RADIO MAGiC

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The Great American Annular Solar Eclipse

Special thanks to Ed Holland, KO6BLM, for providing me with his data of the annular solar eclipse effects on the WWV time signal carrier.

Introduction

On October 14, 2023, an annular (Latin: annulus or "ring") solar eclipse a 200-kilometre-wide path across the southwestern United States. On the average, only three to five annular solar eclipses are visible each decade from any inhabited spots on Earth unless you can travel to the far-off geographical regions that happen to be in the narrow swath of Luna's shadow as it crosses the face of Sol (Figure 1, next page). Fortunately, solar eclipses are now live-streamed from many areas along its path so all you need is an internet connection and your computer/smartphone to watch albeit it is not the quite the same as being there, experiencing and seeing it with your own eyes or a digital camera in the "wild" (Figure 2, next page).

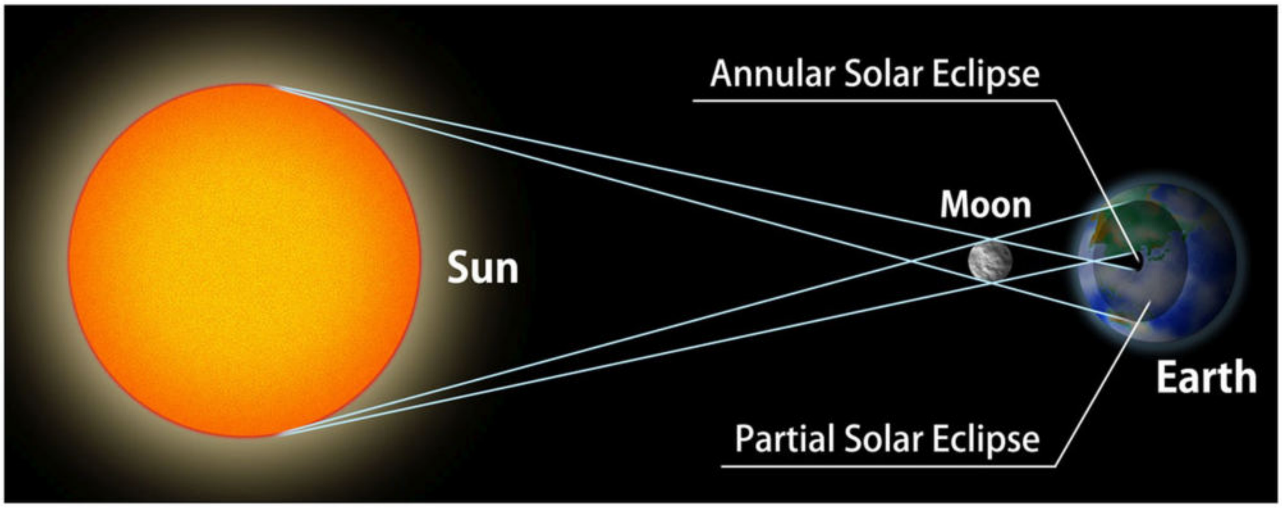


Figure 1: Annular Eclipse
Diagram not to scale: Credit: National Japanese Astronomical Observatory, Tokyo.

