Propagation TeePee: A High Frequency (HF) Radio Spectral Feature Identified by Citizen Scientists

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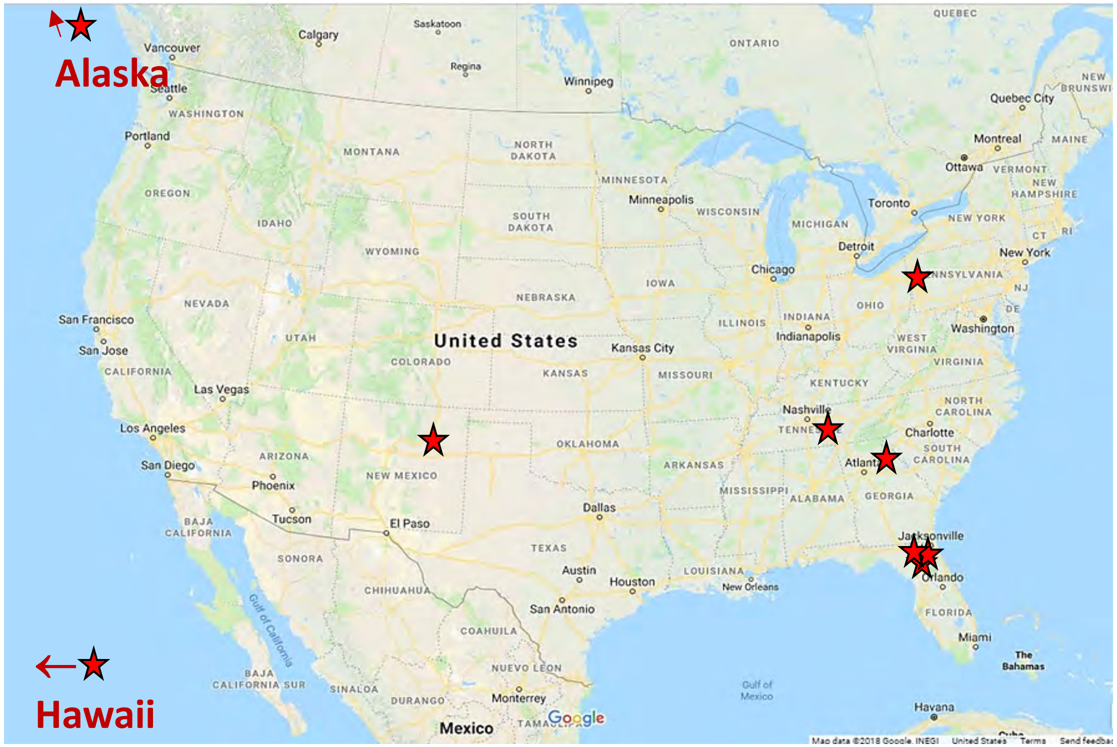
Citizen Science Under the Radio JOVE-NSSEC Partnership

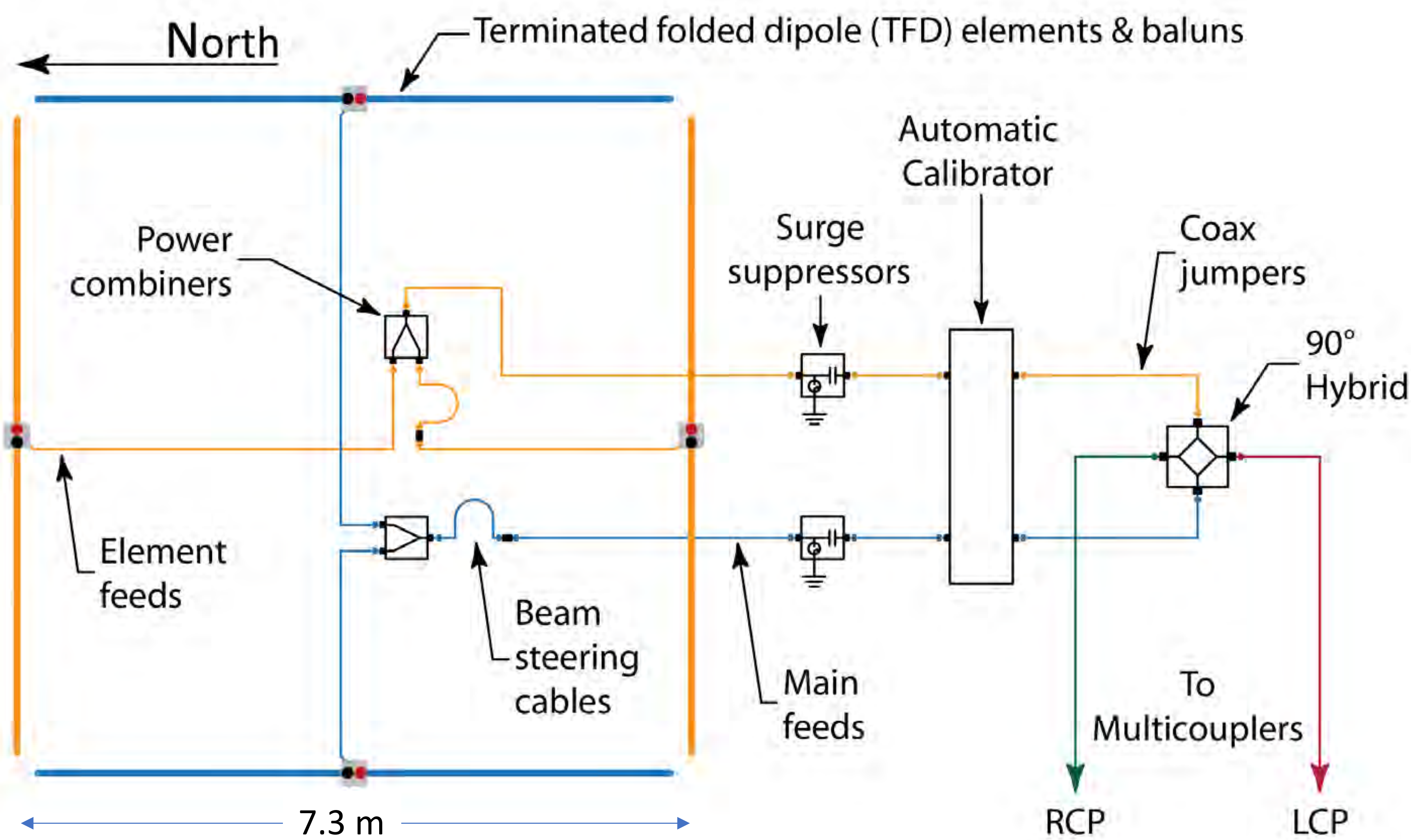
- The Radio JOVE project <http://radiojove.gsfc.nasa.gov/>
  - Established for over 20 years as an informal education & outreach project
  - Over 2400 single-frequency kits distributed worldwide
  - Focuses on radio astronomy of Jupiter, the Sun, and the Galaxy
- The Spectrograph Users Group (SUG) is a more advanced subgroup that operates several radio spectrographs (15-30 MHz) across the continental US, Hawaii and Alaska.
- As a partner with the NASA Space Science Education Consortium (NSSEC) since 2016, the Radio JOVE project has been extended to perform citizen science research in heliophysics and space weather.

