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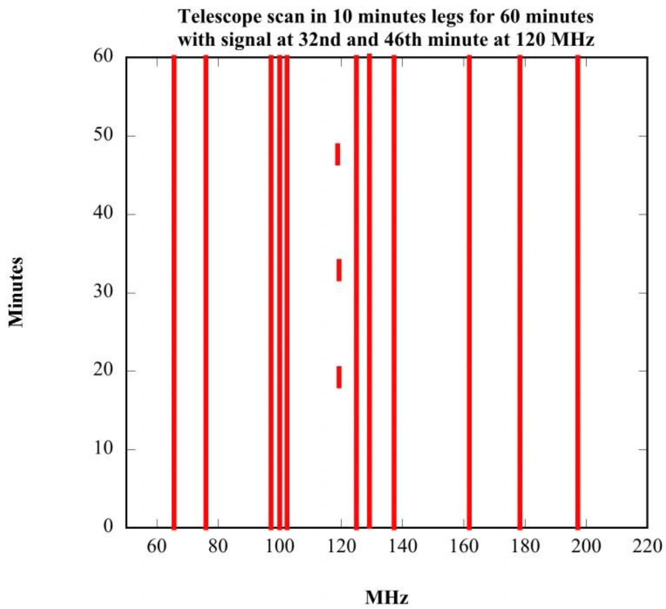
GAVRT/SETI Activity 

What Is a Waterfall Plot? (Lesson One)

Overview:
GAVRT/SETI uses waterfall plots which are not exactly a line graph, bar, pie, or pictograph.



They are a graph that shows an x-y plot with the frequency of light plotted on the x-axis and time plotted on the y-axis. Data from the radio telescope's scans are complied into these graphs which in turn help us separate signals from interference. A real signal will only last for a short period, while the longer signal, which is interference, will always be there. The signals that may be of extraterrestrial origin will disappear when radio telescope points in another direction.

Purpose:
The purpose of this lesson is for the students to be able to work with waterfall plots to determine if the graph includes a true signal.

Required Background Knowledge:

- Read the document entitled, "What is a Waterfall Plot?".

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- Watch the GAVRT/SETI Video.
- Investigate waterfall plots using "SETI DSS28 Spectrometer Data" site

Students will be able to:

- Use the interactive waterfall site to eliminate false signals and isolate possible true signals.

From the National Science Education Standards:

All students should realize:

- As a result of this activity in grades 5-8 and 9-12, all students should develop an understanding of science as a human endeavor, nature of science, abilities of technological design, and understanding about science and technology.
- Scientists formulate and test their explanations of nature using observation, experiments, and theoretical and mathematical models. Although all scientific ideas are tentative and subject to change and improvement in principle, for most major ideas in science, there is much experimental and observational confirmation. Those ideas are not likely to change greatly in the future. Scientists do and have changed their ideas about nature when they encounter new experimental evidence that does not match their existing explanations.
- In areas where active research is being pursued and in which there is not a great deal of experimental or observational evidence and understanding, it is normal for scientists to differ with one another about the interpretation of the evidence or theory being considered. Different scientists might publish conflicting experimental results or might draw different conclusions from the same data. Ideally, scientists acknowledge such conflict and work towards finding evidence that will resolve their disagreement.

From the Common Core State Standards for Mathematics

Eight grade should be able to use functions to model relationships between quantities.

- Construct a function to model a linear relationship between two quantities. Determine the rate of change and initial value of the function from a description of a relationship or from two (x, y) values, including reading these from a table or from a graph. Interpret the rate of change and initial value of a linear function in terms of the situation it models, and in terms of its graph or a table of values.
- Describe qualitatively the functional relationship between two quantities by analyzing a graph (e.g., where the function is increasing or decreasing, linear or nonlinear). Sketch a graph that exhibits the qualitative features of a function that has been described verbally.

Web Links for Further Investigation These should open.

