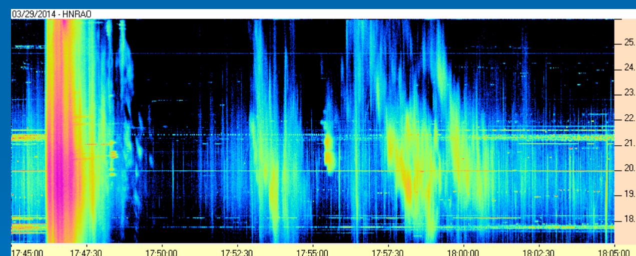
Advanced Systems



Richard Flagg, Radio Jove Meeting, July 2, 2014, NRAO Green Bank

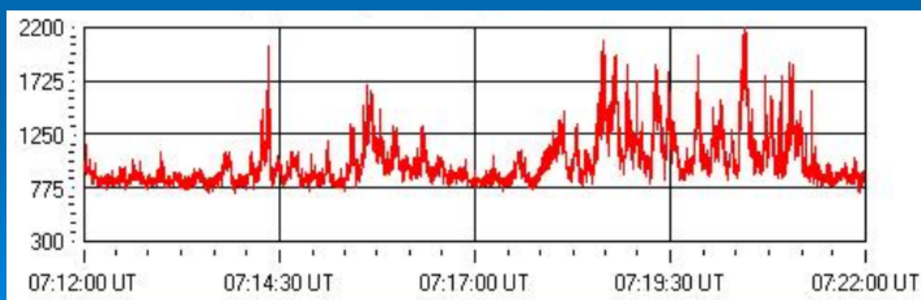
Advanced Systems

- Spectrographs
  - Resolution ΔF, ΔT
  - Solar
  - Jupiter
  - Propagation phenomena
- Polarimeters
- Wideband antennas

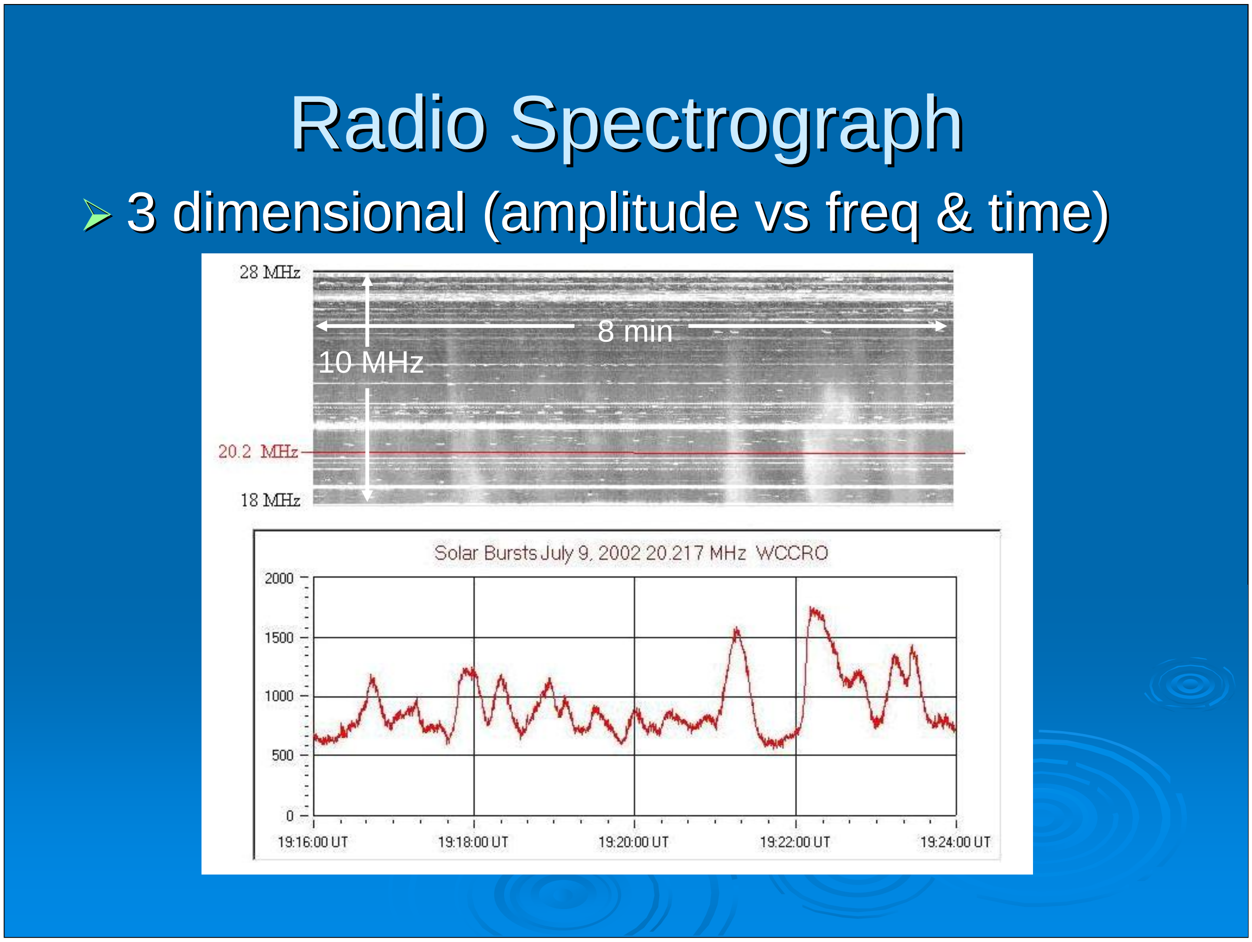
This mornings talks were aimed at the new Jove observer – someone just beginning in radio astronomy with the Jove radio telescope. This afternoon we will move from the basic single frequency Jove receiver to more advanced receiving systems. These include radio spectrographs which function like hundreds of receivers – each tuned to slightly different frequencies, allowing us to view signals over a wide frequency range. We will discuss systems which allow us to look at Jovian emissions in higher time and frequency resolution, as well as allowing studies of polarization. This talk will be a mix of instrumentation and observations. Hopefully you will learn a bit more about Jovian signals and what happens to those signals as they propagate thru the interplanetary medium and the earth's ionosphere.

Basic Jove to Advanced Systems

- Jove receiver: 2-dimensional (amplitude vs time at a fixed frequency) using linearly polarized antenna.



The Jove radio telescope gives us a two dimensional strip-chart view of signal strength vs time. Here we see a 10 minute segment of a Jupiter L-burst storm. The Jove receiver was tuned to a frequency near 20.1 MHz

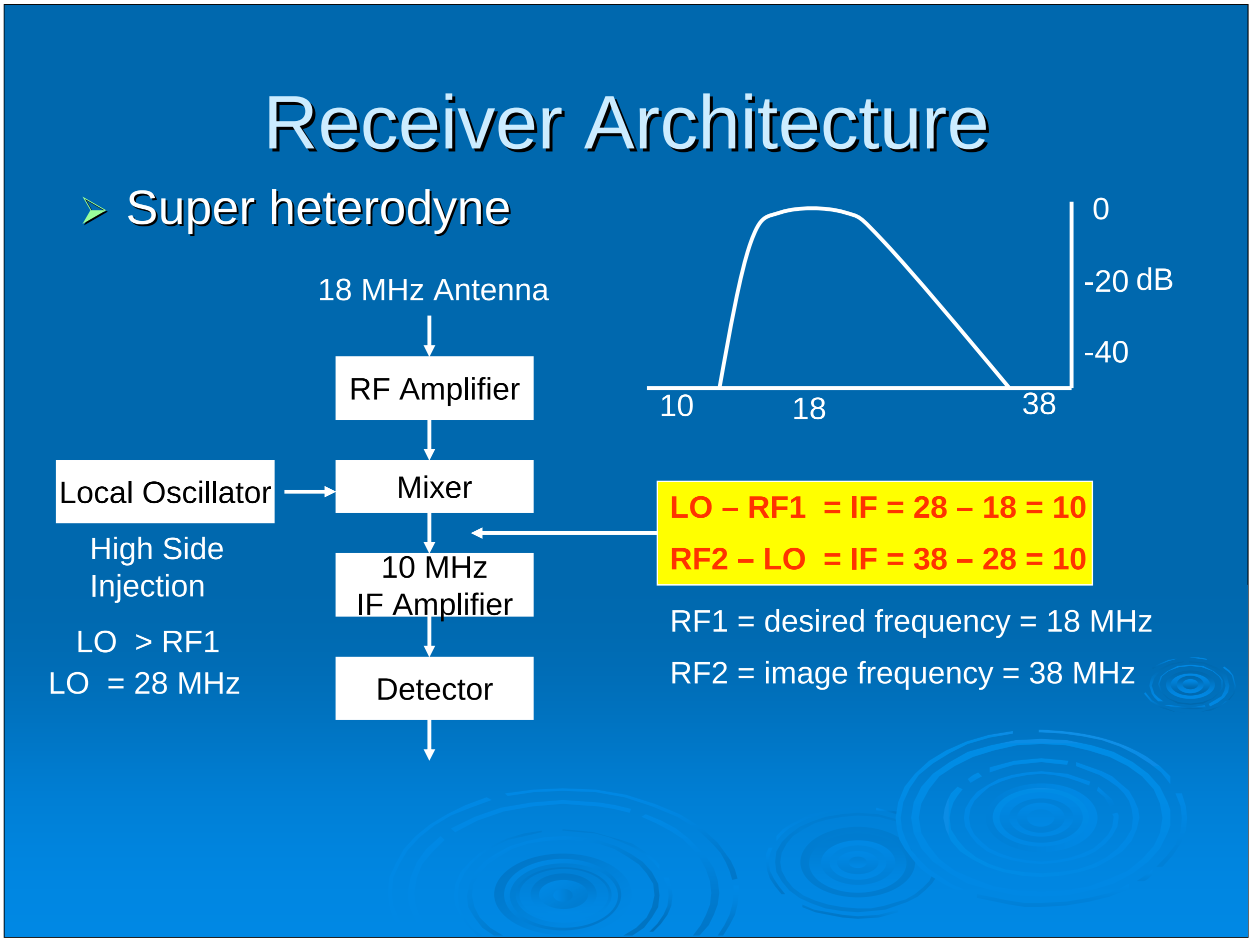


The top panel shows an image of solar activity observed by a radio spectrograph. The spectrograph is monitoring the frequency range from 18 MHz to 28 MHz as seen along the vertical axis. This is a 3-dimensional depiction showing signal strength (shades of grey) vs both time and frequency.

The white horizontal lines are radio stations. The lighter colored areas extending from high to low frequencies are solar bursts.

The bottom panel shows the Skypipe record obtained simultaneously by a Jove receiver tuned to 20.2 MHz (the red horizontal line on the spectrogram). You can see that the white (strong signal) areas in the spectrogram match up with the signal peaks in the Skypipe record.

In a minute or so we will see some better images of solar bursts but first let’s discuss how a superheterodyne receiver works and then take a look at a block diagram of a spectrograph.



The superhet receiver is designed to allow most of the gain to be placed in an intermediate frequency amplifier (IF). This is accomplished by multiplying the RF signal with a local oscillator signal (LO) in a non-linear device called a mixer. There are several signals that come out of the mixer. but the two we are most interested in are shown in yellow.

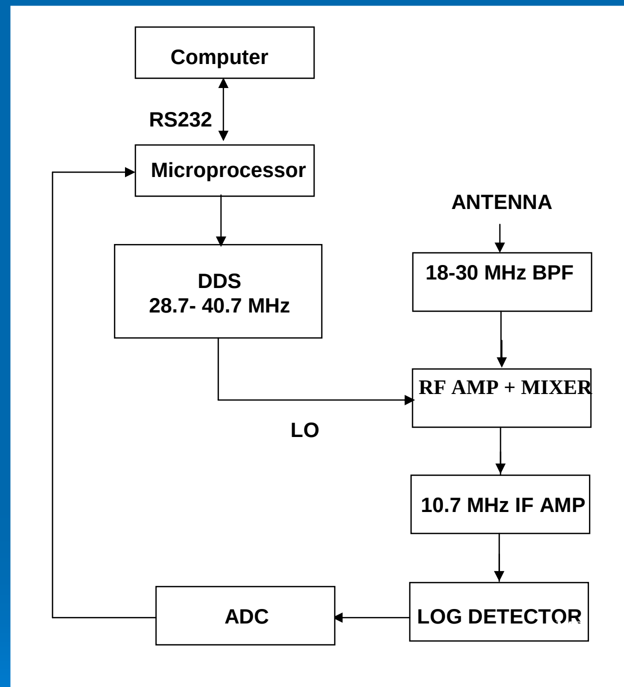
For example, with the LO frequency of 28 MHz there are two frequencies of RF signal (RF1 and RF2) that can be mixed (or heterodyned) to the IF frequency of 10 MHz. One is the desired signal at 18 MHz and the other is called the image frequency – in this case at 38 MHz. The gain of the RF amplifier is tailored to boost the 18 MHz and attenuate the image frequency as we see in the amplifier response curve at the upper right. A second goal of the RF amplifier circuit is to reject signals at the IF frequency. In most superhet receivers the local oscillator and the RF amplifier tuning are coupled together so that they track each other as the receiver is tuned to different frequencies. In this way the desired RF frequency is always converted to the IF frequency of the receiver.

FSX Spectrograph

18-30 MHz

30 kHz IF BW

2000 channels/sec

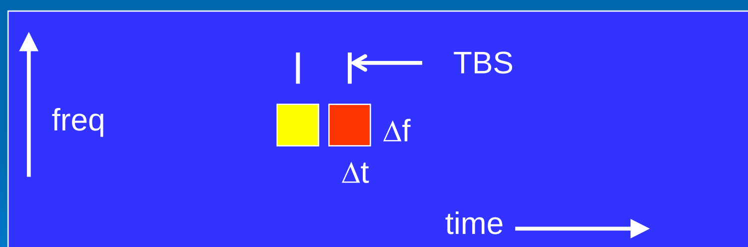


This is a block diagram of the FSX radio spectrograph – an instrument whose ancestor was developed as part of the Jove program. The FSX can be thought of as a receiver that tunes quickly thru 200 frequencies in the range of 18 to 30 MHz. It actually steps thru these frequencies under control of a microprocessor – dwelling at each frequency just long enough to get a signal strength measurement and then stepping to the next frequency.

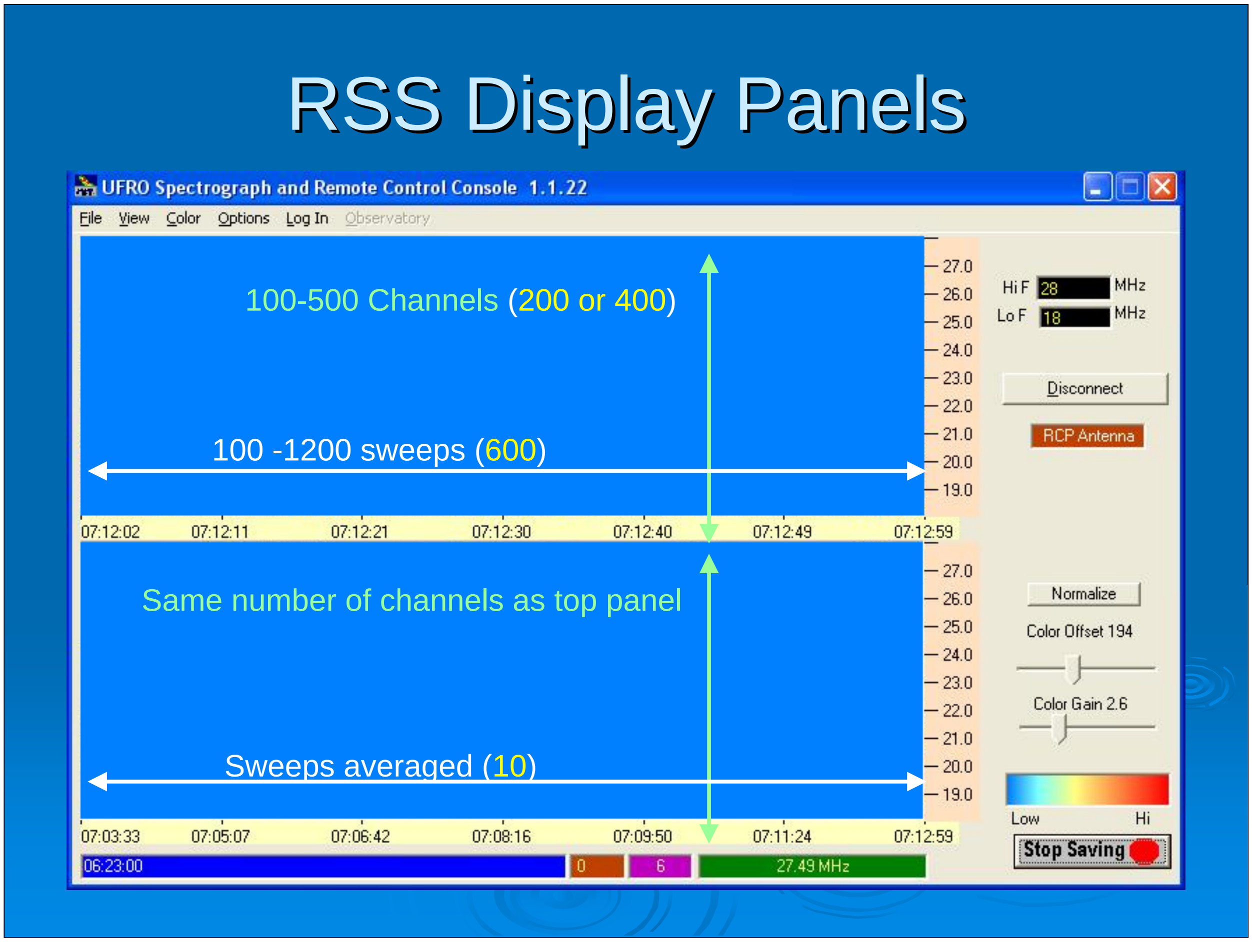
Looking at the block diagram, lets start with the microprocessor. It sends a command to the DDS – a direct digital synthesis oscillator that generates the local oscillator signal (LO) which is injected into the RF Amplifier / Mixer module. This tunes the radio to some specific frequency. The 10.7 MHz output of the mixer is routed to a 30 kHz wide IF amplifier with about 50 dB of gain. The amplified IF signal goes to a logarithmic detector and to a 12 bit analog to digital converter (ADC). The ADC digital representation of the signal strength is sent back to the microcontroller which passes it to the main computer via an RS232 line for processing and display. The instrument steps thru 200 frequencies in 1/10 of a second – dwelling at each frequency for a bit less than 500 microseconds.

