Sunrise: A natural perturbation enables identification of propagation modes from distinct Doppler shifts

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Introduction

Every day sunrise increases ionospheric electron density. Reflection height falls, reducing phase path length, seen as positive Doppler shift. GRAPE Personal Space Weather Station spectrograms show many instances of multiple Doppler traces, e.g. **Fig. 1**. It is easy to spot propagation via the E region and via F2 layer one- and two-hop. But for other traces the propagation mode may be a puzzle.

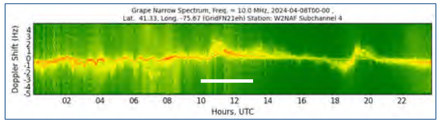


Fig. 1. Spectrogram of WWV 10 MHz Doppler shift at W2NAF on 8 April 2024 with a bar showing the time of interest around sunrise.

In this poster I drop the usual constraints of great circle path propagation and specular ground reflection. Using PyLap ray-trace modelling in creative ways lets us test the possible origins of those puzzling propagation modes.

Method

The hours around sunrise on the 2460 km path between WWV and W2NAF (nr. Scranton, PA) on 10 MHz provides several puzzling Doppler traces. Using data from the PSWS database [1] a simple Python script yields a more detailed spectrogram, **Fig. 2**, than the quick-look **Fig.1**.

Python processing using wavelet transforms and machine learning predictions is used to extract digital values of Doppler peaks for individual propagation modes [2].

Intersection of ray landing spots from 3D PyLap modelling of transmitters both ends of the path suggests likely areas of two-hop sidescatter [3,4], either side of the the great circle path, **Fig. 3**.

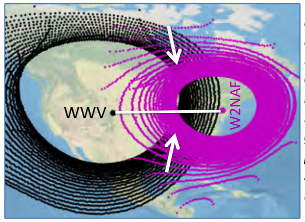


Fig. 3. Map showing the ray landing spots from PyLap with transmitters at WWV and W2NAF immediately before the band opens for two-hop great circle propagation. Likely side scatter arises where the landing spots overlap.

Modelling two separate hops along the great circle path lets us explore non-specular reflection modes. For example, we can try combinations of E, Es and F2 hops where angle of second hop take-off is not exactly angle of first hop arrival.

Results: Ray Tracing in 3D and 2D with Side and Forward Scatter

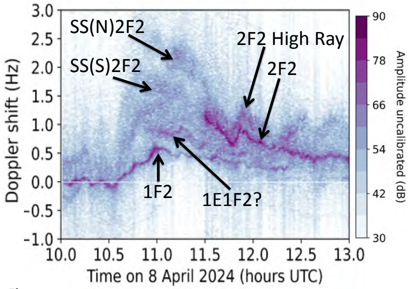


Fig. 2. Zoomed-in spectrogram of WWV 10 MHz Doppler shift at W2NAF around sunrise (11:31 UTC at surface mid path) on 8 April 2024 derived from digital_rf data.

Two hop sidescatter modes from north **SS(N)2F2** and south **SS(S)2F2** indicated in **Fig. 3** are clearer in the likelihood contour map, **Fig. 4**. The N and S tips converge ahead of two-hop great circle propagation onset. This explains convergence of these two Doppler traces in the spectrogram, **Fig. 2**.

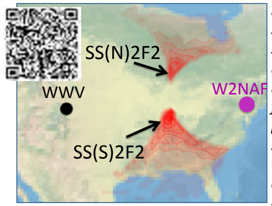
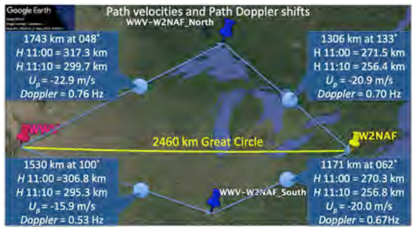
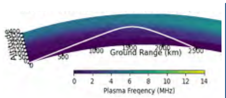


Fig. 4. Contour map showing the linear sidescatter likelihood metric ten minutes before 10 MHz opened for 2F2 great circle propagation. Likely sidescatter areas to the north and south are distinct. Scan QR code for animation.

Around sunrise electron density, hence rate of change of height of reflection (Doppler), varies N/S and E/W. The difference of 2D PyLap ray apogees ten minutes apart at the four sidescatter paths' ionospheric reflection points shows a distinct difference in N vs. S Doppler: higher to the N. But, both are ~40% lower than actual Doppler, **Fig. 2**.

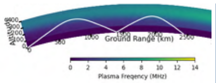


1F2 – At 11:00 UTC the single hop apogee was 234 km at a take-off angle of 3.5˚. Increasing absorption as the sun rose reduced signal to noise ratio. By 12:30 UTC 10 MHz had closed for **1F2** mode. The Table compares measured Doppler at 11:05 UTC with three estimates via 2D PyLap computed from path differences between 11:00 and 11:10 UTC.



