Proving the Doppler Effect at Home

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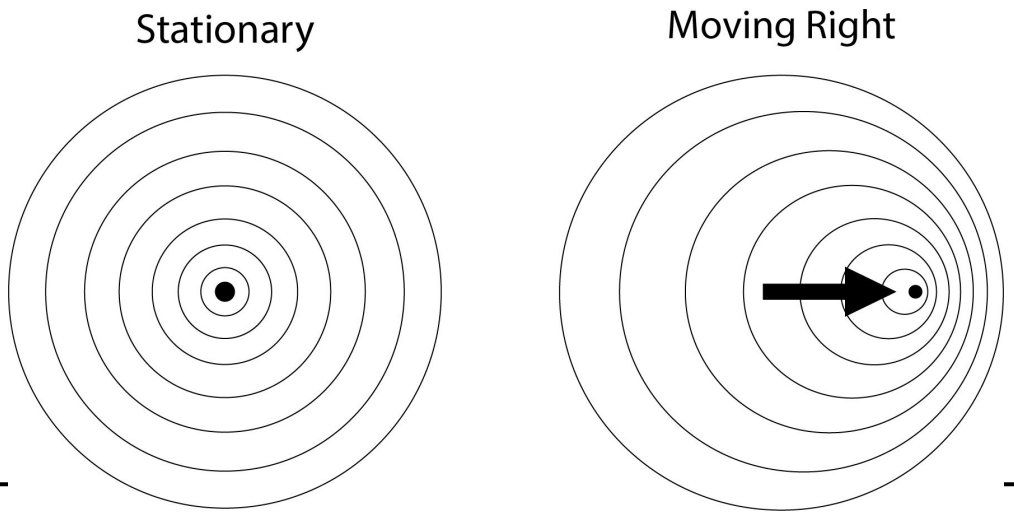
Introduction and Background

What is the Doppler Effect?

The change in frequency of a wave because of the movement of its source (Ex. Siren changing pitch as it passes by).

What causes the Doppler Effect?

Waves are compressed/extended based on the direction and speed of the source's movement.



Doppler Effect History

The Austrian mathematician and physicist, Christian Doppler, developed the theory in 1842 to explain the colours of binary stars. To test Doppler's theory, the Dutch meteorologist Christoph Ballot in 1843 hired 15 trumpeters with precisely-tuned instruments to play on a train as it passed by stationary musicians. The pitch dropped as expected.

Formula for the Doppler Effect

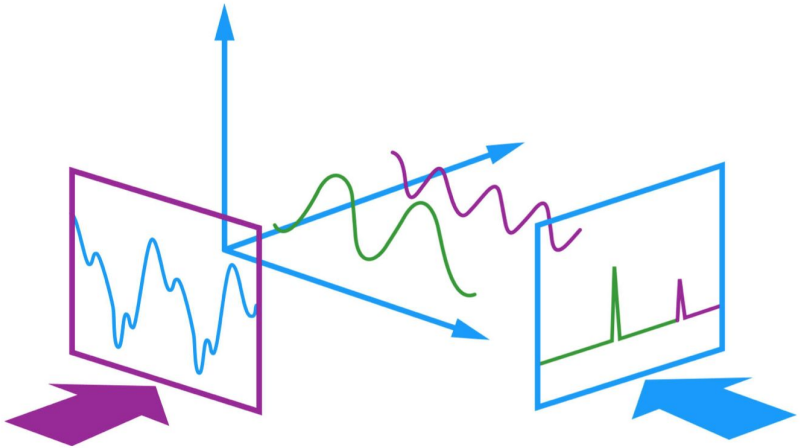
The formula for the Doppler effect is:

$$f' = \frac{343f}{343 - v}$$

f’ is the observed frequency, f is the original frequency, 343 is the speed of sound, and v is the speed of the source.

