RADIO MAGiC
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The Last Great North American Total Solar Eclipse

Introduction

On 8 April 2024, the supersonic shadow of the Moon raced in tandem with the Sun northeastward from Mexico, crossing the heart of America, southern Ontario and Quebec exiting through the Maritimes. It turned day into night along a narrow corridor for over four minutes, and the crew of the International Space Station (ISS) had the best view of all, which they live-streamed back to Earth (Figure 1).

Figure 1: The View from Space

Luna's supersonic shadow created "eclipse-induced atmospheric bow shock waves". Credit: NASA.

In the Beginning

The Ice Age suddenly ended about 12,000 years ago (we do not know why), but it ushered in the Holocene Epoch characterized by warmer global climate, which allowed modern humans to transition from small, nomadic hunter-gather tribes of a few families into large, stay-in-place agrarian societies that became larger and larger, giving birth to civilization with its divisions of labour based on one's natural abilities along with the good and bad that comes with being "civilized". For thousands of years, brilliant and observant shamen/astronomer-priests studied the believed to be divine events and objects seen in the day/night skies, tracked the seasons, created solar/lunar clocks and calendars, discovered the synodic periods of the visible planets and the Moon (the period of time it takes for any celestial object to return to the same sky position relative to the Sun and Earth). They originated and conducted seasonal festivals and worshiping of multiple pagan deities they created that brought order and control to the ever growing and stay-in-place communities under central authorities who were deified and ruled by divine right, which became (and still is) an accepted and integral part of everyday life.

In the beginning, small sticks then stone circles sufficed to mark the repeating sky positions of the Sun and Moon, asterisms (constellations), brightest stars and planets plus the two equinoxes and solstices. Time quickly became a very real and tangible thing, and more precision became necessary in order to keep mortal life on Earth in perfect harmony and alignment with the immortal sky gods and associated astronomical events. This required designing and building larger stone circle observatories, obelisks and eventually pyramids around the world using nothing more than human brain and muscle power plus simple hand tools over the millennia (bone, stone, copper, bronze then iron). Some of the most well-known and famous are: Newgrange, Ireland, the oldest (so far) dates from around 3350 BCE; followed in descending age order by Stonehenge (England), the Giza Pyramids (Egypt) and Chichen Itza (Mayan, pre-Columbian Mexico).

Around 2600 years ago, the Chaldeans'—best known for their association with Abraham and Nebuchadnezzar in the Bible—amazing astronomer-priests discovered the Sun, Earth and Moon relationship that Edmund Halley (Halley's comet fame) later called the "Saros" cycle. It is a perpetually repeating eclipse cycle (solar and lunar) of exactly 223 synod months, where one synod month is precisely 29 days, 12 hours 44 minutes and 3 seconds. One Saros cycle equals 18 years (of 365 days) plus 10, 11 or 12 days (depending on the number of intervening leap years) plus 8 hours. It starts/ends when the Sun, Earth and Moon all return to approximately the same relative geometry in the sky, and this repeating pattern produces nearly identical and repeating eclipse cycle patterns. They also discovered that the interval between any successive two solar eclipses is either one, five or six synodic months with lunar eclipses falling in between solar eclipses.

In 46 BCE, Julius Caesar, with the assistance of the astronomer Sosigenes of Alexandria, reformed the lunar-based Roman calendar because it had become badly out of sync with the seasons of the solar year. The "Julian" calendar added an extra day to "Februarius" (the last month of the Roman calendar) every four years, but even this slight correction (after 1500 years) eventually caused the Julian calendar to become out-of-sync again with the seasons by 10 days, which required another calendar reform (the "Gregorian"). But either calendar system made/makes predicting the exact date and time when any (solar or lunar) eclipse would occur to sundial accuracy a trivial matter. However, the exact location was still difficult to determine because it takes 54 years (three Saros cycles) for the same spot on Earth to have the same eclipse cycle repeated again.

