Eclipses through the Centuries

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1. Introduction

"To the best of our knowledge, our Sun is the only star proven to grow vegetables."

- Philip Scherrer[1]

Other than Earth itself, the Sun and Moon are the celestial bodies most closely related to human reality. Although people in ancient times were curious about the stars and the universe as a whole, the Sun and the Moon have been the main actors in our celestial theater. Since they are most directly associated with quotidian issues such as the day and night cycle, as well as the seasons, they influence vital human economic activities such as agriculture.

The Sun is crucial to us all. It is by far the closest star to the Earth and our ultimate source of warmth, light and energy. Could you imagine life on Earth without the Sun?

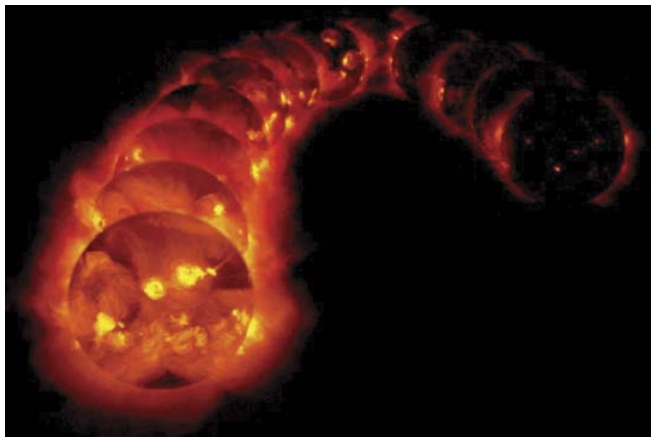

Fig. 1 – The Changing Sun. These 13 x-ray images, obtained by the Yohkoh spacecraft between 1991 and 1995, provide a dramatic view of the Sun, highlighting how the solar corona changes during the waning part of the solar cycle as the Sun goes from an "active" state (left) to a more passive state (right). Source: NASA.

Fig. 2 – Lunar eclipse in Athens, Greece, January 9, 2001. Multiple exposure technique shows an eclipsed Moon, which during totality assumes a deep red color. Credit: © 2002, photo by Fred Espenak.

Early civilizations depended deeply on the Sun. That time, the Sun was essential to estimate the time of day. For this purpose, the Chaldean astronomers developed the gnomon (a shaft erected perpendicular to the horizon), used to indicate the passing hours through its shadow projected on the ground. Ancient people also studied the Sun's cycles in order to know when to plant crops, to get ready for winter, as well as to plan ceremonies related to the changing seasons. Can you figure out when seasons are about to change?

People in early times were usually fearful of eclipses of the Sun and Moon. Indeed, humans are sometimes frightened by the unknown and by whatever they cannot understand or predict. Imagine a spaceship landing in your backyard with creatures from another world – this would be most frightening! If we had no prior knowledge about the Sun's disappearance in broad daylight during a solar eclipse (resulting from the temporary passage of the Moon between the Earth and our star), we would fear that the Sun's light has been truly lost, and that such darkness might last forever.

Eclipses are ineffable astronomical phenomena that have provoked human curiosity, fear, passion, and other strong feelings throughout the course of history. In this paper, you will learn more about solar and lunar eclipses, along with their influence in early and current societies.

Before discussing further on eclipses, let us better understand the subjective and objective meanings of the Sun in early epochs. Ancient civilizations feared so much the disappearance of the Sun, in special because it ruled their economy. Indeed, those agricultural societies needed sunlight and warmth in order to exist. Moreover, it must have been most intriguing for early civilizations to suddenly be deprived of the Sun's bright light during the day. They might have asked, "Is this the end of the world?" "Are the Gods angry with our behavior?"

Human imagination is very creative at filling in gaps of understanding.

Although the Sun was regarded as a powerful god and a cosmic hero, it also had enemies to fight. Sometimes demons of darkness obscured the Sun, and people wondered if their god would not return any longer.[2] Likewise, when a lunar eclipse occurs, the way the full Moon is occulted in a vast area of shadow, and the way its color changes to a blood red certainly would indicate some disturbance in the cosmic order. So it would not be a large stretch to wonder whether this was a signal of divine anger, or the action of some demonic power.[3] As a consequence, several myths associated to eclipses arose.

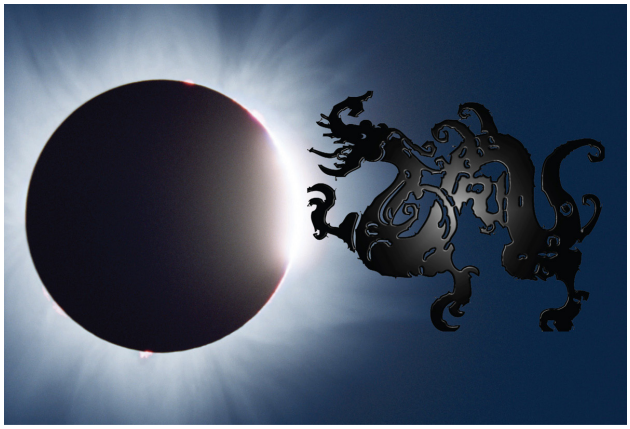

Fig. 3 – The invisible dragon. People in ancient China and old Southeastern Asian cultures believed that a dragon swallowed the Sun during solar eclipses. Source: NASA.

As mentioned, a solar eclipse occurs when the Moon passes in front of the Sun and obscures it totally or partially. This configuration only exists during the new Moon phase, and then only when the Sun, Moon, and Earth are on a single line, with the Moon in between. Since the Moon's orbit is tilted 5 degrees to the Earth's orbital plane, this configuration will not happen every month.

We do not know for certain since how long mankind has witnessed eclipses. Sequences of marks scratched on animal bones dating back 30,000 years suggest the changing phases of the Moon from one cycle to the next.[4]

Though eclipses are well understood today, the apparent disappearance of the Sun and Moon has been attributed to different reasons through the centuries.

The ancient Chinese, for example, thought that there was an invisible dragon in the sky. This dragon was angry with them and, for this reason, would devour the Sun. Whenever this happened, they would follow several rituals intended to scare the dragon away and make the Sun reappear.

One ancient Chinese tradition was to bang drums and pots and make other loud noises during eclipses in order to frighten the dragon away. Even more recently, in the nineteenth century, the Chinese navy fired cannons during a lunar eclipse to scare the dragon that was eating the Moon!

In the ancient Near East, the dragon symbolized the four elements of nature: earth, air, fire, and water. They were usually associated with dark forces, and with the earth-dwelling serpent, representing evil.[5]

The idea of a ferocious animal or beast trying to swallow the heavenly luminaries was common to many civilizations. The battle between the powers of light and the powers of darkness, or the voracious appetite of mythical beasts was the basis for many explanations of eclipses.

In this paper, you will learn more about the mechanism of eclipses and discover interesting stories about these awe-inspiring astronomical phenomena that have changed history through the centuries, advanced science and still today fascinate people of all ages, nationalities and cultures worldwide.

2. Some Eclipse Legends

Eclipses did not frighten some early civilizations, though. The Eskimo and the Aleuts, for instance, interpreted them as signs of good fortune. The Sun and the Moon would temporarily leave their natural places in the sky to reassure themselves that everything on Earth was going fine. Some eclipse legends are love stories and numerous others reflect local beliefs, as follows:

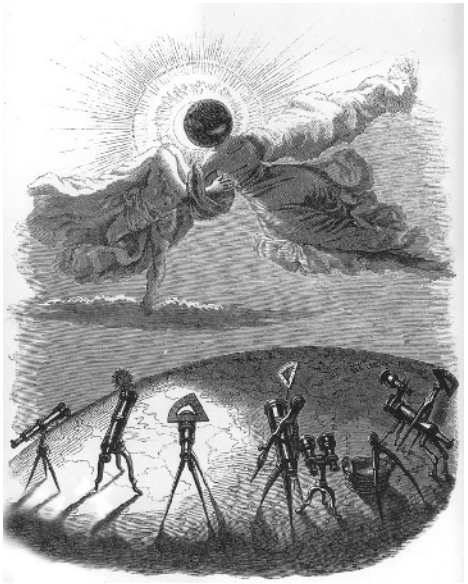

Fig. 4 – Conjugal eclipse. Some people had a romantic view of eclipses. The Sun and Moon are lovers who, when they embrace, turn off the lights to assure intimacy. Source: Bibliothèque nationale de France (BnF), photo Jean-Loup Charmet.

a) In most Aboriginal cultures, it was believed that the Moon and Sun were husband and wife respectively, pulling curtains in the sky to ensure privacy for their union.

b) The Athenians, in ancient Greece, considered an eclipse (solar or lunar) to be caused by angry Gods; therefore they were regarded as bad omens.

c) The Mayans, in Central America, believed that during an eclipse of the Moon, a giant jaguar was eating it. The Jaguar moved through the darkness,

and its coat seemed a starry sky.

d) In Japan, wells were closed to prevent the sky poison, hidden by the eclipse, from falling into them.[6]

e) In Scandinavia, two wolves named Skoll and Hat were believed to terrorize the Sun and Moon.

f) In India, a dragon named Rahu, would have the head of a dragon and the tail of a comet. It rode in a chariot drawn by eight black horses that represented the sky.

g) The Aztecs believed that Tzitzimine were star demons who caused eclipses when they waged battles with the Sun.

h) In Bolivia, it was believed that dogs chased after the Sun and the Moon and the tore the Moon's face apart with their teeth. It was the Moon's blood that would turn the Moon red. The people howled and wailed in order to chase the dogs away.[7]

The fact is that humanity has never been indifferent to eclipses. Through the centuries, they have been mentioned as affecting or even determining important historical events. Empires would rise or fall, kings would be crowned or dethroned, and battles would be lost or won because of chance alignments of the Sun, Earth and Moon.

3. Eclipses and the Advancement of Science

From a scientific standpoint, eclipses have often opened doors to important knowledge. In early times, for instance, lunar eclipses constituted an important proof of the sphericity of the Earth. Lunar eclipses were central to debates of Pythagoras, Aristotle, and other Greek philosophers. Thus, if we have an eclipse of the Moon by the shadow of the Earth, the shape of that shadow must represent the profile of the planet.[8]

For instance, Aristarchus (310 - 230 BCE) used eclipses to estimate the relative sizes of the Earth and Moon by the curvature of the Moon's disk and the curvature of the Earth's shadow cast on it, having the Sun, Earth and Moon aligned in this sequence. He also estimated the distance of the Earth to the

Moon and to the Sun, as well as the size of the latter. Moreover, he demonstrated that the Sun was more distant than the Moon and larger than the Earth.[9]

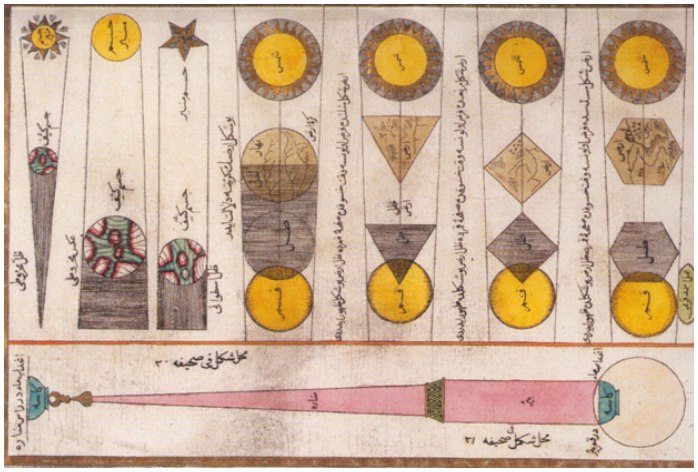

Fig. 5 – Aristotle's geometrical argument. Shown in several ancient astronomy texts, including *Cosmoghaphia,* by Petrus Apianus and Gemma Frisius (1581) and Mustapha Ibn Abdullah's *Book of the Description of the World* (1732). Source: Bibliothèque nationale de France (BnF).

By the late 1800's astronomers realized that the corona[10] was essential to understanding countless solar phenomena, perhaps even the mysterious auroras. In 1930, Bernard Lyot (1897-1952 CE) invented the coronagraph, an instrument that allowed the rare total solar eclipses to be recreated at will, and at a time and place of choosing.[11]

According to Mitchell (1869), *"solar eclipses, at one time the terror of the ignorant, and the study of astronomers only, have come to be specialties also of the chemist, the physicist, and the photographer. The telescope, the camera, and the spectroscope work together, each crowded with work, and each finding its most fruitful field in the Sun."* For instance, during the eclipse of August 16, 1868, Sir Joseph Lockyer of England, and Monsieur Pierre Janssen of France independently discovered by spectroscopic means the telltale signs of helium in the Sun's corona. Helium became the first chemical element to be discovered outside of Earth, taking its name from the Greek word for the Sun — *Helios*.

Eclipses blot out the photosphere and reveal the presence of an atmosphere above the Sun beyond a solar radius. This medium became a matter for extensive study in the 19th century, and eclipse observations revealed a bright inner portion, the chromosphere, and a very extensive halo, the corona.[12]

Arguably, the most important eclipse of modern times occurred on in May 29, 1919, when Arthur Eddington (1882-1944 CE) used a solar eclipse to test Einstein's general relativity theory by showing that strong gravitational fields, such as the Sun's, are capable of bending star light by the amount predicted.

Solar eclipses are used to photograph and study the composition and dynamics of the Sun's corona, which is only visible when the Sun's bright disk or photosphere is completely blocked out.

