The
HF Spectrogram

Describing the bumps, blips, and blobs

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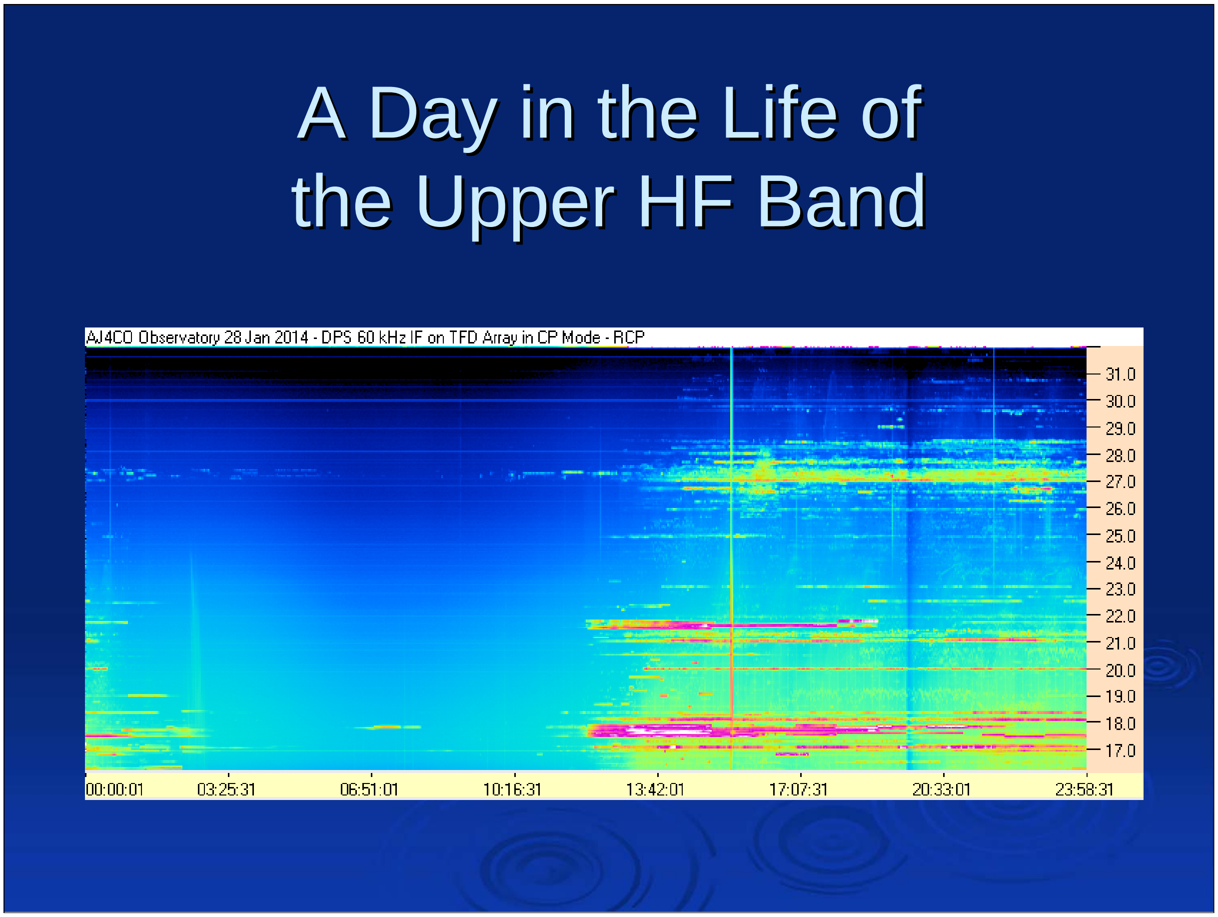
Wes Greenman, LGM Radio Alachua

Version as of 01 June 2017.



There is a lot going on in this spectrogram.

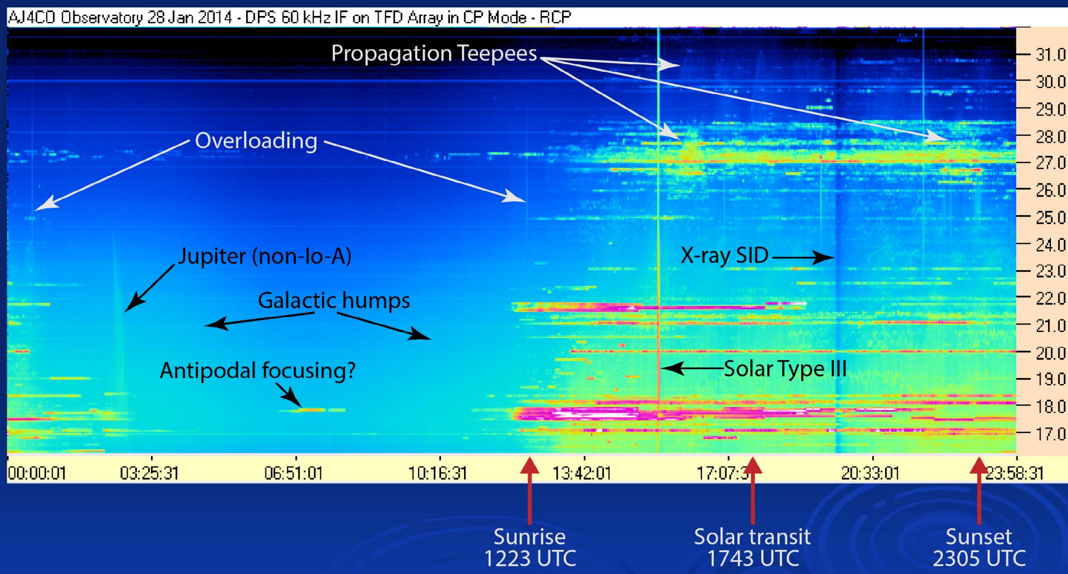
Here is a spectrogram covering 24 hours from January 28th, 2014, from 16 to 32 MHz. This particular day was chosen because there is an instance of almost every kind of HF emission signature in this image: Jupiter, solar, the galactic background, radar, and communications.

Our goal is to help you see these signatures and explain something of what they mean.

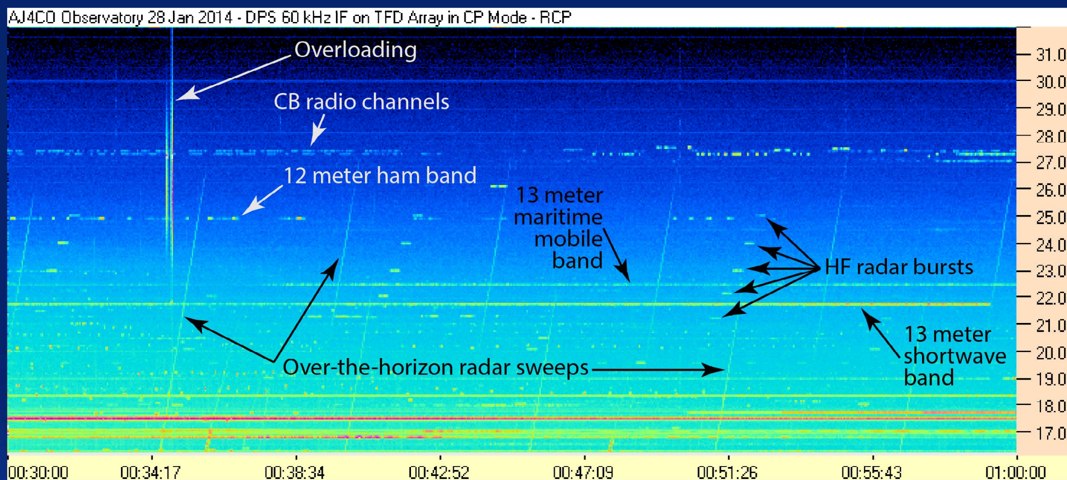
What we can extract from a spectrogram depends a great deal on the time scale. Some emission signatures can only be seen on the longest time scales – such as the diurnal variation in the galactic background. Other emission signatures can only be seen on the shortest time scales, such as individual Jovian S bursts. Therefore, we will look at this day's data on several different time scales.

The spectrograms used in the presentation were recorded by several spectrographs – the DPS, the FS-200, and the FSX-1 – all using Jim Sky's RSS software.