Radio JOVE Spectrograph Network

- Phase-1 network
  - 9 stations operating FSX spectrographs deployed across the Continental US, Alaska and Hawaii
- Phase-2 network
  - Under development
  - Based on SDRs [SDRPlay(2) & others]
    - Lower cost, more capable
    - More new stations to enable citizen science



Radio JOVE Spectrograph Users Group (SUG) Typical Antenna (Phase 1 and 2)

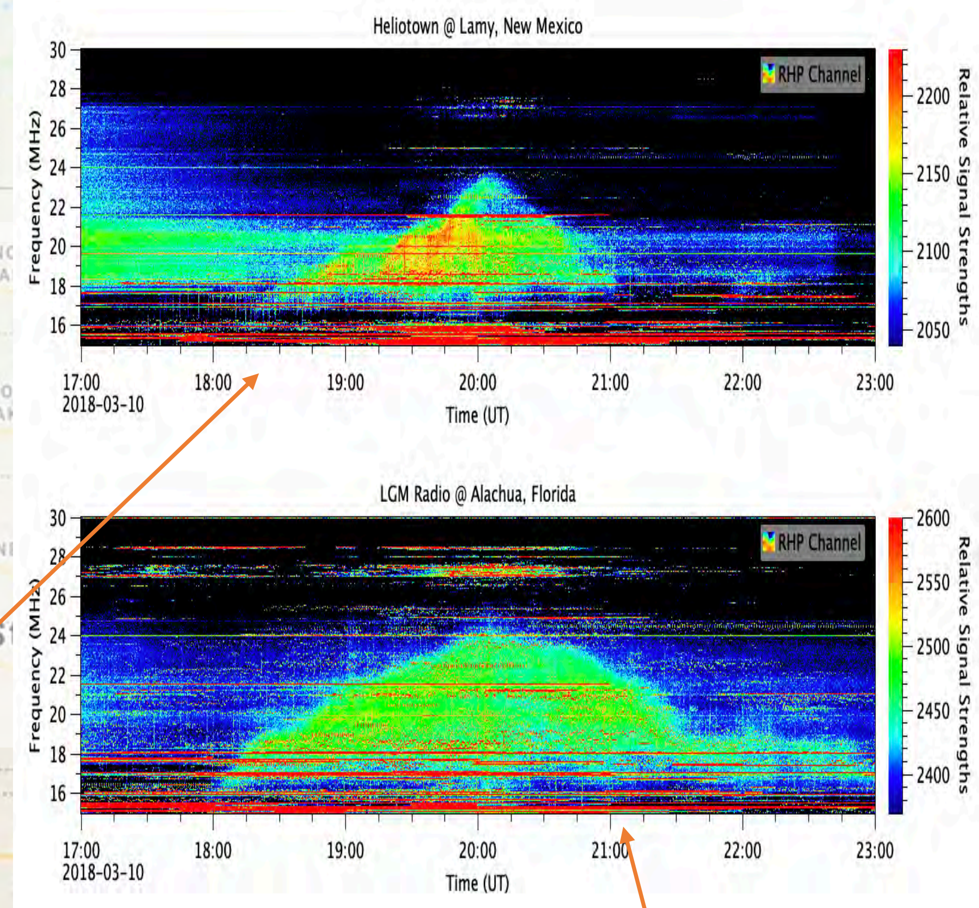


Radio JOVE Spectrograph Users Group (SUG) FSX Spectrograph

Frequency range:	15-30 MHz
Channel bandwidth:	30 kHz
Frequency step size:	50 kHz
Sweep rate:	2000 channels/s
Dwell time per channel:	0.5 ms
Number of channels:	300
Number of inputs:	2 (LCP & RCP)
Temporal resolution:	300 ms