Fig. 6 - The magnificent corona. This dramatic image is a combination of 22 photographs digitally processed, highlighting faint features of a total eclipse that occurred in August of 1999. The outer pictures of the Sun's corona were digitally altered to enhance dim, outlying waves and filaments. Credit: © 1999, photo by Fred Espenak.

Scientists also use these events to study space weather phenomena such as solar flares and coronal mass ejections (CMEs). Such phenomena are important due to the fact that they can directly impact space systems and human activities like telecommunications, navigation, and the extremely complex work of astronauts in space, especially while performing extra-vehicular activities.

Presently, most people understand the basic mechanism of eclipses and are no longer frightened by them. They are usually seen as beautiful and fascinating events. Every year, people of different ages, nationalities and interests join to watch total or partial eclipses of the Sun and the Moon all around the world. But has something been lost? Does knowing how something works reduce its beauty and mystery? Or is the beauty of the world deepened by understanding the things we see?

Fig. 7 – Coronal mass ejection. Huge bubbles of plasma ejected from the solar corona and that can disrupt Earth's magnetosphere. Credit: ESA/NASA.

These magnificent celestial spectacles are also observed worldwide by students and teachers of all levels, capturing youthful imagination towards the universe and encouraging new understandings about space. The example of the Danish astronomer Tycho Brahe (1546-1601 CE) well illustrates that. He made a career shift from law to astronomy after being fascinated by an eclipse at the age of fourteen. Before Brahe, astronomy was quite innacurate. He then decided to develop accurate tables for the observation of stars and planets.[13] Brahe's contributions to astronomy have indeed

been significant. He catalogued with great accuracy more than 1,000 stars!

Eclipses are an effective means of making people curious about the wonders and mysteries of the universe, and they fan the fires of curiosity and the human desire for exploration and discovery. They are a channel to unite people around the world to look at the starry sky as the place where we all came from long ago, cosmologically speaking.

4. Eclipses: Definitions and Terminology

The concept of a solar or lunar eclipse being viewed as the gradual eating of the luminary bodies by a celestial invisible dragon is manifested in the earliest Chinese term for eclipse, *shih*[14] (to eat). They believed that eclipses happened when this dragon attempted to devour the Sun or the Moon.[15]

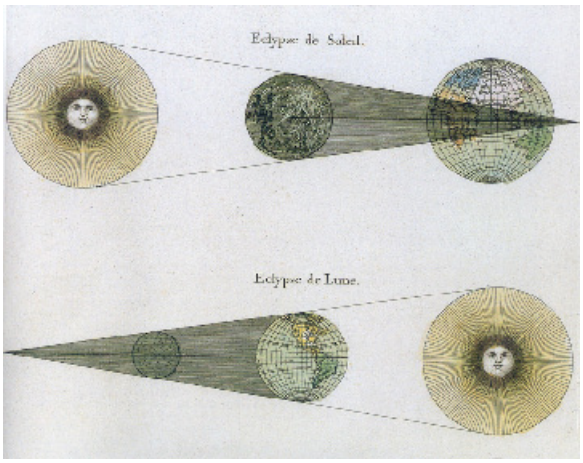

Fig. 8 – Ancient representation for eclipses of the Sun and Moon. Atlas methodique et elementaire de geographie, by Claude Buy de Mornas. Source: Bibliothèque nationale de France (BnF).

The term eclipse originated from the Greek ekleipsis, from ekleipein 'fail to appear, be eclipsed,' from ek 'out' + leipein 'to leave', also meaning 'abandon', 'failure'.

According to the Oxford English Dictionary (1969), eclipse as a noun means *"an interception or obscuration of the light of the Sun, Moon or other luminous body, by the intervention of some other body, either between it and the eye, or between the luminous body and that illuminated by it; as of the Moon, by passing through the Earth's shadow; of the Sun, by the Moon coming between it and the observer; or of a satellite, by entering the shadow of its primary."*

In the figurative, eclipse would mean an *"obscuration, obscurity, dimness; loss of brilliance or splendour"* e.g., the eclipse of an empire.

5. Scientific background

"Some people see a partial eclipse and wonder why others talk so much about a total eclipse. Seeing a partial eclipse and saying that you have seen an eclipse is like standing outside an opera house and saying that you have seen the opera; in both cases, you have missed the main event."

- Jay M. Pasachoff[16]

Fig. 9 – Eclipsed Moon in Stonehenge. A reddened Moon appears between the stones of Stonehenge during the May 2004 total lunar eclipse. Credit: Photo by Phillip Perkins, Astro Cruise Web site, http://www.astrocruise.com/

Compared to other celestial bodies, the Sun and Moon are the brightest when viewed from our home planet. For this reason, solar and lunar eclipses are also closer to our realities than any other celestial phenomenon.

Furthermore, solar eclipses are much more notable than lunar eclipses, because, when total, they can "turn day into night!" During solar eclipses, for example, animals become agitated because they perceive that something is wrong about the natural order of things: Why that sudden darkness in the middle of the day!

Eclipses are basically an alignment of at least three celestial bodies in a straight line.[17] The term solar eclipse is a misnomer, because the phenomenon is actually an occultation.

Why is this so? The answer is simple. An eclipse occurs when one celestial body passes into the shadow cast by another (as with an eclipse of the Moon). An occultation occurs when one body passes in front of another. When the new Moon passes in front of or occults the Sun, as seen from Earth, the Moon also

casts a small shadow on the planet. An "occultation" of the Sun is thus a partial "eclipse" of the Earth as well.[18]

You will find in the sequence a set of questions and answers that will help you better understand the mechanism of eclipses.

A) When do we have a solar eclipse?

When any part of the Earth enters any part of the Moon's shadow, there is a solar eclipse somewhere on the planet.[19]

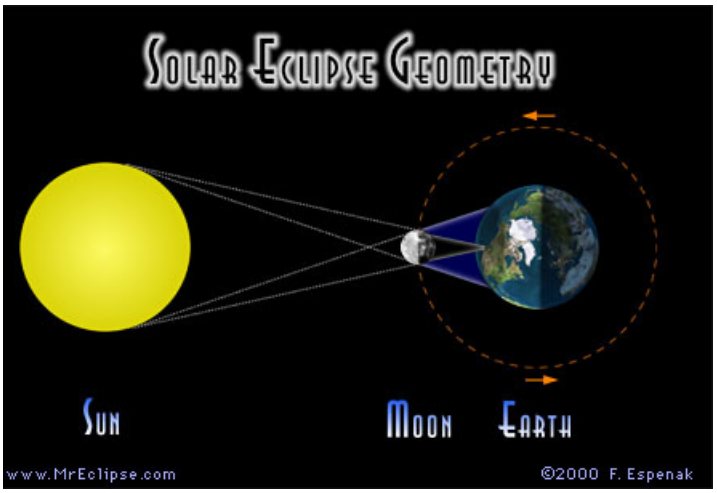

Fig. 10 – The geometry of a solar eclipse. Because of this unique geometry, during a total solar eclipse the Moon occults the Sun with a nearly perfect fit. Extracted by permission from Fred Espenak's Web site, http://www.mreclipse.com/

This configuration can only exist during new Moon, when the Sun, Moon and Earth are aligned with the Moon in between. Since the Moon's orbit is tilted 5 degrees to the Earth's orbital plane, this will not happen every month.

The lunar shadow is composed of two parts: a) the outer or penumbral shadow, and b) the inner or umbral shadow. From within the penumbra, only part of the Sun is occulted. In contrast, the dark, central umbra is the shadow of a total eclipse. During a total eclipse, the umbra sweeps across the Earth from west to east and the course it travels is called the path of totality.

Anyone standing within this zone will see the Sun completely obscured by the Moon for as much as seven minutes. Outside the path of totality but still within the penumbra, a partial eclipse is seen. The path of the umbra is rarely larger than 300 km wide while that of the penumbra is about 7,000 km wide.[20]

B) Why do the Sun and Moon appear to be the same size during a solar eclipse?

The Moon is only 3,500 km in diameter while the Sun is about 1,400,000 km

across. One of the most remarkable coincidences in nature is that the Moon and Sun appear to be the same size when viewed from the Earth. This occurs because, although the Sun is 400 times larger in diameter than the Moon, it is also 400 times farther from the Earth.[21]

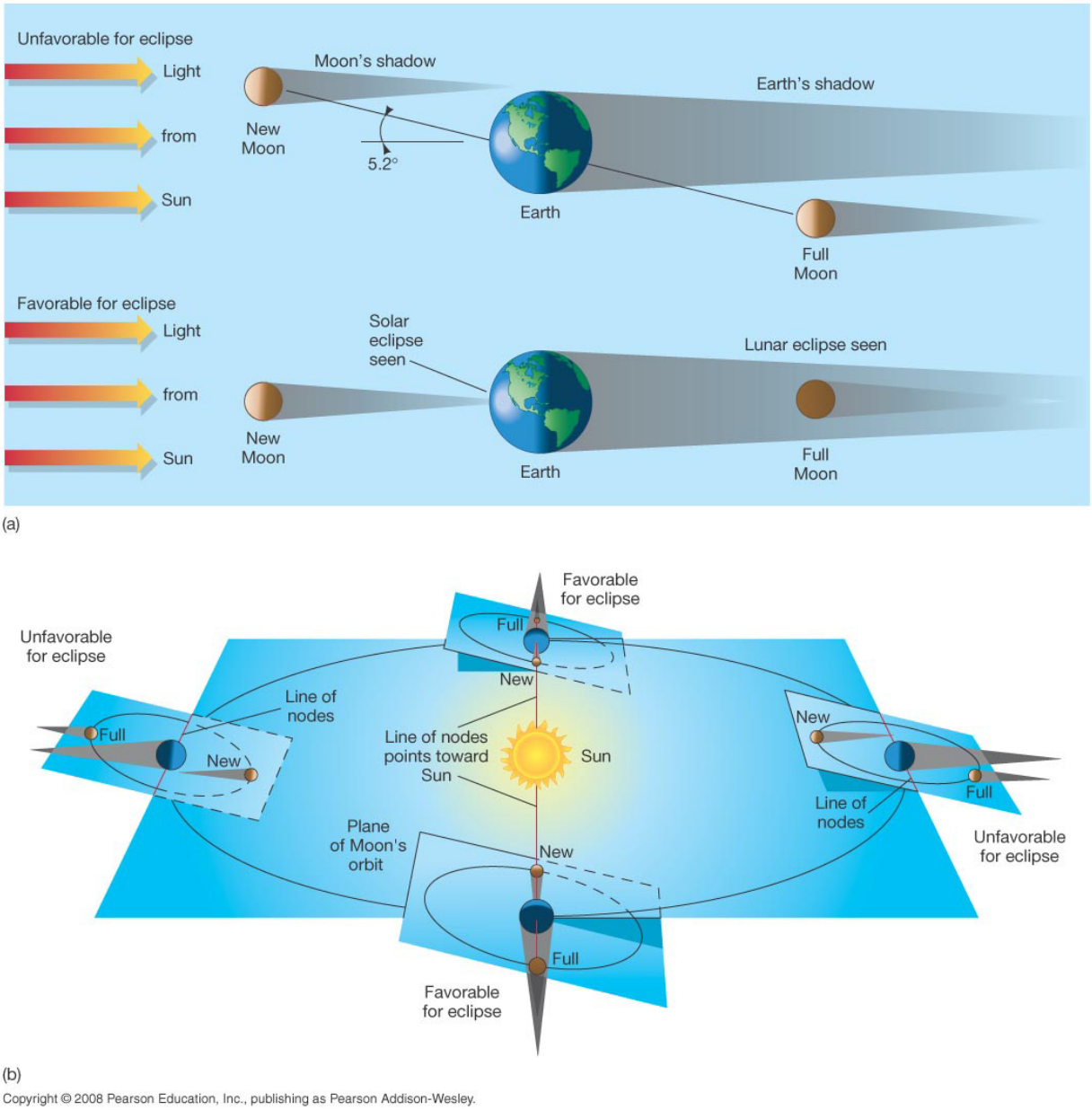

Fig. 11 – Scheme for visibility of eclipses. (a) An eclipse occurs when Earth, Moon, and Sun are precisely aligned. If the Moon's orbital plane lies exactly on the plane of the ecliptic, this alignment would occur once a month. (b) For an eclipse to occur, the line of intersection of the two planes must lie along the Earth–Sun line. Thus, eclipses can occur only at specific times of the year. Credit: Chaisson/ Mcmillan, *Astronomy Today*, 6 ed., Pearson Education.

C) Why doesn't a solar eclipse occur at every new Moon?

The Moon's orbit around the Earth is not in the same plane as the Earth's orbit around the Sun. The Moon's orbit is inclined by about 5 degrees to the Earth's orbital plane, which is on the ecliptic. Our planet's natural satellite crosses this imaginary plane only twice a month at two points called the nodes. At other times, the Moon is either above or below the plane of the Earth's orbit. Complete alignments of the Sun, Moon, and Earth only happen when the new Moon phase occurs at one of the nodes.[22]

D) Are solar eclipses rare phenomena?

