

HF Doppler Studies of the 2024 Total Solar Eclipse

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ABSTRACT

Due to the widespread effects of its variability, study of the Ionosphere, the critical boundary between Earth's atmosphere and space, is of interest to not just to scientists, but also to Ham Radio Operators. The Ham Science Citizen Investigation (HamSCI) combines the efforts of both groups to study the region through crowd-sourced observations, such as the 2024 Solar Eclipse QSO party. An eclipse's resulting change in photoionization affects a transmission's point of reflection, which appears as a doppler shift in the received spectra. High Frequency (HF) doppler measurements are an effective tool for studying ionospheric condition as they reveal atmospheric changes, and with a better understanding of how an eclipse effects ionospheric conditions, we will better understand ionospheric variability.

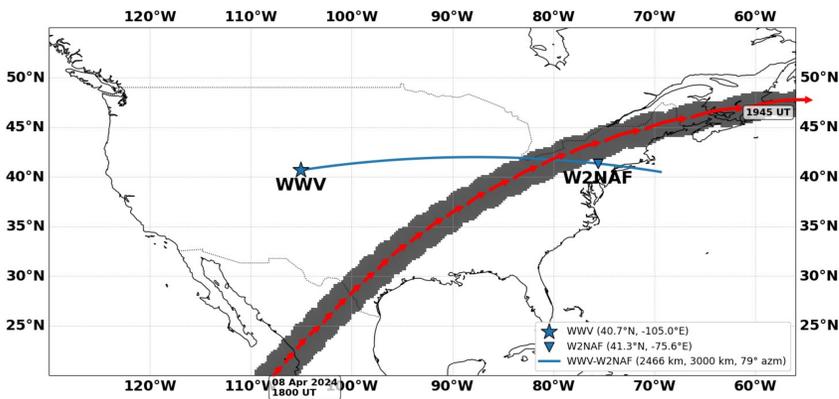


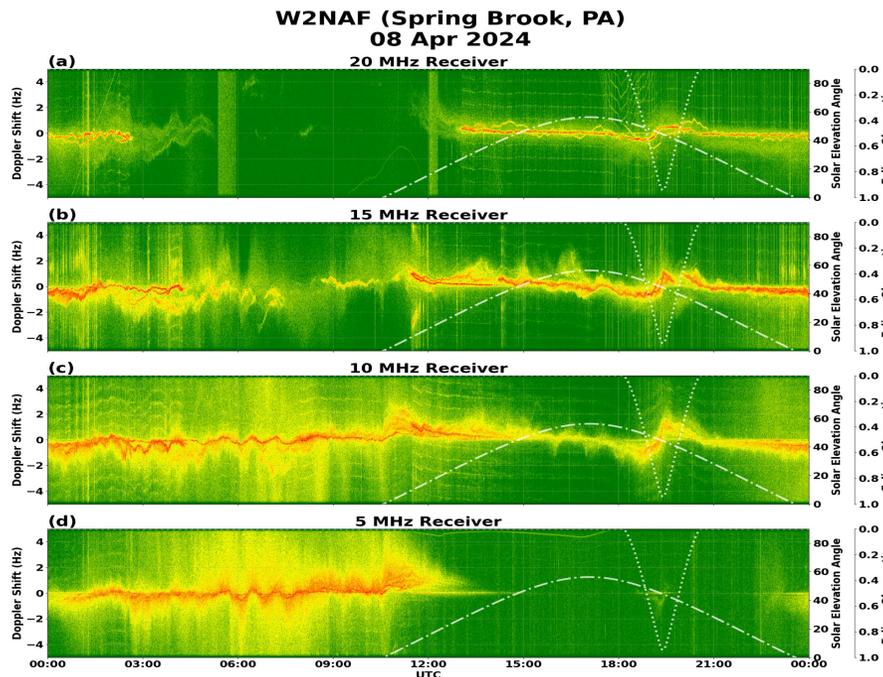
Fig. 1: Map of the United States, marked with the path of totality for the 2024 total solar eclipse. The relevant transmitters (CHU in Ottawa, Canada and WWV in Colorado, USA) are marked with stars. Our receiver, W2NAF, is marked by the orange triangle in Northeastern Pennsylvania.

BACKGROUND

- Studying Ionospheric variability is important to both space physicists (to better the scientific understanding of the Ionosphere) and Ham Radio Operators (due to the region's effects on radio propagation)
- Both groups, via Ham Science Citizen Investigation (HamSCI) collaboration, ran their first eclipse-ionosphere experiment with the 2017 Solar Eclipse QSO Party, a contest-like event that generated ~2.5 million transmissions around the eclipse
- Eclipses, with their impulse-like changes in photoionization and ionosphere electron dynamics, provide constrained experimental conditions ideal for studying Ionospheric variability
- After success in 2017, HamSCI organized more Solar Eclipse QSO parties, including for the 2024 Total Solar Eclipse, with an expanded scope, including examining high frequency (HF) doppler measurements.
- During an eclipse, changes in photoionization shift a transmission's point of reflection: during totality's onset, the point of reflection rises, resulting in a decreased path length and a drop in frequency; the inverse occurs post-totally. Analyzing this doppler shift will allow a better understanding of the Ionosphere's conditions during an eclipse.

