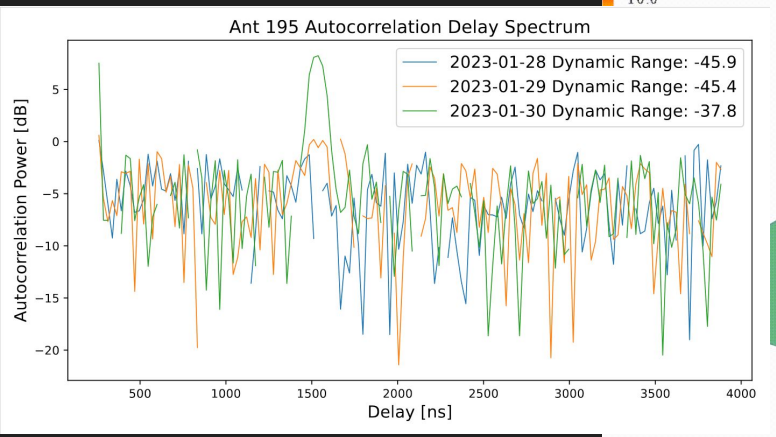
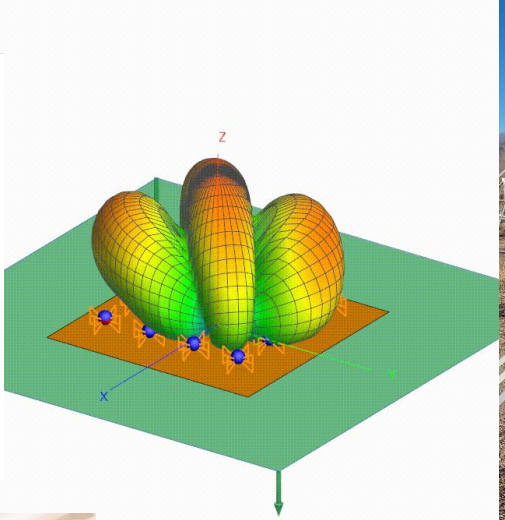
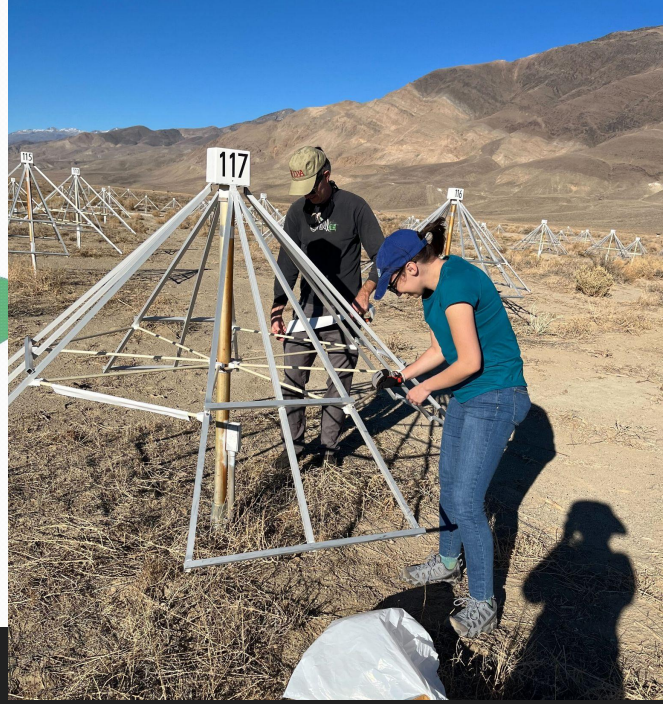
RA Bootcamp 2023

Day 3- Data Processing







2018 Summer Internship

Katherine Elder

3rd year PhD Candidate (Astrophysics)
B.S. Physics, CSU Fresno
Started as a 2018 summer intern at LoCo!
Projects: OVRO-LWA, MWA
I mostly make plots with wiggles on them

