Observations of Jovian Emissions by Multiple Spaced Radio Spectrographs

By:
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With data from Wes Greenman, Dave Typinski and Andrew Mount

Fifty-eight years ago, scientists Bernard Burke and Kenneth Franklin at first mistook radio signals from Jupiter for a Maryland farmhand driving home after a late date (Weintraub, 2005**)**. Since their discovery, thousands of hours have been devoted to the study of the radio emissions of Jupiter.

There are two types of radio noise bursts, long L-bursts, which sound like ocean waves breaking up on a beach, and short S-bursts, which sound like a handful of pebbles tossed onto a tin roof. Both L and S-burst activity are broadband – often covering several hundred kilohertz of bandwidth or more. Less frequently observed are N-events which undulate slowly in frequency and span only a few 10's of KHz in bandwidth.

The location of Jupiter's moon Io in its orbit plays a significant role in Jupiter emissions, influencing the Io-A, Io-B and Io-C emission regions (Fig.2). There are also areas called Non-Io-A, Non-Io-B and Non-Io-C (Fig.1), in which Io appears to play no significant role.

Jupiter emissions can be heard using equipment as simple as a shortwave receiver and a dipole antenna or as complicated as hundreds of antennas connected to a sophisticated receiver. Jupiter emissions can be received on the earth's surface over a wide range of frequencies – typically from below 15 MHz to almost 40 MHz. The lower frequency limit is caused by the ionosphere. Using a single frequency receiver and trying to describe a Jupiter storm is like trying to describe a rainbow after seeing only one color. Since Jupiter emissions can span a dozen or more MHz in a storm, it is advantageous to observe more than one frequency at a time using an instrument called a radio spectrograph.

The spectrograph allows us to see the entire span of Jupiter emissions that make it through the Earths atmosphere. James W. Warwick of the University of Colorado made use of a spectrograph in studying Jupiter emissions as early as 1960. Jorma J. Riihimaa made use of a spectrograph to study Jupiter in 1963. A spectrograph was utilized at the University of Florida in their on going Jupiter studies as early as the mid 1960's.

The spectrographs used in this paper allow observations from 17 – 30 MHz and were custom built by Dick Flagg. It is a model FS-X and a block diagram of it is presented at the end of this paper.[i] Currently, there are four spectrographs observing Jupiter events in the same time zone. Myself, HNRAO (Hawk's Nest Radio Astronomy Observatory), Wes Greenman, (LGM Radio Alachua), Andrew Mount, MRAO (Mountain Radio Astronomy Observatory) and Dave Typinski (AJ4CO) (Fig. 4 - Observatories).

The software used with the spectrograph is called Radio Sky Spectrograph (RSS)[ii]. This software is unique in that it allows you to stream your spectrograph data via the internet so that someone else using the same software can observe your spectrograph remotely.

One problem with operating a spectrograph over a wide frequency range is that one must use a wideband antenna. Surprisingly, a standard Jove dual dipole array cut for 20.1 MHz. is adequate for operation over a range of about 4 MHz. In order to increase the frequency coverage Hawk's Nest also uses a pair of 24 MHz dual dipoles which are power combined with the JOVE dipoles[iii]. This combination of dipoles operates quite well from 18 to 28 MHz.

Wes Greenman in Alachua, Florida and Hawk's Nest would often observe the same Jupiter storm using similar spectrographs. Wes was using the standard Jove array. We immediately noticed that spectrograms from the two instruments often looked very different. Jovian noise burst present at one station might not appear at all at the other station – and if they did appear they were often much stronger or weaker, and sometimes they looked very different in terms of frequency structure. Further comparisons of all four spectrographs showed that none of us were seeing the same things at the same time. Fearing a problem with my new array, I spent considerable time checking and double checking the array searching for a physical problem that would account for the discrepancies.

During one of our many communications, Dick Flagg and I started discussing why there were dramatic differences between the spectrographic results between myself; Wes, Andrew and Dave (see comparative spectrographic image sets 1 through 7 below). Wes and Dave live only a few miles from each other near Gainesville, Florida, Andrew is in NW South Carolina, while I'm in Southwestern Pennsylvania. Since we are all using nearly identical spectrographs and all using JOVE dipole arrays, baring local interference issues, I expected to see nearly identical results.

During the conversation, the ionosphere and its role in Jupiter radio emission observations came up. As Dick pointed out, it's been understood for some time that while one observer will hear Jupiter emissions, someone else listening at the same frequency at the same time might not hear anything. He made the analogy that if two people were observing the same star from two different locations, they would both observe the star twinkle (scintillate), but that they wouldn't see it twinkle the same way at the same time from both locations.

We know that L-Bursts, for example, exhibit the characteristic "ocean wave" sound because of interactions between the burst and the interstellar medium (Riihimaa, J. J. 1978). Louis Pataki (1966) made a report on Jupiter L bursts regarding this phenomenon. "Early two station observations led to the discovery that the L-pulses are caused by a diffraction phenomena in the interplanetary medium. Phase variations introduced in the radiation by clouds of electrons between the earth and Jupiter lead to amplitude fluctuations in the observed flux. These fluctuations are the L-pulses.” In his paper (Pataki, 1966), he reported, “We observe radiation for the planet Jupiter after it has traversed the medium between the source and our receivers. We observe amplitude scintillations, L-pulses, in our records at the three stations.” Simply put, the characteristic “ocean wave” sound L-Bursts make are the result of the velocity factor[iv] of the interstellar medium as the wave travels from Jupiter to Earth and passes through clouds of electrons trapped in the magnetic field lines between Jupiter and Earth.

This explains the characteristic “ocean wave” sound, but why the differences between the observers? All things being equal, the only explanation is that there is another factor involved, and evidence points to the ionosphere, and a phenomenon called ionospheric scintillation.

An early reference to this is in a dissertation,” Analysis of the Decameter-Wavelength Radio Emission from the Planet Jupiter.” (Six, 1963) Six describes simultaneous observations of Jupiter from the University of Florida observatory and a remote site in Chile. He shows times when one observatory was hearing Jupiter emissions while the other was not and also the reverse. Six (1963) stated, “The influence of the terrestrial ionosphere must be classified as one of the unsolved questions. From high speed recordings taken at the stations in Florida and Chile at the same frequencies, it is obvious that the ionosphere is altering the pulse structure.”

J. J. Riihimaa (1968) in his paper, “Spaced-Spectrograph Observations of Jupiter's Decametric Emission”, describes two identical spectrographs 43.5 miles apart in Florida. It is important to note that Riihimaa used circularly polarized antennas for this experiment. He reported negligible Ionospheric Scintillation in his observations when comparing the spectrograph results from the two observatories (Fig. 3). He (Riihimaa, 1968) states, “The fact that at least 95 per cent of the structural details correspond at the two stations strongly suggests that the terrestrial ionosphere has a negligible effect on the spectral fine structure of a circular component of Jupiter's decametric bursts. There appears to be only a slow non-correlated scintillation, having periods from approximately 1 min to several minutes.”