No. They are actually more common than lunar eclipses. In any one calendar year, there can be as many as five solar eclipses. There can be no more than three lunar eclipses per year, and it is quite possible to have none at all. Combining both solar and lunar eclipses, it is possible for one calendar year to contain a maximum of seven eclipses.[23]

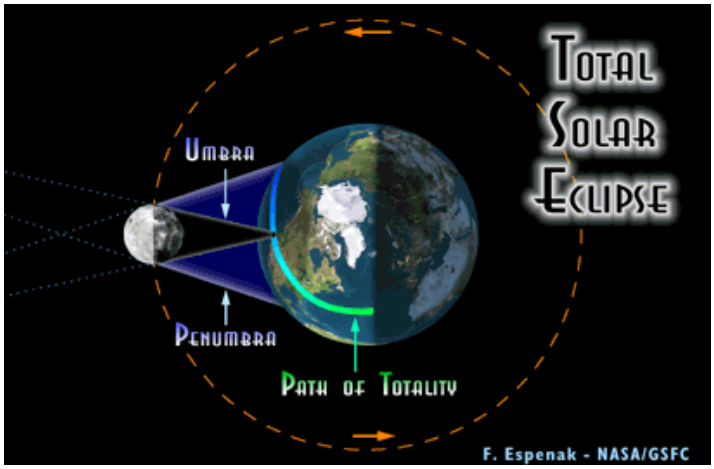

Fig. 12 - Geometry of the Sun, Earth, and Moon during a total eclipse of the Sun. The Moon's two shadows are the penumbra and the umbra (sizes and distances not to scale). Extracted by permission from Fred Espenak's Web site, http://www.mreclipse.com/

Please note that we are referring to eclipses in general. Total solar eclipses are relatively rare and happen at any given specific location on average only once in hundreds of years.

E) What is the most notable phase of a total solar eclipse?

The most dramatic phase occurs during totality, when the Sun is completely obscured by the Moon. Totality never lasts more than 7 minutes 40 seconds.

During each millennium, there are typically fewer than 10 total solar eclipses in which totality exceeds 7 minutes. Only during **totality** (See "The Experience of Totality," at http://www.mreclipse.com/Totality/TotalityCh01.html) can the corona be observed without specialized equipment, so that total solar eclipses

are very important for astronomers.

F) Is it easy to predict a solar eclipse?

Yes! Today, we understand the motions of celestial bodies and can model the forces on them with great accuracy. Computer programs fed with this knowledge easily compute the time and geometry of eclipses well into the future or the past. We can account for corrections due to relativity, tides, precession, and other effects yielding accuracies of within a second of time for eclipses relatively close to the present.

G) Are eclipses visible everywhere on the planet?

No. During a lunar eclipse, when the Moon passes through the Earth's giant shadow, the event is visible during the night time in one entire hemisphere of the Earth, and totality usually lasts more than one hour.[24] However, even the partial phase of a solar eclipse will only be visible over a portion of the sunlit side of the Earth and totality can be seen only along a relatively thin (approximately 60-70 miles wide) line.

Lunar eclipse geometry is shown in Fig. 13. A lunar eclipse occurs when our planet casts its shadow on the Moon, occulting it partially or totally. The Moon assumes a beautiful reddened color pattern when it is eclipsed by Earth. Perhaps it is for this reason that lunar eclipses have frightened early civilizations who associated the red color with blood or warfare.

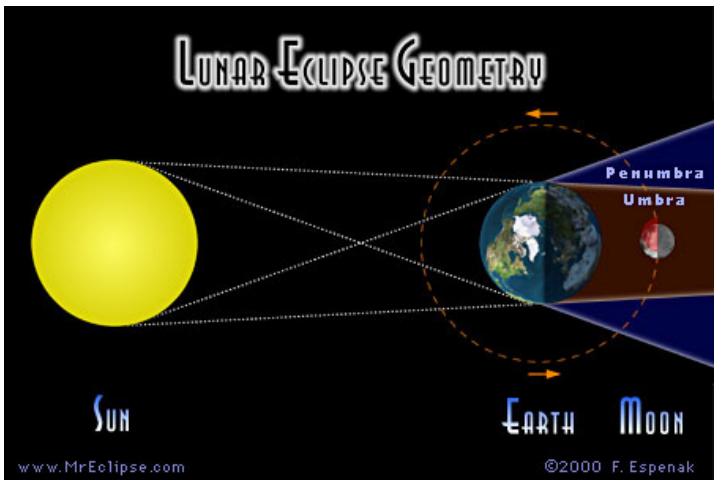

Fig. 13 – Geometry of the Sun, Earth, and Moon during a lunar eclipse. The Earth's two shadows are the penumbra and the umbra (sizes and distances not to scale). Extracted by permission from Fred Espenak's Web site, http://www.mreclipse.com/

For example, during one of Columbus' trips to the Americas, he used his knowledge of a forthcoming lunar eclipse to obtain favors from the natives. How? Basically, he threatened the natives by saying that, if they did not provide him with the supplies he and his people needed, his God would get

angry and darken the Moon, and that would be followed by famine and diseases. There are many other interesting examples in history of how celestial phenomena have influenced people.

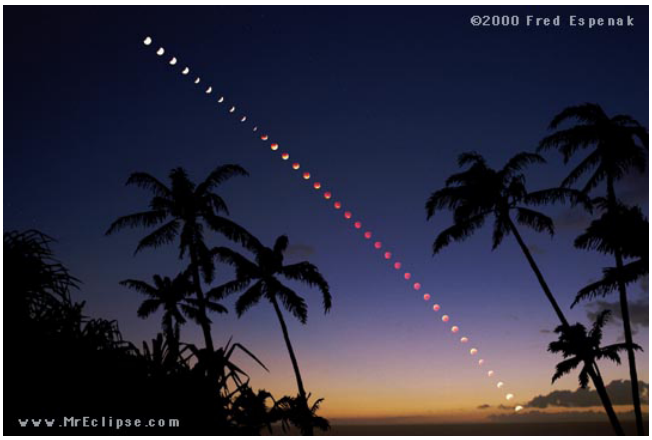

Fig. 14 – Total lunar eclipse over Maui, July 16, 2000. Multiple exposure mode was used to capture the entire eclipse; a second exposure captures morning twilight. Credit: © 2000 photo by Fred Espenak.

H) How many types of solar eclipses are there?

There are three main kinds of solar eclipses as listed in Table 1. Total solar eclipses are rare spectacles that only last for a few minutes and are the only opportunity to observe the Sun's corona without specialized equipment. Although they occur somewhere on Earth approximately every 18 months, it has been estimated that total solar eclipses reoccur at any given spot on average only once every 300 to 400 years. The longest total solar eclipse during the 8,000-year period from 3,000 BCE to 5,000 CE will occur on July 16, 2186, when totality will last 7 minutes 29 seconds.[25]

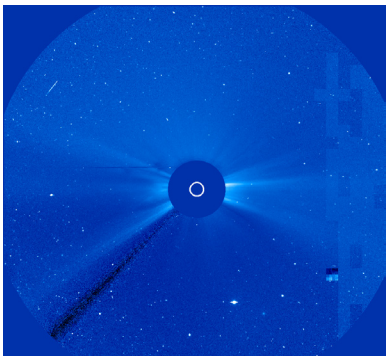

Fig. 15 – Artificial solar eclipse. A spacecraft instrument, called a coronagraph, creates artificial solar eclipses by blocking the Sun's light with an occulting disk. Credit: ESA/NASA.

In addition to the main kinds of natural solar eclipses, astronomers are now able to produce artificial eclipses at any time by blocking out the Sun with an artificial mask or "occulting disk", allowing them to study the Sun's faint corona.

Table 1 - Main types of solar eclipses.

Type	Description
Partial	The Sun is partially covered by the Moon.
Total	The Moon completely covers the Sun.
Annular	The Moon's center passes in front of Sun's center while the Moon is near apogee. The Moon's angular diameter is then smaller than that of the Sun so that a ring of the Sun can still be seen around the Moon.

I) What are transits?

Transit is a special case of eclipse, which happens with the passage of a planet across the disk of the Sun. From the Earth, the observable transits are from planets Mercury and Venus only.

Fig. 16 – Transit of Venus. In a village in Slovakia, Tomas Maruska took this rare picture, showing Venus and the International Space Station (ISS) transiting the Sun at the same time. Credit: Tomas Maruska © 2004. Source: NASA.

They are far more rare than solar eclipses. On the average, there are only 13 transits of Mercury each century. Transits of Venus, by its turn, usually occur in pairs with eight years separating the two events. More than a century elapses between each transit pair.

The first transit ever observed in History was of the planet Mercury in 1631 by the French astronomer Gassendi. A transit of Venus occurred just one month later but Gassendi's attempt to observe it failed due to the fact that the transit was not visible from Europe. In 1639, Jerimiah Horrocks and William Crabtree became the first to witness a transit of Venus.[26]

J) Can I look at the Sun with the naked eye during a solar eclipse?

Looking at the Sun is dangerous when any part of the brilliant disk of the Sun (photosphere) is visible; this can cause permanent eye damage. This is true at any time, including during solar eclipses. Because an eclipse offers an unusually high temptation to look at the Sun, there is a elevated incidence of eye damage caused during solar eclipses. Directly viewing the Sun through any kind of optical aid, binoculars, a telescope, or even a camera's viewfinder, can be extremely dangerous unless certain precautions are taken.

K) How can I safely observe an eclipse?

In order to better experience the amazement of observing a solar eclipse, certain cautions must be taken. Otherwise, what was expected to be a pleasant and

joyful experience could become a real nightmare. Here you will learn how to proceed to safely observe a solar eclipse.

Staring at the Sun without proper protection can cause irreparable damage to the eye and is not recommendable. The Sun is a source of electromagnetic radiation: solar X-ray, gamma ray, microwave, radio wave, ultraviolet, and visible light.[27] When the retina is exposed to intense visible light, two kinds of eye damage can occur, alone or simultaneously - retinal burns and thermal injury, the latter occur without any feeling of pain, but that can cause irreparable damage to the eye or even blindness.[28]

So how can we safely observe the Sun? There are several safe methods, but the best one is **indirect projection** (See "Observing Eclipses Safely," at http://www.mreclipse.com/Totality/TotalityCh11.html). This can be done by projecting the Sun's image on a white piece of paper using a pair of binoculars (with one of the lenses covered), or by putting a small hole (about 1 mm in diameter) in a piece of aluminum foil taped over a paper towel tube, often called a pinhole camera. It allows safe viewing of the Sun's projected image. However, care must be taken to ensure that no one looks through the projector directly, especially if children and teenagers are present, because this would cause severe eye damage.

The Sun can be also observed with appropriate filters to block its harmful radiation. Other improvised methods, such as looking at a reflection on water, or looking through a compact disk, are also dangerous. Only properly designed and certified solar filters should be used for direct viewing of the Sun, and these must be in perfect condition, as even a small defect could cause irreparable damage to the eye.

Please be aware that standard or polaroid sunglasses are not solar filters. Although they may afford some eye relief if one is outside on a bright day, you should never use them to observe the Sun. You cannot use sunglasses, even crossed polaroids, to stare at the sun during partial phases of an eclipse. They provide essentially no eye protection for this purpose.[29]

Strictly speaking, it is safe to observe the total phase of a solar eclipse when the Sun's photosphere is completely covered by the Moon. The Sun's corona will be visible, as will be the chromosphere, solar prominences, and possibly even solar flares. Nevertheless, even under these conditions, there is great danger in

directly viewing the end of the total phase, and return of the "exposed" Sun, without protection, because all parts of the Sun's disk are of similar intensity. Viewing a tiny sliver of the Sun could cause permanent eye damage. Actually, the 1 percent of the solar surface still visible is about 4,000 times brighter than the full Moon.[30] For this reason, viewing even the total phase of a solar eclipse through binoculars, or a telescope, or even with the naked eye, is not recommended.

In summary, **it is completely safe to observe solar eclipses, provided that the necessary precautions are taken.** For this purpose we strongly recommend the use of **indirect projection** for a safe observation. We encourage you to cautiously enjoy the delightful experience of observing this awe-inspiring phenomenon that has both amazed and frightened people, changing the course of history through the centuries, as you will discover in the following pages.

6. Eclipses and History

"We had the sky up there all speckled with stars, and we used to lay on our backs and stare up at them and wonder about whether they was made or only just happened."

- Mark Twain[31]

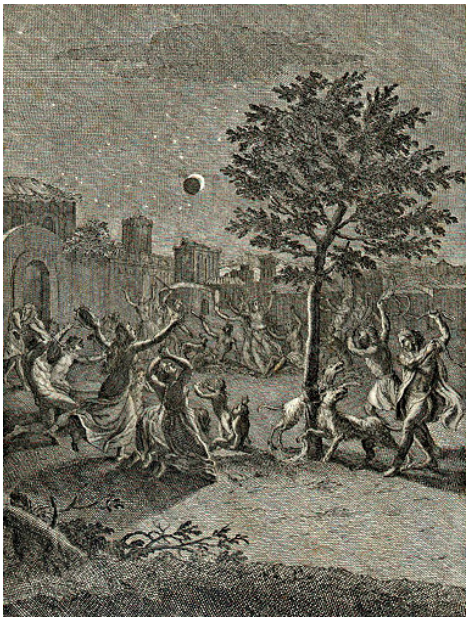

Fig. 17 – Desolation des Peruviens pendant L'Eclipse de Lune. Voyage Historique de l'Amerique Meridionale. The Spanish explorer Don Juan described the Peruvians despair during an eclipse. Source: The Philadelphia Print Shop Ltd., Web site, http://www.philaprintshop.com

Since the very beginning of History, people have been amazed by what they see when they look up at the sky. Indeed, looking at the celestial sphere without the unpleasant interference of city lights is magnificent. It can sometimes mesmerize us with a deep desire of traveling out to those celestial spheres to directly experience what our eyes cannot reach. Human imagination has no boundaries, but the universe is infinite! However, most ancient civilizations have viewed changes in the sky with great fear and apprehension. Comets, meteor showers, supernovae, lunar and

solar eclipses were viewed as bad omens by most societies.