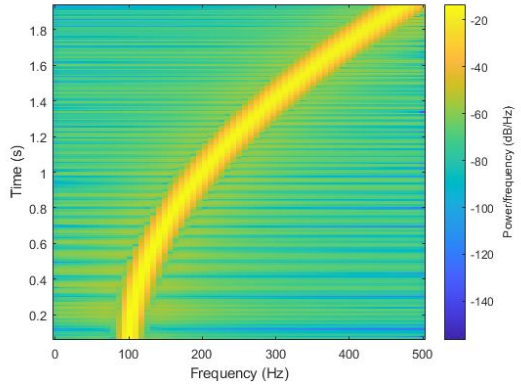
Analyzing Sound Data: Fourier Transform

Sound data is analyzed using the Fourier Transform. It takes a sound signal and figures out which frequencies are present.



Analyzing Sound Data: Spectrogram

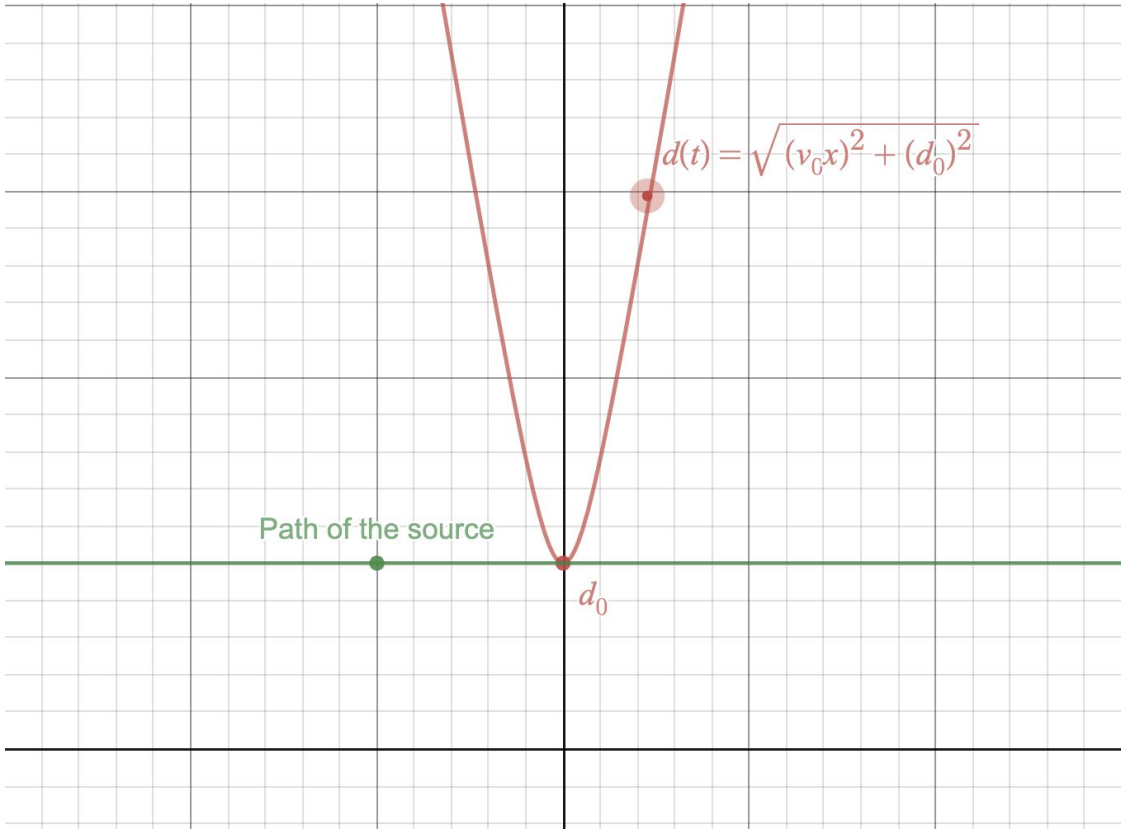
The spectrogram is a tool which uses the Fourier Transform to visually represent the changing of frequencies over time. Here is a free online spectrogram.



