# The Ionosphere:

## That Great Big Fun-House Mirror in the Sky

Jim Farmer, K4BSE

***Much of the material presented is from Dr. Nathaniel Frissell, W2NAF, Principal Investigator, HamSCI project, and professor of electrical engineering, University of Scranton.***

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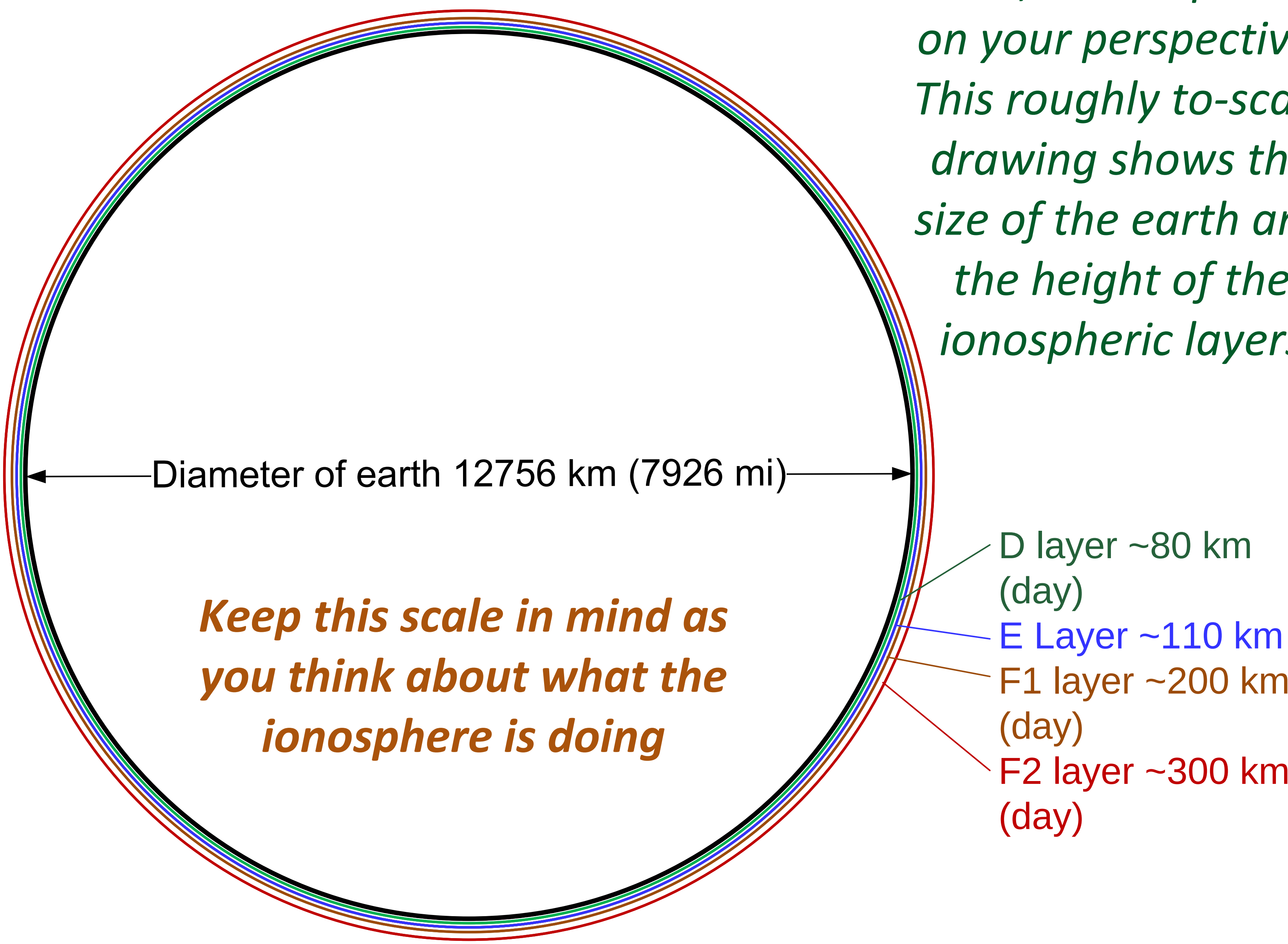
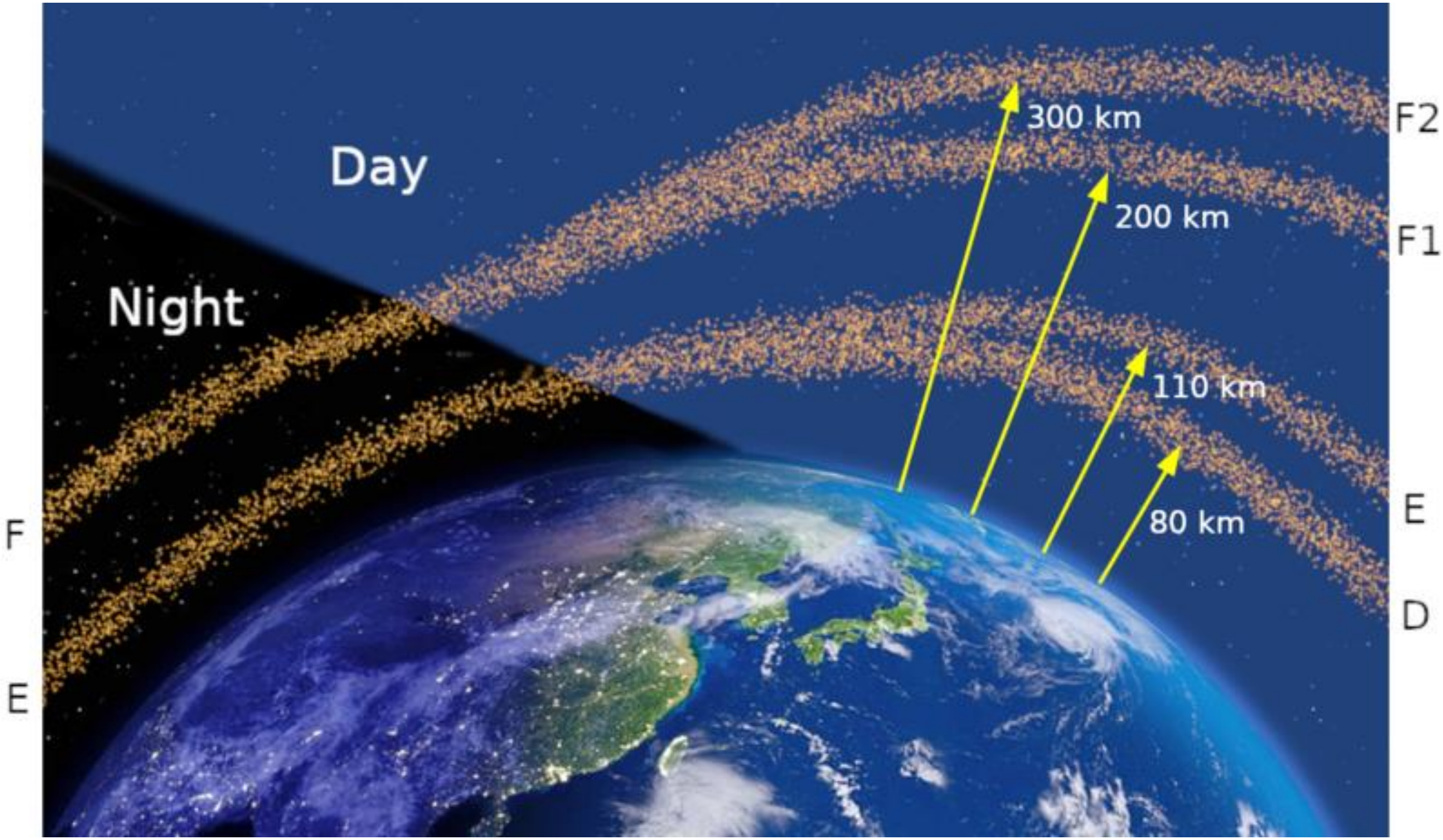
Rev. 5/18/24

# We think of the ionosphere as high, high above the earth's surface

## *But is it?*

*Well, that depends on your perspective. This roughly to-scale drawing shows the size of the earth and the height of the ionospheric layers*



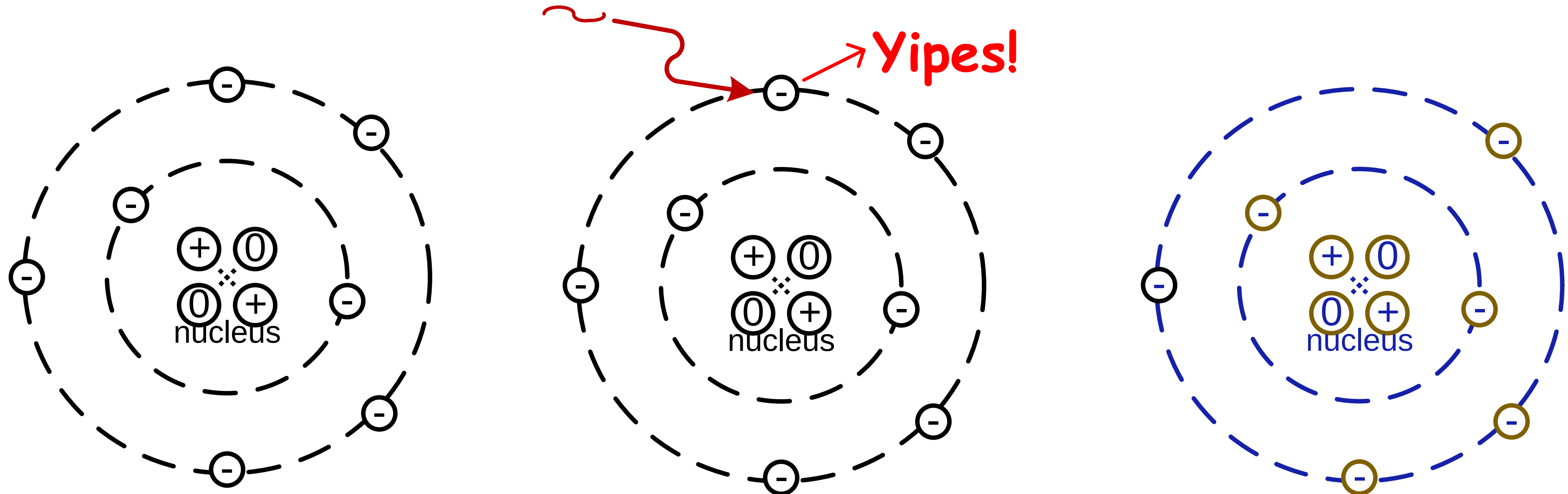



**The ionosphere divides into regions, different for day and night. The height is a complicated combination of the effects of gravity, solar wind pressure, neutral atmospheric composition and dynamics, and the amount of ionospheric penetration of photons of various energy levels, among other variables.**

Figure by Carlos Molina (https://commons.wikimedia.org/wiki/File:Ionospheric_layers_from_night_to_day.png)

What follows is a simplified explanation of the ionosphere, simplified to the point of being ridiculous, except that it seems to help introduce this subject.

# It started out as a quiet morning in the ionosphere, but things took a turn...




1. A nitrogen (or oxygen) atom is sitting there high above the earth minding its own business...

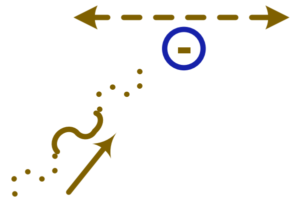
2. when comes a photon of light from the sun, which knocks one of the electrons from the atom...

3. producing a positive ion and a negative electron.

