A Low-Cost Low-Power Chirp Ionosonde for Studying Eclipse Ionospheric Impacts

Gerard N. Piccini[1], Robert W. McGwier[1], Robert A. Spalletta[1], Nathaniel A. Frissell[1], Majid Mokhtari[1], Philip J. Erickson[2]

[1]University of Scranton, [2]MIT Haystack Observatory

Introduction

The ionosphere is a highly active region of the atmosphere characterized by ions and electrons, and as such, the ionosphere experiences changes in electron density based on the energy absorbed from the sun. Ionospheric sounding systems (ionosondes) are radar systems that transmit a signal towards the atmosphere. This signal is refracted back to the Earth's surface where it is received. The recorded time difference between the signal being transmitted and received can be used in conjunction with a knowledge of the speed of light and the path of flight to calculate the height profile of the plasma frequency of the bottomside.

There are two main types of ionosondes. Oblique ionosondes require two separate systems in different geographical locations which is more costly, requires more space, and introduces difficulty in synchronizing the clocks. Vertical instance ionosondes can be contained within one system. This reduces the difficulties associated with oblique ionosondes. New software defined radio (SDR) technology and advanced digital signal processing (DSP) enable significant reductions in the size, cost, and power demands of an ionosonde system compared to traditional systems. In this poster we present our progress in developing a low cost, low power ionosonde.

Methodology

We have an experimental license granted by the FCC that enables us to transmit between 2 MHz and 10 MHz at up to 300 watts. For the 2024 total solar eclipse we used our ionosonde system which utilizes an Ettus N200 Universal Radio Peripheral (USRP), and two multiband fan dipoles. We intend to transition from using the costly Ettus USRP to the more cost-effective Red Pitaya SDRlab 122-16. At the time of the eclipse, our Red Pitaya system was still in development, so to sound the ionosphere during the eclipse, we used an Ettus. By utilizing GNU radio software, we can program the Ettus in a way that will make transitioning to the Red Pitaya straightforward. The software generates a chirp, transmits through our TX antenna, and records the echo on from the RX antenna. Then using python, we cross correlated the chirp and the recorded signal. By finding the difference in time between peaks in the correlation, we were able to find the time delay between the direct path and the return echo. Using this, we calculated the virtual layer height using the known speed of light and accounting for the near vertical path.