As we discussed previously, the Sun and the Moon are the main actors in our celestial theater, the former being vital for life on Earth. The Moon, by its turn, has served as special inspiration for poets, writers, and lovers. The Sun and Moon have also been associated with religion and mythology, and sometimes regarded as gods with influence on the destiny of both societies and individuals.

It is our nature as human beings to attribute meaning to events by whatever history, tradition or thought is available to us. The same is true for eclipses throughout the centuries.

Solar and lunar eclipses were usually regarded as a disturbance in the natural order of the sky - as an indication that something was going wrong. Several historical events coincided with solar or lunar eclipses: battles, crowning or dethroning of emperors, peace treaties, and so forth.

Unlike comets, which for a long time were regarded as unpredictable events, eclipses were accurately predicted at the earliest stages of mankind's history.[32] Early astronomers were able to predict eclipses by around 2300 BCE. Their predictions were based on empirical relationships, governing the recurrence of events by which the relative positions of the Earth, Sun, and Moon reoccur the same way after 6,585 days. The existence of a regular eclipse cycle, such as the Saros cycle, resulted from these coincidences involving complex combinations between the movements of the Moon, Earth, and Sun. This more detailed knowledge of eclipses started to be acquired during the second century BCE, the golden age of Greek astronomy.

However, the general population did not understand these relationships. As governors began to realize the influence astronomical phenomena exerted over the population, they used this knowledge as an instrument of power to influence people's psyche. The population would follow rituals and say prayers in order to prevent the supposed dire effects. Governors wanted to pretend they could influence the obscure powers involved, and likewise, astrologers and astronomers sometimes attempted to use their knowledge to manipulate and influence governors.

Only in the last five hundred years or so, or certainly since the invention of the telescope in 1609, have we come to understand these cosmic concurrences primarily in terms of the natural order of the universe. As previously mentioned,

these events are usually no longer feared, but regarded as singular opportunities to better understand the universe.

In this article, we present some important solar and lunar eclipses, and their impact on people, societies, and science through the centuries.

Ancient History

1) Ho and Hi, the Drunk Astronomers, 2137 BCE

Ancient Chinese astronomy was primarily a governmental activity. It was the astronomer's role to keep track of solar, lunar and planetary motions, and explain what they meant to the ruling emperor.

Throughout the centuries, Chinese astronomers devoted substantial attention towards predicting eclipses. Nevertheless, like all similar efforts prior to the *Renaissance*, this could only be empirical.[33]

The earliest record of a solar eclipse comes from ancient Chinese history. Identifications of this event have varied from 2165 – 1948 BCE,[34] though the favored date is Oct. 22, 2137 BCE.

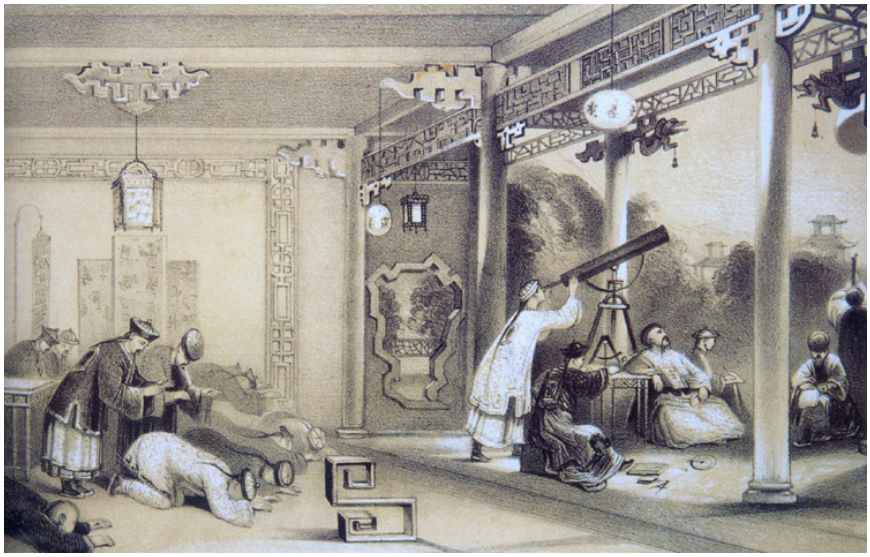

Fig. 18 – Eclipse observation in China around 1840. Astronomers calmly observe an eclipse and the servants, terrified, prostrate themselves on the ground to placate the bad omen. Credit: *History of China and India* © Mary Evans/ Explorer. Source: Brunier and Luminet, Glorious Eclipses, Cambridge University Press.

According to a legend, the Chinese royal astronomers Ho and Hi dedicated too much time to consuming alcohol and failed to predict the forthcoming eclipse. Traditionally, this solar eclipse was

recorded in the *Shu Ching* (Historical Classic), and regarded as from the 3rd millennium BCE. *"On the first day of the month, in the last month of autumn, the Sun and the Moon did not meet (harmoniously) in Fang"*… so runs the text.[35]

The emperor became very unhappy because, without knowing that there was an eclipse approaching, he could not organize teams to beat drums and shoot arrows in the air to frighten away the invisible dragon. The Sun did survive, but the two astronomers did not have the same luck, and lost their heads for such negligence. This verse, whose author is unknown, well illustrates such tragedy: *"Here lie the bodies of Ho and Hi/ Whose fate though sad was visible/ Being hanged because they could not spy/ Th'eclipse which was invisible."*

Since then, a legend arose that no one has ever seen an astronomer drunk during an eclipse.[36]

2) **Eclipse of Abraham in Canaan**, 1533 BCE

See Visibility Map: http://eclipse.gsfc.nasa.gov/5MCSEmap/-1599--1500/-1532-05-10.gif

"And when the Sun was going down... great darkness fell upon him."

Eclipses are also mentioned in sacred books such as the Christian Bible. One of the best-known references to eclipses appears in the book of Genesis, involving the journey of Abraham into the land of Canaan.

It is possible to relate such description with a computed solar eclipse occurring on May 9, 1533 BCE.[37]

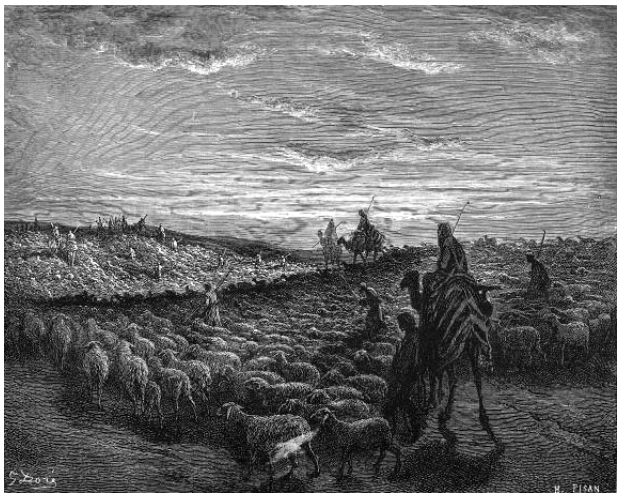

Fig. 19 – Abraham journeying into Canaan. This image was produced by the French artist Gustave Dore and illustrates the journey into Canaan. Credit: Public domain.

3) **Homecoming of Odysseus**, 1178 BCE

See Visibility Map: http://eclipse.gsfc.nasa.gov/5MCSEmap/-1199--1100/-1177-04-16.gif

". . . and the Sun has perished out of heaven,
and an evil mist hovers over all."

- Homer, the Odyssey[38]

The king of Ithaca Island, Odysseus, has been persuaded to go to the Trojan War, which lasted ten years. When Troy fell, the Greeks went back home. However, Odysseus's enemy, the god of the sea Poseidon became angry with him, making that difficult for him to return home.

Odysseus is the hero from Homer's *Odyssey*, and could have returned to his Penelope on day of eclipse. That should have been a very beautiful eclipse, during which all planets were visible simultaneously, and the hidden Sun was "crowned" by the Pleiades.[39]

Basically, we have three evidences to sustain such hypothesis:

a) Plutarch and Heraclitus interpreted a passage in the 20th book of Odyssey to be a poetic description of a total solar eclipse at Odysseus' return;

b) A century ago, astronomers estimated that such eclipse occurred over the Greek islands on April 16, 1178 BCE, the only one in the region close to the probable date of the fall of Troy;

c) Recently, astronomical references led two scientists to suggest that the eclipse of 1178 BCE possibly coincided with the homecoming of Odysseus.

Almost all classic scholars are skeptical of this correlation. If there was an eclipse, Homer must have had it in mind when he wrote of a seer prophesying the death of Penelope's waiting suitors and their entrance into Hades. The story actually does not mention an eclipse, but omens and a poetic description of a total solar eclipse.

The story tells that Odysseus arrived home wearing beggar's clothes and hiding before revealing himself. It happens that, when Penelope's suitors sat down at noon for a meal, they started laughing and saw their food spattered with blood. At this moment, the seer Theoclymenus foretells their death: *"The Sun has been obliterated from the sky, and an unlucky darkness invades the world."*

Fig. 20 – Penelope's suitors, by John William Waterhouse (1912). While Odysseus struggled to return home after the Trojan War, his throne and his wife were being disputed. But Penelope decided to wait for his husband. Credit: Public domain.

This description suggests a solar eclipse over Ithaca. As a matter of fact, Odysseus killed Penelope's suitors, who were planning to steal his throne and his wife, and spent a long night of love with his wife.[40]

4) **The Old Testament Eclipse**, 763 BCE

See Visibility Map: http://eclipse.gsfc.nasa.gov/5MCSEmap/-0799--0700/-762-06-15.gif

One passage in the Christian Bible says: *"And on that day, says the Lord God:"I will make the Sun go down at noon, and darken the Earth in broad daylight."* The corresponding eclipse should have occurred on June 15, 763 BCE.

A cross-reference is provided by an Assyrian historical chronicle known as the *Eponym Canon*. In Assyria, each year was named after a ruling official and the year's events were recorded under that name in the Canon.

Under the year corresponding to 763 BCE, a scribe at Nineveh wrote this simple line: *"Insurrection in the City of Assur. In the month of Sivan, the Sun was eclipsed."* Historians have thus been able to use this eclipse to improve the chronology of early biblical times.[41]

5) **Archilochus Eclipse**, 648 BCE

See Visibility Map: http://eclipse.gsfc.nasa.gov/5MCSEmap/-0699--0600/-647-04-06.gif

It is believed that the Greek lyric poet Archilochus witnessed a total solar eclipse, which happened on April 6, 648 BCE.[42] Delighted, he said: *"Nothing there is beyond hope, nothing that can be sworn impossible, nothing wonderful,*

since Zeus father of the Olympians made night from midday, hiding the light of the shining sun, and sore fear came upon men."

6) Thales Eclipse, 585 BCE

See Visibility Map: http://eclipse.gsfc.nasa.gov/5MCSEmap/-0599--0500/-584-05-28.gif

Is an eclipse capable of drastically changing the course of history? This story refers to the final battle of a fifteen-year war waged between the Lydians and the Medes. Also known as the "Battle of the Eclipse," it occurred at the Halys River, Turkey, and was suddenly terminated on May 28, 585 BCE,[43] due to a total solar eclipse, interpreted as an omen indicating that the Gods wanted the fight to stop.

In the West, the first prediction of a solar eclipse is associated with the Greek philosopher Thales of Miletus (624-547 BCE) who, according to Herodotus (490-425 BCE), foretold this eclipse.[44]

> *"In the sixth year a battle took place in which it happened, when the fight had begun, that suddenly the day became night. And this change of the day Thales the Milesian had foretold to the Ionians laying down as a limit this very year in which the change took place. The Lydians however and the Medes, when they saw that it had become night instead of day, ceased from their fighting and were much more eager both of them that peace should be made between them."*

Fig. 21 – Battle of Halys. Source: Wisdom Portal Web site, http://www.wisdomportal.com

Although it is argued that Thales used the Babylonian Saros[45] period of 223 lunations,[46,47] it is today agreed by historians that the Saros period was not discovered before the fifth or fourth century BCE, therefore Thales could not have used that time system.

Considering that the exact dates of eclipses can be calculated, this battle is the earliest historical event for which a precise date is known. Thales was proclaimed a wise man by the oracle of Delphi in 582 BCE, possibly due to this

prediction credited to him. However, it is evident that Thales did not understand the scientific basis of the phenomenon.

7) **Olympic Games**, 413 BCE

See Visibility Map: http://eclipse.gsfc.nasa.gov/5MCSEmap/-0499--0400/-412-08-14.gif

Either success or failure could be sides of the same coin. They usually result of someone's beliefs, here associated with an eclipse of the Moon, which frightened an entire army who believed that would indicate a bad omen for them. This eclipse occurred on August 14, 413 BCE, during the 91st Olympiad and influenced a battle in the Peloponnesian War.