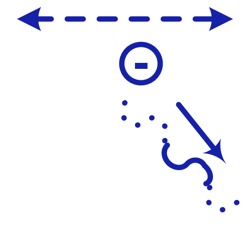
4. The free electron ⊝ wanders in space until it finds another charged ion with which it can combine

# Looks like our quiet day is not so quiet any more

While our electron is wandering around looking for a positively-charged ion it can combine with...



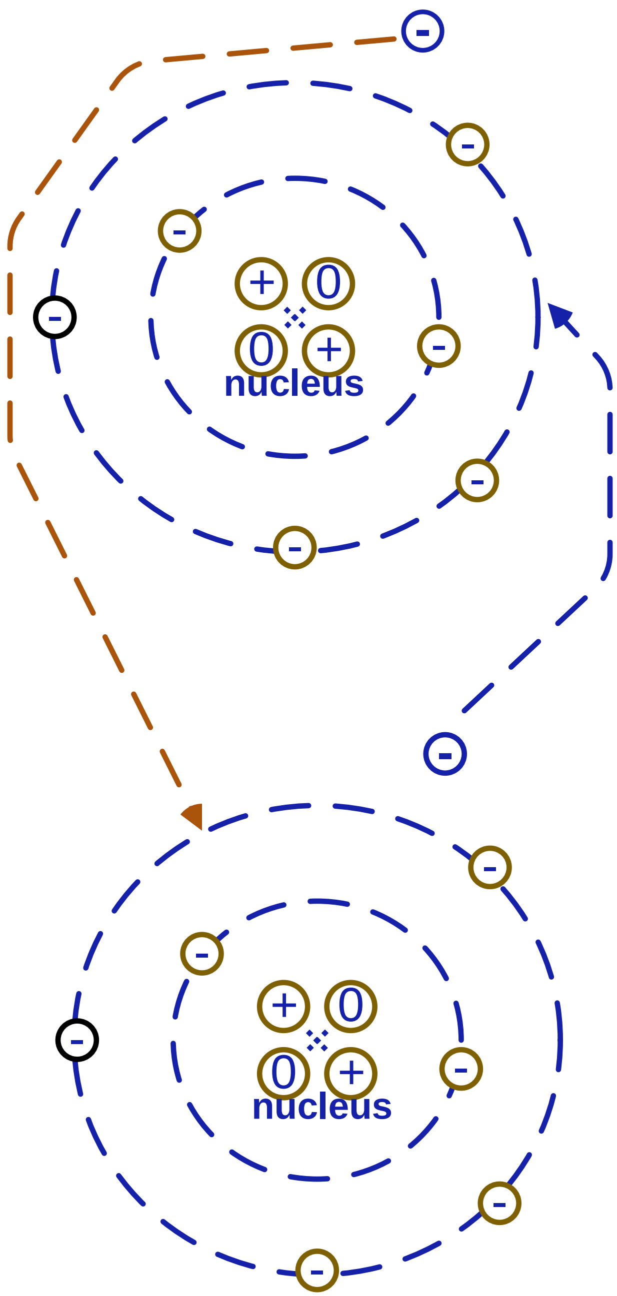
Along comes a 14.15 MHz electromagnetic wave from K4BSE, pushing the electron back and forth 14,150,000 times a second...



The movement of the electron and millions like it creates an electromagnetic wave heading back toward the earth, what we call a *reflection* (really *scattering*) from the ionosphere.

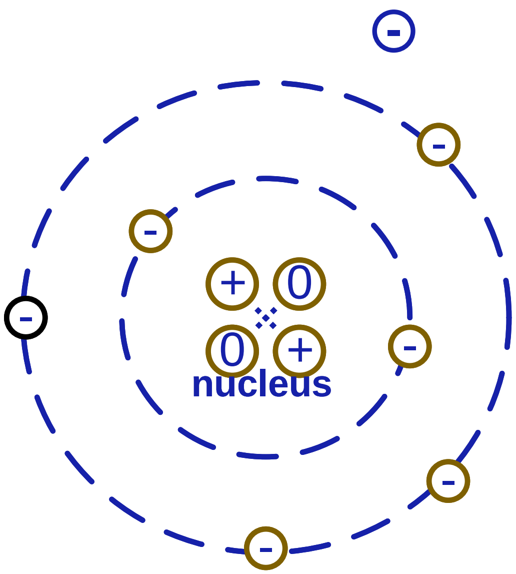
*This process continues until our electron finds another positively-charged ion with which to reunite. How long that takes depends on the density of ions in the neighborhood, which in turn depends on the air pressure. (The same thing is happening with the positively-charged nucleus, but since it is much more massive than the electron, it plays only a negligible role in the scattering.)*

# A High Pressure Situation



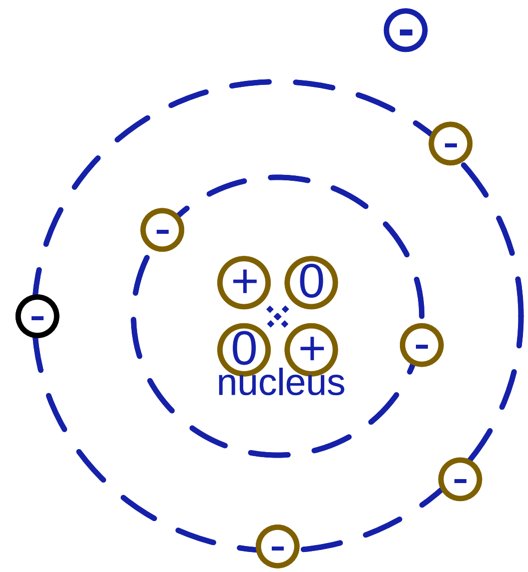

In the lowest part of the ionosphere, the ions are spaced close together, so the free electron quickly finds an ion with which to reunite. Thus, at night the D layer, the lowest layer of the ionosphere, goes away (all of the ions have reunited), but quickly reforms the next morning when a bunch of photons from the sun reach it. Because the electron density is so high in the D layer during the day, electrons don't have to travel far until they find an ion with which to reunite, so it does more attenuating (or *collisional damping*) of the signal than it does reflecting of it. (Well, to be honest, no level of the ionosphere *reflects* anything. It's more accurate to say it *refracts* the signal.)

# Going Up!




**As we go higher, through the E layer and toward the F1 and F2 layers, the air is "rarified" (has a very low density and hence a low *collision frequency*), so the ions are fewer and farther between. With the electrons free to move greater distances before recombining, we get more refraction.**

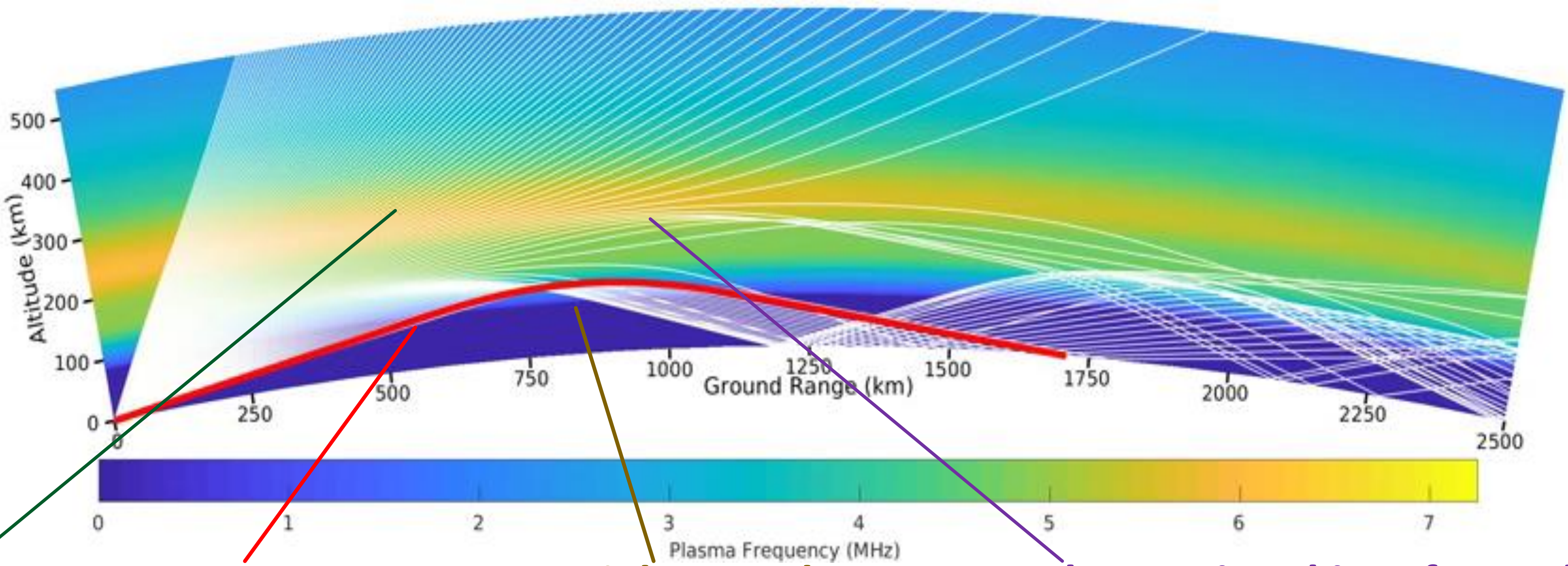
**And at night, what with less recombining of positively and negatively charged ions (though without ion production from photoionization), the ionosphere survives the night better, albeit weaker and at different altitudes.**



# Ionospheric Refraction of HF Radio Waves

**Eclipsed SAMI3 - PHaRLAP Raytrace**

1600 UT 21 Aug 2017 • 14.03 MHz • TX: AA2MF (Florida) • RX: WE9V (Wisconsin)




**Low angle of incidence: low refraction altitude but goes a long way.**

**Higher angle, ray comes down sooner, might hop multiple times.**

**When a signal is refracted from a higher altitude in the ionosphere, it goes further.**

**At even higher angles of incidence, the ray is refracted some, but goes into free space.**

**We don't really know about something until we can measure something about that something. So what can we measure about the ionosphere?**


PHaRLAP: Cervera & Harris (2014), https://doi.org/10.1002/2013JA019247 SAMI3: Huba & Drob (2017), https://doi.org/10.1002/2017GL073549

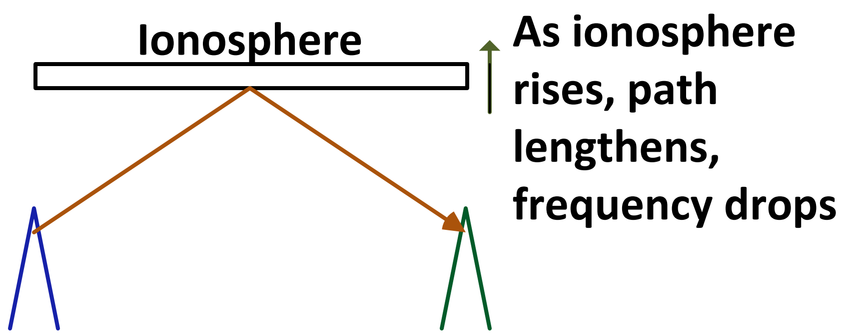
Amateur Radio and the Eclipse: Frissell et al. (2018), https://doi.org/10.1029/2018GL077324