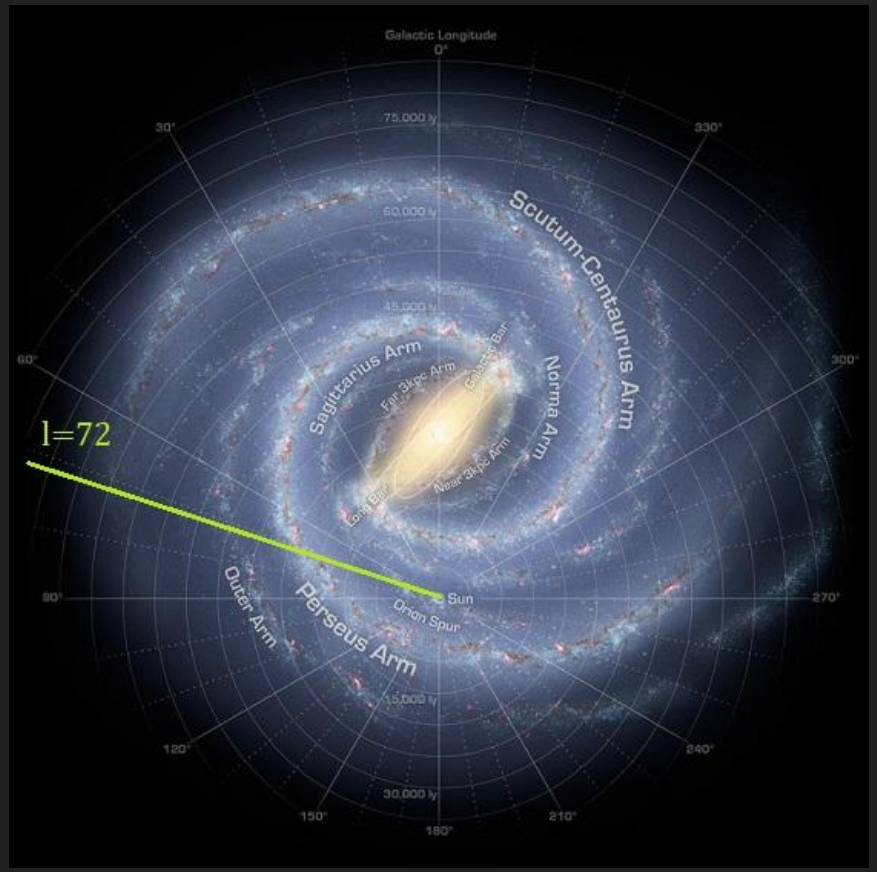
What data will we be looking at?

- Downtown Phoenix
- Zenith Pointing
- Scans over 1417-1422 MHz
  - Observation (sky) vs Control (ground)
- What will we see?
  - Board art!


StellariumWeb
Search...
FOV 185°
OBSERVE
Sun
Venus
Saturn
Jupiter
W
Vega
E
Uranus
Arcturus
Pleiades
Capella
NEAR PHOENIX
17:32:26
2022-11-21

Where are we looking?

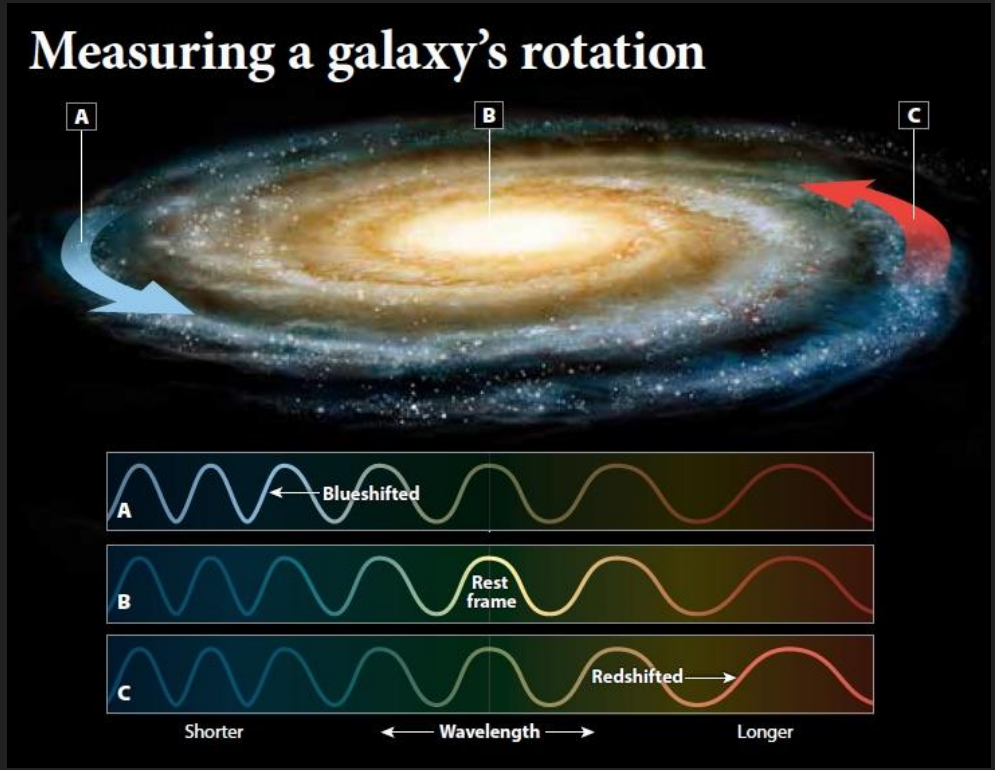
- Line of sight
- Looking for hydrogen
  - 21 cm line
- Where will the line be in your spectra?
  - More board art!