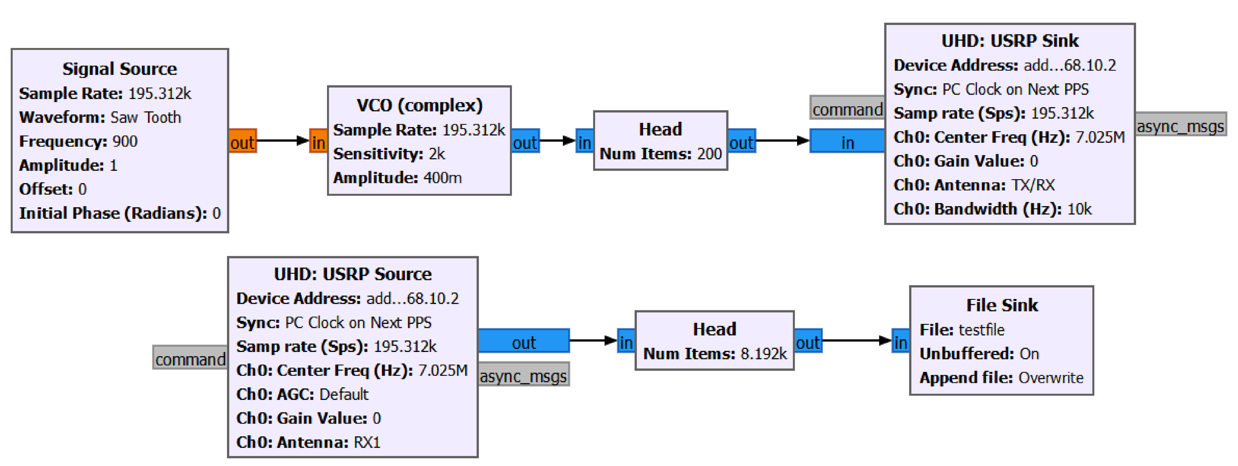

Figure 1. GNU Radio software that runs the ionosonde

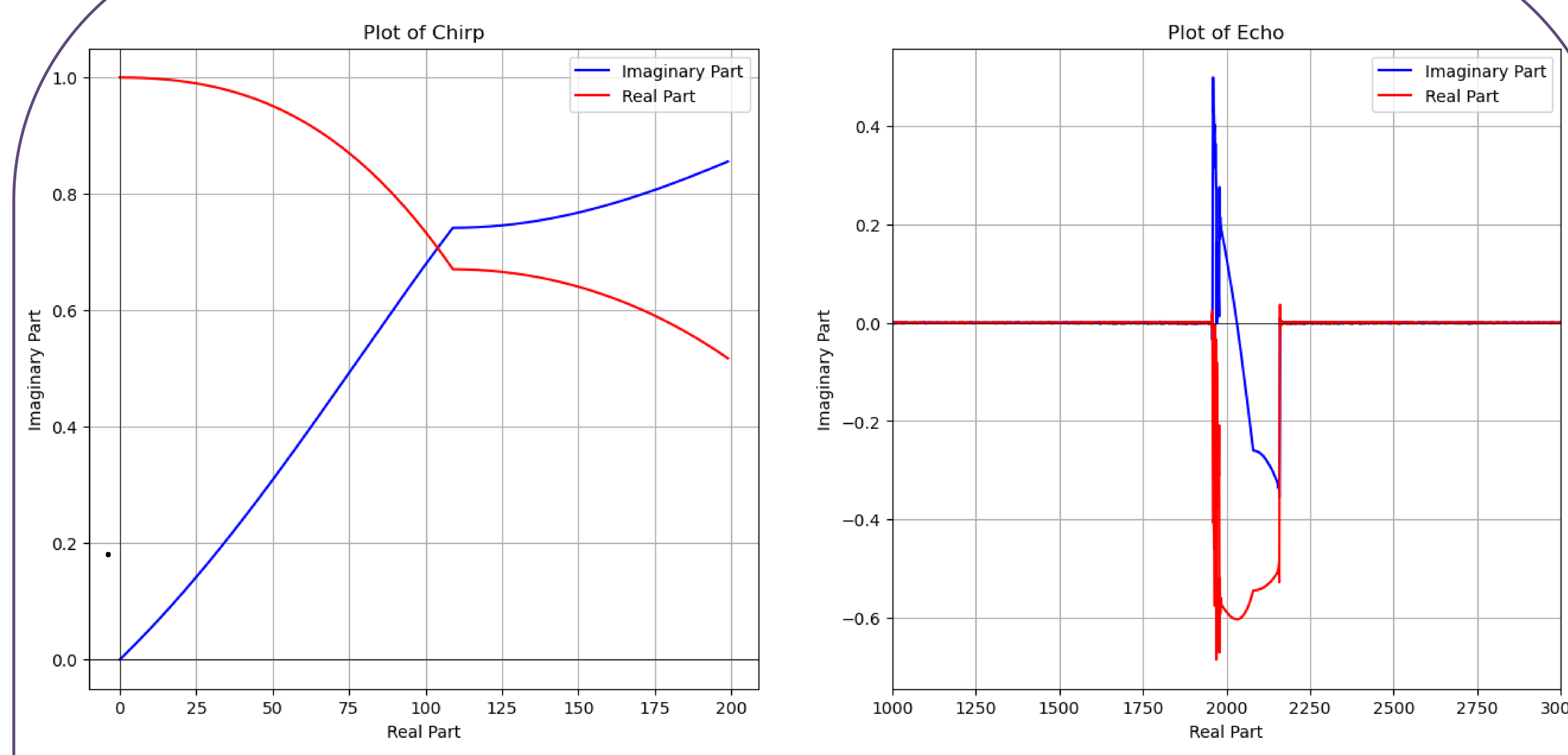

Figure 2. The left plot shows the chirp that we transmitted through the USRP, and the right plot shows what was recorded by our receive antenna. This includes the direct path of the chirp between the TX and RX antennas as well as the echo off the ionosphere

Results and Discussion

Using our system, we were able to sound the ionosphere during the 2024 solar eclipse. We calculated the virtual layer height and plotted the results in Fig. 3. For reference, the virtual layer heights measured by the ionosonde on Wallops Island are also plotted in Fig. 4. The heights from our Scranton Ionosonde align very closely to the Wallops values, and the trend of our data follows closely to the trends of the Wallops data. In addition to the trends being similar, in Fig. 4 during the night, Wallops Island stop detecting echoes on 6.8-7.2 MHz which validates our system lacking data for the majority of the night since we transmitted at 7.025 MHz.