Both the Carthaginians and the Greeks had settled parts of the south coast of Sicily, resulting in permanent conflicts.[48] The Athenians were ready to move their forces from Syracuse when the Moon was obscured, bringing disastrous consequences to an Athenian army thanks to the lack of decisive leadership by Nicias, the commander. The Athenian army was confronted in Sicily by the Syracusan army and, having somehow failed, they embarked and left the island. Read this excerpt from by Plutarch, in *Life of Nicias*:

> *"Everything accordingly was prepared for embarkation, and the enemy paid no attention to these movements, since they did not expect them. But in the night there happened an eclipse of the Moon, at which Nicias and all the rest were struck with a great panic, either through ignorance or superstition. As for an eclipse of the Sun, which happens at the Conjunction, even the common people had some idea of its being caused by the interposition of the Moon; but they could not easily form a conception, by the interposition of what body the Moon, when at the full, should suddenly lose her light, and assume such a variety of colors. They looked upon it therefore as a strange and supernatural phenomenon, a sign by which the Gods announced some great calamity. And the calamity came to pass, but only indirectly was it caused by the Moon."*[49]

Indeed, soldiers and sailors were very frightened by this celestial omen and were reluctant to leave. Nicias consulted the soothsayers and postponed the departure for twenty-seven days. This delay gave an advantage to the Syracusans, who

defeated the entire Athenian fleet and army, killing Nicias.[50]

8) **Eclipse of Alexander**, 331 BCE

Fig. 22 – The battle at Arbela, Alexander versus Darius. Credit: Public domain.

Eclipses are sometimes interpreted as lucky signals coming from the sky. This was the case with Alexander the Great (356-323 BCE) after conquering Egypt. He marched east and pushed the Persians out of Babylonia, pursuing them north into Assyria.[51]

Just some eleven days before the victory of Alexander over Darius, in Arbela, Assyria, Plutarch and Pliny mention that the Moon had been totally eclipsed. See this excerpt of Plutarch, in *Life of Alexander*:

> *"There happened an eclipse of the Moon, about the beginning of the festival of the great mysteries at Athens. The eleventh night after that eclipse, the two armies being in view of each other, Darius kept his men under arms, and took a general review of his troops by torch-light."*

This unexpected occurrence seems to have created considerable tumult in an alarmed Assyrian camp, a fact noticed by Alexander. His friends suggested an attack on the enemy's camp at night, but Alexander preferred that the Macedonians should have a good night's rest.

It was then that he uttered the celebrated answer, *"I will not steal a victory."* The eclipse happened on September 20, 331 BCE, and the celebrated Battle of Arbela, by its turn, was fought on October 1st, 331 BCE.[52]

The Greek knowledge of eclipses was largely derived from the Babylonians after 330 BCE, so probably Alexander obtained that information with the expert Babylonian astronomers.[53]

9) Ceasar Eclipse, 51 BCE

See Visibility Map: http://eclipse.gsfc.nasa.gov/5MCSEmap/-0099-0000/-50-03-07.gif

Julius Caesar (100-44 BCE) died in 44 BCE and Arago associated his death with an annular eclipse of the Sun. Pliny, Plutarch and Tibullus describe that; Seneca and Suetonius add a comet to make the story more impressive.
Shakespeare used it for his dramatic purposes.[54] When he was writing, the belief that God intervened in the world to punish individuals or nations for their sins was strong, so it is reflected in his writing, such as in the excerpt below, from Hamlet 1.1:

"In the most high and palmy state of Rome,
A little ere the mightiest Julius fell,
The graves stood tenantless, and the sheeted dead
Did squeak and gibber in the Roman streets:
As, stars with trains of fire and dews of blood,
Disasters in the sun; and the moist star,
Upon whose influence Neptune's empire stands,
Was sick almost to doomsday with eclipse."

Actually, there was no eclipse when Caesar passed away. The factual record is that about the time of the great warrior's death there was an extraordinary dimness of the Sun. Johnson suggests that Arago should have confused the record of an eclipse with some sort of meteorological interference.[55] Suetonius also implies that the event had a meteorological origin, so that may be regarded as some type of cloud formation.

Nonetheless, we know accurately the day Caesar crossed the Rubicon, seven years before his death, on March 7, 51 BCE, because that was the only possible eclipse corresponding to the one mentioned by Dion Cassius.[56]

10) Augustus' Eclipse, 14 CE

Soon after the death of Augustus, Tacitus mentions a lunar eclipse, which has been identified with the eclipse of September 27, 14 CE. Soldiers thought the phenomenon was associated with their adventures, favoring their efforts. They

believed that if they made much noise they could have the eclipse to favor them. Tacitus says: *"The Moon in the midst of a clear sky became suddenly eclipsed; the soldiers who were ignorant of the cause took this for an omen referring to their present adventures: to their labors they compared the eclipse of the planet, and prophesied 'that if to the distressed goodness should be restored her wonted brightness and splendor, equally successful would be the issue of their struggle.' Hence they made a loud noise, by ringing upon brazen metal, and by blowing trumpets and cornets; as she appeared brighter or darker they exulted or lamented."*[57]

11) The Crucifixion Eclipse, 33 CE[58]

See Visibility Map:
http://eclipse.gsfc.nasa.gov/5MCSEmap/0001-0100/29-11-24.gif

Jesus Christ should have been crucified on day of eclipse, during the period when Pontius Pilate was procurator of Judea (26-36 CE). However, there is no consensus on the date. According to the evangelists, Jesus was crucified on a Friday afternoon, some hours prior to the beginning of the Jewish Sabbath. Evidence suggests April 3, 33 CE,[59] while others suggest April 7, 30 CE.
Another hypothesis is that of a solar eclipse visible at Jerusalem on November 24, 29 CE.[60] The Greek historian Phlegon mentions this eclipse in his History of the Olympiads, and says that it has been accompanied by an earthquake.[61] *"In the fourth year*

Fig. 23 – The crucifixion eclipse. According to the evangelists, the Sun darkened during the crucifixion of Christ. Later, the event was associated with an eclipse that was visible at Jerusalem. Credit: © Valenciennes, Musee des Beaux Arts, photo R.G. Ojeda.

of the 202nd Olympiad, there was an eclipse of the Sun which was greater than any known before and in the sixth hour of the day it became night; so that stars appeared in the heaven; and a great Earthquake that broke out in Bithynia destroyed the greatest part of Nicaea." In fact, mention is also made in the Bible to the Sun being darkened earlier that day: *"The Sun shall be turned into darkness."*

However, there are also various allusions in the Bible to the Moon being dark and turned to blood when it rose in the evening after the crucifixion, which sounds like a lunar eclipse. In Acts of the Apostles, Peter also refers to a Moon that is the color of blood and a darkened sky. There is other evidence that on that day the Moon appeared like blood.

A New Testament Apocryphal fragment, the so-called Report of Pilate, states *"Jesus was delivered to him by Herod, Archelaus, Philip, Annas, Caiphas, and all the people. At his crucifixion the Sun was darkened; the stars appeared and in all the world people lighted lamps from the sixth hour till evening; the Moon appeared like blood."*[62] This may be the result of a dust storm caused by the khamsin, a hot wind coming from the south. Under such circumstances, a lunar eclipse while there is much suspended dust, one would expect the Moon to appear the dark crimson of blood.[63]

The reason why the Moon is blood red is that, although it is geometrically in the Earth's shadow, sunlight is refracted through the Earth's upper atmosphere, where normal scattering will prevent blue light from penetrating. But this refracted light would be much weaker than direct light from even a small portion of the Sun and the blood color associated with the eclipse would not be visible to the unaided eye. However, the Moon would have an amber color from atmospheric absorption, similar to any other occasion when the Moon is low in the horizon.[64]

As mentioned, there is controversy among researchers whether that was a solar or a lunar eclipse, and also controversy about the date. In any case, an eclipse occurring in the very same day of the crucifixion would have been interpreted by believers as a supernatural sign and influenced the change of mind of the Jews and Pilate towards the body of Christ, leading to the placing of a military guard on the tomb.[65]

Middle Ages

12) **Muhammad's Eclipse**, 632 CE

See Visibility Map: http://eclipse.gsfc.nasa.gov/5MCSEmap/0601-0700/632-01-27.gif

In ancient times, births and deaths of leaders were correlated to celestial omens. However, Islamic theology did not believe that God sent an eclipse as an omen of its prophet's birth, Muhammad. Some eclipses have been historically associated to him, though.

Muhammad was born in Mecca in the Year of the Elephant, CE 569-570. His birth year got its name from an invasion by the Abyssinians, who used elephants in the assault. The Year of the Elephant was also memorable because of its solar eclipse.

Afterwards, when Muhammad's infant son Ibrahim died tragically on January 22, 632 CE, the Sun was eclipsed. Some Meccans said it was a sign from God, but Muhammad said *"The Sun and Moon are signs of God and do not eclipse for the death or birth of any man."*

Another solar eclipse related to Muhammad occurred 39 years after his death. In 661 CE, Mu'awiyah became leader of the empire after a revolt against Ali, the son of Muhammad's chief Meccan enemy. Mu'awiyah decided to transfer the prophet's pulpit from Medina to his capital in Damascus, Syria. As his men were removing it, stars became visible in a dark sky. It was considered a sign of divine anger and the relic remained in Medina as a symbol of Mu'awiyah's failure.[66]

13) **The Eclipses of Tatwine and Beda**, 734 CE

An *Anglo-Saxon Chronicle* records that on January 24, 734 CE,[67] *"the Moon was as if it had been sprinkled with blood, and Abp. [Abp. denotes "Archbishop"] Tatwine and Beda died and Ecgberht was hallowed bishop."* The inference apparently is that the Moon was somehow connected with the deaths of the

two ecclesiastics. It is clear from the description of the Moon on that occasion that it exhibited the well-known coppery shade that is a recognizable feature of many lunar eclipses.

14) European Eclipses, 828 CE

Two lunar eclipses were observed in Europe in 828 CE, the first on July 1, very early in the morning, and the second in the morning of Christmas day. Totality occurred after midnight.[68]

The event has been associated with the following fact, described by the Anglo-Saxon Chronicle: *"In this year the Moon was eclipsed on mid-winter's Mass-night, and the same year King Ecgbert subdued the kingdom of the Mercians and all that was South of the Humber."*

15) Solar Eclipse of the Emperor Louis, 840 CE

See Visibility Map: http://eclipse.gsfc.nasa.gov/5MCSEmap/0801-0900/840-05-05.gif

This is the story of the Eclipse that influenced the division of Europe as we know it today. Louis of Bavaria, the son of Charlemagne, was head of a great empire when, on May 5, 840 CE, he witnessed a solar eclipse.

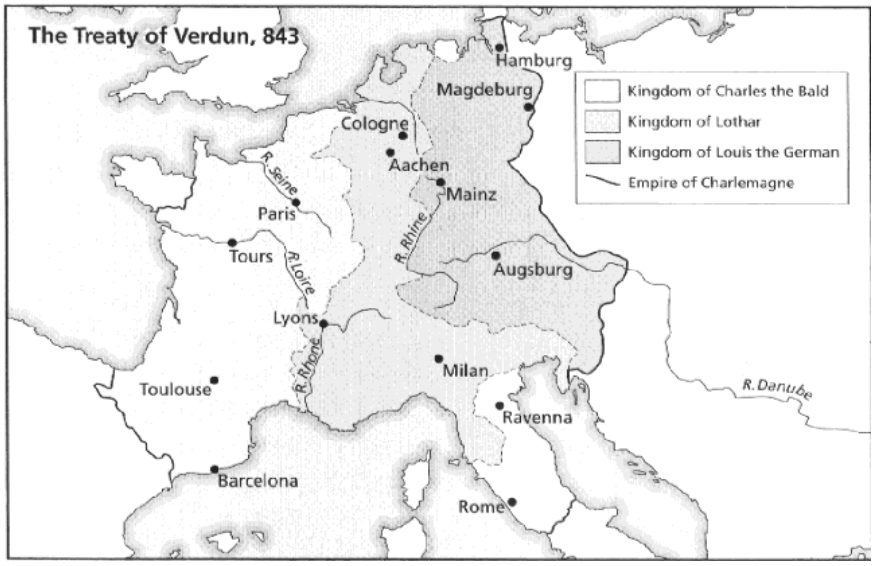

Fig. 24 - The Treaty of Verdun. Source: Northvegr Foundation, http://www.northvegr.org

His imagination worked hard against him. Indeed, he interpreted the phenomenon as a finger pointed at *him*. He took fright and never recovered, believing that his days must be numbered. Sure enough, he died a month later.[69]

"In the third year of the Indiction, the Sun was hidden from this world and stars appeared in the sky as if it were midnight, on the third day before the Nones of May (May 5) during the Litanies of Our Lord."[70]

After this, his three sons began to dispute his succession. Their quarrel was settled three years later with the *Treaty of Verdun*, dividing Europe into three large areas, namely France, Germany and Italy.[71]

16) **King Henry's Eclipse**, 1133 CE

See Visibility Map: http://eclipse.gsfc.nasa.gov/5MCSEmap/1101-1200/1133-08-02.gif

Visible in England and Germany, this total solar eclipse occurred on August 2, 1133 CE, and prompted many descriptions in the chronicles of both countries.

Fig. 25 - King Henry I. Credit: Public domain.

For the English, the eclipse took place on the day after the departure of King Henry I, being interpreted as an omen of his death. In fact, he died shortly afterwards in Normandy, subsequently confirming the superstition. As for the Germans, they associated the darkening of the Sun to the sack of the city of Augsburg and the massacre of its inhabitants by Duke Frederick.[72]

The *Anglo-Saxon Chronicle* mentions in 1135 CE:

"In this year King Henry went over sea at Sammas, and the second day as he lay and slept on the ship the day darkened over all lands; and the sun became as it were a three-night-old moon, and the stars about it at midday. Men were greatly stricken and affrighted, and said that a great thing should come hereafter. So it did, for the same year the king died on the following day after Saint Andrew's mass day, December 2, in Normandy."

