a few seconds to maximum 7½ minutes, and the maximum duration of the annular eclipse stage could be 12½ minutes.

Table 1. Dimensions and distances in Sun–Earth–Moon system

Diameter (km)			
Sun	Earth	Moon	
1 392 530	12 756	3 476	
Distance from Earth (km)			
	Minimum	Mean	Maximum
Sun	147 000 000	149 600 000	152 000 000
Moon	354 400	384 400	406 700
Apparent Diameter (arc min.)			
	Minimum	Mean	Maximum
Sun	31.49'	32.03'	32.57'
Moon	29.38'	31.45'	33.53'

**Gamma** parameter conveys the distance, in terrestrial radius, between the Moon's shadow axis and the Earth's centre, being one of the crucial parameters of a solar eclipse. Thus, **gamma** = 0 means the axis of the umbral cone goes right through the Earth's centre; **gamma** < 0 means the axis goes South of the Equator; **gamma** > 0 means the axis goes North of the Equator; **gamma** = ±1 means the axis is the tangent of the Earth in its North or South Pole. A solar eclipse could be visible on Earth up to **gamma** ≈ ±1.5. The place where the umbral cone axis intersects the earth surface is the **maximum point** of the total or annular eclipse; it means the maximum of duration and coverage (**the greatest eclipse**).

## II. PERIODICITY OF ECLIPSES

Solar eclipses periodicity is resulting from the studies of the Sun–Earth–Moon motion and the geometry of the eclipse phenomenon. The Earth moves round the Sun on an elliptic orbit (the ecliptic). Likewise, the Moon moves round the Earth on an elliptic orbit (the sidereal period of rotation = 27.32 days) (Fig. 2).

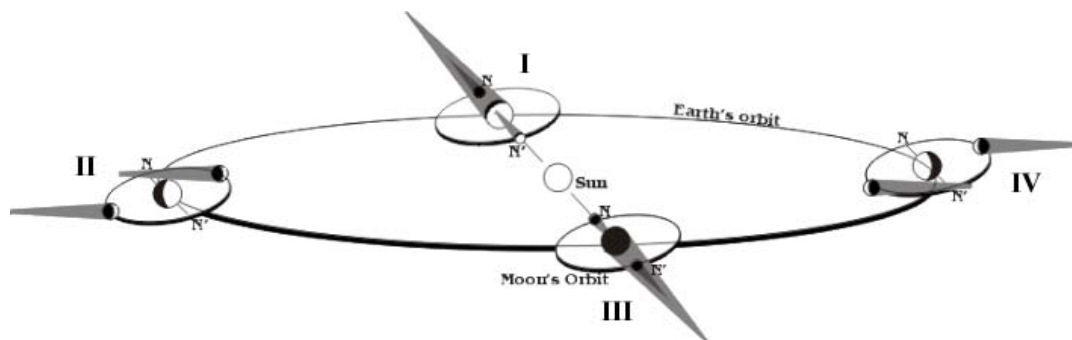


Fig. 2 – The geometry of the Earth and Moon orbits

Due to about  $5^\circ$  inclination of the Moon's orbit plane with respect to the Earth's orbit plane, the sun eclipses can solely occur if the "Sun-Moon-Earth" conjunction takes place along the NN' nodes line and only during New Moon (Fig. 2 – cases I and III; in cases II and IV the Moon's shadow does not reach the Earth).

The "Sun-Earth-Moon" conjunction results in moon eclipses. Total moon eclipses solely occur during Full Moon. Taking the ecliptic plan as reference point, the Moon's cross through one of the nodes is made either upward or downward so as the solar eclipses can occur at the upward node or at the downward node.

This could happen twice a year after 6-month intervals ("eclipse seasons"). The time when the Moon's disk covers (either totally or partially) the solar disk could last 18.75 days, on either side of the respective node, so that during 37.5 days (Fig. 3) even two phases of New Moon could occur, and thus, two solar eclipses (partial).