FSX Spectrograms

- Dwell time Δt = 500 usec
- Time between scans (TBS) = 0.1 – 0.25 s
- Frequency resolution Δf = 7.5 - 60 kHz
- Visual dynamic range 10 - 40 dB

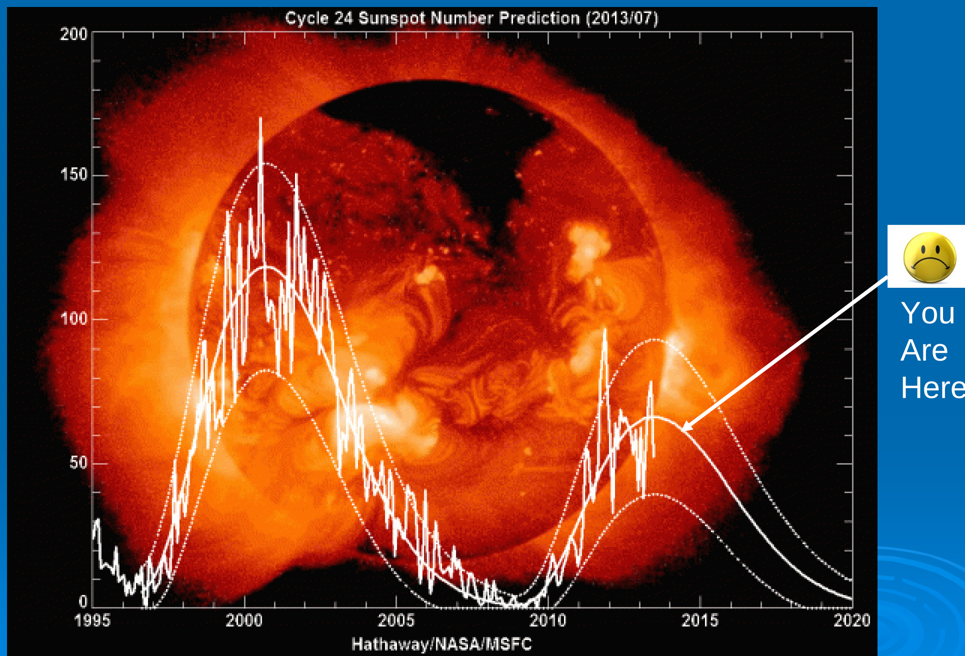


The color of each pixel in the spectrogram represents signal strength received in the IF bandwidth (normally 30 kHz). For Jim Sky's RSS spectrograph software the sweep rate of the FSX is fixed at 2000 channels per second. The number of channels however can be adjusted between 200 and 500 channels per sweep. If the instrument is sweeping thru 200 channels then the time between scans is 0.1 second. For 500 channels the time between scans is ¼ second. The spectrograph has a dynamic range of over 40 dB – from the galactic background which is often seen as deep blue to the strongest signals which appear as red. By adjusting color gain and offset controls the visual sensitivity (visual dynamic range) can be varied. The basic FSX spectrograph uses a 30 kHz wide IF amplifier, however several different IF bandwidths have been made for different experiments.



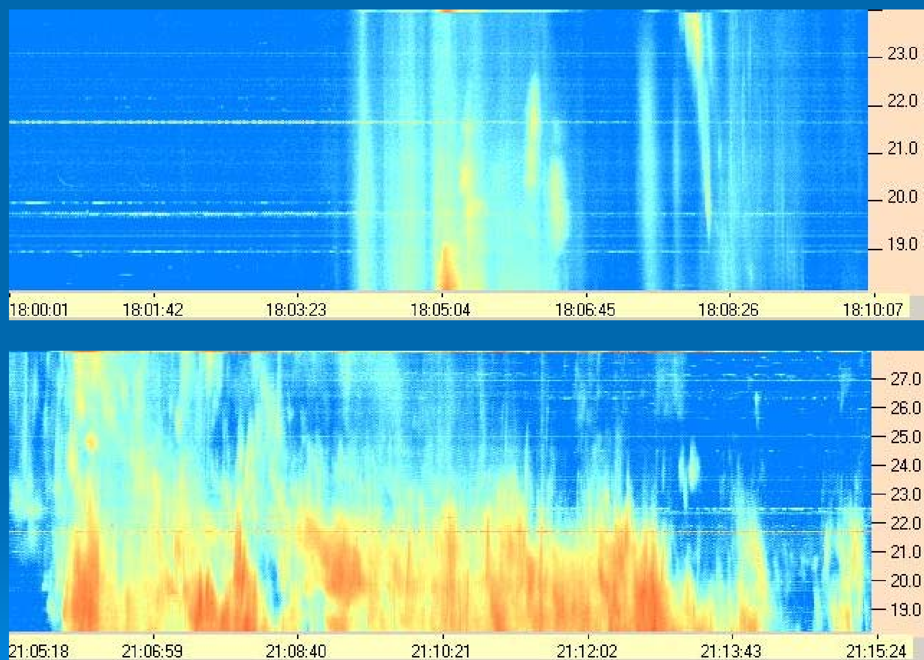
Here is a view of the RSS display. There are two panels. Typical settings are shown in yellow. The top panel typically displays either 200 or 400 channels and 600 sweeps. Since the sweep rate is 2000 channels per sec the top panel with 200 channels displays one minute of data. The bottom panel averages the data seen in the top panel typically averaging ten adjacent sweeps which means if the top panel shows 1 minute of data the bottom panel will display 10 minutes worth. Many of the slides you see will contain a couple of single panel shots from different events.

Solar Bursts



Next we will look at some spectrograms of solar bursts – which occur most frequently near times of solar maximum. These are generally caused by jets of electrons streaming outward from the sun thru the solar magnetic field. The radio bursts usually drift from high to low frequencies as the electrons move thru progressively weaker magnetic field regions.

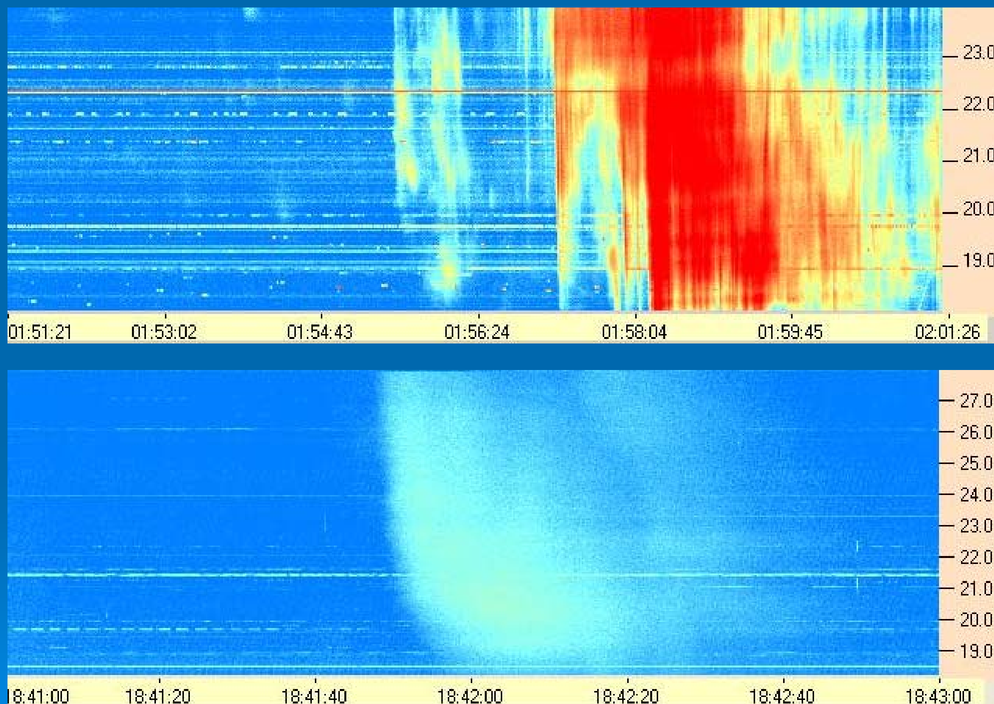
Spectrograms - Solar



WCCRO Images

Each of these spectrograms are 10 minutes long and were taken on different days. The top one goes from 18 to 24 MHz while the bottom one is from 18 to 27 MHz.

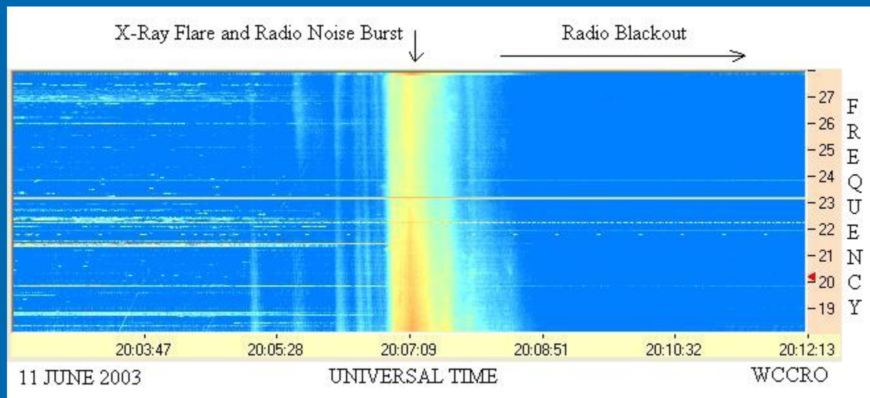
Solar Bursts

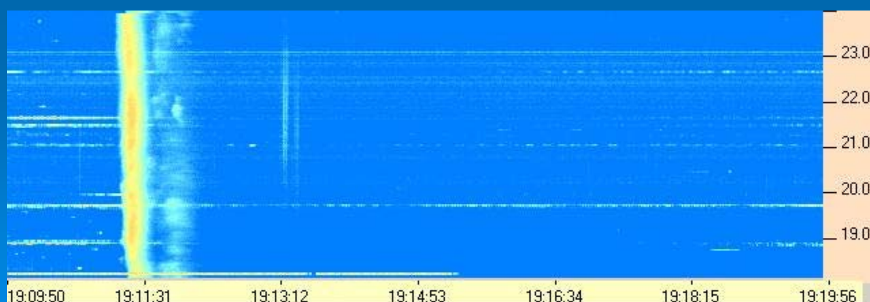


WCCRO Images

Another pair of spectrograms of solar activity.

Ionospheric Effects - Radio Blackouts

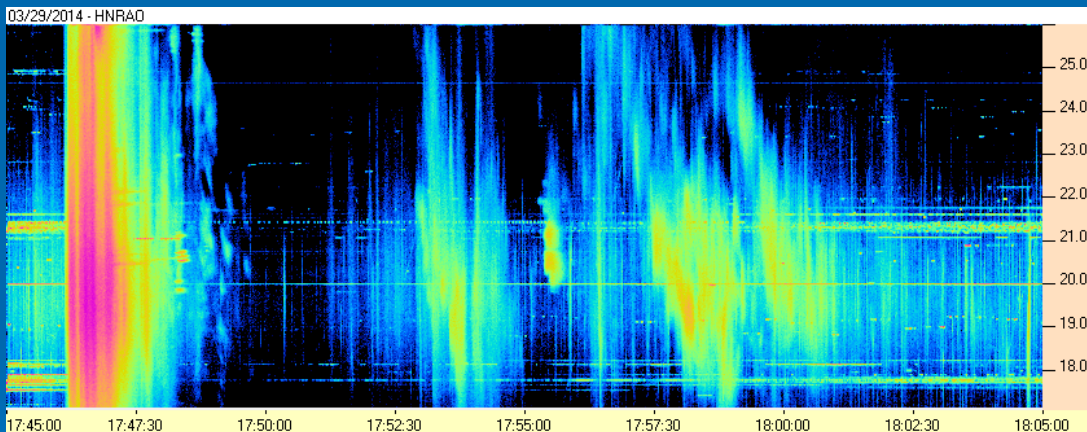




WCCRO Images

During a solar flare there is often X-ray and ultra-violet emission that has a profound effect on the earth's ionosphere. Prior to the flare we see normal daytime station activity. These signals, many from distant stations, are reflected off the upper layers of the ionosphere back to our receiving site. When the ionosphere is hit with the X-ray and UV flux from a flare the lower layers are ionized and these layers absorb terrestrial signals resulting in a radio blackout. After several minutes the ionosphere slowly returns to its usual happy daytime reflective self.

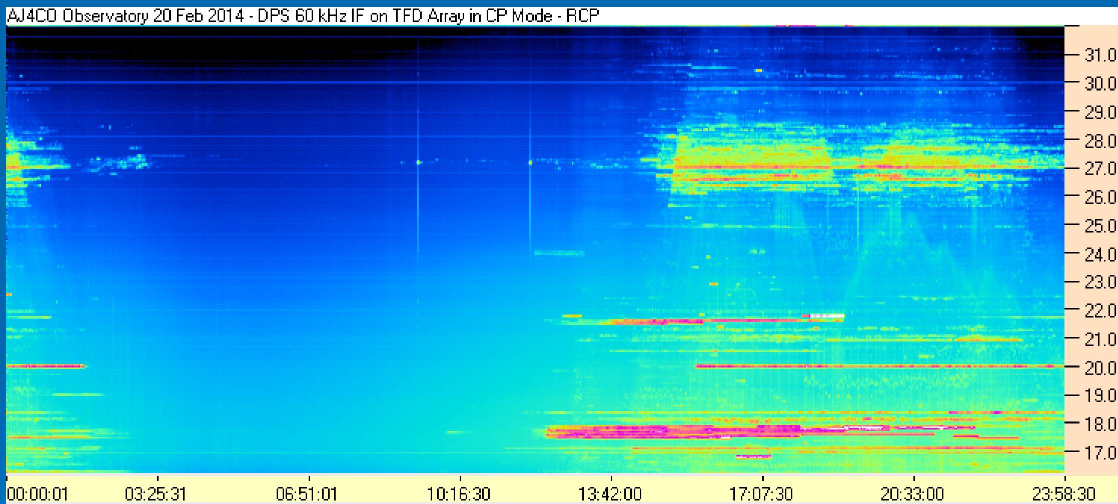
X-1 Solar Flare 29 March 2014



HNRAO Image

This flare during the 2014 CQ WW WPX contest caused a major suckout in the 15 meter ham band

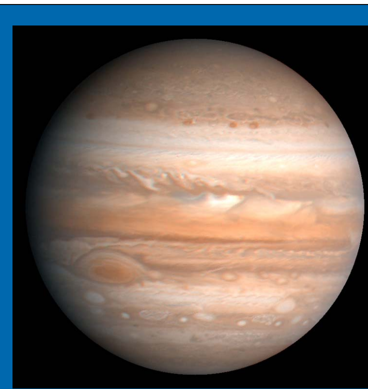
Ionospheric effects - The Ghost TPs



Typinski Image

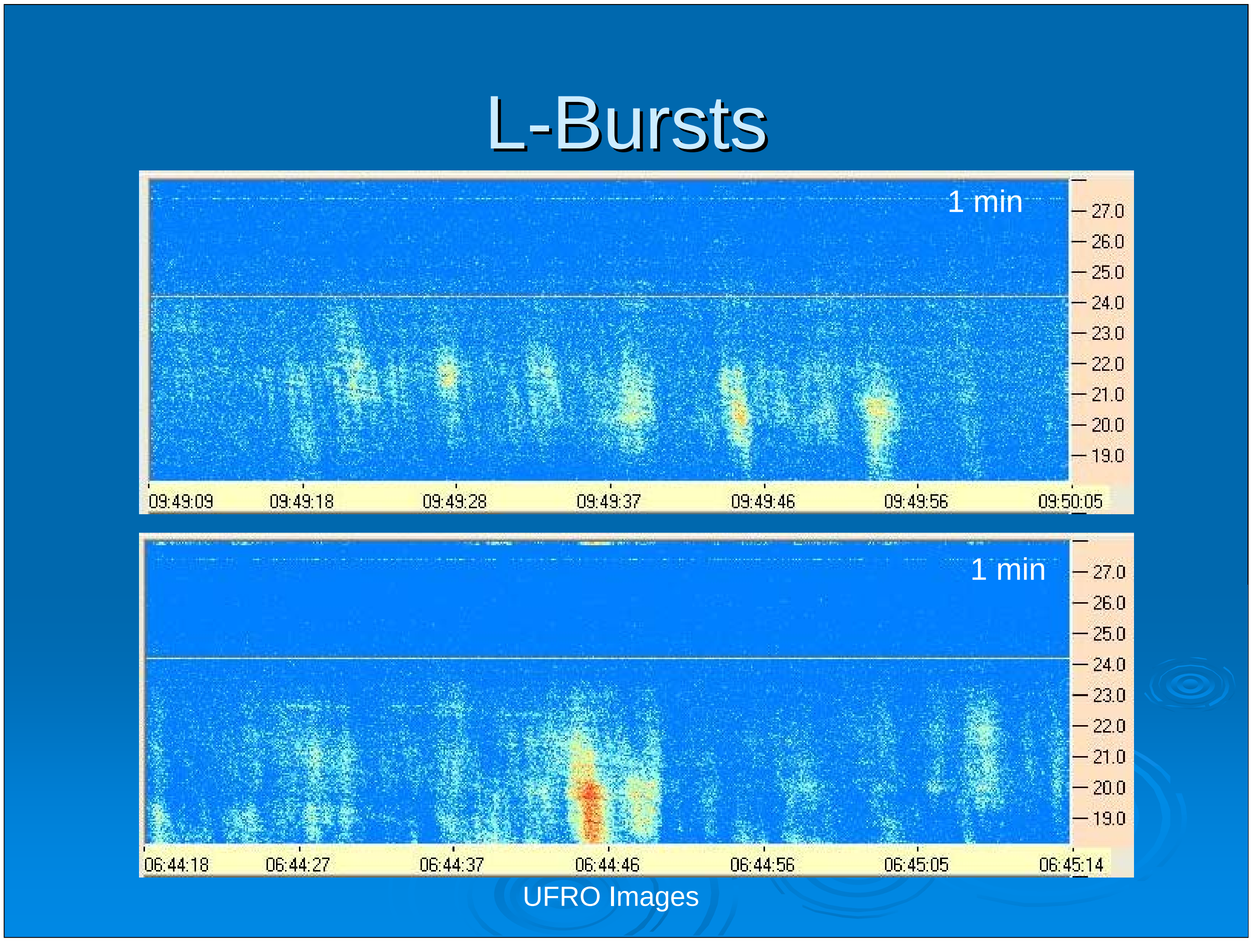
This 24 hour long spectrogram clearly shows the difference between daytime and nighttime listening conditions. On the right hand (daylight) side we see some faint structures which have a TP – like shape. These background noise enhancements are seen rising and falling through out the daylight hours and are clearly related in some manner to the maximum usable frequency (MUF) on some propagation paths.

