PARI

Astronomer's Corner

The August 21, 2017 Total Solar Eclipse

Part 1: Science and History of Solar Eclipses

by

Bob Hayward, Astronomer/Educator

> "…the monk raised his hands above my head, and his eyes toward the blue sky, and began some words in Latin: in this attitude he droned on and on, a little while, and then stopped. I waited two or three moments; then looked up; he was standing there petrified. With a common impulse the multitude rose slowly up and stared into the sky. I followed their eyes, as sure as guns, there was…"

What? What was it Sir Boss saw up there in the sky? If you're familiar with American literature, you might recognize the situation unfolding in Mark Twain's A Connecticut Yankee In King Arthur's Court. Hank Morgan, the protagonist of Twain's tale (played by Bing Crosby in a Hollywood version), is about to be burned at the stake when he remembers that a total solar eclipse is due to start within minutes. (Actually, to be true to Twain's narrative, there was a misunderstanding in the exact date on the part of Sir Boss' servant Clarence. But, that's just an added twist to the plot.) What the crowd awaiting Sir Boss' flaming execution had just noticed was the beginning of a solar eclipse. Of course, Sir Boss used his knowledge to gain advantage over the superstitious crowd and, more important, King Arthur to escape from his imminent fate by fire. After he and the king came to terms, our hero agreed up return the sun to the sky and, as a thin sliver of light reappeared in the sky, "… the assemblage broke loose with a vast shout and came pouring down like a deluge to smother me with blessings and gratitude; and Clarence was not the last of the wash, to be sure."

Christopher Columbus: While the above is unabashedly fictitious, there is a similar story, supposedly true but admittedly undocumented and of questionable veracity regarding the fourth voyage of none other than Christopher Columbus. The unfortunate Columbus left Cadiz, Spain on May 11, 1502 with four ships. An epidemic of shipworms invaded the hulls of his wooden ships, forcing him on June 25, 1503 to abandon two ships and beach the remaining pair on the north coast of Jamaica. During the lengthy repairs the natives at first were supportive and furnished the Spanish crew with food and other materials. However, as sometimes happens when guests overstay their welcome, relations between the natives and the crew got nasty and Columbus needed to resolve the situation.

Regiomontanus: Being a resourceful sea captain, the admiral had with him an almanac containing detailed information on the sun, moon, planets, stars and constellations for the years 1475-1506. This valuable almanac had been published by the German mathematician, astronomer and (horrors!) astrologer, Johannes Müller von Königsberg (1436-1476) more commonly known by his Latin pseudonym *Regiomontanus*. Consulting this almanac Columbus discovered that on the evening of Thursday, February 29, 1504 there was to be a total eclipse of the moon visible from Jamaica shortly after moonrise. Columbus gave the Jamaicans three days warning and, at the predicted time, the moon rose with a notch out of it and slowly turned bloody red. The natives were terrified and, according to Columbus' son Ferdinand, "…with great howling and lamentation came running from every direction to the ships laden with provisions, praying to the Admiral to intercede with his god on their behalf." Needless to say, Columbus agreed to do so and the moon slowly reappeared. He and his crew were rescued on the following June 29.

Ernst Mayr: Unfortunately, this scheme of influencing the "natives" using knowledge of upcoming eclipses hasn't always worked out as planned. Award winning evolutionary biologist Ernst Mayr (1904-2005) on a 1928 ornithological expedition to then Dutch New Guinea checked his own almanac and noted that a lunar eclipse was about to occur. The Museum of Comparative Zoology's informal chronology records the event: "Mayr announced to the tribe, through an interpreter, that the moon was about to totally darken. Unlike Twain's characters, however, they were not impressed, and the elderly chief said to Dr. Mayr, 'Don't worry, my son, it will soon get light again.'"

Eclipses Across Cultures: While the first story above involving a solar eclipse is purely fiction and the second involving a lunar eclipse is of questionable authenticity, eclipses are certainly very real and are among the most spectacular events in all of nature. The word eclipse originates in the Greek where it literally means "abandonment." Archilochus wrote

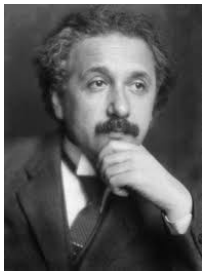
> Since Zeus father of Olympians
> made night from mid-day
> hiding the light of the shining-sun
> and sore fear upon man.