TeePee Spectral Characteristics:

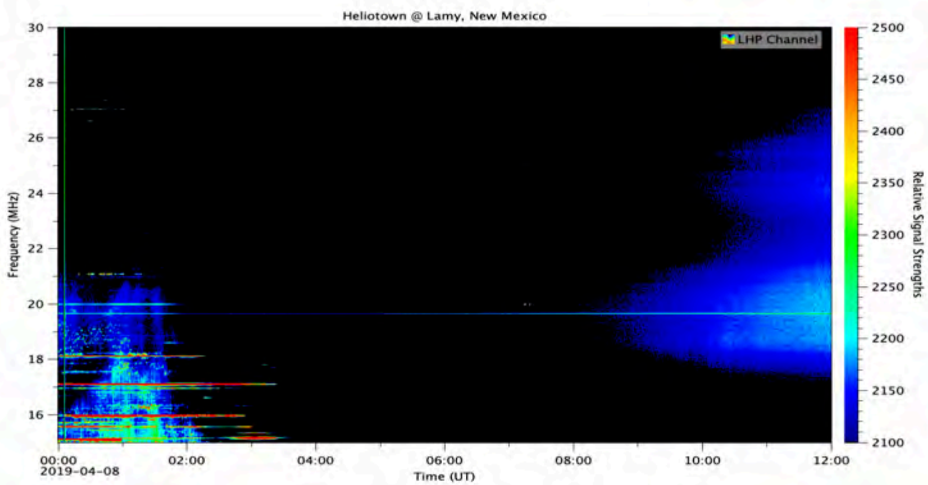
Spectral enhancement with upper cutoff frequency first increases, then decreases with time, resulting in a spectral feature resembling a TeePee tent.

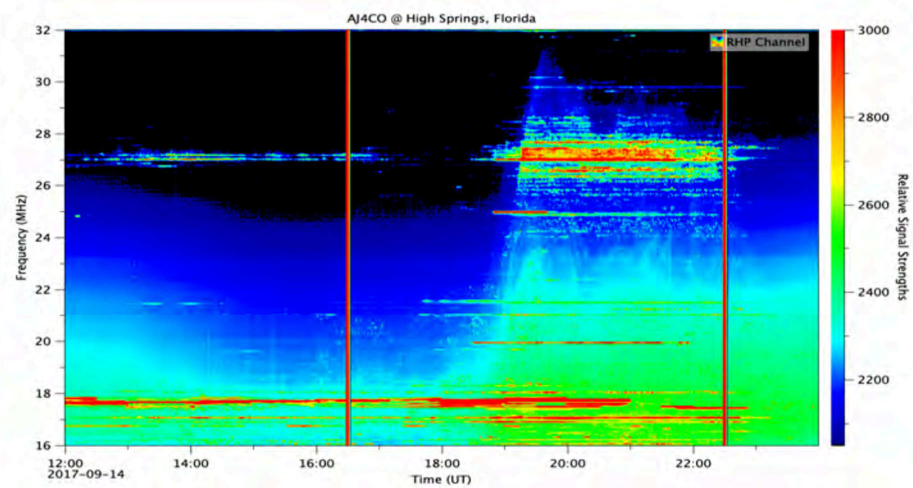


Examples show two TeePees observed simultaneously in Florida and New Mexico

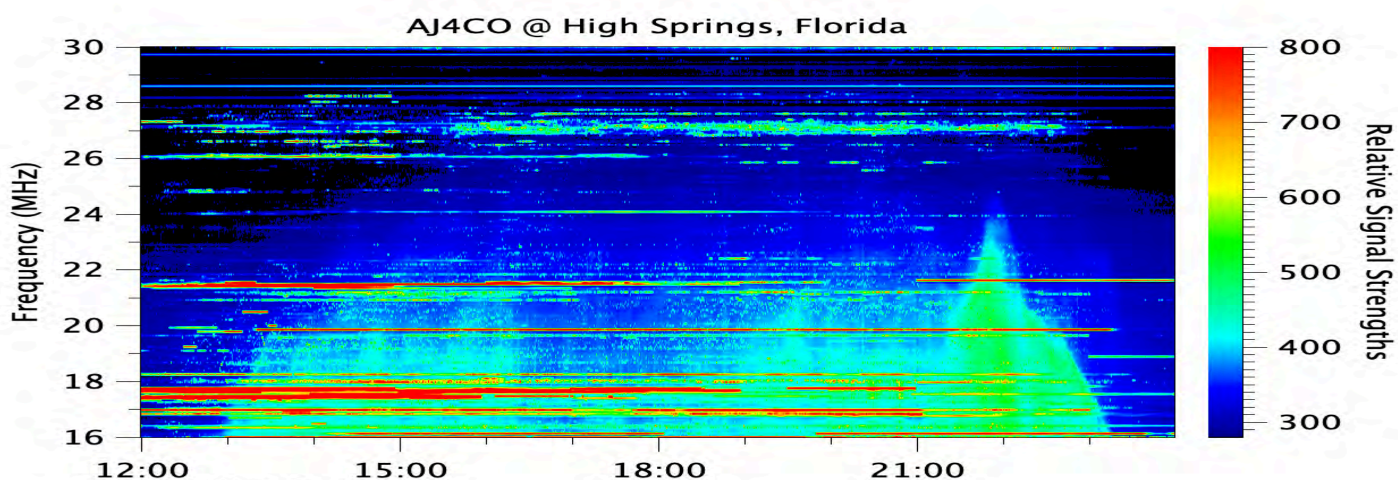
- Distance between the two observing stations ~2280 km, implying source range ~1000 km