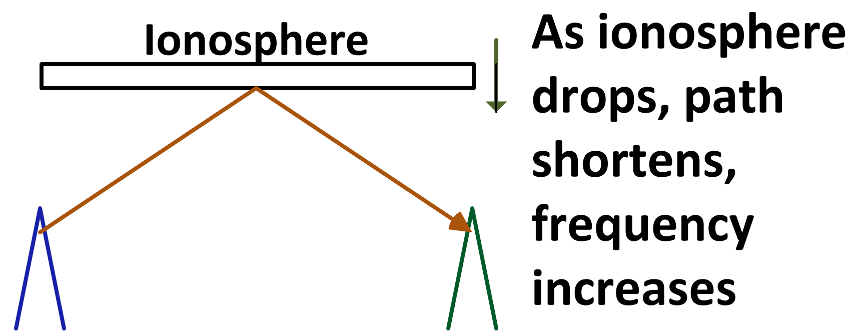
# A Conversation Between Red Ham and Blue Ham

**What can we measure with ham-priced equipment?**

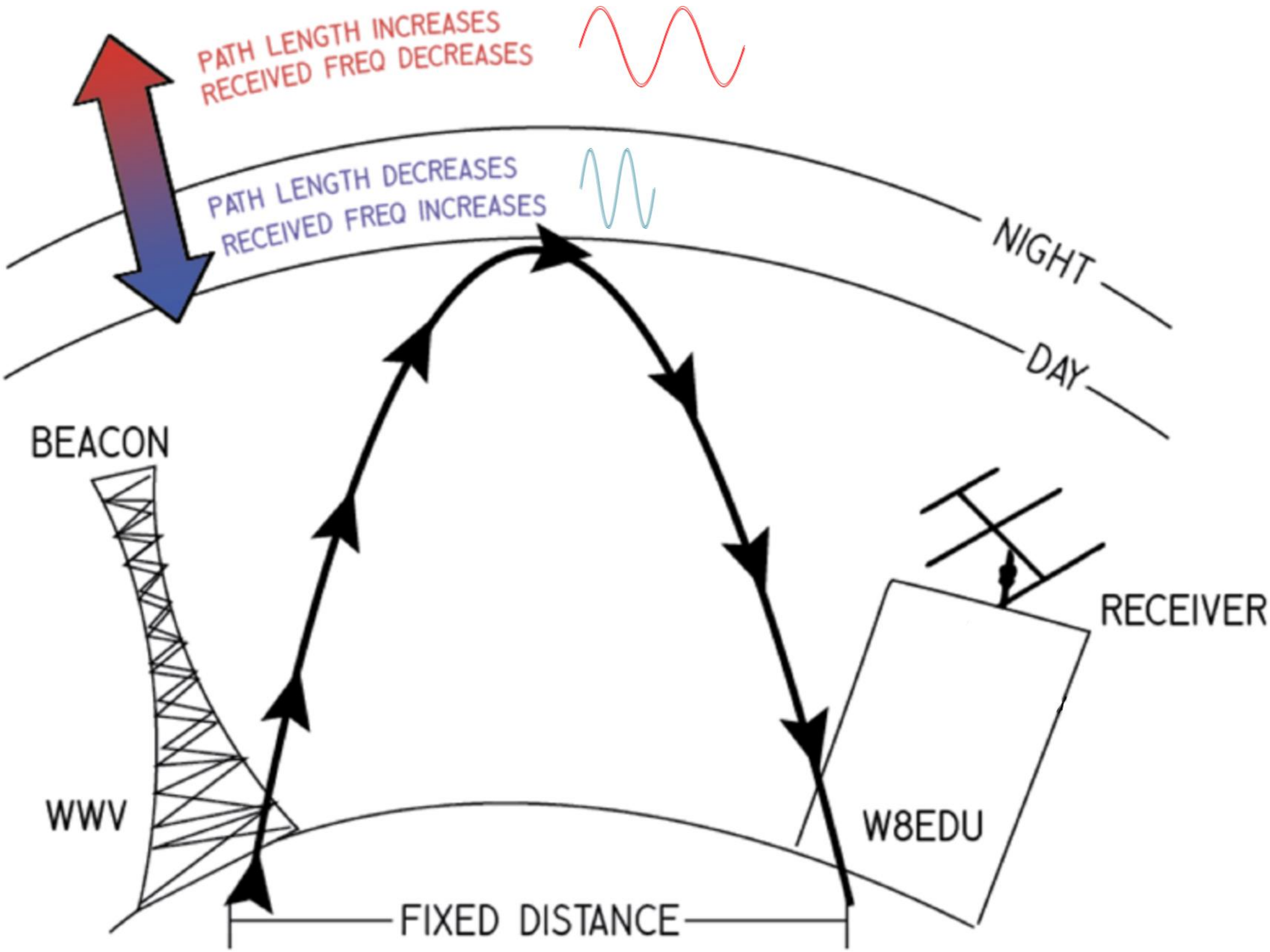
**Well, I guess we could measure the height of the ionosphere (really the mean refraction height) at different frequencies. That's what professionals do with ionosondes, but while we can do some of that, the cost of the whole thing is a bit steep for my ham budget.**

**But we *can* measure the relative strength of the received signal. And we *can* measure the frequency of the received signal. Same as the transmitted signal - what's that gonna prove? Nope, the two are different. You mean to tell me that the transmitted and received frequencies are different? Where did you go to school? Well, as the refraction height of the ionosphere rises, the distance the signal travels to get from there to here goes up. But no more cycles of the signal, so the frequency has to go down. And vice versa; as the refraction point comes down, so the frequency must go up. That sounds like Doppler shift, the same thing that changes the pitch of a train whistle from when it approaches you to when it goes away from you. You got it!**



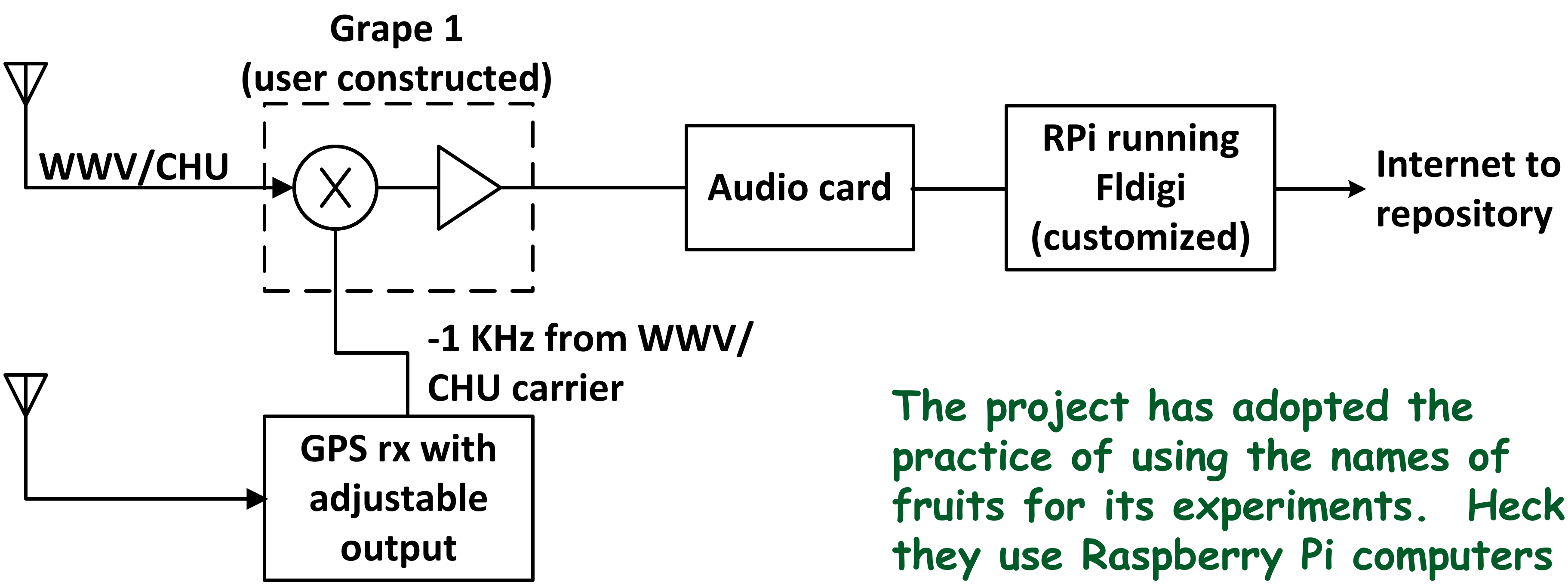



# The received frequency varies due to Doppler shift as the ionosphere rises and falls



# And that Brings Us to the HamSCI Frequency Measuring Experiments

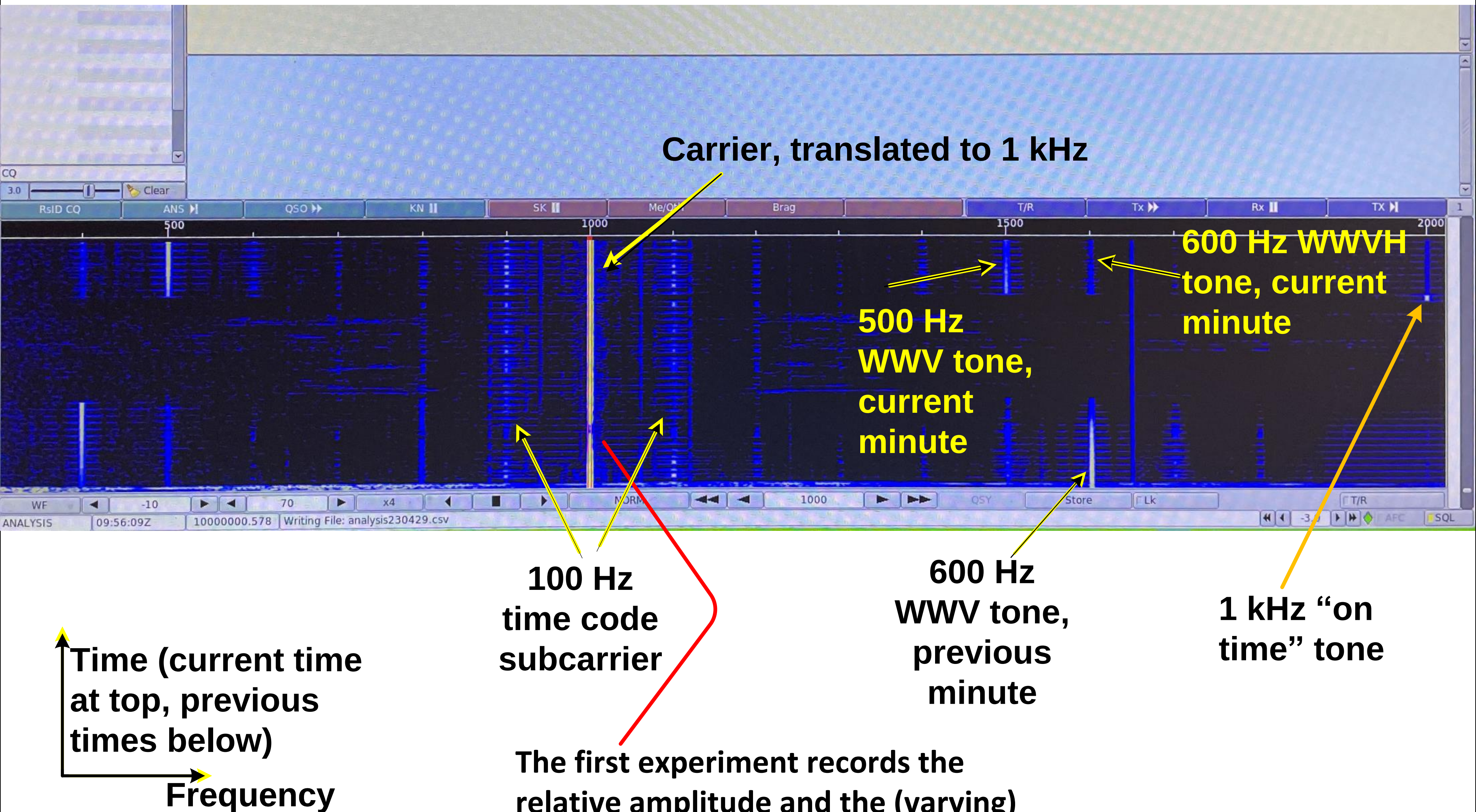
## The first experiment




e.g., Leo Bodner Mini Precision GPS Reference Clock
https://www.leobodnar.com/shop/

The project has adopted the practice of using the names of fruits for its experiments. Heck, they use Raspberry Pi computers for control and data collection, so why not? The first prototype was the Tangerine, then the Grape series. Next will be the Clementine receiver.