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- What is a waterfall plot?
- Waterfall plots interactive site (SETI DSS28 Spectrometer Data site)
- GAVRT/SETI Video

Resource/Materials Needed:

- Computer or downloaded video, “GAVRT/SETI Video.”
- Computer or printed copies of “What Is a Waterfall Plot?”
- Computer so that groups of students are able to interact with the “SETI DSS28 Spectrometer Data Interactive Site”

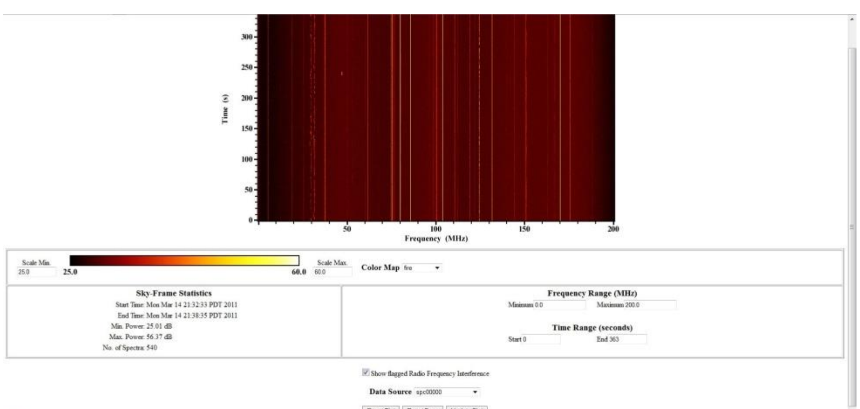
One-Computer Classroom:

If there is only one computer in the classroom, it is recommended that teachers use an overhead, LCD, white board, or television screen to project images from the computer onto a classroom screen. Have your students work through the SETI DSS28 Spectrometer DATA site. You can do this by having individual students come forth and manipulate the page or you can have small teams of students work together to eliminate noise and discover if a signal is present. If the class has trouble watching others operate the activity, provide other work for the class to do.

Teacher notes:

Please view the GAVRT/SETI Video, read through the document entitled “What is a Waterfall Plot”, and investigate the interactive site before doing this activity with your students. **It is very important that your students also view the video and read “What is a Waterfall Plot” before attempting either of the lessons.**

Student Activity: Before attempting these lessons please read “What is a Waterfall Plot” and view the GAVRT/SETI video.
Lesson 1for http://galileo.gavrt.org/seti/ and selecting “Data” from the side menu.



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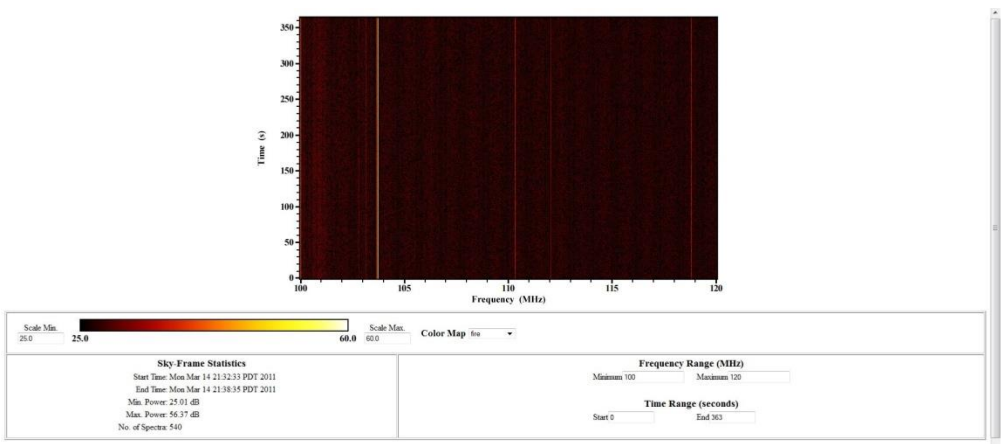
At the top of the image you can see a representation of the data. The x-axis represents the frequencies observed by GAVRT ranging from 1 to 200 MHz. The y – axis shows the time axis, in this case in seconds ranging from 0 to 340 seconds.

Like the figures before you can see that as the telescope scanned the sky, the noise sources were always constant at their various frequencies. It is your job to isolate then and eliminate them from the plot.

To do this you will use the Minimum and Maximum on the Frequency Range to find exactly where the noise sources are.