Jupiter Spectrograms



- Visual Features
  - L-bursts: Amorphous blobs
  - S-bursts: Short bursts – often high rep rate
  - N-events: Narrow band emissions, 0.2 MHz
  - Modulation Lanes: drifting features 100 kHz/sec
  - Arcs
- All features modified by propagation effects such as interplanetary and ionospheric scintillation, and Faraday rotation

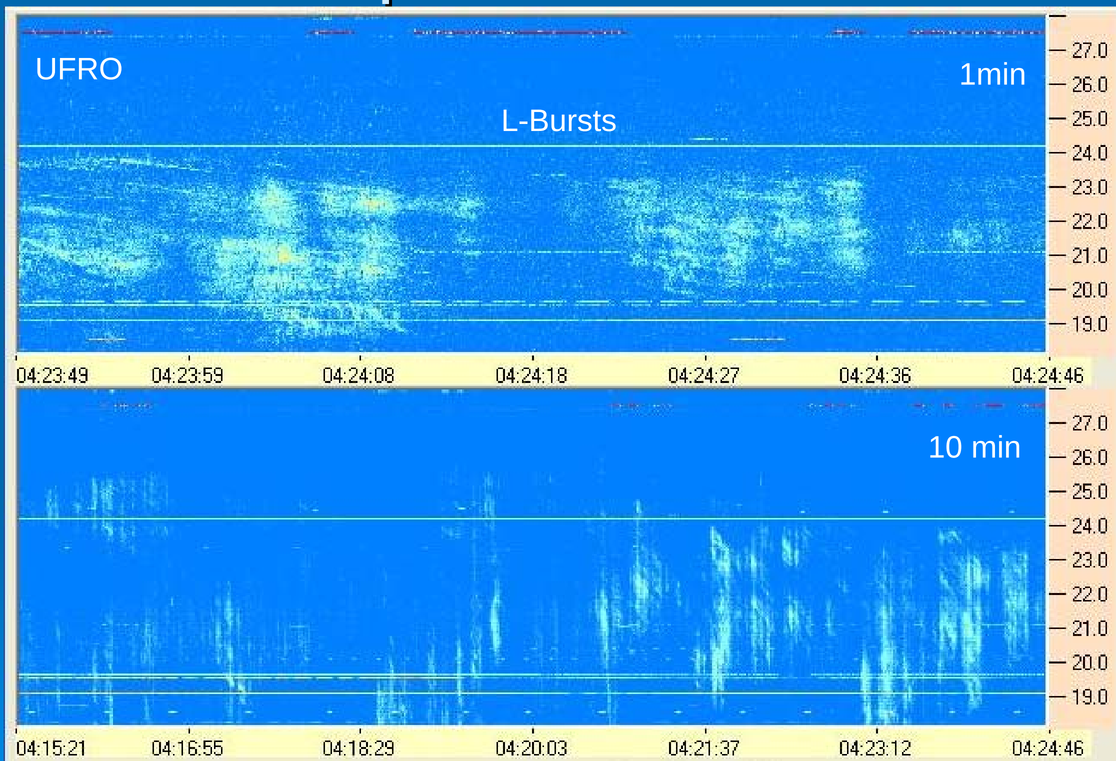
We have all heard what Jupiter bursts sound like on a narrow band single frequency receiver: L-bursts sounding like ocean waves breaking up on a beach and S-bursts that sound like pebbles tossed onto a tin roof. Next we will learn to recognize these burst types by their signatures on a radio spectrogram. As we look at these bursts on the frequency-time plane remember that we are looking at signals that have traveled a few hundred million miles thru interplanetary space and then thru the earth's ionosphere.



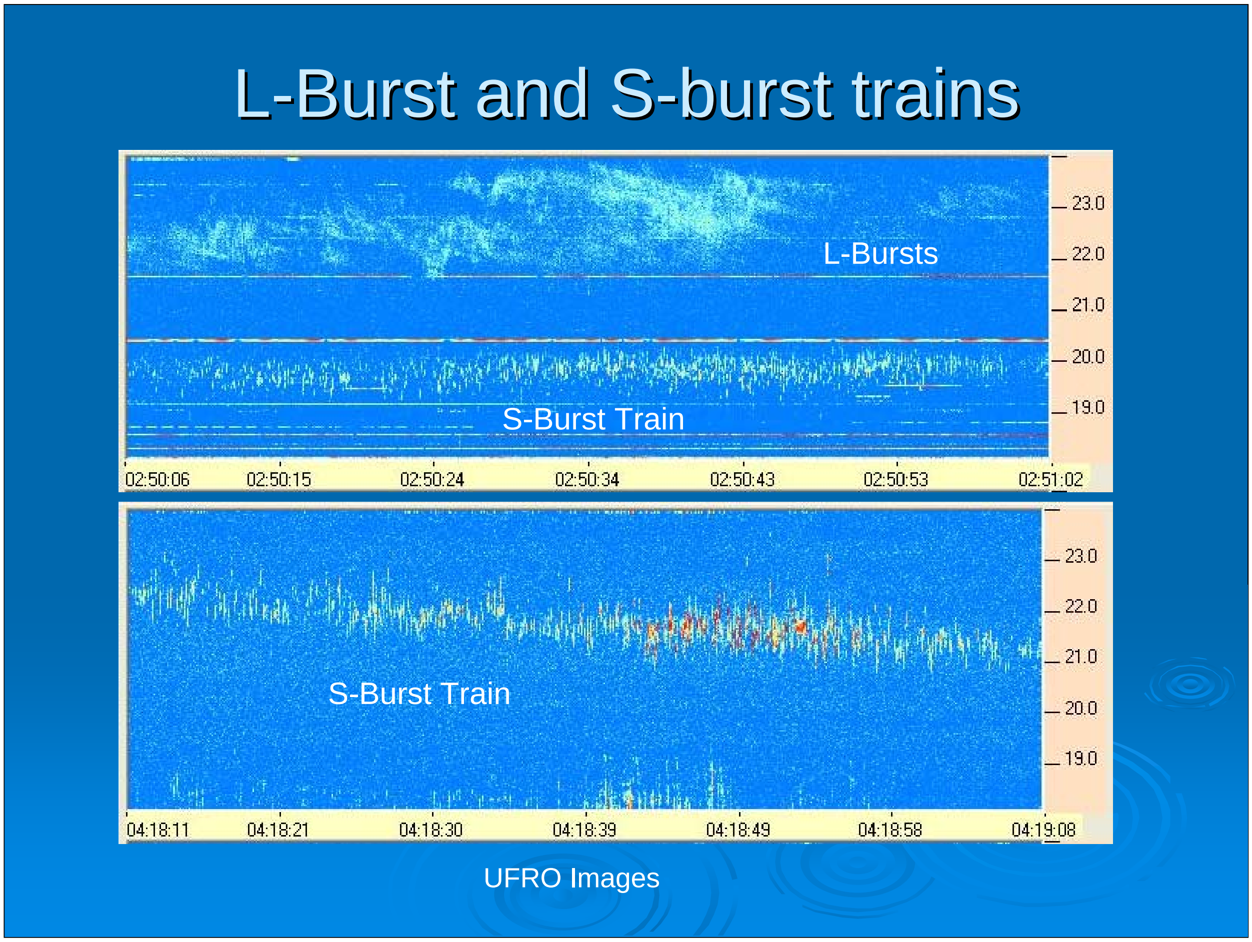
The top and bottom panels are each 1 minute long. Its not hard to imagine how these bursts would sound at a single frequency – like ocean waves breaking up on a beach.

In both panels the bursts are a few MHz in extent in the frequency domain. Amplitude variations are on a time scale of a few seconds. These amplitude variations are primarily imposed on the L-burst as it travels thru the interplanetary medium. Turbulence in the interplanetary medium causes the Jovian signals to be refracted in different directions. Near the source at Jupiter these signals would appear as much longer amorphous blobs. Stars twinkle because of turbulence in the earth's atmosphere. Jovian radio signals gain much of their bursty nature because of turbulence in the interplanetary medium.

Jupiter L-Bursts

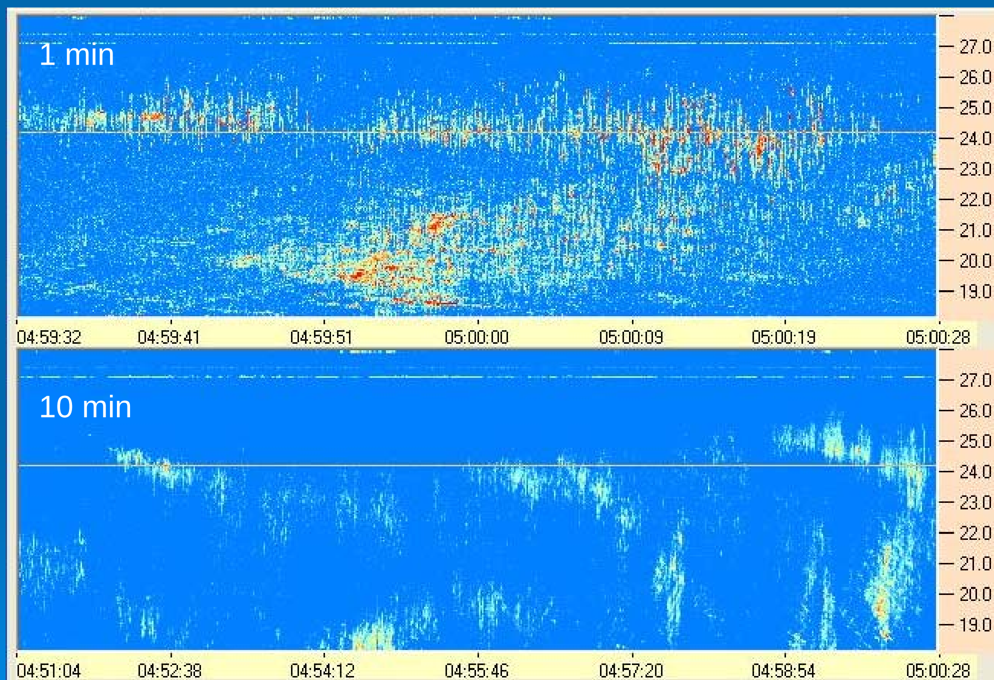


More Jupiter L-bursts – this time the top is one minute long while the bottom panel shows 10 minutes of activity.



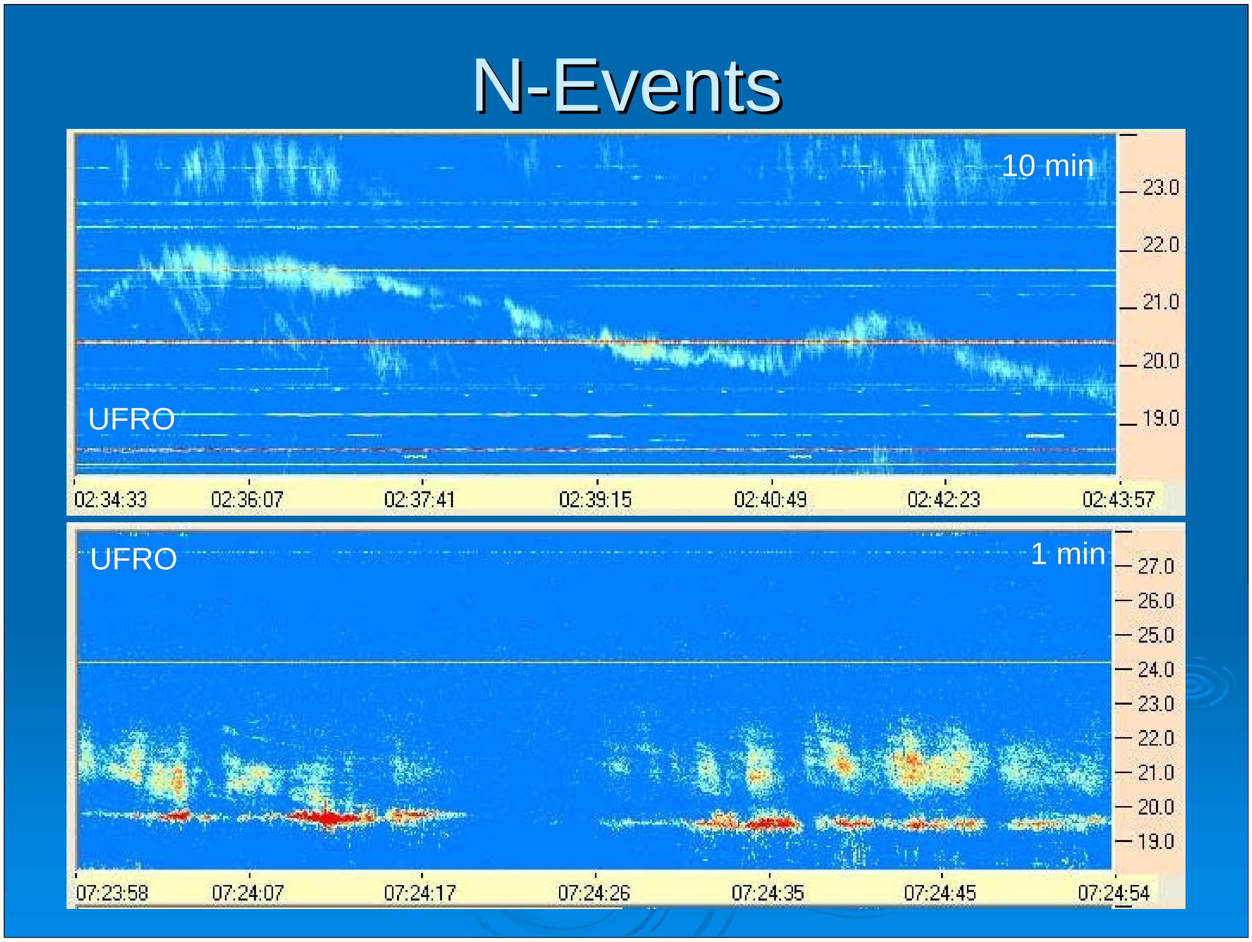
In the top panel between 22 and 24 MHz we see more L- bursts, while just below, at 20 MHz, is a narrow train of S-bursts. Individual S-bursts are not resolved by the spectrograph. What we see is a result of very short S- bursts captured as the spectrograph sweeps in frequency. In the bottom panel another S-burst train – this time drifting slowly down in frequency from 22 to 21 MHz. The train shows stronger and weaker segments as a function of time – just as the L- bursts do – at least part of this effect is the result of interplanetary scintillation.

