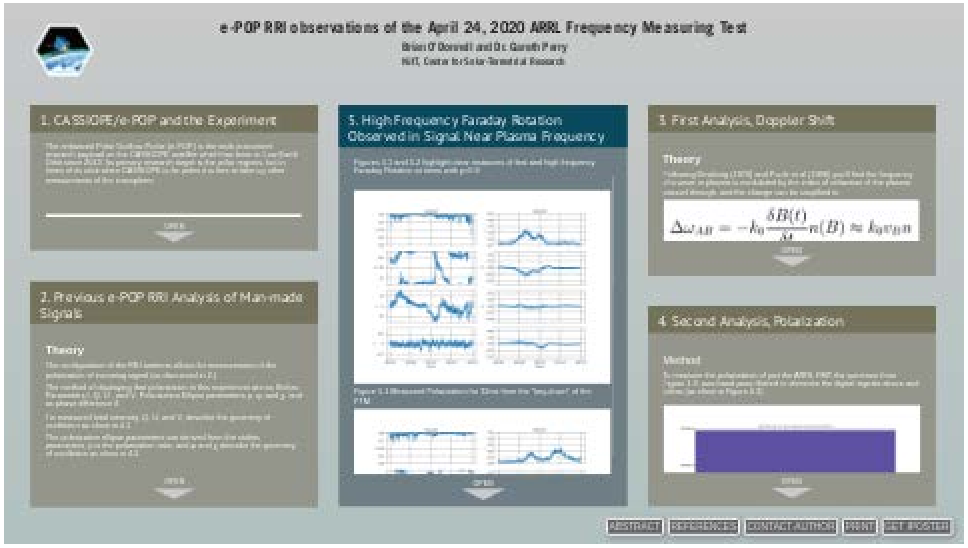
e-POP RRI observations of the April 24, 2020 ARRL Frequency Measuring Test



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PRESENTED AT:

1. CASSIOPE/E-POP AND THE EXPERIMENT

The enhanced Polar Outflow Probe (e-POP) is the multi-instrument research payload on the CASSIOPE satellite which has been in Low Earth Orbit since 2013. Its primary research target is the polar regions, but in times of its orbit when CASSIOPE is far poles it is free to take up other measurments of the ionosphere.

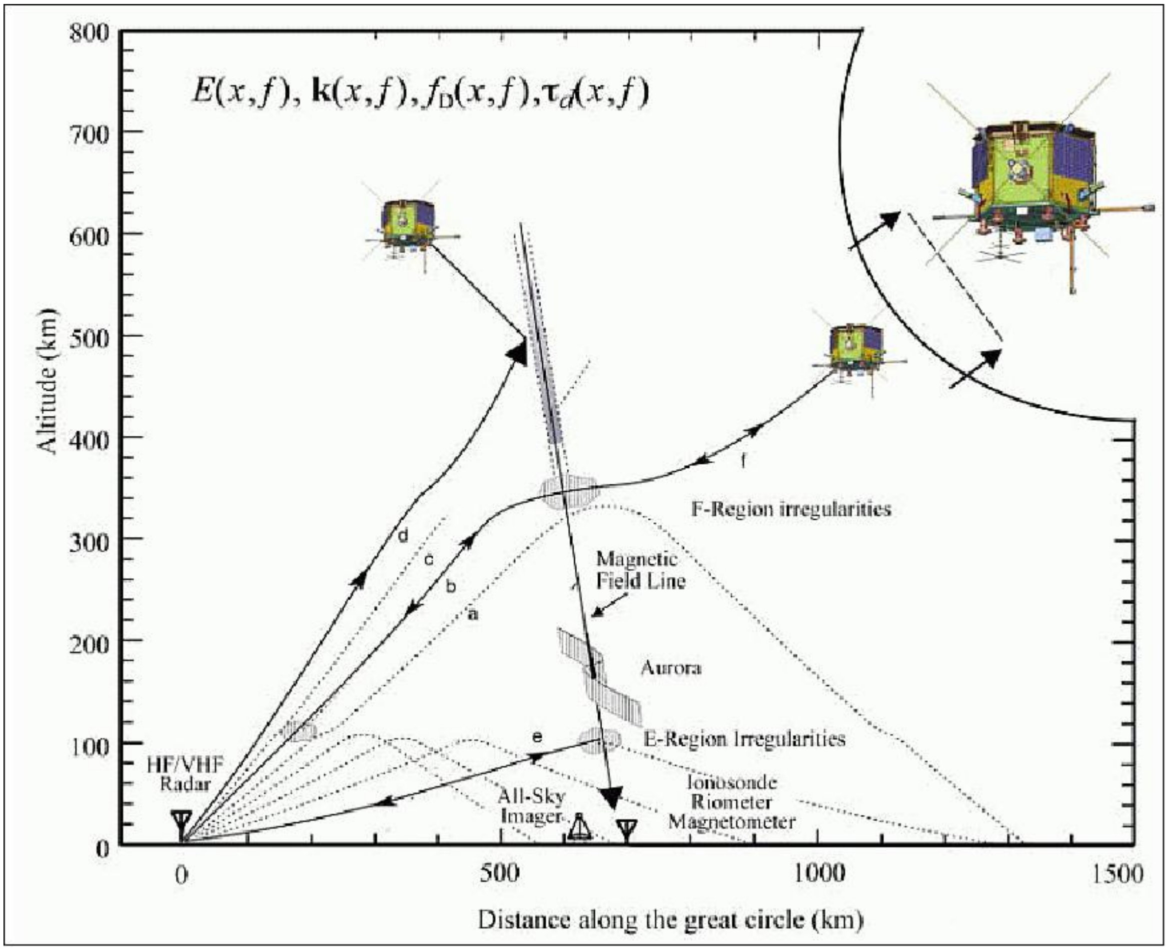


Figure 1; e-POP RRI as a probe of man-made signals radio

(image credit: University of Calgary, CSA, MDA)

RRI, the Cross configuration 4 3-m antenna radio receiver is insturment in the e-POP's suite that concerns us today . RRI can be used as an in-situ antenna inside the atmospheric plasma. Figure 1 is a cartoon meant to illustrate the paths that HF radio waves take through the atmosphere, and the sort of ray-paths that e-POP can be in position to measure