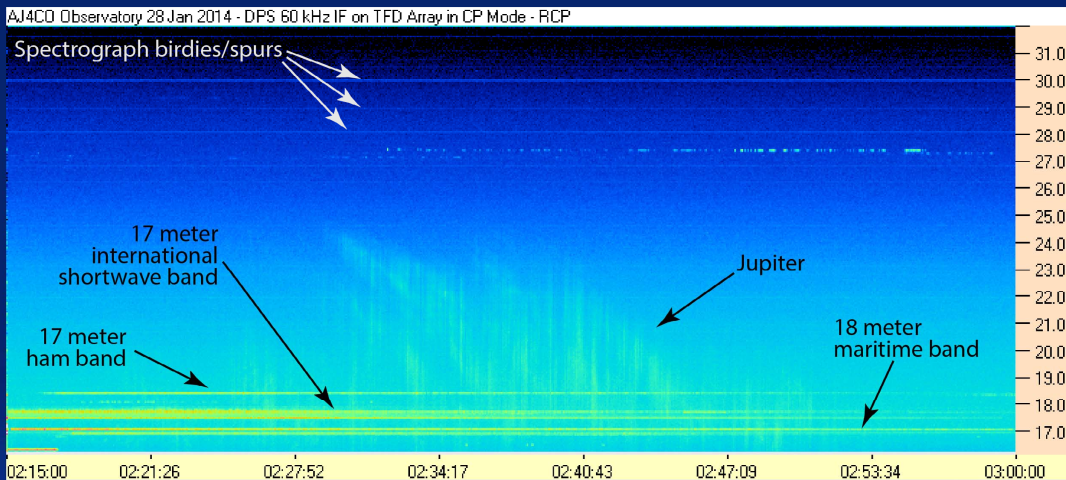
24 Hour Spectrogram

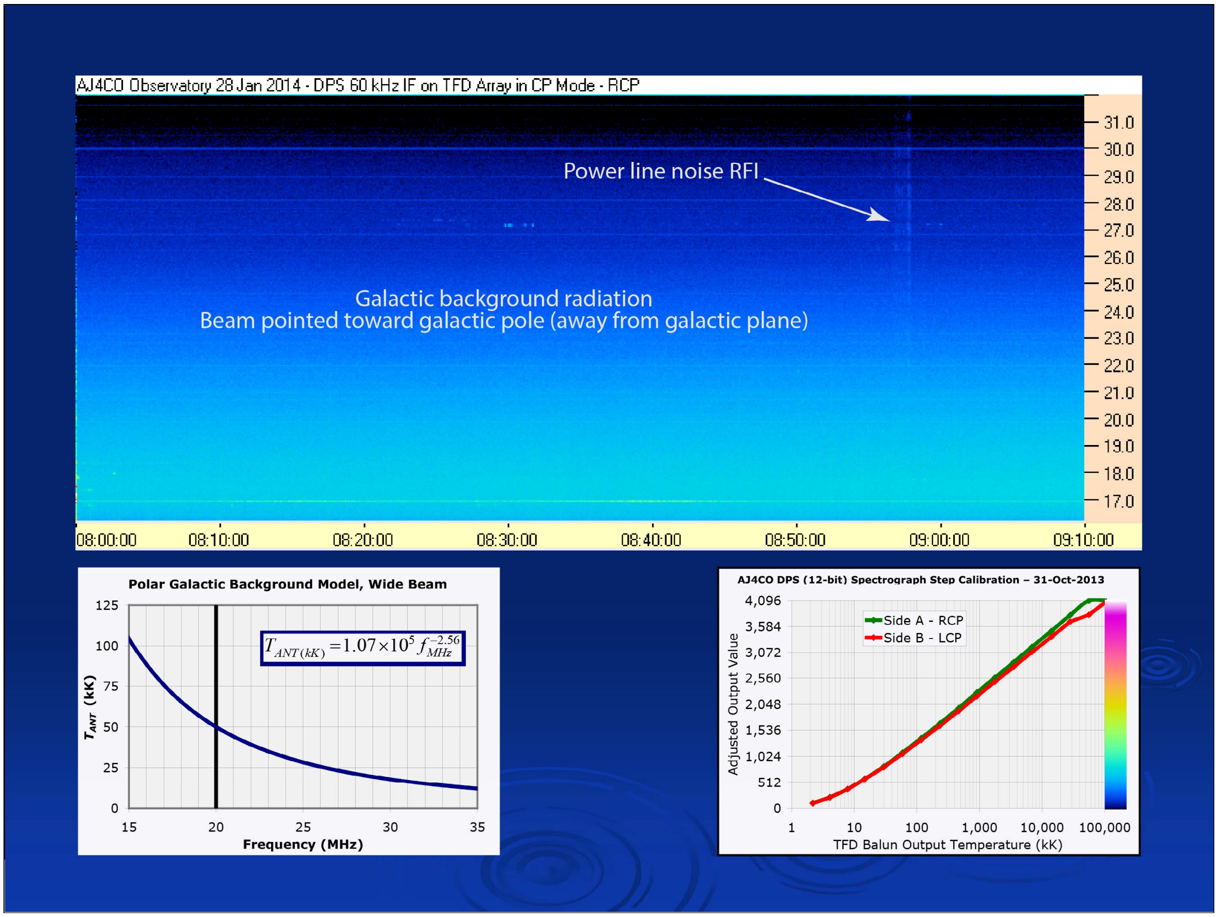


Spectrogram Details



Spectrogram Details



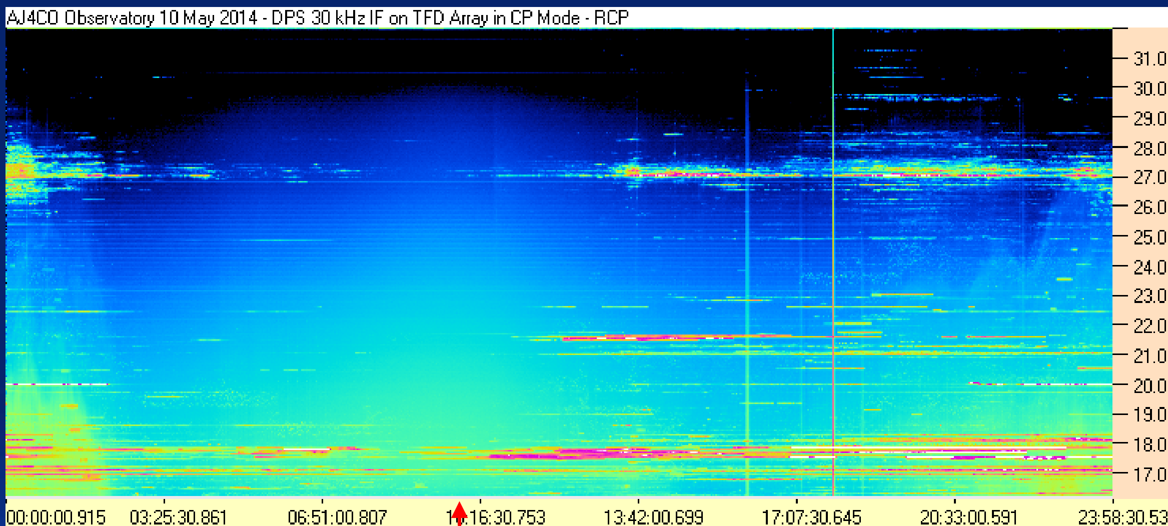


Here is a spectrogram showing the temperature of the galactic background increasing with wavelength (decreasing with frequency).

Bottom left is the common model for the galactic background in the HF band (ref Typinski, *The Galactic Background in the Upper HF Band,* SARA (2013).

Bottom right is the calibration plot for the two channels of the DPS.

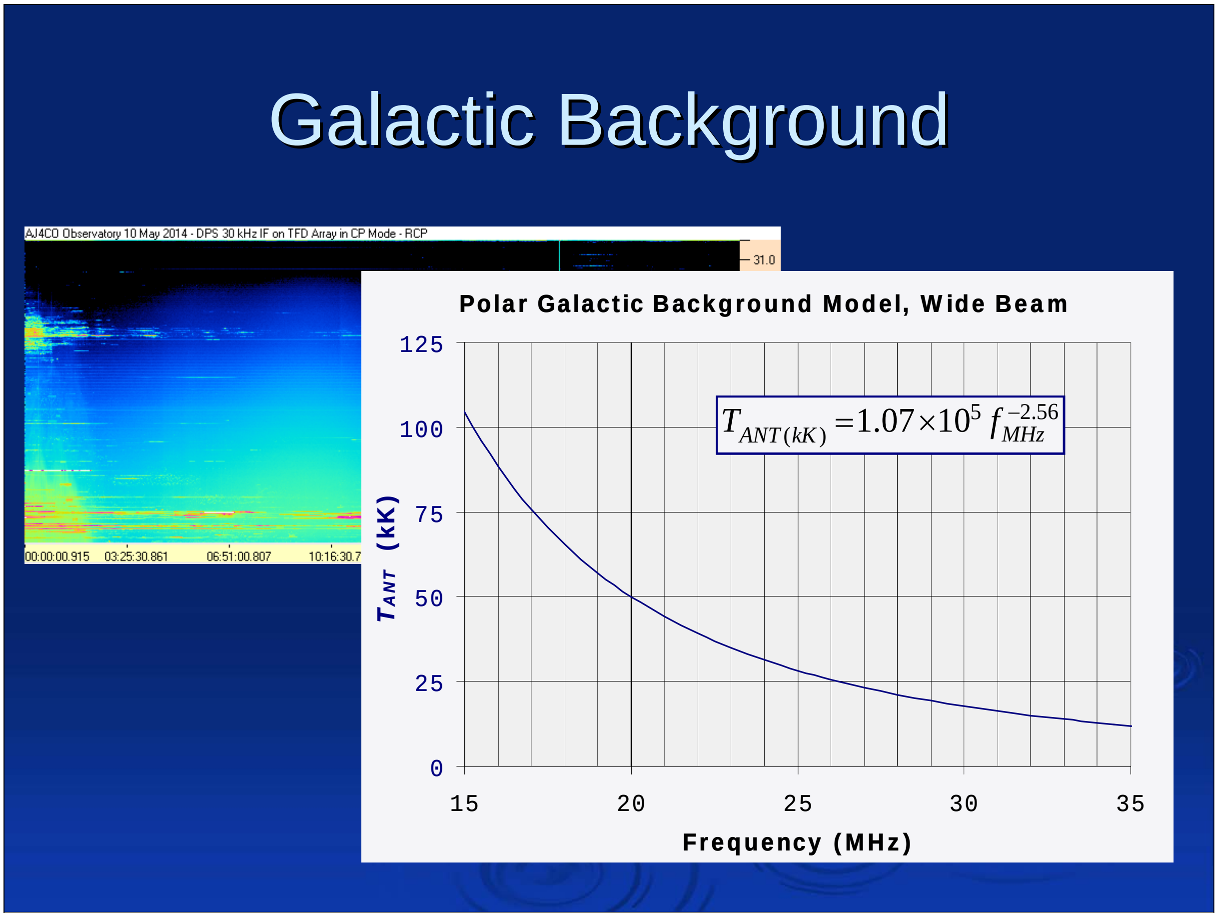
Galactic Background



Galactic core transit at 1000 UTC

Here is an exceptionally clean record of the galactic core transiting the beam of an HF radio telescope. Minimal line noise or local RFI along with depressed HF propagation for reduced band noise helped make the galactic hump easier to see. The brightening in the spectrogram centered on 1000 UTC represents a roughly 3 dB increase in the galactic background.

The vertical stripes are solar bursts.



In the upper HF band between 16 and 32 MHz, the galactic background (GB) temperature is not constant with frequency. Rather, it gets weaker as frequency increases. In the spectrogram above (and on the preceding page) this is seen by the color shift from bottom (hotter) to top (colder). Note that in this particular case, some of the apprent change is due also to the response of the antenna array, it being slightly poorer at higher frequencies.

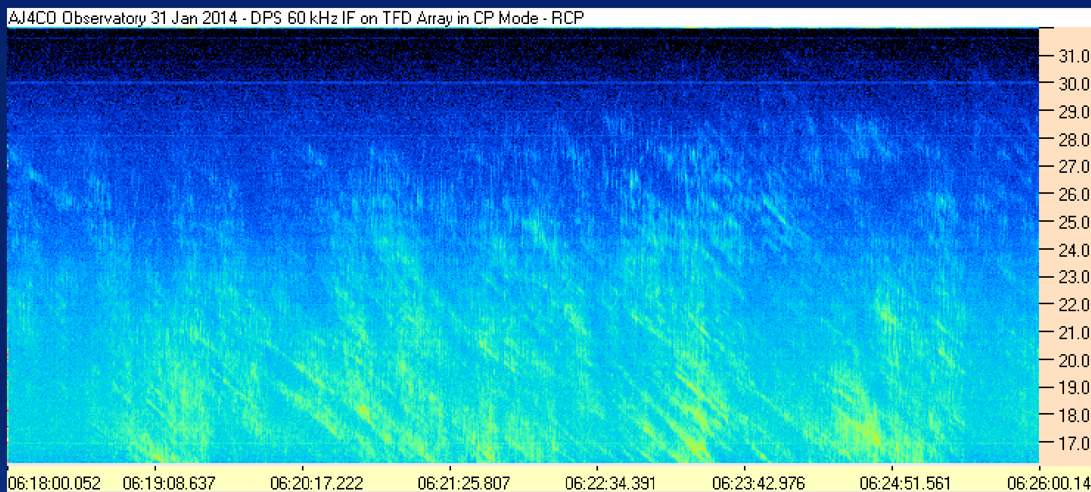
The GB itself is about 8 dB colder at 32 MHz compared to its temperature at 16 MHz.

For more information, see:

The Galactic Background in the Upper HF Band, Typinski (2013)

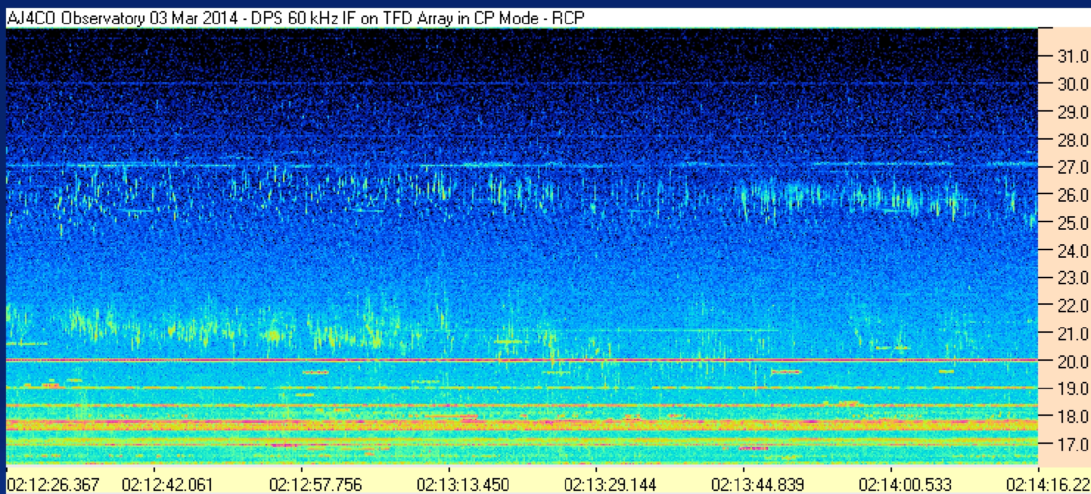
http://www.radiojove.org/SUG/Pubs/The%20Galactic%20Background%20in%20the%20Upper%20HF%20Band,%20Typinski%20(2013).pdf

Jovian L Bursts (Io-B)



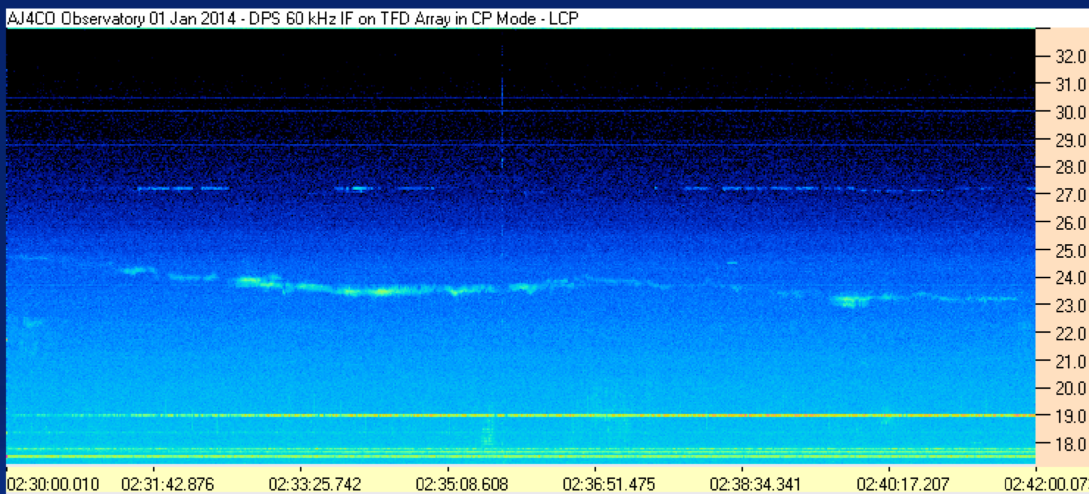
Sloped features are called “modulation lanes.”