Actually, the eclipse occurred two years before the King's death, just after his final departure for France.[73]

17) A Witch's Eclipse, 1349 CE

Eclipses have also been used through the centuries to trick ordinary people who ignored the science behind the phenomenon. This was the case of a lunar eclipse occurring on June 30, 1349 CE, visible in London. A "smart" witch tried to use that to threaten people to provide her with what she asked for. According to Archdeacon Churton,

> *"The worthy Archbishop Bradwardine, who flourished in the reign of the Norman Edwards, and died A.D. 1349, tells a story of a witch who was attempting to impose on the simple people of the time. It was a fine summer's night, and the Moon was suddenly eclipsed. 'Make me good amends,' said she, 'for old wrongs, or I will bid the Sun also to withdraw his light from you.' Bradwardine, who had studied with Arabian astronomers, was more than a match for this simple trick, without calling in the aid of the Saxon law. 'Tell me', he said, 'at what time you will do this, and we will believe you; or if you will not tell me I will tell you when the Sun or the Moon will next be darkened, in what part of their orb the darkness will begin, how far it will spread, and how long it will continue'."*[74]

Evil plans like that sometimes just do not work, and the presence of Bradwardine should have made that lady just unhappy.

18) The Black Hour, 1433 CE

See Visibility Map: http://eclipse.gsfc.nasa.gov/5MCSEmap/1401-1500/1433-06-17.gif

One of the most celebrated eclipses of the Middle Ages was called the *"Black Hour."* It happened in Scotland and it has been said that darkness came about 3 pm on June 17, 1433 CE, and was very deep.[75]

The eclipse is said to have been unusually extensive, lasting around one hour. The scientific explanation relates to a specific angle between the Sun and Moon that day: at the time of the eclipse, the Sun was only two degrees from perigee and the Moon no more than thirteen degrees from apogee.[76]

Some other interesting facts about this eclipse is that records of the epoch relate that nothing was visible during the height of totality – although it sounds

exaggerated – and in the context of a very superstitious time, the pestilence that then prevailed has been attributed to the eclipse.

19) Fall of Constantinople Eclipse, 1453 CE

The Roman Emperor Constantine, in 324 CE, moved the capital of his realm to ancient Byzantium, which he renamed Constantinople. This capital has ruled the eastern Mediterranean and the Black Sea region for more than a thousand years, providing a strong government and the continuation of the Roman Empire after it collapsed elsewhere.[77]

Fig. 26 – The Siege of Constantinople. Scene from the battle of defense of Constantinople, painted in 1499, in Paris. Credit: Public domain.

By the 15th century, the Ottoman Empire, in a large expansion, set out to conquer Constantinople. The Turks laid siege to it in 1402 and 1422, without success, the city being surrounded by its famous impenetrable walls. In 1453, the troops of Sultan Mohammed II returned to the walls. In addition to 250,000 men, the Turks brought a new eight-meter long cannon, capable of firing 600-kg cannonballs.

Despite everything, the city's defenders, scarcely 7,000 men in number, repelled three assaults and repaired their damaged walls each night. They were confident in old predictions, according to which Constantinople would never fall. The full Moon rose in eclipse on May 22 and their morale collapsed. Six days later, Mohammed II tried a new assault and succeeded, routing the defenders.

A postern gate had been accidentally left open and some Turks entered the city. As the Sultan's men crossed the walls, the fight turned into a tumult and Constantinople's defense collapsed. The terrible sack of Constantinople that followed lasted three days and was a major shock to western civilization.[78] The eclipse had been seen as a bad omen by the Constantinople side and influenced their losing the battle.

Modern Ages

20) Christopher Columbus' Eclipse, 1504 CE

After a long trip to the Americas in 1503 CE, in his fourth voyage, Columbus was stranded on the island of Jamaica. In principle, he managed to obtain provisions from the Caciques natives in exchange for some trinkets and rubbish. As the months went by, novelty and hospitality started to decrease and also the sailors started to become aggressive with the natives to obtain food. Upset, the Indians communicated to the Spanish that they would not provide any more supplies.

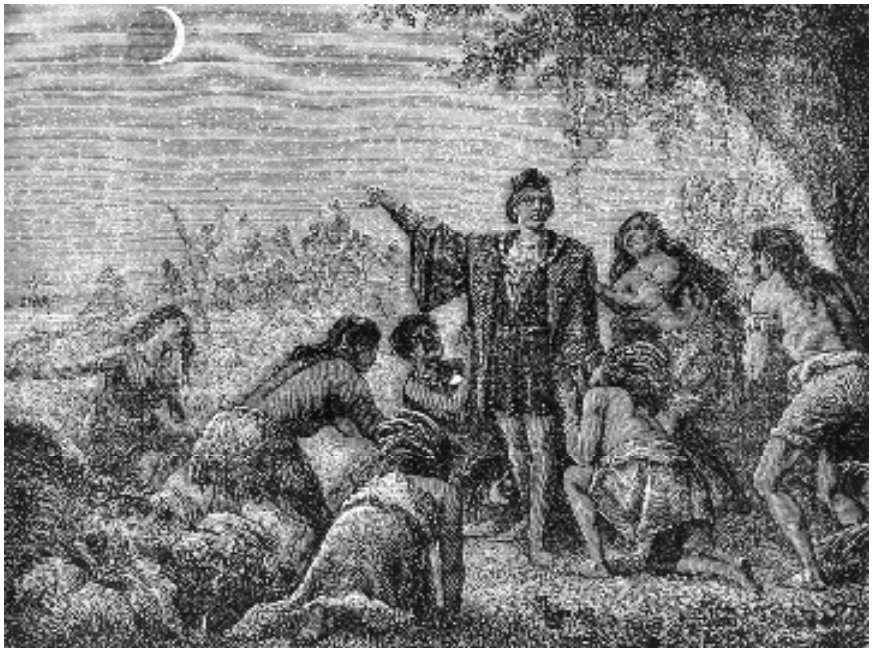

Fig. 27- Columbus impressing the natives. This illustration from Camille Flammarion's *Astronomie Populaire* shows how Christopher Columbus used an eclipse of the Moon to assert his power over the Indians in Jamaica. Credit: © photo Jean-Loup Charmet.

Desperate with the threat of famine, Columbus came up with an ingenious plan. He checked his *Calendarium*, which contained predictions of lunar eclipses for several years. In particular, it predicted a total eclipse of the Moon on the Antilles on February 29, 1504 CE. That evening, Columbus invited the Caciques onboard his *Capitana* for a serious conversation. He told them that

they were Christians and their God did not appreciate the way they had been treating them and would punish the Indians with famine and pestilence and, as a sign of dissatisfaction, he would darken the Moon.

As soon as he said that, the Earth's shadow started to cover the white disk. Terrified, the natives begged Columbus to bring back the light. According to Ferdinand Columbus (second son of Christopher Columbus), cited by Sinnot (1992):

> *"The Indians observed this [the eclipse] and were so astonished and frightened that with great cries and lamentations they came running from all directions to the ships, carrying provisions and begging (…) and promising they would diligently supply all their needs in the future."*

He replied that he needed to consult his God. He shut himself in a cabin for nearly two hours. Just before the end of totality, he reappeared and announced that God had given his pardon, and would bring them back the Moon provided that the Christians were given provisions. Immediately, the Moon reappeared. Astonished, the natives provided Columbus and his crew their needed provisions until they were able to return to Europe.[79]

The use of eclipses as a tool to manipulate populations less knowledgeable about eclipses is also present in diverse works of fiction. In 1889, Mark Twain published *A Connecticut Yankee in King Arthur's Court*, a novel envisioning life in the sixth-century England. The author has Hank Morgan, the yankee in the title, hoodwinking the ignorant folk of that era by invoking prior knowledge of a solar eclipse on June 21, 528 CE. Twain has Morgan, who is jailed awaiting execution, threaten King Arthur with a blanking out of the Sun:[80]

> *"Go back and tell the king that at that hour I will smother the whole world in the dead blackness of midnight; I will blot out the Sun, and he shall never shine again; the fruits of the Earth shall not rot for lack of light and warmth, and the peoples of the Earth shall famish and die, to the last man!"*[81]

The description provided by Twain is accurate in many senses, except for the fact that there was no solar eclipse at all visible in England in 528 CE. There are more examples of this theme in literature, such as *The Adventures of Tintin* by Georges Remi and *King Solomon's Mines* by H. Rider Haggard.

21) **Cartographic Eclipse**, 1706 CE

See Visibility Map: http://eclipse.gsfc.nasa.gov/5MCSEmap/1701-1800/1706-05-12.gif

This eclipse was of high interest to scientific geographers who relied on astronomical calculations to produce terrestrial maps. The moment of the eclipse became a cartographic point of reference, so that maps represented the world as it was in 1706 CE.[82]

From the tops of the Swiss mountains, at Montpellier, and other places in Europe, several stars were observable at the naked eye at the time of full moon, such as the Aldebaran and Capella, as well as the planets Venus, Mercury and Saturn.

This eclipse caused great commotion. It is said that at Geneva the Council was compelled to close their deliberations, as they could see neither to read nor write. In several places people prostrated on the ground and prayed, wondering the Day of Judgment had come.

Animals are also sensitive to these changes in the sky. Actually, in that day bats were flying, fowls and pigeons flew hastily to their roots, cage-birds become silent, hiding their heads under their wings, and animals at labor in the fields stood still.[83]

22) **Edmond Halley's Eclipse**, 1715 CE

See Visibility Map: http://eclipse.gsfc.nasa.gov/5MCSEmap/1701-1800/1715-05-03.gif

Fig. 28 – The solar eclipse of 1715. Visible as partial at Paris, it provided the chance to observe the event in various ways: directly through telescopes, smoked glass, pinholes, sieves, and various filters, or indirectly by reflection in a bucket of water. Source: Bibliothèque nationale de France (BnF).

"A few seconds before the Sun was all hid, there discovered itself round the Moon a luminous ring about a digit, or perhaps a tenth part of the Moon's diameter, in breadth. It was of a pale whiteness, or rather pearl-color, seeming to me a little tinged with the colors of the iris, and to be concentric with the Moon."

- Edmond Halley[84]

This was the poetic, inspirational description of the British astronomer Edmond Halley (1656-1742 CE) for the solar corona during the total solar eclipse of April 3, 1715 CE, visible in England and Wales. The King of France and some of the royal family of England should have also had observed the eclipse.[85]

Halley became famous for discovering the periodicity of certain comets and predicting their return, such as the comet he had observed in 1682 and calculated to return after 76 years, and which was named after him. Basing his calculations on the law of universal attraction by Newton, he provided the first physical explanation for the appearance of these wandering bodies that had previously terrified people.[86]

23) Total Solar Eclipse of Louis XV, 1724 CE

See Visibility Map: http://eclipse.gsfc.nasa.gov/5MCSEmap/1701-1800/1724-05-22.gif

This eclipse was visible in Paris on May 22, 1724 CE. The young King Louis XV, at the time fourteen years old, observed it. The path of its shadow, very similar to the eclipse of August 11, 1999 CE, shifted southwards, and crossed England, France, and Germany. It was carefully calculated and mapped, and painters depicted scenes of the crowds of spectators.[87]

Fig. 29 – Eclipses and the French royal family.
This print shows Louis XIV sitting on a box with fan-shaped back in the center of a sun. The numerous rays of the Sun document indignities attributed to the King between 1667 and 1705 as well as the eclipse of May 12, 1706. Source: On-line Catalog, Library of Congress.

24) **Banneker's Eclipse**, 1731 CE

See Visibility Map: http://eclipse.gsfc.nasa.gov/5MCSEmap/1701-1800/1790-04-14.gif

Benjamin Banneker (1731-1806 CE) is the first Black American scientist of note. Born free on November 9, 1731 CE, he was son to Robert, a slave from Guinea, West Africa, and to his free wife Mary Banneky, of English-African descent. At that time, it was rare for Black people to be born free, but that occurred because his mother was a free woman.

As a child, he was very curious: he enjoyed numbers, and learning how things worked. One of his first significant projects was to build his own clock. One day, a friend showed him a pocket watch. Benjamin was so fascinated that he decided to make his own. After two years of work he had a totally wooden-made clock![88]

Despite working hard to support his family, Banneker had eight years of schooling from a Quaker teacher at an integrated private academy. He borrowed and read books by Addison, Pope, Shakespeare, Milton, and Dryden, studied the stars, and created and solved math puzzles as both entertainment and self-education.[89]

Unarguably, his most remarkable accomplishment has been to accurately predict the solar eclipse of April 14, 1789 CE. Other famous scientists of the time disbelieved Banneker's prediction, as they had their own dates; but as the Sun was partially being covered on April 14, 1789 CE, Benjamin Banneker' 'star' began to shine![90]

Banneker is a brilliant example of a scientist who fought against socioeconomic and ethnical constraints, as well as social class determinants for Black researchers at the time, showing that barriers can and should be overcome and giving important contributions to Astronomy.

25) **Nat Turner's Eclipse**, 1831 CE

See Visibility Map: http://eclipse.gsfc.nasa.gov/5MCSEmap/1801-1900/1831-02-12.gif

The greatest slave revolt in North America was led by Nat Turner (1800-1831 CE). Very clever, Turner learned how to read with his masters' son – an undesirable skill from the masters' viewpoint for a slave during these times

due to fear of rebellion. Turner, afterwards, dedicated himself to religion and became a preacher for his followers.[91]

Fig. 30 – Nat Turner points at a lunar eclipse. He foresees the rebellion that would take place with the eclipsed Moon. Credit: Bernarda Bryson.