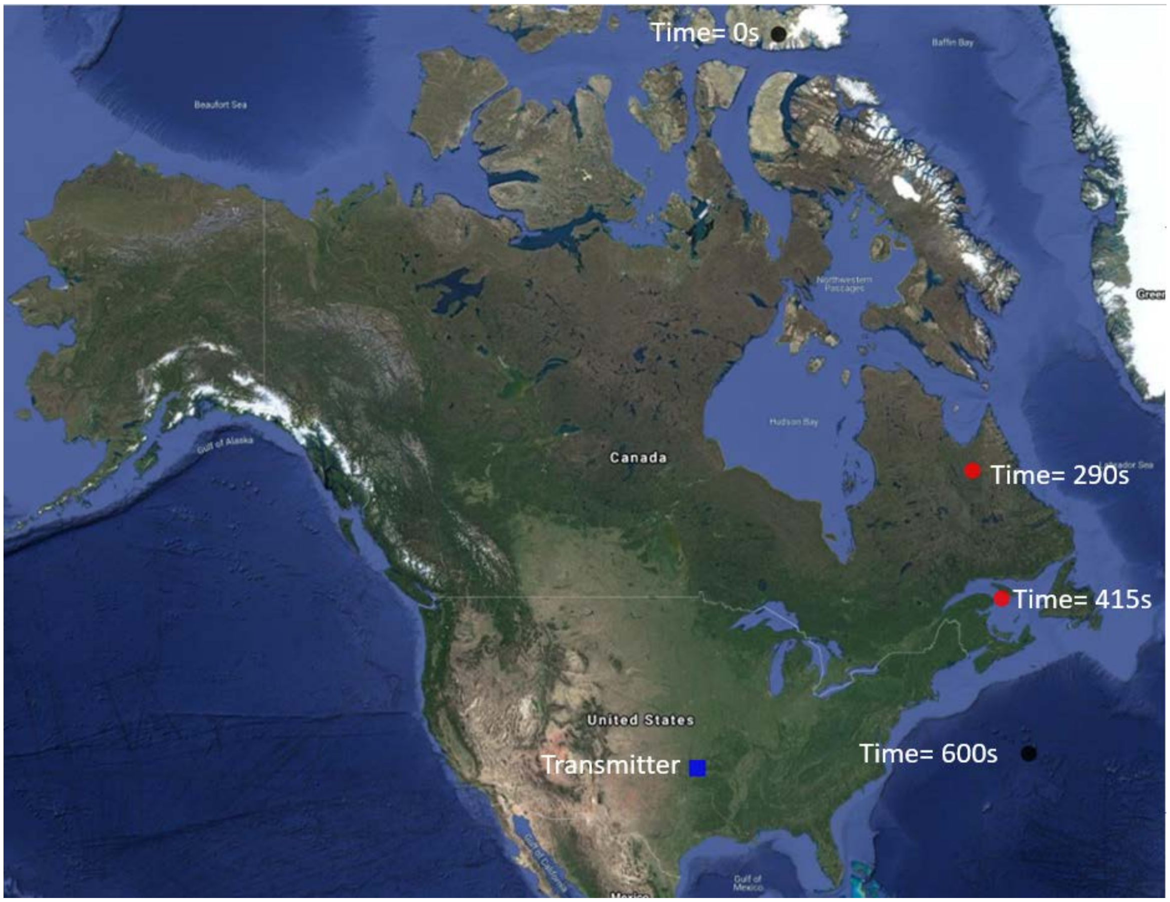


Figure 1.2 The geography of the experiment CASSIOPE's location goes between the black points, heading south and is between the red points at the time of "key down". The transmitter was located at the blue square

The April 24 2020 ARRL Frequency Measuring Test happened to coincided with a portion of that down time when CASSIOPE was just leaving the North Pole headed south over Québec.

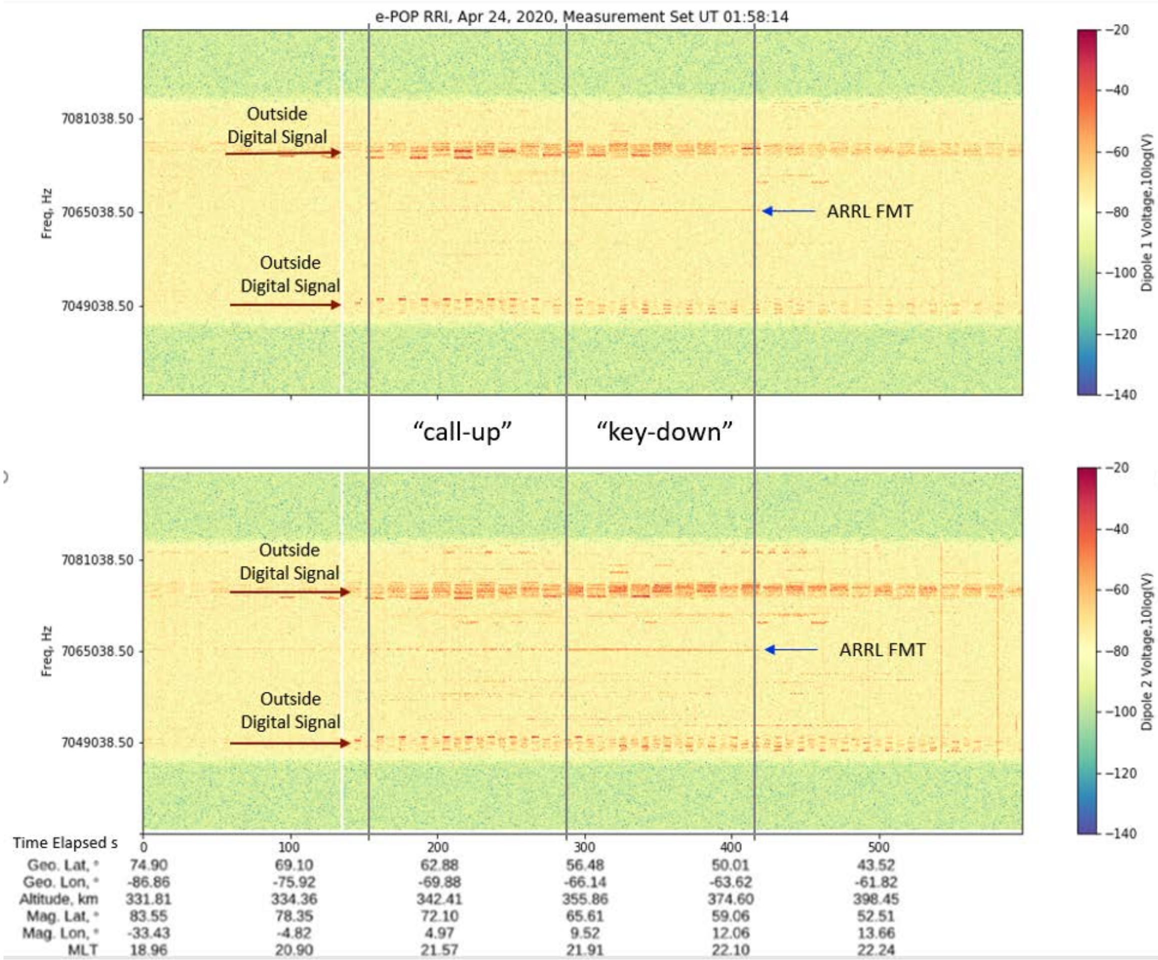


Figure 1.3 e-POPs measurement of the ARRL FMT on April 24, 2020

This test in particular was an exciting opportunity for RRI because of the character of the signal, after a morse coded announcement of the test, a clear 2 minutes of "key-down" is sent. That is a pure tone held to ±.01Hz, a signal that all measurable change in the signal can be reliably expected to be atmospheric effects, and even better still the 7.06MHz signal is on the order of the plasma frequency of the atmosphere, so it could be expected that disturbances cause by the atmosphere in the otherwise clean signal may be dominated plasma effects

2. PREVIOUS E-POP RRI ANALYSIS OF MAN-MADE SIGNALS

Theory

The configuration of the RRI antenna allows for measurement of the polarization of incoming signal (as discussed in 2.).