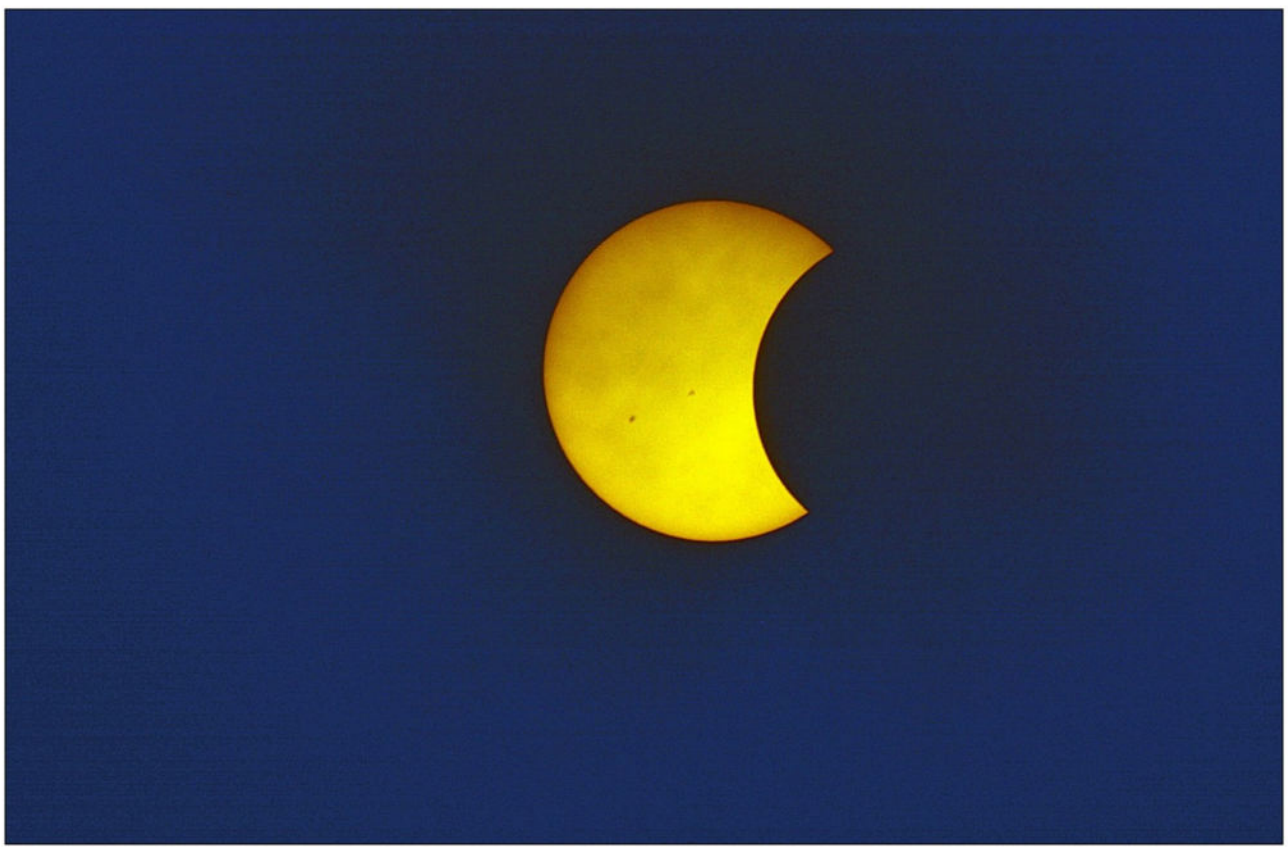


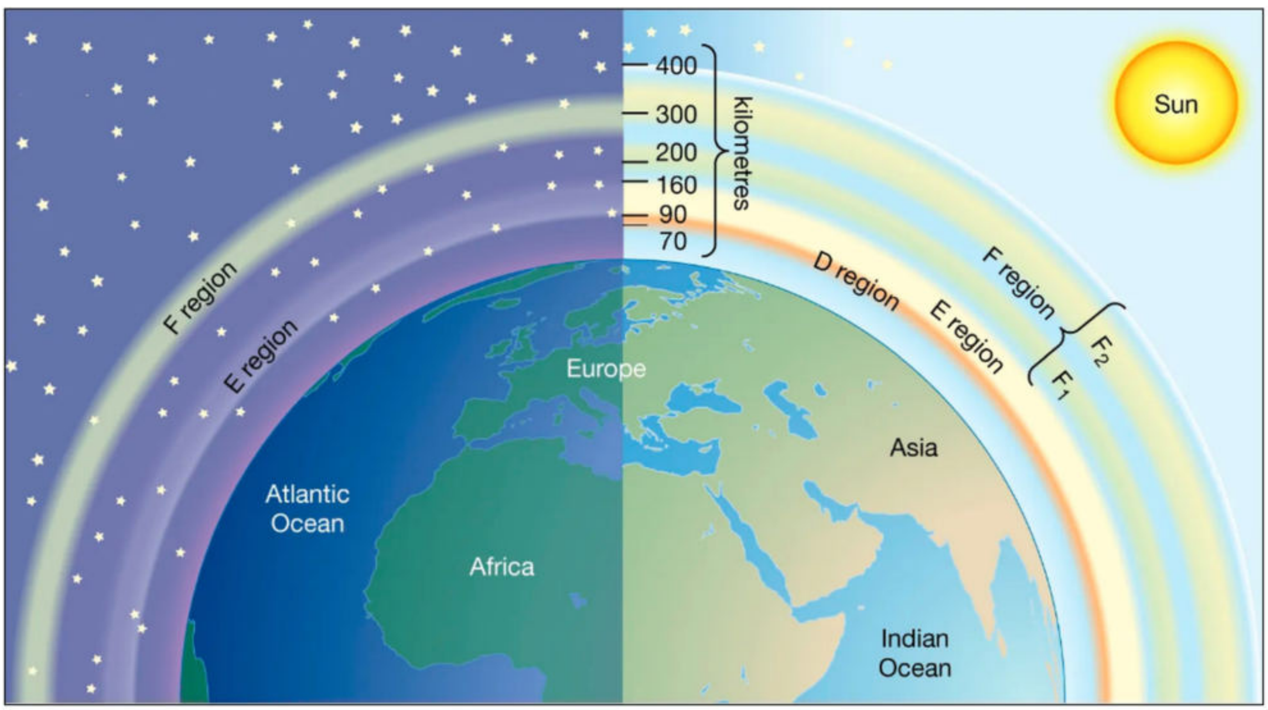
Figure 2: Partial Eclipse View from my Backyard
My sky was obscured by clouds so I only had a few fleeting views, but managed to get one good telephoto “Pac-Man” photograph that also caught a couple of large sunspot groups.