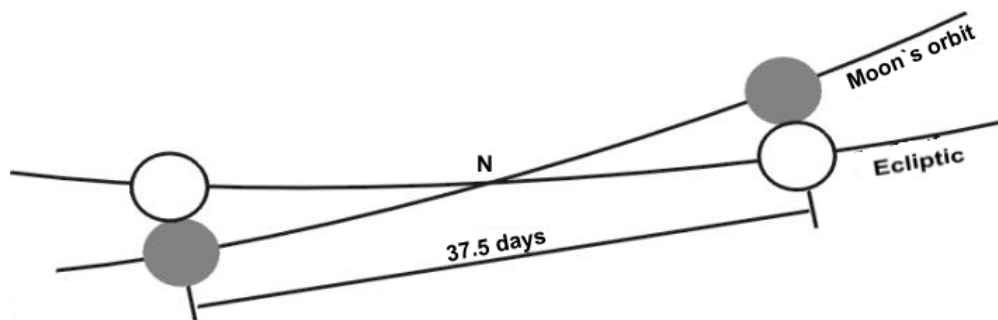


Fig. 3. The time interval near the node of the Moon orbit when the Moon's disk covers (partial or total) the solar disk

The motion of nodes' line on the ecliptic, together with moon phases' periodicity (known as synodic period or "lunation" = 29.53 days), generates a period of 18 years and 10.32, 11.32 or 12.32 days (depending on how many leap years are included in a 18-year period), for eclipses creation in the same configuration of the three astral bodies. This 18.03-year period (or 223 lunation) is named Saros cycle ("saros" meant repetition in the ancient Babylon). The 0.32 fractions out of a day means an approximately  $120^\circ$ -Earth rotation, so as after 18.03 years, each eclipse could be observed on the Earth with  $120^\circ$  Westwards than the previous one. After 3 Saros, the solar eclipse will occur at the same longitude but will be moved North or South with respect to latitude, thus having another value of **gamma** parameter. In 1955, van den Bergh, a Danish astronomer, proposed a system in which all the eclipses occurring at the 18.03-year interval, at the same node, ascendant or descendent, and having gamma between +1.5 and -1.5, could be grouped in a **Saros series**. Such a series has from 70 to 85 eclipses and can last between 1200 and 1500 years (the 29 March 2006 eclipse belongs to 139 Saros series).

#### IV. PHENOMENA OBSERVED DURING A TOTAL SOLAR ECLIPSE

Every total solar eclipse has two phases: a partial one and a total one. The partial eclipse lasts proximately 1 hour since the first contact (the two disks are exterior tangents). During it, the Moon's dark disk goes over the Sun's shiny disk and covers it completely just at the second contact (the two disks are interior tangent) (Fig. 4). This is the beginning of the total eclipse, which is completed at the third contact, when the Moon's disk, on its way, becomes interior tangent to the Sun's disk, in a diametrically opposite point. At that moment, the second part of the partial eclipse begins, and it also lasts proximately 1 hour. During that time,

the Moon's disk leaves the solar disk gradually. At the last contact, when the Moon's disk has completely left the solar disk (the two disks are exterior tangents again), the eclipse ends.

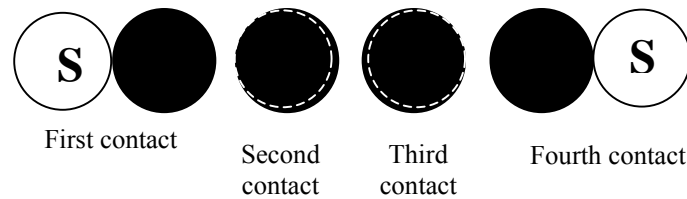


Fig. 4 – The four contacts during a total solar eclipse

At the beginning of the partial eclipse, right after the **first contact**, a small dark spot will be noticed at the edge of the solar disk, and it will continuously grow. It is the Moon's disk gradually covering the Sun's disk. While the visible Sun area is lessening, a small decrease in temperature could be sensed. About 20 minutes before the totality, when Sun's image is a narrow crescent with its points directed to West, the air temperature and sunlight sharply decrease and it seems, as it is getting dark. While temperature is decreasing, the solar **eclipse wind** occurs. An unwelcome meteorological phenomenon occurring during the eclipse is the **clouds' appearance** due to air-cooling.