Method	Doppler (Hz)
Measurement	0.53
PyLap apogee + simple symmetric geometry	0.27
PyLap geometric path length	0.29
PyLap phase path length	0.35
PyLap's own computed Doppler	*-3.04*

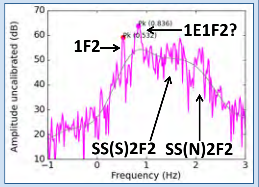
2F2 – Increasing electron density as the sun rose reduced **2F2** skip zone with sudden appearance of **2F2** mode at W2NAF at 11:30 UTC. A high angle of arrival (30˚ at 12:05 UTC) and less distance through D and E absorption regions gave a stronger signal. This was especially so during the first 30 minutes due to convergence of high and low rays [2].



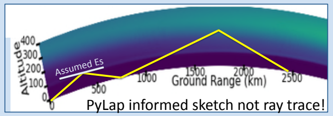
Method	Doppler (Hz)
Measurement	0.65
PyLap apogee + simple symmetric geometry	0.39 + 0.50 = 0.89
PyLap geometric path length	0.49 + 0.56 = 1.04
PyLap phase path length	0.33 + 0.43 = 0.76

For both **1F2** and **2F2** paths the modelled Doppler shifts computed from phase path differences most closely matched the measurements. This is encouraging. However, note that PyLap's own computation of Doppler shift (list *ray_data*, numpy array *Doppler_shift*) is incorrect.

The trace labelled **1E1F2?** is open for discussion. It does not occur every day. On 8 April 2024 it appeared suddenly at ~11:00 UTC. It had greater Doppler, a wider spectrum, and higher amplitude than **1F2**.



These features are compatible with a two-hop mode. The wider spectrum might suggest a degree of forward scatter: that is, ground reflection not entirely specular. Here's one possible scenario: a sporadic Es first hop, apogee 97 km, 14˚ angle of arrival, on a 755 km path. One hop F2, apogee 245 km, take-off angle 12.9˚, at 1705 km completes the path.



Method	Doppler (Hz)
Measurement	0.84
PyLap apogee + simple geom	0.05 + 0.36 = 0.41
PyLap phase path length	0.09 + 0.38 = 0.47

Similar Doppler calculations to above show **1E1F2** to have a higher Doppler than **1F2** but the phase path result was only 56% of the measurement.

Conclusions

HamSCI GRAPE Personal Space Weather Station spectrograms may show several Doppler traces from different propagation modes. Attribution to a particular mode may be simple in some cases yet a real puzzle for others. Not all traces are distinct, some are fuzzy: yet they are not noise but signals.

Here are some pointers for traces encountered around sunrise, although details will depend, among others, on path length, frequency, sunspot number:

- Distinct, fine-line traces that show a positive Doppler shift rise and then fall are likely via the F2 layer. One- and two-hop may co-exist, or two-hop may follow on from one-hop.
- A single distinct fine-line trace that hardly varies through sunset may be via the E region. E region change in height through sunrise is less than for the F2 layer. However, do check there is no local RF source e.g. at 5 MHz or 10 MHz giving fine trace at these frequencies or harmonics.
- Fuzzy traces are the signature of two-hop sidescatter. This family of modes may precede the band opening for one- or two-hop propagation. If the path is east/west the sidescatter sources will be to the north and south (and vice versa). The Doppler may be different from the distinct scattering areas, but will likely converge immediately prior to the band opening for a great circle mode.
- A trace may exist for a short time. If after the band opens it may be a 'high ray' [2]. Or, if it appears suddenly with minimal Doppler it may be sporadic Es, if it has significant Doppler it may be a combination of E or Es and F2.

References

[1] Quick-look plots and data in digital_rf format can be obtained from https://pswsnetwork.caps.ua.edu/

[2] Discussed in Griffiths, G., HamSCI Science online 31 October 2024 available at https://youtu.be/qcM5_IKjvw4?feature=shared&t=83

[3] PyLap, 2024. https://github.com/hamsci/pylap

[4] Griffiths, G. et al., Ray-trace Modeling of Diurnal Variation in Two-hop Sidescatter Propagation. HamSCI Workshop, 2024.

Acknowledgements

The impetus for this study were questions raised on propagation modes on the day of the April 2024 eclipse from Dr Mary Lou West and collaborators during enjoyable HamSCI Science discussions. I'm grateful to Dr Nathaniel Frissell , Devin Diehl and University of Scranton for PyLap ray tracing, supported by NSF Grant AGS-2045755. (*PyLap uses the HF propagation toolbox, PHaRLAP, created by Dr. M. Cervera, Defence Science and Technology Group, Australia, available from manuel.cervera@dsto.defence.gov.au*). I acknowledge use of the International Reference Ionosphere (IRI, irimodel.org), and open-source software including python, numpy, cartopy and others.