The "Ionosphere"

The ionosphere is a sub-region of the thermosphere (Figure 3) created by incoming solar extreme ultraviolet (EUV) ionizing radiation. On Earth's daylight side, the EUV photons contain so much energy that they are literal light speed quantum particle bullets blasting electrons free from atoms, creating positively charged "clouds" of ions (hence the name), and more importantly, negatively charged clouds of electrons, which creates a superhot, charged particle gas or "plasma". Earth's gravity is strong enough to hold these clouds close so they travel together in the Ionosphere so that ions cannot repel ions and electrons cannot repel electrons else our atmosphere would have slowly dissipated away as it did on Mars.

Figure 3: Regions of the Ionosphere

Credit: Encyclopaedia Britannica http://tiny.cc/rctivz



Ions are much too big and heavy for radio waves (lower energy photons) to affect them, but they can and do interact with electrons, which are responsible for reflecting/refracting of radio waves depending on their wavelengths and the ionosphere's total (free) electron count (TEC) or density in a specific region. After sunset, this plasma cools and ions and electrons recombine into neutral atoms. It is interesting to note that sunrise ionization occurs at a much faster rate than sunset recombination does.

In 1902, shortly after Marconi's transatlantic wireless conquest, Arthur E. Kennelly and Oliver Heaviside independently proposed that an electrical, "E" or Kennelly-Heaviside layer existed in the upper atmosphere and was created by daytime solar radiation. But it was the Amateurs of the early 1920s who had been legislated up to the "useless" shortwave radio bands in 1912—and off-air during World War I—who discovered that not all radio waves are created equal, and that they behaved differently depending on their wavelengths, time of day, time of year plus how many sunspots were visible on Sun's surface.

Amateurs on both sides of the Atlantic conducted coordinated and now very famous transmitting/receiving experiments, which proved the existence of the Kennelly-Heaviside layer because they could easily span the Atlantic using less transmitter power and smaller Hertzian or dipole antennas and Marconi (quarter-wave) verticals using short waves. By the mid-1920s, this reflecting/ refracting layer was scientifically probed and it was quickly discovered that there were actually multiple electrical regions at different altitudes, eventually named D, E and F (further subdivided into F1 and F2). In 1926, in keeping with the naming convention of atmospheric layers, "ionosphere" was coined by Robert Watson-Watt in a letter published in the scientific journal *Nature*.

The Ionosphere's Behaviour during Solar Eclipses

Earth's ionosphere influences both the reflection (longer wavelengths) and refraction (short wavelengths) of radio waves, and solar eclipses affect the various regions of the ionosphere to differing degrees.

1) Very Low Frequency (VLF)

VLF radio waves are typically used for communication with submarines and for studying atmospheric phenomena. The decrease in overall incoming solar radiation weakens the lowest D (or "absorption") region and decreases the TEC density allowing VLF radio waves to travel higher up and farther out because they are now reflected by the E region. Unfortunately, my "go to" VLF beacon NML (Lamoure, North Dakota) was off air so I was not able to use receive and analyze its signals during the annular eclipse.

