



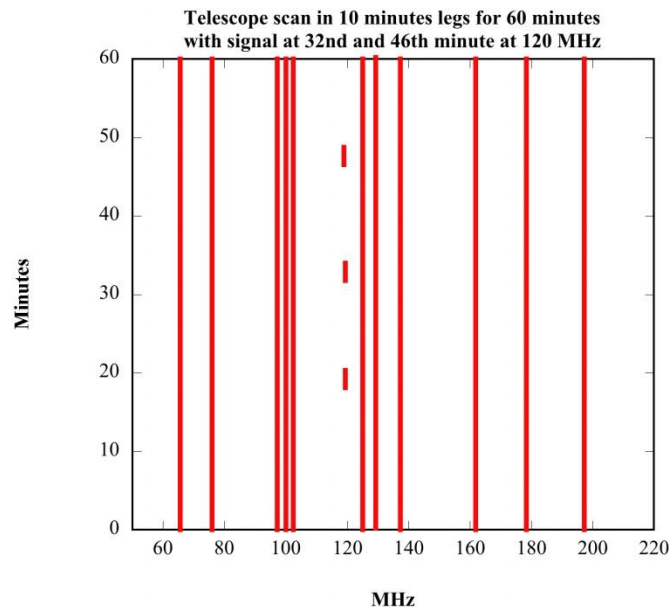
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## Which Waterfall Plot? (Lesson Two)

### Review the Overview from Lesson One:

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 compiled 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 and match their signal to an explanation of what is seen in the plot.

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## **Read or review if not covered in Lesson one. Required Background Knowledge:**

- Read the document entitled, "What is a Waterfall Plot?"
- Do lesson one which is an investigation of waterfall plots using "SETI DSS28 Spectrometer Data" site.
- Watch the GAVRT/SETI Video.

## **Students will be able to:**

- Look at samples of waterfall plots and match them to definitions that explain what each particular plot is showing

## **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

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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.

- 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?"
- Printed copies for each student of the Waterfall Matching Activity and work pages that go with it.
- Scissors
- Pencils

## **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. You can view the "GAVRT/SETI Video as a class, small groups, or individually before attempting the activity.