This quote alludes to the general fear among unscientific cultures of both solar and lunar eclipses. In India during an eclipse food is neither eaten nor cooked in belief that when the rays of the sun don't reach the earth, germs increase in food. In Thailand the color black denotes evil. In China banging pots created enough noise to scare away the dragon eating the sun.

While many cultures have a variety of mythologies regarding eclipses, eclipses are very well known to observers of the sky and, long before the invention of computers, mathematicians and astronomers have been able to calculate and predict them. Chinese and Babylonian records make note of eclipses over 4000 years ago and the Egyptians observed eclipses before that. Astronomers from NASA's Jet Propulsion Laboratory have used Chinese observations of eclipses as far back as 1226 BCE to measure the change in the rotation rate of the earth. They found that the day back then was 0.047 second shorter than it is today. On May 28, 585 BCE a total solar eclipse motivated the Lydians and the Medes to stop a battle and agree to a peace

treaty later cemented by a double marriage. This eclipse was predicted by the Greek astronomer and philosopher Thales although it's not know if the generals of those armies were aware of his prediction. While generally eclipses are seen as bad omens, that is not always the case. In Tahiti they have had a romantic meaning in the belief that and eclipse is a lovemaking of the sun and moon.

Einstein's Relativity: The most obvious use of eclipses to further scientific knowledge is, of course, to make observations of the sun, specifically its chromosphere and the beautiful corona visible to the naked eye during a total solar eclipse. For example, during a total solar eclipse on August 18, 1868 French astronomer Jules Janssen (1824-1907) discovered the element helium in the spectrum of the sun. (This element is named for the Greek god of the sun, Helios.) But, probably the most famous bit of science coming out of eclipses observations took place during the total solar eclipse of May 29, 1919.



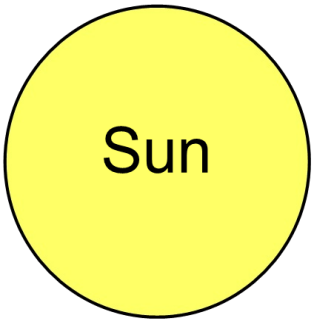
Up until that time physicists had accepted the long-established law of universal gravitation put forth by Sir. Isaac Newton. But a newcomer to the field named Albert Einstein took exception to Newton's law. Einstein's general theory of relativity predicted that space was warped by mass. This was not a large effect, and no means of measuring it and, thus, confirming or disproving Einstein, was available.

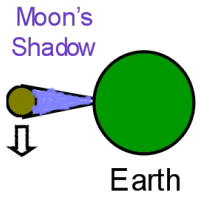
However, in 1917, Sir Frank Watson Dyson, Astronomer Royal of Britain, noted that on May 29, 1919, there would be a total solar eclipse in front of the Hyades star cluster that forms the face of Taurus the bull. He noted that light from the stars in the cluster would have to pass close to the edge of the eclipsed sun. He suggested that if those stars were displaced by about 1.75 arcseconds from their normal locations, then it would be confirmation that the gravity of the sun had bent their light rays. (Einstein's theory basically says not that light rays are bent but rather that the space through which they travel is warped.)

Sir Arthur Eddington measured the "true" locations of the Hyades stars in January and February 1919. Then in May he went to the island of Principe off the west coast of Africa and took several pictures during the six minutes of totality. Back in England his measurements confirmed Einstein's theory. When Eddington announced his findings on November 6, 1919, Albert Einstein became a worldwide celebrity. The bending of light around massive celestial objects, now known as *gravitational lensing*, is a valuable tool in astronomical studies today often utilizing the Hubble Space Telescope's magnificent cameras.

Solar Eclipses: We've seen that eclipses are very predictable even in historical times. Thus, it is very reasonable to believe that documents such as Regiomontanus' almanac were very accurate. Obviously, Sir Boss' ability to predict an upcoming eclipse was an accurate representation of the state of the art in Twain's time and not a figment of his vivid imagination. So, let's look at the mechanics of eclipses.

August 21, 2017. Does that date ring a bell? Well, if you are in any way, even the slightest, interested in astronomy or science in general, you know that August 21 is the date of what some are calling the "Eclipse of the Century." In the rest of this article we will discuss solar eclipses in general. In the next issue, we will zero in on the August 21 eclipse that will be visible from throughout North America.