# Fldigi waterfall display

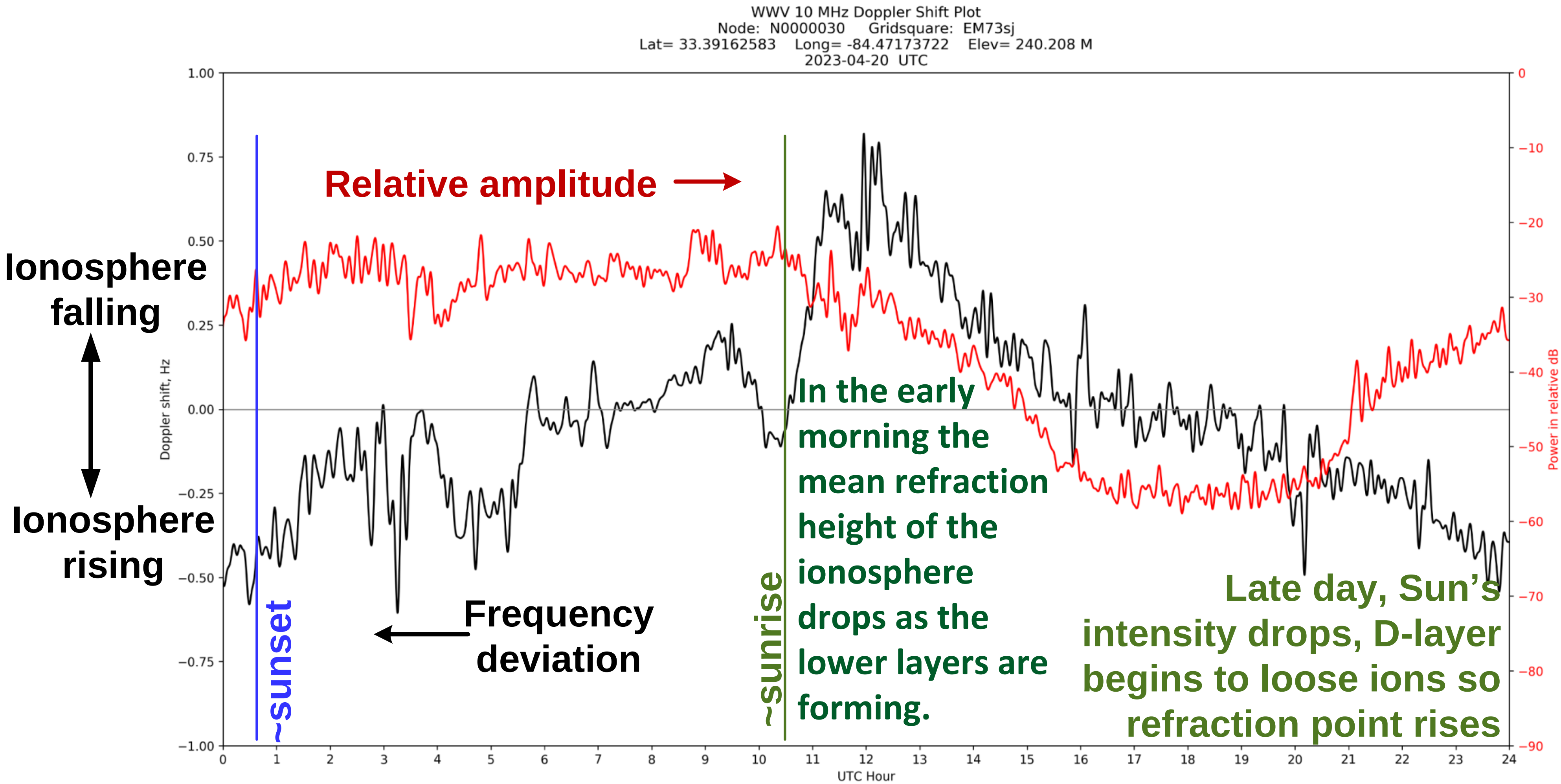



The first experiment records the relative amplitude and the (varying) frequency of WWV's carrier

# A Quiet Day On the Sun

## (Original HamSCI experiment)

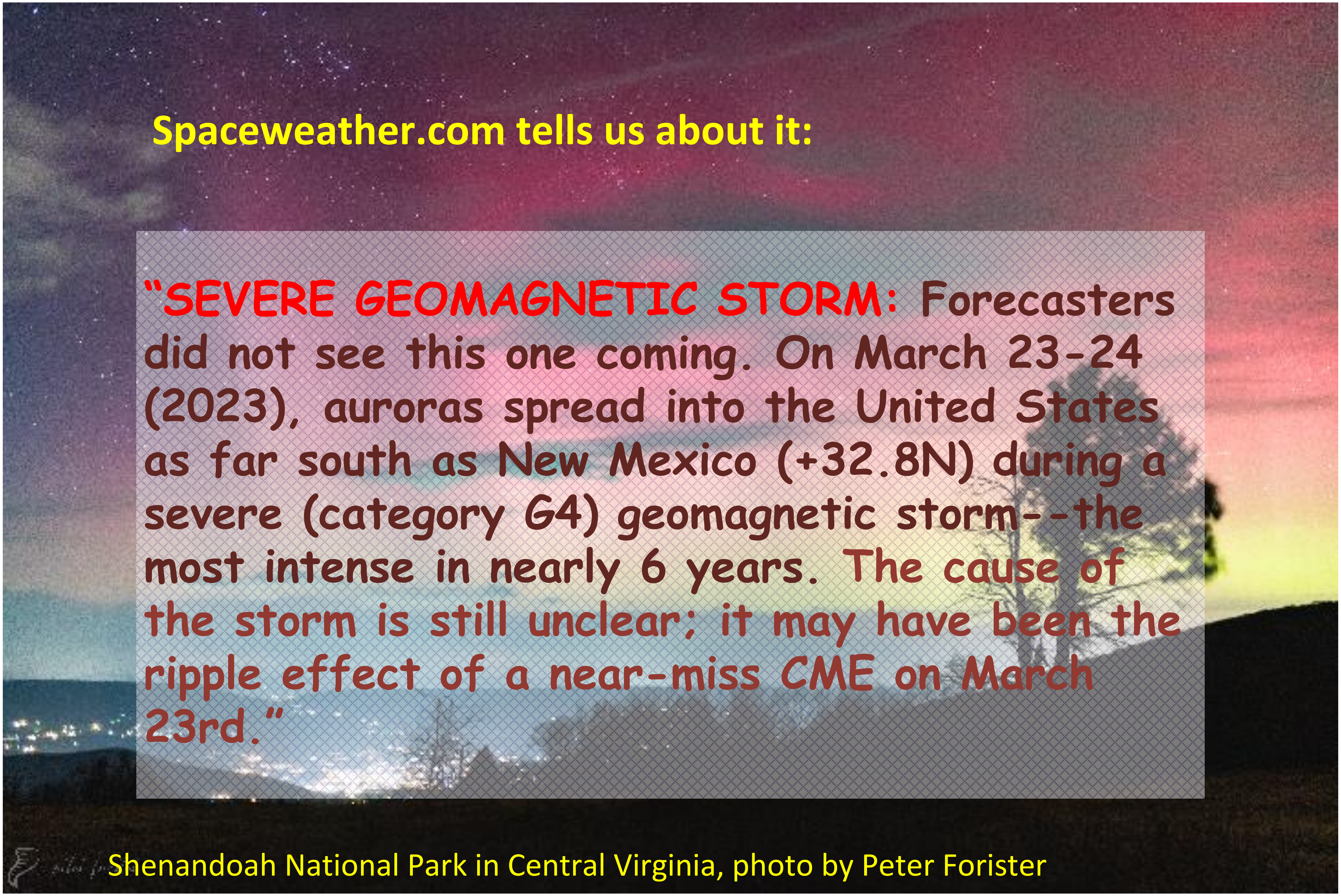
## 4/20/23




As night begins the D layer is dissipating and the higher E- and F- layers are assuming nighttime positions, so the refraction altitude rises

Midday, much reflection is from the E layers, which are more stable than the F layers, and the D layer offers shielding, so the refraction point is more stable