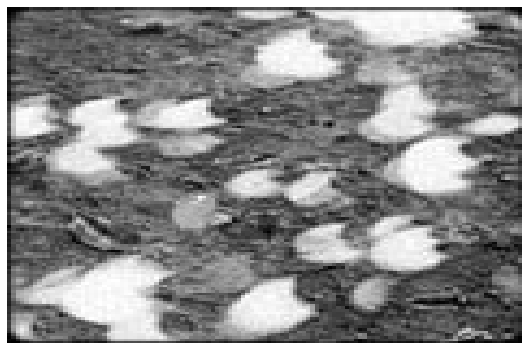


Fig. 5 – Light crescents

Before the totality phase, when only a small piece of the Sun's disk remains, light and dark bands moving on Earth or buildings could be seen. They can be easily seen if a big white piece of paper or sheet is put on the soil. Under certain circumstances, one can take pictures of those bands. Narrow **light crescents**, projected on soil can be seen under the trees or bushes (Fig. 5). These are images of the solar disk "crescent", projected on the soil through the spaces between the leaves, which act like pinholes.



Fig. 6– Bailey's beads

Some seconds before the totality, the Sun's crescent becomes increasingly narrowed, splitting in light rings after a short period of time, known as **Baily's pearls** or **beads** (Fig. 6). They are produced by the last sunrays that succeed in passing through the "valleys" and "depressions" on the edge of the Moon's disk.

Just before the **second contact**, a single light diamond-shining spot has remained between "Baily's beads", having two "arms" that are generated by the points of the solar disk's crescent, and aim to encompass the Moon's disk. This phenomenon is known as the **diamond ring** (Fig. 7). When the diamond ring has vanished, the reddish crescent of the **solar chromosphere** – which is the solar atmosphere region lying between photosphere and corona – will be visible for a few seconds. The chromosphere is properly visible only in the immediate proximity of the central line of the totality band and if the totality phase is not very

short. For those observers who are positioned near the edge of the totality area, Baily's beads could be seen during all the totality phase.

Just before the second contact, the **Moon's shadow** moves towards the observer from



Fig. 7 – Diamond ring

West, with 1700 km/h. It looks like a Moon's huge veil, unfurling from the sky to the Earth, reaching us, the eclipse's observers, and covering us. If the visibility is excellent, this phenomenon induces a weird effect! When the "shadow veil covers us", the Sun's external pearl-white atmosphere, known as **solar corona** suddenly appears on the sky, surrounding the solar disk, which is entirely obturated by the Moon (Fig. 8). The solar prominences at the edge of the dark disk, together with the corona, can be seen with the naked eye. They appear as red shining jewels with various shapes and sizes. They can be easily observed with binoculars but **beware using it without special filters before the beginning of the eclipse's totality phase and after its ending.**

The total phase of an eclipse is accompanied by the onset of a rapidly darkening sky whose appearance resembles evening twilight about half an hour after sunset. The effect presents an excellent opportunity to view *planets and bright stars in the daytime sky.*



Fig. 8 – Solar corona

At the end of the totality phase, the first blink of the Sun could be seen to the West of Moon's disk after the **third contact** and then, in the reverse order, appear: the chromosphere, the diamond ring and the Baily's beads. The sky will be lighted gradually, the stars will disappear, and Sun's lightning disk "flashes" little by little from behind the Moon. After proximately one hour, the last part of the Moon's dark disk disappears, right after the **fourth contact.**