Modelling the frequency of a passing car

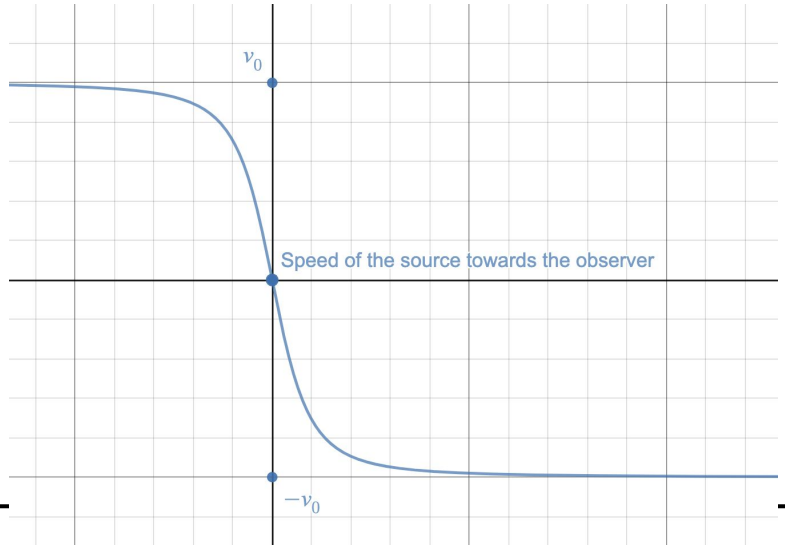
What does the ‘v’ in the formula actually mean?

In the formula for the doppler effect, the variable ‘v’ is really asking how quickly is the source moving in your direction. Since v = d/t, the first step is to determine a formula for the distance between the source and the observer at any given time.


$d(t) = \sqrt{(v_0 x)^2 + (d_0)^2}$
Path of the source
d_0

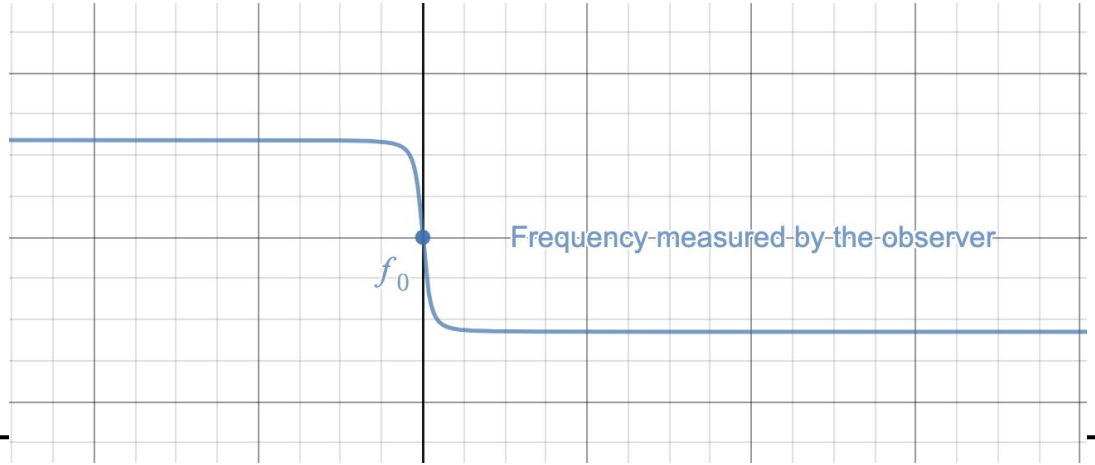
Coming up with a formula for the speed

Given our formula for distance, we can now derive a velocity time graph by taking the first derivative.



Putting it all together

Now that we have a function for velocity, we can plug it back into the original doppler equation to get our model for the frequency of a passing car.