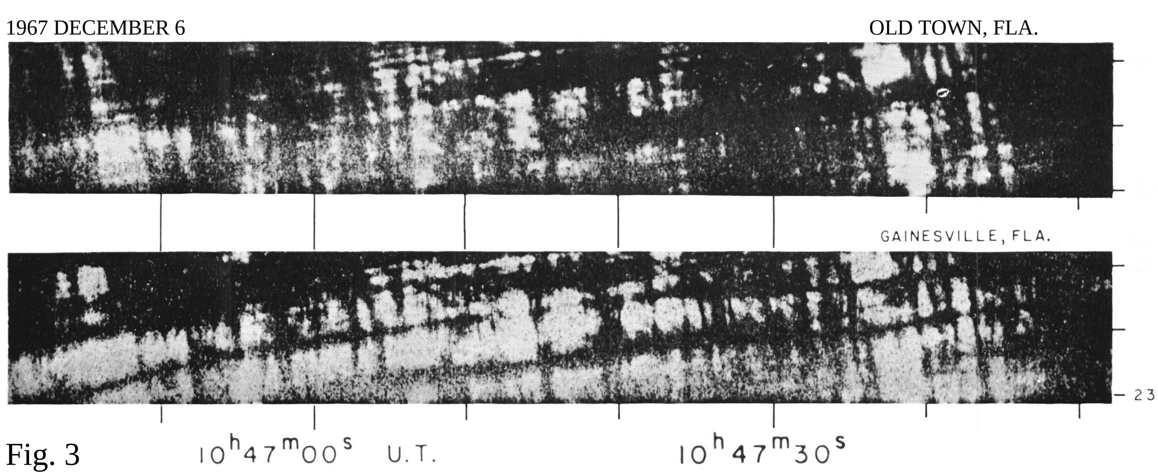


Fig. 3

Riihimaa (1978), modified his earlier statement that the “terrestrial ionosphere has negligible effect” when he wrote, “L-bursts in Jupiter's decametric radio spectra”, “that in certain years, when Jupiter can be observed due north-west and north-east (while the altitude of the planet is not very high), pronounced affects of ionospheric scintillation are to be expected in the Jovian record.” And, this affect is not limited to Jupiter, but to decametric radio astronomy in general. Riihimaa (1978) points out that the same ionospheric scintillation was seen in decametric observations of Cass A.

It appears, then, that the cause of the differences seen at the different observatories is due to variations of the index of refraction of the ionosphere. In the paper, “Ionospheric Electron Density Profiles Obtained with the Global Positioning System” (Hajj and Remans, 1997), state, “In the ionosphere, the index of refraction is related to electron density.” So, the amount of refraction is determined by the electron density of the ionosphere between the observer and Jupiter. And, it appears to be a “localized” affect. Further, the amount of refraction is affected by solar activity. Higher solar activity results in a greater refraction. The paper (Hajj and Remans, 1997) also states, “Very sharp variations of bending are associated with sporadic E layers.”

At the University of Illinois at Urbana-Champaign, College of Engineering, researchers have been studying this phenomenon. They observed (UIUC, 2009), “High up in the ionosphere, plasma bubbles invisible to the naked eye wreak havoc on communication and navigation systems back on Earth. Instabilities in the bubbles often cause over-the-horizon radars to either lose signals or to register readings from different regions than where they should be looking. GPS receivers can fail as these structures pass overhead. Scientists, who have been studying the phenomenon for decades, are stymied about why the bubbles develop one night but fail to materialize under similar conditions the next night.”

The Australian Bureau of Meteorology describes it as ionospheric scintillation. They characterize it as (ABM, 2013), “a rapid fluctuation of radio-frequency signal phase and/or amplitude, generated as a signal passes through the ionosphere. Scintillation occurs when a radio frequency signal in the form of a plane wave traverses a region of small scale irregularities in electron density. The irregularities cause small-scale fluctuations in refractive index and subsequent differential diffraction (scattering) of the plane wave producing phase variations along the phase front of the signal. As the signal propagation continues after passing through the region of irregularities, phase and amplitude scintillation develops through interference of multiple scattered signals.”

They go on to address the impact of ionospheric scintillation. “Ionospheric scintillation affects trans-ionospheric radio signals up to a few GHz in frequency and as such can have detrimental impacts on satellite-based communication and navigation systems (such as GPS-based systems) and also on scientific instruments requiring observations of trans-ionospheric radio signals (e.g. radio-astronomy).”

Conclusions:

A great deal of research into ionospheric scintillation has been done since the Riihimaa observations in 1967. While the observations presented in this paper are not the first to observe ionospheric scintillation in Jupiter emissions, with advances in electronics and technology, they are considerably clearer and more detailed than the Riihimaa spectrographs.
Optical scintillation (the twinkling of a star or planet) occurs in the neutral atmosphere while radio scintillation occurs in the ionosphere in areas of high electron density. We can think of these areas of high electron density in the ionosphere as blobs or bubbles. Since there is no way to accurately predict when and where these bubbles will occur, it's impossible to gauge the affect it will have on the observations of Jupiter from any given observatory on any given night. The affects of these bubbles in the ionosphere can create a dramatic difference in Jupiter emissions from one location to the next. The affect is not emission dependent as it was seen to occur in L-bursts, S-bursts and N-events.

Ionospheric scintillation should be kept in mind when comparing Jupiter observations from different stations. If you are confident of your antenna and receiver system, and are not hearing Jupiter, when another station is, you may just be the victim of ionospheric scintillation. While the detailed burst structure may vary from station to station in terms of frequency and amplitude it is likely that over a period of several minutes all stations will receive some bursts during a Jupiter storm.

This also suggests that to get a clearer picture of Jupiter emissions, we either need to get above the ionosphere to observe, or establish a full time network of widely spaced spectrographs. As long as the private observatories mentioned in this paper continue to operate, we effectively have accomplished that. In the future, perhaps software could be developed that would be able to combine the data from the spectrograph network to provide a unified display.

Below are the results of observations taken of the same events, on the same nights, using nearly identical spectrographs and similar antenna systems. The comparisons are between HNRAO, LGM Radio Alachua and MRAO. This is the first time it's been possible to compare spectrographic data from widely separated observatories to see this phenomenon of ionospheric scintillation.