Doppler Effect

Observed frequency

$$f = \left(1 + \frac{\Delta v}{c}\right) f_0$$



Open your data!

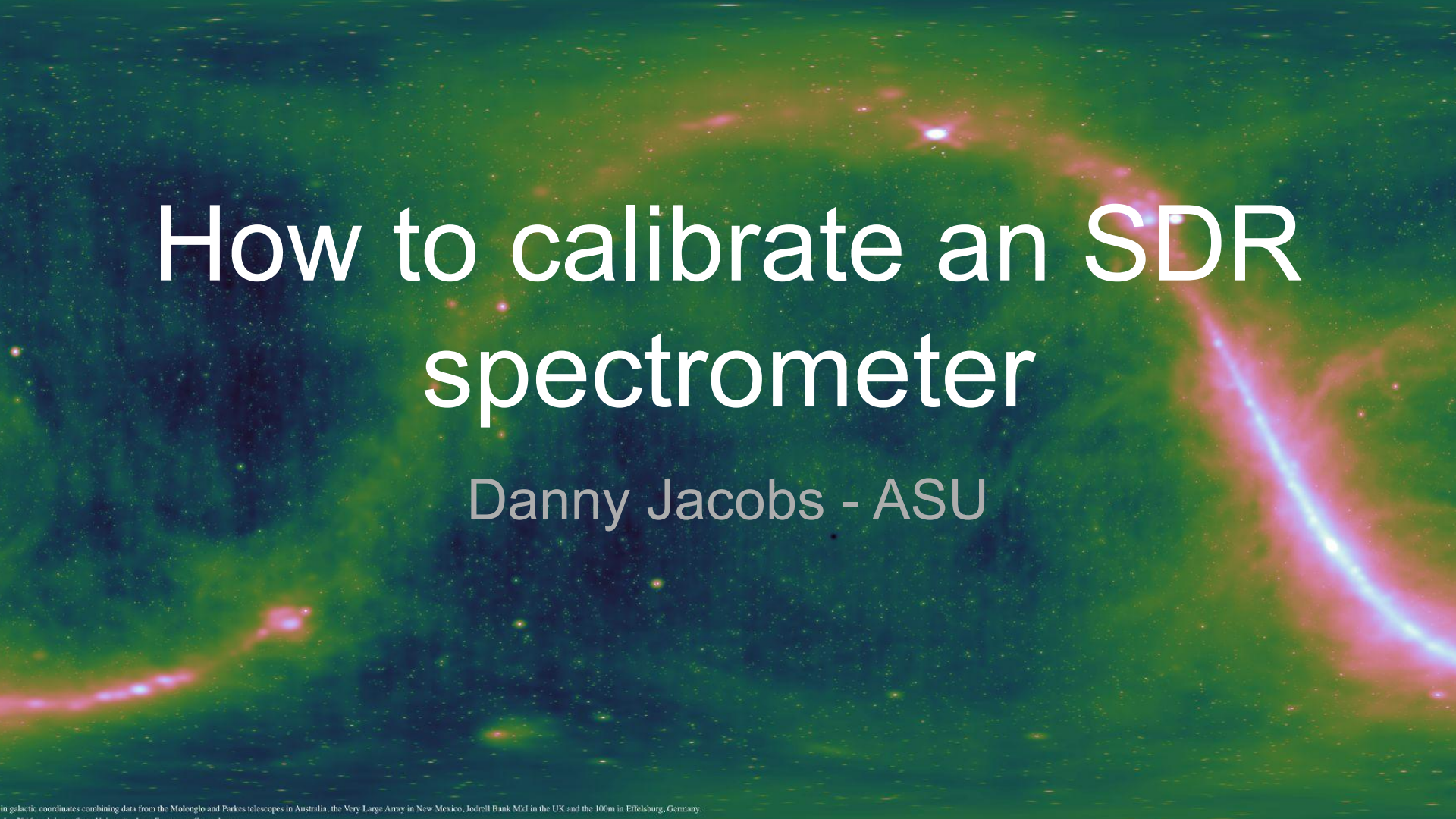
Log into enterprise.sese.asu.edu/jupyter
Uname: locouser#
Pass: bootcamp2024