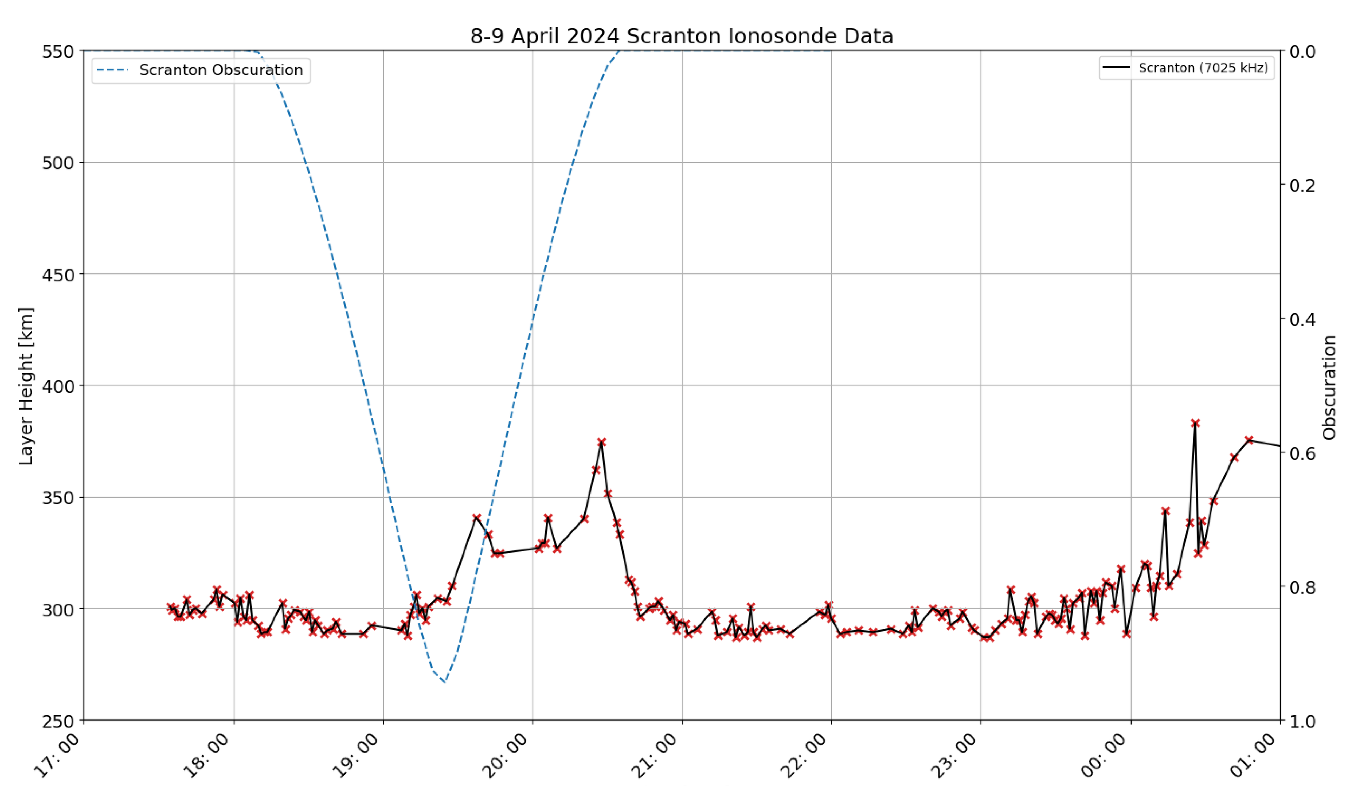

Figure 3. This plot shows how the ionosonde detected the change in layer height following the eclipse.

Conclusion

During the 2024 total solar eclipse we were able to sound the ionosphere, record the return echoes, and detect the rising and falling of the ionosphere caused by the eclipse and the day/night cycle. Our system accurately shows the trends of the ionosphere and is able to provide reliable virtual layer height values. Our system performs comparably to multimillion dollar ionosondes, and costs less than a few thousand. We plan to collect more data and improve upon the system so we may calculate the true height. This can be done by recording multiple echoes on different bands. As of right now both the Ettus and Red Pitaya systems work. Going forward we will package our Red Pitaya system to improve the ease of setting up the system and recording data.