# But Not Everything Always Plays Nice in Space

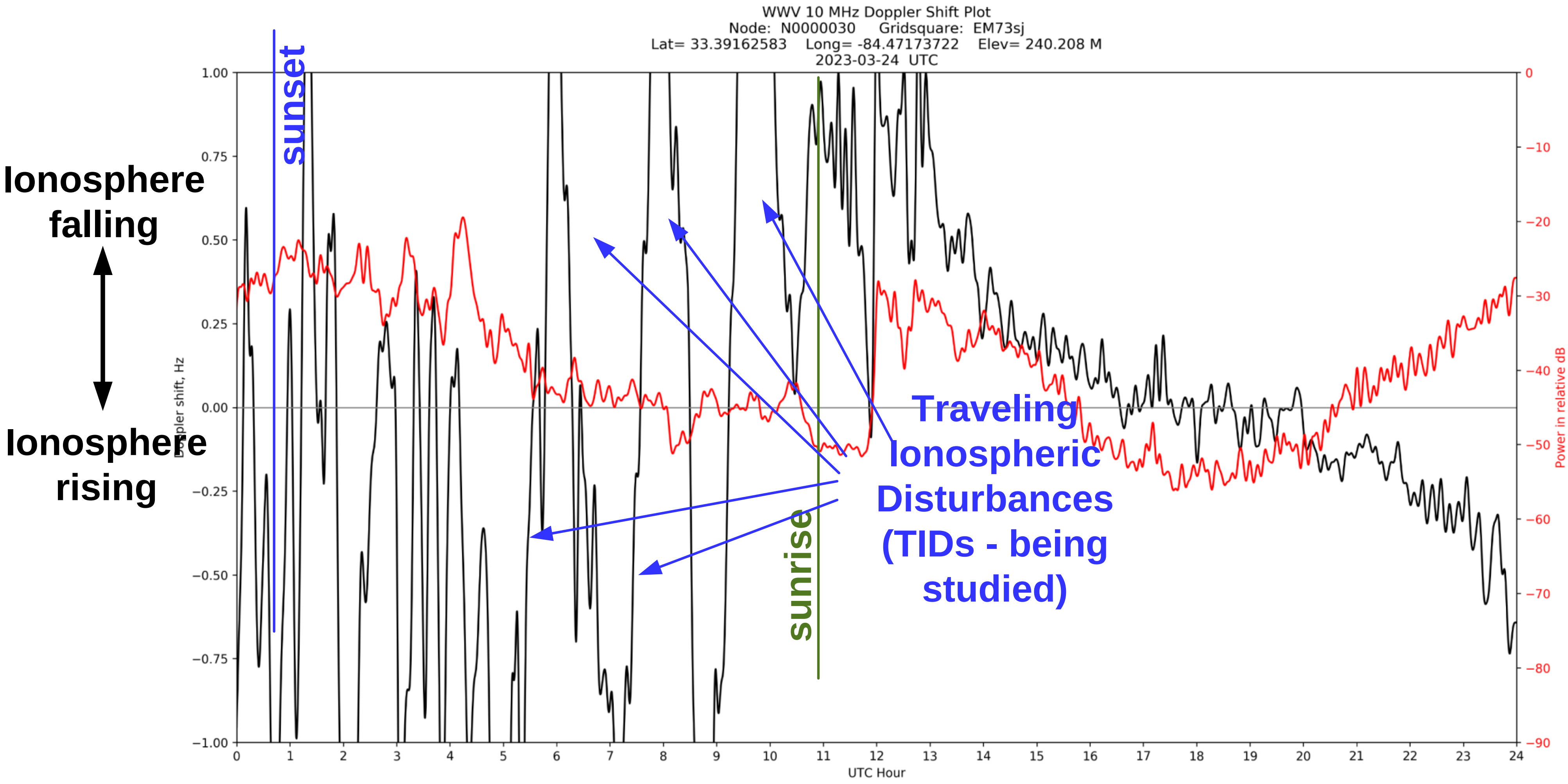


Shenandoah National Park in Central Virginia, photo by Peter Forister

https://spaceweather.com/archive.php?view=1&day=24&month=03&year=2023

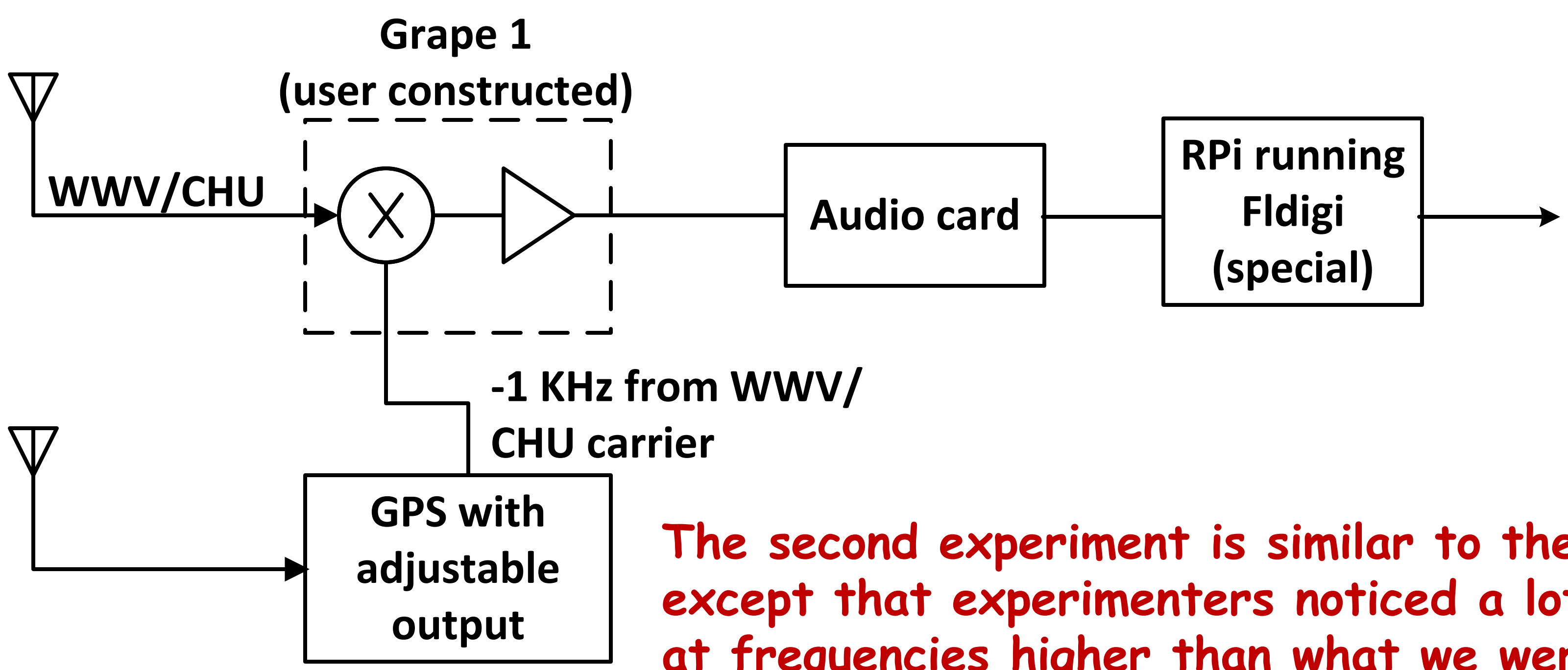
# Not Such a Quiet Day On the Sun

## 3/24/23

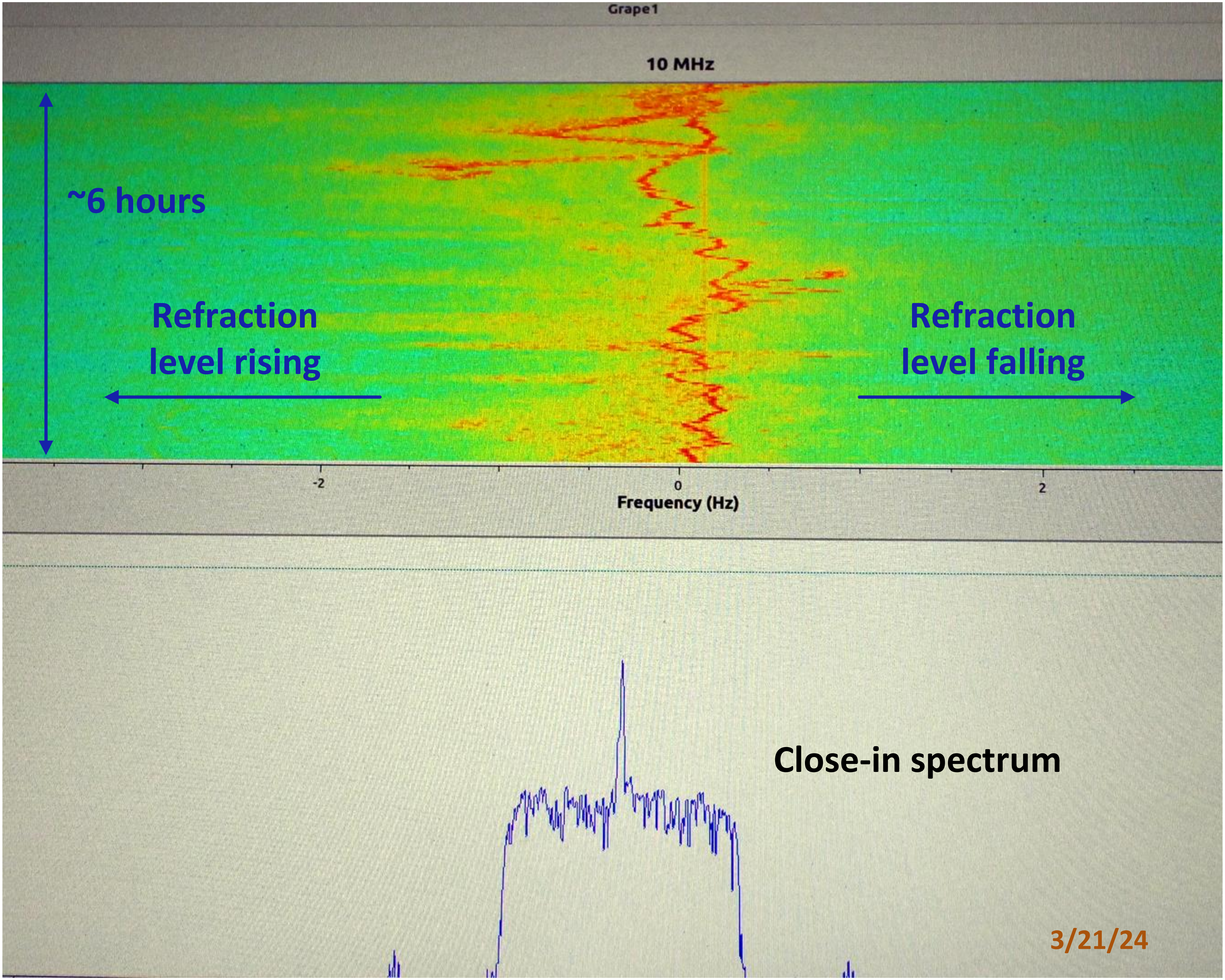


# And that Brings Us to another HamSCI Frequency Measuring Experiment

## The second experiment



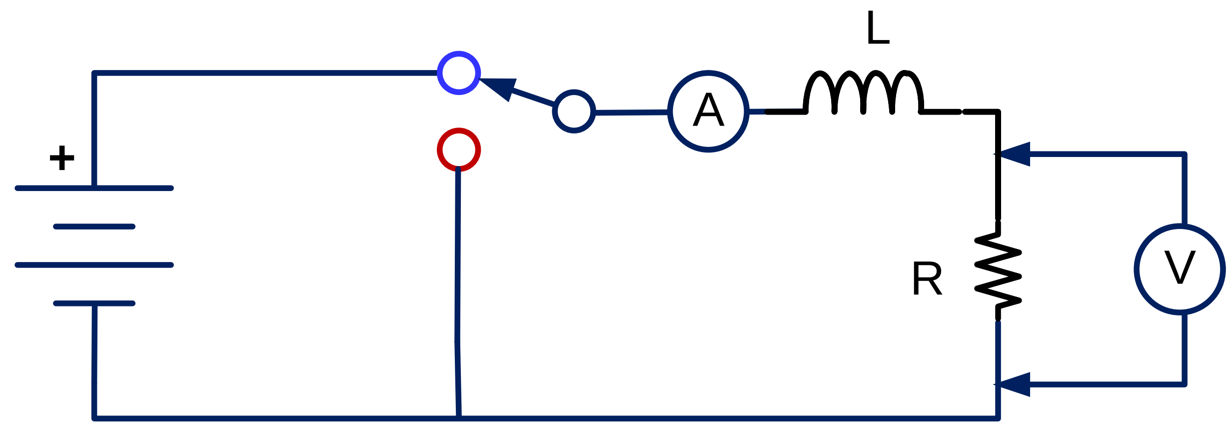

The second experiment is similar to the first, except that experimenters noticed a lot happening at frequencies higher than what we were capturing. So while the first experiment continues to provide useful information, the second experiment provides higher frequency data capture than does the first.