TeePees Often Appear in Groups

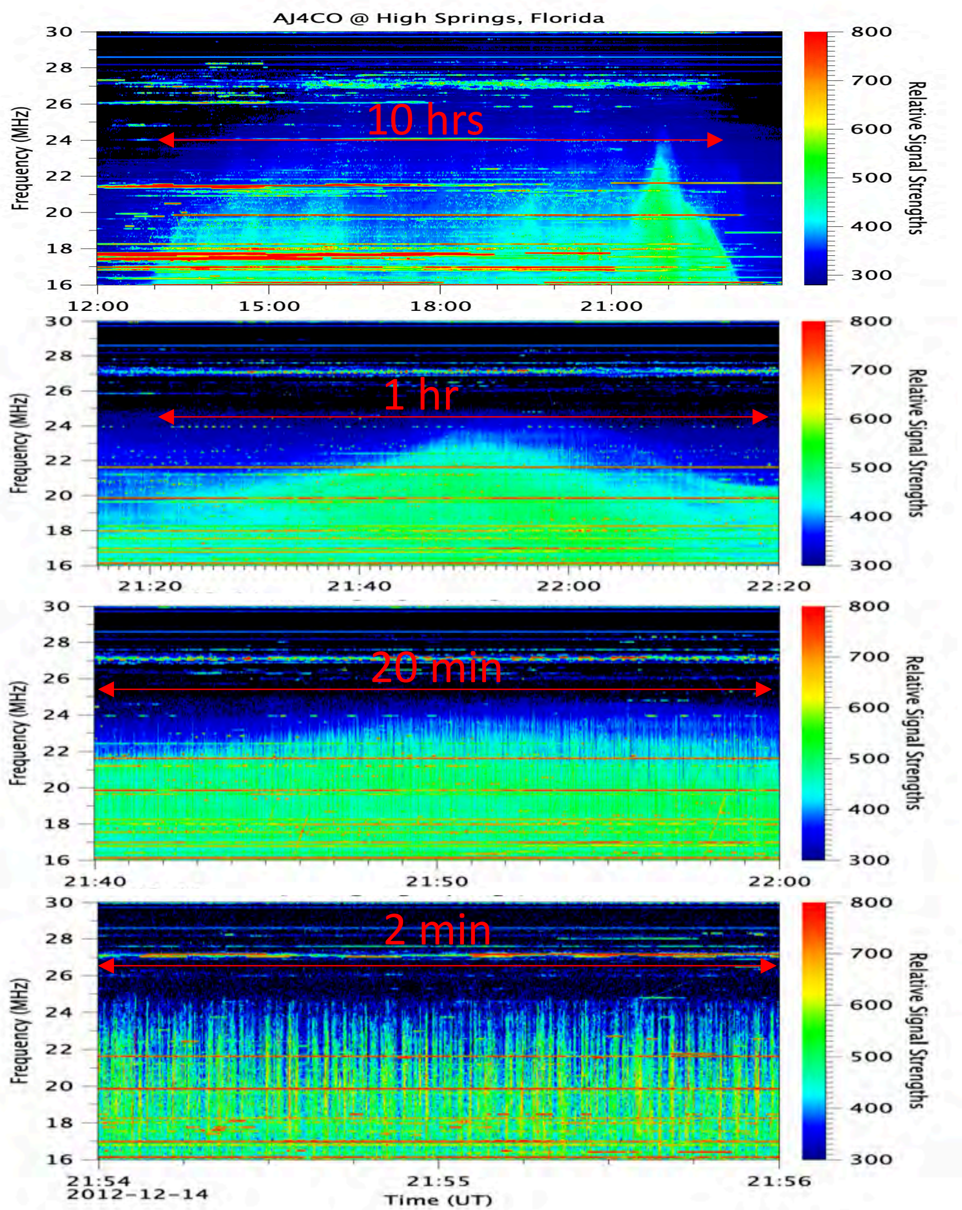


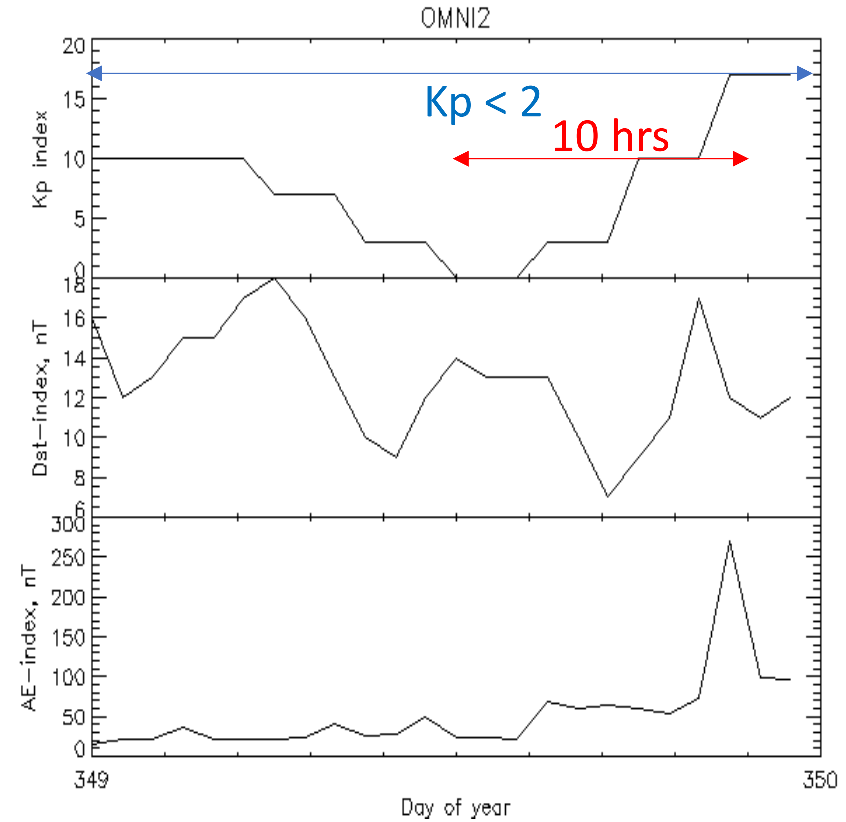


- Nested TeePees (above)
- TeePee Series (below)