The method of displaying that polarization in this experiment are as Stokes Parameters I, Q, U , and V, Polarization Ellipse parameters p, ψ, and χ, and as phase difference δ

I is measured total intensity, Q, U, and V, describe the geometry of oscillation as show in 4.1

The polarization ellipse parameters are derived from the stokes parameters, p is the polarization ratio, and ψ and χ describe the geometry of oscillation as show in 4.2

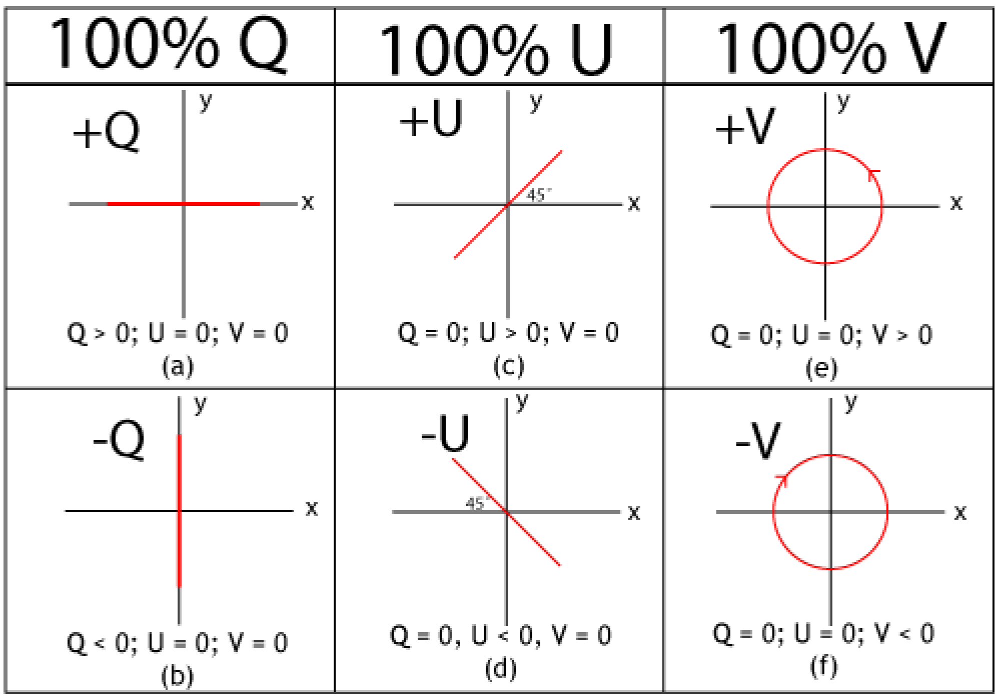


Figure 4.1 Geometric interpretation of Stokes Parameters (Image credit Dan Moulten- Wikimedia)

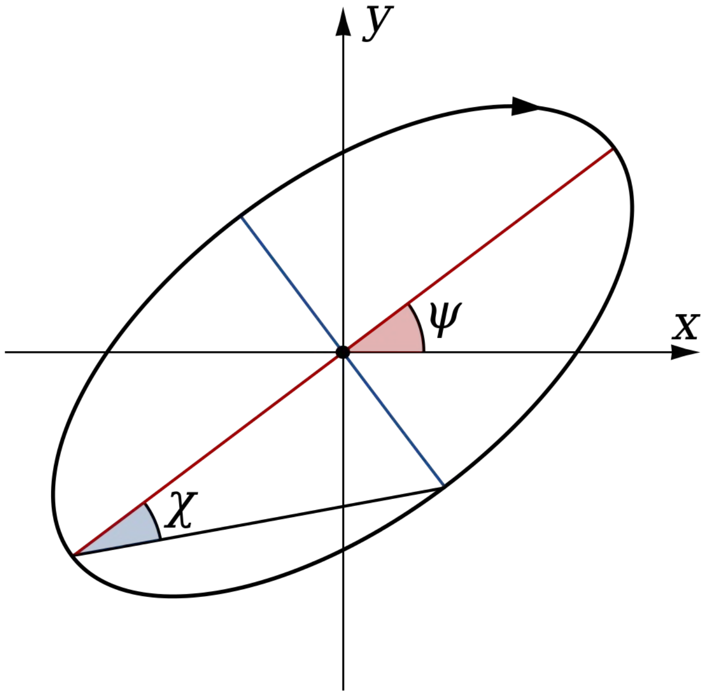


Figure 4.2 Polarization ellipse diagram

Two Previous RRI studies that are useful reference,

Danskin et al in 2018 measured Faraday Rotation (around 22:30:45 in Figure 2.1) in polarization of a signal around 10MHz, which was much larger than the plasma frequency during the experiment.

Other than the clear result in ψ, notice the stability of p for all red points (which are all the points above a power threshold), and the constant sign of χ

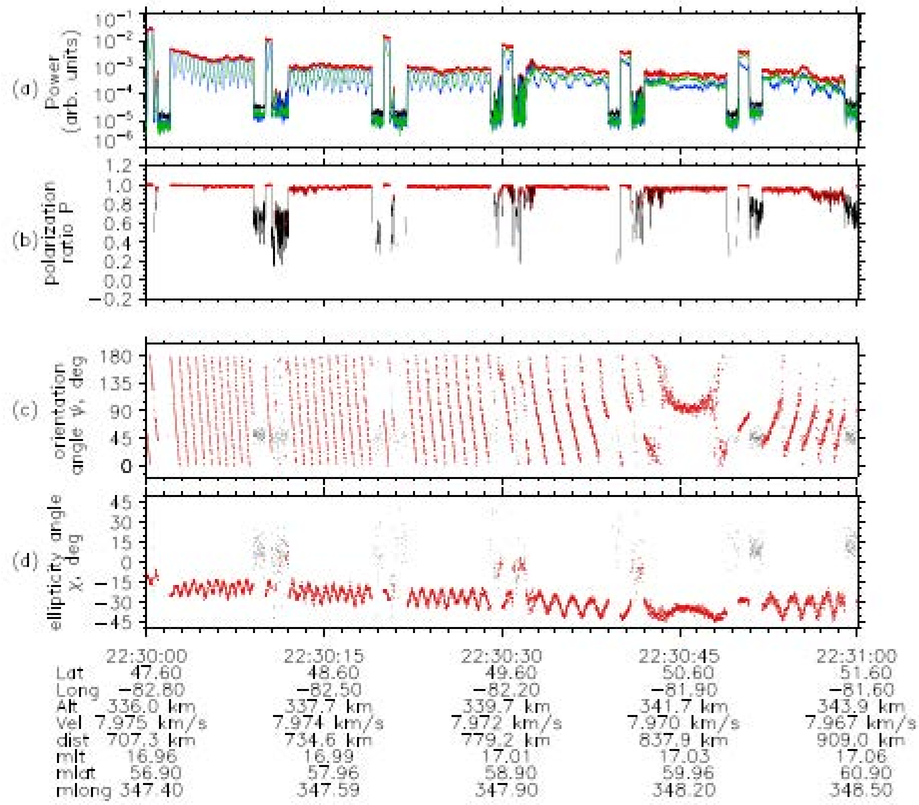


Figure 2.1 A Polarization analysis of a signal at ~10.4MHz received by e-POP (Danskin et al 2018)

A higher time resolution was necessary for Perry et al in 2016, when they saw looked at the behavior of ψ during a SuperDARN pulse, and found each propagation mode of the pulse arriving separately, including sudden change in ψs in the middle of the pulse.