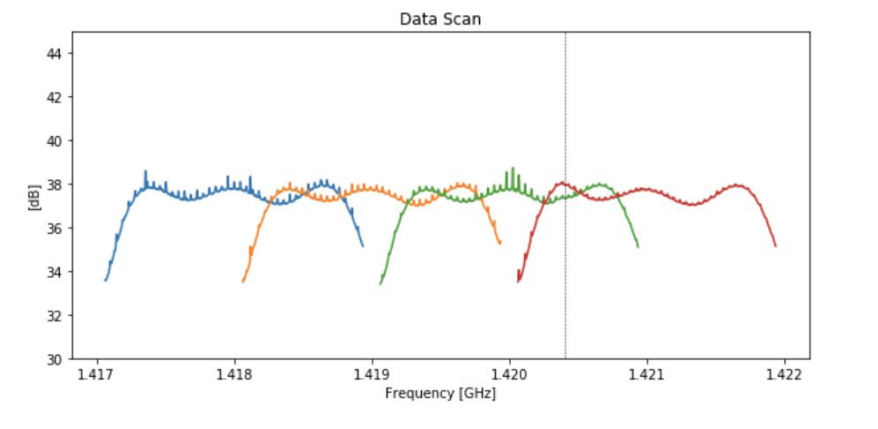
Open the notebook at /data/ra_bootcamp_day3.ipynb

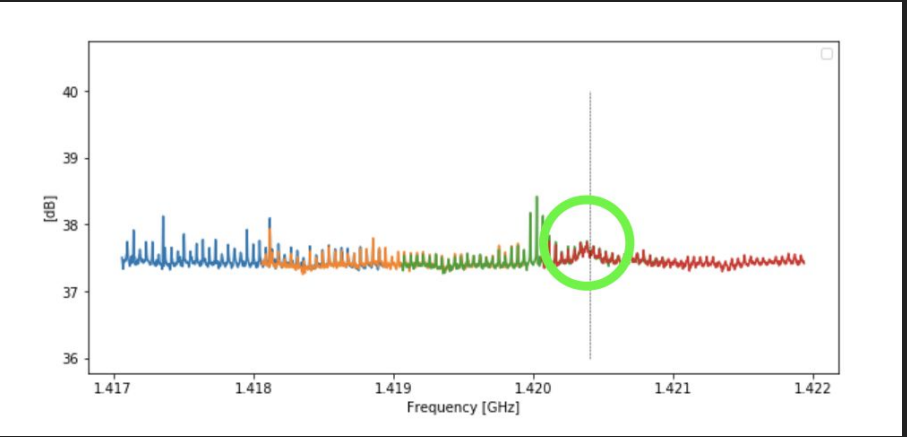
Run cell 1, 2, and 3. Does it look like you expect?

How to calibrate an SDR spectrometer

Danny Jacobs - ASU







How to get from this

To this!

What is G?

$$P_M(f) = G(f) P_T(f)$$

Each of these have a gain as a function of frequency!