Jovian S Bursts (Io-B)

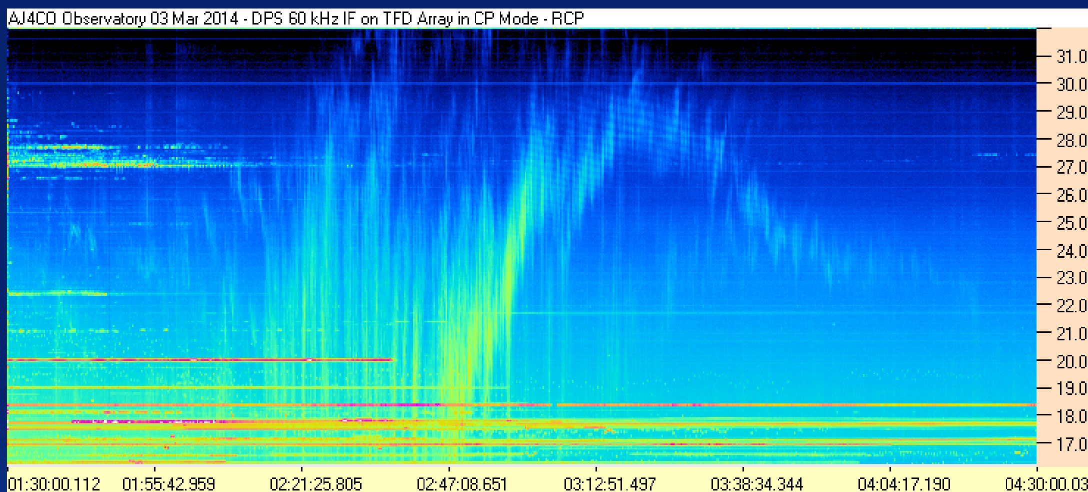


S bursts often occur in bands.

Jovian N Event (Io-B)

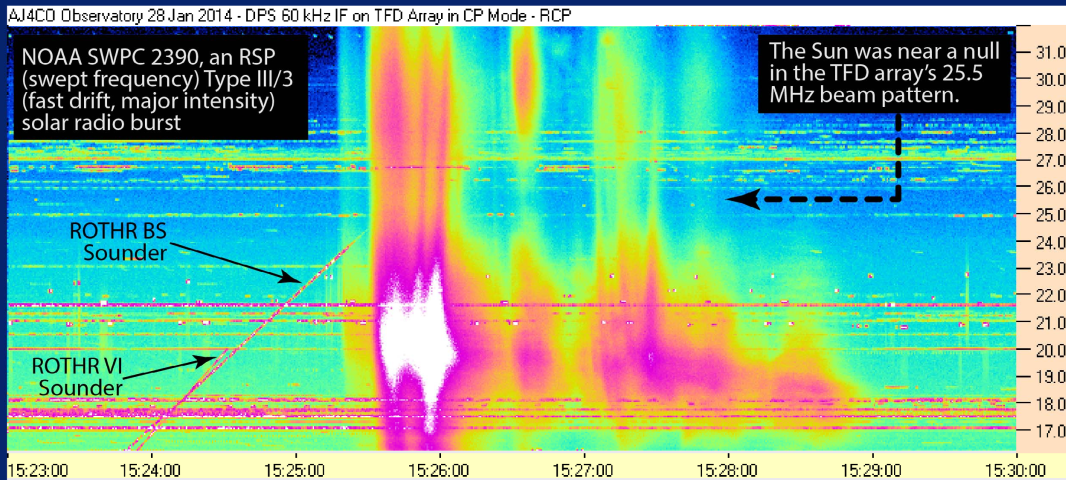


Jovian Io-B Storm



This is called Io-B because of its location on the Io-CML(III) phase plane — i.e., the particular Jupiter-Io-Earth geometry at the time the radio emission occurred.

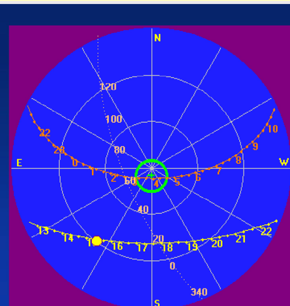
Solar Burst

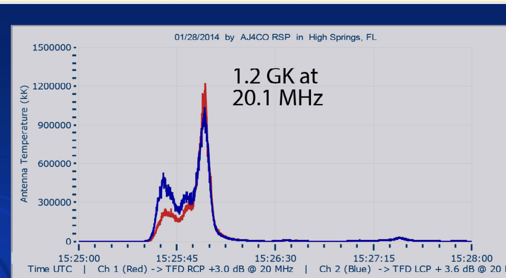


Relocatable Over The Horizon Radar (ROTHR) US Navy AN/TPS-71

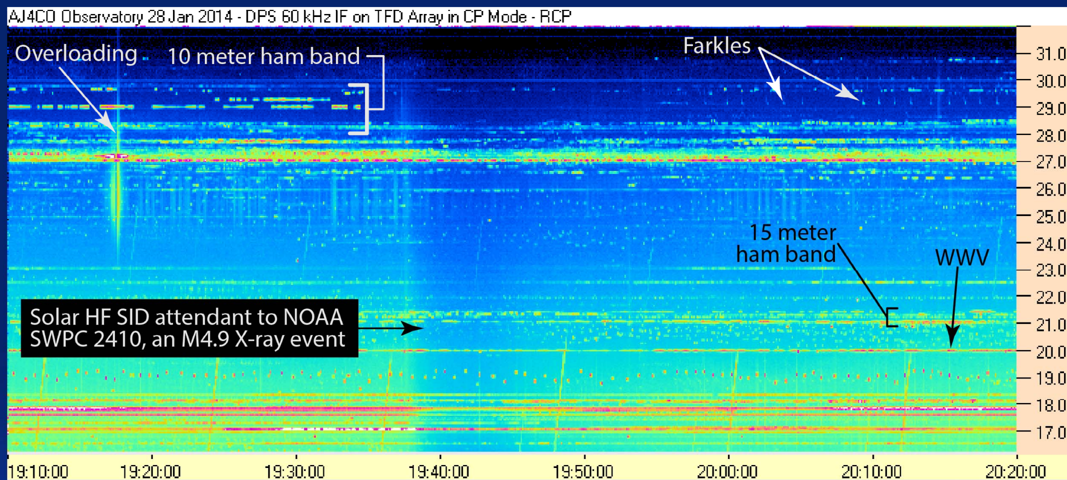
Vertical Incidence (VI) sounder - an ionosonde

Backscatter (BS) sounder - the radar emission

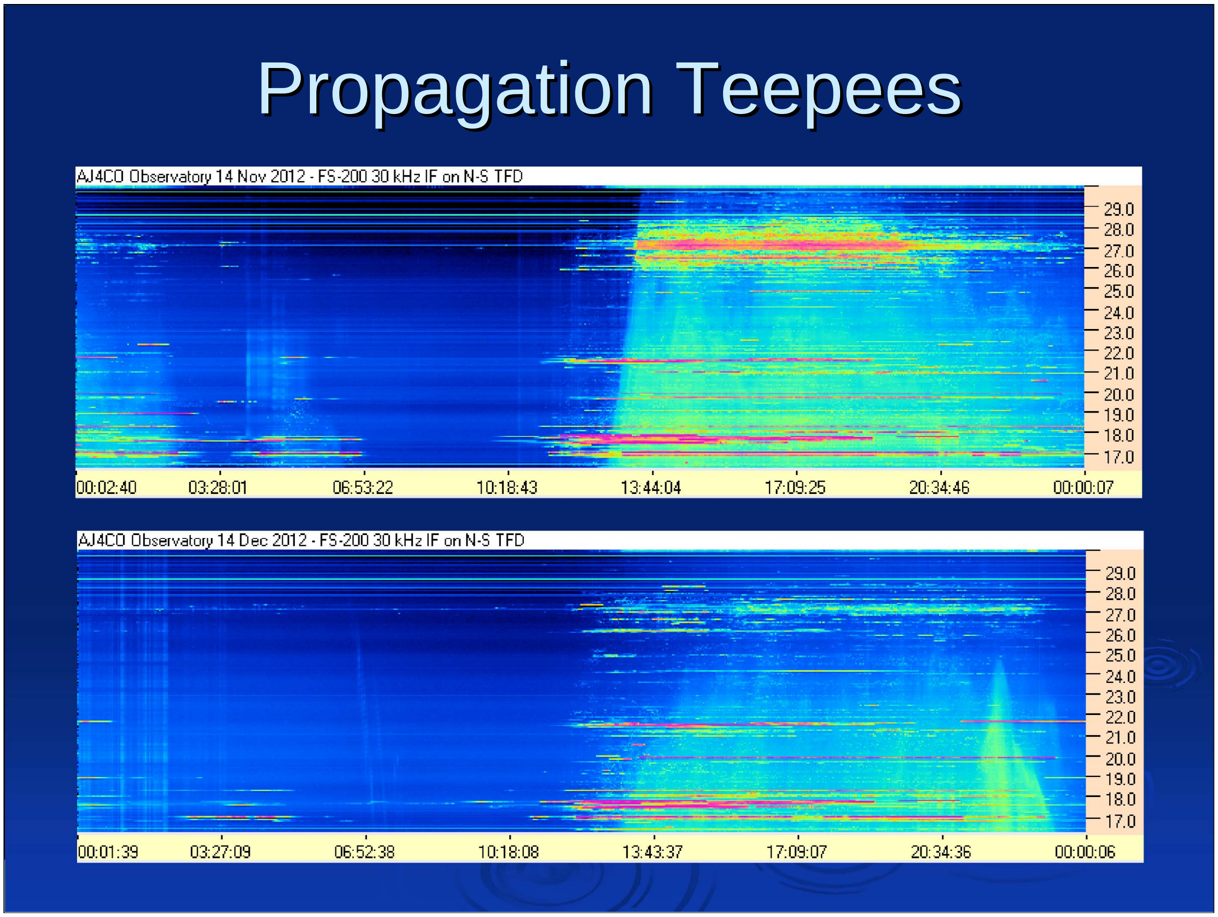




Sudden Ionospheric Disturbance (SID)



Sudden Inospheric Disturbance (SID) - seen in the HF band as an attenuation of the galactic background and terrestrial propagation due to increased ionization of the D layer causing D layer absorption to increase.



These teepee-shaped artifacts are caused as the maximum usable frequency (MUF) increases and decreases throughout the day in tune with the density changes within the observer's regional ionosphere.

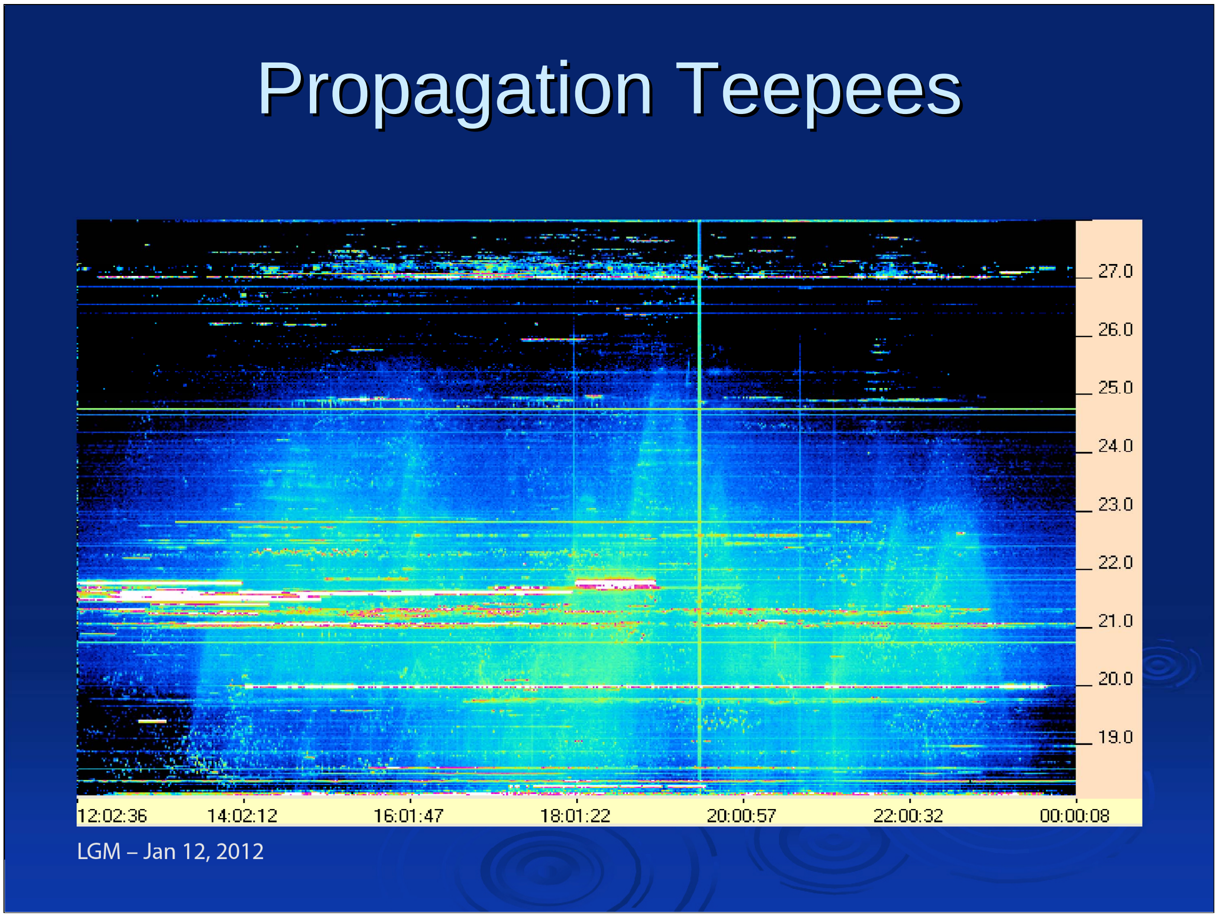
The MUF is the highest frequency at which terrestrial signals bounce back down to Earth's surface instead of escaping into space. The denser the ionosphere is, the higher the frequencies that get bounced back down.