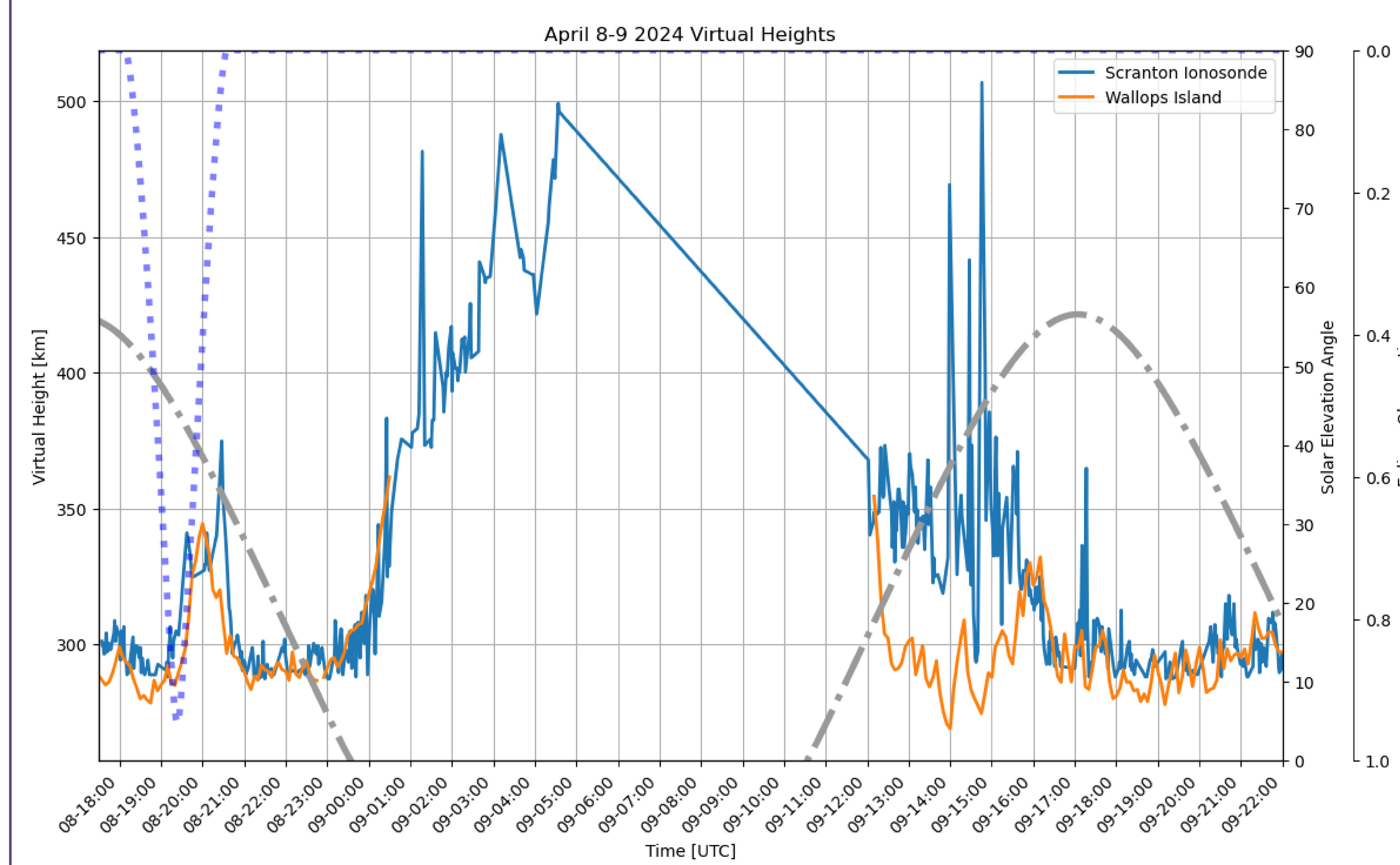

Figure 4. Plot showing our F-region layer heights compared to Wallops island ionosonde. Scranton data was collected at 7.025 MHz and Wallops data is averaged over 6.8-7.2 MHz

References

Lloyd, William C. (2019). Ionospheric Sounding During a Total Solar Eclipse. Master's Thesis, Virginia Tech Department of Electrical and Computer Engineering, http://hdl.handle.net/10919/89951.

McGwier, Robert (2018). "Using GNU Radio and Red Pitaya for Citizen Science" in *GNU Radio Conference 2018*, Las Vegas, NV, https://www.gnuradio.org/grcon/grcon18/presentations/Using_GNU_Radio_and_Red_Pitaya_for_Citizen_Science/.

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gerard.piccini@scranton.edu