Hypothesis

Hypothesis

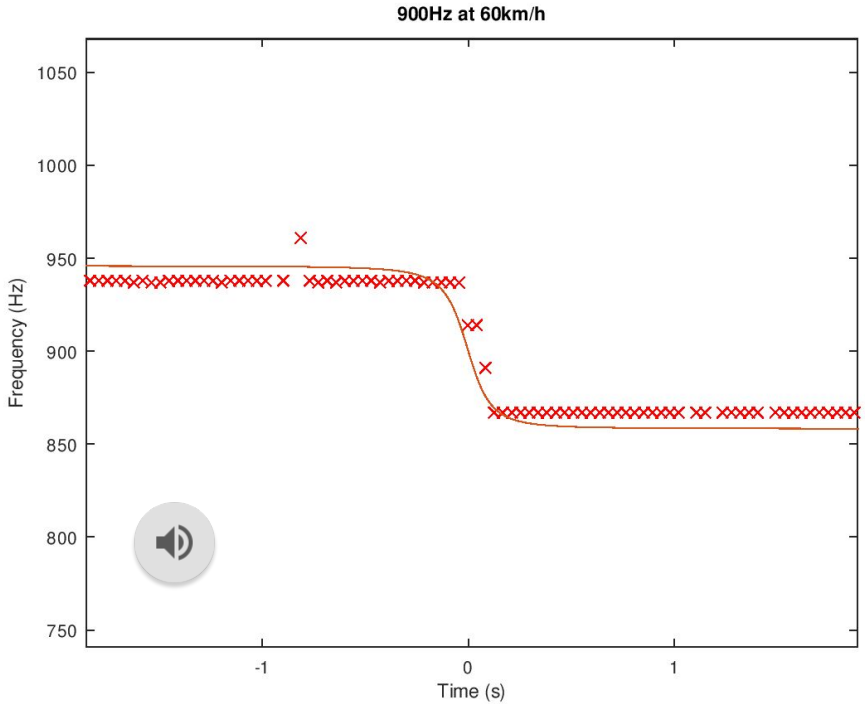
The hypothesis that we will try and prove is that

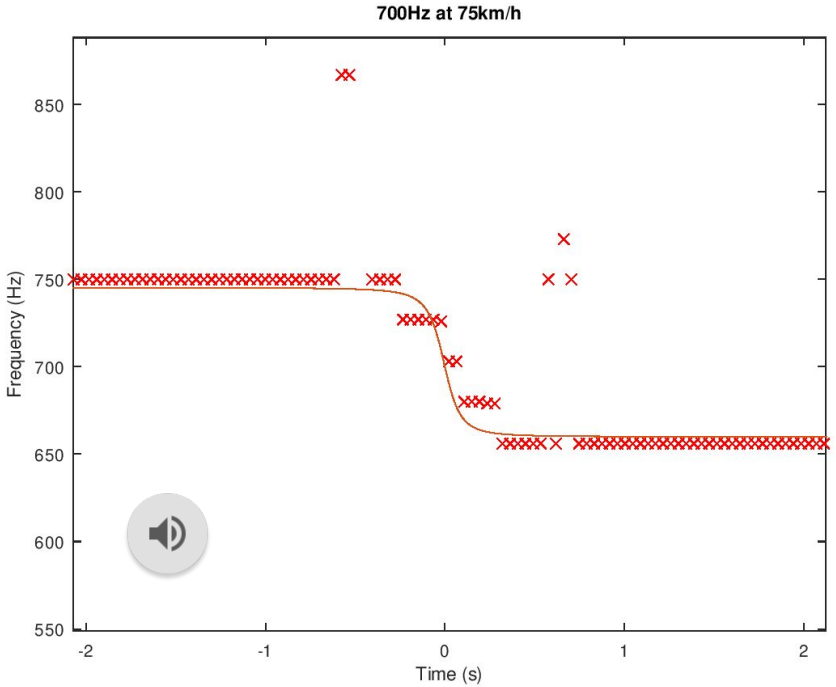
$$f' = \frac{343f}{343 + \frac{v^2 t}{\sqrt{(vt)^2 + d^2}}}$$

is an accurate model of the frequency of a passing vehicle.