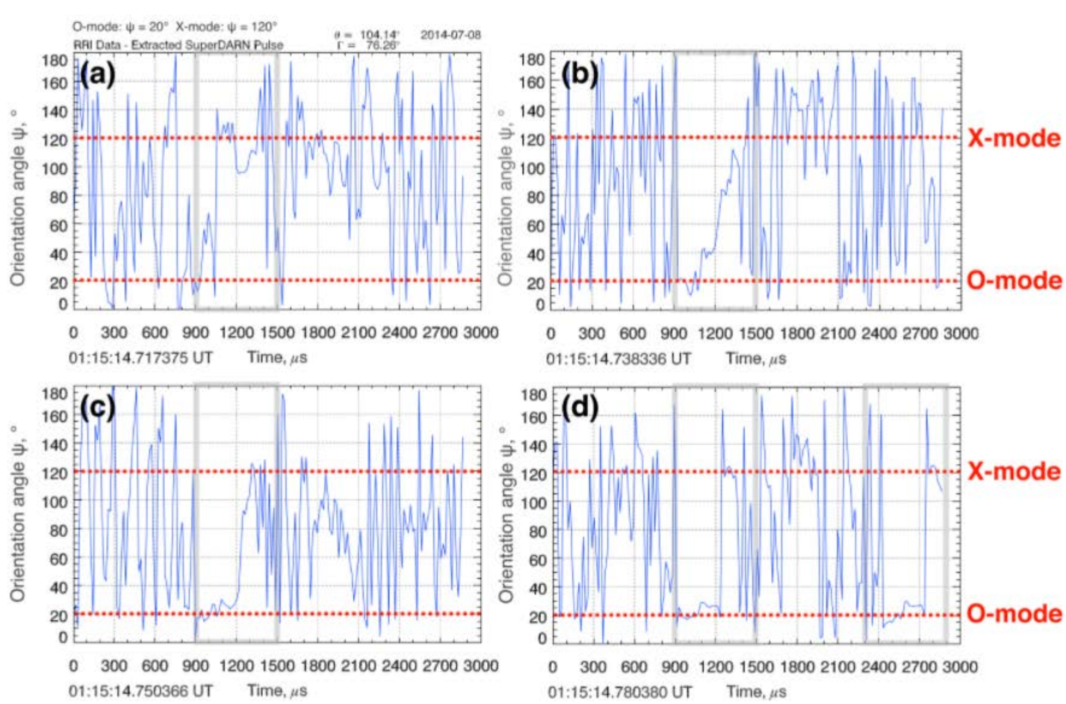


Figure 6. The (a) first, (b) second, (c) third, (d) seventh, and eighth pulses voltage of a single katscan sequence, received by RRI starting at 01:15:14.717375 UT. The orientation angle, ψ, is plotted. The horizontal axis gives the microsecond past the zero time, listed at the bottom left of each panel. Values for θ and Γ are given in the top right corner of Figure 6a. A gray box in each plot is plotted to help guide the eye. A red dashed line indicates the O- and X-mode values.

Figure 2.2 Separation of Propagation Modes shown by Perry et al 2016

5. HIGH FREQUENCY FARADAY ROTATION OBSERVED IN SIGNAL NEAR PLASMA FREQUENCY

Figures 5.1 and 5.2 highlight clear instances of fast and high frequency Faraday Rotation at times with p>0.8