2) Low and Medium Frequency (LF and MF)

As with VLF, LF and MF radio waves can experience changes in propagation behaviour. These bands are used for global navigation beacons, time signal stations (WWVB, et al), commercial AM broadcasting stations along with Amateurs who have been allowed to return to the to the radio world below 200 metres. WWVB and similar time signals as well as distant commercial AM broadcast stations may suddenly appear briefly or even for a few minutes when the D-region weakens or totally dissipates then just as suddenly disappear when the solar eclipse is over and the D-region reforms quickly. By using 80 or even 160 metres, combined with a fast, two-way, weak-signal digital data mode like FT8, you could make some very interesting solar eclipse-dayside to nightside long-distance (DX) contacts that would not normally be possible.

3) High Frequency (HF)

HF (shortwave) is commonly used for long-distance communications and the ionosphere's response to a solar eclipse can lead to sudden variations in signal strength along with changes in propagation. In some cases, these changes in ionospheric conditions may enhance HF propagation, but it can sometimes result in sudden and strong signal absorption or fading.

My Locally Observed Annular Eclipse Effects

In this century, anyone can become an on-the-spot "i-reporter" or "citizen scientist" and observe, record and live-stream terrestrial and/or celestial events. A local astronomy club can be very helpful because they usually set up observation sites open to the general public. Amateurs can also join in and show off the radio besides the visual side of such events. As it turns out, many of us are also amateur astronomers plus quite a few are also amateur meteorologists with backyard personal weather stations (PWS).

1) Weather

Under ideal clear sky conditions, I would normally use my handheld infrared (IR) thermometer to shoot a narrow IR beam straight up, which is reflected back by atmospheric water vapour to measure the background sky temperature at minute intervals. This determines if the solar eclipse has any affect on the background sky temperature, but there cannot be any much warmer clouds in the way reflecting the IR beam. I recently replaced my old wired weather stations with the awesome Tempest Wi-Fi PWS (http://tiny.cc/8hjjvz and https://tempestwx.com/map), which has the usual weather sensors plus a skyward looking ambient light, solar radiation and UV index integrated sensor. All weather sensor data are live-streamed (also archived) to your Tempest and (optionally) Weather Underground web server (or other) accounts for free use by fellow hobbyists, scientists, meteorologists, climatologists and so on.

2) Commercial AM Radio (MF)

I was able to receive the 5-kilowatt (kW) ESPN AM radio station WEBC on 560 kilohertz (kHz) located in Duluth, Minnesota, 150 nautical miles (nm) to the southwest at about a "3 by 3".

3) Weak Signal Propagation Reporter (WSPR) (HF)

Joe Taylor, K1JT's, weak signal propagation reporter (WSPR) hit the airwaves in early March 2008 so we have 15 years of archived data that can be used for research. But downloading humungous zip files from the WSPRnet server archives then extracting the data you need is not easy especially if you do not have any experience using database processing languages such as "SQL" (Sequel). But now there is "WSPR Live" (https://wspr.live) with its amazing and easy to learn Grafana graphical user interface (GUI or "gooey"), which provides many ways to extract, analyze and display all WSPR data going back to day one! But I only had enough received data at my location for the 40-metre band to see the effects of the solar eclipse (Figure 4, next page).