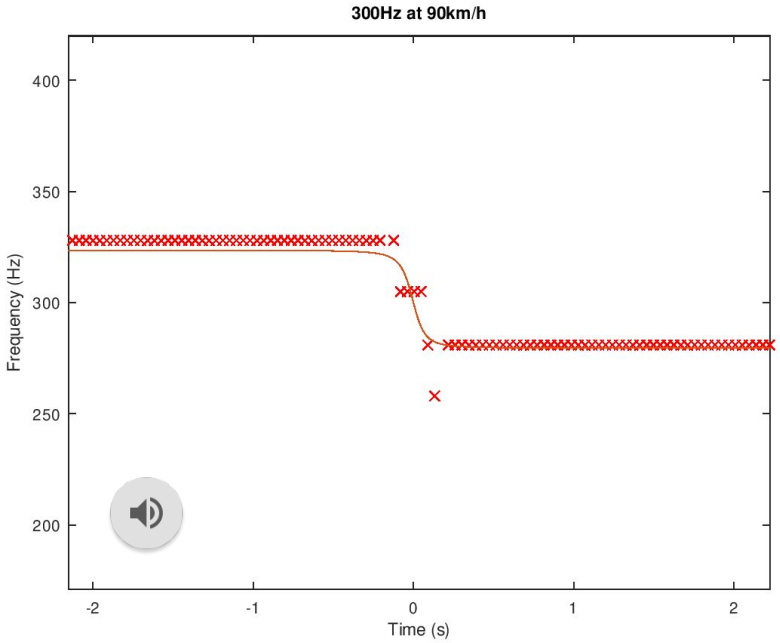
Results

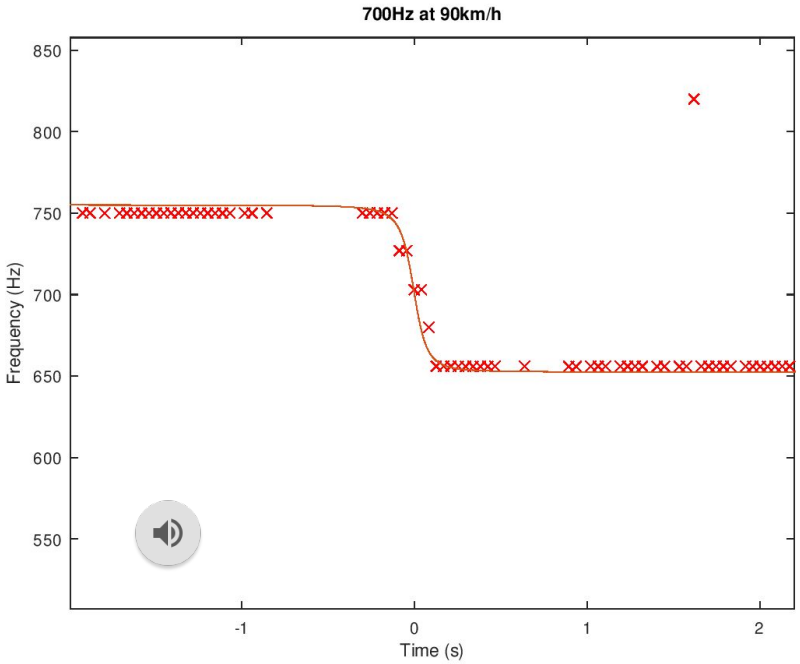
The Experimental Data: Sound files



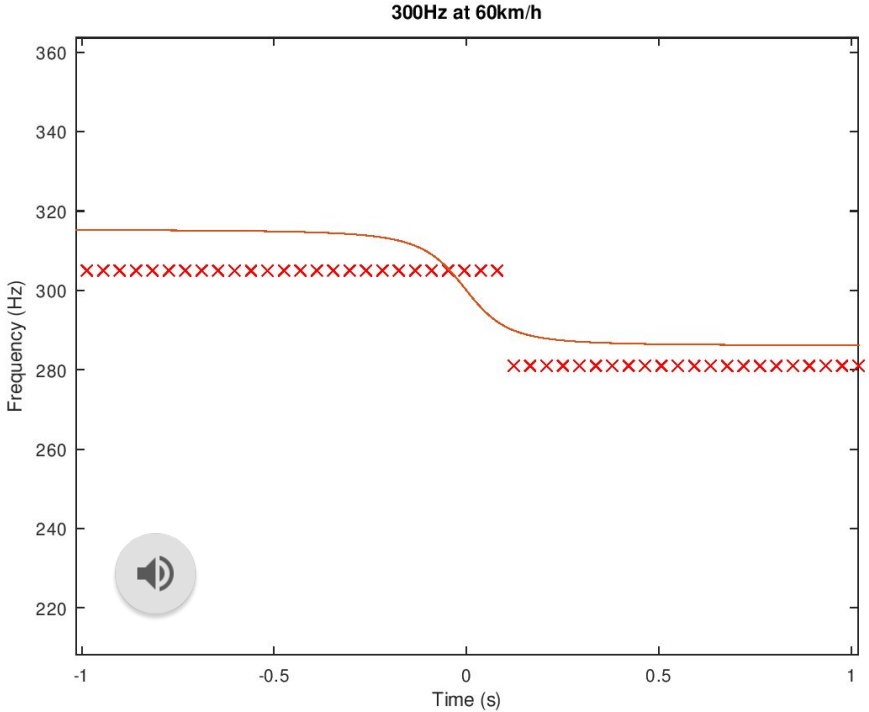


More nice samples

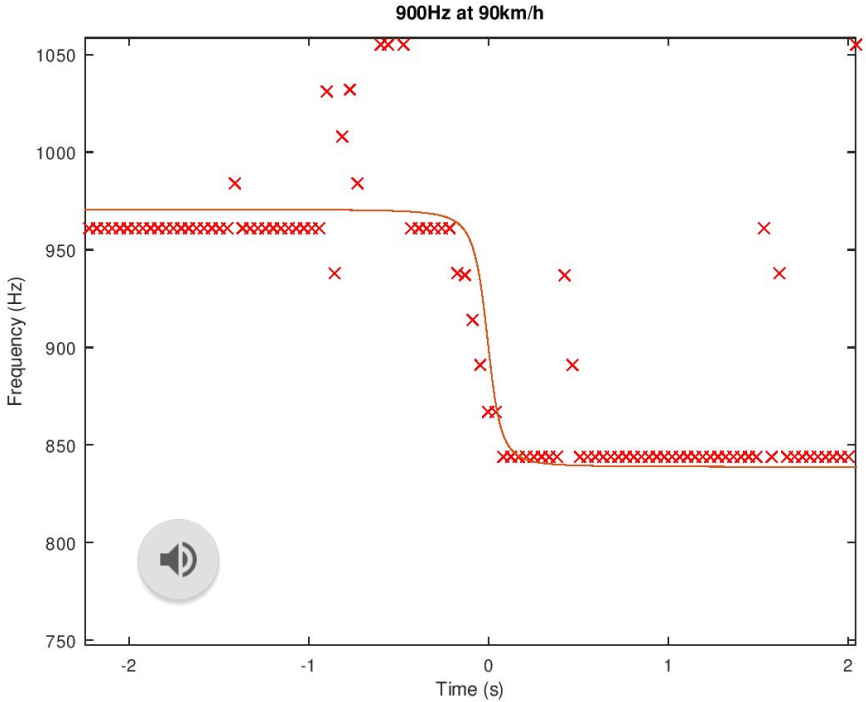