In 1828 CE, he had a vision: he would lead his people to liberty, but he should wait for a sign from God – and it came from the sky. An annular eclipse of the Sun occurred on February 12, 1831 CE. Turner interpreted it as a 'black angel' occulting a white one – the time had arrived for blacks to overcome whites, so the time had come for rebellion.

Several months later, after having murdered his original masters, Turner and his band of insurgents headed for the small town of Jerusalem where militiamen promptly interrupted their march. Most of the slaves, including Turner, went into hiding for seventy days before being taken to the gallows and hanged.[92]

Many people died during this revolt, and in no other episode in American history have a so large number of slave owners perished, a reason why Turner is considered a hero of the resistance to oppression against black people in the United States.

26) Adams' Eclipse, 1851 CE

See Visibility Map: http://eclipse.gsfc.nasa.gov/5MCSEmap/1801-1900/1831-02-12.gif

The total solar eclipse of July 28, 1851 CE, was the first subject of an eclipse expedition. The total phase was visible in Norway and Sweden, and many astronomers from all parts of Europe traveled to those countries to observe the eclipse.

Red flames were in evidence, and the fact that they belonged to the Sun and not

to the Moon was clearly established. The first photograph of the solar corona was taken during this solar eclipse and the best observations were made in Scandinavia. Edwin Dunkin wrote:

> *"The prominences were clearly visible, especially a large hooked protuberance. This remarkable stream of hydrogen gas, rendered incandescent while passing through the heated photosphere of the Sun, attracted the attention of nearly all the observers at the different stations."*

The best account comes from the brilliant astronomer John Couch Adams. In 1845 CE, he calculated, at the same time as the Frenchman Le Verrier, the position of Neptune. At this time in history, many astronomers had never observed a total eclipse, because these phenomena rarely occurred at any given place, and transport facilities were few and far between.

In his inspirational article that appeared in the Memoirs of the Royal Astronomical Society, Adams' lyrical style conveys the extraordinary emotion of an experienced astronomer who realizes that he is a complete novice in the arts of observing this spectacle for the first time:

> *"The approach of the total eclipse of July 28, 1851, produced in me a strong desire to witness so rare and striking a phenomenon. Not that I had much hope of being able to add anything of scientific importance to the accounts of the many experienced astronomers who were preparing to observe it; for I was not unaware of the difficulty which one not much accustomed to astronomical observation would have in preserving the requisite coolness and command of the attention amid circumstances so novel, where the points of interest are so numerous, and the time allowed for observation is so short."*

Adams then describes the awe-inspiring, magical appearance of the corona:

> *"The appearance of the corona, shining with a cold unEarthly light, made an impression on my mind which can never be effaced, and an involuntary feeling of loneliness and disquietude came upon me… A party of haymakers, who had been laughing and chatting merrily at their work during the early part of the eclipse, were now seated on the ground, in a group near the telescope, watching what was taking place with the greatest interest, and preserving a profound silence… A crow*

was the only animal near me; it seemed quite bewildered, croaking and flying backwards and forwards near the ground in an uncertain manner."

In another written piece, he compares the corona with the luminous halo that painters draw around the heads of saints.[93]

27) **General Gordon Fatal Eclipses**, 1863 and 1885 CE

See Visibility Map: http://eclipse.gsfc.nasa.gov/5MCSEmap/1801-1900/1885-03-16.gif

Fig. 31 – General Gordon. Here he wears his uniform as governor-general of the Sudan. Source: DigNubia – Exploring the Science of Archaeology, http://www.dignubia.org

An ancient Chinese aphorism says that every dynasty starts with the replacement of an old, degenerate regime ruled by corruption and ineffectiveness. Nevertheless, as time goes by, new governors, in principle virtuous, come into the same vices and the so-called "Mandate of Heaven" (as they reign by divine gift) is passed on.

In such a society, signs of the sky can significantly influence politics.[94] The *Ch'ing* dynasty began in 1644 CE, and achieved great splendor. By the mid-19th century, however, it started to become ineffective and corrupt.

At this time, the British general Charles Gordon was charged by the western powers to help the Emperor of China and his dynasty in their fight against the Taiping revolt. Skilled with military genius and leadership, Gordon commanded an army of Chinese mercenaries and had many victories.

On November 25, 1863 CE, a partial eclipse of the Moon frightened his troops during the siege of Soochow (*Suzhou*) in Kiangsu (*Jiangsu*). The superstitious Chinese interpreted the event as a bad omen for the Emperor. Soochow was not conquered and the Taiping revolt was settled peacefully. This eclipse was thus the cause of General Gordon's first defeat.

Another eclipse, solar this time, on March 16, demoralized Gordon's troops and was directly responsible for his death. In 1885 CE, he was in charge of the

defense of Khartoum, the capital of the Sudan, under attack by a charismatic religious leader, the Mahdi. A solar eclipse demoralized Gordon's troops. The city was taken before British troops could arrive with reinforcements and the British general did not survive the massacre.[95]

28) The Great Eclipse of 1878

See Visibility Map: http://eclipse.gsfc.nasa.gov/5MCSEmap/1801-1900/1878-07-29.gif

Considered one of the greatest eclipse events of that century, it is known as the great eclipse of 1878 CE for its large path of visibility. The Moon's shadow took some 20 minutes to cross Wyoming and Colorado, in the United States, on July 29, 1878 CE. Many tourists filled hotels to see the spectacle - even the famous inventor Thomas Edison was there!

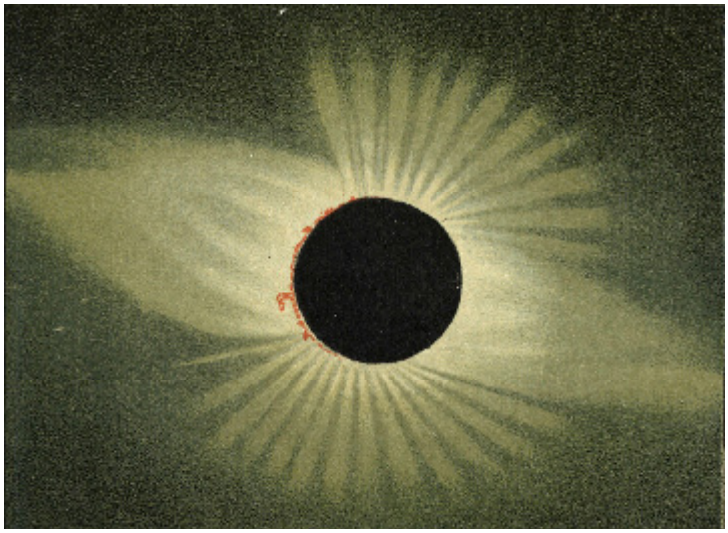

Fig. 32 – Capturing the corona. Magnificent pastel drawing by E.L. Trouvelot of the total eclipse of Sun's corona during the May 29, 1878 eclipse. Credit: American expedition to Wyoming; from the E.L. Trouvelot, Meudon Collection.

Extensive preparations were made by officers in charge of the National Observatory to observe the eclipse. Five expeditions were assigned to observe the phenomenon and conduct relevant scientific investigations, such as making drawings of the corona, and to study the physical constitution of the Sun.[96] Although the corona was photographed in 1851 CE, the results were not satisfactory and, in 1878, drawings provided the best information about its size and shape.[97]

The 1878 eclipse was observed by the American astronomer Maria Mitchell, the first woman astronomer to join the prestigious American Academy of Arts and Sciences. She led a team of five of her female students on a cross-country journey to Denver, Colorado, to observe and scientifically report a total solar eclipse.[98] They traveled by train at a time when ladies did not travel unescorted. Her students were fascinated with the trip, although a little frightened.

Maria took care of all the logistics of sending telescopes to an observational site and gave each student instructions, telling them the observations they should make. "You will see Nature as you never saw it before – it will neither be day nor night – open your senses to all the revelations", she pointed out.

Fig. 33 – Maria Mitchell. Image courtesy of the Maria Mitchell Association. Source: Pocantico Hills Central School Web site, http://www.pocanticohills.org

"Let your eyes take note of the colors of Earth and Sky. Observe the tint of the Sun. Look for a gleam of light in the horizon. Notice the color of the foliage. Use another sense – notice if flowers give forth the odors of evening. Listen if the animals show signs of fear – if the dog barks – if the owl shrieks – if the birds cease to sing – if the bee ceases its hum – if the butterfly stops its flight – it is said that even the ant pauses with its burden and no longer gives the lesson to the sluggard." [99]

She described also the most glorious moment, that is, the observation of the corona! *"As the last rays of sunlight disappeared, the corona burst out all around the Sun, so intensely bright near the Sun that the eye could scarcely bear it; extending less dazzlingly bright around the Sun for the space of about half the Sun's diameter, and in some directions sending off streamers for millions of miles…"*

The young ladies were enthusiastic about the experience and harbored a brave attitude at a time when women were not supposed to be inside scientific circles. At an epoch when men's colleges rarely engaged science students with direct field experience like this, Mitchell's students were entering a new era of

learning for women. This event represented significant scientific, societal, and pedagogical advancement promoted by a pioneering woman.

29) Eclipse of Lawrence of Arabia, 1917 CE

During the First World War, Thomas Edward Lawrence, known as Lawrence of Arabia, advised the Arabs in their revolt against the Ottoman Empire. One of his greatest exploits was the capture of Aqaba, a fortified port on the Sinai Peninsula, with a small troop of 50 Bedouin.

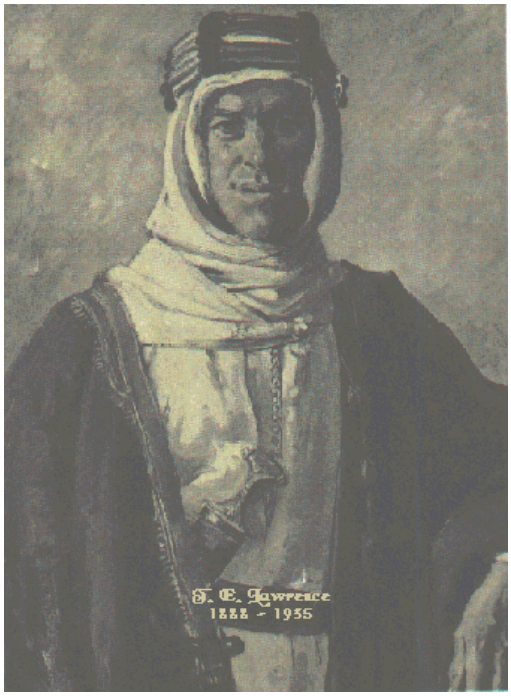

Fig. 34 – Lawrence of Arabia. Credit: Public domain.

In the *Seven Pillars of Wisdom*, he reports a lunar eclipse in Egypt that helped him overcome the first defensive position, Kethira:

> *"By my diary there was an eclipse. Duly it came, and the Arabs forced the post without loss, while the superstitious soldiers were firing rifles and clanging copper pots to rescue the threatened satellite."*

Aqaba was taken a few days later. Thanks to this strategic port having fallen to the British, the Allies soon recaptured Jerusalem and Damascus. The Turkish soldiers had another reason to fear the eclipse: according to an Islamic tradition, the Day of the Last Judgment is linked to an eclipse in the middle of the month of Ramadan, and this was exactly the case on that date.[100]

This is just one illustration of how eclipses through the centuries have been recurrently associated by different civilizations to prophecies of the end of the world. Indeed, even today there are people who do not feel very comfortable to observe the shining solar disk being occulted by the Moon, wondering that such event would represent far more than a mere astronomical event, and that there would not be tomorrow.

30) Einstein Eclipse, 1919 CE

See Visibility Map: http://eclipse.gsfc.nasa.gov/5MCSEmap/1901-2000/1919-05-29.gif

This eclipse has definitively revolutionized the history of science in the twentieth century, as it helped to confirm the General Theory of Relativity by Albert Einstein (1879-1955 CE). Indeed, one of Einstein's most remarkable contributions to science was his General Theory of Relativity (GTR), formulated between 1913 and 1916 CE. This theory contradicted Newton's and provided fundamental new understandings of time and space measurement. GTR was extremelyy complex to understand though and, in order to be accepted, it was necessary that Einstein's theory predicted or explained some observed phenomenon that the Newtonian theory could not.[101]

In this scenario, Eddington came up with the idea that a total eclipse of the Sun would provide such a unique opportunity to quantitatively test Einstein's theory. How? If it were correct, the light from stars would be bent by the strong gravitational field of the Sun. And what circumstance was necessary to observe this? Totality and stars appearing close-by because the test required several bright stars close to the limb of the Sun during the eclipse. The eclipse of May 29, 1919, offered such conditions.

Fig. 35 – Total solar eclipse in Sobral, Brazil, 1919. The large city of Sobral in Ceara, Brazil, as it was in 1919 (left), and a recent monument to celebrate the eclipse (right). Source: Sociedade Brasileira de Fisica Web site, http://www.sbfisica.org.br

The path of totality crossed Brazil, in South America, and Principe, an island owned by Portugal in the Gulf of Guinea, just to the north of the equator and 150 miles from the African coast. In northeastern Brazil, the city of Sobral, Ceara state, was the best post of observation of the phenomenon and two expeditions of American and English scientists joined the Brazilians to observe the eclipse.