Looking at the image above you can see that there are some very bright streaks around half way across the x-axis. Since the x-axis goes to 200 MHz then half of that is 100 MHz. So let's zoom into the region around 100 MHz by putting a minimum frequency of 100 MHz and Maximum frequency of 120 MHz.

The web page should now look like the following figure:



You can see the very bright line towards the left side of the plot. But now having zoomed into the image you can see that there are several other vertical lines indicating lower levels of noise also present.

Still the first task is to eliminate the obvious noise before we go to the fainter ones so we will estimate the range of frequencies where that bright line may be and we will enter them into the Minimum and Maximum of the Frequencies until we have isolated the line.

The next figure shows the range after having tried several different numbers for the limits of the frequencies:

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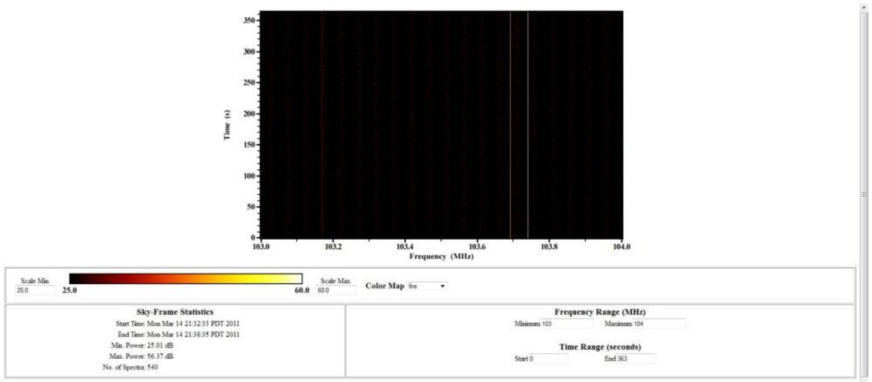
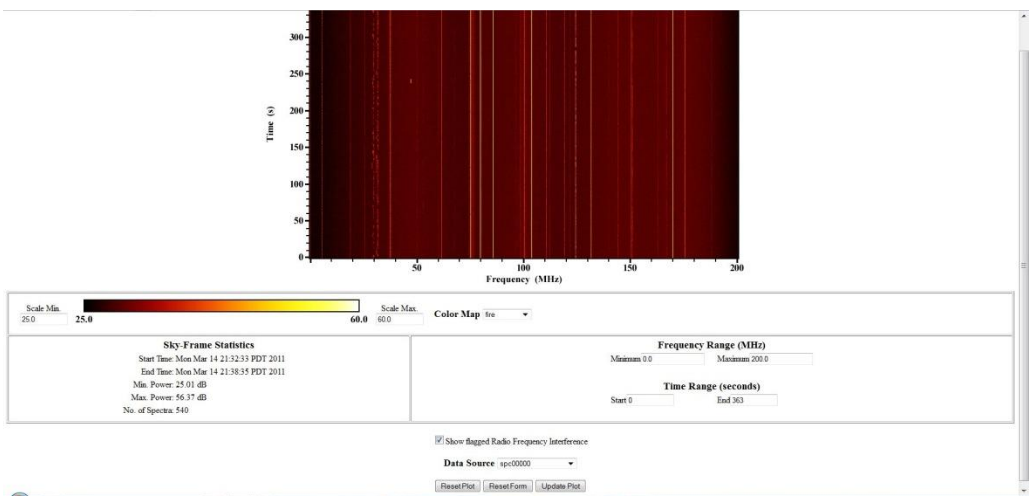
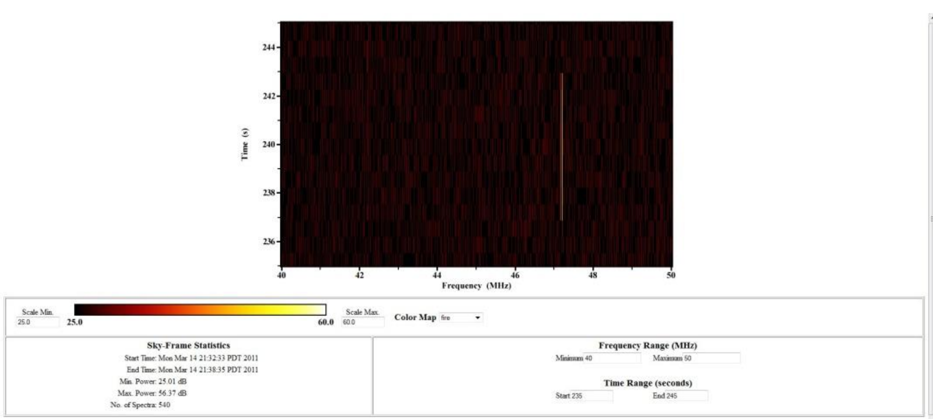