The not so nice samples

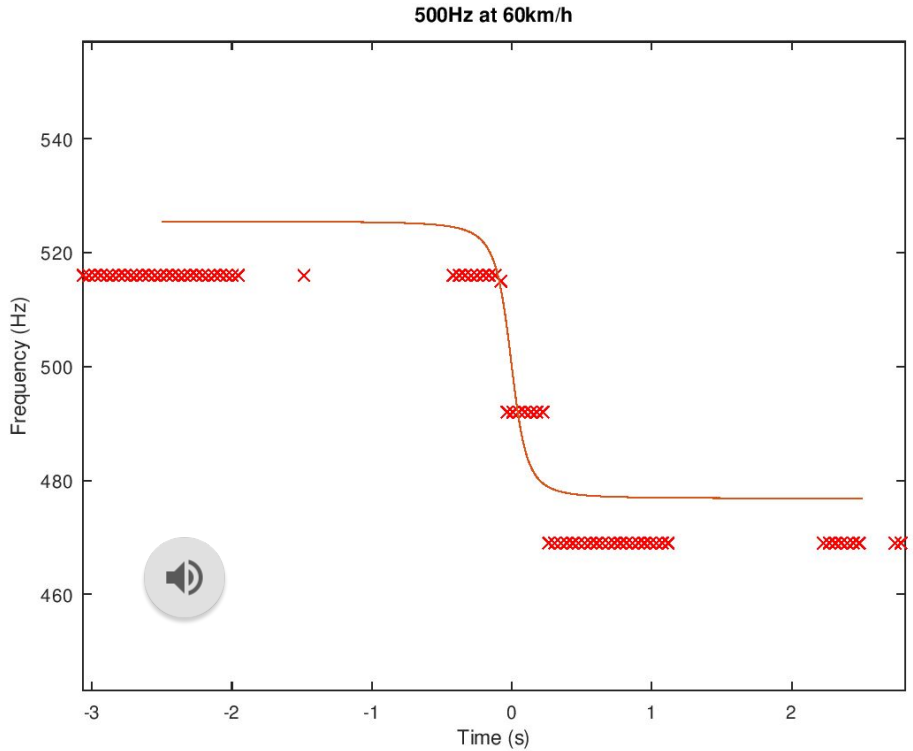


Cause: Fourier Transform Limitations



Cause: Simplification Algorithm

The worst sample...



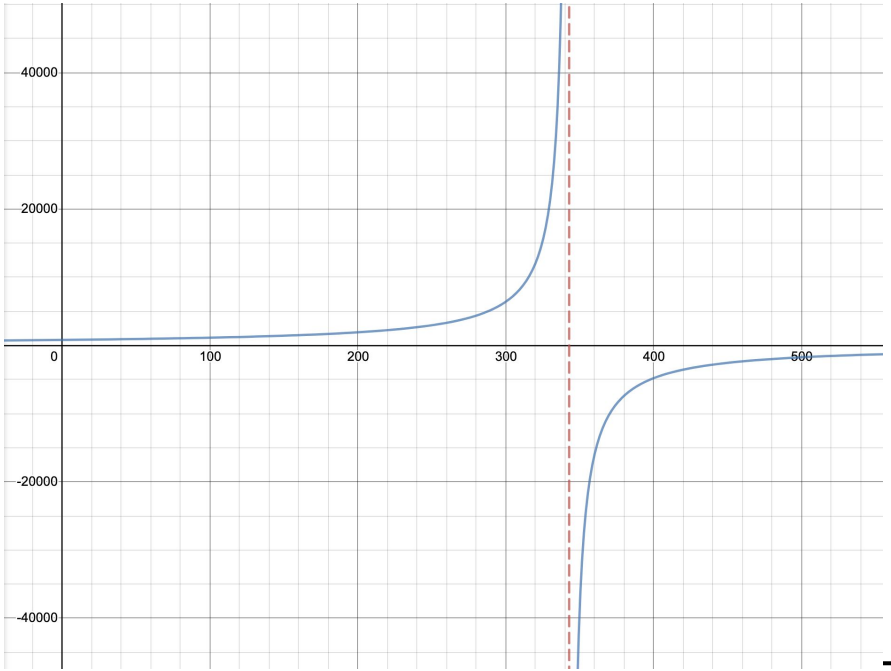
Triple Whammy: Wind, Simplification Algorithm, and Fourier limitations

Conclusion:

The hypothesis was proven to be correct! Most of the samples worked quite nicely, with practically 0 error, and even the worst sample was only off by 10Hz.