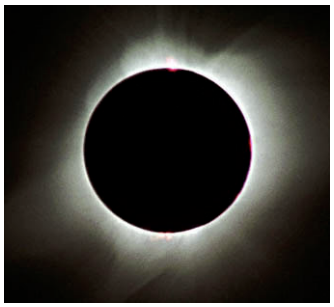




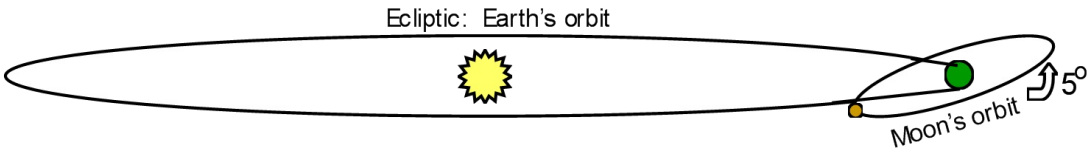
There are two types of eclipses, solar and lunar. In a solar eclipse or eclipse of the sun, the moon comes between the earth and the sun.

In this not-to-scale diagram as seen from above, the moon orbits the earth in a counterclockwise direction. During a solar eclipse the new moon's shadow touches the earth. If the moon were too far above or below the line between the sun and earth, there would be no eclipse since the moon's shadow would miss, passing above or below our home planet.

The sun is approximately 400 times larger than the moon and approximately 400 times farther from the earth. This amazing coincidence of nature means that when the moon comes directly between the earth and the sun, it appears to just about perfectly fit over the sun. Since both the moon and the earth follow orbits that are not perfect circles, this fit does vary slightly. There is no physical reason for this coincidence as no other planet-moon pair in our solar system experiences such a nearly perfect fit of a moon over the sun.

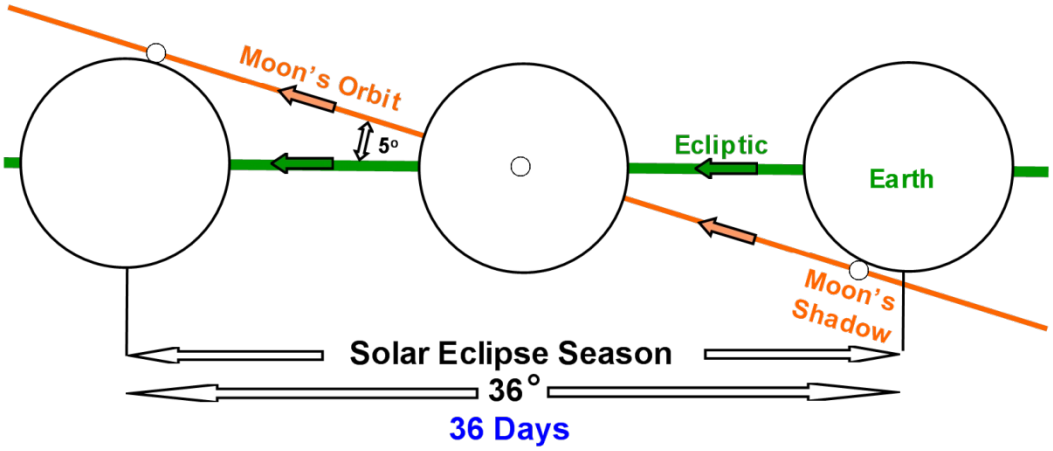


The moon orbits the earth with respect to the sun in 29½ days. This is known as the *synodic month.* Thus, it passes by the sun that often as it goes through the phase of *new moon*. So, the question often arises, "Why don't we have a solar eclipse every time the moon passes by the sun, i.e., new moon?" The answer is that the orbit of the earth, called the *ecliptic*, and that of the moon are not coplanar. That's a fancy way of saying they don't lie in the same plane.



The moon's orbit is tilted 5° from the ecliptic, i.e., the plane of the earth's orbit.
Thus, for half of its orbit the moon is above the ecliptic and, for the other half, below.