Here you can see that we have settled on a frequency range between 103 and 104 MHz where the noise is. So we will now mark that range as noise so that we do not think that the signal there is coming from a real extraterrestrial source.

Now continue to do this for all the obvious noise sources until there are no continuous vertical line/noise left.



Now go back to the original image range, frequency range between 1- 200 MHz. You can also isolate a limited range in time as well as frequency. See that there are a couple of short signals in the 235 to 245 second timeframe. Enter that range into the “Time Range.”



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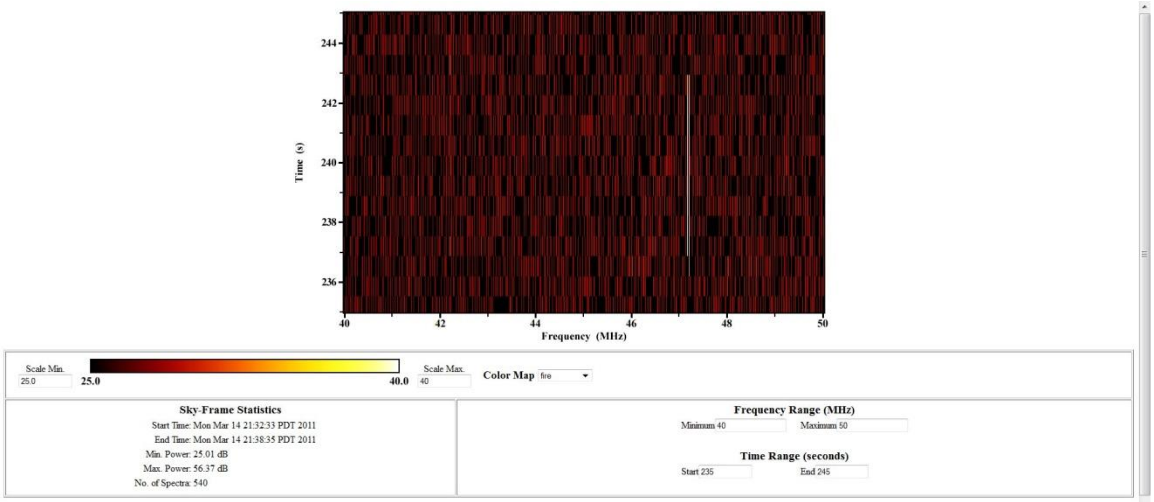
In the above image you may notice that there may be two vertical lines. To make the dimmer line more obvious, change the "Scale Max" to 45.



Now notice that the two lines are now very obvious because of the change in the scale.

So by choosing different values for "Frequency Range," "Time Range," and the "Scale Min" and "Max" you can find the noise and eliminate them.

Continue making adjustments with this page until you are confident that you understand how to eliminate noise from the waterfall plot.

Additional Information:

This material should be read or covered before doing the lessons, either completing the online activity or the matching activity.

What is a waterfall plot?

A waterfall plot is an x-y plot with frequency of light plotted on the x-axis and time plotted on the y-axis. Follow the text below to see what a waterfall plot tells us about observing the sky.