## **Teacher notes:**

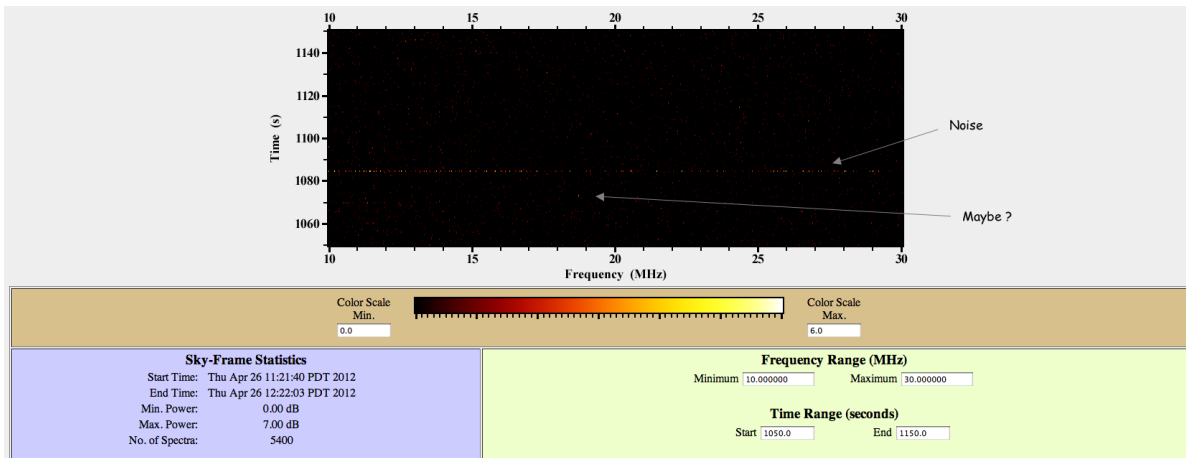
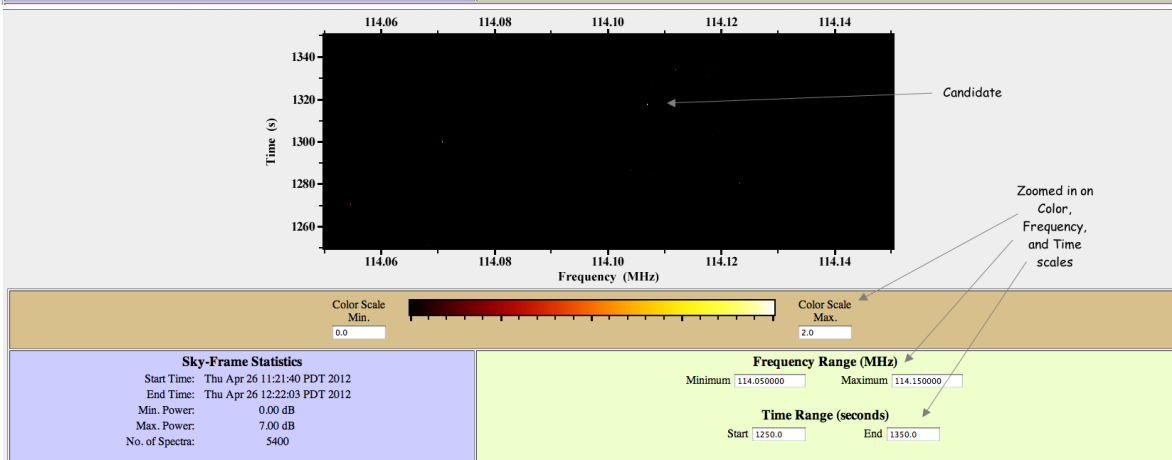
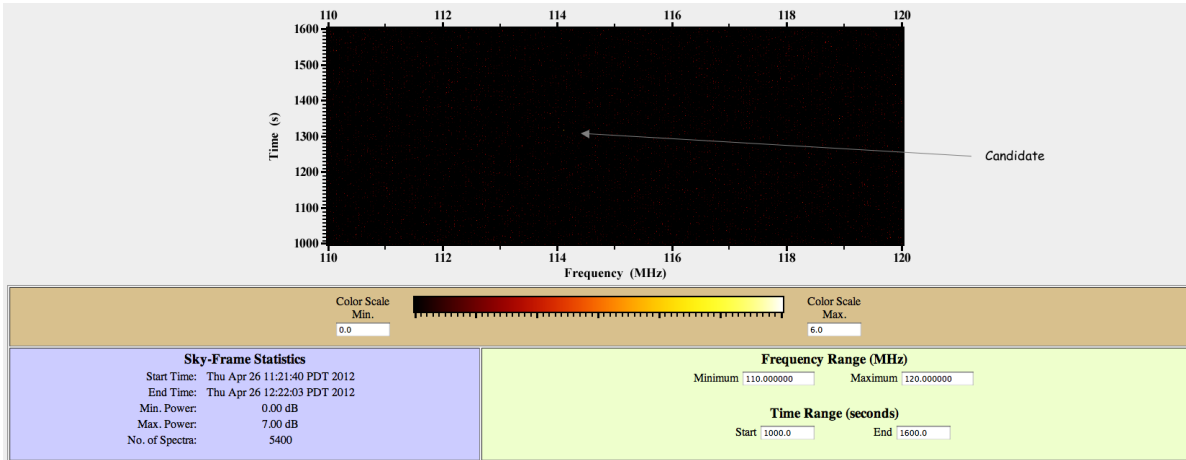
Please view the GAVRT/SETI Video and read through the document entitled "What is a Waterfall Plot". **It is very important that your students also view the video and read "What is a Waterfall Plot."**

## **Student Activity: Before attempting these lessons please read "What is a Waterfall Plot" and view the GAVRT/SETI video.**