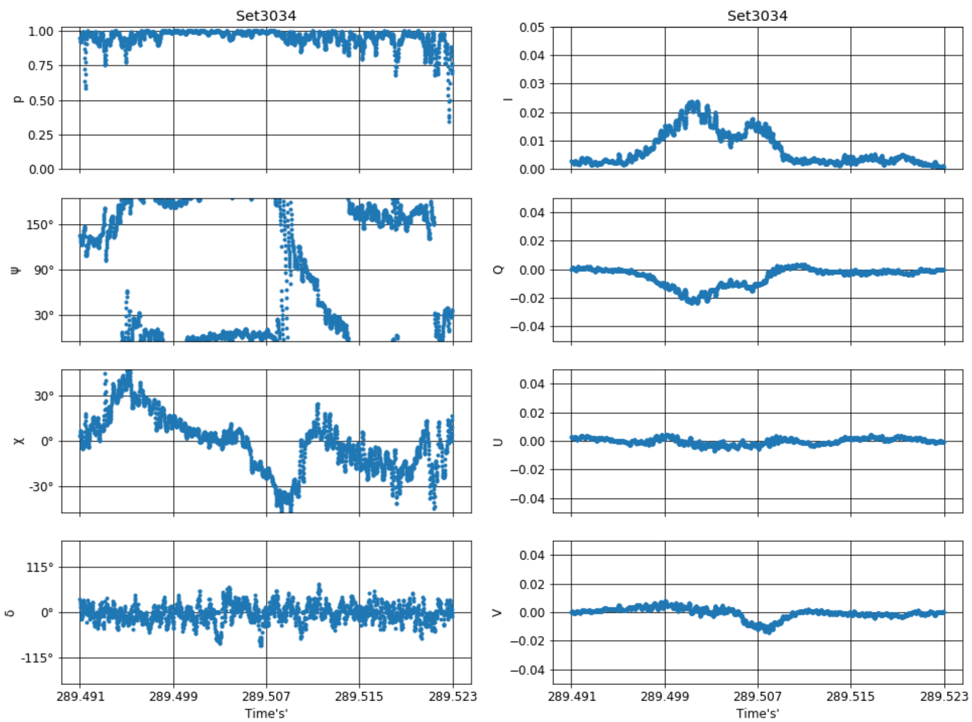


Figure 5.1 Measured Polarization for 32ms from the "key-down" of the FTM

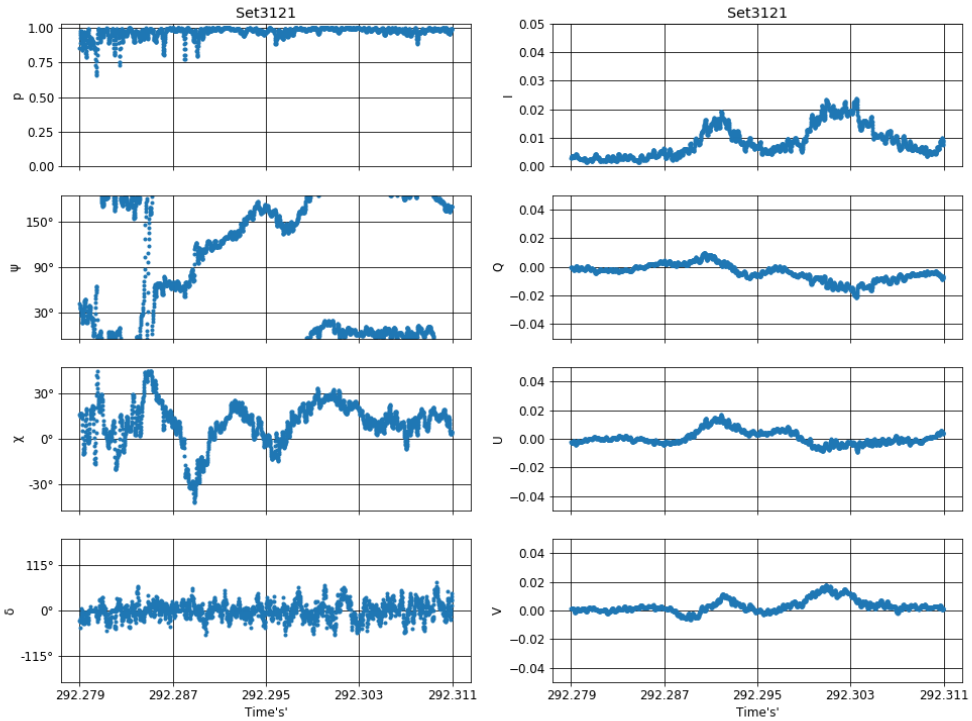


Figure 5.2 Measured Polarization for 32ms from the "key-down" of the FTM

This includes full 180 direction rotations (in ψ) in millisecond

This includes transitions (in χ) from circular polarization to elliptical to linear and back rotating the other direction in similar millisecond time scales in both figures

Explanatory Hypothesis

If the FMT test had a relatively constant intensity on the ground, why are I and P seen to be so dynamic? This is especially noticible when in comparing p of the FMT the p that Danskin measured (Figure 2.1), which is well behaved and above 0.9 for the bulk of the signal time

Perhaps it's a simple as Frequency choice.
Danksin's 10.4 MHz around mid day is $\sim 2\omega_p$

Our 7.05MHz in the evening is $\sim 1.2\omega_p$

So it stands to reason plasma effects from the atmosphere should the cause of the speed of the high speed Faraday rotation and could be the cause of the lack of signal strength as well, but this explination doesn't describe why the Plamsa Doppler correction is missing

Areas for Further Study

First, can the HAM community continue to help in pushing this area?

Absolutely! Just keeping doing FMTs, closer to the plasma frequency the better (so keep it in the 5-8MHz range) and perhaps a similar experiment will show the Doppler effects we examined clearly

but alas, these measurement may not be doable with e-POP because of a malfunction in CASSIOPE's steering making it much harder to point the antenna

3. FIRST ANALYSIS, DOPPLER SHIFT

Theory

Following Ginsburg (1970) and Poole et al (1988) you'll find the frequency of a wave in plasma is modulated by the index of refraction of the plasma passed through, and the change can be simplfied to

$$\Delta\omega_{AB} = -k_0 \frac{\delta B(t)}{\delta t} n(B) \approx k_0 v_B n$$

under most atmospheric conditions
(Where $\Delta\omega_{AB}$ is frequency change caused by defraction, k_0 is the wave vector of the radiation, B(t) is the location of the reciever, making v_B the veleocity of B and n is the index of refraction of the plasma)

which is equivalent to the Doppler shift times the index of refraction

And it is a well known result that the index of refraction of a plasma is a function of its plasma frequency and of the frequency of the refracted wave in question

$$n = \sqrt{1 - \frac{\omega_p^2}{\omega^2}}$$

As can be seen from these equations,

a) the index of refraction (n) of a plasma is <1

b) but it's only noticeably different from 1 near the plasma frequency

c) this should result in a measureable decrease in the magnitude of the Doppler shift of the wave that, proportional to n, is only important near the plasma frequency

In Figure 1.2 notice that e-POP is heading south and during the "key-down" which is net towards the receiver, so the Doppler shift itself was positive ie, the frequency increased. This along with c) would give the prediction of refraction decreasing the magnitude of the Doppler shift, which in this case would mean the frequency would increase less that the classic Doppler formula predict

Results

Measurements made contemporaneous to the FMT by Digisonde in Atlanta TX (Figure 3.1) found ω_p (or foF2) = 5.8MHz which at the FMT frequency would mean n=0.57

From the above equations this should imply that the effect of Doppler shift should be massively cut

Which in our expeiment would be an expected decrease of the signal frequency by 20-35Hz from the unrefracted

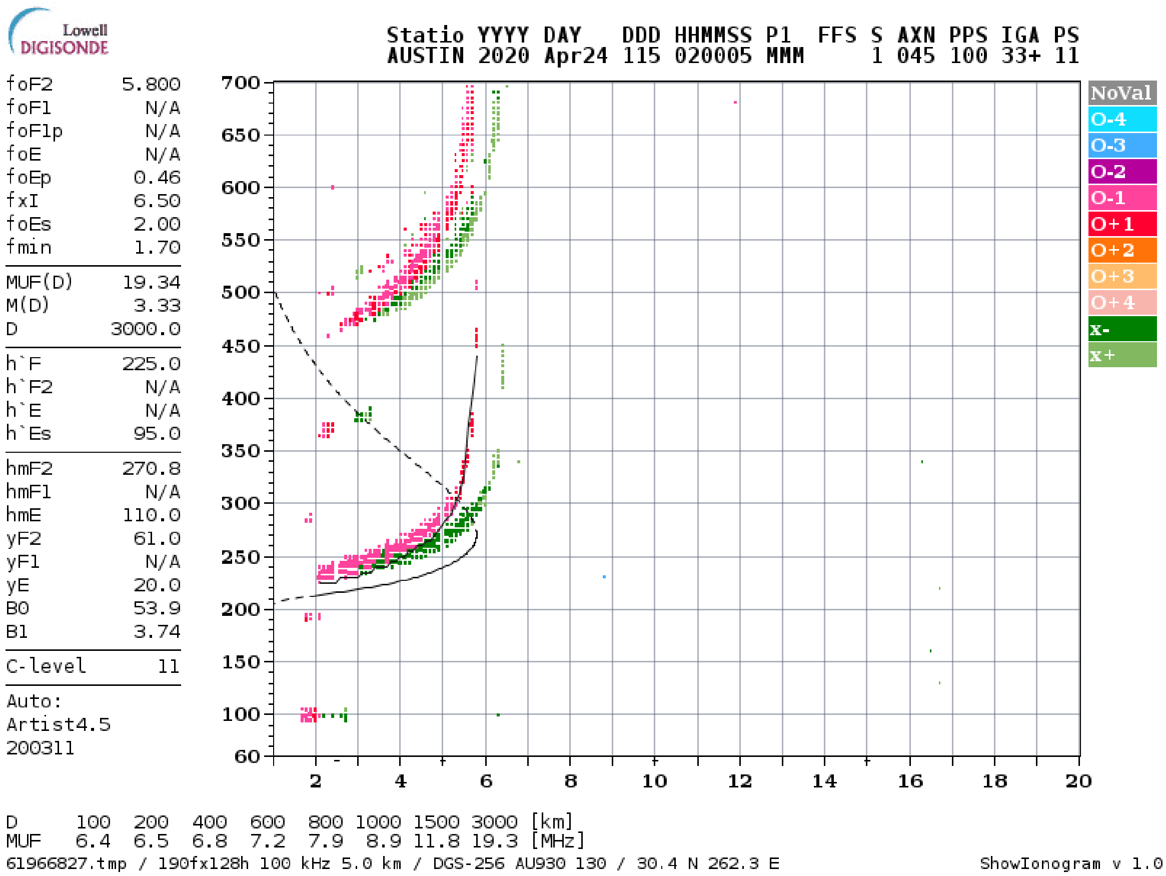
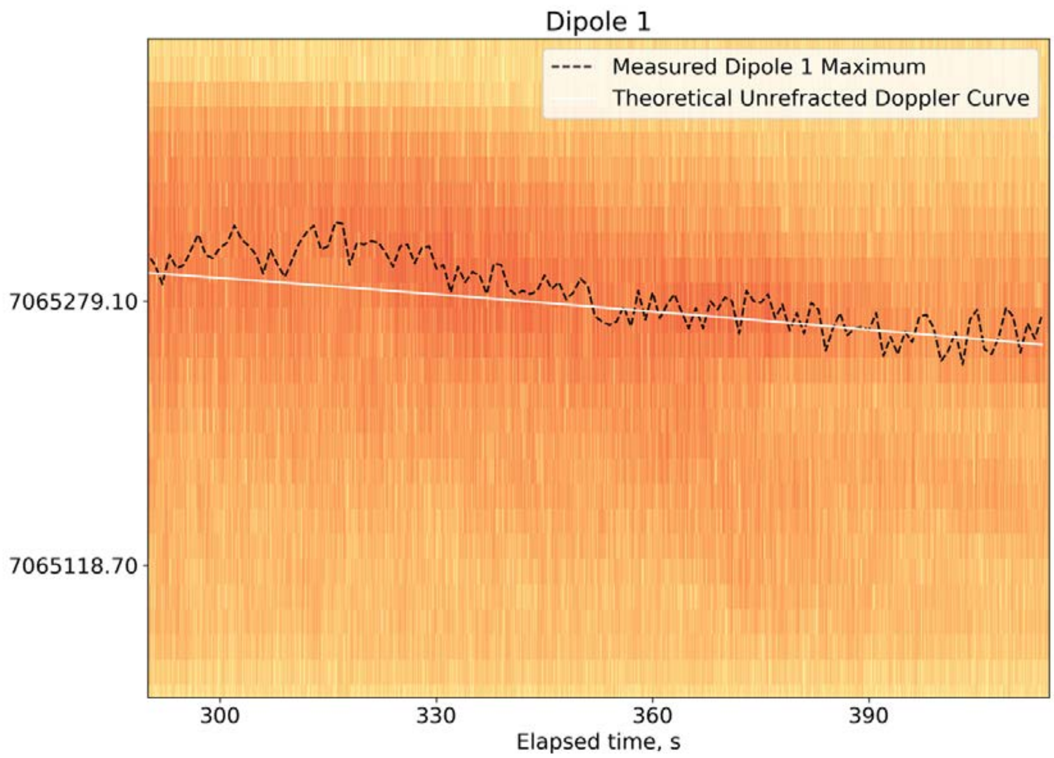