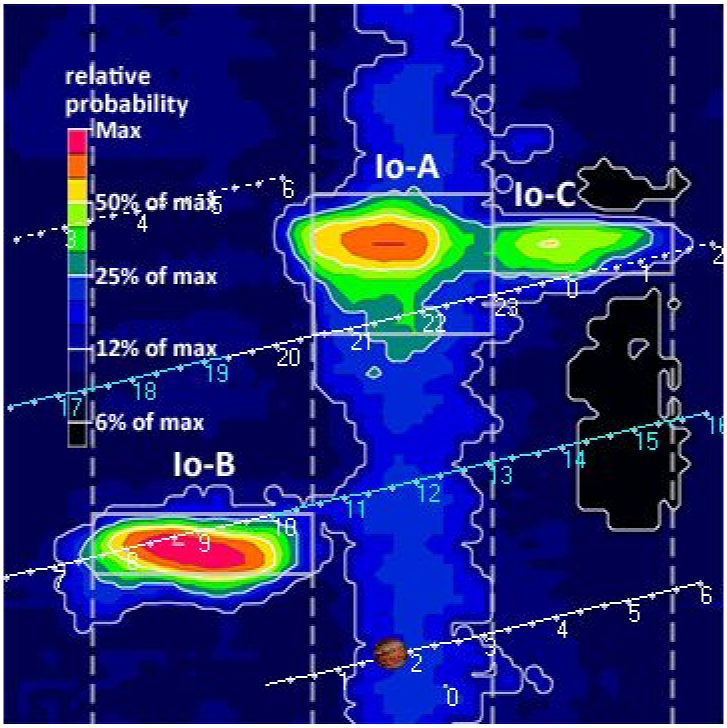
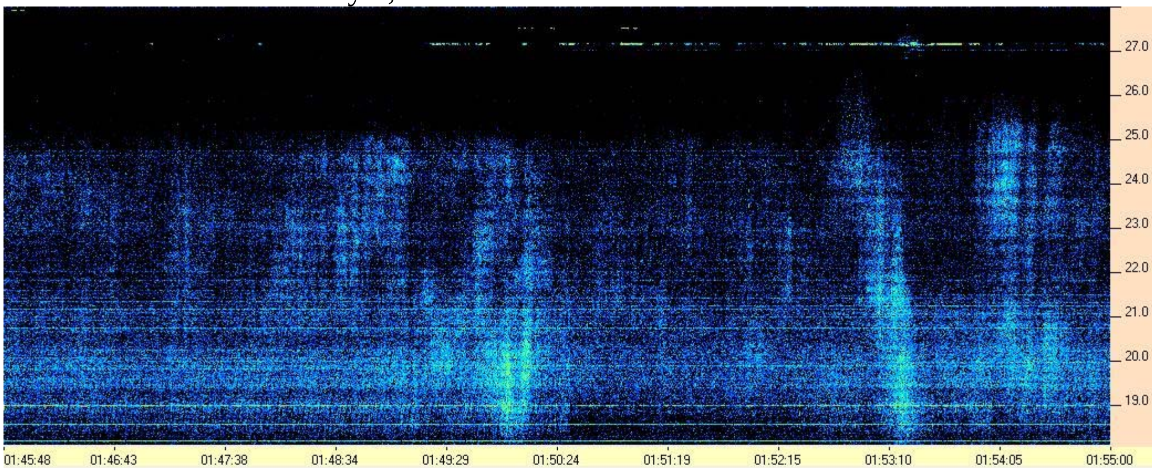


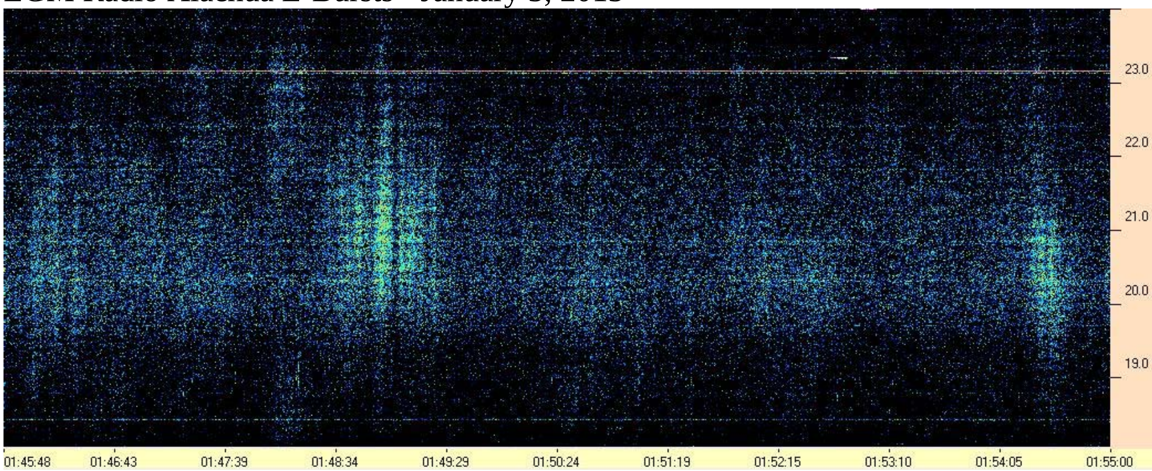
Fig. 1 - This is the Radio Jupiter Pro display of the location of Jupiter during the January 3, 2013 Non-Io-A event.

In the images below, the observatory/spectrograph source is indicated at the top left of each image. Time is in UT in the horizontal scale, frequency in MHz in the vertical.