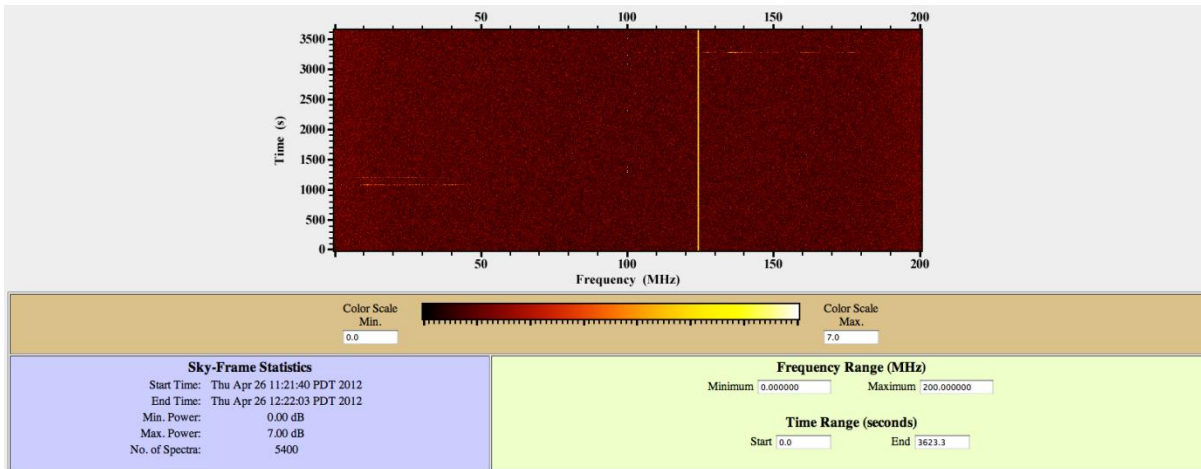
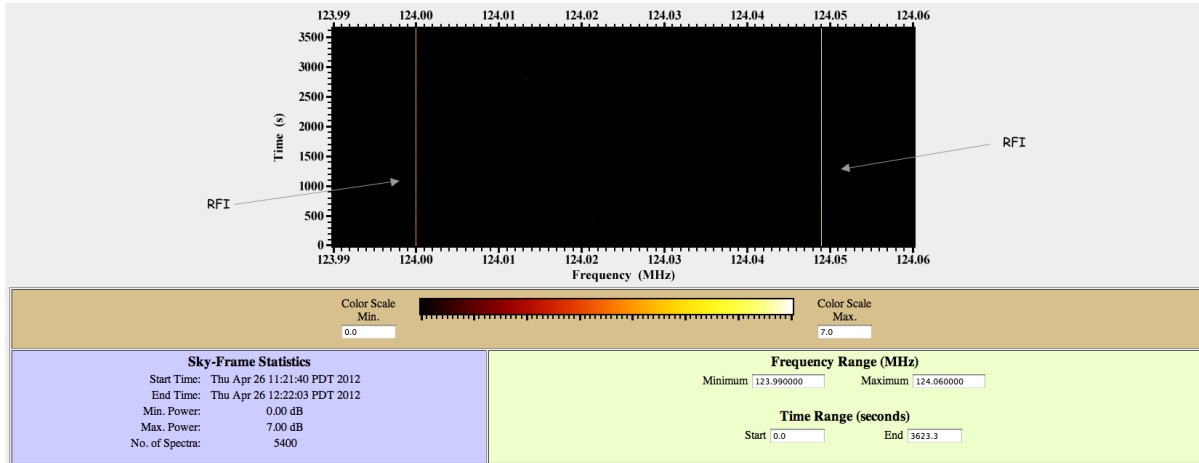
In this lesson you will have several waterfall plots and several explanations of such plots. Your task is to assign the waterfall plots to the explanation that explains what is shown in the plot.

## **Examples of Waterfall Plots**

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## Explanations for Waterfall Plots

**This "Waterfall Example" is just an overview of the entire data set.**

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**“RFI” shows two examples of obvious Radio Frequency Interference. Both signals last much too long to be valid, since the radio telescope would sweep across a real source in just a few seconds.**

**“Maybe” shows some noise, which is spread out over too many frequencies to be a real signal. Near the noise is a possible candidate, but it’s a judgment call, because it could be associated with the noise. Dr. Levin suggests keeping it as a possible candidate.**

**“Candidate” shows a SETI candidate, worthy of follow-up to see if it shows up again at the same time and frequency when this patch of sky is next observed.**

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**“Candidate Zoom” shows the same SETI candidate, but with the frequency, time, and color all zoomed in to examine it more closely. If it showed up as 2 or 3 dots when we do this, that would be exciting, because a real signal would show up for a second or two as the telescope sweeps across it. Nonetheless, this image is pretty bright and is not obviously RFI or noise, so we add it to the list of candidates.**

### **Procedures for matching waterfall plots with an explanation:**

After you match the waterfall plots with an explanation, show your match to a fellow student and discuss your findings. Add your reasons in the boxes below. Make adjustments to your decisions.