S-Bursts

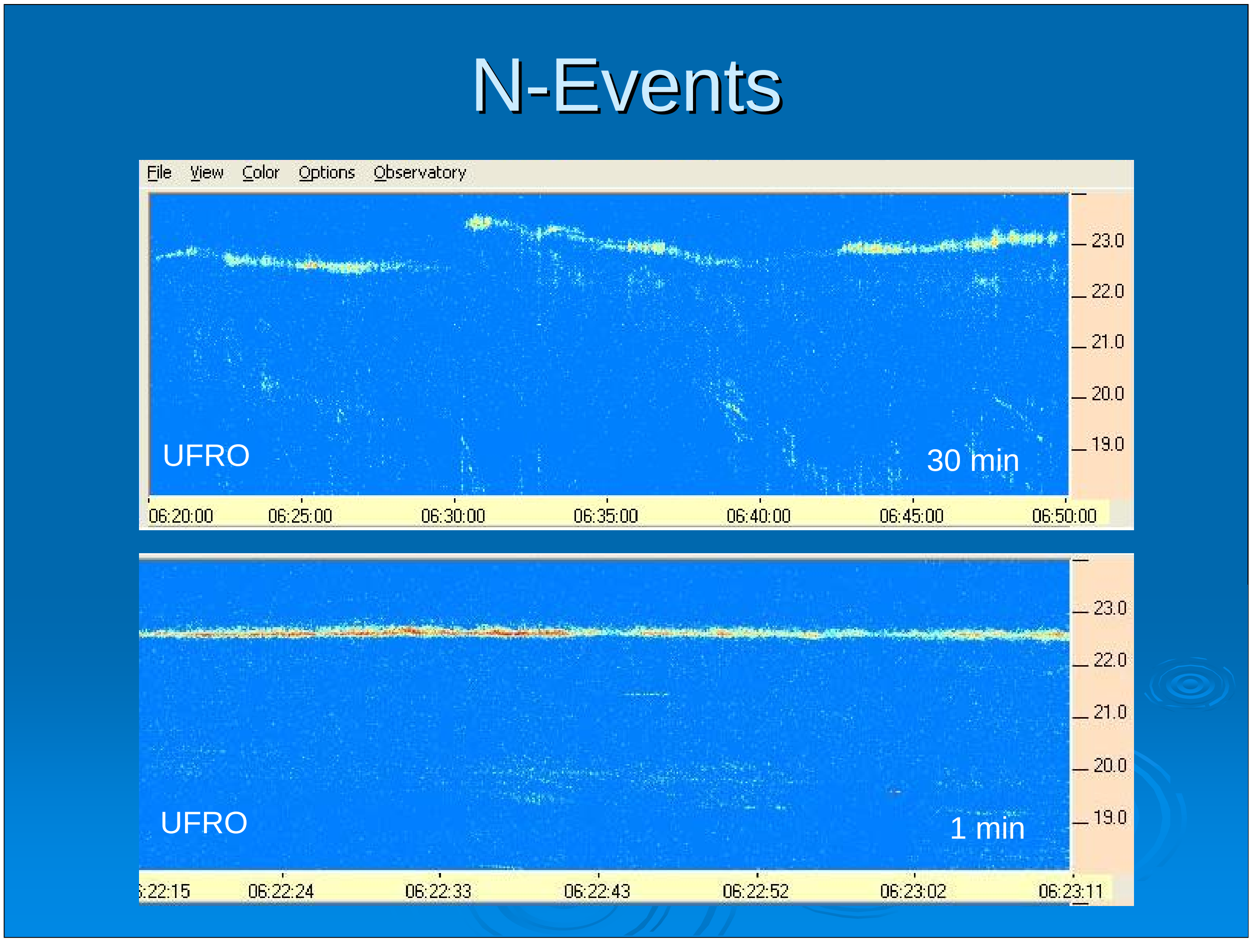


UFRO Images

The top panel shows S-bursts near 24 MHz and a mix of S and L bursts lower in frequency. The backward C-shape of activity in the top 1 minute panel is seen at the right hand edge of the 10 minute bottom panel. The bottom image is generated by averaging 10 spectrograph scans together while the top panel shows each individual scan line. You can see faint drifting features in the top panel which become more prominent in the bottom image.

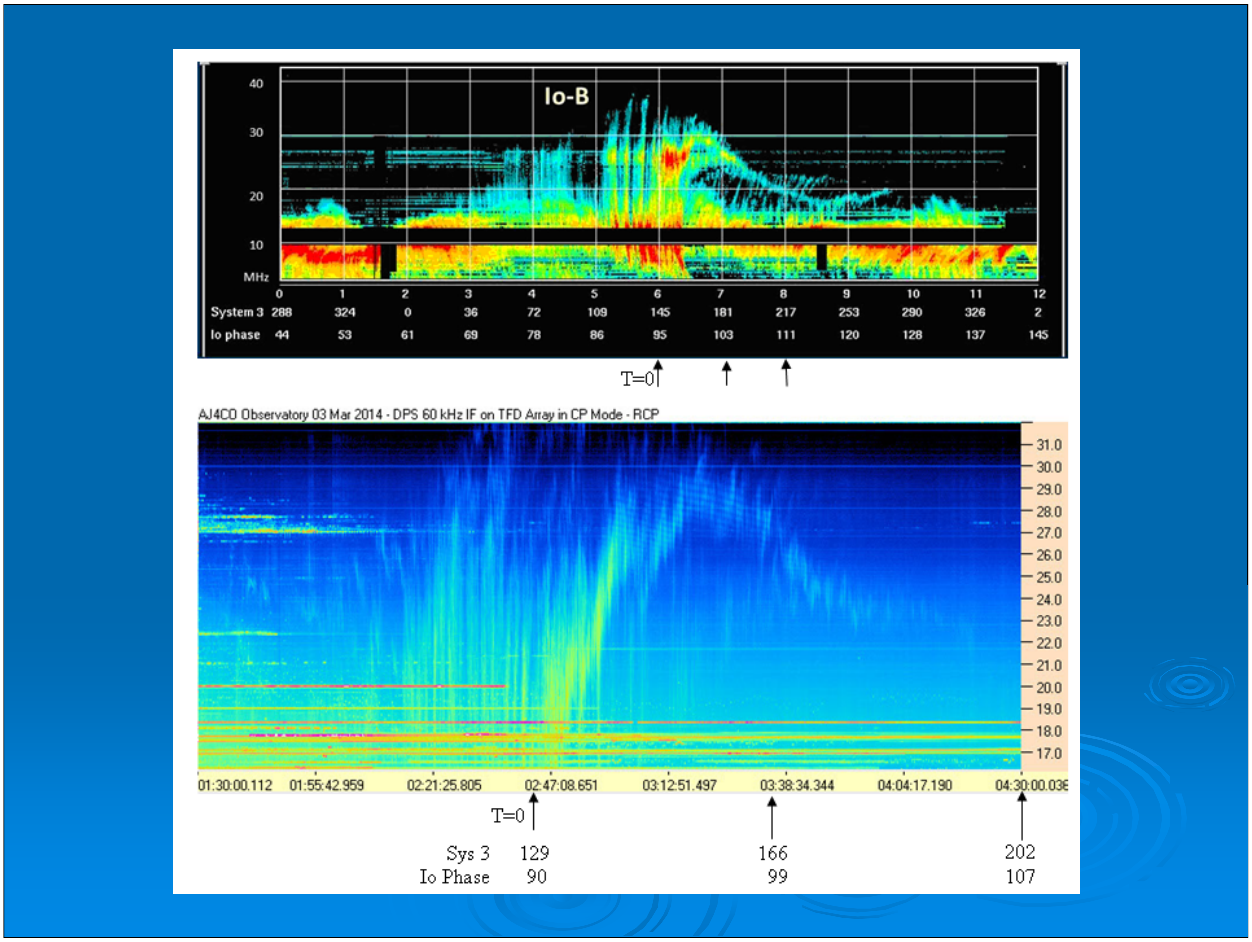


In addition to the familiar L and S-bursts we sometimes observe N-events. As you might guess, N stands for narrow band emissions. In the top 10 minute panel we see an N-event a few hundred kilohertz wide drifting slowly between 19 and 22 MHz. In the bottom 1 minute panel a narrower N-event lies at almost a constant frequency of 19.5 MHz. Interestingly there is some positive correlation between the strength of the N-event and the occurrence of bursting activity between 20 and 21 MHz. Perhaps this is a source phenomena or simply interplanetary scintillation.

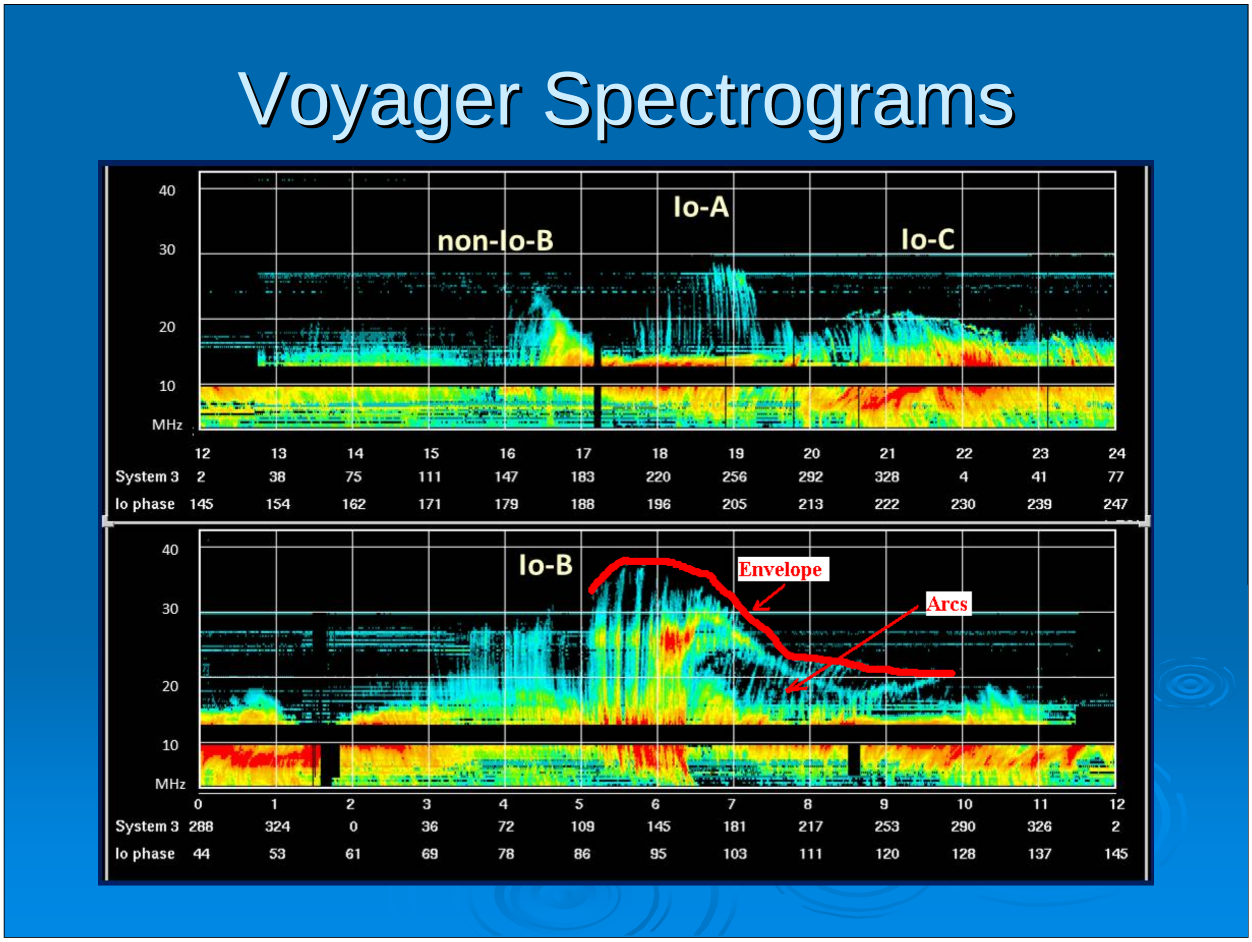


N-events can be long lived – in excess of a half hour. They often undulate and drift in frequency over a MHz or so. Sometimes they are very narrow and stable in frequency as seen in the bottom panel.

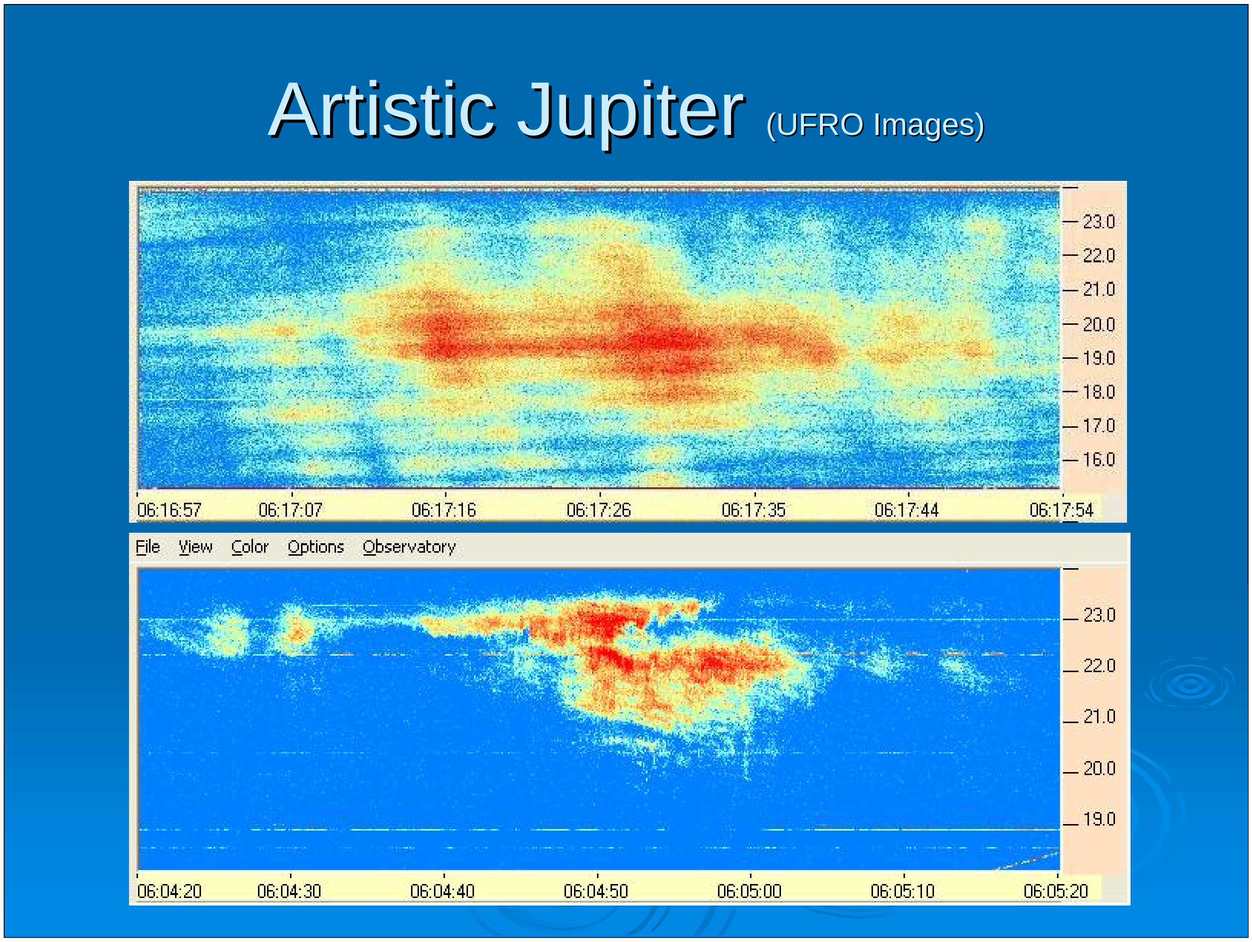
In addition to the L-bursts, S-bursts and N events which comprise Jupiter noise storms, the storms themselves have characteristic shapes on the frequency-time plane.



Here we see two records – the top one from the Voyager spacecraft heading to Jupiter in 1979, the bottom one from Dave Typinski in 2014. While the Voyager record represents 12 hours, the Typinski spectrogram is closer to 3 hours in duration. Note the To times on both records which represents a good point of visual alignment. The additional arrows denote 1 hour increments. Taking into account the different time scales there is an amazing similarity in the two records – particularly since they were taken 35 years apart. From these spectrograms we see that there are permanent features in Jupiter's dynamic spectrum.



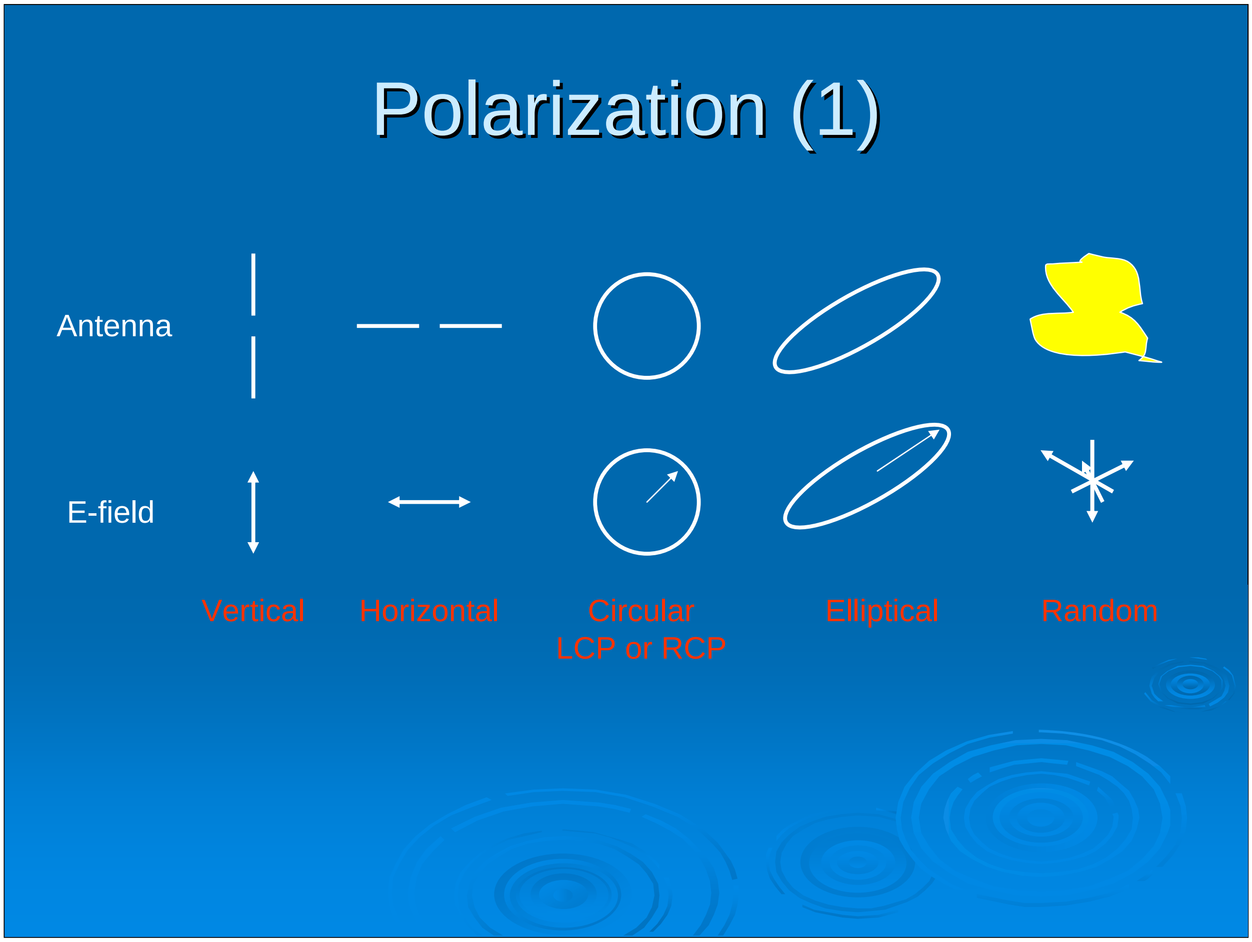
From the Voyager spectrograms we see that each storm type has different characteristics. The envelope extends up above 35 MHz during some Io-B storms while Io-C rarely gets above 20 MHz. Internal to each storm are curved features called arcs. These have the shape of open and close parenthesis and are called vertex early and vertex late arcs. The Io-B arcs are of the vertex early shape. The arc structure is difficult to pick out on narrow range spectrograms but can sometimes be identified.