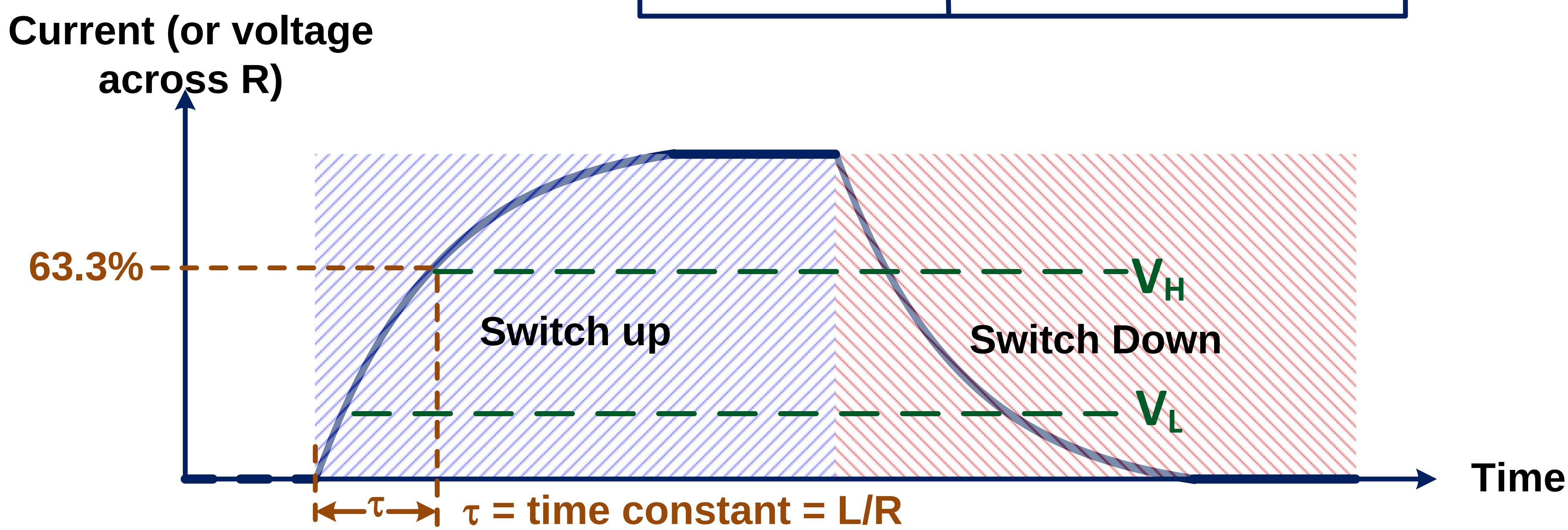

Grape1
10 MHz
~6 hours
Refraction
level rising
Refraction
level falling
-2
0
2
Frequency (Hz)
Close-in spectrum
3/21/24

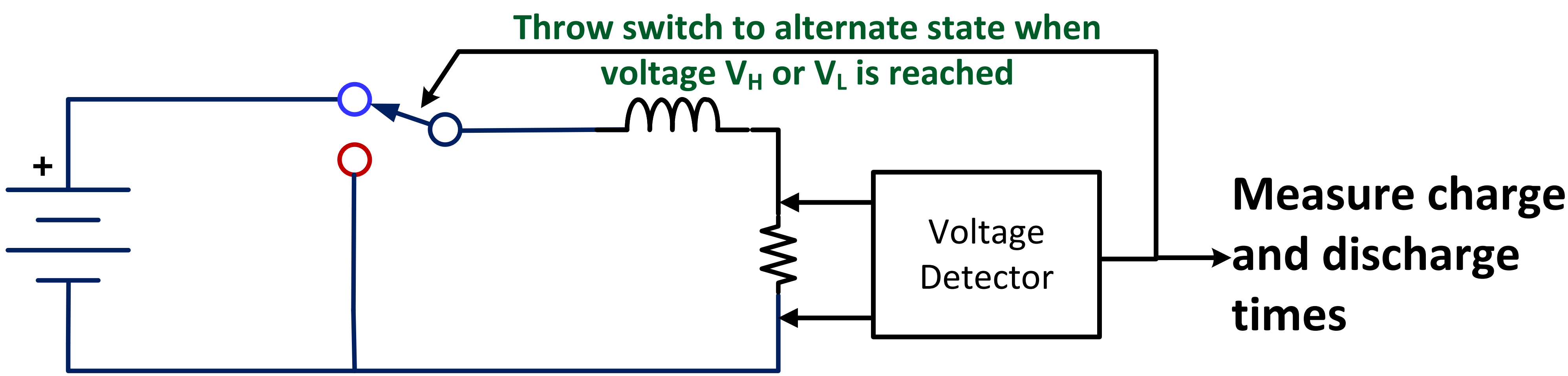
# The Third Experiment
## Magnetometer

The earth has a big bar magnet running between the north and south poles. This enables the magnetic compass. But now we find out that the magnetic field is perturbed by radiation of the sun! We use a magnetometer to study the slight variations of the magnetic field.

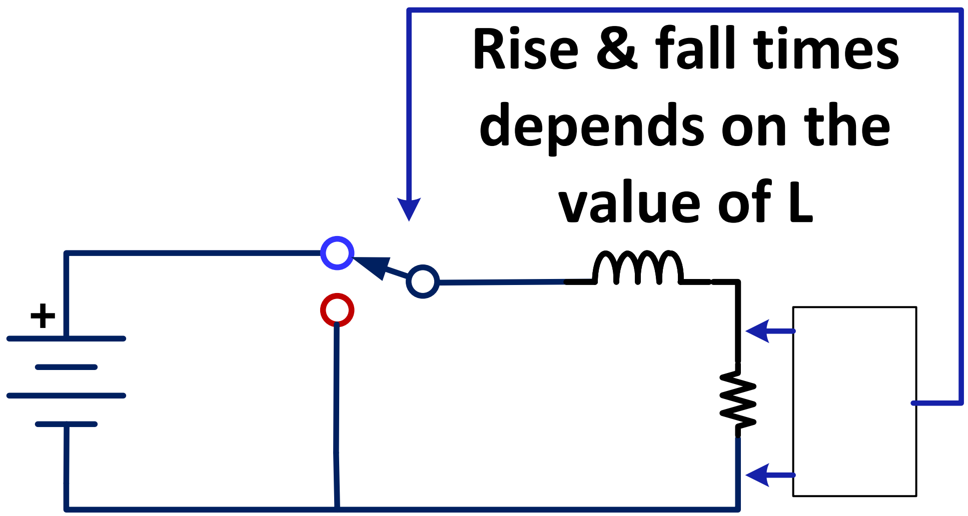
# Principle of this Magnetometer



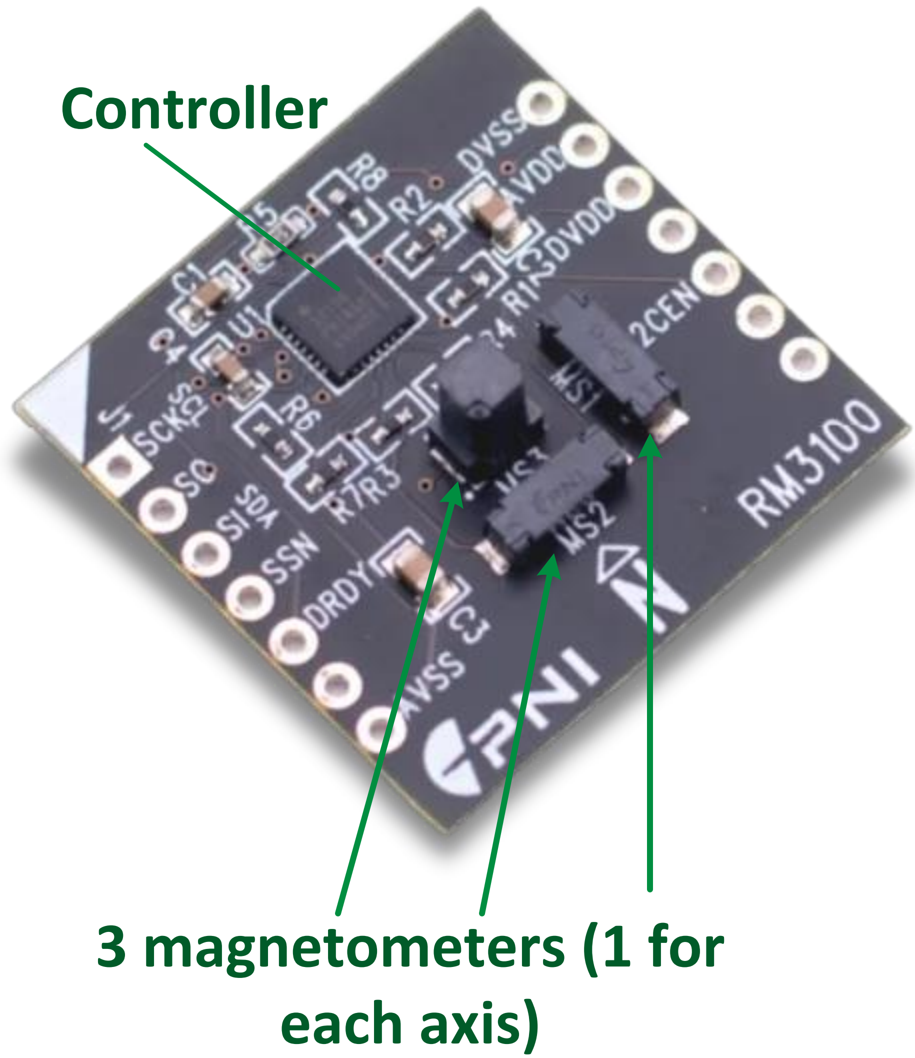



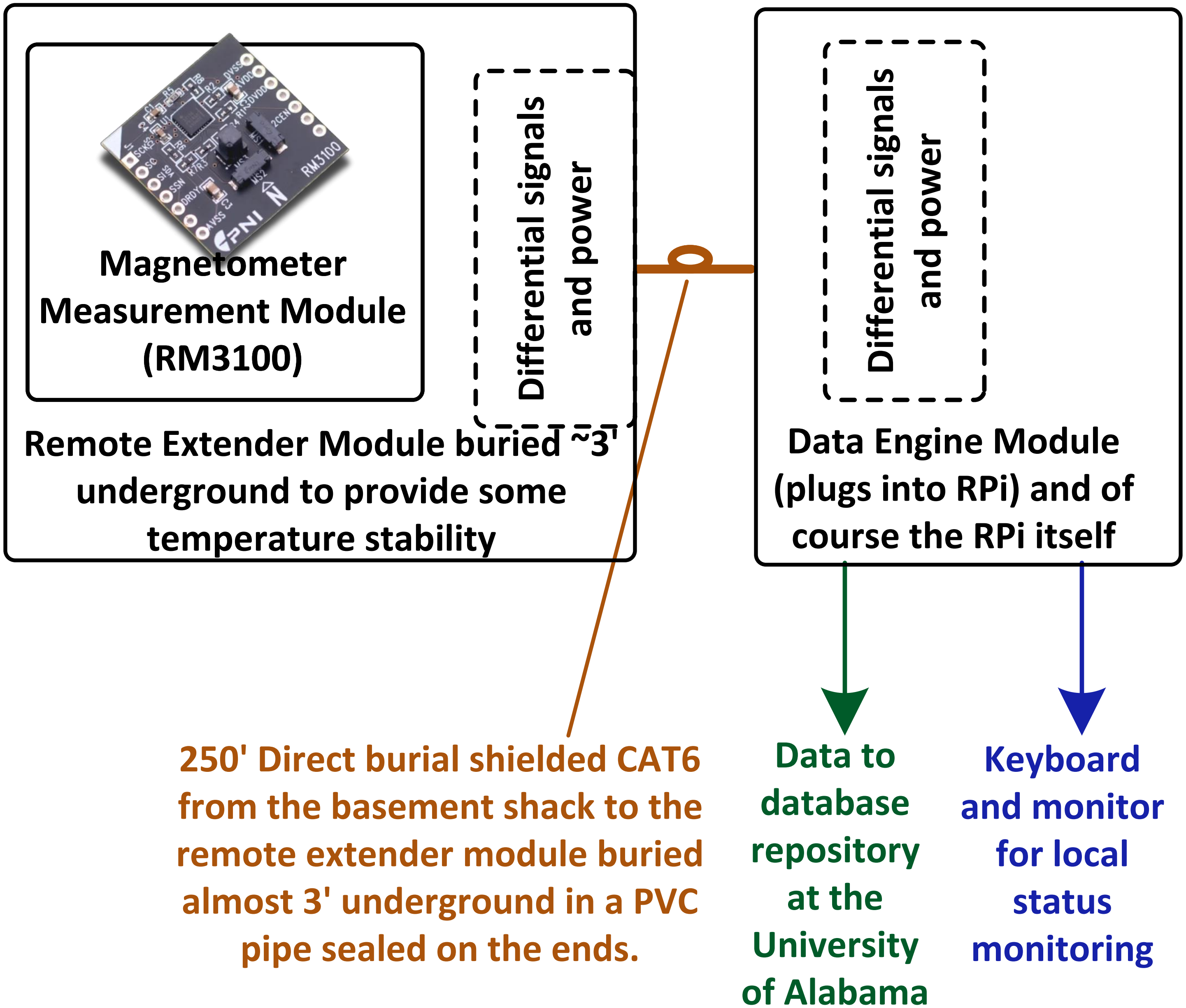
# Principle of this Magnetometer Operation




Effective value of L during 1-way (not full-cycle) operation depends on the winding of the inductor and to a small extent on the value of the magnetic field through it. The magnetic field is that of the earth.