That is until polymath genius Edmund Halley used his friend Isaac Newton's calculus and law of universal gravitation, to produce the first mathematically accurate map of the path of totality to within a two-minute time error with distance error of only 32 kilometres for the "Great British Total Solar Eclipse" of 22 April 22 1715 (Figure 2, next page). Cartographers are still amazed by Halley's accurate perspective view drawn as if from seen from low Earth orbit! Afterwards, he reviewed the timing and sighting data supplied by ground observers and discovered that the lunar ephemeris used by 18th astronomers contained fractional orbital errors, which he corrected in time for the next solar eclipse.

Figure 2: Halley's Total Solar Eclipse Map

Halley's detailed map depicts the passage of Luna's shadow over England on 22 April 1715. Credit: Royal Astronomical Society of Great Britain.

Magic, Religion and Science Collide

The earliest (so far) recorded solar eclipse (near total) is depicted by petroglyphs carved on three stone monuments at Loughcrew Cairns, Ireland. They depict the exact alignments of the Sun, Moon and horizon on the late afternoon of 30 November 3340 BCE. Some cairns are also aligned with sunrise on the spring (start of nature's life cycle) and autumn (end of nature's life cycle) equinoxes (equal hours of day and night).

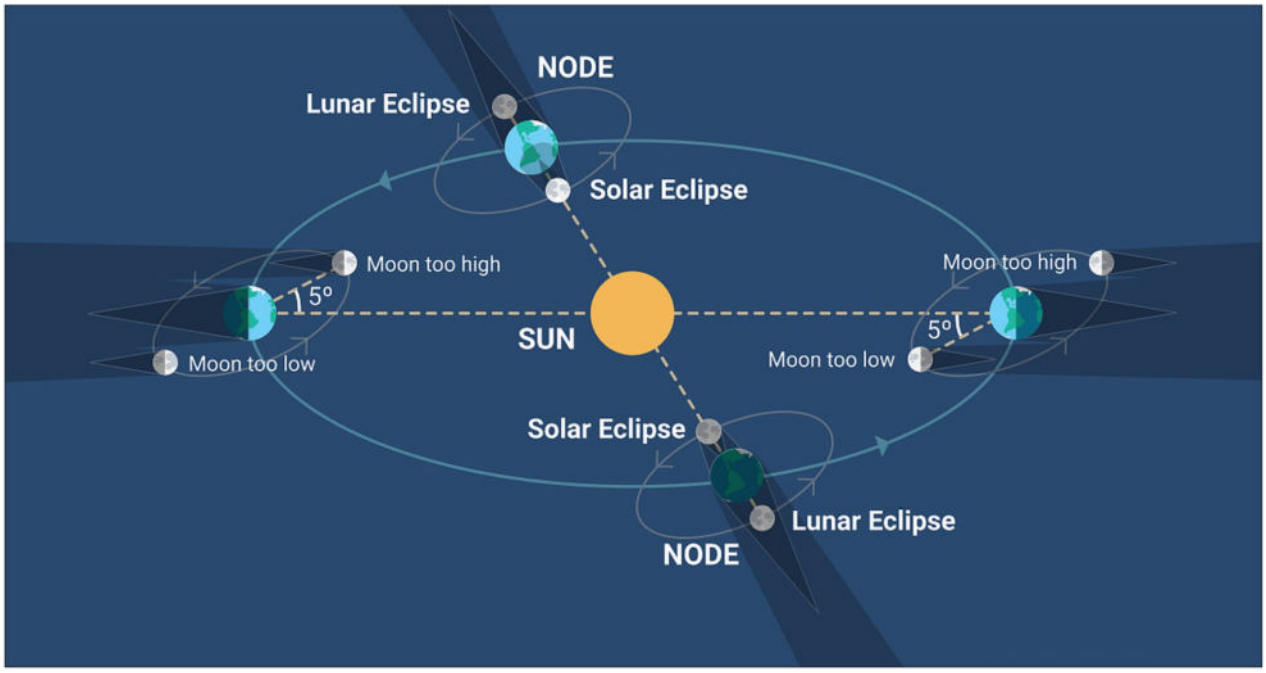
A cuneiform account was found on a Babylonian clay tablet that described the total solar eclipse of 3 May 1375 BCE as seen in the port city of Ugarit (modern Syria). And, in 28 BCE, the first known written (paper and ink) account of a visual sunspot sighting is found in the Chinese Book of Han (Han Dynasty): “The sun was yellow at its rising and a black vapour as large as a coin was observed at its center.” Figure 3 depicts a more “modern” petroglyph example found in a New Mexico canyon carved on a large, precisely shaped and placed pyramidal boulder used by the Pueblo Peoples (or Puebloans) astronomer-shamans. The earliest possible total solar eclipse visible in that area was in the year 900, and the site was used as a solar observing station for approximately 250 years. This boulder is aligned with the northeast horizon, and during the summer solstice, guess what? Sol rises up from the northeast horizon (in the northern hemisphere) between June 20 and 22!