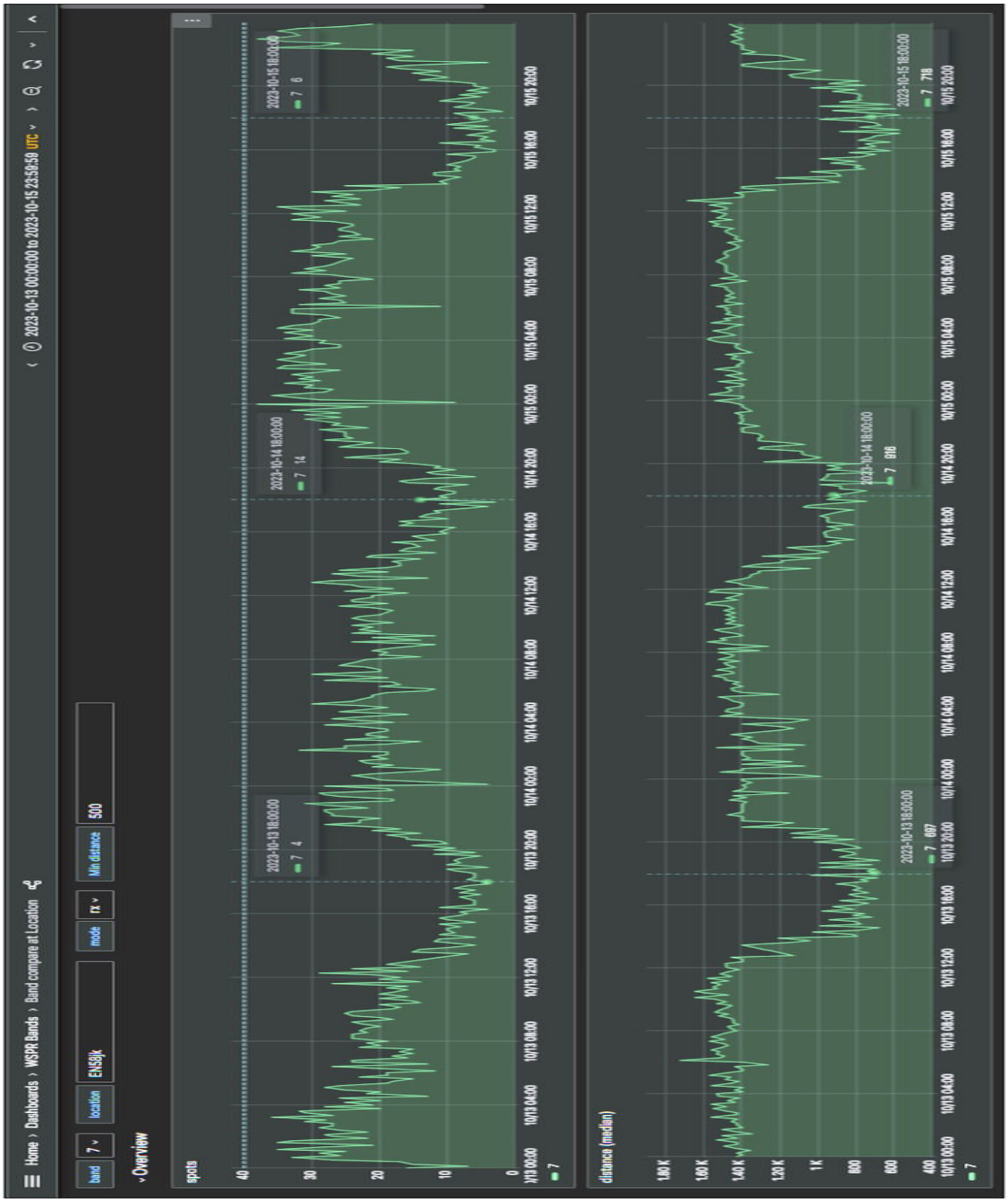


Figure 4: Solar Eclipse Effects on Received 40m WSPR Signals

Analysis of my 40 m received WSPR signals for the day and times before, during and after the annular solar eclipse. At 1800 UTC, each day: 4 spots/max range 697 km, 14 spots/max range 916 km (annular solar eclipse) and 6 spots/max range 718 km. Grafana can help you analyze all solar eclipses or any other space weather events from March 2008 to the present to hunt for any ionospheric effects on the various wavelengths/frequencies of WSPR signals.

Credit: https://wspr.live

4) WWV (HF)

The free ldigi (http://www.w1hkj.com) digital transmitting/receiving signal processing (DSP) software has a nifty frequency measuring test (FMT) module to detect, record and plot even millihertz Doppler frequency shifts in time signal carriers caused by the ionosphere along its undulating path to you (Figure 5).