HNRAO L-Bursts - January 3, 2013



LGM Radio Alachua L-Bursts - January 3, 2013



MRAO L-Bursts - January 3, 2013

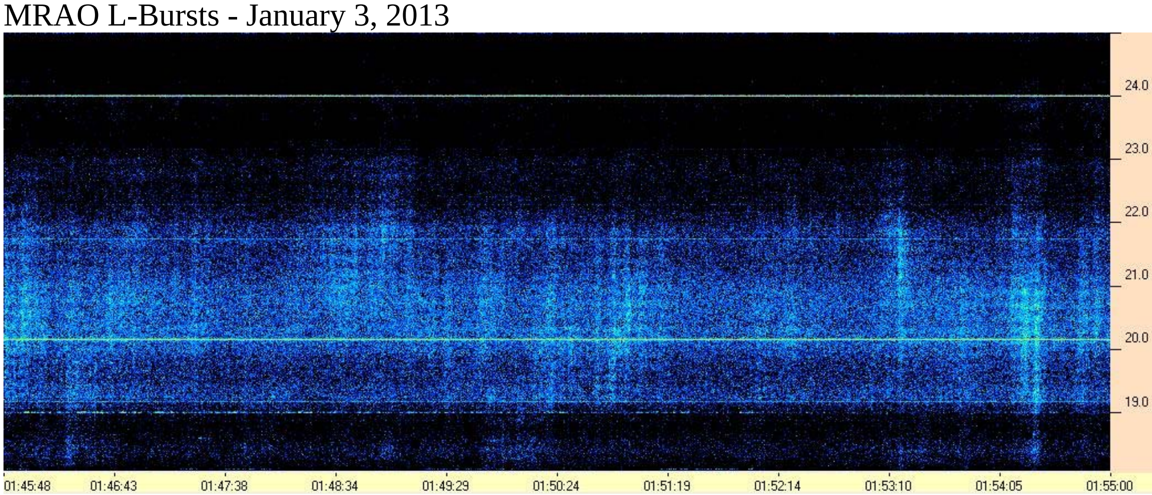
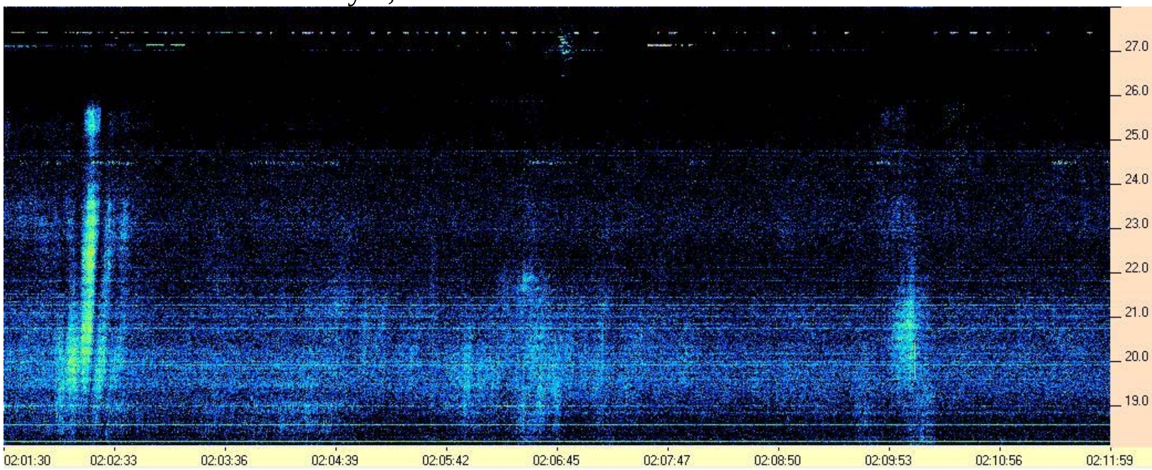
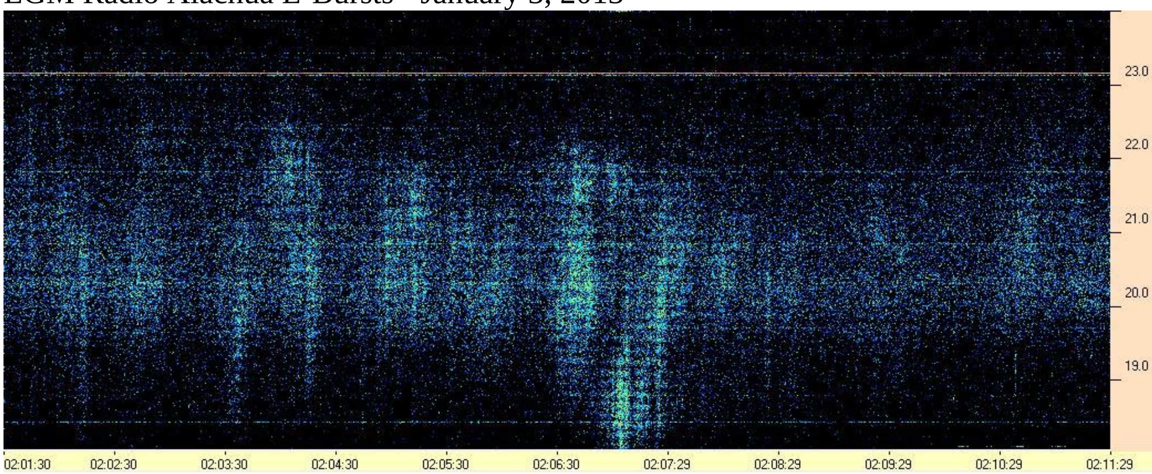


Image set 1. A strong burst at 0148 UT by LGM is hardly seen at HNRAO and MRAO. HNRAO has a strong burst at 0150 UT & 0153 UT that was not seen at LGM with the 0153 UT event just registered at MRAO. All three observatories saw the 0154 UT event to some degree.

HNRAO L-Bursts - January 3, 2013



LGM Radio Alachua L-Bursts - January 3, 2013



MRAO L-Bursts - January 3, 2013

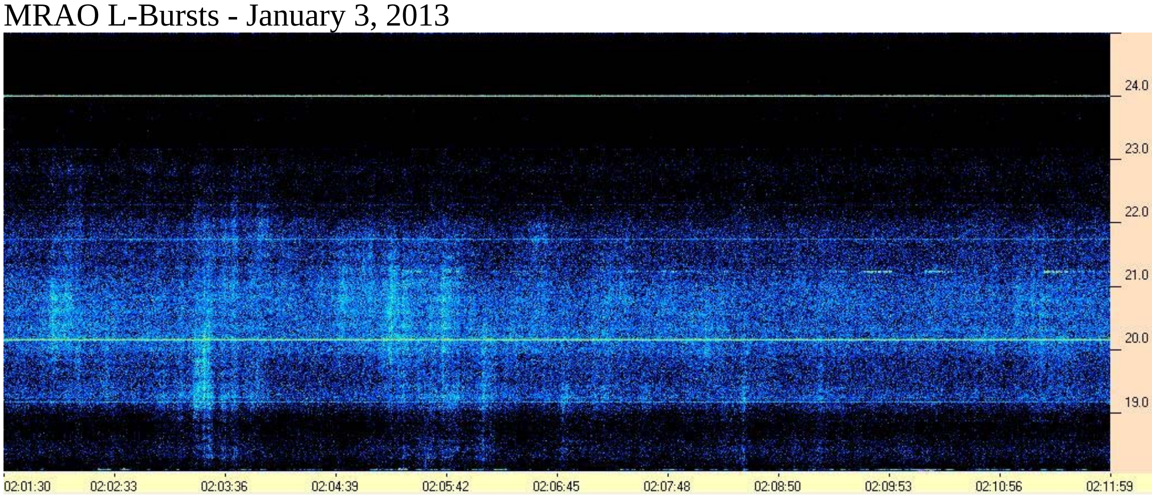
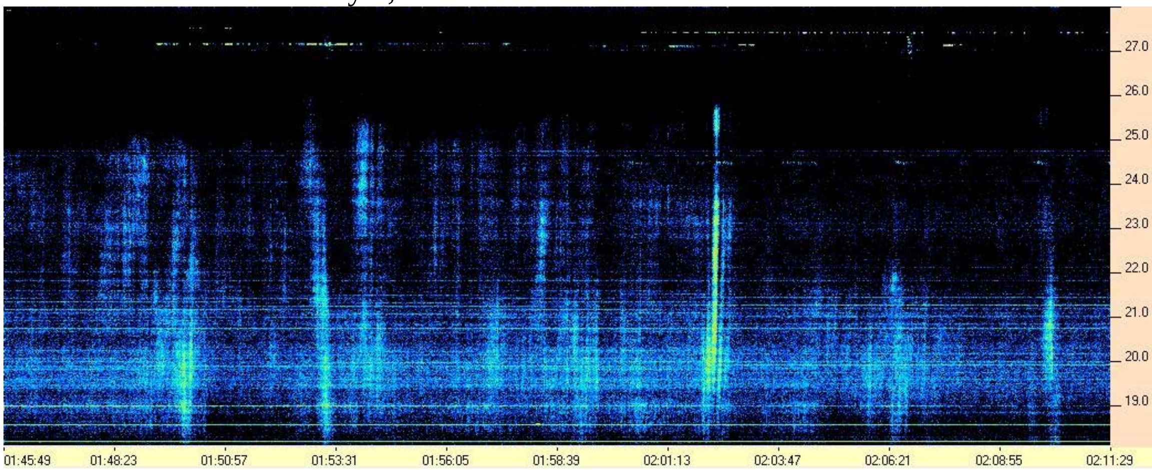
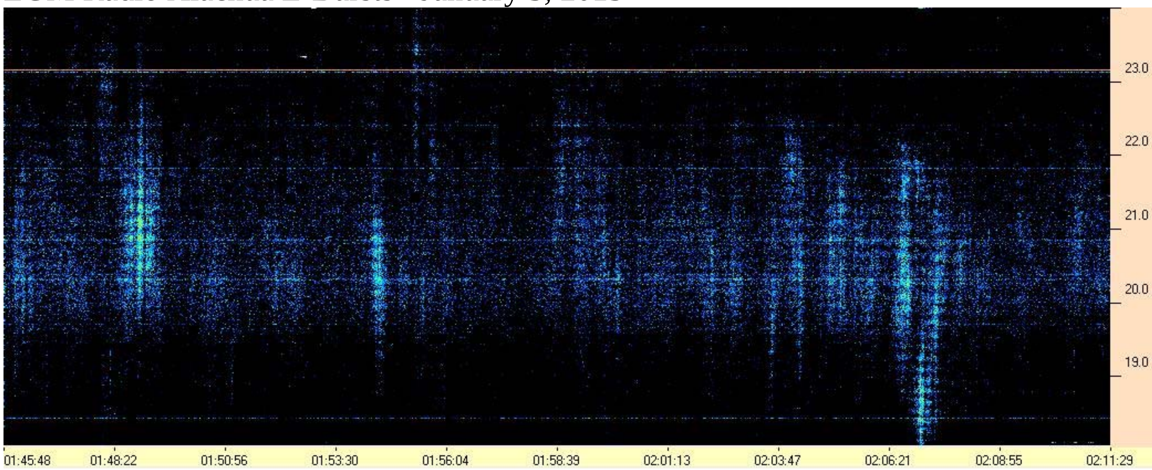