Figure 3.1 Measurements made by Digisonde in Atlanta TX

With the Velocity of e-POP, the Transmission Frequency, and the location all known, it was fairly straight forward to compare the expected (unrefracted) Doppler curves to the maxima of the signal in the spectrogram

That curve is then compared to the spectrogram in Figures 3.2 + 3.3



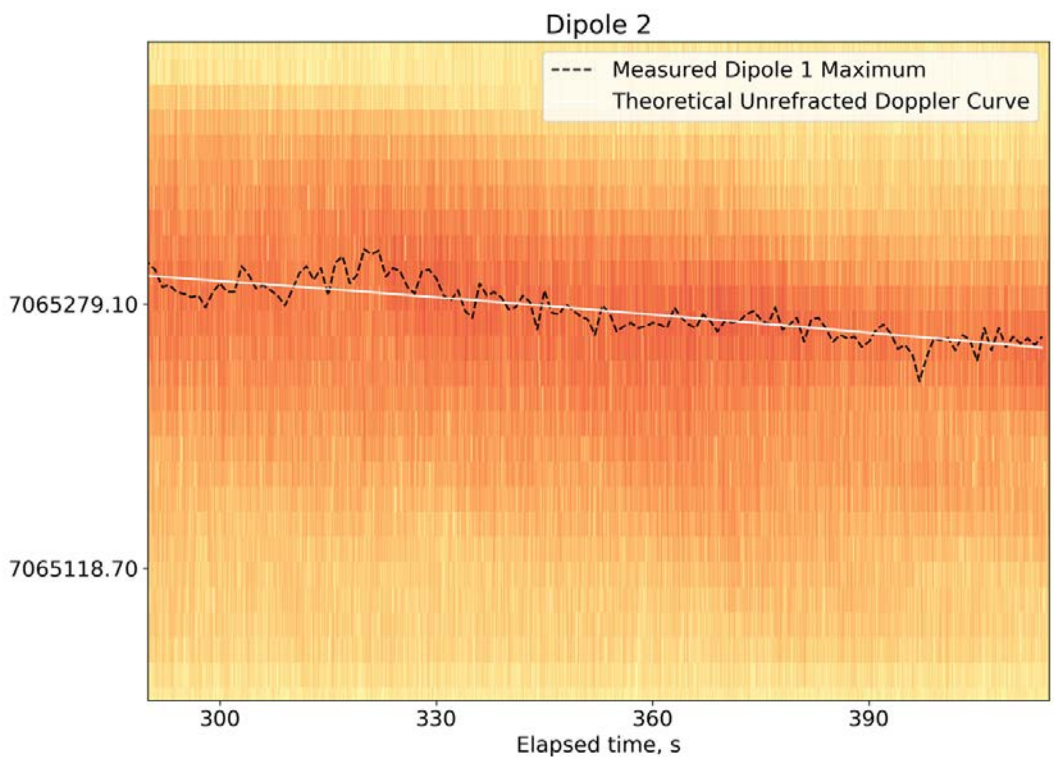
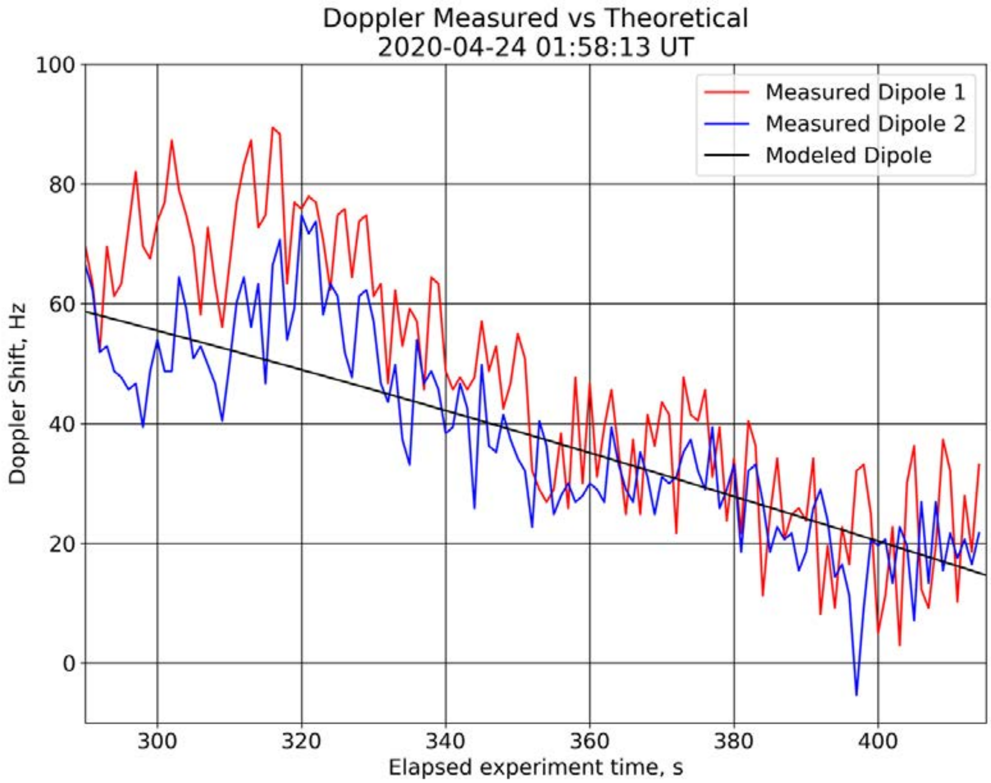