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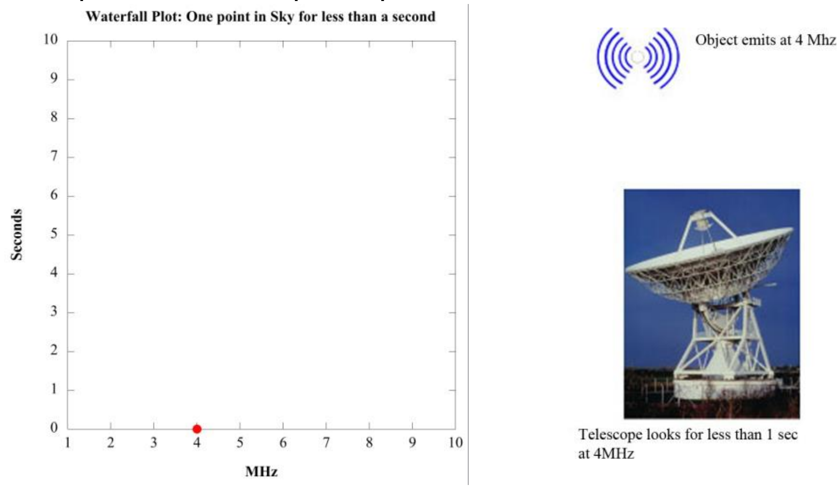
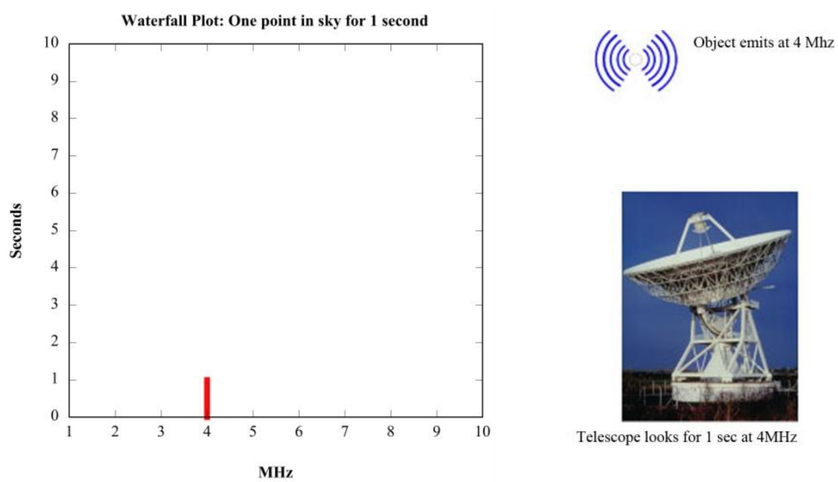
If a radio telescope looks at one point in the sky at one frequency, let's say 4MHz, for just a quick instant, and there is a source emitting radio waves at that location then in a waterfall plot we would put a point at 4MHz and almost zero seconds.



Now what would the waterfall plot look like if the telescope stared at a 4MHz source for 1 second? There would be a line from 0 seconds to one second at 4MHz:



Now what would the waterfall plot look like if the telescope stared at a 4MHz source for 10 seconds? There would be a line from 0 seconds to ten seconds at the 4MHz:

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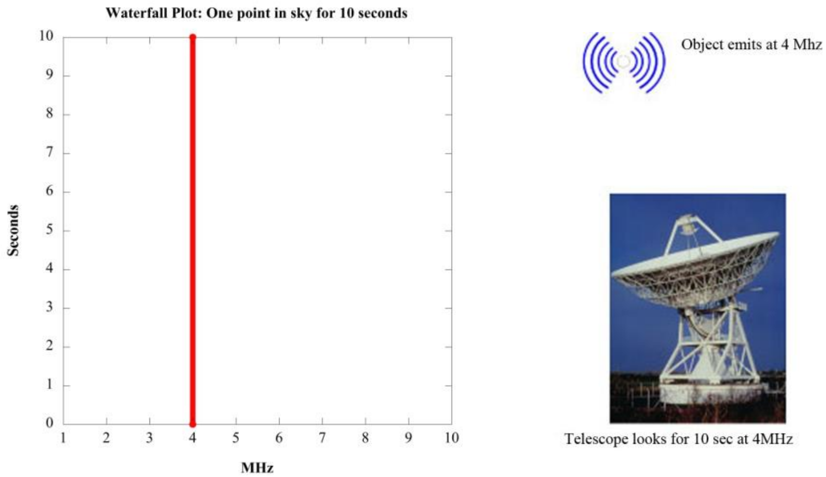
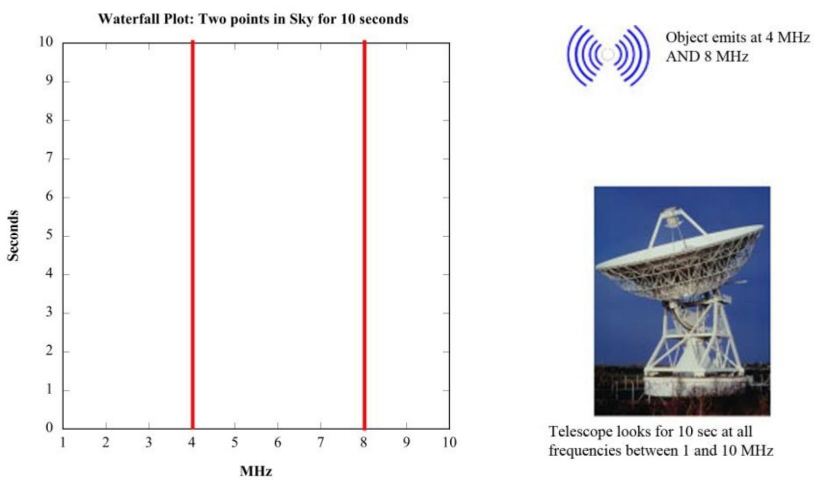
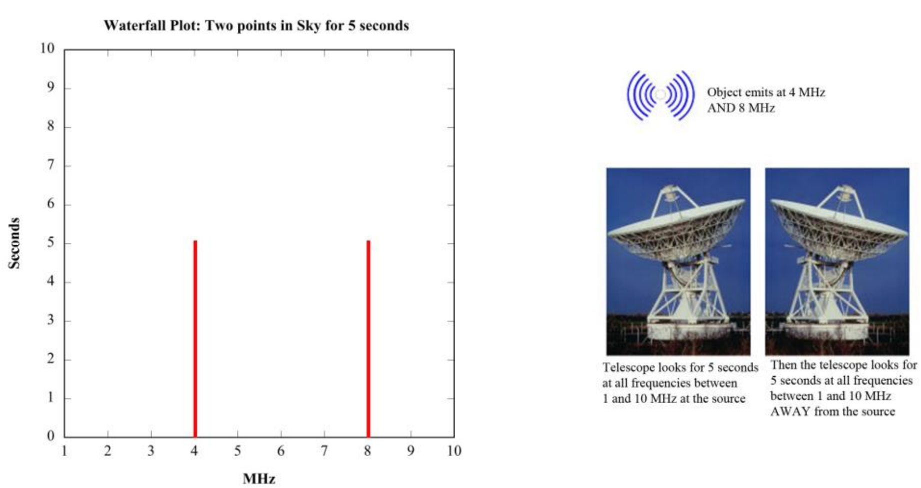


But if the source was emitting at two frequencies, like 4 AND 8 MHz and the radio telescope was observing at all frequencies between 1 and 10 MHz then the waterfall plot would look like this:



Now let's have the telescope look for 5 seconds at the emitting source and for 5 seconds away from the emitting source:



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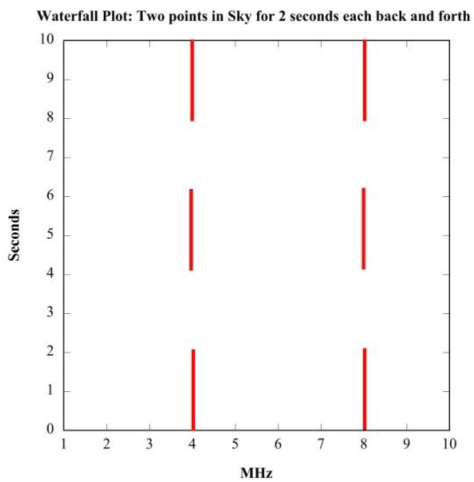
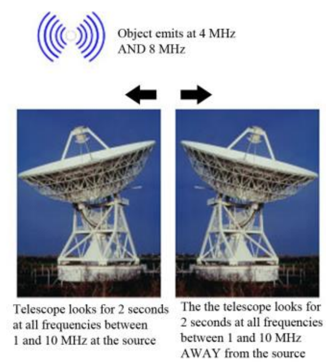
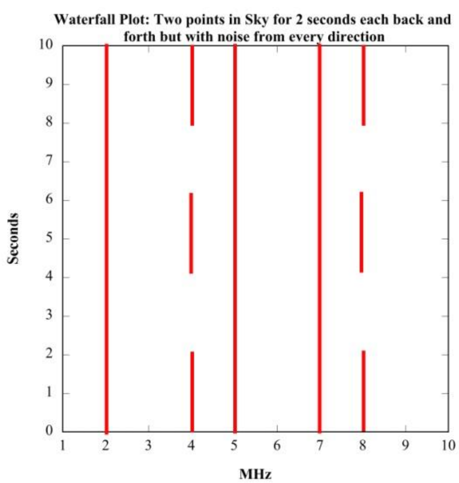
Notice that the lines in the graph show that the signal is detected only while the telescope is looking at it. So there is a line lasting 5 seconds corresponding to the time the telescope is looking at the object, and no signal while the telescope is looking away for 5 seconds.