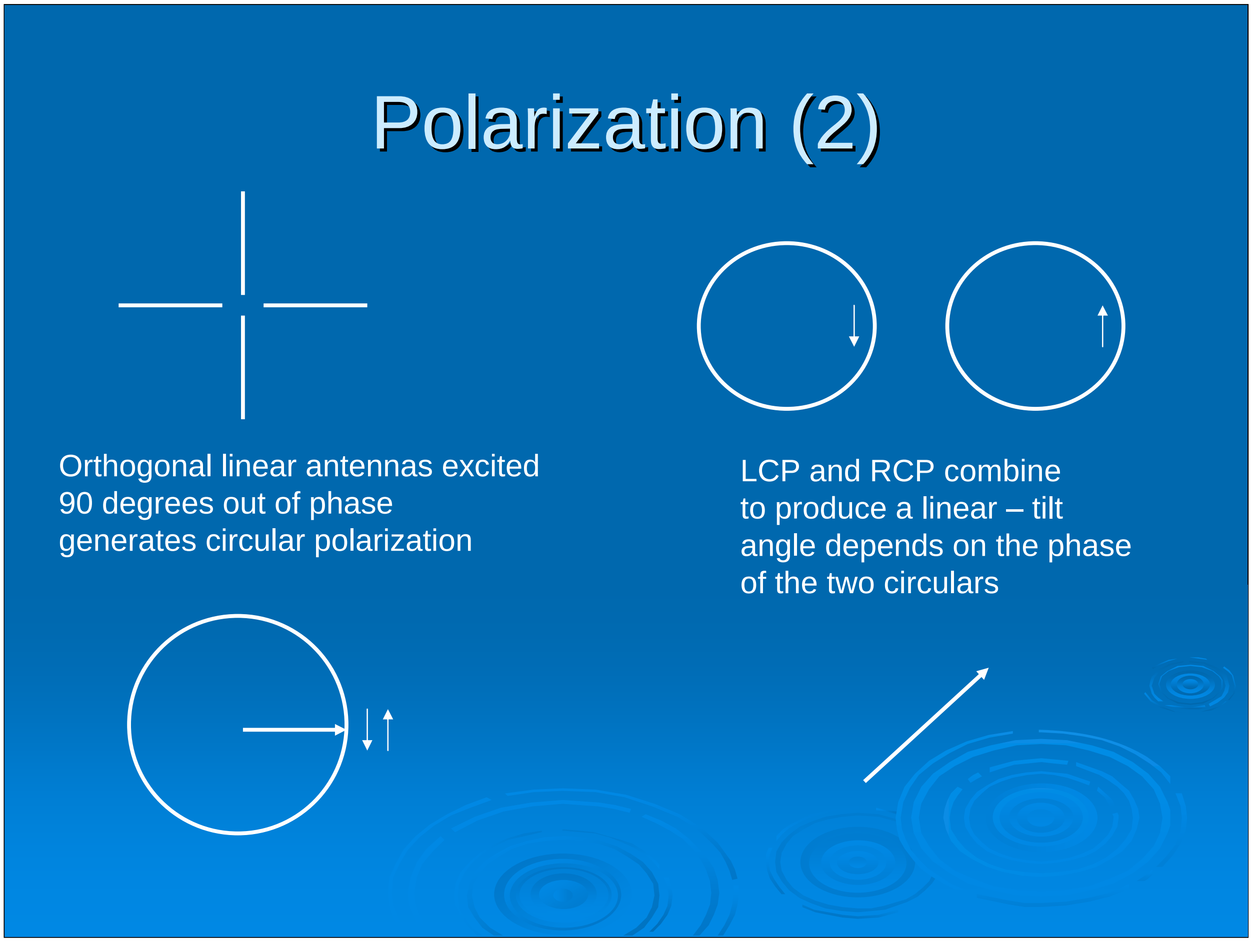
At times Jupiter spectrograms depict easily recognized objects - -

An airplane and the starship enterprise – and an interesting new feature – horizontal banding in the top panel. Lets take a couple of minutes to understand how these bands occur. To do this we need to talk about polarization.

Not this kind of Polarization

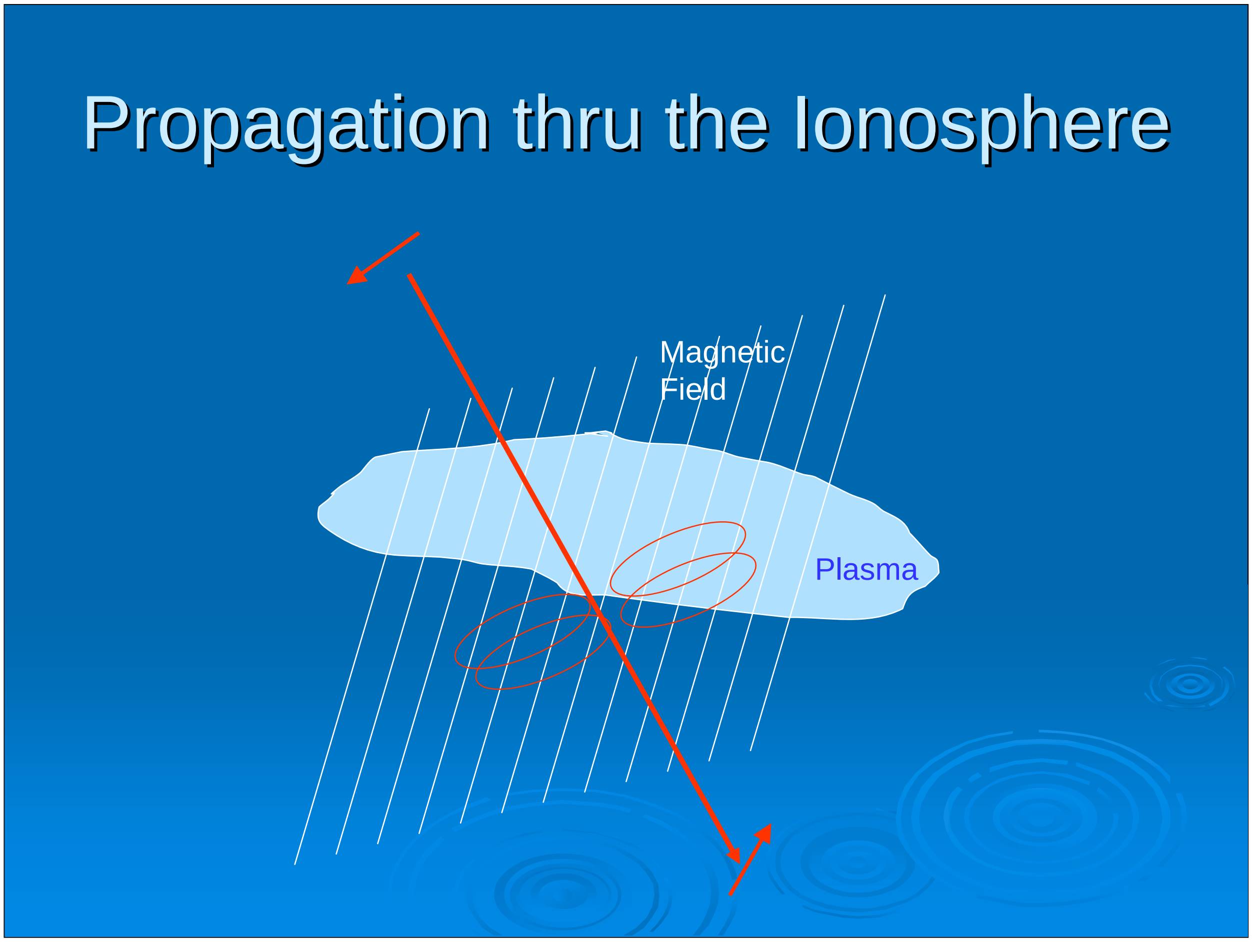


But this kind of polarization – meaning the orientation of the electric vector component of an electromagnetic wave. A vertical antenna generates a vertically polarized E field. Likewise a horizontal dipole generates a horizontal E-field. A helix could generate either a left hand or right hand circular polarized field - depending on the helix winding direction. This rotating electric field vector completes a rotation every RF cycle. The more general case of linear or circular polarization is elliptical. Some signals – like from a hot plasma with electrons vibrating in every direction are randomly polarized.

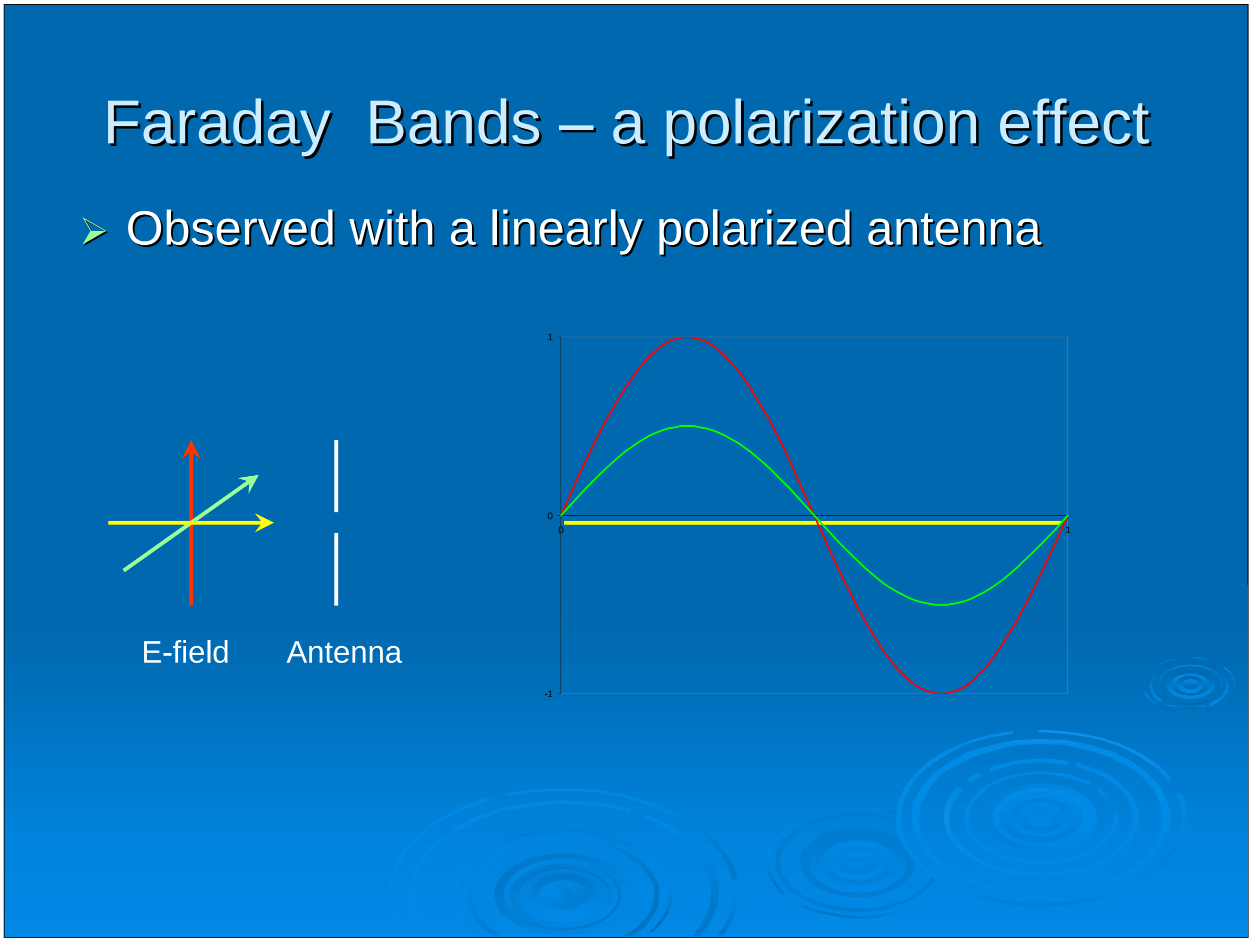


We can generate circular polarized signals using two linear antennas at right angles. If you think of it in the transmitting case the way to generate circular is to feed each linear antenna with the same signal but introduce a 90 degree phase shift into one signal path. The resulting circular polarized signal will be right hand or left hand depending upon if the 90 degree phase shift is leading or lagging.

Similarly you can generate a linearly polarized signal by using RCP and LCP circular polarized antennas. The tilt angle of the resulting linear signal depends upon the phase shift between the two circular components. If the phase between the two circular components varies the tilt angle of the resulting linear will change.



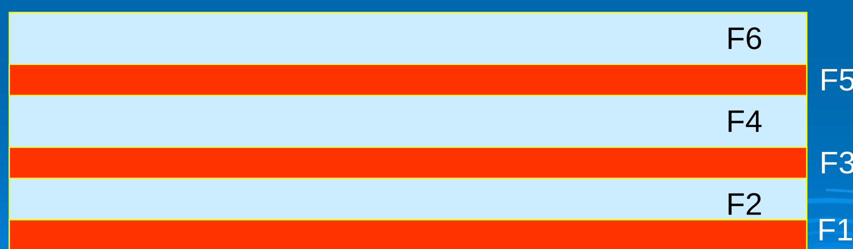
When a linear polarized signal propagates thru a magnetoionic medium like the ionosphere (which has free electrons immersed in a magnetic field) the two equivalent circular components propagate at slightly different velocities at different frequencies causing the resulting linear E-vector to change its tilt angle. This leads to the horizontal banding – called Faraday bands. In this case the two circular components are termed the ordinary and extraordinary waves



With these thoughts in mind let’s consider the result of a linearly polarized signal on our antenna as the tilt angle of that E-field changes. The red E field vector is aligned with the plane of our antenna so it generates the maximum signal. The yellow E-field vector is cross polarized (perpendicular) to the plane of our antenna and generates nothing.

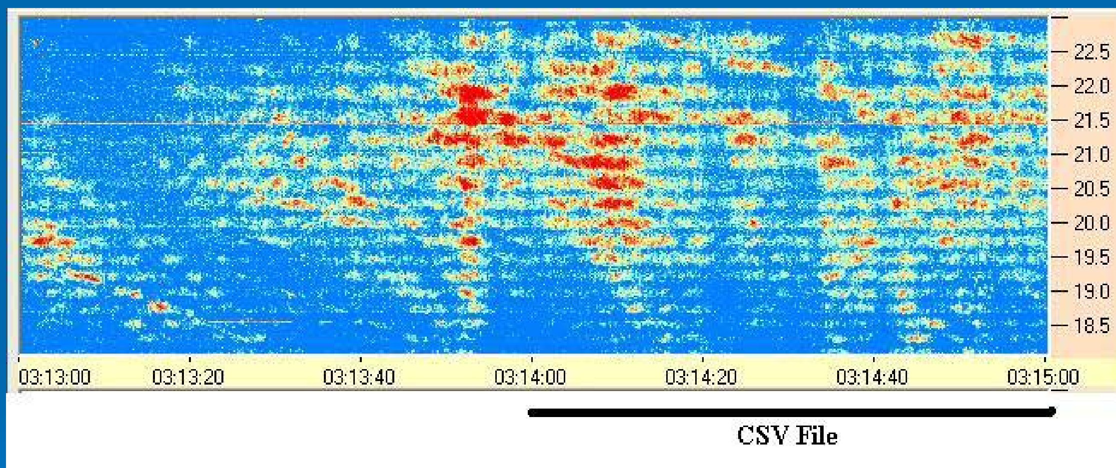
Faraday Bands (2)

- If the E-field is aligned with our antenna at some frequencies (F1, F3, F5) and cross polarized at other frequencies (F2, F4, F6) the resulting spectrogram should look like:



As the linear or highly elliptical signal from Jupiter propagates thru the Earth's ionosphere the resulting electric vector is rotated different amounts at different frequencies. If the E-field is aligned with our antenna at some frequencies (F1, F3, F5) and cross polarized at other frequencies (F2, F4, F6) the resulting spectrogram should look like this.