Image set 2. At 0202 UT, the strong burst seen by HNRAO was not seen by LGM, and hardly seen by MRAO. LGM has stronger activity at 0207 UT but hardly seen by HNRAO and not seen at all by MRAO. At 0210 UT, a strong burst seen only by HNRAO.

HNRAO L-Bursts - January 3, 2013



LGM Radio Alachua L-Bursts - January 3, 2013



MRAO L-Bursts - January 3, 2013

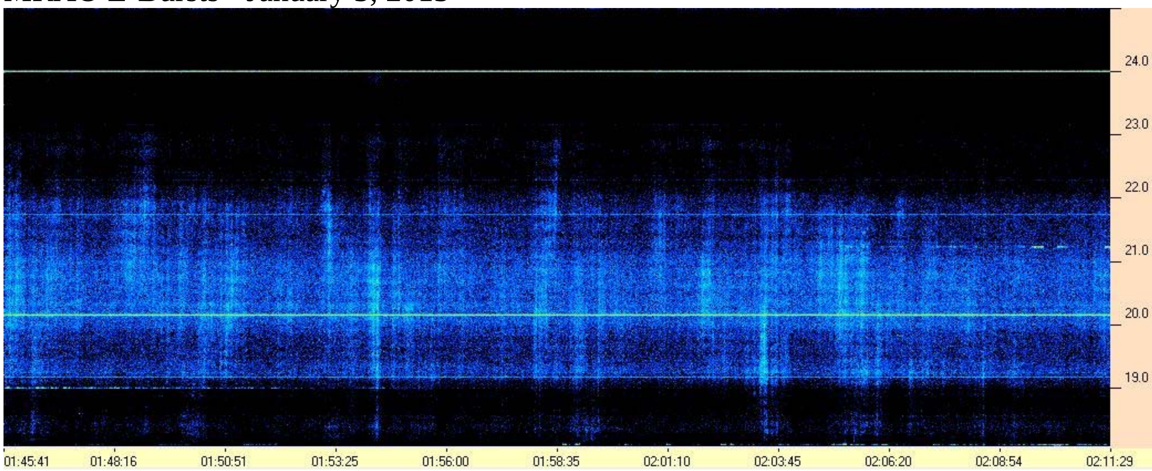


Image set 3. Through this time sequence, HNRAO had strong activity, particularly at 0150, 0153, 0202 and 0210 UT. LGM had no activity that matched HNRAO and MRAO saw only moderate to weak activity.

Io-B and Non-Io-A, January 5, 2013

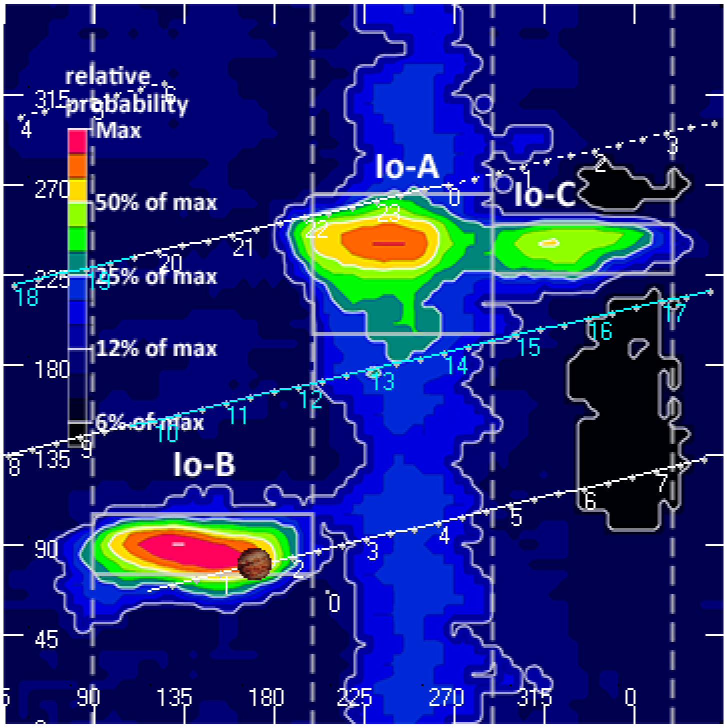
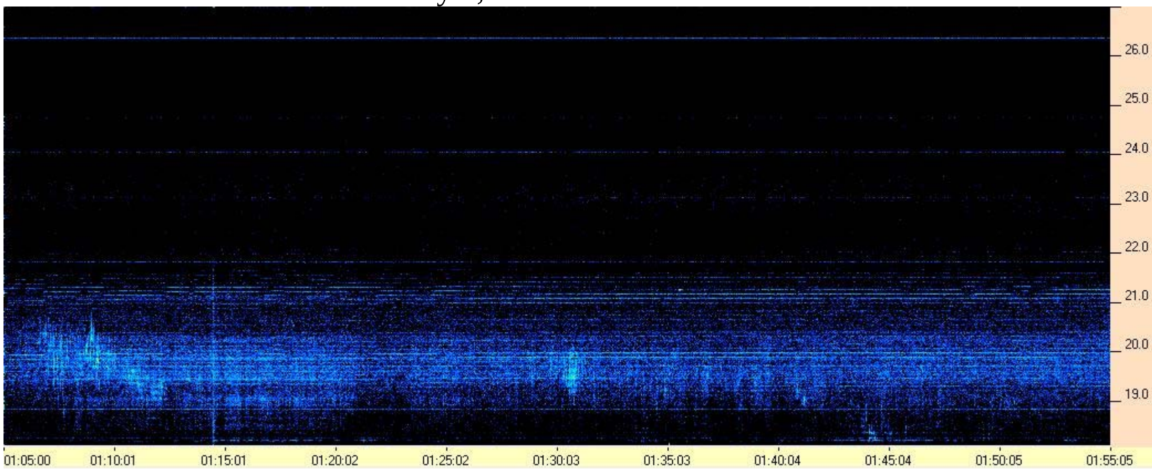


Fig. 2 - This is the Radio Jupiter Pro display of the location of Jupiter during the January 5, 2013 Io-B event.