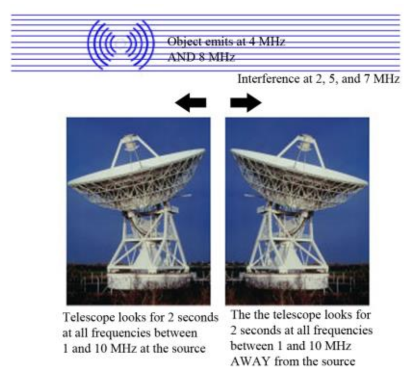
For the next example the telescope will look at the object for 2 seconds, and then off of it for 2 seconds, and repeat this pattern for 3 times. Notice how that shows up on the waterfall plot.





Now what would happen if we did the exact same thing, except this time there was a source of Radio Frequency Interference (RFI) that came from every direction? In this case the radio noise is at 2, 5, and 7 MHz.





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So for radio emission that comes from every direction which could be from space or from local sources like cell phone towers then the waterfall plot shows a straight line during the whole time you are observing. This is because in the affected channels there is always a signal.

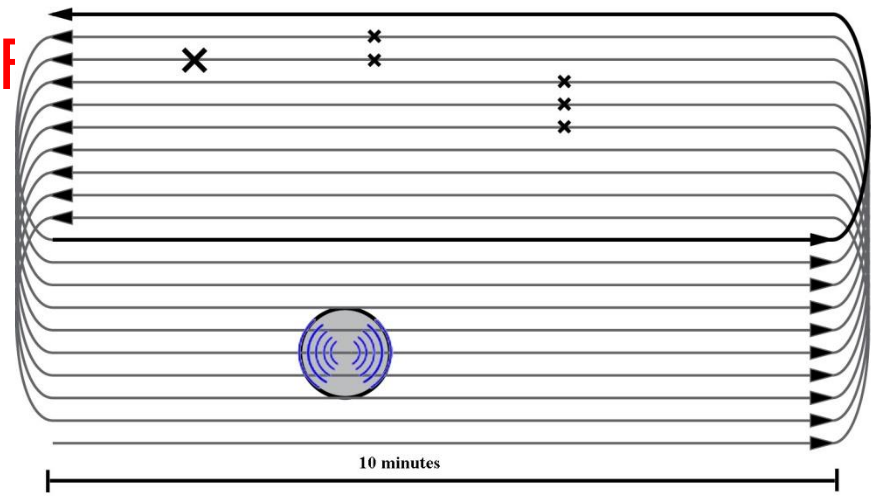
But if the telescope is moving then only when the telescope is pointing at a radio emitting object in the sky will there be a signal and every time the telescope returns to that location in the sky then the signal should still be there. If the telescope points in another direction then that signal should go away. That is why we have the broken lines in the above waterfall plot. Those represent real radio emitters at 4 and 8 MHz while the straight lines indicate RFI coming from all directions.

So how does a waterfall plot help us do a Search for Extraterrestrial Intelligence (SETI)?