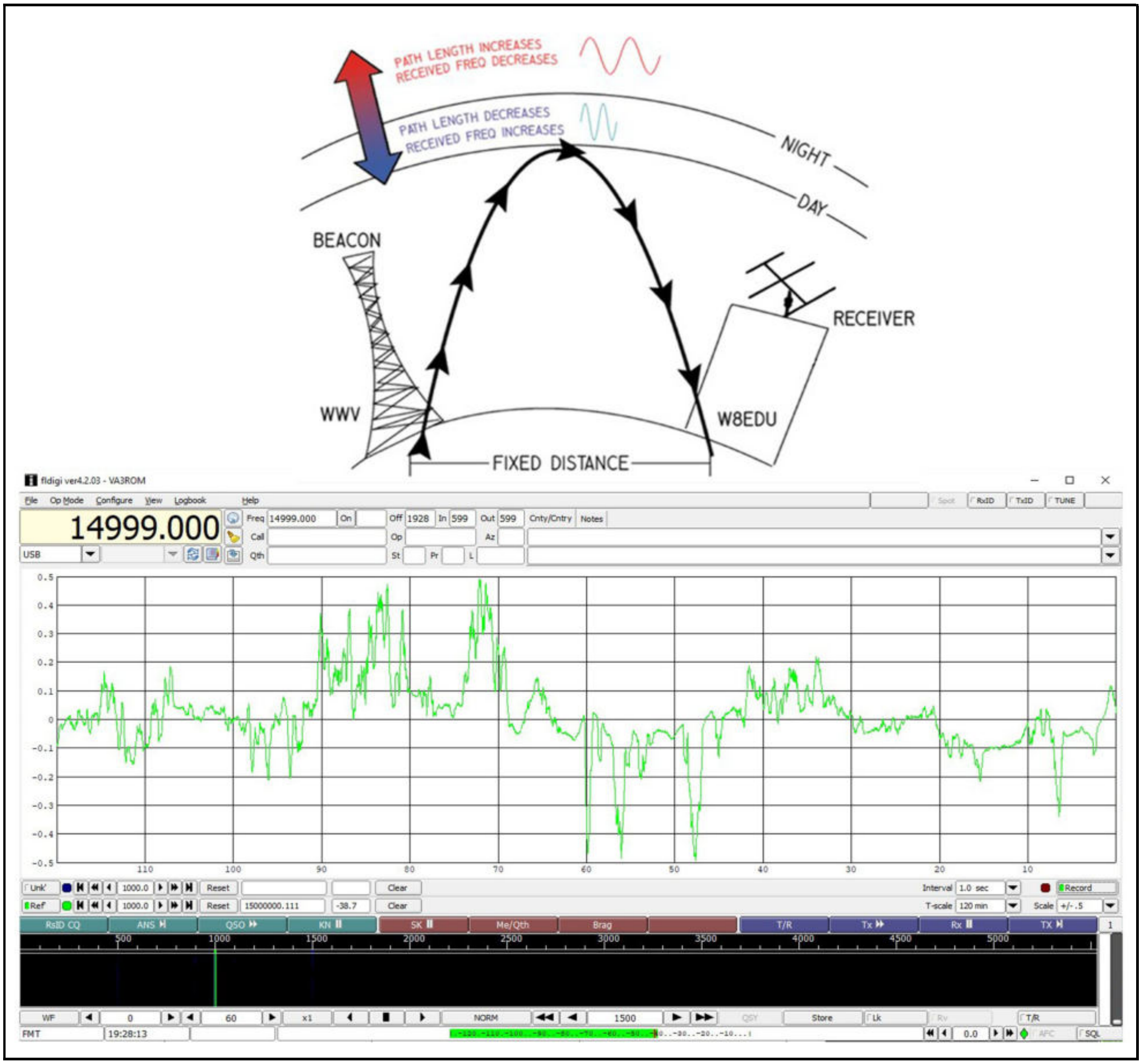


Figure 5: Measuring WWV Carrier Ionospheric Induced Doppler Shifts
Example using the Fldigi FMT module to monitor the WWV 15 MHz carrier at one second intervals with real-time plotting over two hours (option to save data to CSV files). The insert explains the ionosphere's Doppler frequency shift effects. Credit: Insert Case Western Reserve University ARC (W8EDU), Cleveland.

Normally, these Doppler frequency shifts are usually only about +/- 0.5 Hz, but sunrise, sunset, solar flares, particle storms and solar eclipses, and so on can really intensify the Doppler shifts. Simply tune your receiver (analog or digital) in the upper sideband mode (USB) 1000 hertz (Hz) below any WWV (or other) time signal carrier to heterodyne (algebraically mix radio signals) with the carrier creating a 1000 Hz audio signal difference and Fldigi will do the rest. Because the lower HF bands are the most affected, you would use the 2500 kHz WWV time signal (for North America) and tune to 2499 kHz (USB), which results in 2500 – 2499 = 1 kHz or a 1000 Hz audio signal that any computing device's soundcard can easily process using Fldigi or other DSP software.