Figure 3: Total Solar Eclipse Petroglyph
This petroglyph depicts the solar corona. It was carved on the south facing (Sun) side of a large boulder near the Una Vida ruins (Pueblo Peoples), Chaco Canyon, New Mexico. Credit: High Altitude Observatory, “Solar Astronomy in the Prehistoric Southwest”.

Arthur C. Clarke's "Third Law" states: "Any sufficiently advanced technology is indistinguishable from magic." But this law can also be inverted because even for all our advanced science, technology and knowledge, there is still simply something ethereally magical or spiritual that overwhelms us when we go outside to watch and experience a total solar eclipse or some other spectacular celestial events (aurora, meteor showers or comets), and it is especially amplified by what sociologists call "mob/herd mentality" or "groupthink". It is a social phenomenon where individuals in a group act collectively without centralized direction causing infectious behaviours that are driven by the group's influence instead of individual decision-making. Many who gazed skyward during "The Great American Total Solar Eclipse" of 8 April 2024 were so caught up by it that even Bill Nye, "The Science Guy", got swept away by the crowd and confused the suddenly visible and spectacular solar prominences with solar flares. Totality triggers something primordial, spiritual, emotional and physical people collectively and spontaneously gasped, cried, cheered, chanted, sang, prayed, applauded, raised their hands to the sky, fainted or swayed back and forth caught up in a form of rapture. The Neolithic people of 10,000 years ago, watching the same event unfolding, would have reacted no differently, and astronomical events gave birth to the first pagan religions.

Solar eclipses are still rare events for most of us to see in person because they occur mostly over isolated areas of our planet (80% ocean covered). However, we can now literally chase after them (and many fanatics do) no matter when and where they happen (every 18 months). The question most people ask is "How come we do not have total solar eclipses every month?" The answer is that while the Sun and Earth are always in perfect visual alignment with each other, our Moon has an elliptical orbital tilt to that alignment (just over five degrees) and not in right orbital space-time orientation most of the time (Figure 4, next page). However, total solar eclipses would not even happen if it not for a unique relationship (for all we know). Our Sun is exactly 400 times larger than our Moon, but our Moon is also exactly 400 times closer to the Earth so both celestial bodies have the same apparent visual diameter in the sky of one-half degree; coequal deities of the day and night sky to the ancients.

Figure 4: Orbital Mechanics of Eclipses
Credit: TimeandDate.com. A comprehensive website that provides a wide range of tools and information related to time, time zones, calendars and astronomy.



Just before totality, the Sun's chromosphere, that part of its atmosphere extending up from the surface to about 2000 kilometres, suddenly appears as a thin, bright red layer around the edges of the solar disk for a few fleeting seconds. At totality, the extensive outer atmosphere of the Sun or the corona (Latin: "crown") suddenly appears in all its full glory and majesty (Figure 5, next page). Everyone can now safely watch this truly overwhelming vision without needing any eye protection for the few fleeting minutes of totality, and scientists can observe and record the corona's finer details from both the ground and space.

The entire process from first contact to last contact with Luna takes a couple of hours, but totality only lasts from a minimum of about two minutes to a maximum of about seven and a half minutes, depending on the observer's latitude. Radio wave propagation changes as the ionosphere's "D" or absorption region weakens and dissipates like it does after sundown while the "F1" and "F2" regions recombine into the "F" region. But totality is not necessarily needed because even partial solar eclipses can produce similar effects albeit they can be more subtle and less dramatic.