Beware the mixer which moves things around!

Collects our photons!

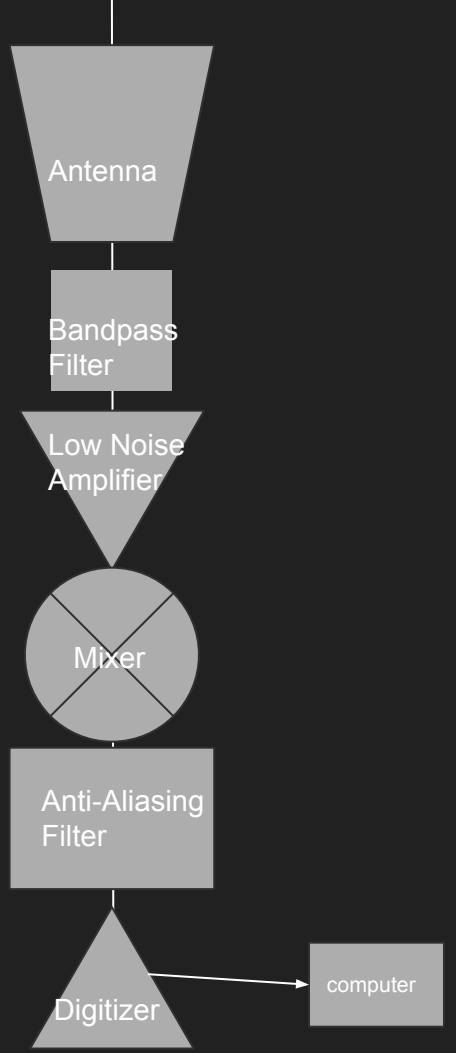
Filters out the cell phones and what not, before they get to the LNA

Embiggens those small signals, tries not to add noise

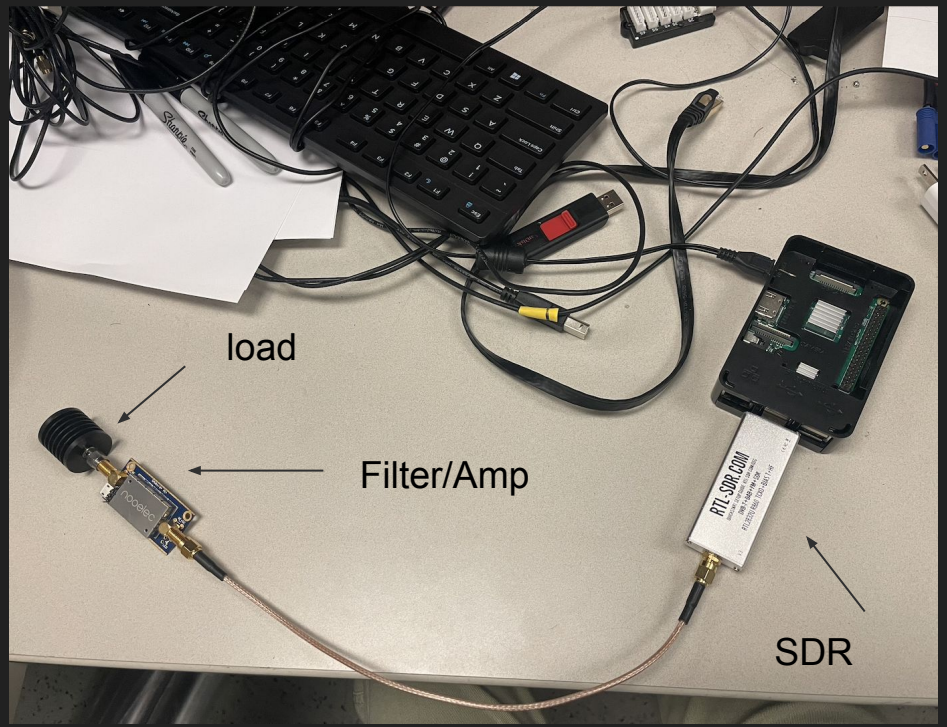
Moves our band from GHz (fast!) to MHz (slow)