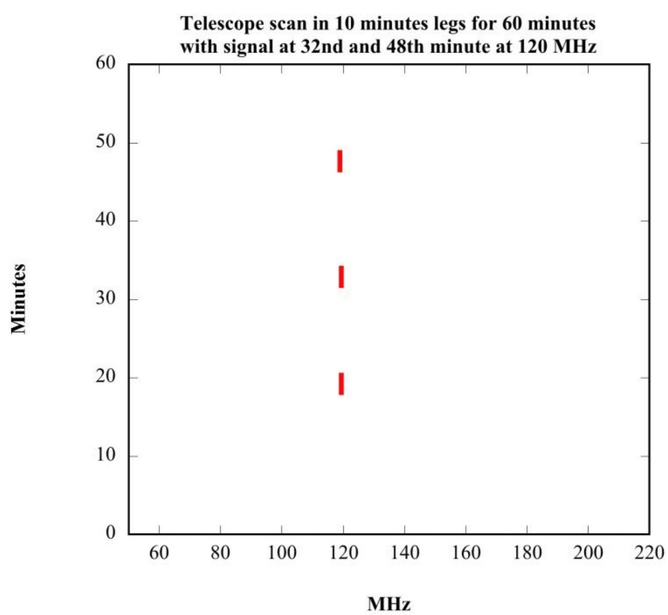
If there are any alien civilizations out there and they are trying to communicate to us using radio signals, then we have to separate their signals from RFI. The waterfall plot shows us how we can separate RFI from real signals because if a radio telescope is scanning across the sky then a real signal will only last a short while but a signal that is RFI will always be there.

So what is necessary is to isolate the real signals? There are two parts to isolating real signals. First the telescope has to scan the sky not only to cover a large area of space but also to verify signals by looking repeatedly at the same piece of sky so that if a signal is real, it can be double checked (that is when the telescope comes back to the same sky location the signal would be detected again). The second part of isolating a real signal is getting rid of frequencies dominated by RFI.

To accomplish both these goals the telescope takes the following pattern to look at the sky:



The telescope starts at a point in the sky. Then it slowly scans a part of the sky. In this example it takes 10 minutes to go from left to right. Then it goes up and then tracks back for 10 minutes. And it makes a racetrack pattern on the sky. Notice that the separation is such that if there is a signal then the telescope will cross it at least twice (In this case 3 times). The waterfall plot for the above scan and signal pattern would look something like this if the signal was coming at 120 MHz:



Notice that in the absence of RFI that the first three 10 minute tracks had no signal so there is nothing . Then the telescope scanned across a signal which lasted two minutes (red line covering 2 minutes starting at 32 minutes on the y axis) which was emitting at 120 MHz. Then the telescope crossed the signal two more times for a total of three.

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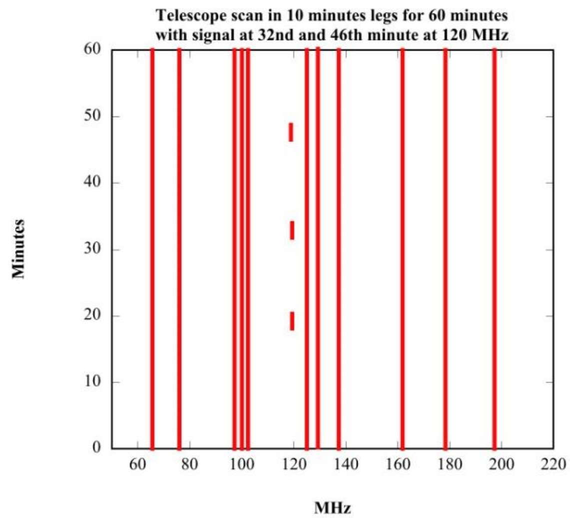
But of course this is for a perfect case. There will always be RFI so the waterfall plot is more likely to look like this:



But now let's look at some real data. On the following figure you can see the representation of data taken by the GAVRT telescope on the web page you will be using to analyze the data and to eliminate the noise.

Notice that one of the main problems with the noise is that it is very bright while we expect any signal that may be coming from extraterrestrials to be very weak. So to be able to pick out the weak signals we need to eliminate the strong noisy ones.

Questions: As with all investigations, one question may give rise to more. Keep a journal of your questions as you complete your investigation. If these questions have not been answered when you have finished your GAVRT/SETI scan, you may need to do further investigations using NASA websites. You are on the cutting edge of scientific research. Your journey may need to continue after your project is complete.