Image \_\_\_\_\_ is \_\_\_\_\_

because \_\_\_\_\_

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Image \_\_\_\_\_ is \_\_\_\_\_

because \_\_\_\_\_

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Image \_\_\_\_\_ is \_\_\_\_\_

because \_\_\_\_\_

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Image \_\_\_\_\_ is \_\_\_\_\_

because \_\_\_\_\_

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Image \_\_\_\_\_ is \_\_\_\_\_  
because \_\_\_\_\_  
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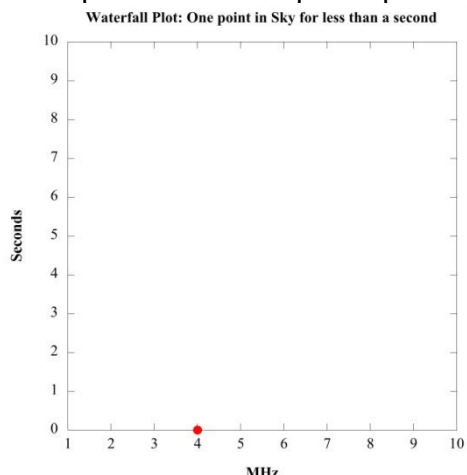
## Additional Information:

**If you did not read through this material in Waterfall Lesson 1, make sure you read it before doing this lesson.**

## 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.

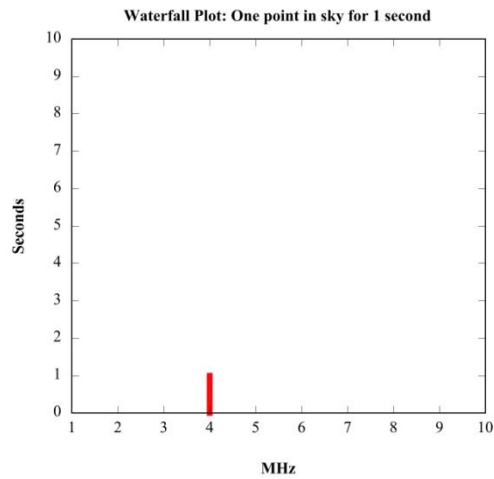
If a radio telescope looks at one point in the sky at one frequency, let's say 4MHz, for just a quick instant, and there is a source emitting radio waves at that location then in a waterfall plot we would put a point at 4MHz and almost zero seconds.



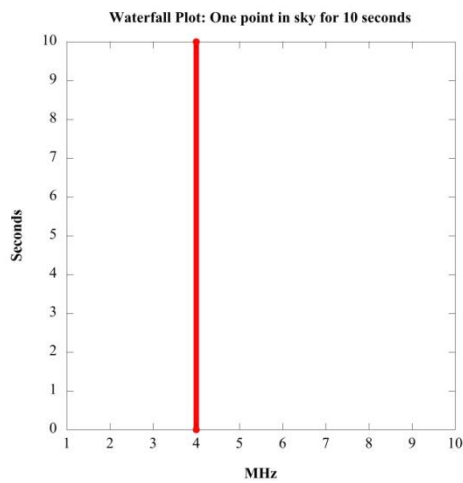
Telescope looks for less than 1 sec at 4MHz

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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:

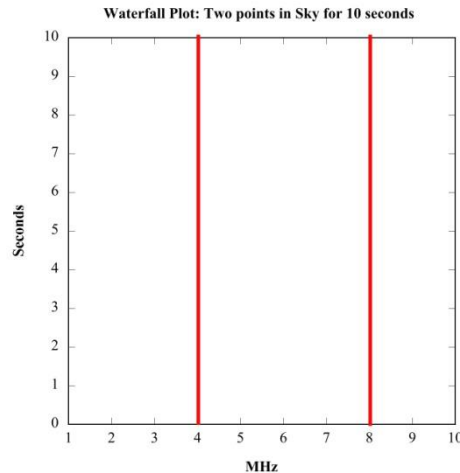


Now what would the waterfall plot look like if the telescope stared at a 4MHz source for 10 seconds? There would be a line from 0 seconds to ten seconds at the 4MHz:



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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:

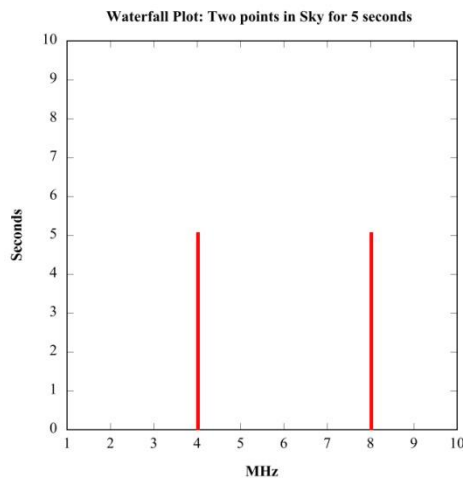


Object emits at 4 MHz  
AND 8 MHz



Telescope looks for 10 sec at all frequencies between 1 and 10 MHz

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



Object emits at 4 MHz  
AND 8 MHz



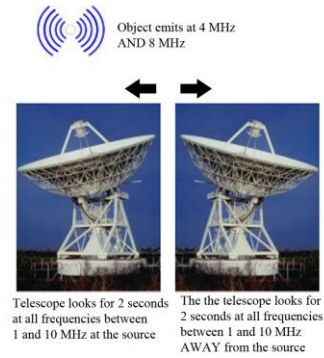
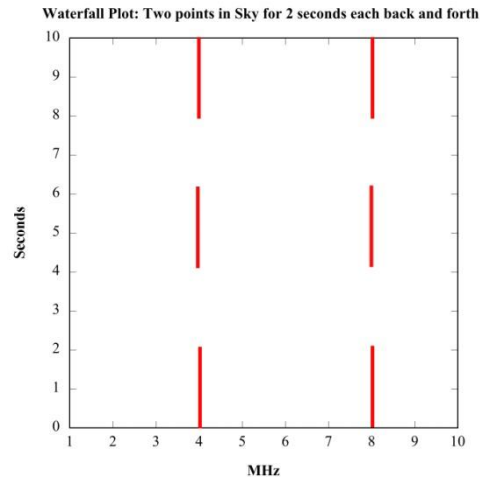
Telescope looks for 5 seconds at all frequencies between 1 and 10 MHz at the source

Then the telescope looks for 5 seconds at all frequencies between 1 and 10 MHz AWAY from the source

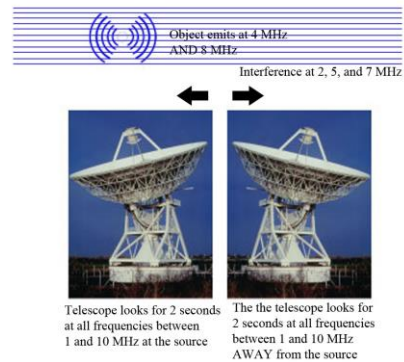
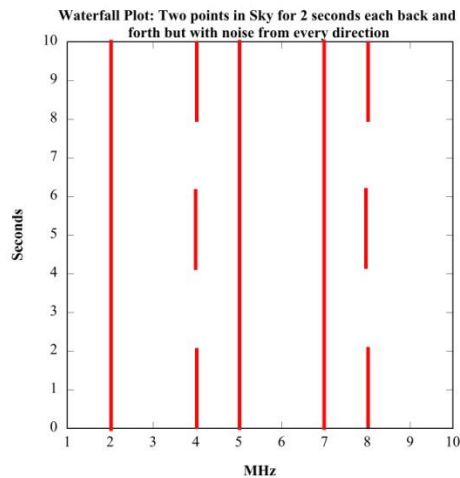
Notice that the lines in the graph show that the signal is detected only while the telescope is looking at it. So there is a line lasting 5 seconds corresponding to the time the telescope is looking at the object, and no signal while the telescope is looking away for 5 seconds.

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.

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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.



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.