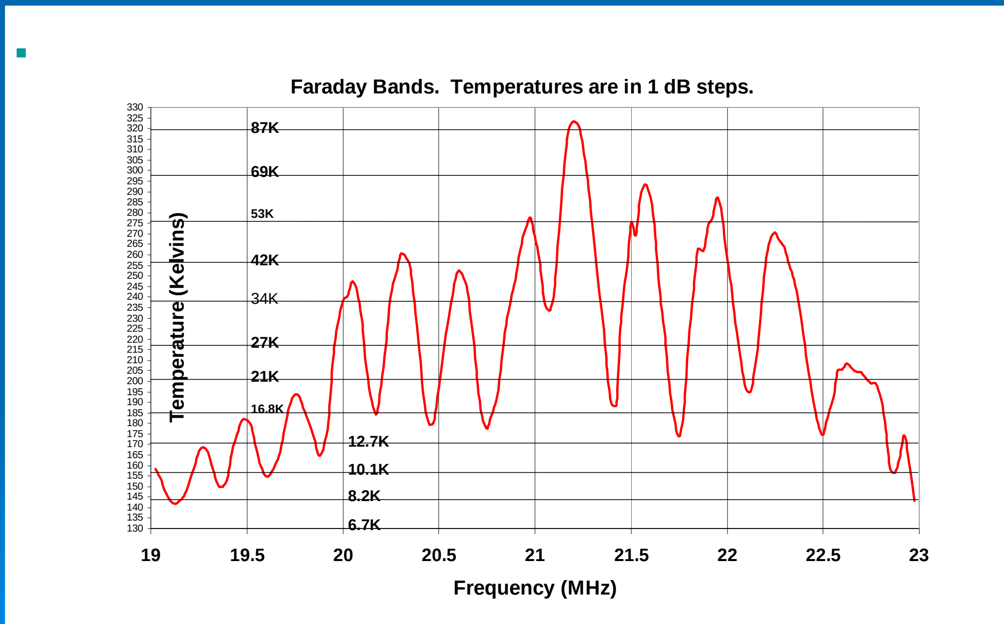
Faraday Bands (3)



Greenman, Radio Alachua Image

And this is exactly what we often see if we are receiving Jupiter signals using a linearly polarized receiving antenna. At some frequencies the incoming signal is aligned and at other frequencies the signal is cross polarized with our antenna.

Faraday Bands (4)



This plot showing antenna temperature vs frequency is a cut of the previous spectrogram at a fixed time. It is obvious that the Faraday fringes occur closer together in frequency at the lower frequencies than they do at the higher frequencies. This result closely follows the theoretical prediction.

Before moving on – this is probably a good point to close our discussion of polarization with one final comment – how to measure circular polarization components with linear antennas.

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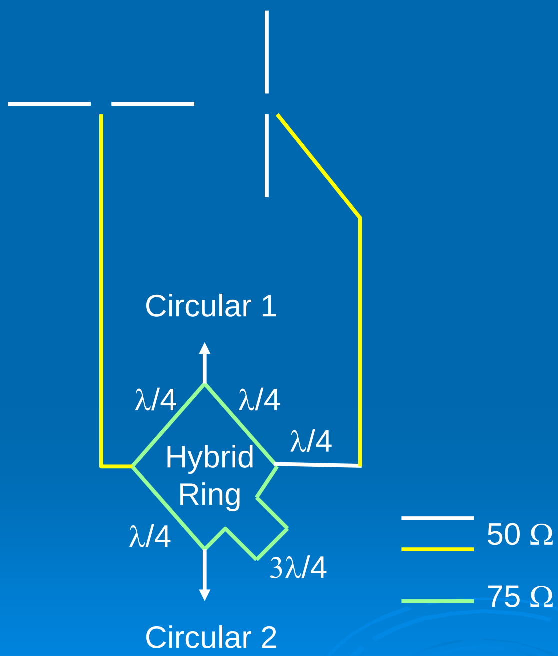
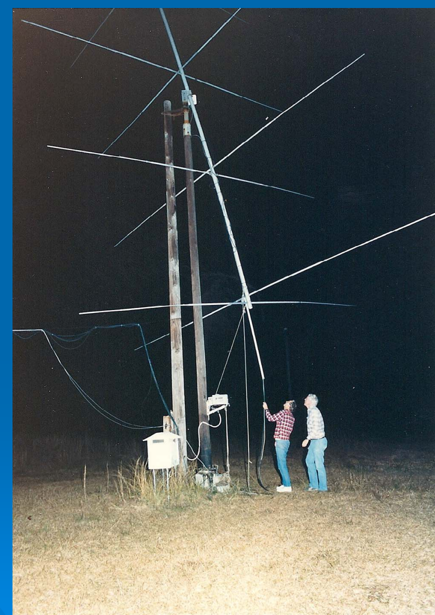
Polarization (3)





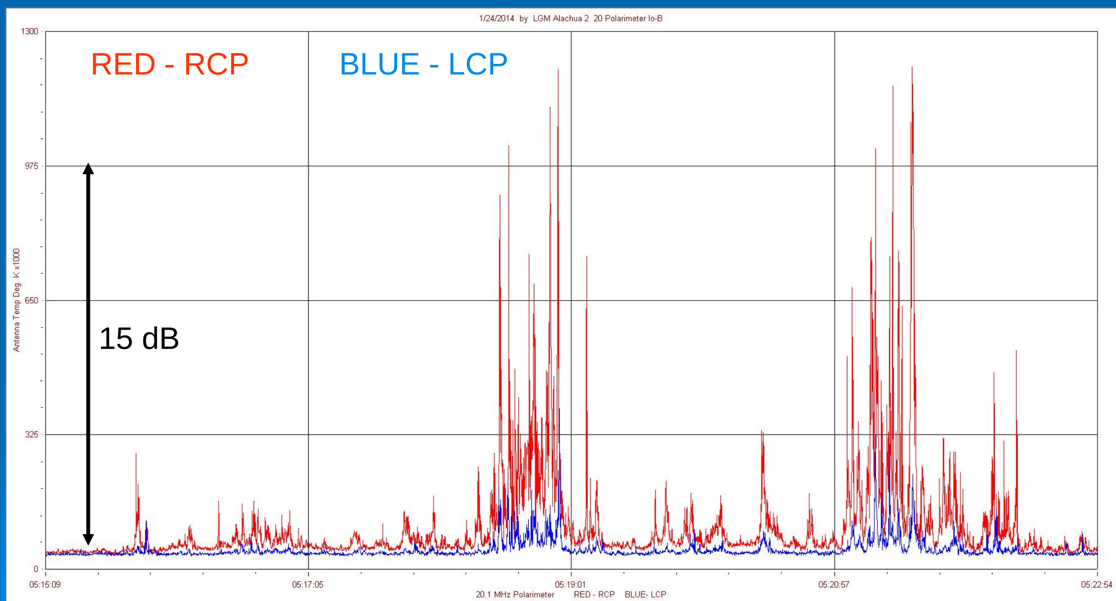
UFRO

Earlier we saw that you can generate a circular polarized wave with two crossed linears. Similarly you can combine two crossed linear antennas to receive the left and right hand circular components of an incoming wave. The cable arrangement shown on the left comprising a hybrid ring and an extra quarter wave cable produces the two circular components when fed with signals from two crossed linear antennas. The two ports labeled circular 1 and 2 are where you would connect two receivers – one for RCP and the other for LCP. I have not the slightest idea which port is left and which is right, as I have never gotten it right on the first try – ever. Nor do I know anyone that has. Fortunately Io-B emission from Jupiter is predominantly right hand polarized so it is easy to switch the labels after an Io-B storm when you know which is the RCP port.

On the right we see an 18 MHz polarimeter antenna at UFRO being aimed at Jupiter by two formerly young and handsome radio astronomers. The antennas are basically two 5 element linearly polarized Yagis.

What can we learn from polarization measurements?

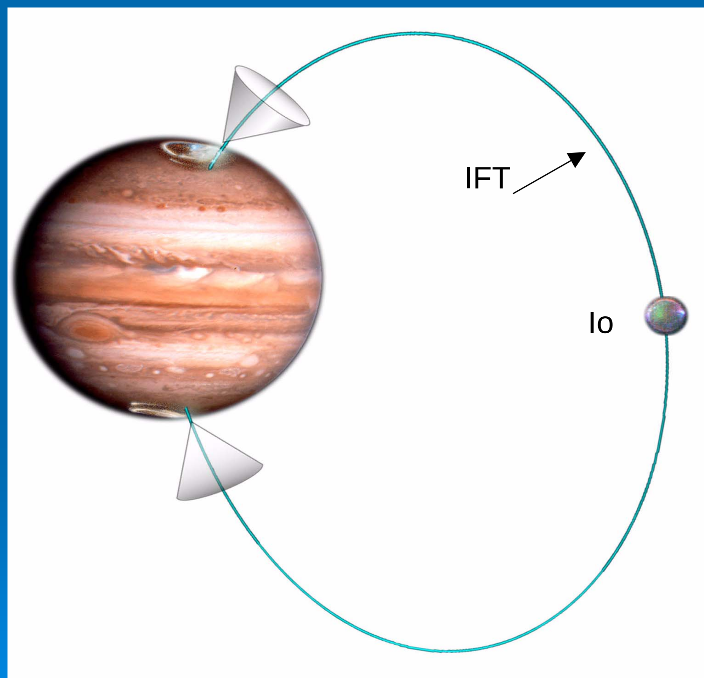
Io-B Polarization



LGM Alachua 1/24/14 Four dipole square array

Here is a polarization record by Wes Greenman who is using a 4 dipole square array and two Jove receivers. You can see that the RCP component is much stronger than LCP – typical of Io-B. Although most of us only use a single channel, SkyPipe can plot up to 8 channels simultaneously.

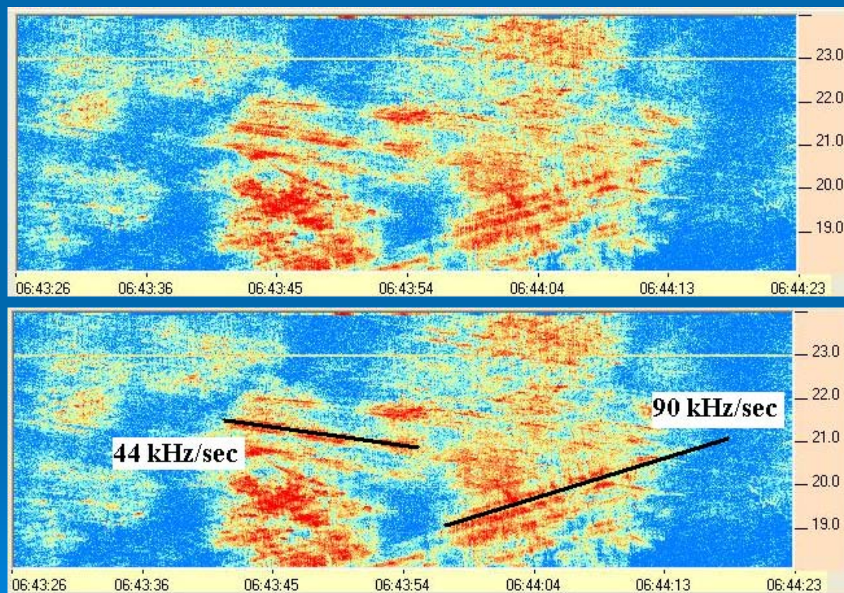
JUPITER AND IO



Without encroaching too much on Chuck's science talk I will simply point out that using polarization data we can probably determine from which hemisphere of Jupiter our signals are being emitted. Here we see Jupiter and the innermost Galilean satellite Io along with the Jovian magnetic field line passing thru Io. There is reason to believe that the emissions we are receiving are generated along this Io-threaded flux line – the IFT. Electrons gyrating around the field lines are the source of our signals and they gyrate in different directions near the two poles of Jupiter's magnetic field. So a source near one pole should radiate left hand and one near the other pole right hand emissions. In fact we see that Io-B is predominately right hand while Io-C is predominantly left hand polarized.

Next we will look at modulation lanes - a Jovian source phenomena first recognized by Jorma Riihimaa of Finland

Modulation Lanes, Io-B

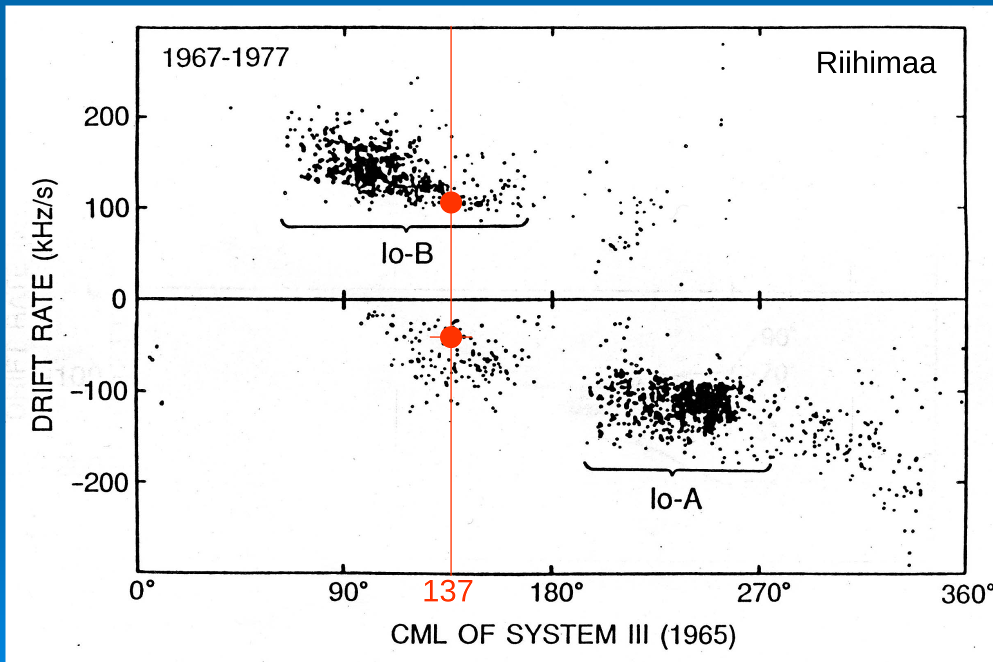


Feb 16, 2004 CML = 137 deg, Io phase = 100 deg

UFRO Images

The top and bottom panels are identical images showing diagonal modulation lanes imposed on L-burst activity. The bottom panel has been annotated with the measured drift rates of the modulation lanes. Riihimaa showed that the occurrence and drift rates of these diagonal features depend on the Jovian CML. Therefore modulation lanes are believed to be source related rather than a propagation phenomena. The spectrogram above was obtained when the CML was 137 deg - lets see how our drift rates compare with Riihimaa's measurements.

Modulation Lane Drift Rates



Plot from Riihimaa, Decametric Spectra of Jupiter Modulation Lanes Revisited 1993

Here we see Riihimaa's plot of modulation lane drift rates vs Jovian central meridian longitude. The 135 deg CML of our spectrogram is shown by the red vertical line. Positive and negative drift rates match quite well with the range of values mapped by Riihimaa.

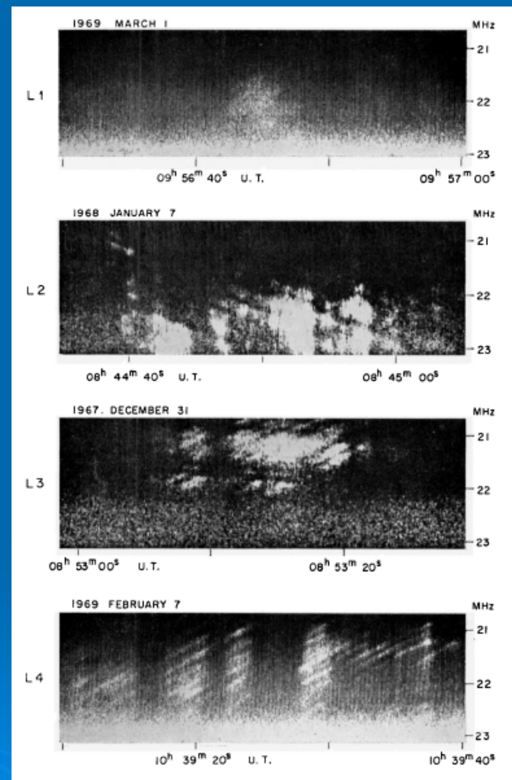
Lane Types

L1: No lanes

L2: Positive (low to high frequency)

L3: Both Positive and Negative

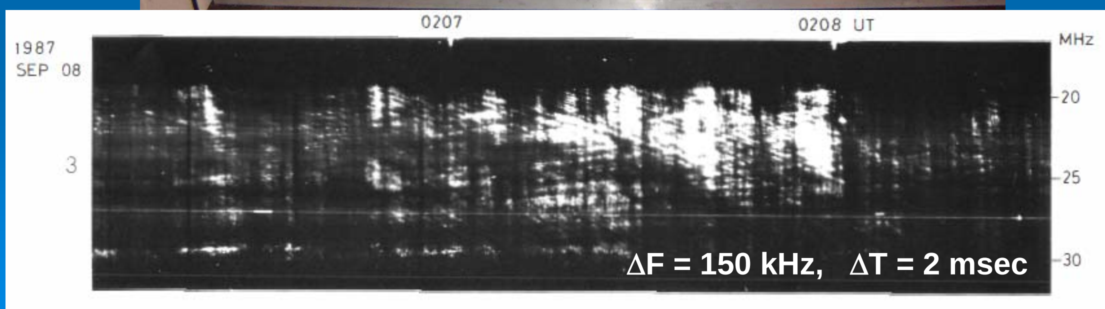
L4: Negative (high to low)



Astronomy & Astrophysics 4, 180-183 (1970)