Their purposes were distinct. The Brazilian commission focused on studies of the solar corona, its form and shape, and performed spectroscopic analysis of its constitution. The American and English intended to verify experimentally the consequences of GTR.[102]

After analysis of the eclipse results, the royal astronomer Frank Dyson announced, in November 1919 CE, that the results confirmed the theory and it was made public: Einstein was right! In fact, what provoked such commotion was precise measurement of the deviation of starlight passing close to the Sun. The value of such deviation agreed with the prediction of Einstein's GTR (1.75 arc seconds), but was almost double the value predicted by Newton's gravitational theory (0.87 arc seconds).

This is one of the most dramatic events in the history of science and was front-page news around the globe. The London Times featured the headlines, *"Revolution in science. New theory of the universe. Newtonian ideas overthrown"* and The Washington Post, with *"New theory of space: has no absolute dimensions, nor has time, say Savants."* The president of the Royal Society, J J Thomson, described the general theory as *"the greatest discovery in connection with gravitation since Newton... Our conceptions of the fabric of the universe must be fundamentally altered."*[103]

Although people were still mystified by Einstein's theory, his worldwide popularity as a legendary sciencist[104] increased exponentially almost overnight[105] thanks partly to the fanfare that followed the eclipse. Einstein was also very charismatic and became famous for his equation $E=mc^2$.

31) **Eclipse of End of Millennium**, 1999 CE

See Visibility Map: http://eclipse.gsfc.nasa.gov/5MCSEmap/1901-2000/1999-08-11.gif

The eclipse of August 11, 1999 CE, was eagerly awaited and witnessed for millions of people, many having traveled around to see the show. It covered the Atlantic near Newfoundland, and the path of totality proceeded eastwards to the southwestern tip of England. The Moon's shadow then crossed France, Germany, several eastern European countries, Turkey, the Middle East, Pakistan, and India, before eventually reaching the Bay of Bengal.[106]

Stories about the end of the world have always frightened people throughout history. An eclipse of the Sun in the last year of the millennium would be the perfect scenario for consternation about this issue. One key ingredient for this eclipse was related to the forthcoming millennium, including predictions of catastrophes.[107]

32) **First Eclipses of the Third Millennium**, 2001 CE

See Visibility Map: http://eclipse.gsfc.nasa.gov/5MCSEmap/2001-2100/2001-06-21.gif

There were two eclipses opening the Third Millennium: a lunar and a solar one. The first happened on January 9, 2001 CE, and was lunar. That was total as viewed from most of Asia, Africa, Europe, and the eastern seaboard of North America.

In Nigeria, the eclipse caused great commotion, and its advent was blamed on sinners. In the northeastern part of the country, there were rampages by gangs of youths. Similar destruction occurred in other towns. "The immoral acts committed in these places are responsible for this eclipse," explained one of the leaders of the riots.

Five months later, on June 21, 2001 CE, the first total solar eclipse of the millennium was also witnessed in Africa. As the track passed over Angola, Zambia, Zimbabwe, Mozambique, and finally the southern part of the island of Madagascar, thousands of tourists and millions of local inhabitants watched the spectacle.

Elsewhere wailing and gnashing of teeth accompanied what was considered the "rooting of the Sun," from which the world would not recover.[108] The world did recover quite promptly, and we keep on waiting for the next meeting between our two closest celestial bodies in their marvelous space ballet.

33) **Eclipse seen from space**, 2006 CE

See Visibility Map: http://eclipse.gsfc.nasa.gov/5MCSEmap/2001-2100/2006-03-29.gif

In Africa, many regard eclipses not simple astronomical phenomena, but attribute some metaphysical meaning to them, usually related to prophecies of the end of the world.

In the countdown to the 29 March eclipse, for example, an Islamic "scholar", a Mallam Muniru Hamidu, declared that the world was going to end because it is written in the Qur'an that when the end of the world got nigh, "God would cause the sun and the moon to come together". Other religious books such as the Christian Bible connects eclipses with facts such as the Final Judgment. One of the signs is the descent of darkness in the daytime.[109]

The image below, obtained from the International Space Station, 230 miles above the planet, was positioned to view the umbral shadow cast by the Moon as it moved between the Sun and Earth during the solar eclipse on March 29, 2006 CE. The astronaut image captures the umbral shadow across southern Turkey, northern Cyprus, and the Mediterranean Sea. People living in these regions observed a total solar eclipse in which the Moon completely covered the Sun's disk.

Fig. 36 - Eclipse in outer space. The Moon's shadow passing over the Earth during eclipse. Source: NASA.

Epilogue

The Sun sends energy to the Earth and other planets in our solar system as heat and light, along with particles that constitute the solar wind. Therefore, the space between the Earth and the Sun is not empty, but filled with *plasma* - an electrified "gas" composed of ions, electrons and fields.

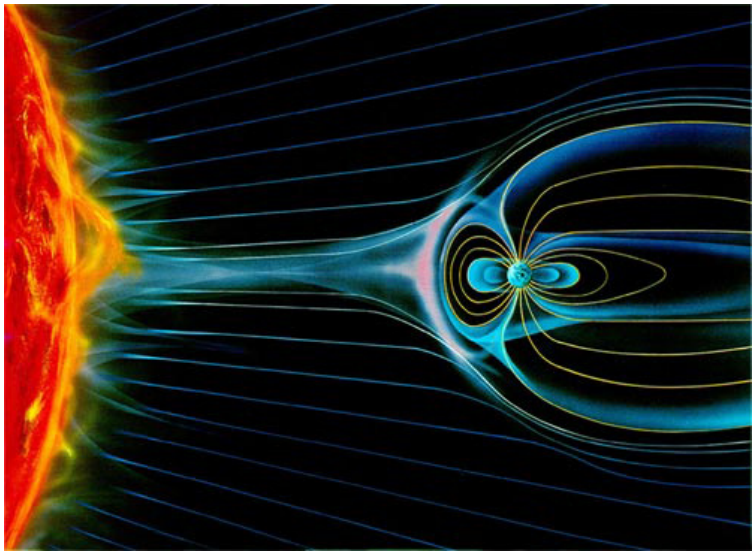

Fig. 37 – Space plasma environment of the Sun and Earth. Magnetic energy bursts near the solar surface hurl plasmas outward from the Sun. Clear magnetic field structures appear in light blue. Source: NASA.

Energetic radiation within this plasma coming from the Sun would be dangerous to human life if the Earth's surface was not shielded by our atmosphere and its geomagnetic field and space plasma environment,[110] that is, the magnetosphere.

The Earth's magnetosphere and ionosphere is a plasma system. It is the region in space defined by the interaction of solar plasmas with Earth's dipole-like magnetic field, extending from about 85 km above Earth's surface to more than 60,000 km in the sunward direction and to several hundred Earth radii in the anti-sunward direction.[111]

As mentioned, the magnetosphere shields the Earth against space weather: solar wind, solar flares, coronal mass ejections, solar energetic particles and so on. Similar to our atmosphere, the magnetosphere is a huge magnetic field with lines running along it and, at the poles, right to the planet itself.[112] The solar wind interacts with the magnetosphere so that the side facing the Sun is compressed and the side opposite to the Sun is elongated.

Amazingly, there are plasmas out to the far reaches of the solar system. Space environments surrounding planets and their satellites are filled with plasmas such as the solar wind, solar and galactic cosmic rays (high-energy charged particles), and particles trapped in planetary magnetospheres. All planets, and

the solar system itself, have their own unique space plasma environments.

Plasma is also the state of matter inside the Sun. Basically, what we see when we observe a total eclipse of the Sun are huge amounts of plasma being ejected from our star to form the solar corona and the solar wind. Look at this magnificent image of the Sun and its corona taken by the SOHO spacecraft (Fig. 38), in combination with a ground-based image, during a period of maximum solar activity.

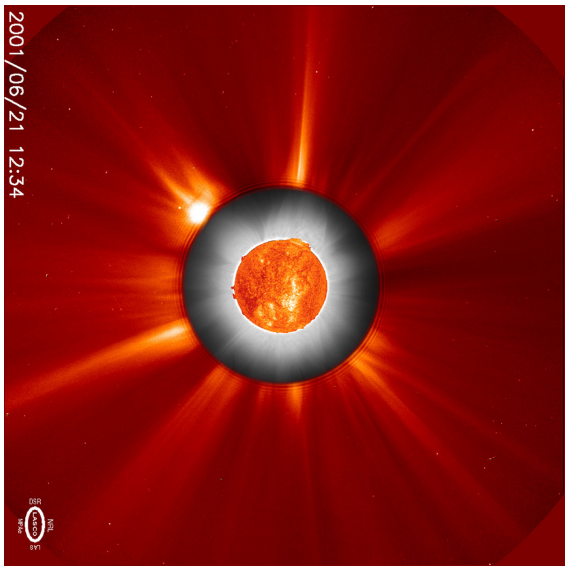

Fig. 38 – Composite images from the 2001 total solar eclipse. Three distinguished images form this picture. In the center, an image obtained from space; the intermediate picture has been taken from the ground and the outermost image shows the corona as seen from space. In that year the Sun was in a period of maximum activity, so the corona is notably expanded. Source: ESA/NASA.

But what are plasmas, anyway, and where can we find them? Plasmas are basically an electrically conducting, interactive combination of uncharged and charged particles, positive ions, negative electrons, electric and magnetic fields, constituting the fourth state of matter (see http://www.plasmas.org/). Plasma exists at very high temperatures, thousands or perhaps millions of degrees. At these temperatures the atoms break and individual elementary particles are free in space.[113]

The fraction of uncharged particles in a plasma varies substantially, ranging from more than 95% in the lower ionosphere to less than 1% in the solar wind – the continuous stream of plasma from the Sun. Plasmas conduct electricity and have other properties that make them more than simply a type of electrical 'gas.'[114]

On Earth, plasmas are very common. For example, they are used for fluorescent lamps, arc lamps, and laboratory experiments in sealed chambers. Tiny plasma discharge elements constitute the pixel arrays of plasma televisions. And of course, lightning: brief, long-range electrical discharges through the atmosphere. Lightning is part of a global electrical circuit that links the Earth's surface to the conducting ionosphere. There are plasmas inside our body as well. Today, plasmas are beginning to be applied as well in medicine: surgery without cutting and "bloodless scalpels" are now becoming a reality through

cold plasmas that can inactivate bacteria through a combination of free radicals, charged particles, and ultraviolet radiation, which work together to disrupt the integrity of bacterial cell membranes.[115]

Travelling farther, more than 99% of the visible Universe is in the plasma state, giving rise to Tony Peratt's metaphor "Plasma Universe." Actually, in space, we can find plasmas in the interstellar and intergalactic medium, in diffuse forms like nebulas and in more condensed and hotter forms like stars or supernovas.[116] Much closer to home, energy from the Sun produce phenomena such as auroras, rainbows, sunrises.[117]

Fig. 39 – The plasma universe. Intense regions of star birth within the Orion nebula appear in this Hubble image. All visible regions here and most of the low-density regions in between are dominated by plasmas containing neutral particles, ions, electrons and electric and magnetic fields. Source: NASA.

Solar particles carry a magnetic field that can sometimes disrupting the magnetosphere, causing magnetic storms or auroras.[118] In special, auroras shimmer and glow in the polar regions of the Earth. They are also known as the Northern and Southern lights.[119] According to Peratt and Strait (1999), auroras are "indefinite, undulating sheets that move and dance (…) It is the visible manifestation of huge, invisible electric currents embracing Earth. The aurora is a natural plasma light show."

These beautiful auroral displays result from solar wind plasmas that filter through the magnetic field surrounding the Earth, eventually striking and exciting ionospheric atoms or molecules and causing them to radiate different colors.

Fig. 40 – Aurora. This image obtained in January 2005 shows a marvelous aurora borealis over a gelid landscape in Alaska. Source: NASA.

Next time you have an opportunity to observe a total solar eclipse, or even some beautiful aurora, be aware that you are witnessing a prime nearby spectacle of the same plasma processes that pervade the cosmos - a window to the plasma universe!

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Fig. 41– Dr. Timothy E. Eastman. Plasma physicist and group manager at NASA Goddard. Creator of the Web site plasmas.org.

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Fig. 42 – Dr. Lou Mayo. Astronomer, space science education specialist at NASA Goddard.

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Fig. 43 – Dr. Fred Espenak. Astronomer, NASA Goddard, creator of the Web site mreclipse.com

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[9] Wilson, 1997.

[10] The outermost layer of the Sun's atmosphere, visible to the naked eye during a total solar eclipse, can also be observed through special filters and X-ray cameras aboard satellites. The corona is composed of hot plasmas, up to 1.5 million degrees centigrade, and generates the solar wind.

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[45] According to Fred Espenak, from NASA Goddard, the Saros cycle consists of a period of 18 years, 11 days and 8 hours. If one goes forward or backward within this period, another solar eclipse, very similar to the first one, will be encountered. It will occur approximately at the same season, and with approximately equal distances to the Moon-Earth-Sun system. The Babylonians and the Chaldeans discovered it by keeping records of lunar eclipses. The Saros family of eclipse is imperfect, presenting northward or southward shifts.

[46] The mean time for one lunar phase cycle (i.e., the synodic period of the Moon) is 29.530.589 days, or 29 days, 12 hours, 44 minutes, 3 seconds. More specifically, a lunation is also commonly defined as the mean time between successive new moons. Extracted from: http://scienceworld.wolfram.com/astronomy/Lunation.html

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