Figure 3.2: The Spectrograms of each dipole of the experiment (as in Figure 1.3) zoomed in to the "key down" segment of the ARRL Test. Overplotted is the measured maxima of the given spectrogram (in black) and the expected doppler curve of the signal assuming n=1 (in white)



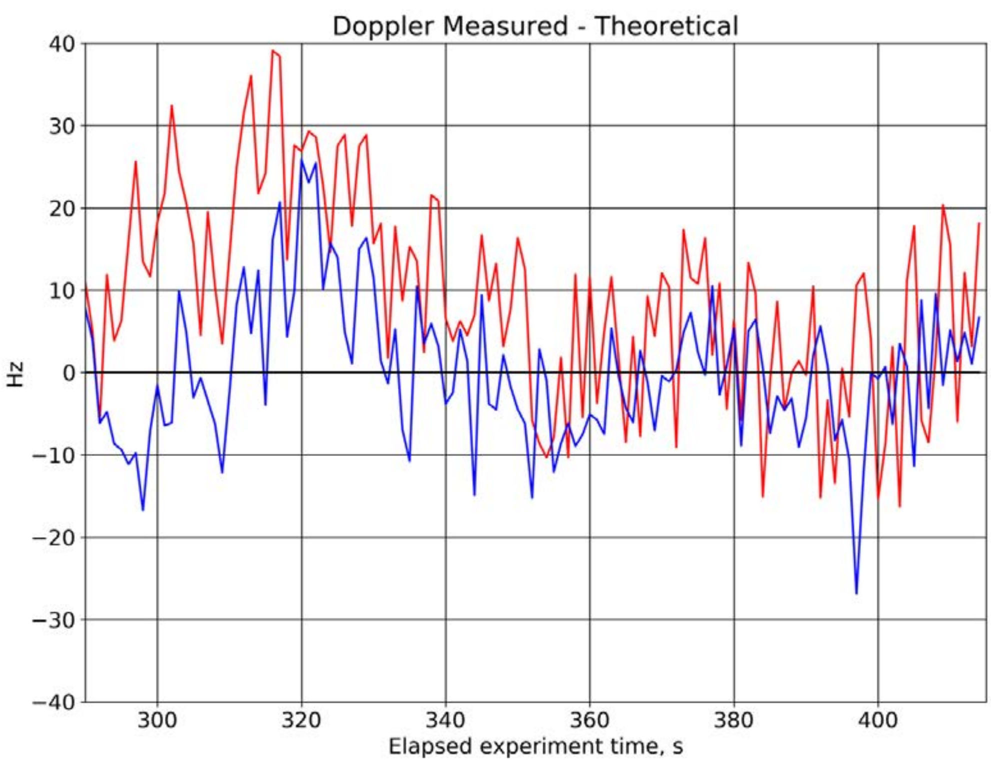


Figure 3.3: Derived from Figure 3.1

(a) The maxima of Dipole 1 (red) and Dipole 2 (Blue) and the Predicted Doppler Curve

(b) The Difference between the maxima of Dipole 1 (red) and Dipole 2 (Blue) and the Predicted Doppler Curve,

Discussion:

The results are inconclusive, our data is pretty well centered on the unrefracted doppler curve, and if there is any bias it is maybe a bit above the curve early in the measurement, the opposite of what the plasma Doppler correction would predict

4. SECOND ANALYSIS, POLARIZATION

Method

To measure the polarization of just the ARRL FMT the spectrum from Figure 1.3, was band-pass filtered to eliminate the digital signals above and below (as show in Figure 4.3)

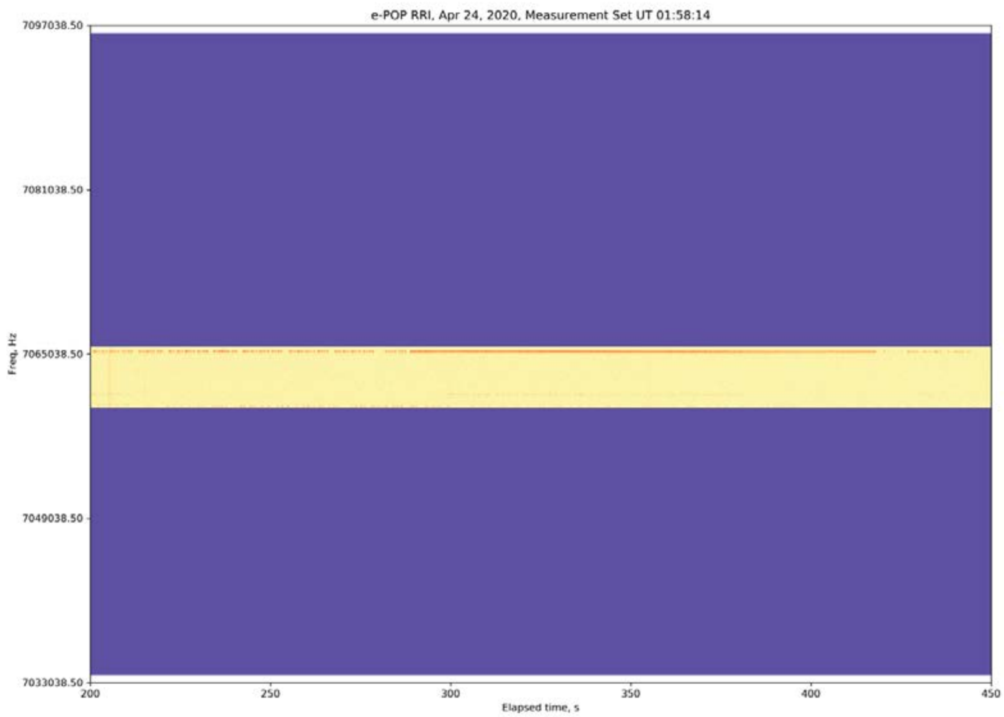


Figure 4.3 Filtered Spectrogram of Dipole 1, derived from Figure 1.3

After filtering, the signal was Inverse Fourier Transformed back into voltage space, where a 10 data point (160µs) rolling average was applied, the polarization parameters were then calculated.