Reject signals too fast for our digitizer

Convert from voltage to 1s and 0s

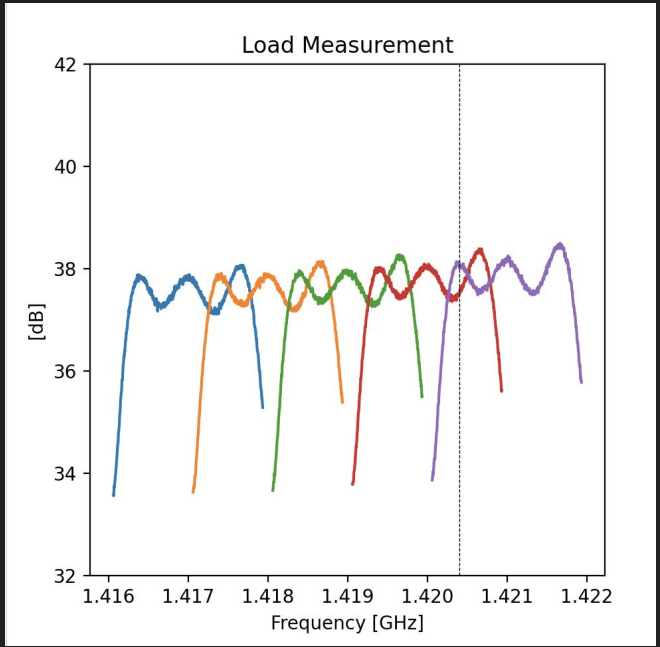


The answer is “Bandpass Calibration”



Write down a physical model of the system.
It has some unknowns
Put in a known input, solve for the unknowns.

Step 1: Physical model



A spectrum of a 50Ohm load (ie a resistor!)
Physics says it should be nice and flat.

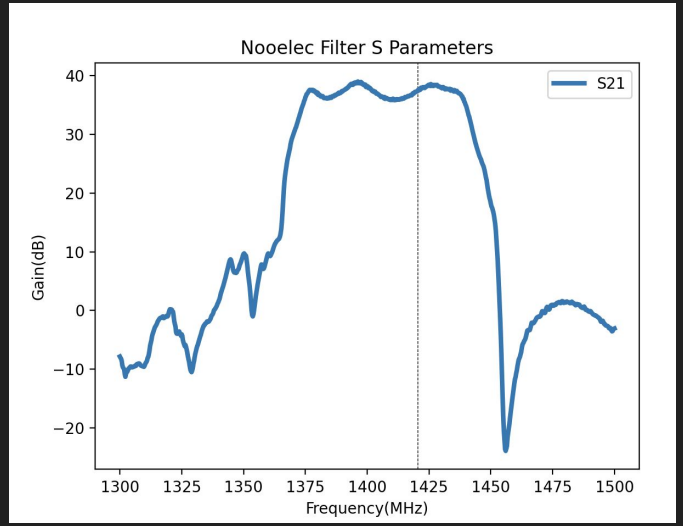
What are the dependent and independent variables?