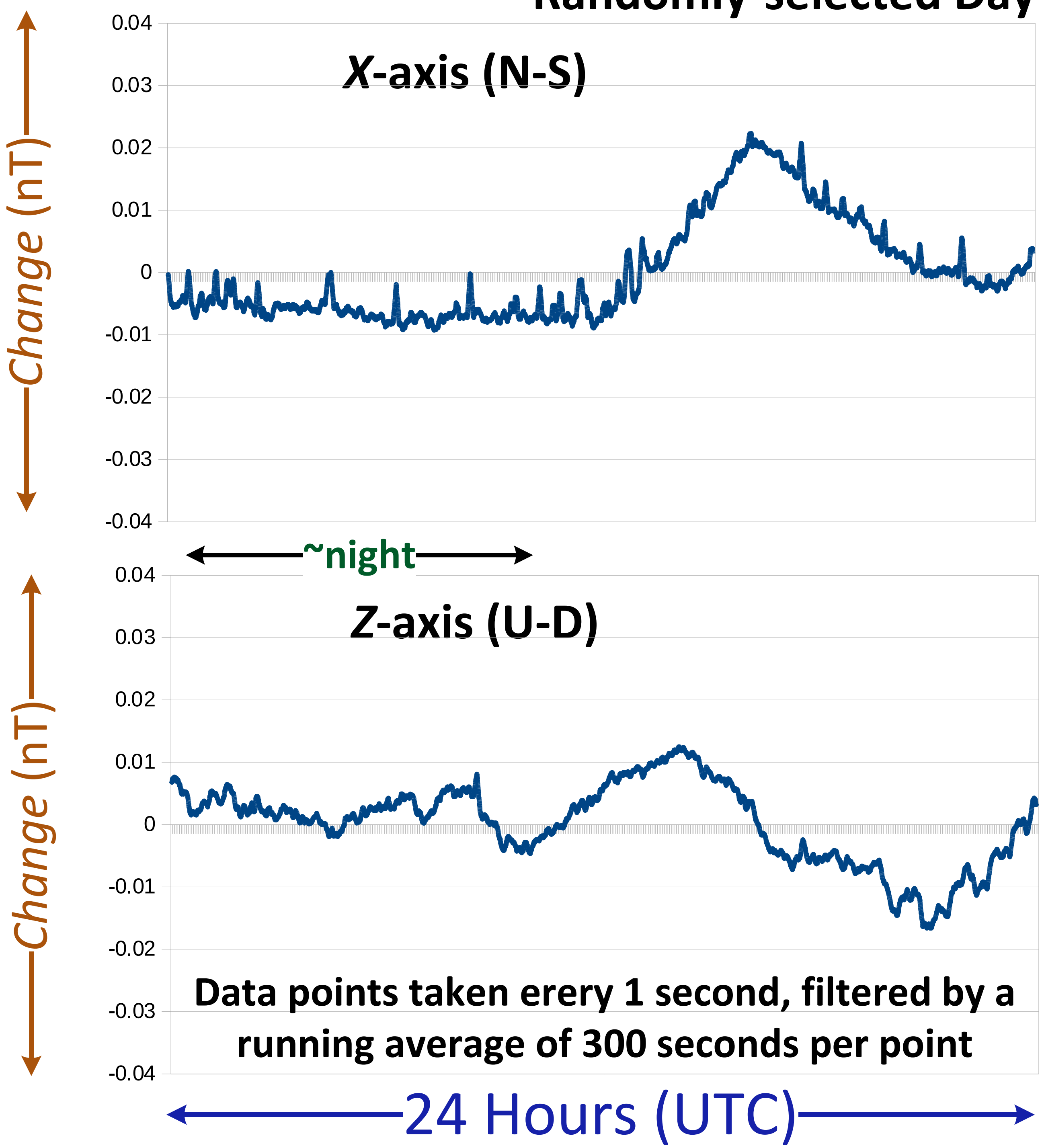


# Magnetometer Experiment



# Magnetometer Plots

## Randomly-selected Day




*Woahh. What did you do with the Y-axis (E-W)? Ain't no magnetic field in the E-W direction. Well, there ain't one when our reference frame is the magnetic poles (as opposed to the geographic poles). In fact, we point the magnetometer by minimizing the Y-axis reading. (OK, there is a little field along the Y-axis and it changes during the day, but it's small)*

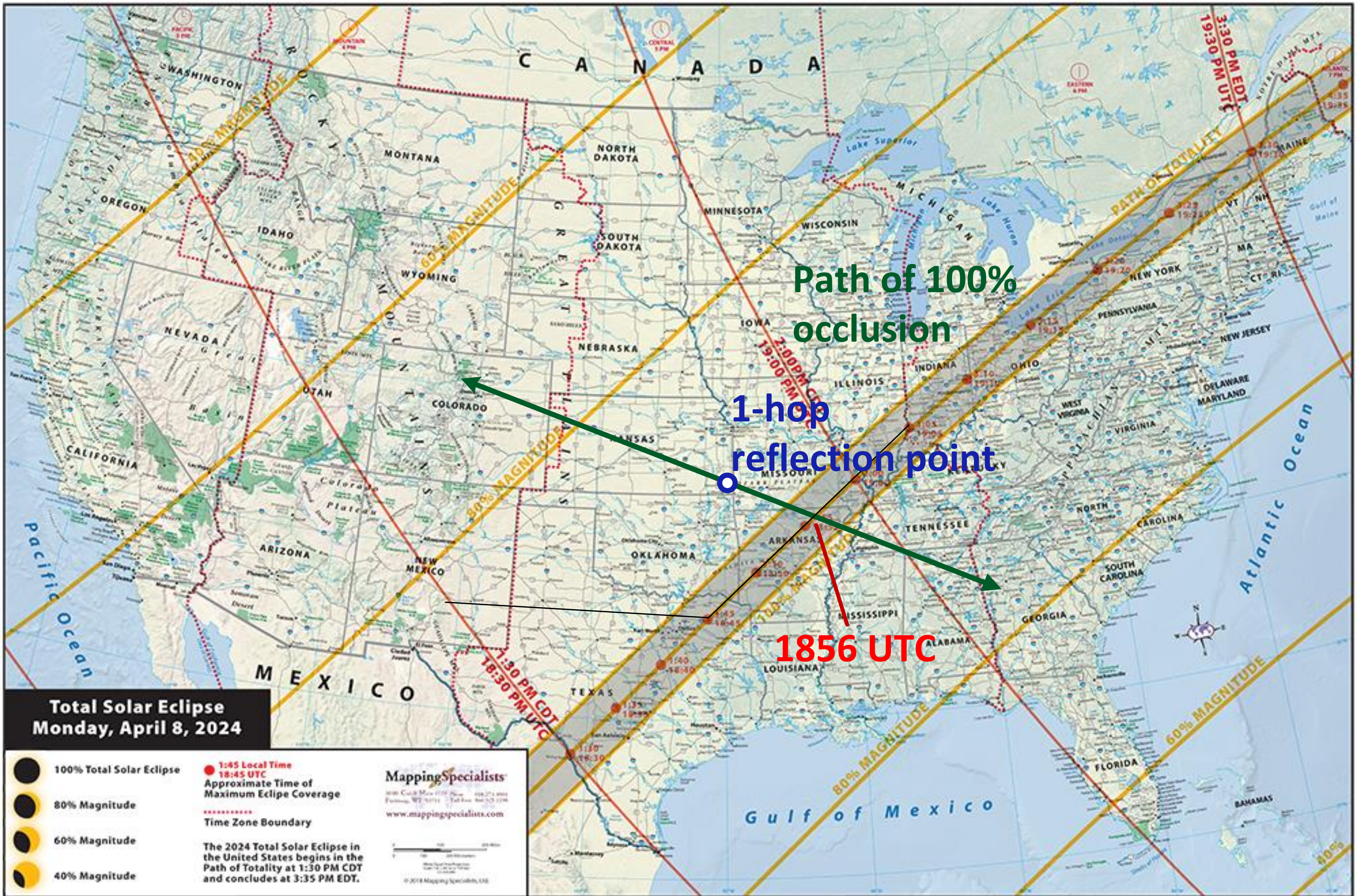
3/20/24

Recently the project released a limited number of a new Grape 2 receiver. This one does all that the earlier Grape receivers did and adds simultaneous receipt of WWV on 5, 10, and 15 MHz. It has a magnetometer capability but I've elected to continue running the older one because I am too lazy to bury another magnetometer – the two are incompatible due to the addressing scheme used. I was lucky to snag one of the Grape 2 receivers because the midpoint of the path from WWV to my house is kinda close to the April 8 route of total eclipse. I just got it running the day before the eclipse!

Now in case you missed it, I scheduled a solar eclipse to cross over a pretty good swath of the U.S. on April 8, 2024 in order to celebrate one of my daughters' birthday. The ionosphere didn't miss it!