HNRAO – Io-B S-Bursts - January 5, 2013



LGM Radio Alachua - Io-B S-Bursts - January 5, 2013

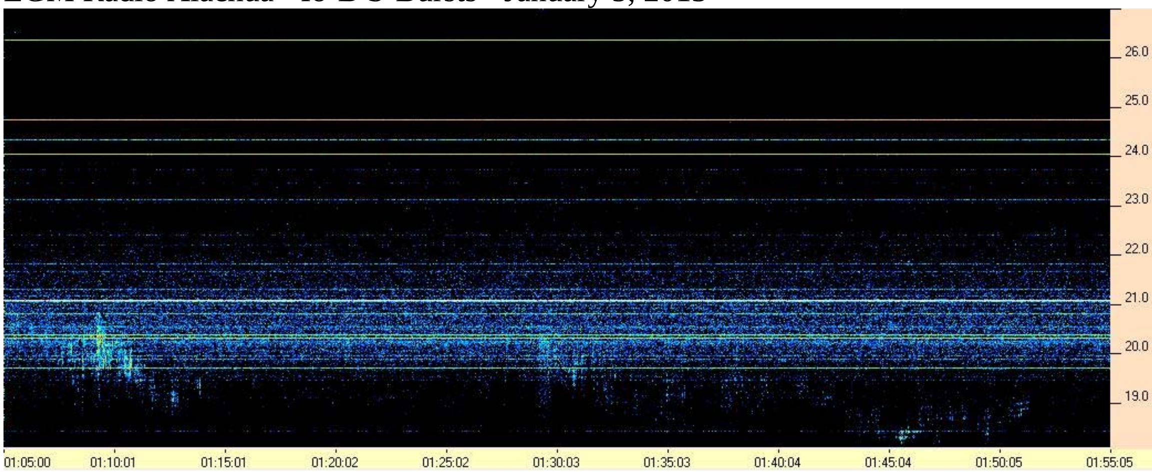
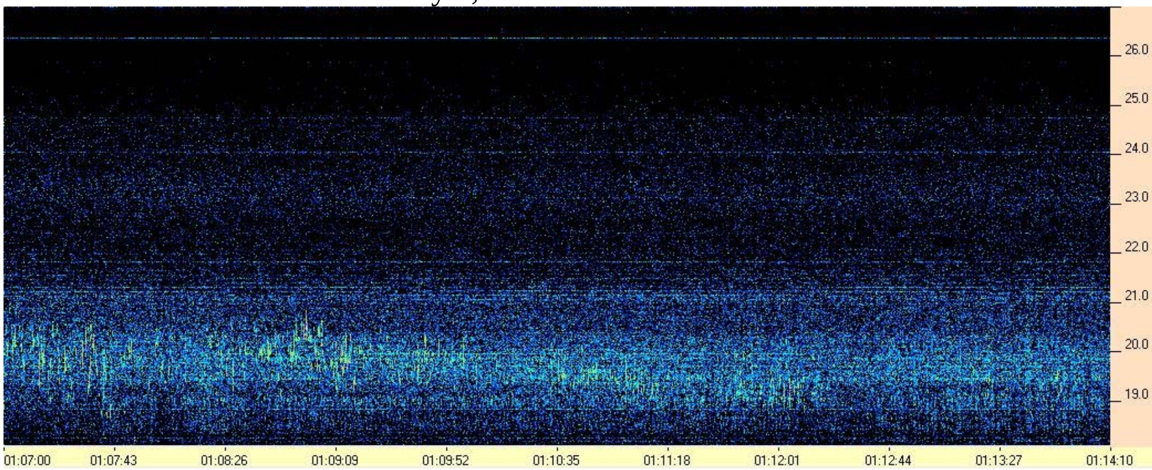


Image set 4. Even S-bursts show evidence of ionospheric scintillation. At 0110 UT, LGM clearly sees the S-burst group stronger, where as at 0130 UT, HNRAO sees the burst slightly stronger.

HNRAO - Io-B S-Bursts - January 5, 2013



LGM Radio Alachua - Io-B S-Bursts - January 5, 2013

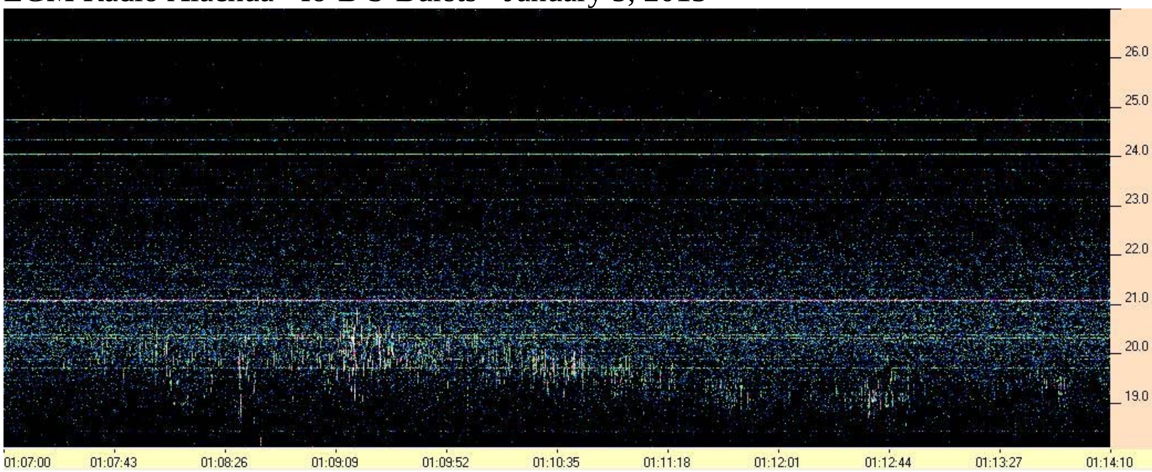
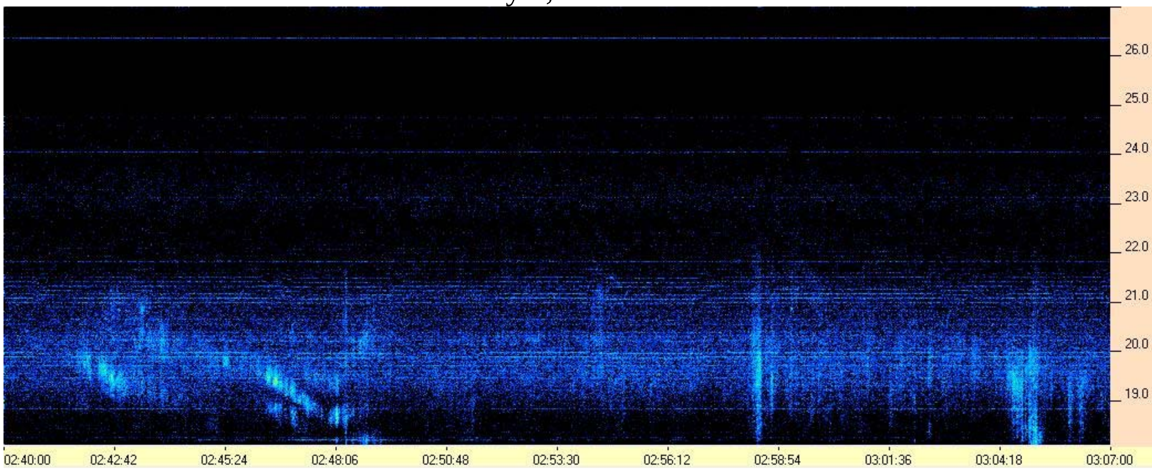