$P_M(f) = G(f)\, P_T(f)$

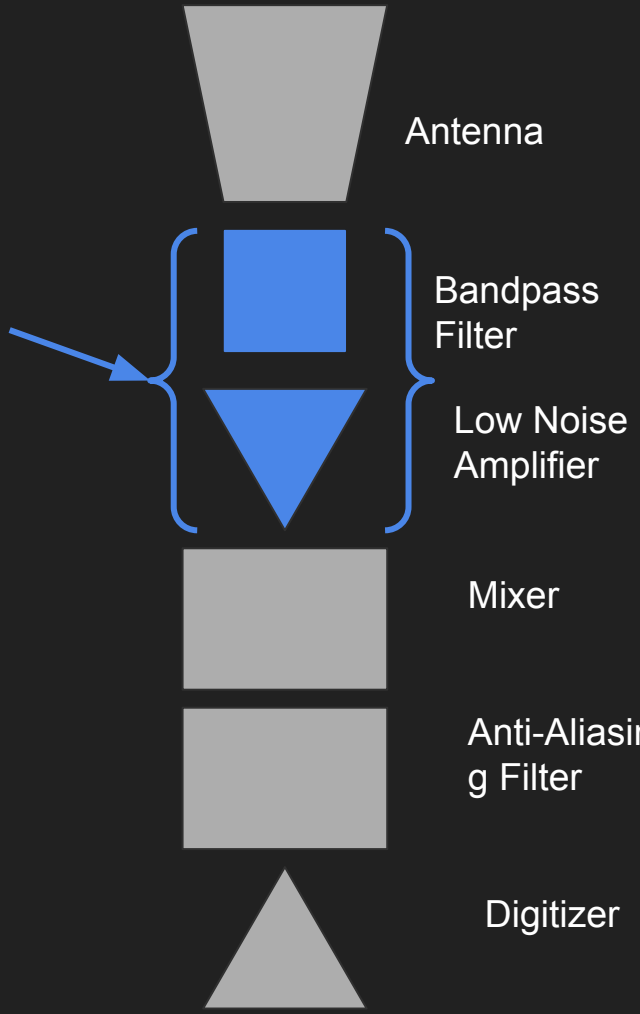
Measured power Gain True Power

All as a function of frequency (f)!

LNA Passband

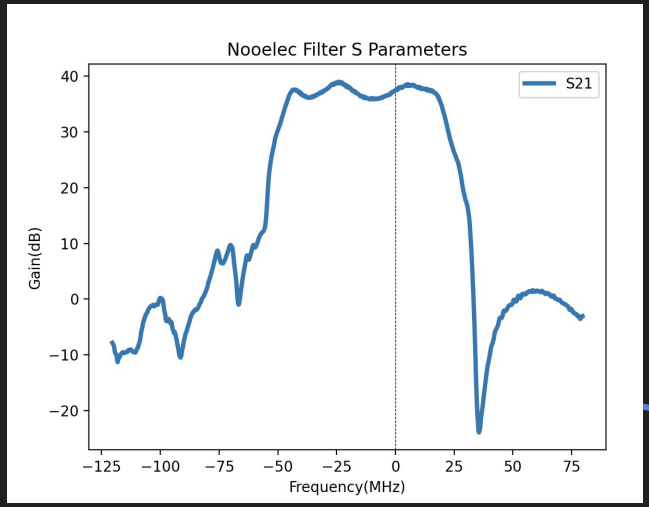


Bandpass Filter gain vs Frequency



dB(x) = 10 * log10(x)
note x must be a unitless ratio quantity!