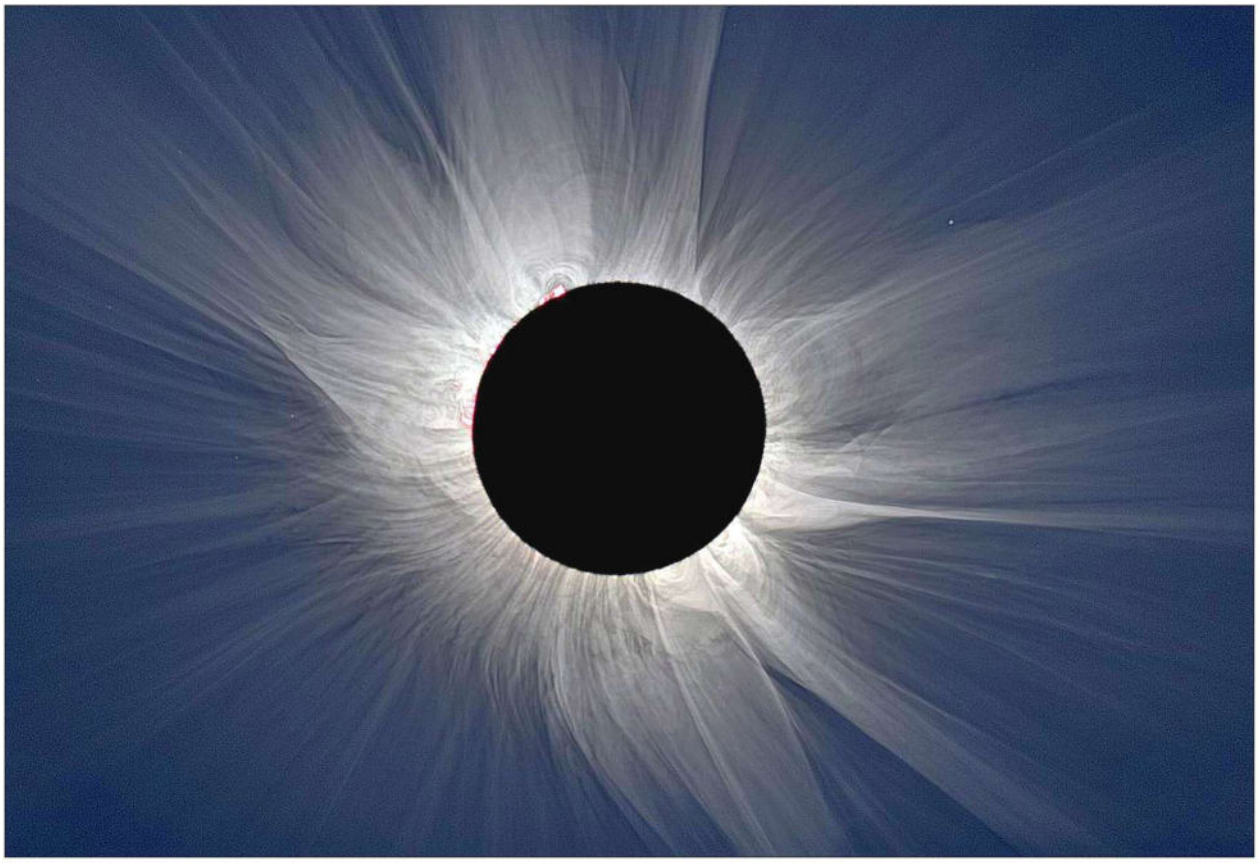


Figure 5: Sol Invictus. This white-light photograph of the corona shows the spectacular sight only visible during totality along with some of naked eye bright stars and planets that also appear in the background. Normally, it is a million times fainter in normal daylight. Credit: NASA.