The MUF in one direction, say southeast, may be completely different from the MUF in another direction, say northwest. And it may also be different depending on range: the MUF to the southeast for a source 500 miles away may be completely different from the MUF to the southeast for a source 1,500 miles away. This happens because the ionosphere is neither uniform nor smooth — despite our best wishes otherwise.

Thus, what we see here is terrestrial "band noise" propagating to the observer from wherever the source(s) are, but only below the MUF. Since the MUF changes up and down throughout the day, as ionospheric blobs pass between the observer and the source(s) of band noise, we often see teepee-shaped artifacts in long duration spectrograms. "Propagation teepees" seems like as good a name as any other.

One source of band noise is distant lightning. Lightning strikes the earth thousands of times per second, so the lightning spikes from very distant storms get blended together into a nearly featureless increase in background noise. But that's not the only source. As you can see, terrestrial propagation in the CB band up at 27 MHz also turns on and off as the MUF rises above — and then decreases below — this region of intense RF pollution. Then there are all the other communications channels -- shortwave broadcasts, ham bands, marine comm -- within the upper HF band that also come and go as the MUF changes.

Since the MUF is site and range dependent, the propagation TP's won't be the same from observer to observer unless the observatories are fairly close to each other.

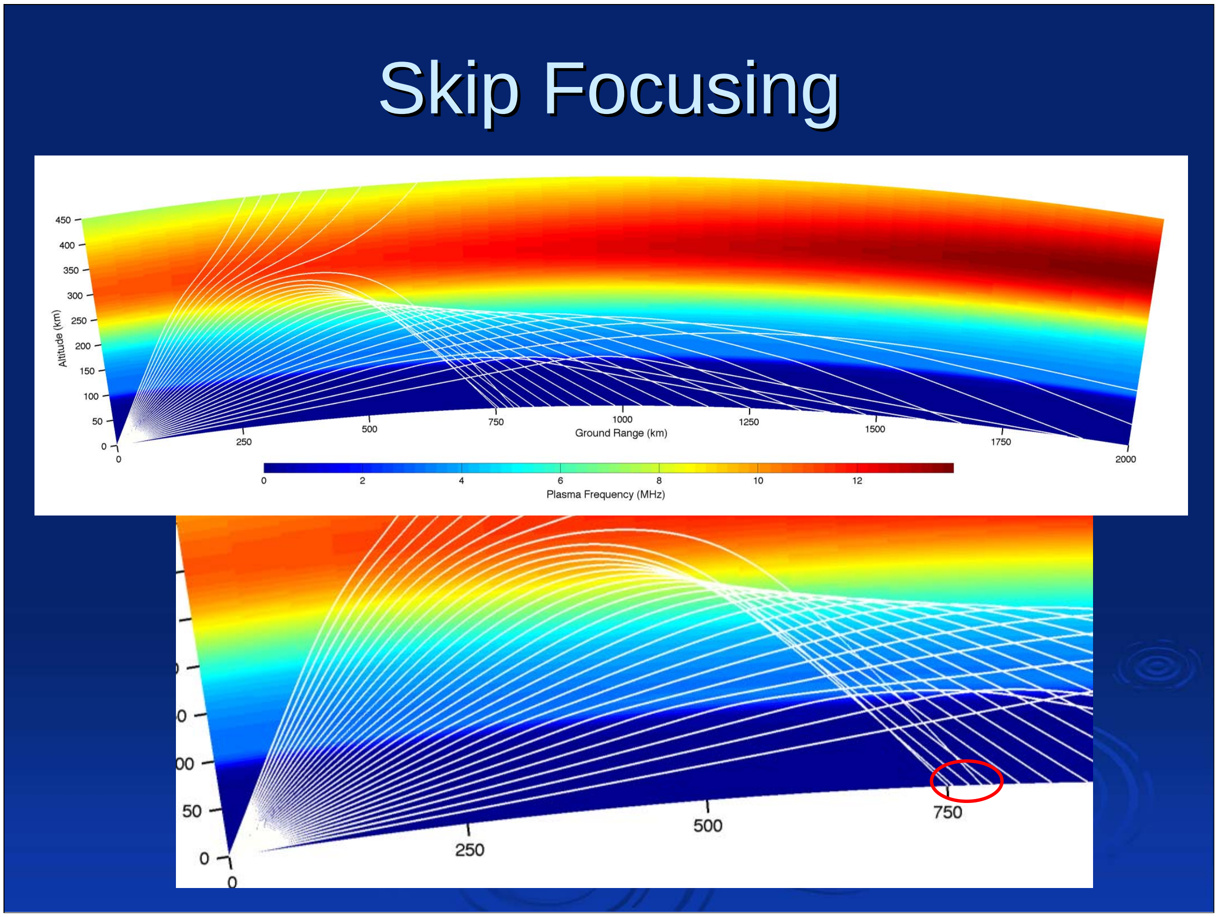


The MUF is important, but not the whole story. A changing ionosphere also means a skip distance that is constantly changing. The skip distance is the distance between successive hops as a terrestrial signal bounces between the ground and the ionosphere. At any given time, the skip distance is different for each RF frequency being monitored.

As the skip distance changes with time and frequency, the ground reflection area of the each hop moves across the Earth's surface. If one of the nearby ground reflection areas moves across a source of band noise, the observed band noise will increase and decrease.

Another factor may be gray line propagation during sunrise and sunset at either the observer, the terrestrial noise source, or both. Gray line propagation works for signals traveling along the Earth's terminator (hence the name) and allows a terrestrial HF signal to travel much further than it otherwise would. This phenomenon is put to good use in the lower HF band by amateur radio operators, but it has some bearing in the upper HF band as well. The relatively sharp leading edge (the morning increase) of daytime terrestrial propagation shown circa 1300 UTC in the top spectrogram on the previous page may be due in part to gray line propagation.

The propagation TP's shown above have a pronounced edge. In fact, the edge is hotter than the interior of the TP's. This is an effect called "skip focusing" – the subject of the next slide.



This image shows how rays at a single RF frequency at different takeoff angles are refracted and reflected by the ionosphere. At the near side of the first hop, several rays are bunched together. This means that more of the antenna's aperture is focused here compared to the amount of aperture covering an equivalent area of the ground further into the first hop area. The red circle in the lower image shows how multiple rays converge on a relatively small spot on the ground. Skip focusing also occurs on the second hop, but to a lesser extent due to the spreading of the rays at the first ground reflection.

The first key is to realize that these curves change with frequency. The skip distance at higher frequencies is generally shorter than at lower frequencies.

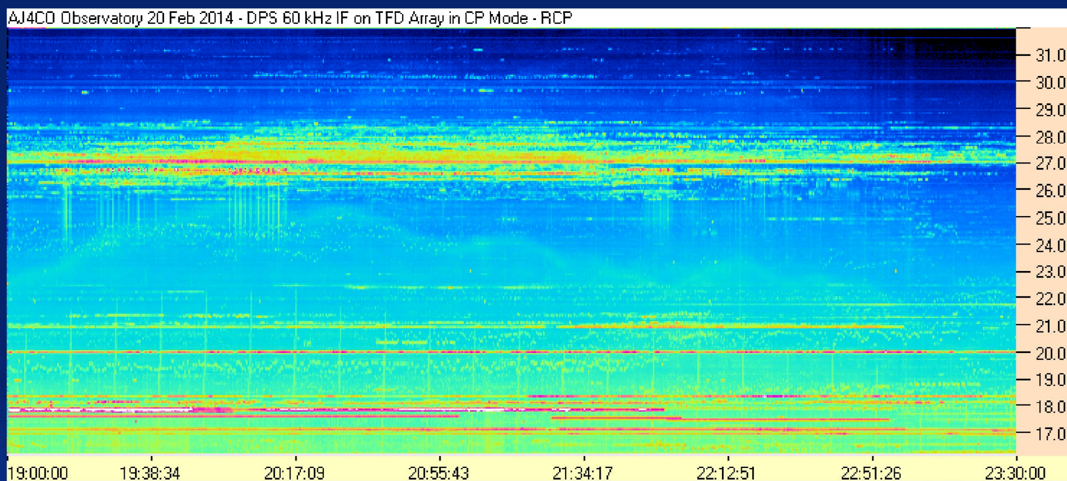
The second key is to realize that the MUF is changing, so even the single-frequency set of curves will change throughout the day.

If a source of band noise – a distant thunderstorm – is located in the skip-focused region of the first hop area, the noise will appear hotter in the spectrogram compared to an equivalent signal further into the first hop zone. This can occur at the same time ionospheric changes cause the location and maximum frequency of the first hop area to change. It is the latter aspect – the dynamic nature of the first hop area's location with time and frequency – that allows skip focusing to form a hotter band at the edge of the propagation TP envelope seen in a spectrogram.

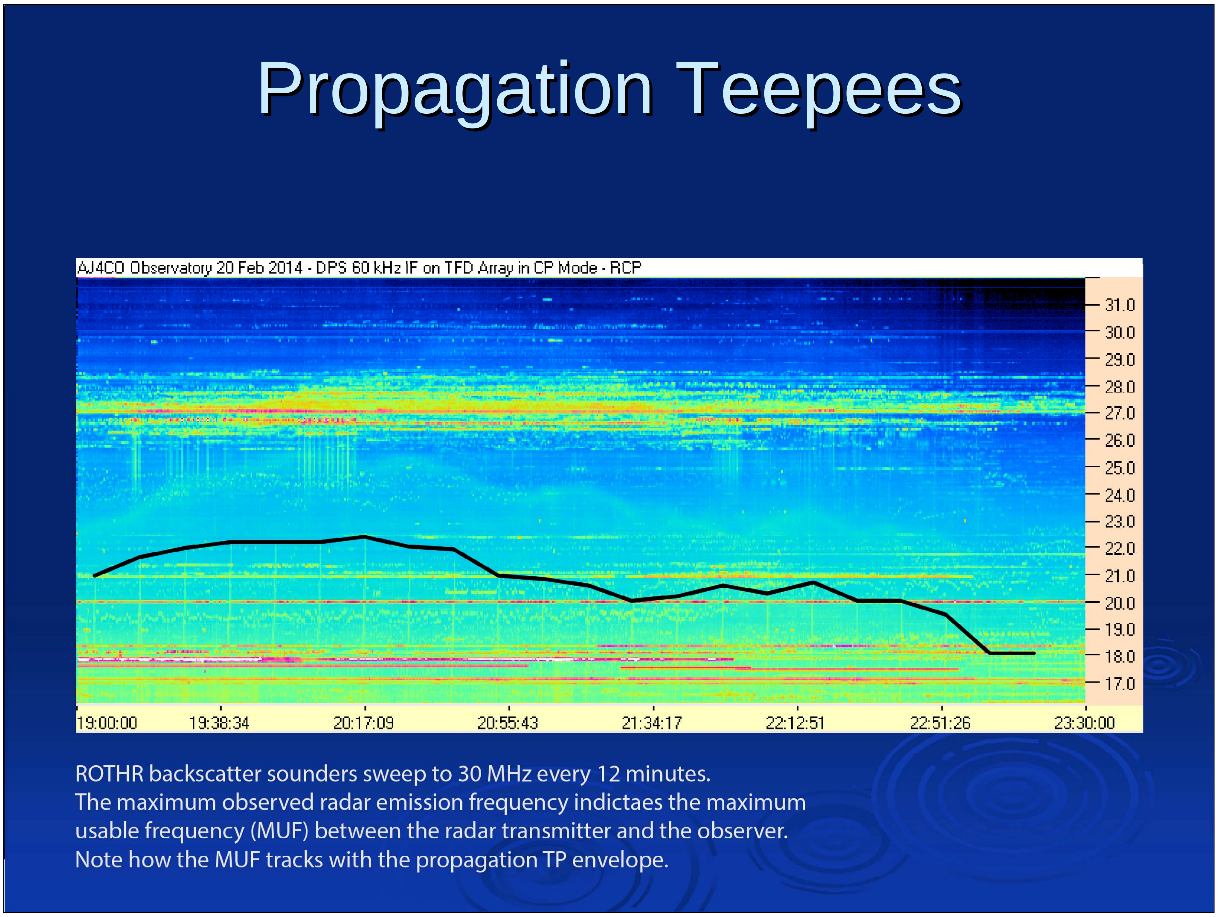
Ray tracing figure © Commonwealth of Australia 2011, copied from Cervera and Harris, *Modelling the effects of ionospheric disturbances on quasi-vertically incident ionograms using 3D magneto-ionic raytracing,* Intelligence, Surveillance and Reconnaissance Division, Defence Science and Technology Organisation, Edinburgh SA 5111, Australia (2011).