## V. EYE SAFETY PRECAUTIONS DURING THE SOLAR ECLIPSES

Any people suffer **serious, incurable eye damage** when viewing solar partial or annular eclipses. To prevent eye damage, you **must** be informed of the dangers, the many misunderstood and dangerous viewing methods, and the few (but cheap and easy) **safe-viewing methods.**

Note that during the totality phase, when the Moon's apparent disk entirely covers solar disk, we may observe the phenomenon with the naked eye, without any danger. It is only the phases of the partial eclipse, before or after the totality phase, from the places included in the totality band, as well as the partial and annular eclipses, that **MUST NOT** be watched unless appropriate optical filters are used.

### The Dangers

The solar radiation that reaches the Earth surface comprises a wide optical spectrum, starting with ultraviolet radiation (UV) wavelengths ( $\lambda > 290$  nm) and ending with infrared radiation (IR) ( $\lambda < 1400$  nm); the visible range spreads out between 380 and 780 nm. Biological tissues in the eye transmit an important quantity of radiation (between 380–1400 nm) to the light-sensitive retina. **UV exposure** contributes to an accelerated "aging" of eye's

external layers and cataract rise. **Sun's observation during an eclipse without any eye safety precautions could therefore result in retina's burning – "eclipse blindness"**.

**Retina's exposure to intense visible light** also results in the destruction of its cells by a photo-oxidation process. This destructive process, called photochemical retinopathy takes place especially due to the radiation between 380 nm and 500 nm. By **watching the Sun without any special filters**, the time limit of retina's exposure without having a destructive effect is less than 60 seconds, but sight damage due to repetitive exposures, even shorter, could occur, as the destructive effects on the retina are cumulative. If an optical instrument such as refractor, telescope, and binoculars is used, the time limit of the exposure will be shorter than a fraction of a second. The risk for solar retinopathy is high due to these lesions' lack in pain sensation, as the retina does not have any nervous sensors. In addition, the symptoms do not occur immediately, but within 12–48 hours after the exposure.

The recovery process of visual function is not a foreseeable one, and it can be expanded depending on retina's thermal and photochemical damages. Though many injured persons might recover the visual acuity they had before the eclipse, **there could be cases when this illness is permanent, spreading from light visual dysfunction to total blindness.**

The conversion into heat of the incident light energy within the 380–500 nm wavelength range results in the photocoagulation of retina's pigmented epithelium, if either an optical instrument is used or a longer watch with the naked eye is unprotected. This thermal injury might occur due to the unprotected exposure to radiant energy within 500–1400 nm ranges. Photocoagulation induces a permanent blindness area on the retina.

**We emphasize again that the Sun could be safely watched with the naked eye only during the total eclipse phase, when the Moon completely covers Sun's disk. Only those observers who are in the totality area can capitalize on this "favour"**.

Only adequate equipment, provided with special filters to stop the harmful part of solar radiation, can allow the observers to safely view the partial and annular eclipses, as well as the partial phases of a total solar eclipse. **Right when 99% of Sun's surface is covered during the partial phases of solar eclipse, the solar "crescent" is still intense enough to induce retina's burning.** Thus, special attention must be given both to the eclipse observation methods and related media information.

### **Safe Viewing Methods**

**Projection** is the safest and cheapest method for watching the eclipse. A small circular orifice in cardboard for catching Sun's image on a screen (cardboard) that is placed about one meter behind the orifice could be used. The numerous spans occurring by crossing fingers or the orifices in a straw hat can be used to "project" Sun's image on a screen. A similar effect could be noticed at ground, under the tree's leaves. A simple mirror is also enough to obtain the projection of partial eclipse's image, as well. A magnified image of the Sun could be projected on a white screen (cardboard) by using both binoculars and small telescopes. The projection methods can be used in order to prevent the partial phases of the eclipse to small observers groups, and to make them aware of not looking directly through the instrument. **The main advantage of the projection methods is that nobody is looking directly to the Sun.**

The Sun can be directly watched if **special protecting filters** are used. Such filters have a thin chromium–aluminium–alloy layer deposited on their surface, in order to attenuate the visible radiation and the one in the near infrared. This type of solar filter will transmit less than 0.003% (density ~4.5) of the visible light (380–780 nm) but no more than 0.5% (density~2.3) of the near infrared radiation (780–1400nm).