Citizen Science Radio Experiments

NASA, HamSCI and W8EDU (Case Western Reserve University ARC, Cleveland, Ohio) developed various citizen scientist radio monitoring experiments and one and two-way communication events. In the case of Radio Amateurs using digital modes and/or WSPR beacons, those communications and beacon data were automatically live-streamed to the PSKReporter, WSPRnet or RBN web servers. Terabytes of data was collected, which will take time to analyze it all and write the various scientific papers explaining the results. The W8EDU CHU eclipse monitoring experiment (https://w8edu.wordpress.com/chu-eclipse-data-collection) appealed to me because it used the Canadian CHU time signal station located in Ottawa, Ontario, and I also knew that the day of the eclipse would be overcast with rain in my area so radio would have to be my “eyes” and “ears”.

Instead of just monitoring CHU on the day of, participating stations from Mexico to Atlantic Canada, could listen to one, two or all three CHU frequencies (3330, 7850 and 14670 kHz) for the two weeks prior. Fldigi was the digital signal processing (DSP) program used to record the CHU time signal carrier diurnal Doppler effect frequency shifts plus signal strengths as WAV (audio) files. I also had Fldigi record a separate CSV data file for my own use. The D-region forms at sunrise because of the incoming solar extreme ultraviolet (EUV) ionizing radiation—high-energy quantum particle "bullets"—which blast electrons free from atoms creating ions and the "ionosphere"—a hot plasma "soup" of "clouds" of charged particles (positive ions and negative electrons) that travel closely together because Earth's gravity keeps them from repealing each other and flying off into space; after sunset, they slowly recombine. Vertical and horizontal movements within the ionosphere's three regions (D, E and F) are influenced by: atmospheric dynamics, geomagnetic activity, very strong earthquakes and solar activity. It can twist, turn and/or undulate at velocities ranging from tens to hundreds of metres per second. In general, whenever the ionosphere dips over your head, incoming radio waves, depending on wavelength, are Doppler shifted up in frequency and vice versa when it rises (Figure 6).