A further discussion of skip focusing may be found in Fabrizio, *High Frequency Over-the-Horizon Radar*, McGraw-Hill (2013), pp. 36-37. We thank Dr. Fabrizio for his advice concerning skip focusing beyond the first hop.

Propagation Teepees



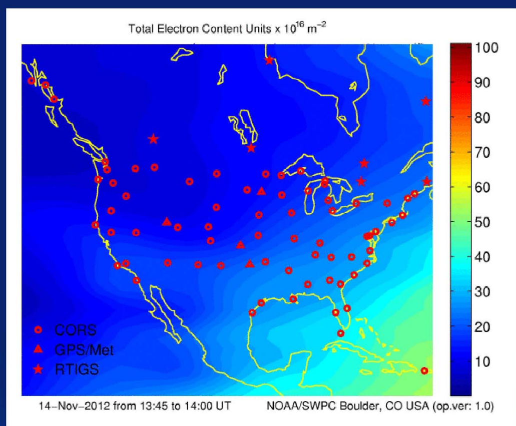
Here is a close up view of one propagation teepee. Do the upper ends of the radar sweepers track the MUF shown by the teepee?

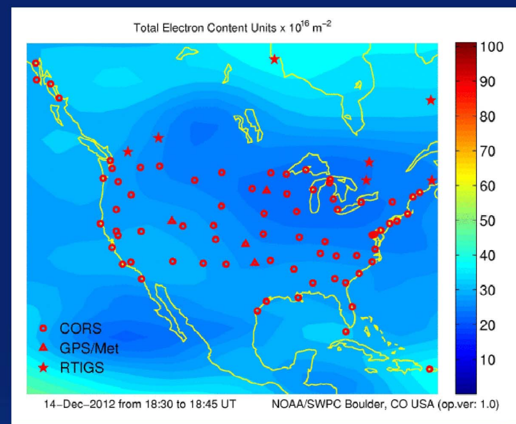


The MUF observed between the radar transmitter and the observer more or less follows the MUF indicated by the band noise.

It does not follow the band noise precisely, however. The difference in frequency and shape of the two envelopes occurs because the observer may be seeing band noise from a place widely separated from the transmitter site. Otherwise, the ROTHR sweeps would extend right up to the top edge of the band noise envelope. Since the ionosphere is not uniform, the MUF in one direction is often different from that in another direction. This slide shows precisely that effect.

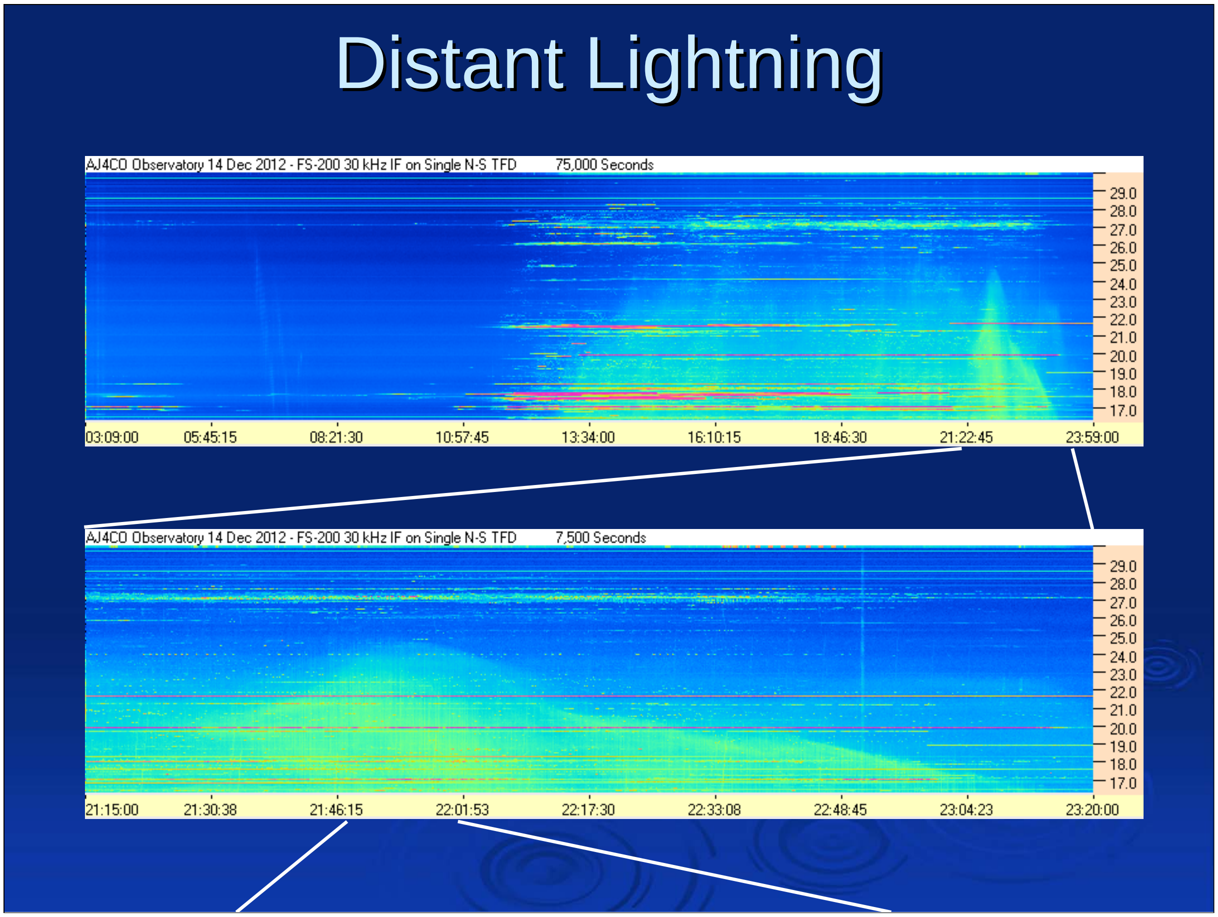
US Total Electron Count (TEC)





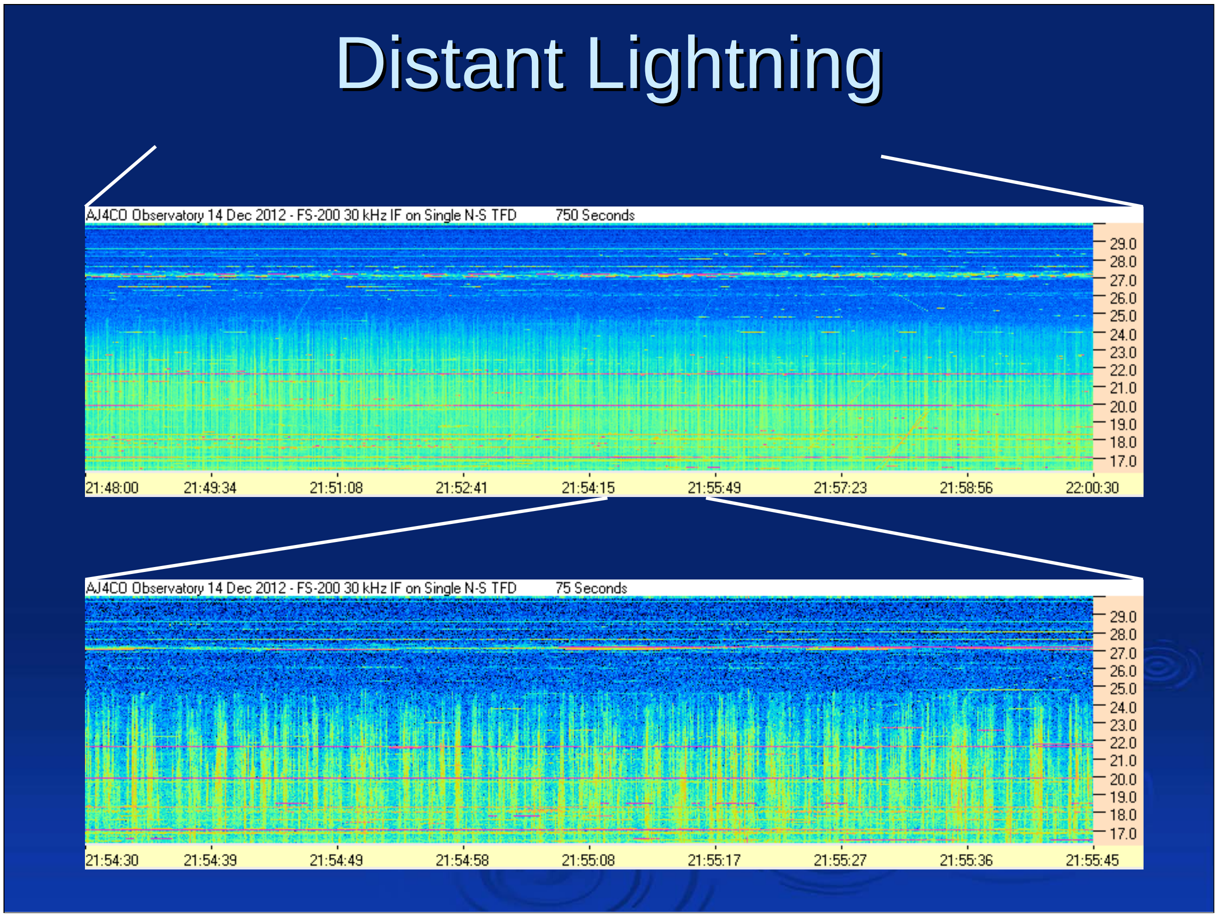
US Total Electron Content (TEC) - number of free electrons in a vertical column - units are 10^{16} electrons per square meter. Larger numbers indicate more propagation of terrestrial radio emissions. See http://www.swpc.noaa.gov/ustec/

As ionospheric "blobs" – areas of higher TEC – pass near an observer, the propagation teepees are observed.