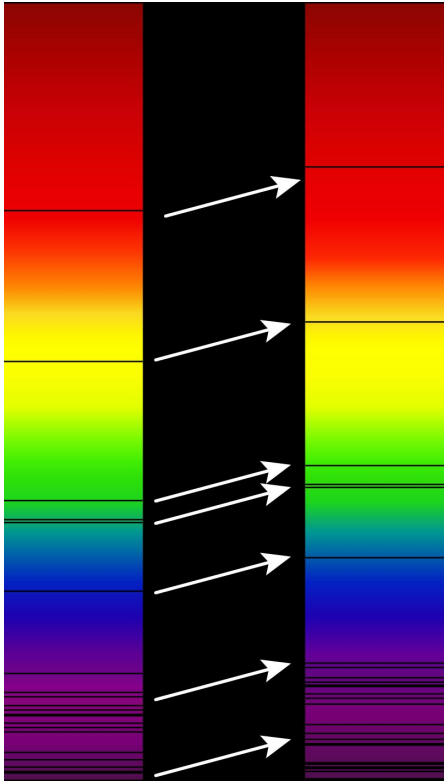
Analysis and Connection

Doppler effect, the Sound Barrier and Supersonic flight



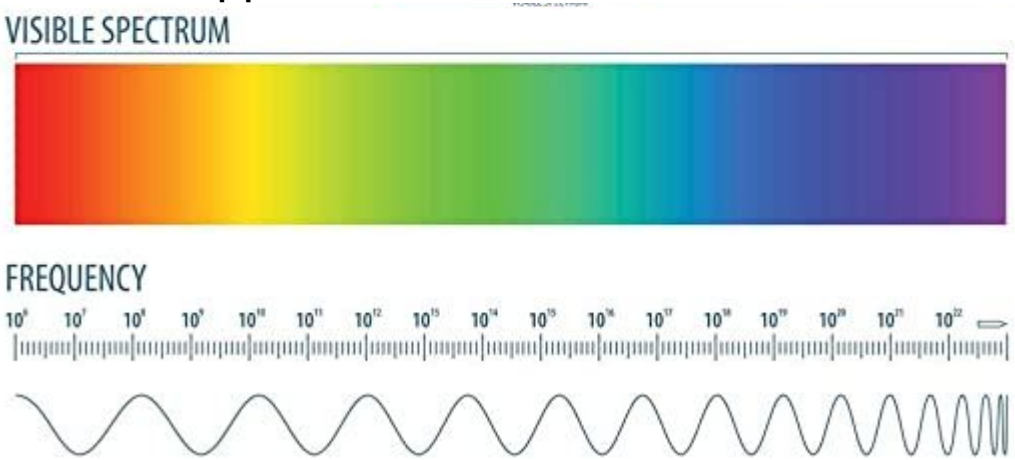
The formula for the doppler effect predicts the sonic boom which happens when you travel at the speed of sound. It explains why the sound barrier is so hard to cross. It also tells us that you couldn't hear a supersonic vehicle approaching you.

More on the Sonic Boom

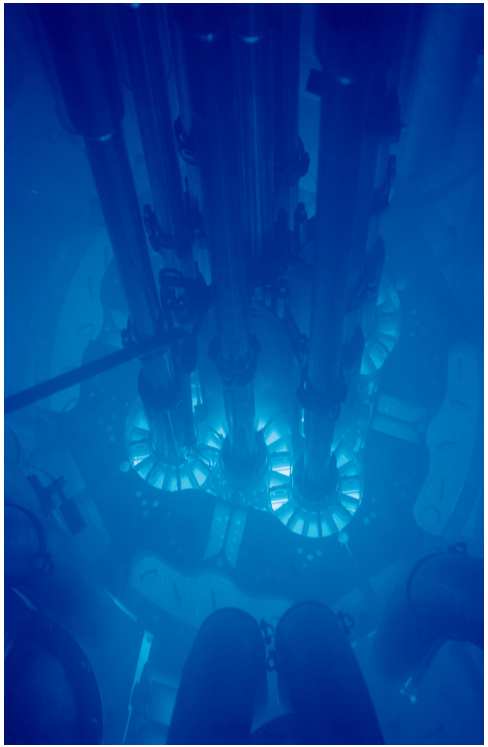


Redshift

The redshift is a phenomenon where stars who are moving away from us appear more red than they should. This is crucial evidence that the universe is expanding. The color changes because of the doppler effect.



Cherenkov Radiation



Perhaps the coolest phenomenon in this list. This is when subatomic particles travel faster than light in a medium (ex. water). This is analogous to a sonic boom, but with light! This is why nuclear reactors emit a blue glow.

Further Resources

Question? Comments?

Thank you!