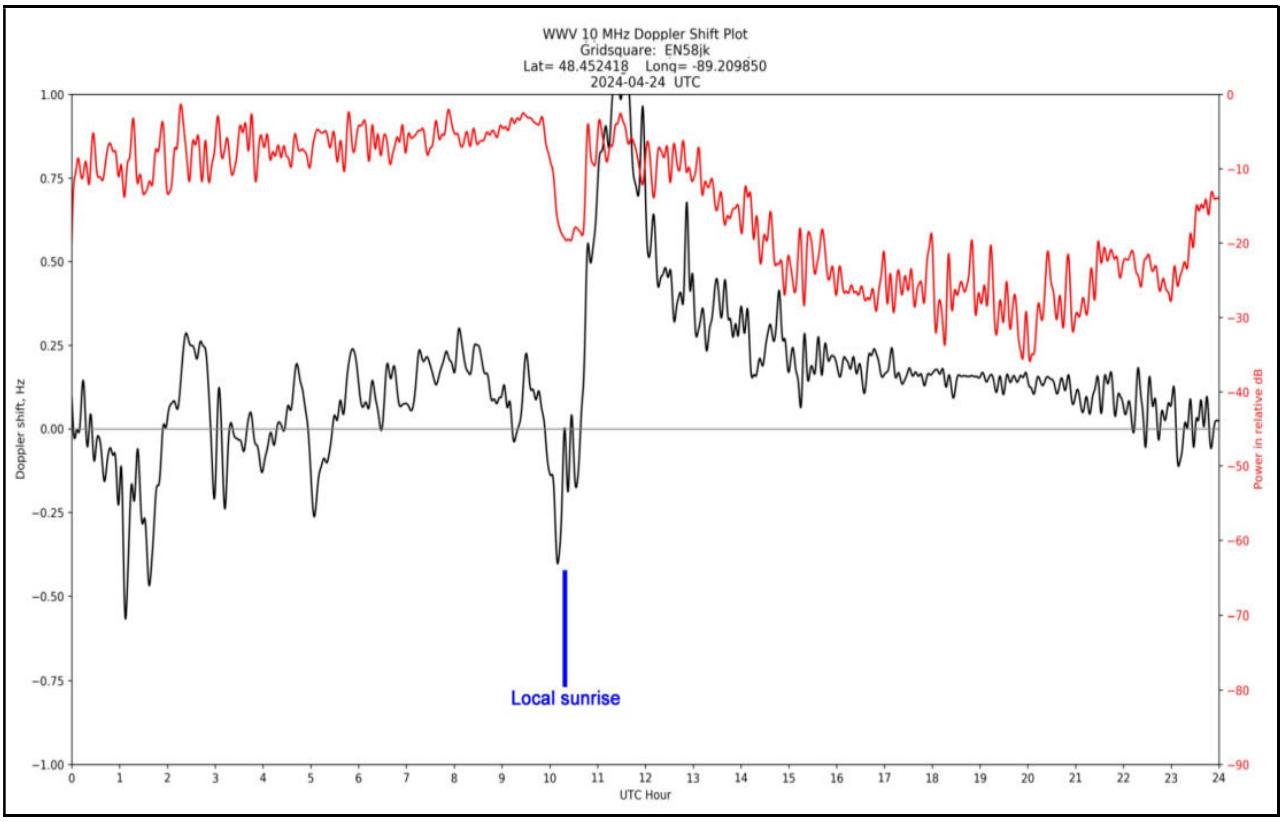


Figure 6: Normal Diurnal Ionospheric Doppler Shifts and Signal Strengths (10 MHz)

My Eclipse Monitoring Radio Results

A GPS disciplined software define radio (SDR) was used for the CHU two-week monitoring period, along with a ground-mounted multiband vertical antenna, Fldigi and SDR Console. Most modern consumer radios (receivers or transceivers) have slight plus/minus frequency errors that are usually less than one part-per-million, which is excellent for normal communications and data modes but not quite good enough for ionospheric research. Radios that can use GPS, correct receiver frequency errors to less than one part-per-billion, which allows the DSP software to detect, record and measure even millihertz Doppler shifts. Figure 7 is a graph of ionospheric effects on the NML VLF transmitter (25200 kHz) during the eclipse, followed graphs of the Doppler shifts caused to the CHU time signal carriers and changes in propagation for received WSPR spots (Figures 8 and 9, next page).