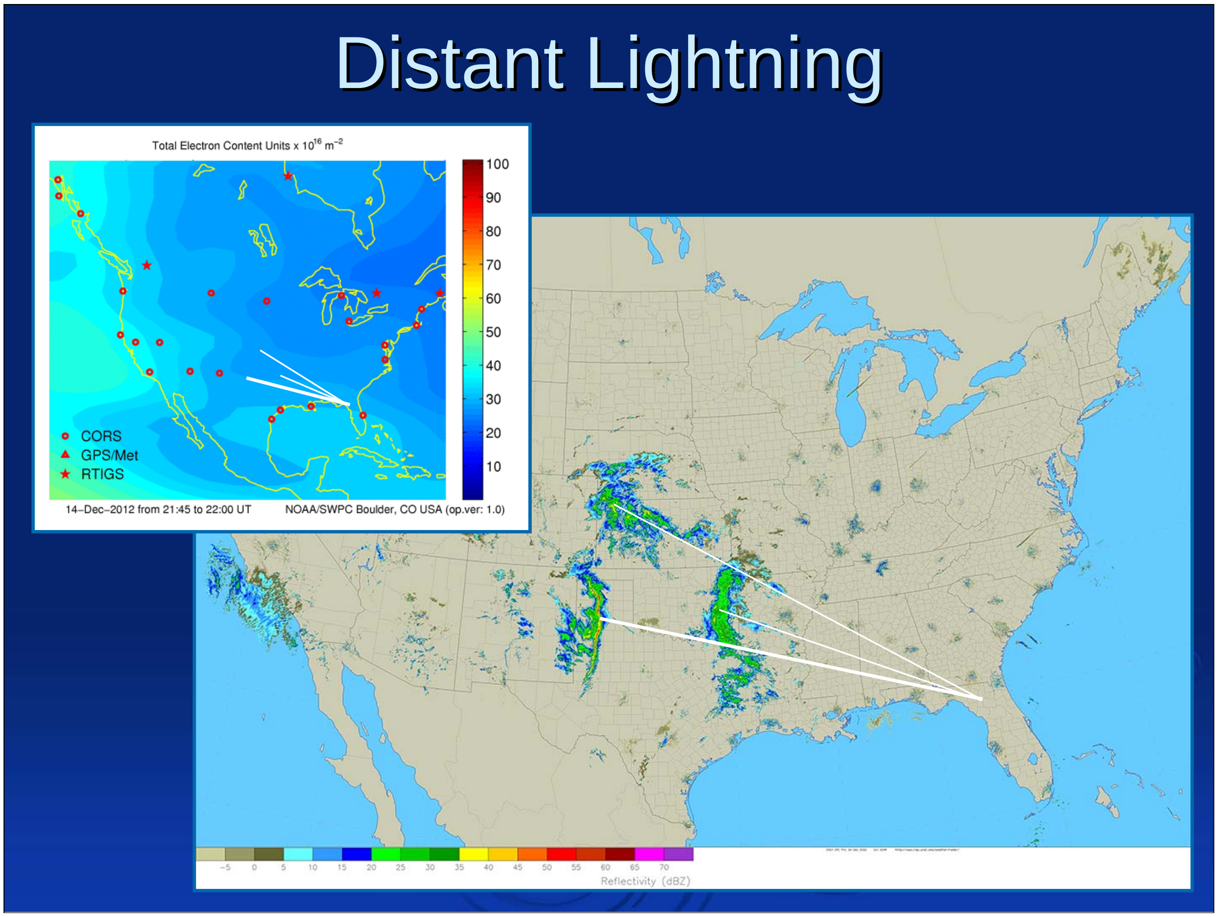
Top spectrogram is 75,000 seconds long (20h 50m 0s)

Factor of 10 zoom to 2nd spectrogram of 7,500 seconds long (2h 5m 0s)



Another factor of 10 zoom to 3rd spectrogram of 750 seconds long (12m 30s), roughly 1 second per pixel. We can almost see individual lightning strikes at this scale.

Another factor of 10 zoom to 4th spectrogram of 75 seconds long (1m 15s), 107 millisec per pixel. We can easily see individual lightning strikes at this time scale. The average lightning bolt's RF emission lasts for several hundred millisec and is comprised of hundreds of short strokes, each lasting on the order of a hundred nanoseconds.



Here is a weather map and the US TEC for the time shown in the spectrograms in the preceding two slides.

The heavy white line shows the direction between the observer in Florida and the line of severe thunderstorms in the Texas panhandle. The weather front was roughly 1,200 miles away. The front along the Oklahoma-Arkansas border was about 800 miles away, but much weaker in terms of radar reflectivity. The system in Kansas and Nebraska were 1,200 miles away and also much weaker.

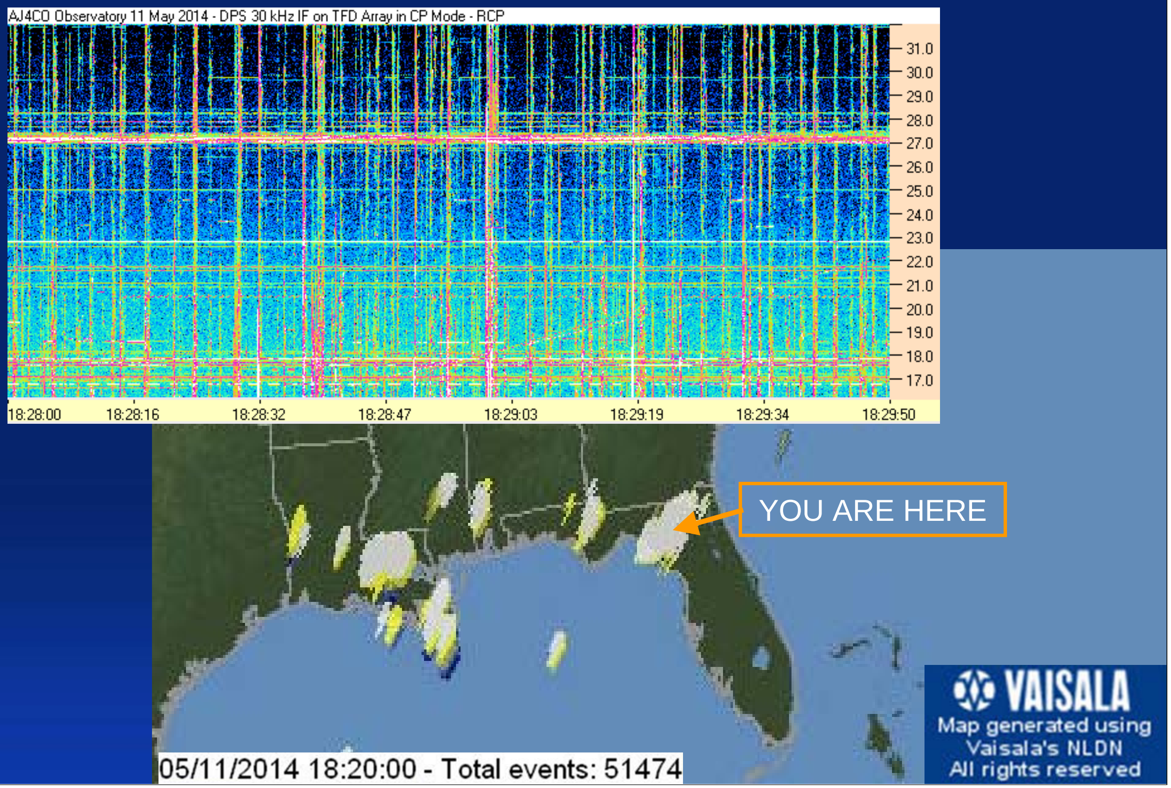
There is no way to tell for sure which weather front produced the lightning that was observed. All three wx systems were at more or less the one-hop daytime skip distance for the upper HF band, roughly 1,000 miles. The system near Amarillo, TX surely produced much more lightning than the other two systems.

The TEC was somewhat low along the path between Florida and the Texas panhandle, which means that the maximum usable frequency (MUF) was decreased to some degree, apparently to the point where the higher frequency portions of the lightning emission could not be received at the observatory in Florida. The same also holds true for the paths to the other two wx systems.

US TEC map from **http://www.ngdc.noaa.gov/stp/IONO/USTEC/products/**

US WX radar map from **http://weather.rap.ucar.edu/radar/**

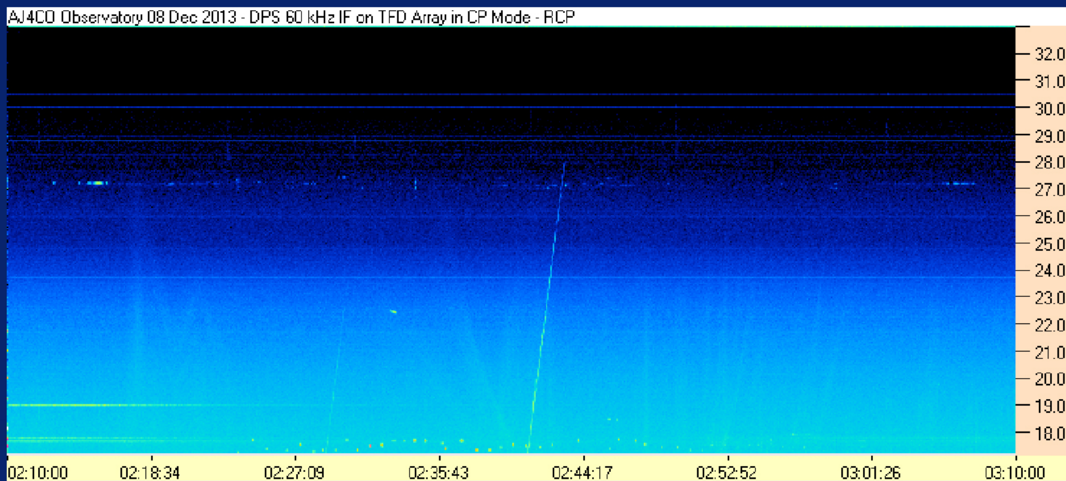
Local Lightning



Local lightning visibility does not depend on the ionosphere. We see this via the ground wave (while we see distant lightning via the sky wave).

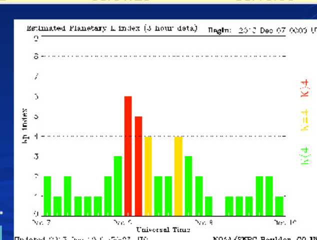
Lightning occurrence map from **http://thunderstorm.vaisala.com/explorer.html**

Geomagnetic Upset

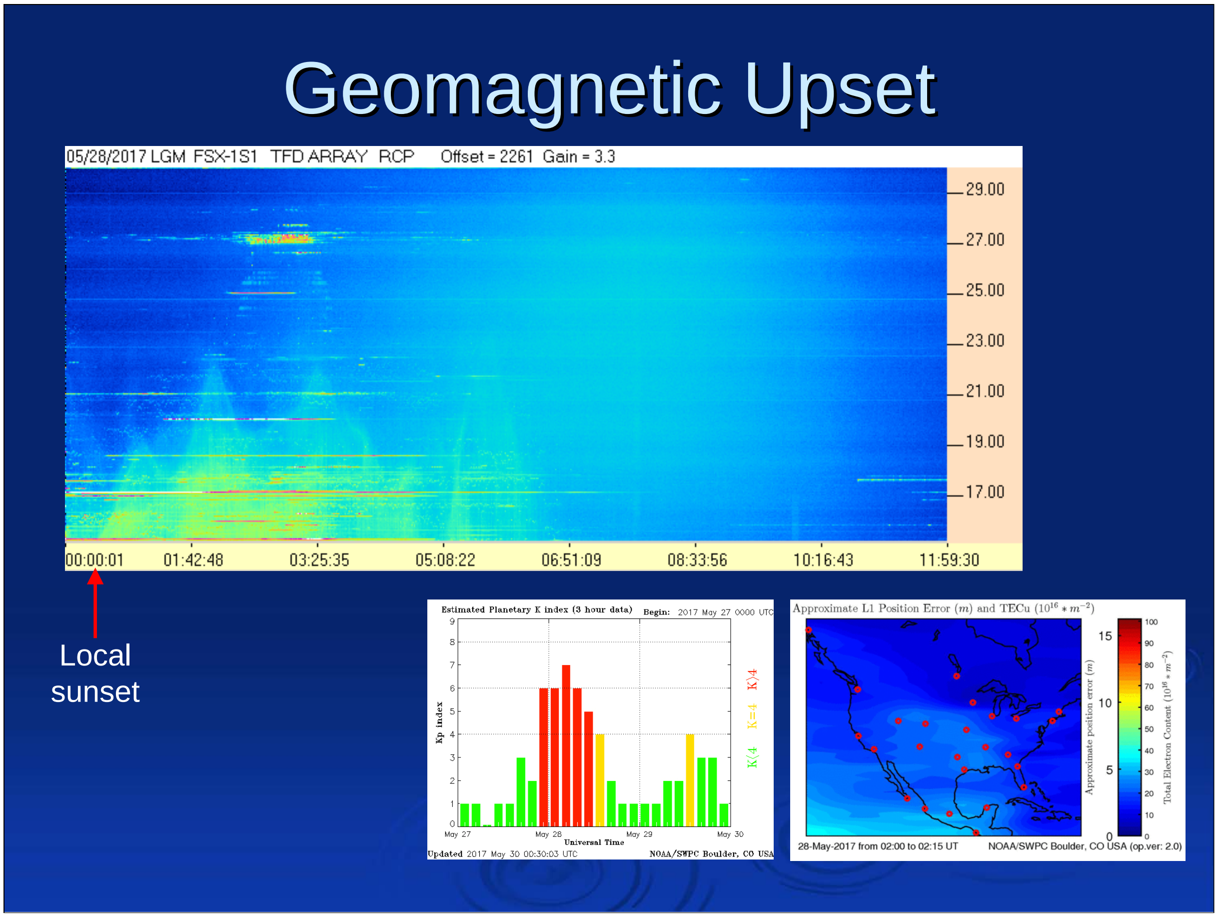


Sunset at 1730 UTC previous day.

CME impact causing changes in the ionosphere observed as scintillation in Cas A radio emission.