Zoomed-In View of Quiet-Time Event

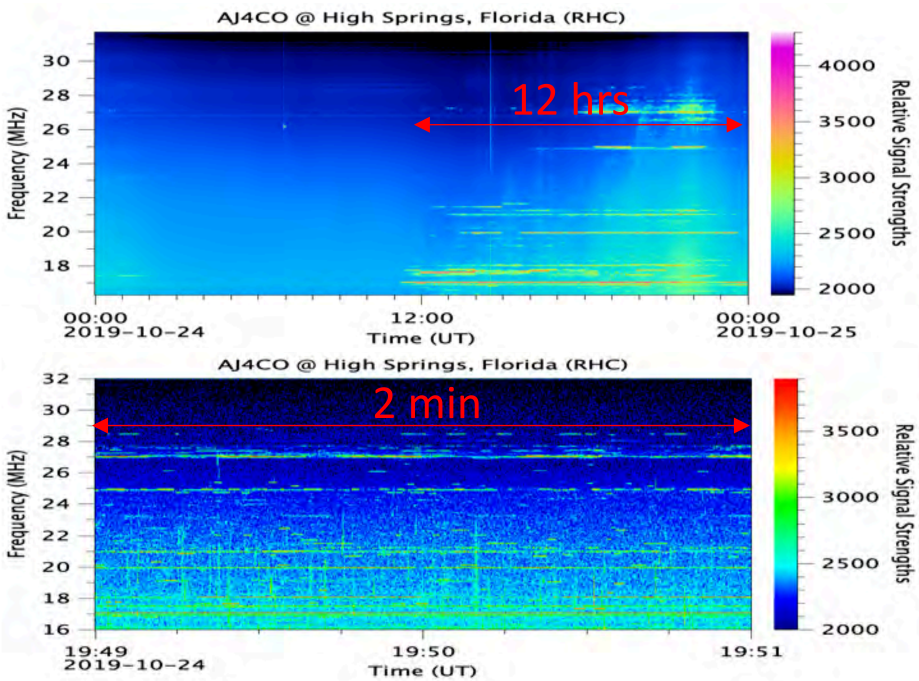


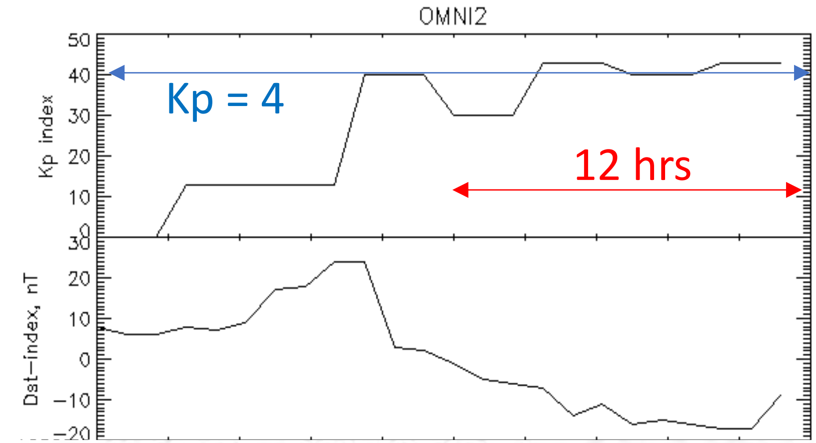


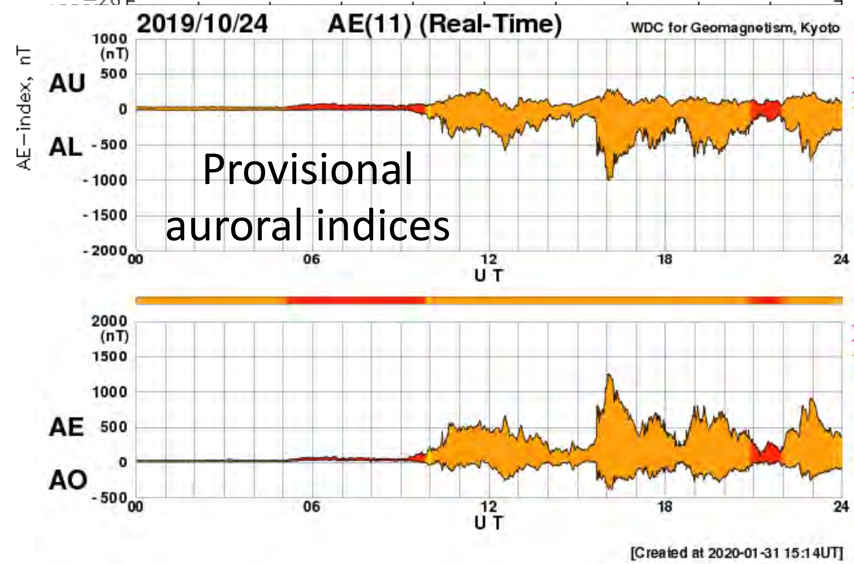
https://omniweb.gsfc.nasa.gov/

Discrete bursts seen occasionally during geomagnetically quiet times (Kp <2) suggest lightning flashes might be the HF radiation source.

Event During "Disturbed Time"