One of the most convenient filters to safely watch the Sun is the **protection solders glasses**. A not expensive alternative is **aluminized Mylar filter**, especially produced for solar observations. Mylar could be easily cut to fit each optical instrument or to manufacture simple



cardboard-mounted glasses. It has recently been pointed out that some aluminium polyester filters may have large (up to approximately 1mm in size) defects in their aluminium coatings that may be hazardous. When in doubt, an aluminium polyester solar filter that has coating defects larger than 0.2mm in size or more than a single defect in any 5mm circular zone of the filter, should not be used.

An alternative to aluminium polyester that has become quite popular is "*black polymer*" in which carbon particles are suspended in a resin matrix. This material is somewhat stiffer than polyester film and requires a special holding cell if it is to be used at the front of binoculars, telephoto lenses, or telescopes. Intended mainly as a visual filter, the polymer gives a yellow image of the Sun (aluminium polyester produces a blue-white image). This type of filter may show significant variations in density of the tint across its extent; some areas may appear much lighter than others. Lighter areas of the filter transmit more infrared radiation than may be desirable. The advent of high resolution digital imaging in astronomy, especially for photographing the Sun, has increased the demand for solar filters of higher optical quality. Baader AstroSolar Safety Film, *a metal-coated resin*, can be used for both visual and photographic solar observations. A much thinner material, it has excellent optical quality and much less scattered light than polyester filters. Filters using optically flat glass substrates are available from several manufacturers, but are quite expensive in large sizes.

Many experienced solar observers use one or two layers of black-and-white film that has been fully exposed to light and developed to maximum density. The *metallic silver* contained in the film emulsion is the protective filter; however, any black-and-white negative with images in it is not suitable for this purpose.

### Unsafe Viewing Methods

Unsafe filters include color film, **black-and-white film that contains no silver (i.e., chromogenic film)**, **film negative with images on them**, **smoked glass**, **sunglasses (single or multiple pairs)**, **photographic neutral density filters and polarizing filters**. Most of these transmit high levels of invisible infrared radiation, which can cause a thermal retinal burn.

Solar filters designed to thread into eyepieces that are often provided with inexpensive telescopes are also unsafe. These glass filters often crack unexpectedly from overheating when the telescope is pointed at the Sun, and retinal damage can occur faster than the observer can move the eye from the eyepiece. Avoid unnecessary risks.

Sometimes **CD ROM** or usual **diskettes** are used as protective filters for viewing the eclipse. The optical quality of these is inferior to the mylar filters or to the welding glasses. The CDs through whose thin aluminium layers the edges of the objects in a normally illuminated room can be seen are not safe.

Smoked glasses must be used with special care, because they do not present a homogenous darkening, and noxious IR or UV invisible radiation can penetrate the surfaces which have not been properly darkened. It is recommended to use 2 pieces of smoked (darkened) glass of equal sizes, placed one above the other with the darkened faces inside and fixed on the edges with adhesive band (like a picture frame).

Anyway, the filters of an optical instrument (binocular, telescope, refractor) must be specially designed for this purpose and must not be placed between ocular and eye, firstly because they could be broken or deteriorated due to the rapid heat of the instrument, and secondly because the eye could be damaged before stopping looking. Each filter must be mounted before the objective, namely towards Sun.

The persons who wear contact lenses or glasses with many dioptries must take special measures into consideration. If at a normal eye the UV radiation does not touch the retina,

being absorbed by the crystalline, in the case of the persons mentioned above the UV radiations can cause chronic alterations of the retina if adequate filters are not used.

## References

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