Results

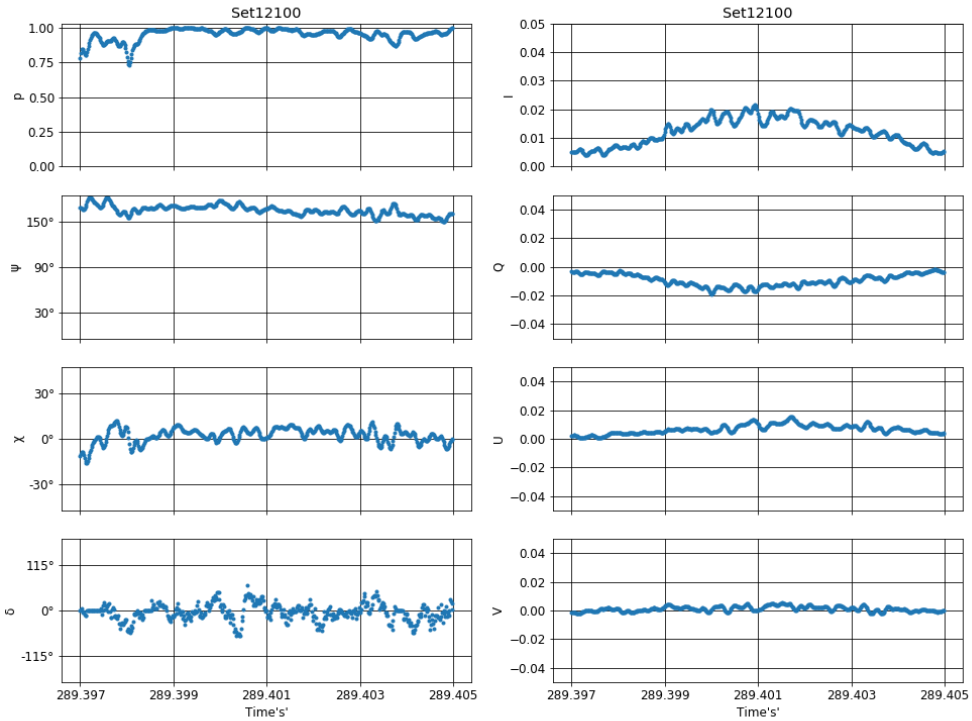


Figure 4.4 Measured Polarization for 8ms from the "key-down" of the FTM

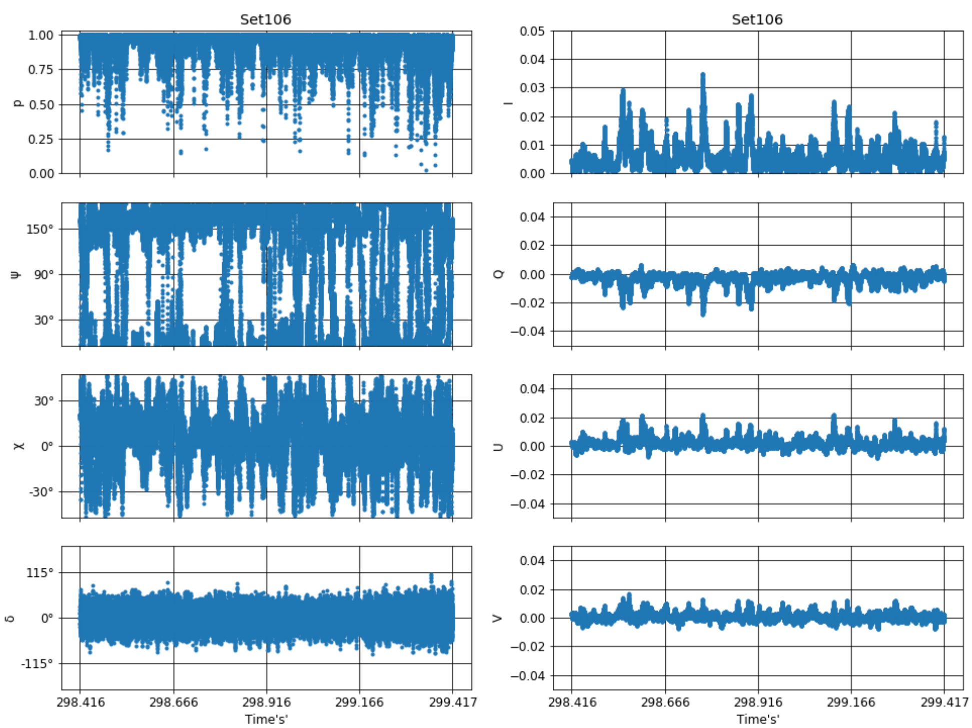


Figure 4.5 Measured Polarization for 1s from the "key-down" of the FTM

Notice how different the general character is to that of Danskin's measurement (Figure 2.1), p is much less stable during signal time, and ψ and χ changings direction once (in a geomagnetically sensible place) was main Danskin's result, but here were see countless wraps and winds in just the 1 second show in Figure 4.5

ABSTRACT

One of the science objectives of the Radio Receiver Instrument (RRI) on the CAScade, Smallsat, and Ionospheric Polar Explorer/enhanced Polar Outflow Probe (CASSIOPE/e-POP) satellite is to study ionospheric influences on high frequency (HF) radio wave from low Earth orbit. RRI is made-up of 4, 3-m monopoles which can be electronically arranged into a crossed-dipole configuration. On April 24, 2020, RRI tuned to measure the ARRL frequency measuring test (FMT) on 40 m, and successfully recorded part of the “call up” and all of the “key down” segments of the test. The FMT provides a unique chance to study the effects of the ionospheric plasma on stable and reliable radio signals at frequencies that are close to the ionosphere’s critical frequency, a frequency regime in which the influence of the ionospheric plasma on radio wave propagation conditions is most pronounced. In this presentation, we give preliminary results of our analysis of RRI’s FMT measurements which include an examination of the FMT’s Doppler characteristics, and the identification tell-tale signatures of ionospheric effects on the transmitted signal such as Faraday rotation

REFERENCES

Danskin, D. W., Hussey, G. C., Gillies, R. G., James, H. G., Fairbairn, D. T., & Yau, A. W. (2018). Polarization characteristics inferred from the Radio Receiver Instrument on the enhanced Polar Outflow Probe. Journal of Geophysical Research: Space Physics, 123, 1648–1662. https://doi.org/10.1002/2017JA024731 (http://dx.doi.org/10.1002/2017JA024731)

Perry, G. W., H. G. James, R. G. Gillies, A. Howarth, G. C. Hussey, K. A. McWilliams, A. White, and A. W. Yau (2017), First results of HF radio science with e-POP RRI and SuperDARN, Radio Sci., 52, 78–93,doi:10.1002/2016RS006142 (http://dx.doi.org/10.1002/2016RS006142).

Ginzburg, V. L.: The propagation of electromagnetic waves in plasmas, Pergamon Press, Oxford, 1970.

Poole, A. W. V., Sutcliffe, P. R., and Walker, A. D. M.: The Relationship Between ULF Geomagnetic Pulsations and Ionospheric Doppler Oscillations: Derivation of a Model, J. Geophys. Res., 93, 14656–14664, 1988.