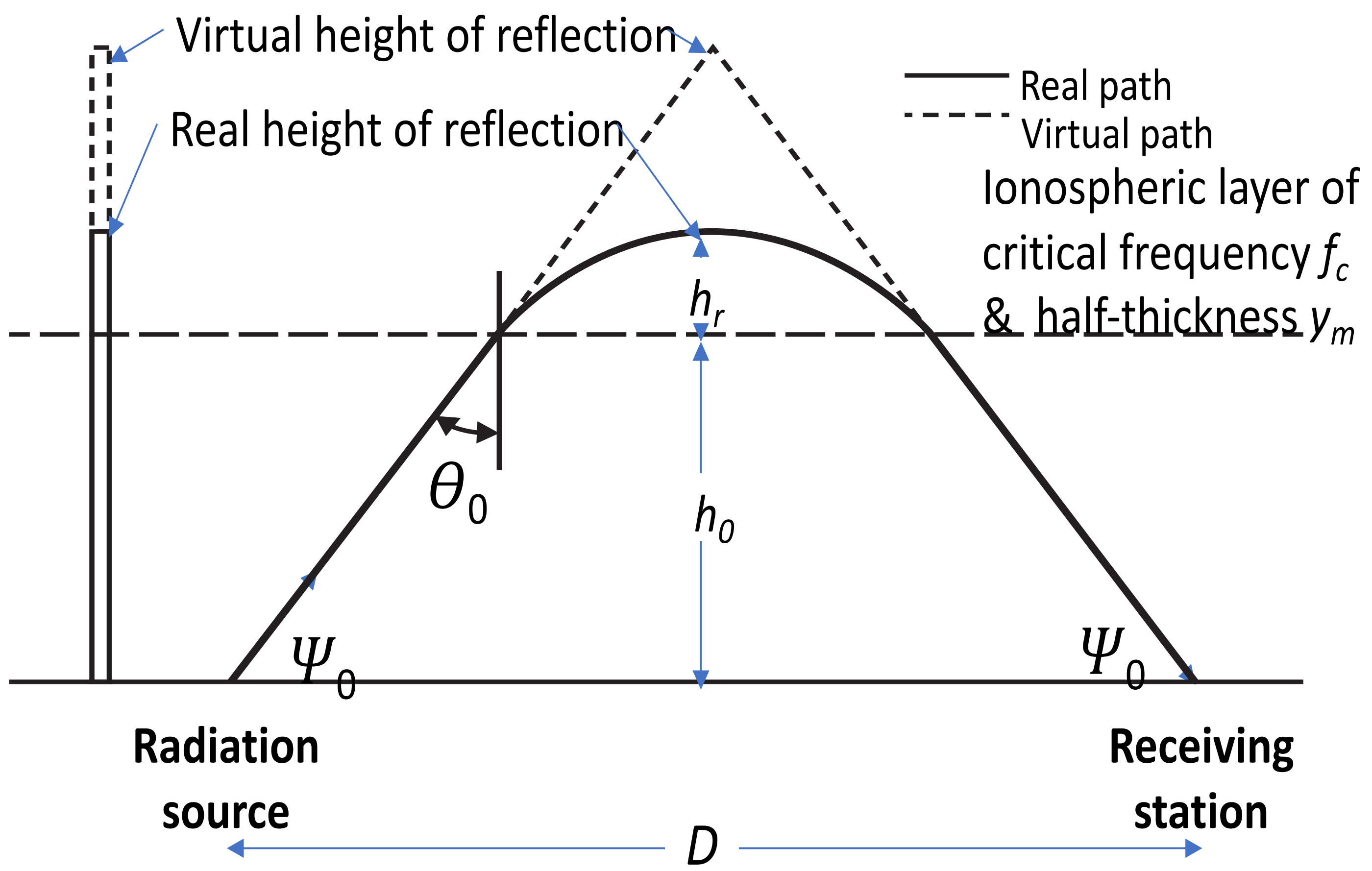




- Zoomed-in views of TeePees often appear diffuse with short discrete bursts over limited frequency ranges.
- Diffuse appearance may imply significant ionospheric scattering associated with moderate geomagnetic activities (Kp ~ 4).

https://omniweb.gsfc.nasa.gov/
http://wdc.kugi.kyoto-u.ac.jp/ae_realtime/201910/index_20191024.html

Hypothesis: Lightning as TeePee Source



Breit & Tuve Theorem [1926]

- Successive refraction can be regarded as a single reflection from a virtual reflection point at a virtual height.