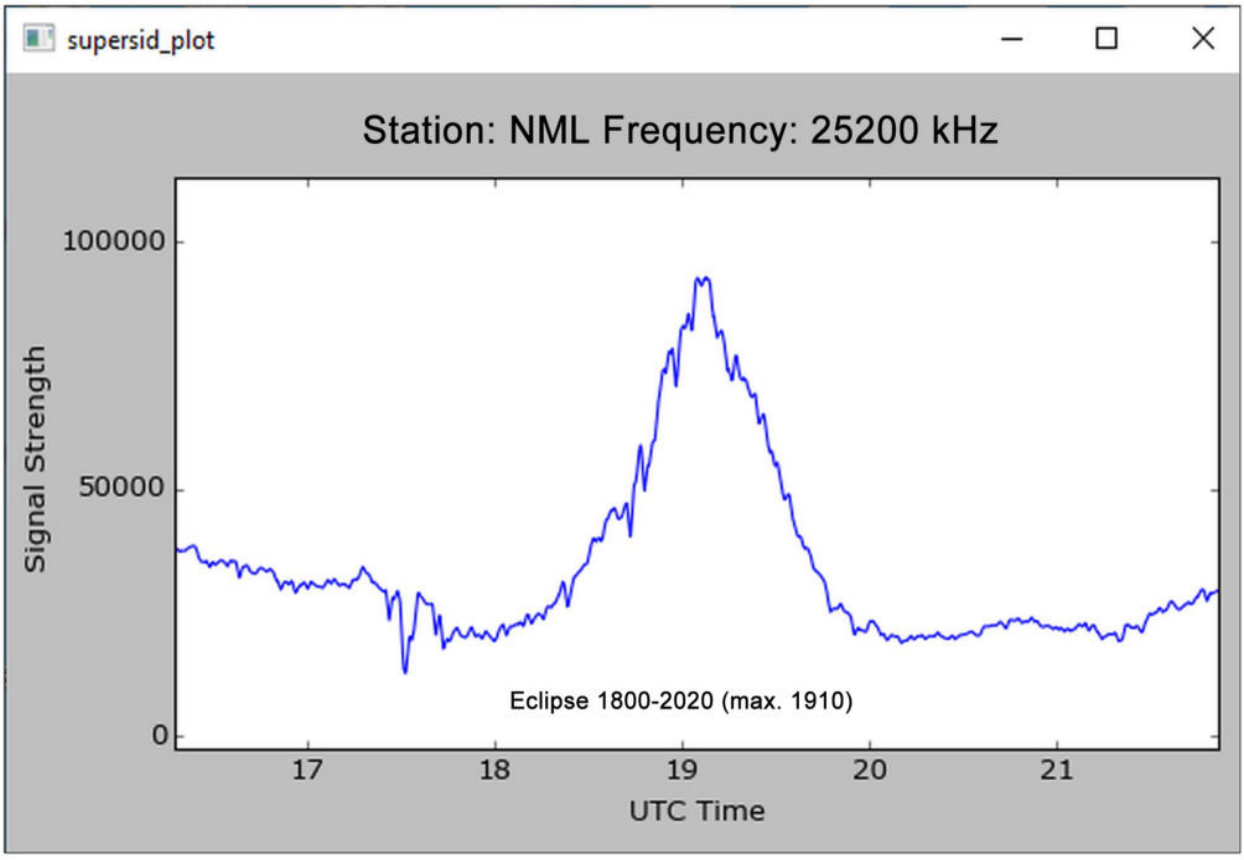


Figure 7: Effect on VLF Navy Beacon NML

During a normal space weather day, NML's high-powered (500 kW) signal transmitted from LaMoure, North Dakota (36 solar minutes to my west) is a flat line in VLF receiver plots, but the 70% partial solar eclipse in my area noticeably increased its signal strength from start to finish and especially at mid-eclipse.

Figure 8: Effect on CHU Signal Strengths

This plot clearly shows that the 3330 kHz time signal carrier signal strength (a 50 dB increase!) was affected far more than 7850 kHz ("only" a 20 dB increase). Note that the signal strength increase continues well after mid-eclipse for 3330 kHz but not 7850 kHz.