Image set 5. In this closer view of the S-burst event, HNRAO sees the bursts at 0107 UT, where LGM doesn't. LGM has S-bursts at 0110 UT, where HNRAO has minimal activity. LGM has S-bursts at 0112:44 UT, but none are seen at HNRAO.

HNRAO – Non-Io-A L-Bursts - January 5, 2013



LGM Radio Alachua – Non-Io-A L-Bursts - January 5, 2013

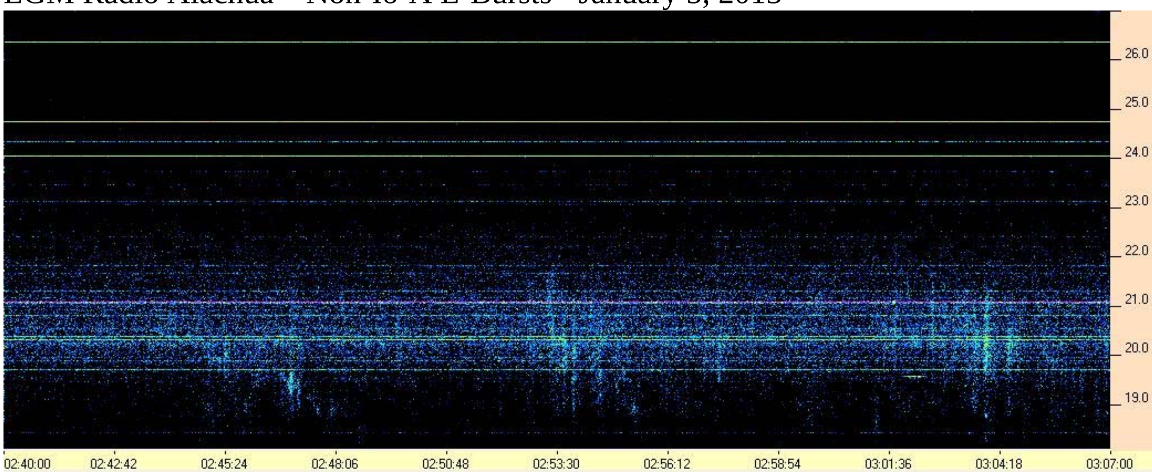
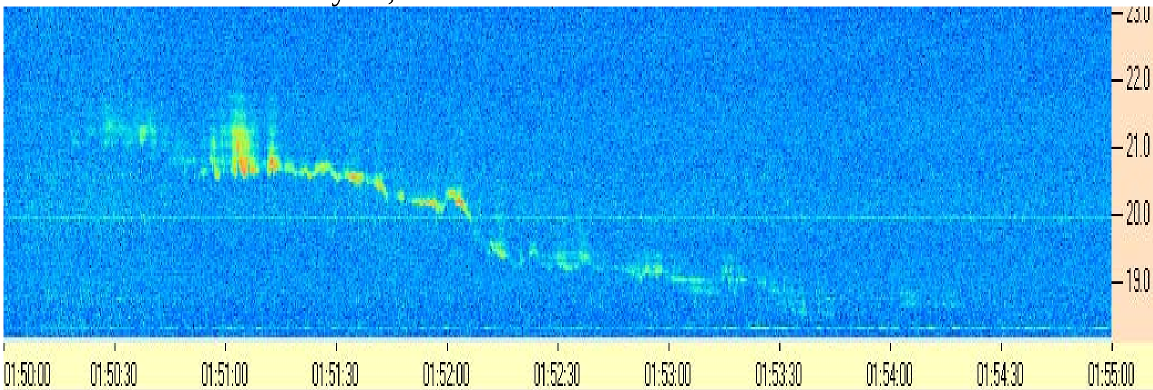


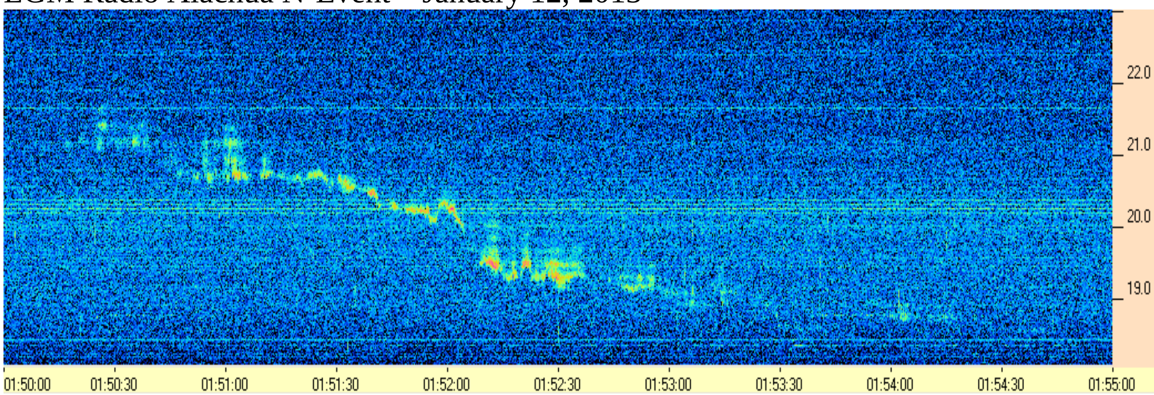
Image set 6. From 0240 UT through 0250 UT, HNRAO has strong activity and LGM has only weak signal. A stronger burst at 0250:54 UT at HNRAO does not even register at LGM. Activity at LGM at 0304:18 UT is not seen at HNRAO.

Image set 7, N-event. This four observatory comparison was put together by Dick Flagg. At first glance, they all appear to be similar, but a closer examination does show amplitude variations at all four sites at 0151 UT, 0152 UT and 0152:30 UT. At 0151 UT, AJ4CO has the strongest signal of the four observatories. At 0152:30 UT, LGM has the strongest signal of the four.