Ground Range as a Function of Wave Frequency (f/f_c) and Incident Angle (θ_0)

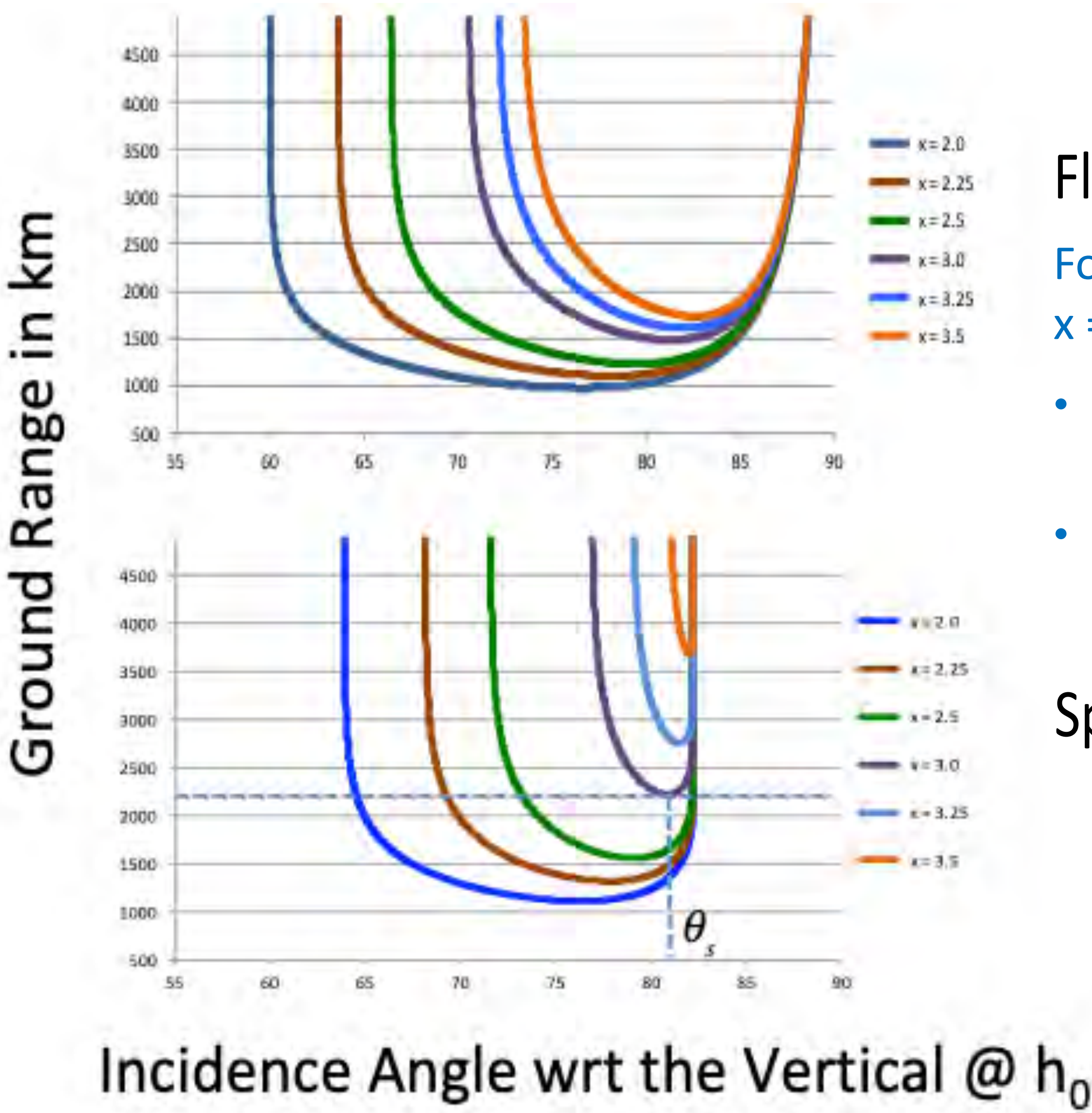
- For flat earth surface and horizontally stratified ionosphere

$$D = 2h_0 \tan\theta_0 + \frac{f}{f_c} y_m \sin\theta_0 \ln\left[\frac{\left(1+\frac{f}{f_c}\cos\theta_0\right)}{\left(1-\frac{f}{f_c}\cos\theta_0\right)}\right] \qquad y_m = \left\{\left[\left(f_p^{-1}\right)\partial^2 f_p(h)/\partial h^2\right]\Big|_{h_c}\right\}^{-1/2} \approx h_c - h_0$$