Estimated Planetary K Index (K_p) was 6.
http://www.swpc.noaa.gov/rt_plots/kp_3d.html

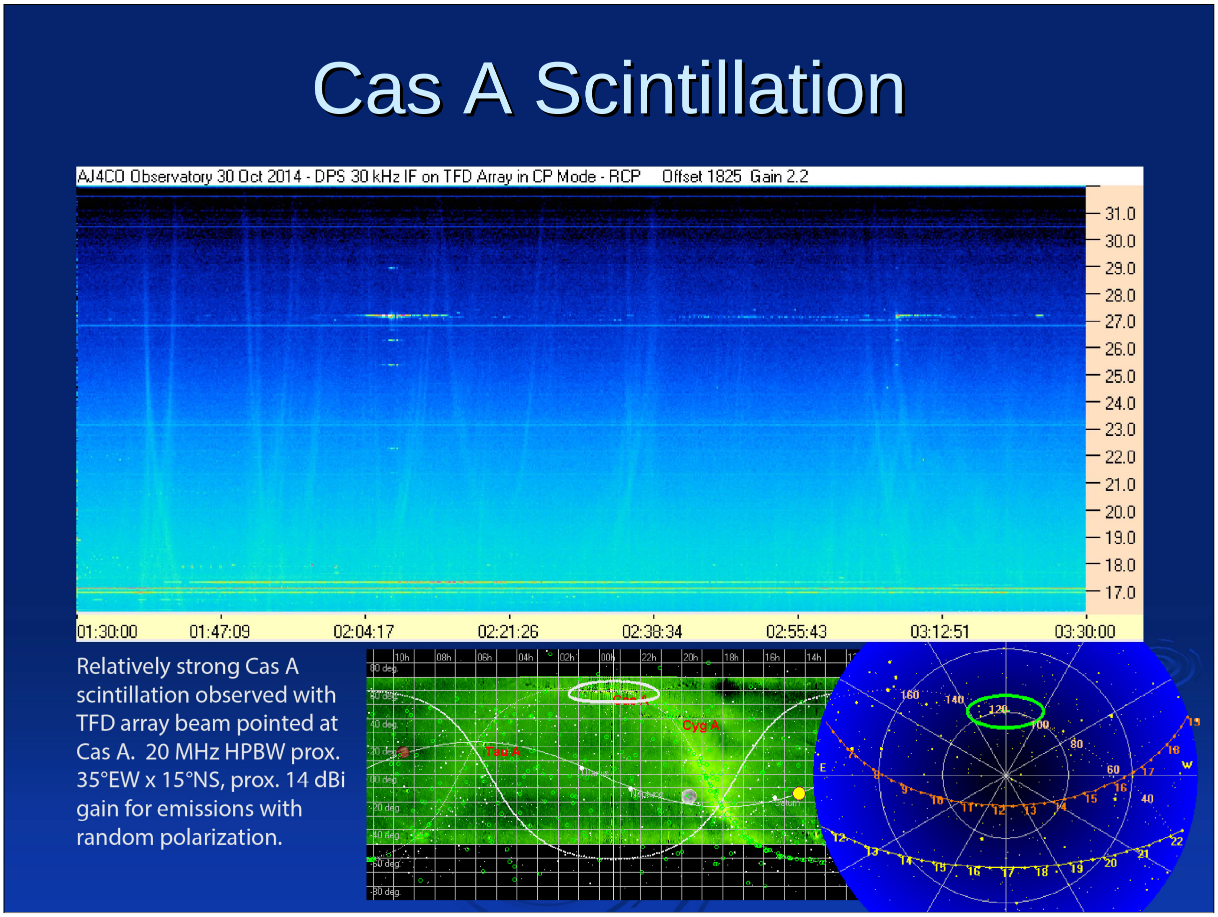


A geomagnetic upset can also cause anomalous night-time propagation TP's. They are anomalous because the ionospheric F-layer doesn't normally exist at night, which means terrestrial signals in the upper HF band are not normally reflected back to Earth at night.

In this spectrogram, propagation TP's can be seen from just after sunset (0024 UTC / 2024 local) until about 0630 UTC (0230 local).

The planetary K-index was very high at the time, indicating a very disturbed geomagnetic field. The vertical TEC over the USA at the time shows some unusual variations (unusual compared to a normal day, but not unusual when the K index is very high as in this example).

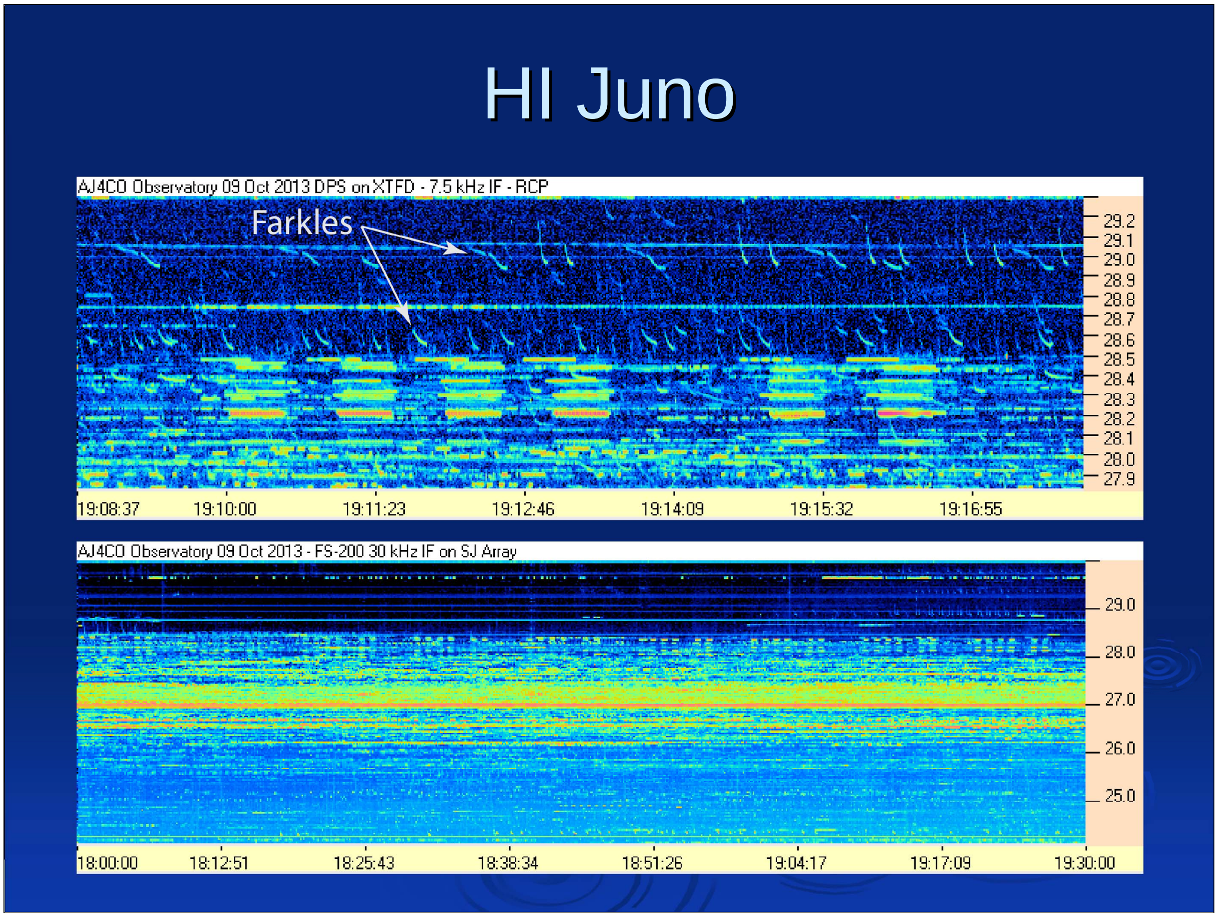
The diffuse gradual brightening and dimming in this spectrogram is the inner galactic plane transiting the antenna beam circa 0745 UTC.



Cassiopeia A is a supernova remnant roughly 11,000 light years away (about 3.4 kiloparsecs). Discovered by amateur radio astronomer Grote Reber in 1947, it is the strongest radio source outside our solar system with a 20 MHz flux density of 65,000 Janskys.

Since Cas A is a point source, it is very difficult to detect at HF with modest antenna arrays. Ionospheric disturbances, however, can intermittently act like lenses at HF, temporarily and dramatically increasing the effective aperture of a ground-based HF radio telescope. This is what causes the nearly vertical sweeping streaks in the spectrogram in this slide. As the ionospheric disturbances change, once in a while the lens effect sweeps past Cas A, briefly increasing the received signal strength. The streaks in the spectrogram are not perfectly vertical because ionospheric effects are frequency dependent.

Cas A scintillation does not always need a CME impact (as shown on the previous slide), but it helps, especially if the antenna is not pointed at Cas A. A disturbed ionosphere will cause the scintillation, regardless of the cause of the disturbance. High solar activity can cause this, but Cas A scintillation can also be observed at times when the Sun is only moderately active. Sometimes when the Sun is active, no Cas A scintillation is observed. The fine structure and variability of the ionosphere is very much a field of continuing research. Cas A scintillation is one probe of the ionosphere's dynamics.



October 9th, 2013, 1800 to 2040 UTC

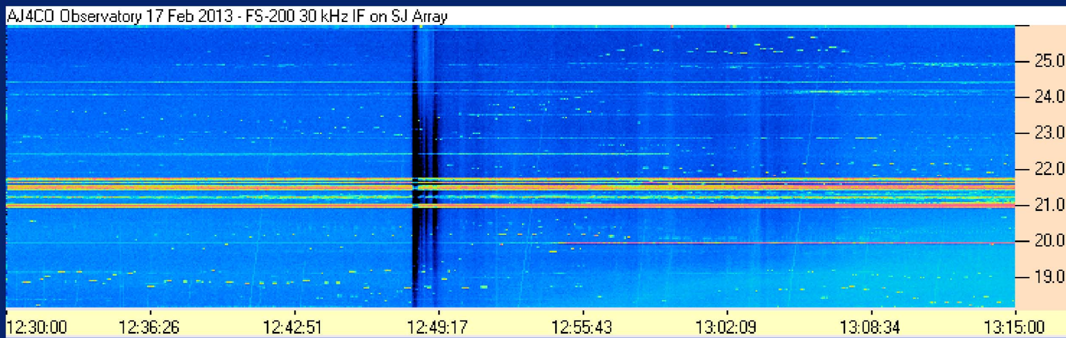
CW on the 10 meter band at 1/25th WPM, 30 seconds per 'dit'

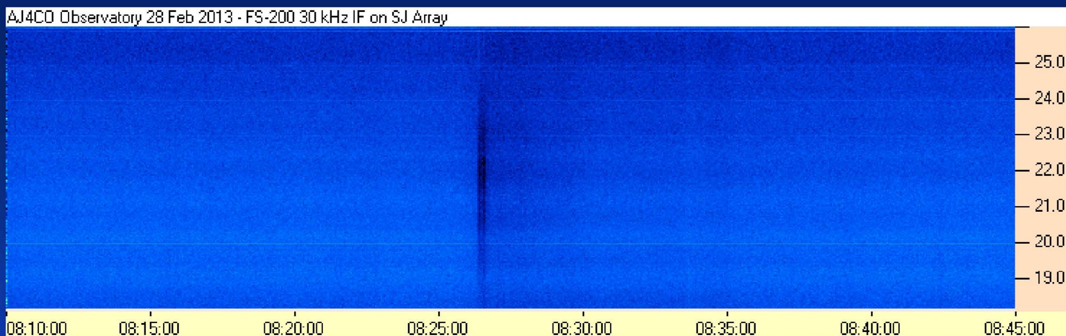
More info here:

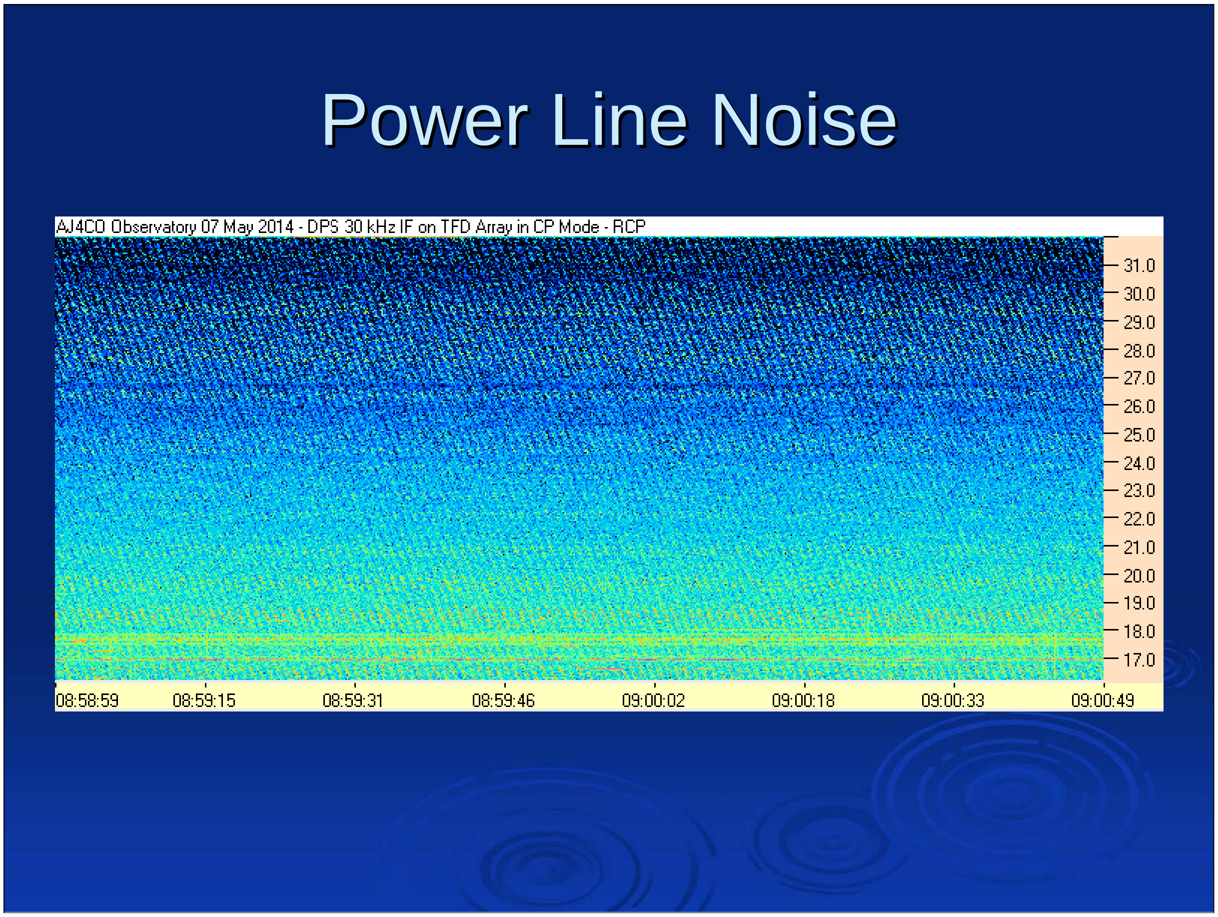
http://www.arrl.org/news/nasa-s-juno-spacecraft-hears-hams-say-hi

http://www.youtube.com/watch?v=_yqHy_MpNiQ&feature=youtu.be

Poor Coax Connection

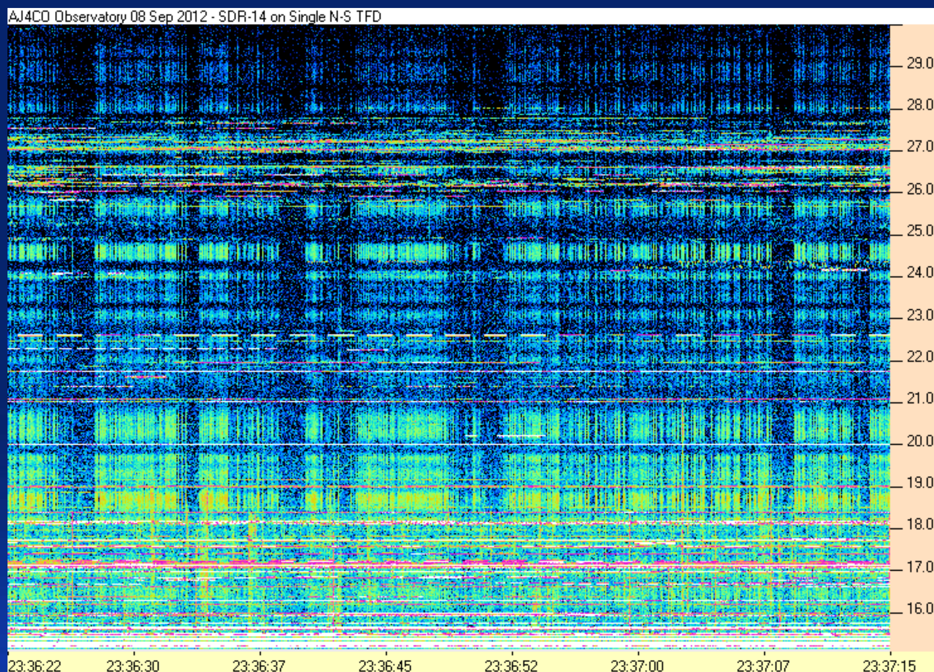






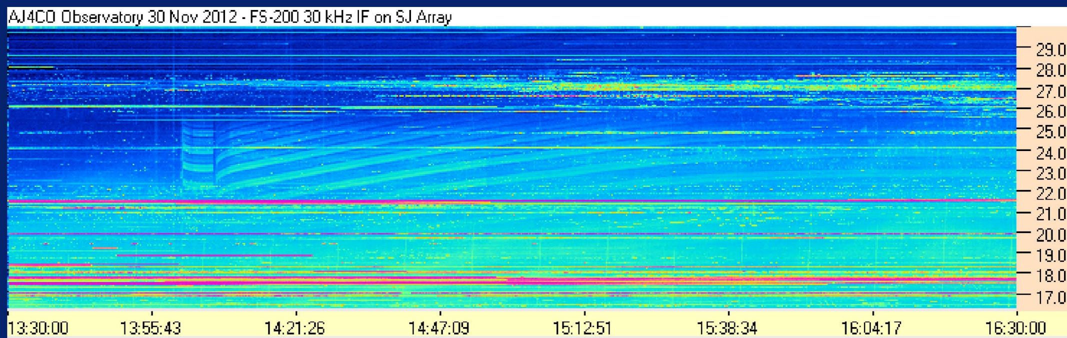
Power line noise produces spikes with a repetition rate of 120 Hz. The DPS in the 300-channel configuration sweeps about 6 times per second. The diagonal lines are due to the beat frequency between the sweep rate and the emission repetition rate.

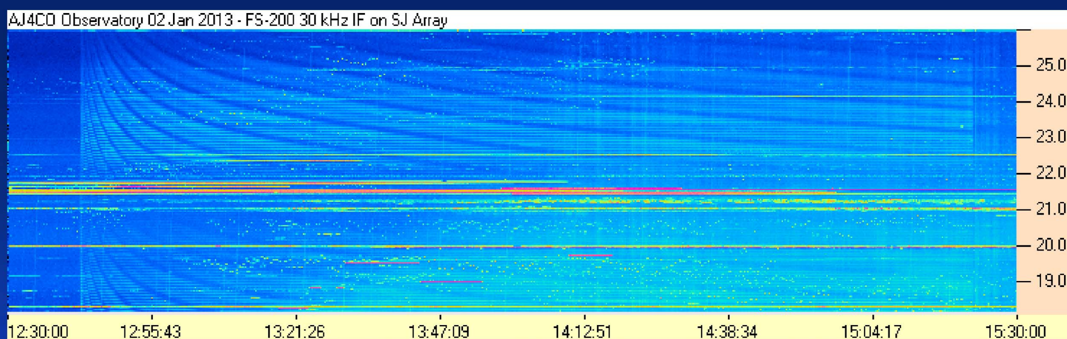
Power Line Noise



Here is what power line noise looks like to an SDR-14. Several front end band pass filters were added in series ahead of the receiver to no avail.

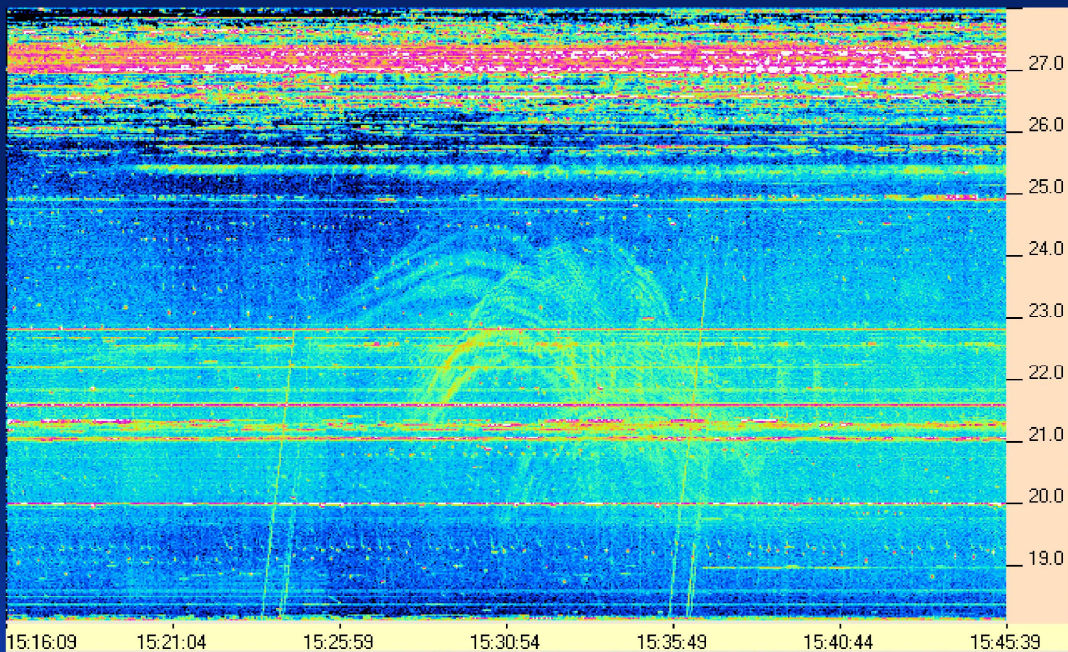
RFI Oddities





RFI of unknown origin

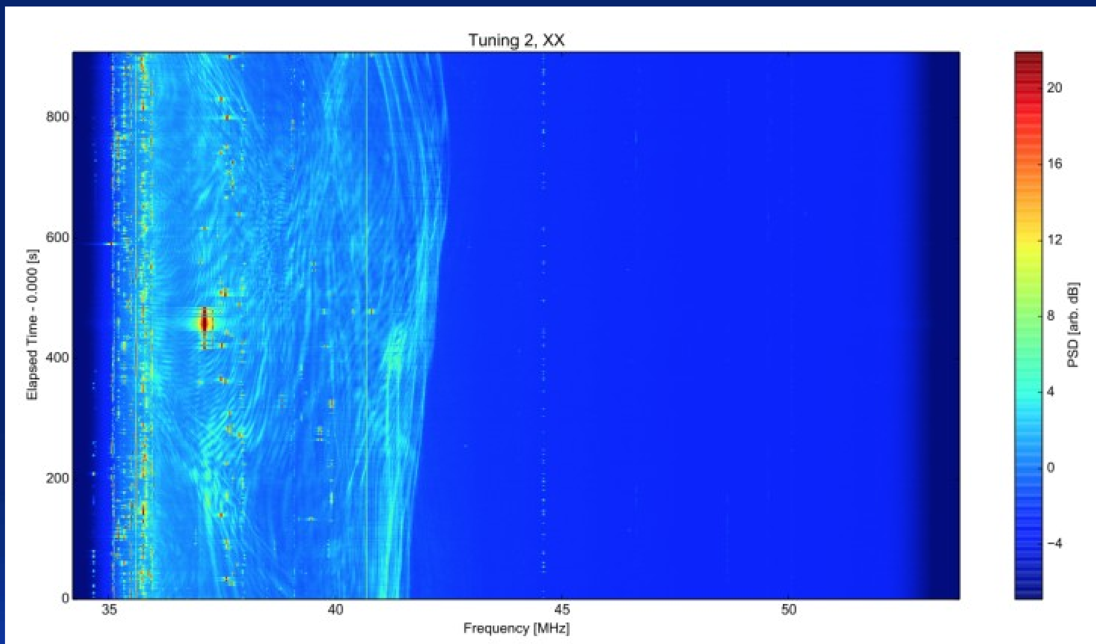
RFI Oddities



LGM – Jan 3, 2012

RFI of unknown origin

RFI Oddities



LWA-1, New Mexico – circa November, 2014

Even the large profession observatories must contend with RFI.

From Dr. Chuck Higgins' email to the Jove Data mailing list on Dec 5, 2014:

Hi Radio Jovers,

You see, even the big guys are fighting radio interference. The Long Wavelength Array (LWA) in New Mexico has a new RFI problem. See the waterfall spectrogram below. This has amazing structure to it, and a pretty sharp cutoff around 42-43 MHz. After some discussion, they have a plan to investigate the cause. But I wanted to show it to you just to let you know that RFI happens to the best of them.

Any comments are welcome, and I will pass them along to the LWA Team.

Regards,
Chuck

A few details from the LWA observatory director Greg Taylor:
1) This seems to have switched on sometime between Oct 17 (when it was not present) and Oct 20
2) The source is resolved which makes me think it must be nearby.
3) Crude direction finding indicate that it is centered on the Control Building, but could also come from the antennas (or beyond).
4) It very consistently starts with the sunrise and fades away just before sunset.
5) It is present every day including weekends and holidays.