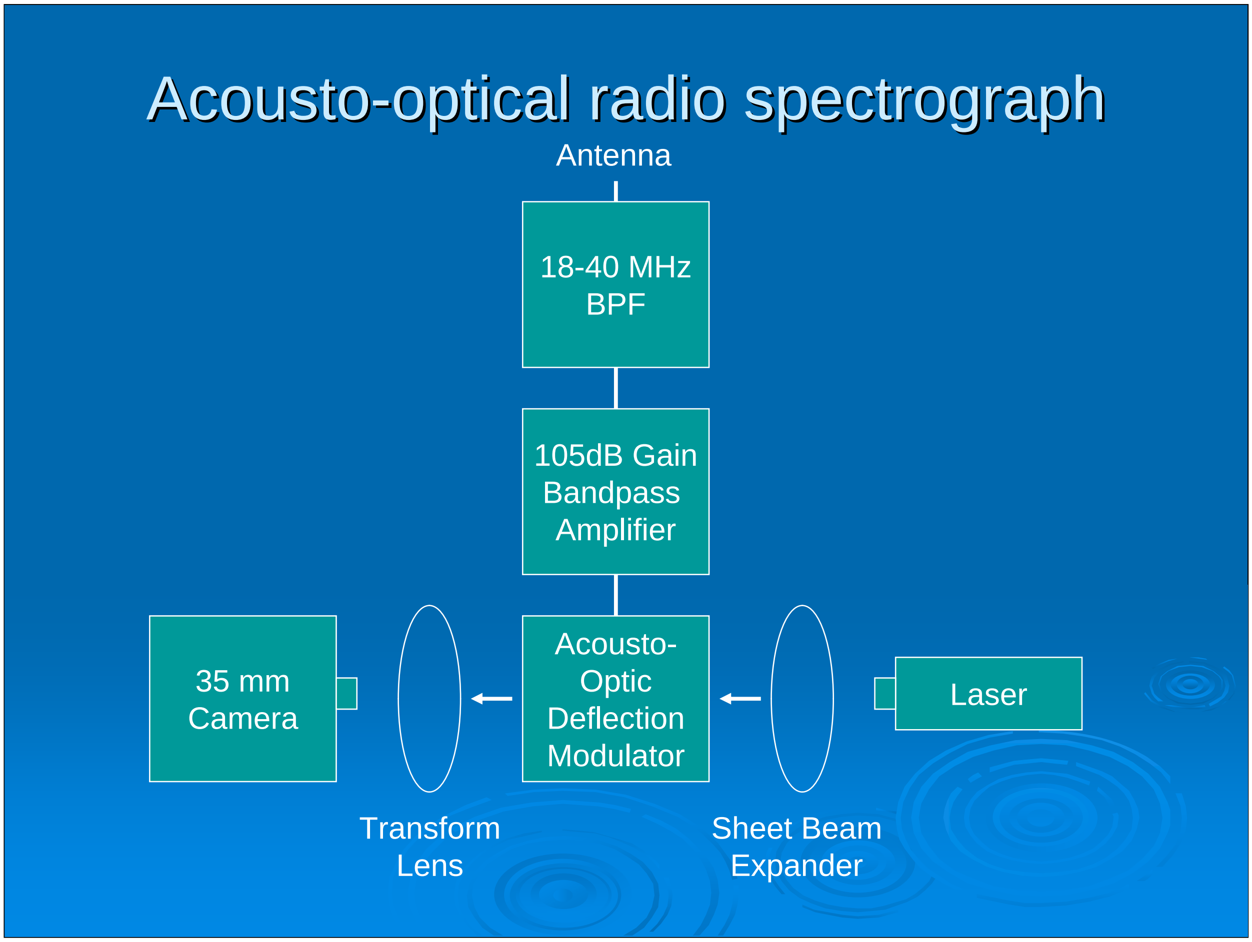
Riihimaa's modulation lane type designations. L1 thru 4 are for L – bursts, and S1 thru S4 are for S-bursts. Note the upside down vertical axis with the low frequency at the top and high frequency at the bottom. This is opposite to the display convention used by the FSX and Jim Sky's RSS software. However the naming conventions are still valid.

Acousto Optic Spectrograph

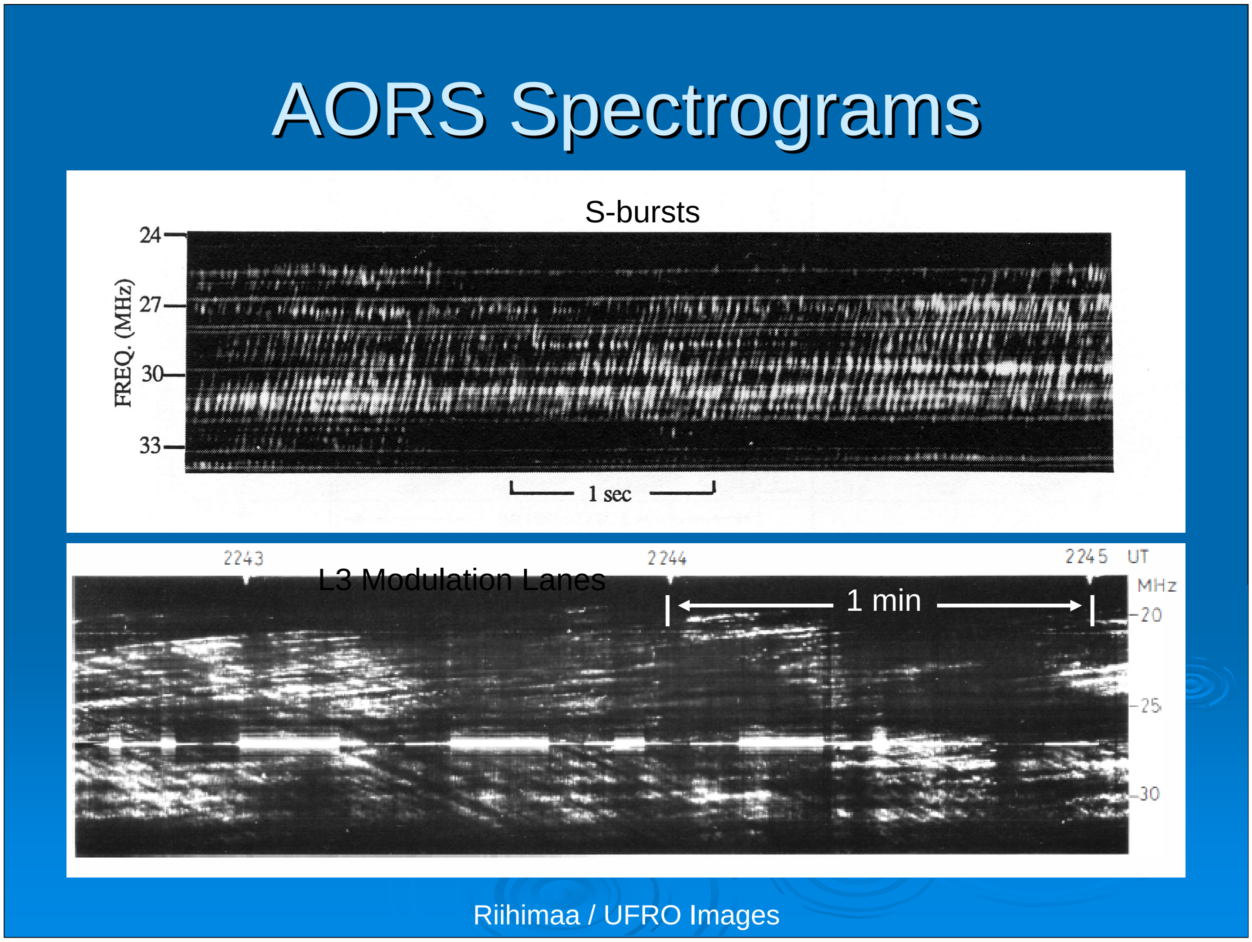


Riihimaa / UFRO Images

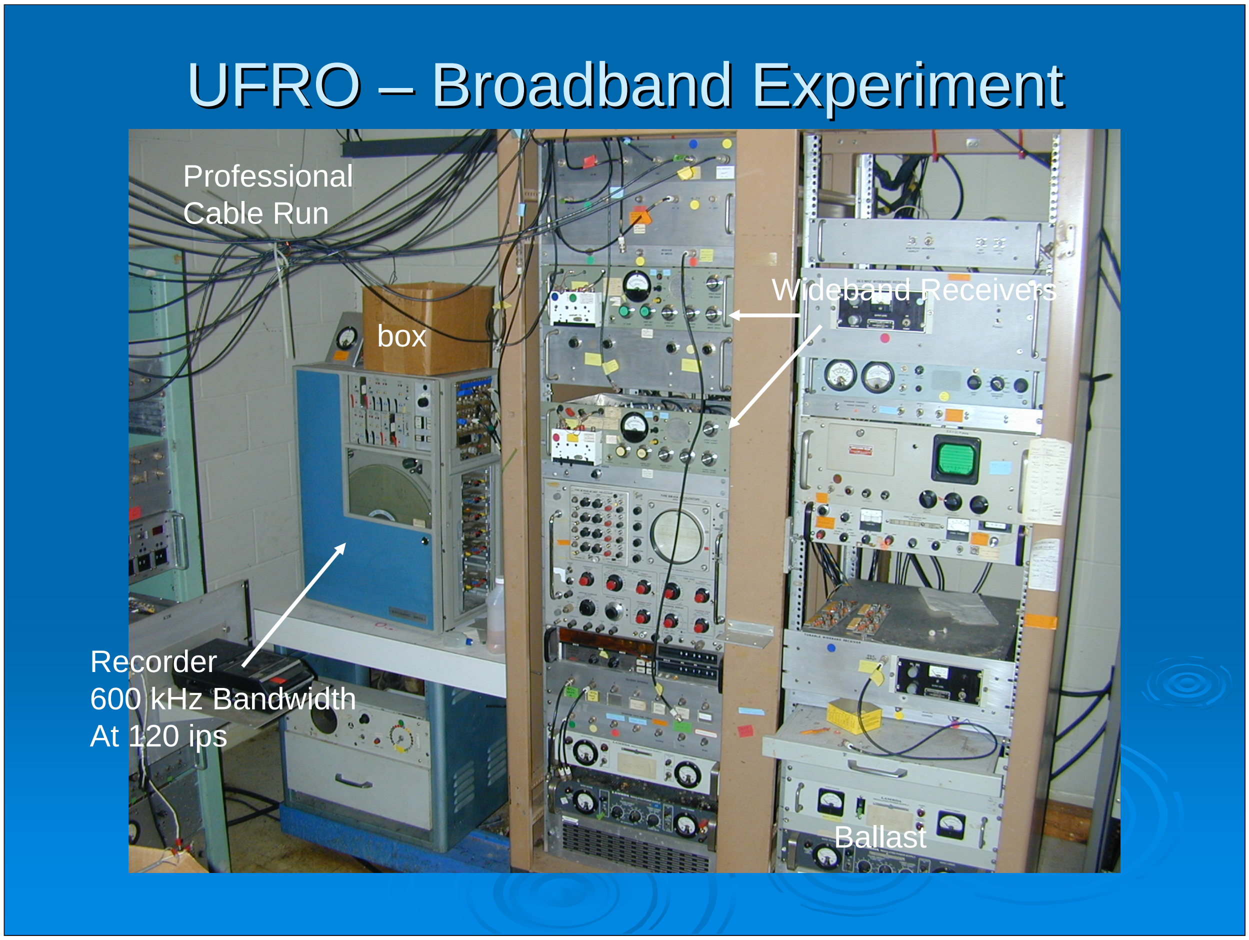
Many of Riihimaa's later observations were conducted using an instrument called an acousto optic spectrograph. One of Jorma's favorite comments about this instrument was "Don't laugh – it works". The AORS predated the FSX by several decades. Although it does not have very high time and frequency resolution it is well suited to observe many of the spectral features of Jupiter.



The RF section of the AORS is simply a bandpass filter and a high gain wideband RF amplifier. The RF amplifier feeds an acousto-optic deflection modulator where the wideband radio signal is converted into ultrasonic pressure waves across an optical aperture illuminated by the laser beam. The pressure waves act as a phase grating for each frequency present. This modulator also known as a Bragg Cell, simultaneously amplitude modulates and spatially deflects the laser beam thru an angle proportional to the frequency of the RF signal – producing the desired spectrogram. The modulated laser beam exiting the Bragg cell is aimed at a moving film strip to capture the time history of the spectral information – forming a familiar waterfall display. If the laser beam exiting from the transform lens falls on a wall or white piece of paper in place of the camera what is seen is a red horizontal line with bright spots at each location corresponding to the frequency of a radio station. By place a photodiode, driving an audio amplifier and headphones on the bright spot on the wall you can listen to the radio station. Good fun -

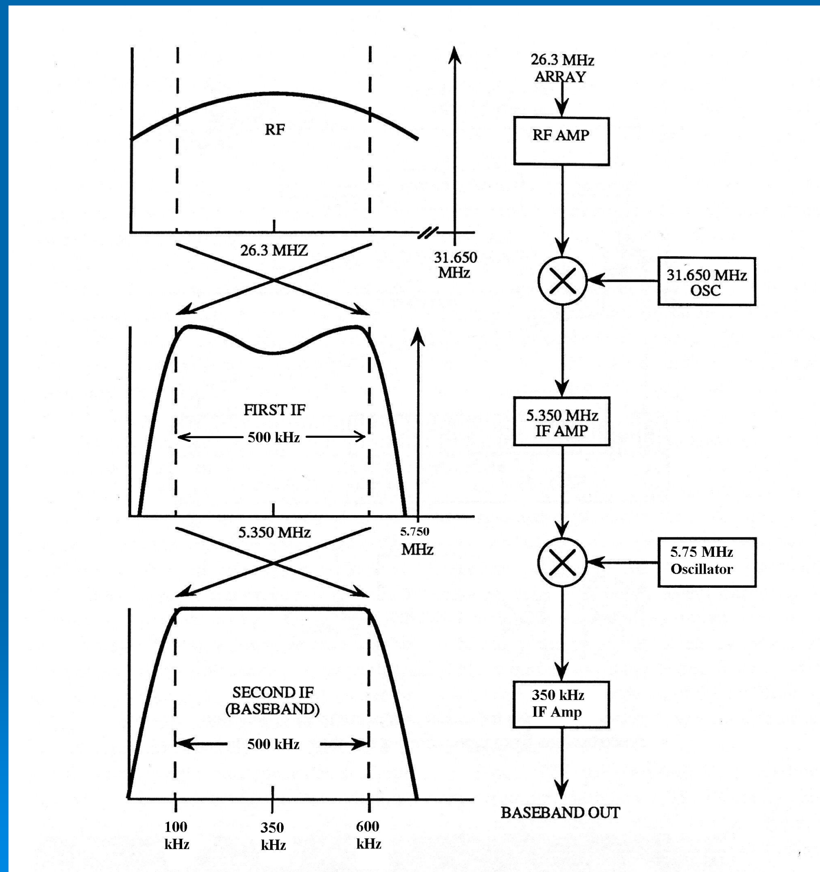


More of Riihimaa's AORS spectrograms. The bottom panel shows nice examples of L3 type modulation lanes with the annoying citizen's band interference at 27 MHz. Looking at the S-bursts in the top panel we see that there are dozens of these bursts per second drifting from high to low frequencies. The desire is of course to look at S-bursts in greater detail –with higher resolution in both the time and frequency domain.



The University of Florida along with other groups developed techniques to study S-bursts in high resolution. At UF this technique entailed heterodyning a chunk of RF spectrum down to baseband where it could be recorded with a high speed instrumentation tape recorder. The tape was then slowed down on playback which translated the RF spectrum down to an audio band, much expanded in time. Spectrum analysis was then performed using an audio spectrum analyzer.

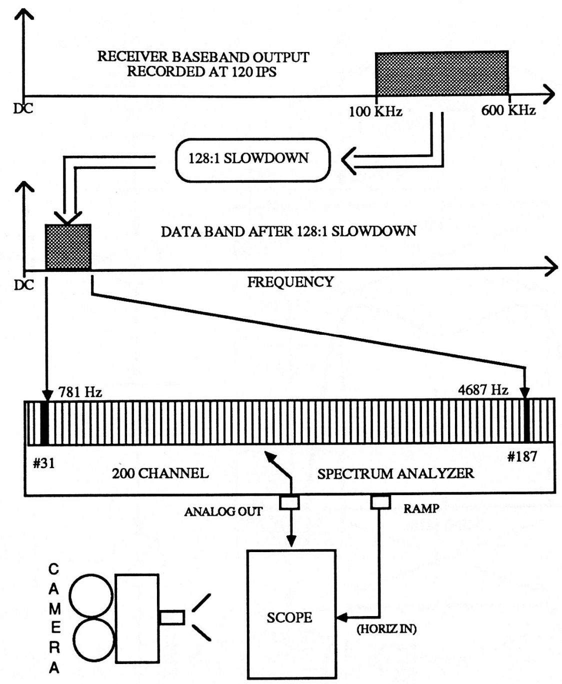
Tape Slowdown System Receiver



The purpose of this receiver is to translate (or heterodyne) a 500 kHz wide chunk of the RF spectrum centered at 26.3 Mhz down to baseband.

It's a double conversion receiver with a 5.35 MHz 1st IF and a 350 kHz 2nd IF. The 2nd local oscillator running at 5.75 MHz lays 100 kHz off the IF band edge – a wide enough margin to insure good image response. There is no detector. The 500 kHz wide 2nd IF signal extending from 100 to 600 kHz is recorded on the high speed tape recorder. After a few years using this 500 kHz wide system Wes Greenman built a 1.3 MHz bandwidth receiver for use with a wider bandwidth tape recorder. Some of the spectrograms you will see were obtained with that receiver.

Tape slowdown (2)



At the top we see the 500 kHz wide band extending from 100 kHz to 600 kHz – this is the 500 kHz wide piece of RF spectrum centered at 26.3 MHz translated down to baseband. The next step is to play this data back at a low tape speed – yielding a slowdown of 128:1. This slowdown reduces the100 to 600 kHz band to 781 to 4687 Hz and expands the time scale so that every second of data takes over 2 minutes to play. A 200 channel audio spectrum analyzer intensity modulates the horizontal beam of an oscilloscope which is photographed by a shutterless motion picture camera. All this to produce a waterfall display with a time resolution of 300 microseconds and a frequency resolution of 3 kHz.