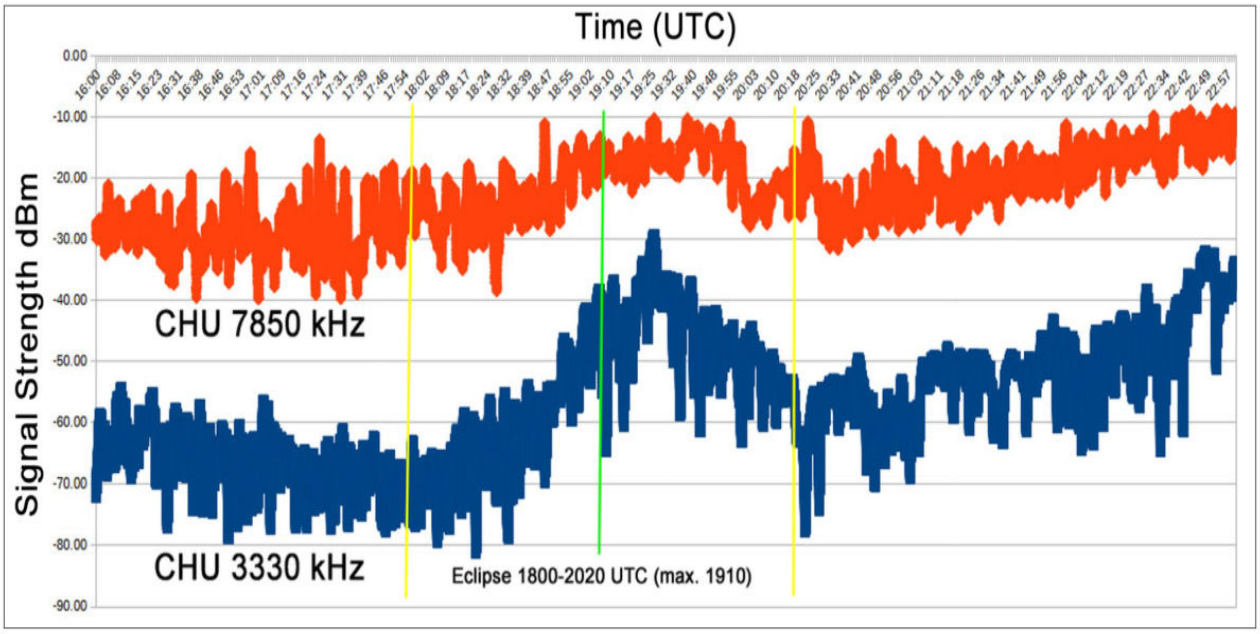
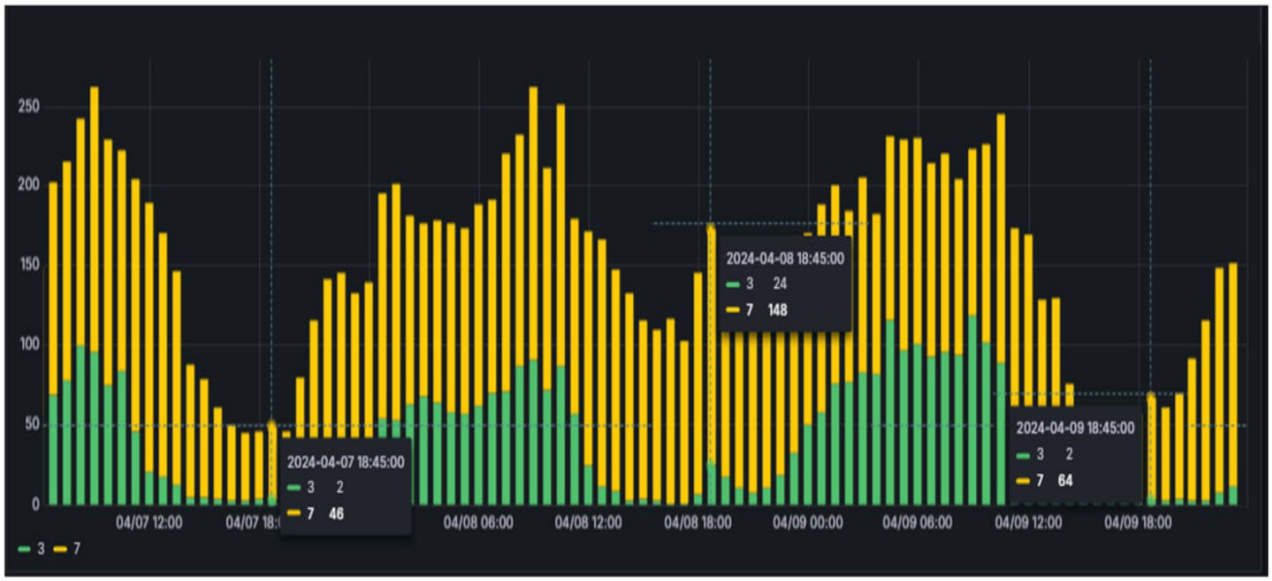


Figure 9: WSPR Spot Comparisons

My plotted WSPR receiving station spots for the days before, on and after the total solar eclipse for the 80 and 40 metre bands. Statistically speaking, there are far more 40 metre WSPR beacons transmitting in the day time as compared to 80 so there is a bit of "bias" that requires using other methods to analyze data. In this case, the spot increase for 80 metres was a factor of twelve (24/2) but only three (148/46) for 40.



My Final

This was the last “great” total solar eclipse that will cross the North American continent until 23 August 2037. If you cannot want until then, there is one visible from the far northern regions of North America travelling across to Europe on 12 August 2026, but because it is occurring farther north in latitude, totality will only last between two to three minutes. —73

Resources

CHU https://en.wikipedia.org/wiki/CHU_(radio_station)

Fldigi https://en.wikipedia.org/wiki/Fldigi

PSKReporter https://en.wikipedia.org/wiki/PSK_Reporter

Reverse Beacon Network (RBN) https://www.reversebeacon.net/index.php

WSPRnet https://en.wikipedia.org/wiki/Amateur_radio_propagation_beacon