- For spherical earth surface and concentric ionospheric layers

$$D \approx 2R_E\left\{\frac{\pi}{2} - \theta_0 - \cos^{-1}\left[\frac{\left(R_E + h_0\right)\sin\theta_0}{R_E}\right]\right\} + \frac{x\, y_m R_E \sin\theta_0}{\left(R_E + h_0\right)} \ln\left[\frac{\left(1-\alpha\right)+\gamma}{\left(1-\alpha\right)-\gamma}\right]$$

Ground Range as a Function of Wave Frequency (f/f_c) and Incident Angle (θ_0)



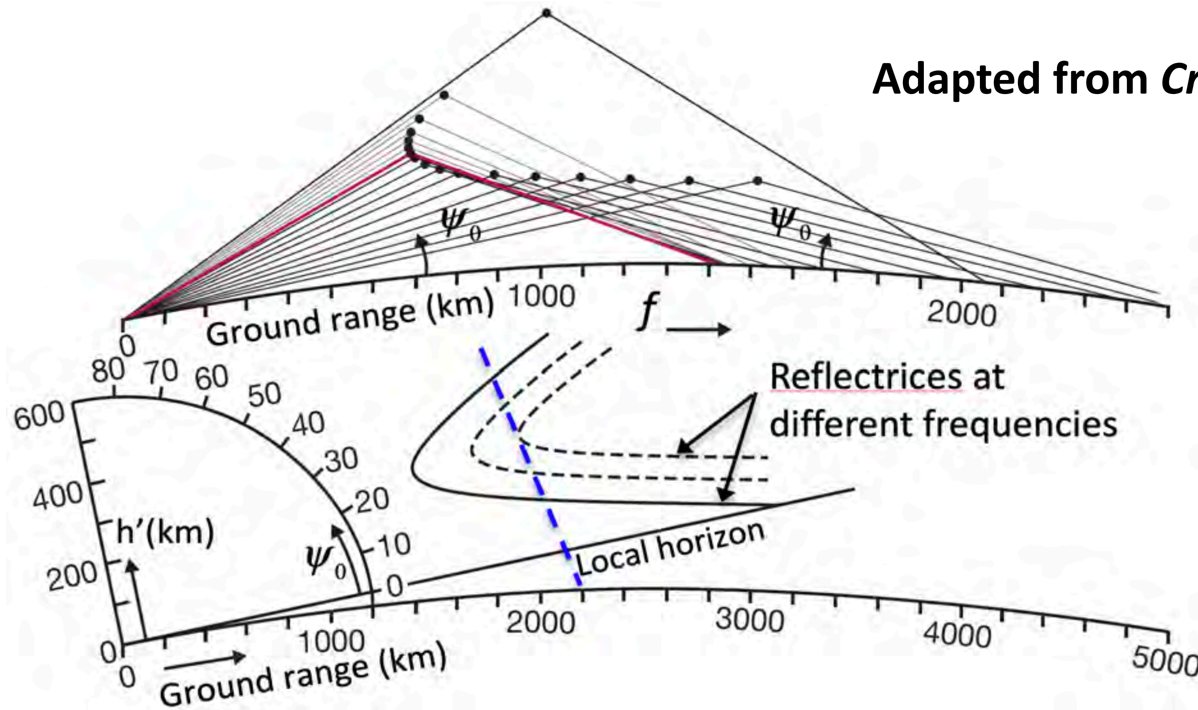
Flat Earth

For any U-curve at a given frequency, x = f/f_c

- The U-minimum gives the MUF(D) and MUF ray direction, θ_S.
- Rays with $\theta_0 > \theta_S$ are called low-angle rays. One with $\theta_0 < \theta_S$ are high-angle rays.

Spherical Earth

2-D Ray Tracing Calculations



- For a fixed frequency *f*, the loci of the virtual reflection point as a function of $\boldsymbol{\psi}_0$ (= 90° - θ_0) is the reflectrix.
- Each reflectrix corresponds (per frequency) to a U-curve.
- TeePee spectral signature results from thunderstorm motion (*in any direction*) relative to the fixed observing location.

Summary

- TeePee signature can be explained in terms of ionospheric reflection of HF emissions from remote lightning storms.
- Nested TeePees may be due to line of lightning storms moving *along* antenna beam.
- TeePee series may be due to line of thunderstorms moving *across* antenna beam.
- TeePee observations can provide a means to study remote ionospheric conditions (h_0, y_m, f_c).
- TeePee fine structures can help deduce scale sizes of bottom-side ionospheric irregularities.