It's only when the moon is passing through the ecliptic, in what mathematicians call a *node*, that the earth, sun and moon are all lined up in a direct line. If the moon comes to new moon too long before it's at a node, it's shadow will miss the earth and there will be no eclipse (on the right below). Likewise, if it comes to new moon too long after the node (on the left below), the shadow will not touch the earth. It is only if it comes to new moon while it is close to its node that we will have a solar eclipse (in the middle below).



The figure above illustrates the moon at the *ascending node* of its orbit. On the opposite side of its orbit, i.e., approximately six months later, there would be an eclipse at the *descending node.*

Solar Eclipse Seasons: How long is "too long"? From the geometry of the system, it turns out the moon must be within 18° of the node for its shadow to hit the earth; otherwise, it passes the earth, either below or above, too far away from the ecliptic. Thus, if new moon occurs anywhere within this 36° stretch of the earth's orbit, there will be a solar eclipse. Since the earth moves 360° in its orbit in 365.2422 days, it moves almost 1° per day. Thus, there are two 36-day periods, one around each of the nodes in which we can have a solar eclipse. In fact, we must have one, and could have two eclipses, since the moon comes to new moon every 29½ days. We call this 36-day period a *solar eclipse season*.

Since there are two solar eclipse seasons in a calendar year and since there has to be an eclipse in each solar eclipse season, each calendar year there are a minimum of two solar eclipses somewhere on the earth. Since there could be two solar eclipses in each solar eclipse season, there could be four. Now, just to keep you awake worrying about it, it turns out that because of something called the *regression of the nodes* of the moon's orbit, there could be part of a third solar eclipse season in a calendar year and we could have one more solar eclipse. In summary, there are a minimum of two solar eclipses each calendar year and there could be as many as five.

Note: The geometry of lunar eclipses follows the same logic but the *lunar eclipse seasons* are only 24 days long. Since there are is 29½ days between full moons, we don't have to have any lunar eclipses in a calendar year and we could have a maximum of three.

Who sees a solar eclipse: Where will the moon's shadow touch the earth in any given solar eclipse? This will be determined by three things:

- The distance of the new moon above or below the node will affect how far above or below the center of the earth the shadow falls.
- The rotation of the earth will determine which side of our home planet is facing the moon. Obviously, if new moon occurs during our night hours, we miss out.
- The seasons, i.e., the tilt of our hemisphere towards or away from the sun.

On August 21, the shadow of the moon will hit North America including PARI since…

- New moon at 2:30 p.m. EDT will occur within the 18 days of the descending node.
- The western hemisphere will be in daytime.
- The northern hemisphere will be tilted towards the sun in our summer.

More details in the next issue.

Final thoughts: While solar eclipses might seem to be events of interest mainly to astronomers, we find they are intimately entwined with culture as well. Observations of eclipses may be of primary interest to scientists and those "eclipse chasers" who travel great distances just to see one more of them. But, understanding this spectacular presentation of nature is essential to our understanding of our home planet and the universe in which we live.

So, look forward to the afternoon of August 21 in the Carolinas. Mark your calendars NOW!

References:

AmericanScience A Team Blog. "On Eclipses and Scientific Thinking: Simon Newcomb. Mark Twain, Ernst Mayr, and Bing Crosby," 2012. http://americanscience.blogspot.com/2012/10/on-eclipses-and-scientific-thinking.html

Buchen, Lizzie. WIRED, "May 29, 1919: A Major Eclipse, Relatively Speaking," 29 May 2003. https://www.wired.com/2009/05/dayintech_0529/

Colors of India.com. "Solar Eclipse Stories," http://colorsofindia.com/eclipse/events1.htm

International Center for Theoretical Physics. "Total Solar Eclipse," 29 March 2006. http://bibalex.org/eclipse2006/Home.aspx

New World Encyclopedia, "Regiomontanus." http://www.newworldencyclopedia.org/entry/Regiomontanus

Rao, Joe, SPACE.com Skywatching Columnist. "How a Lunar Eclipse Saved Columbus," February 8, 2008: http://www.space.com/2729-lunar-eclipse-saved-columbus.html

Royal Astronomical Society of Canada, Observer's Handbook 2017, Toronto, Canada

Twain, Mark. A Connecticut Yankee In King Arthur's Court, Chapter 6: "The Eclipse." Charles L. Webster and Co, New York, NY: http://etc.usf.edu/lit2go/174/a-connecticut-yankee-in-king-arthurs-court/3049/chapter-6-the-eclipse/