Of course, I forgot to do this on the day of the solar eclipse, but fortunately Ed Holland, KO6BLM, a newly-minted Amateur did. He was also much closer of the path of annularity with 76% coverage near San Jose, California as compared to my 34% up in Thunder Bay. Ed used a different, free DSP program called "Spectrum Laboratory" https://www.qsl.net/dl4yhf/spectra1.html (Figure 6).

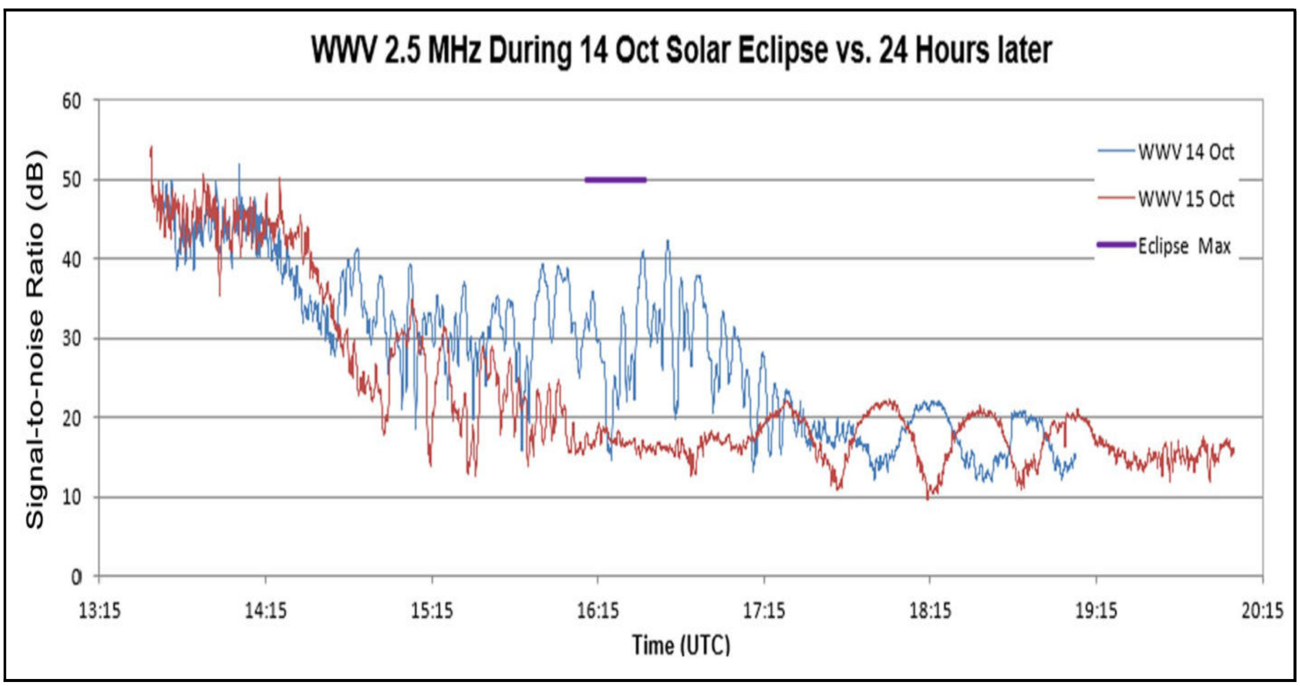


Figure 6: Using Spectrum Laboratory to Observe Solar Eclipse Effects
KO6BLM's, plots of the WWV 2.5 MHz carrier's signal-to-noise ratios (SNR) for the day before and day of the annular solar eclipse (partial for him, too). Credit: Ed Holland, KO6BLM.

My Final

The HamSCI group has designed many interesting ionosphere and propagation experiments that Amateurs, citizen scientists, schools, groups and clubs can participate in during solar eclipses and other space weather events (https://hamsci.org/projects). I call your attention to this because on April 8, 2024 the last "great" North American total solar eclipse (in this decade) will start in Mexico, cut across the United States (from Texas to Maine) then travel through Canada (southern Ontario/Quebec and the Maritime provinces). Weather permitting, a partial solar eclipse, in varying percentages of solar disk coverage, will be visible across almost all areas of North America (except Alaska). Clear skies! —73