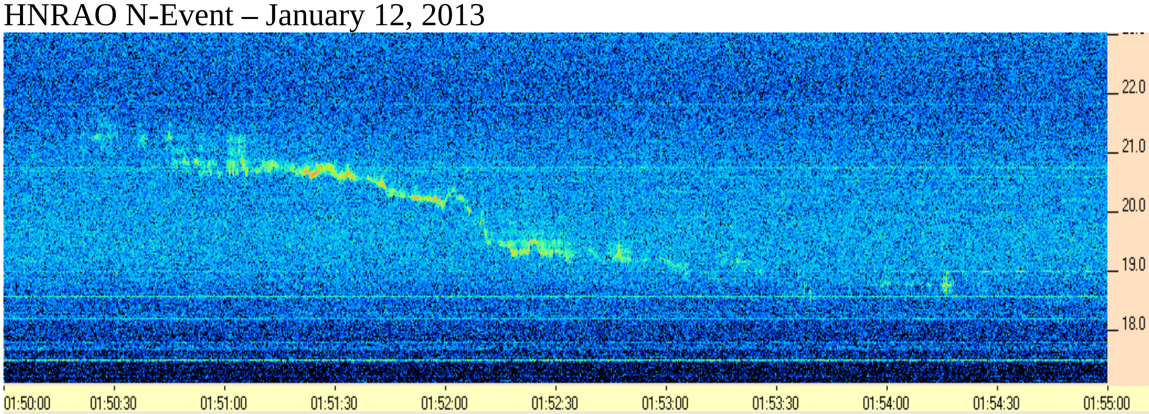
AJ4CO N-Event – January 12, 2013



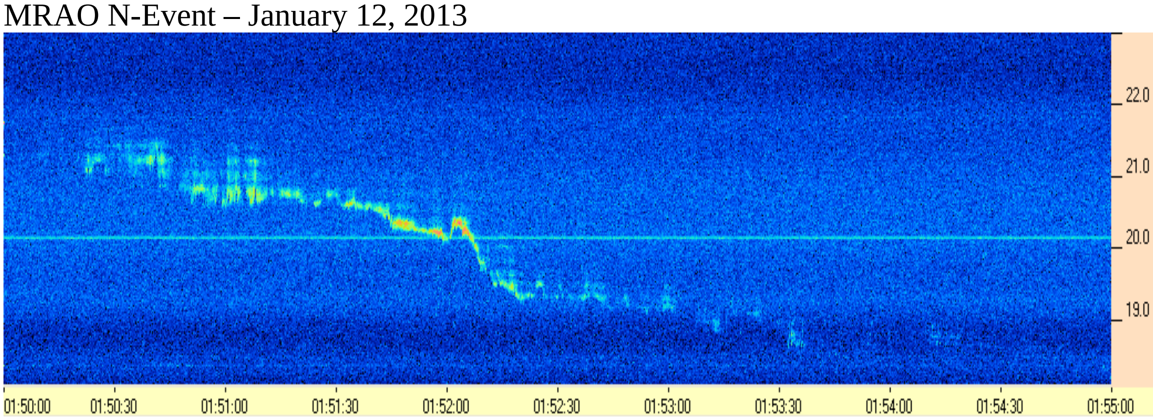
LGM Radio Alachua N-Event – January 12, 2013



HNRAO N-Event – January 12, 2013



MRAO N-Event – January 12, 2013



References:

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2. Pataki, Louis P. University of Texas Radio Astronomy Observatory, 20 December 66. NASA Grant NGR 44-012-055. Spaced Receiver Observations of Jovian Decameter Flux, Progress Report IV.
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5. Six, Jr., Norman Frank. University of Florida, April, 1963. Analysis of the decameter-wavelength radio emission from the planet Jupiter. http://ufdc.ufl.edu/AA00004951/00001
6. Weintraub, Rachel A., NASA Goddard Space Flight Center, 2005. http://www.nasa.gov/vision/universe/solarsystem/radio_jupiter.html
7. University of Illinois at Urbana-Champaign, College of Engineering. http://www.csl.illinois.edu/news/bursting-bubble-researchers-study-ionospheric-plasma-bubbles-interfere-communications-systems, September 24, 2009.
8. Australian Government, Bureau of Meteorology. About Ionospheric Scintillation. http://www.ips.gov.au/Satellite/6/3, 2013.

Fig. 4 - Observatories:

A: Jim Brown, HNRAO
Industry, PA
FS-X Spectrograph, RF Engineering.
JOVE phased dipoles combined with 24 MHz phased dipoles.

B: Wes Greenman, LGM Radio Alachua & Dave Typinski (AJ4CO)
Alachua, FL and High Springs, FL.
FS-X Spectrograph, RF Engineering
JOVE phased dipoles / Carr Array

C: Andrew Mount, MRAO
Located in the Northwest corner of South Carolina.
FS-X Spectrograph, RF Engineering.
JOVE phased dipoles

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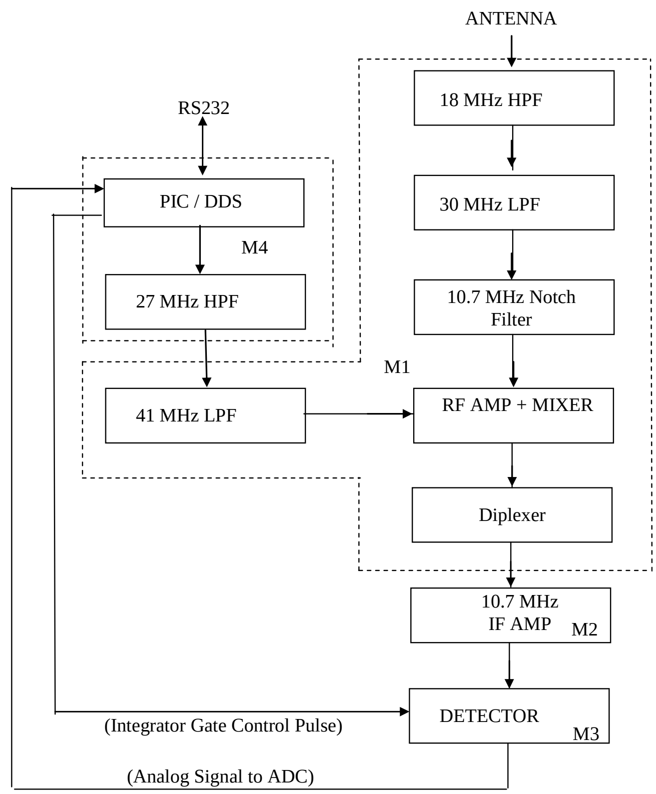

FSX Spectrograph Block Diagram

The LO signal steps thru up to 500 frequencies in 0.1 seconds causing the spectrograph to scan across the receiving frequency range.

[ii] http://jupiter.wcc.hawaii.edu/spectrograph_software.htm

[iii]

HNRAO Array

[iv] The velocity factor (VF), also called wave propagation speed or velocity of propagation (VoP or v_P), of a transmission medium is the speed at which a wave front (of an acoustic signal, for example, or an electromagnetic signal, a radio signal, a light pulse in a fiber channel or a change of the electrical voltage on a copper wire) passes through the medium, relative to the speed of light. For optical signals, the velocity factor is the reciprocal of the refractive index.

The speed of radio signals in a vacuum, for example, is the speed of light, and so the velocity factor of a radio wave in a vacuum is unity, or 100%. In electrical cables, the velocity factor mainly depends on the insulating material.

http://en.wikipedia.org/wiki/Wave_propagation_speed