# RF Path (Boulder – Fayetteville)

## (center is close to the path of totality)



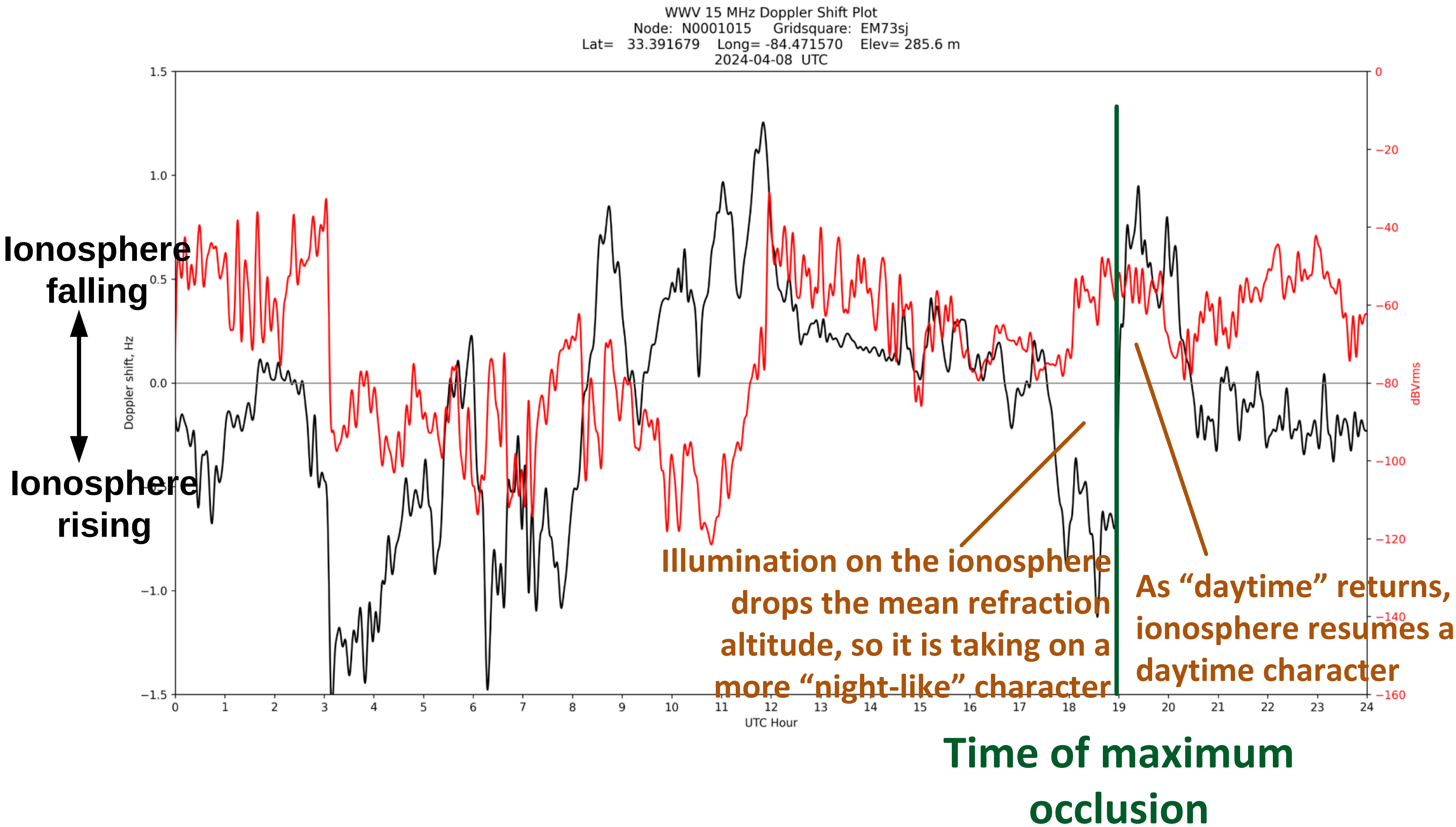
# An Excuse to Show My Picture

**Here in Fayette County we only had around 85% occlusion but, hey, it made a pretty decent picture**

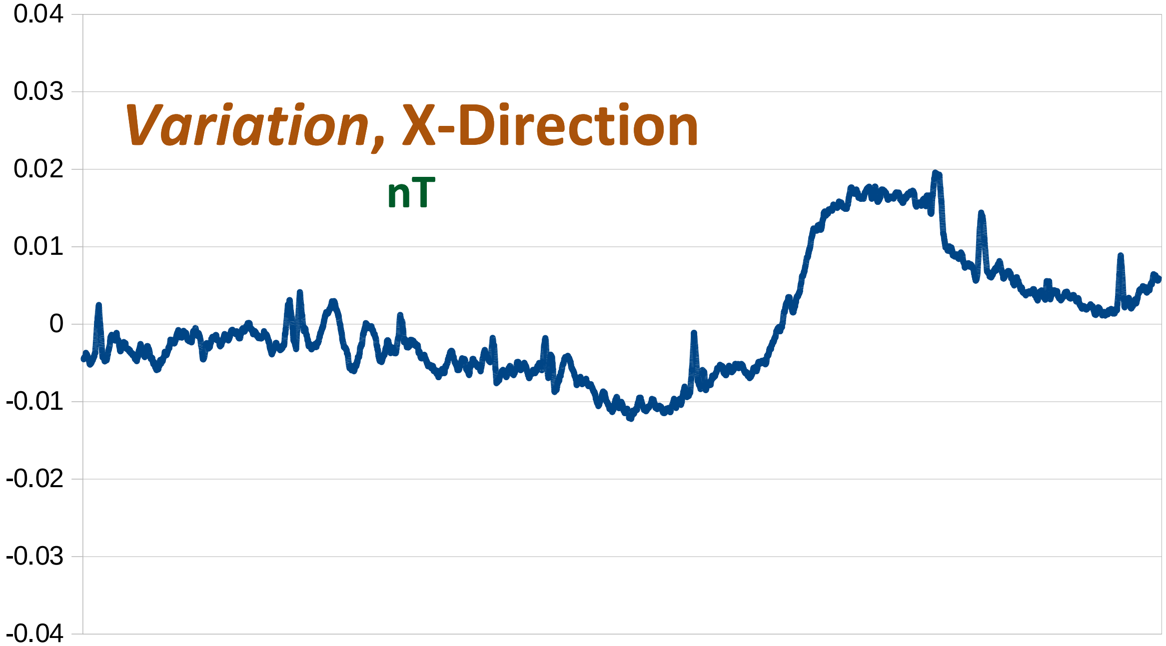
Nikon Zfc with solar filter, 250 mm lens (375 35mm eq), ~2x enlargement in software, f/6.3, 1/30 sec, ISO 3200, exp. bias -2 step

# Likely Effect of Eclipse on Ionosphere

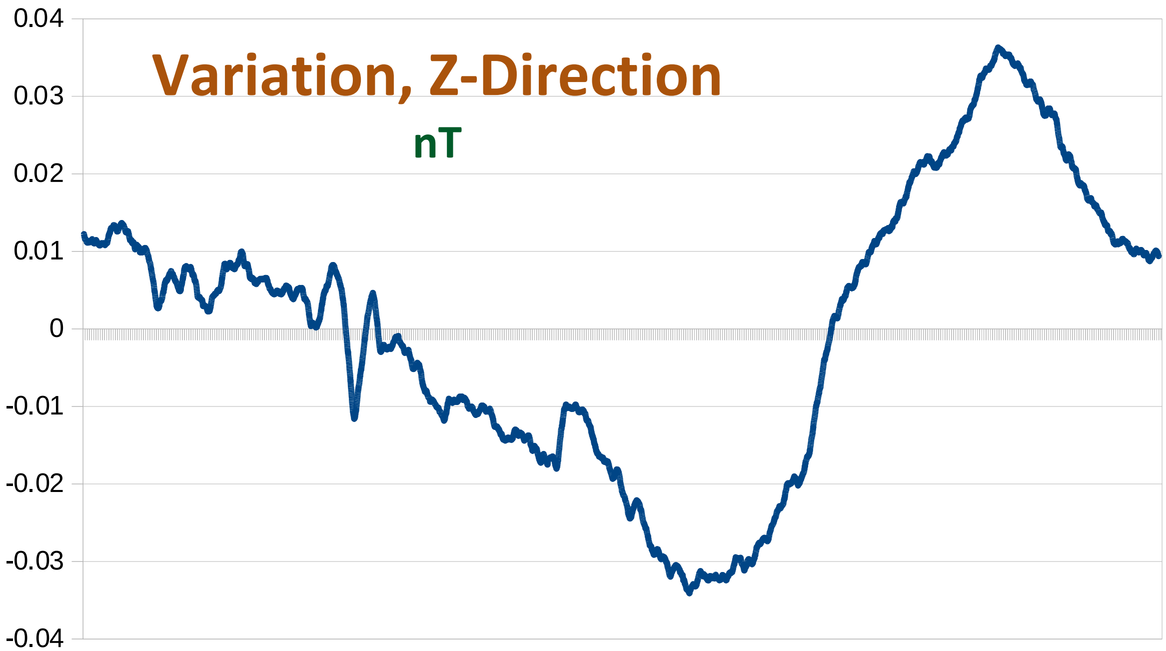
## (15 MHz WWV from Grape 2)



# Magnetic Field, Eclipse Day




~night



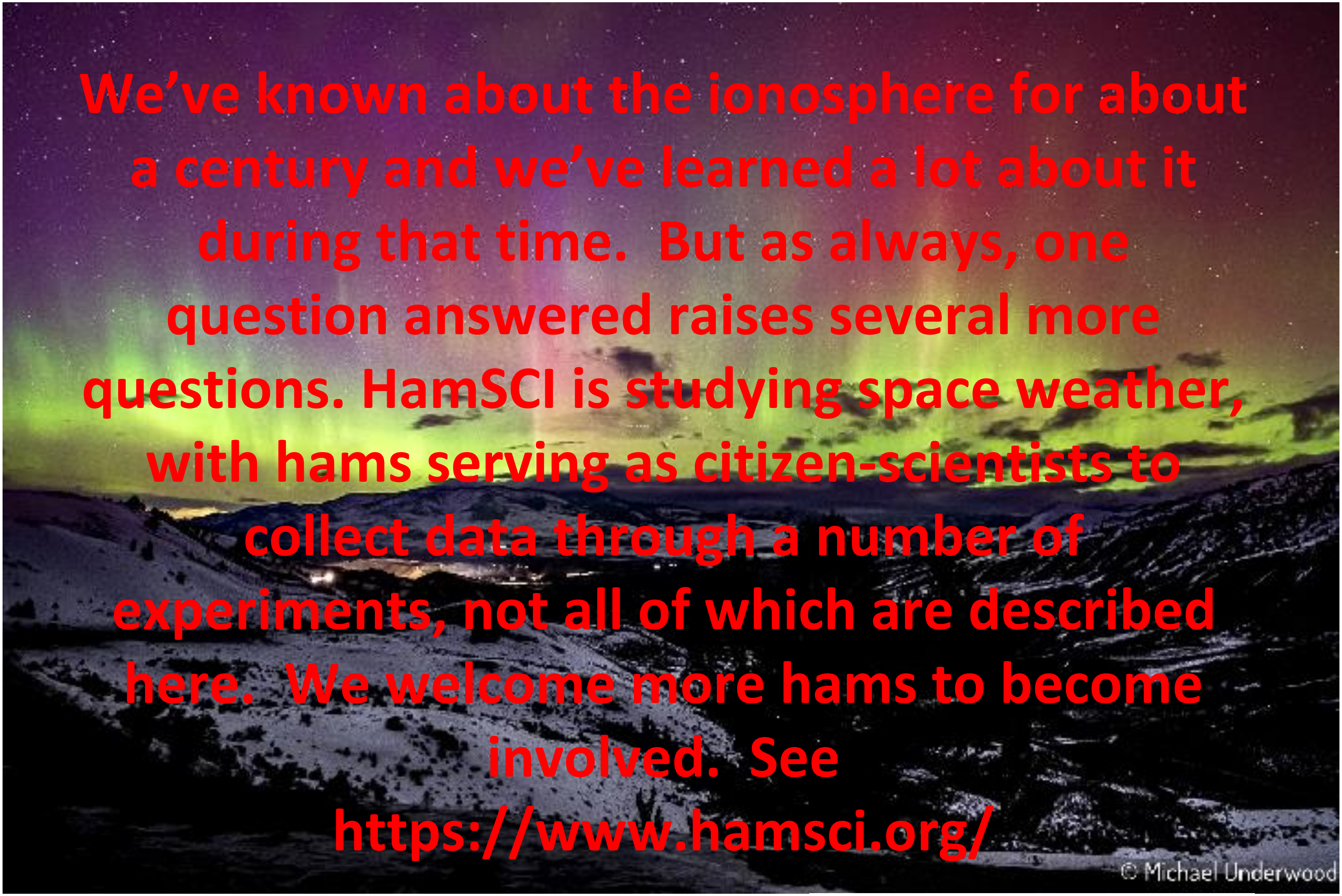

24 Hours

We do see differences between the randomly selected day and eclipse day

The Accutron Watch was produced by Bulova beginning in 1960, as the first major improvement in watches since the wrist watch was developed in the late 1800s. The Accutron didn't depend on a weighted wheel rotating back and forth to determine the time accuracy. It used a miniature tuning fork vibrating at 360 Hz. The tuning fork was "kicked" by a single transistor circuit on each cycle to keep it going. The tuning fork turned a gear through a pawl arrangement in order to move the hands. *It exhibited the then-unheard-of accuracy of better than a minute a month!*


**You've come a long way, baby!**

**HamSCI is helping advance the state-of-the-art even further.**




Mammoth/Yellowstone National Park 3/24/23

https://spaceweathergallery2.com/indiv_upload.php?upload_id=194567