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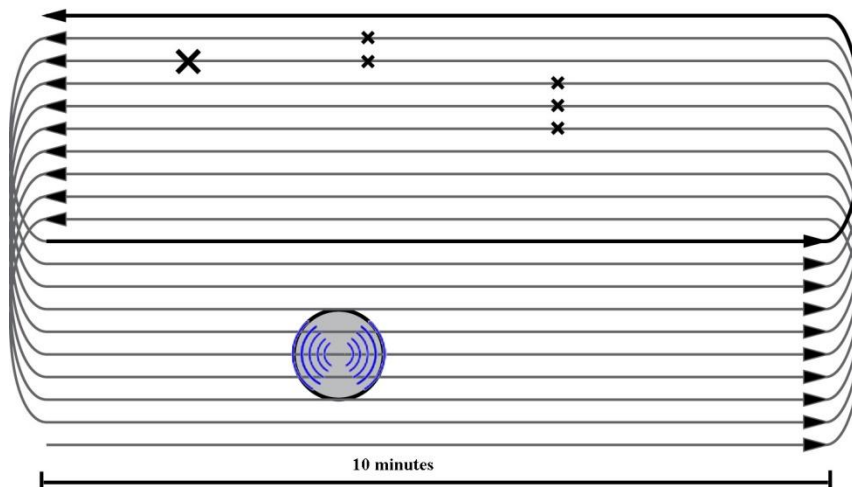
But if the telescope is moving then only when the telescope is pointing at a radio emitting object in the sky will there be a signal and every time the telescope returns to that location in the sky then the signal should still be there. If the telescope points in another direction then that signal should 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.

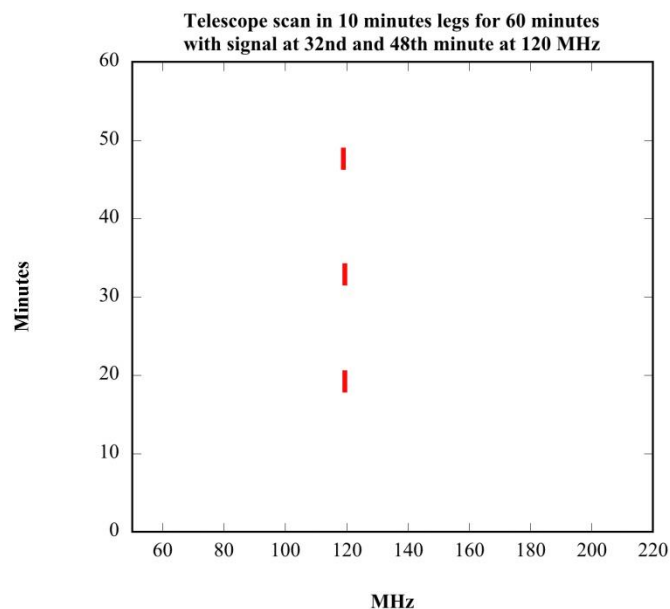
So what is necessary is to isolate the real signals? There are two parts to isolating real signals. First the telescope has to scan the sky not only to cover a large area of space but also to verify signals by looking repeatedly at the same piece of sky so that if a signal is real, it can be double checked (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:



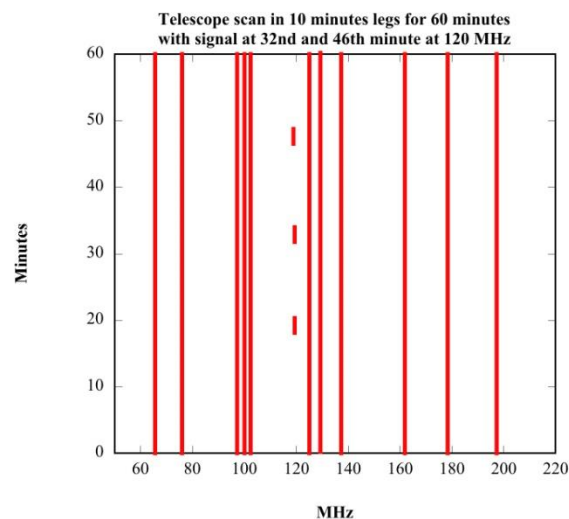
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The telescope starts at a point in the sky. Then it slowly scans a part of the sky. In this example it takes 10 minutes to go from left to right. Then it goes up and then tracks back for 10 minutes. And it makes a racetrack pattern on the sky. Notice 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 starting at 32 axis) which was Then the telescope two more times for

But of course this is There will always be



covering 2 minutes emitting at 120 MHz. crossed the signal a total of three.

for a perfect case. RFI so the waterfall

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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.