AORS & Hi-Res Tape Slowdown

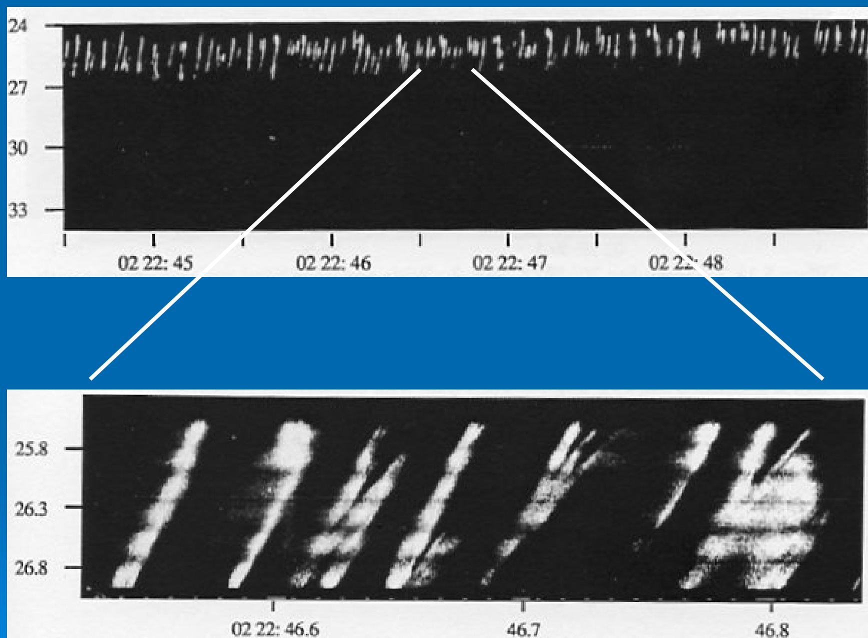
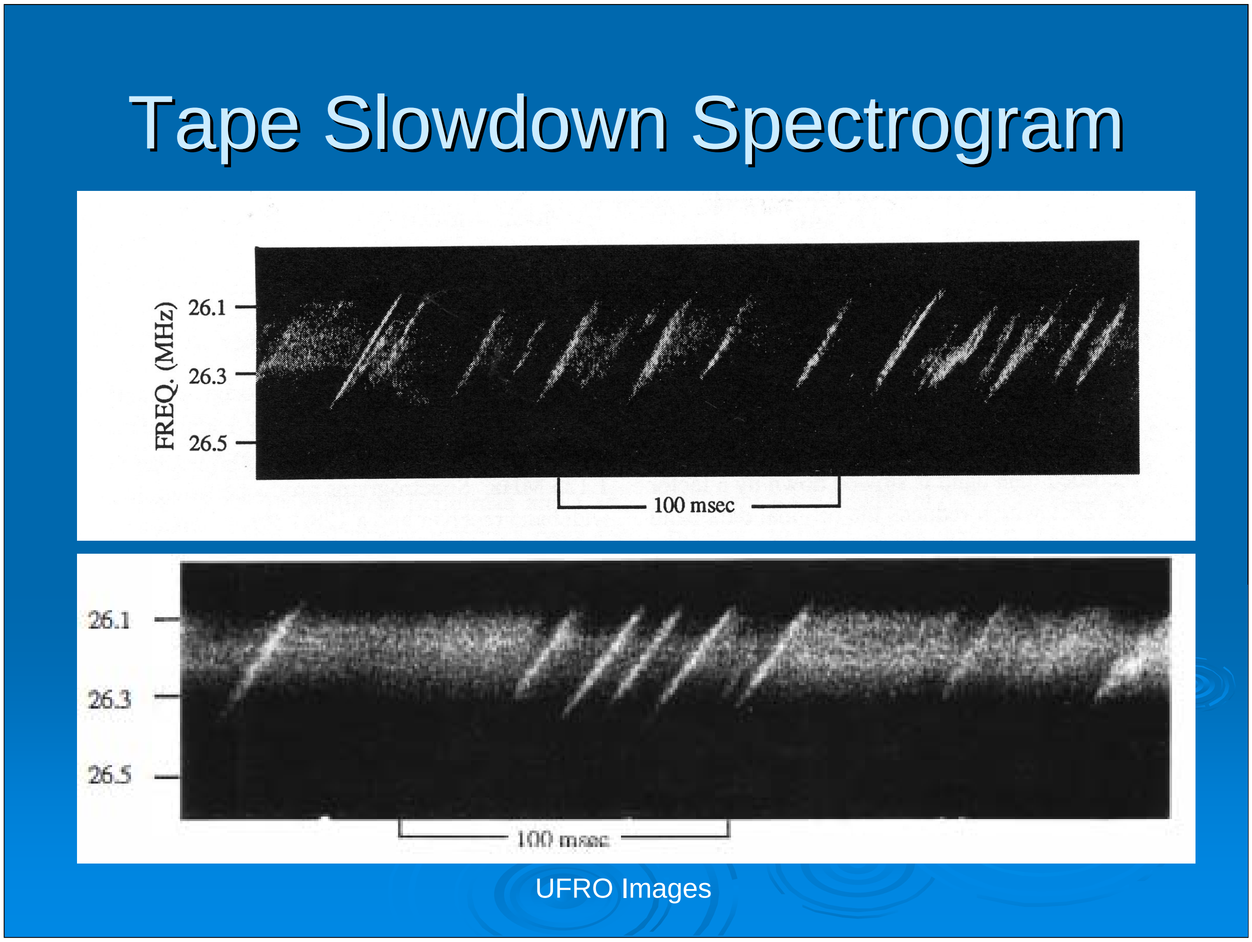


Plate 5.18.8 December 20, 1988 Seg. 8. Wide emission band, multiple split S-bursts, interactions and weaker Faraday lanes.

UFRO Images

The tape slowdown spectrograph shows a significant improvement in resolution – here we see an event viewed with both the AORS and the UFRO instrument. Both views are useful – with the high res data viewed in the context of the lower resolution “big picture”. Now we are beginning to see details of individual S-bursts.

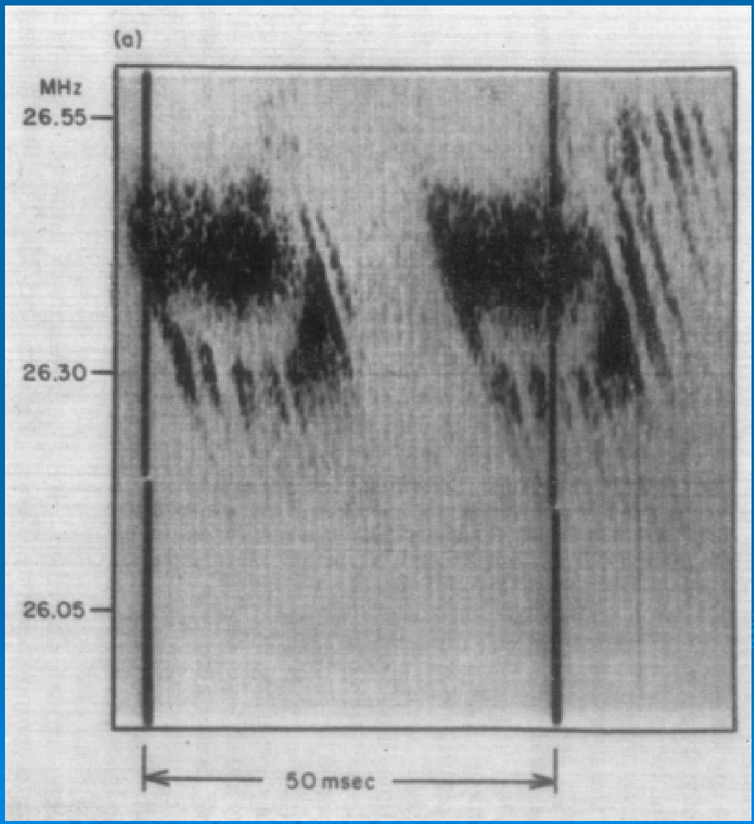


Notice the frequency axis is still upside down in keeping with early convention. The tape slowdown process is allowing us to see much more detail than the AORS –but over a narrower frequency range. Isolated S-bursts in the top panel and an interesting interaction between S-bursts and an N-event in the bottom panel. The S-bursts appear to cast a shadow as they pass thru the N-event.

Dolores Krausche did her doctoral work analyzing thousands of slowed down S-bursts at UF. After perhaps too many hours in the lab she began to name individual S-bursts.

Images from: A Catalog of High Resolution Jovian decametric Radio Noise Burst Spectra, Flagg, Greenman, Reyes, and Carr. University of Florida 1991

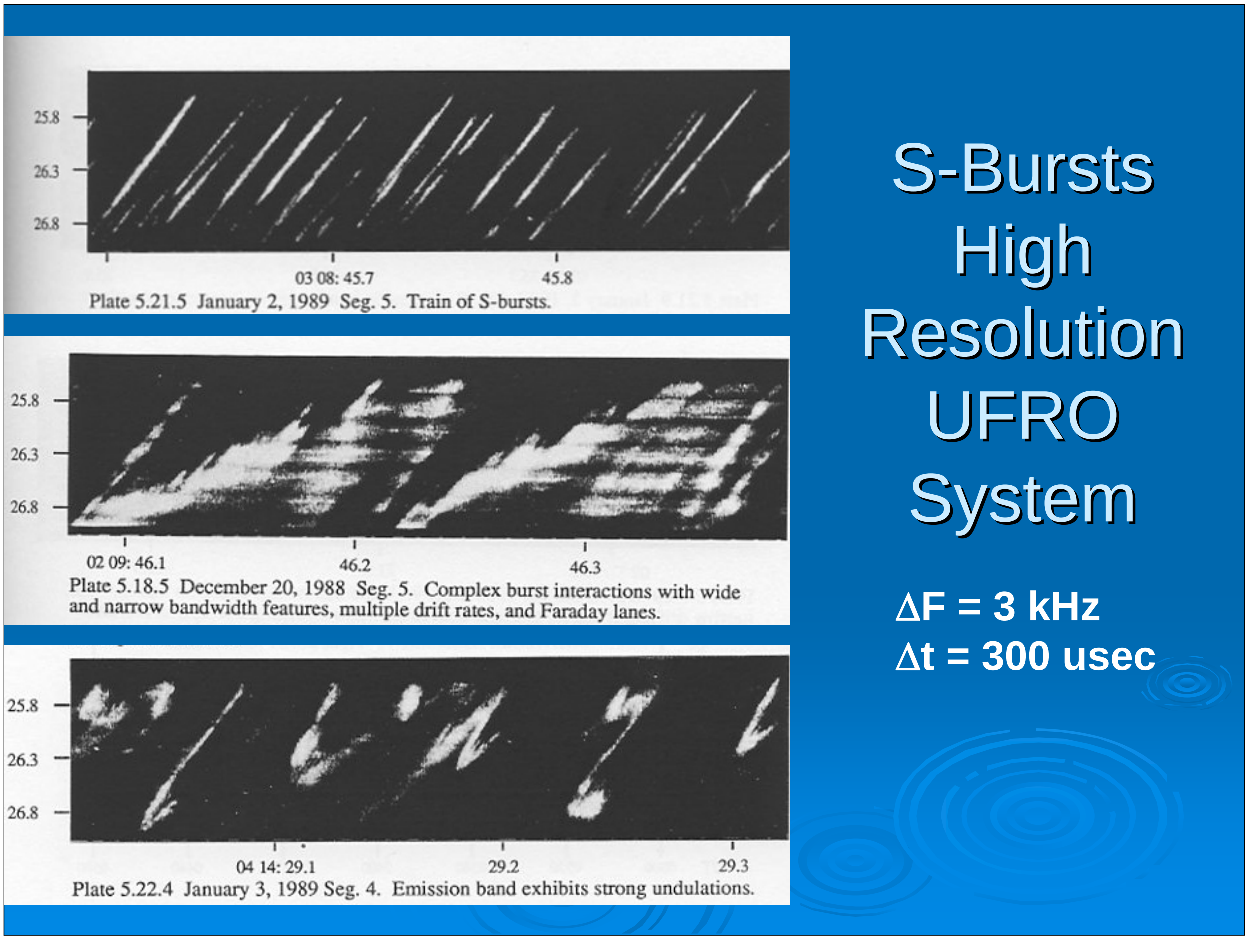
The Bear Tracks



Krausche et al 1976 UFRO

A pair of bursts with amazingly similar characteristics. The short narrow drifting bursts occur at an exceptionally high rate of several hundred per second.

Image from High Resolution Spectral Analysis of the Jovian Decametric Radiation, Krausche, Flagg, Lebo, Smith, ICARUS 29, 463--475 (1976)



And a few more images from the UFRO high resolution zoo. Unfortunately the UFRO observatory has been out of operation for some years now. Recently however Dave Typinski, Wes Greenman, and I have built a new instrument to study Jovian emissions in high resolution.

Images from: A Catalog of High Resolution Jovian decametric Radio Noise Burst Spectra, Flagg, Greenman, Reyes, and Carr. University of Florida 1991

A New High Resolution Spectrograph

But we have to wait for those details in a later talk.

Wideband Antennas

A radio spectrograph is not much good without a wideband antenna.

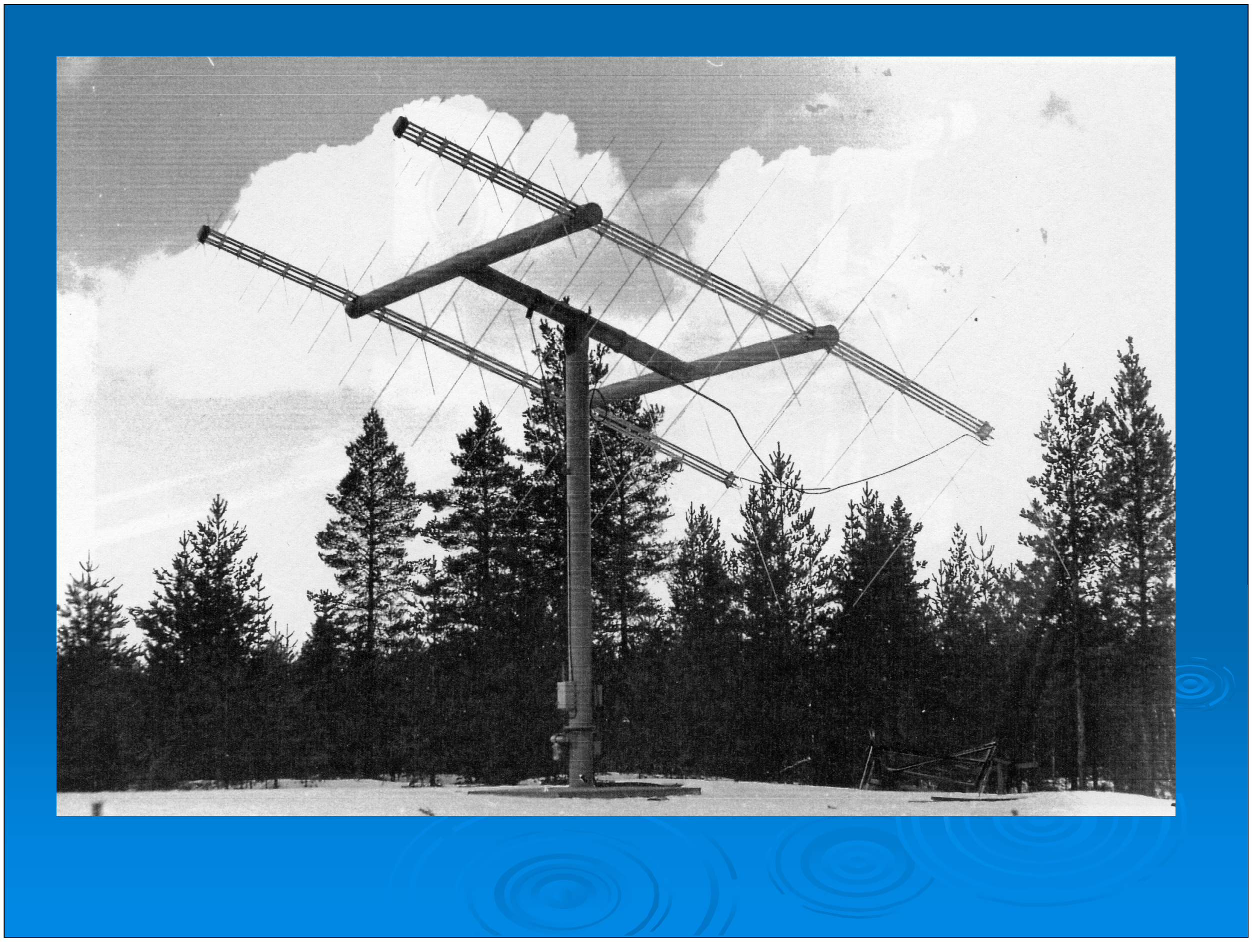
The Jove dual dipole array – easy to erect with a little help. While it is cut for 20 MHz operation it is usable with a spectrograph over as much as 4 MHz.

The 17-30 MHz M2 log-periodic antenna at WCCRO. Unfortunately the 7 dB gain is a bit low for Jupiter but the antenna works well for solar bursts.

UFRO Images

The University of Florida TP antenna array produced spectacular results and was circularly polarized so Faraday fringes were seldom seen. There were 8 RCP and 8 LCP TPs with each array developing about 13 dBic gain from 10 to 40 MHz

A huge right hand circular helix – likely erected by Riihimaa in Finland



Riihimaas steerable, dual, cross polarized, Log-periodic antennas.

Nancay

The Nancay TP array. 144 antennas , 72 right hand and 72 left hand. Each polarization array effective area is 4000 square meters. Frequency range is from 10 to 100 MHz. Gain is 25 dBic.

Ukraine – UTR2

Ukranian T Radio Telescope second modification (UTR-2) comprises 2040 elements arranged in the form of a T. The effective area is 150,000 square meters with a beamwidth at the zenith of half a degree. Frequency range is 8 to 40 MHz.

UTR-2

Another view of the UTR-2.

LWA (long wavelength array)

Here we see an LWA wideband, dual polarization, droopy, dipole antenna.

LWA

LWA-1 New Mexico near the VLA 256 antenna elements

And a field of 256 antenna elements near the VLA.

In conclusion I would like to show just one more spectrogram.

Dave, I just couldn't wait till your talk on the tuneable wideband receiver and its high resolution spectrograms.

Its just too important a discovery to wait any longer –

And so presented here for the very first time – proof of intelligent extraterrestrial life - - -

The road runner lives (on Jupiter)