DOPPLER MEASUREMENTS

Fig.2: Doppler HF Measurements (in Hz) for the 2024 total eclipse received at W2NAF at 5, 10, 15 and 20 MHz



- Doppler measurements were observed via a GRAPE receiver in Spring Brook, PA. Transmissions were received from WWV (2.5, 5, 10, 15, 20, 25 MHz) or CHU (3.33, 7.85, 14.67 MHz). Geomagnetic and solar conditions were mild on Eclipse day
- GRAPE observations were analyzed by code written by G. Griffiths G3ZIL, estimating the mean doppler shift via time domain processing. Path Velocities were calculated by $v = -f' = (c/f_0)$

ACF Doppler W2NAF at 10.0 MHz

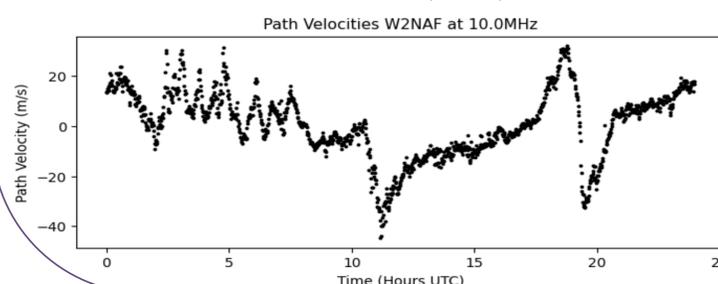
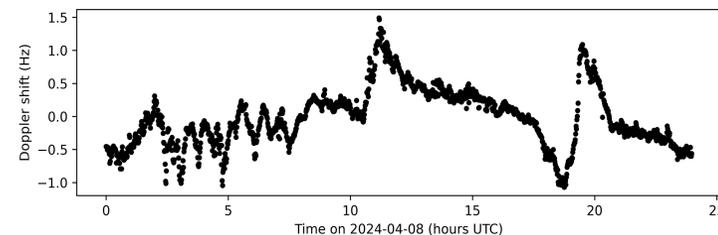


Fig. 3 (Above): Extracted Doppler HF Measurements (in Hz), and Fig. 4 (Below) the resulting path velocities (in m/s) for the 2024 total and the resulting path velocities for the 2024 total eclipse received at W2NAF at 10MHz. In both plots, the distinct S-curve for eclipse doppler shift is visible.

RAY TRACING

- For our purposes, we wish to extract the path length of the transmission from the path velocity plot
- True path length is the area under the curve (as the variation in path length due to ionospheric activity) added to the geometric path length
- We estimate the geometric path length (pl_g) via raytracing, via Shibaji Chakraborty's Trace Python wrapper for the raytracing software PHaRLAP
- Isolating the ray that reaches the receiver, our simulation estimates a pl_g of ~4099 km for a 2-hop path between WWV and W2NAF
- Our simulation uses the International Reference Ionosphere (IRI) model, which does NOT account for the eclipse: next step is to raytrace with a model that does account for the eclipse for all 9 frequencies
- Then with our estimated path lengths, we can estimate the heights of the ionosphere layers during the eclipse

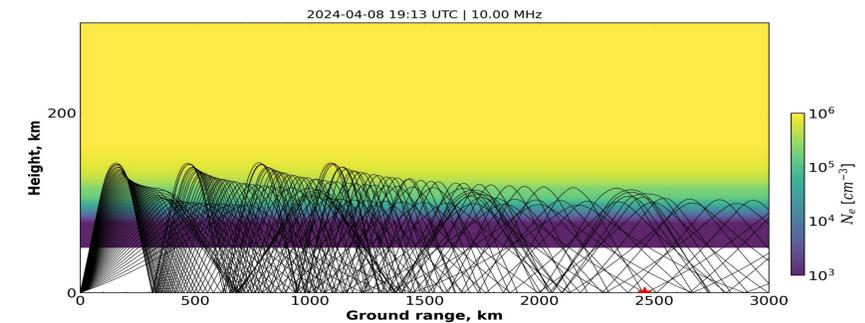


Fig. 5: PHaRLAP trace of the transmissions between WWV (the origin) and W2NAF (marked with a red star) on April 8th, 2024, plotted as a height of the transmissions vs the ground distance covered, both in km. The colored region represents the ionosphere, with the gradient showcasing its electron density. A 2-hop transmission reaches the receiver at W2NAF

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