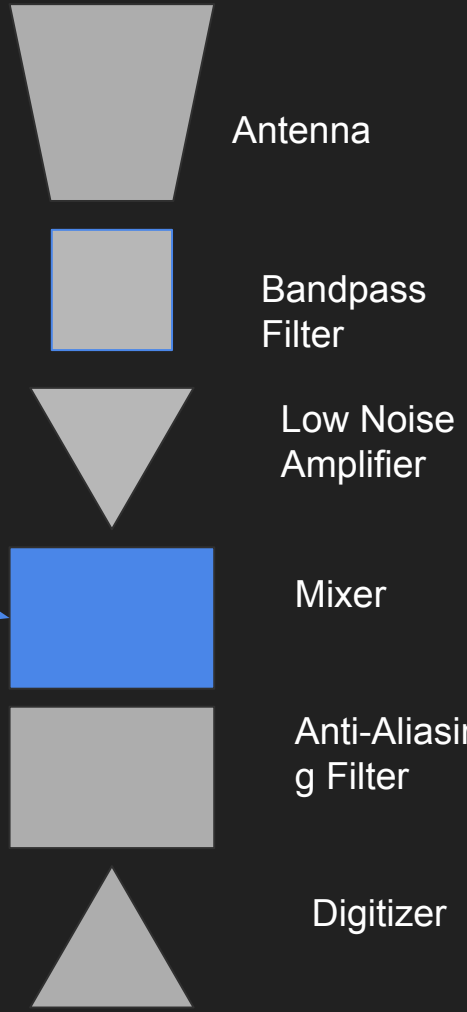
Mixer brings the band down local 0MHz



Mixer brings our band of interest closer to 0MHz

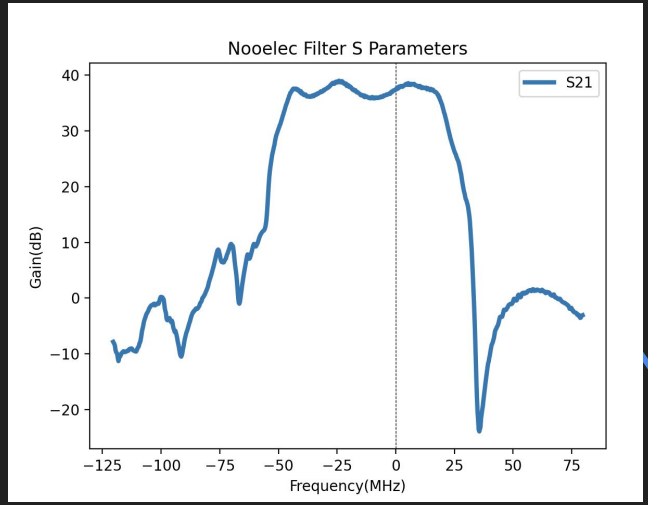
Mixer moves us down to a range the ADC can actually sample

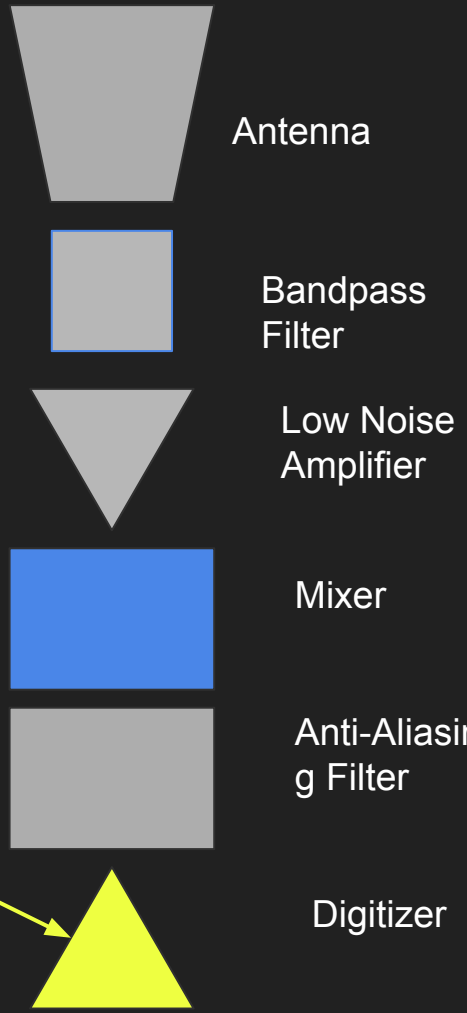
“Input x Local Oscillator = Baseband”



Down with Aliasing

Bandpass filter… passes… us 200MHz of bandwidth!



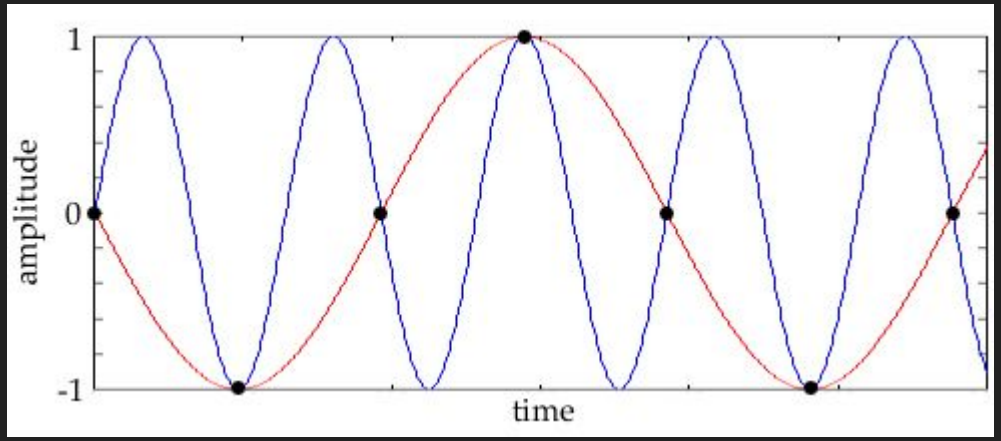


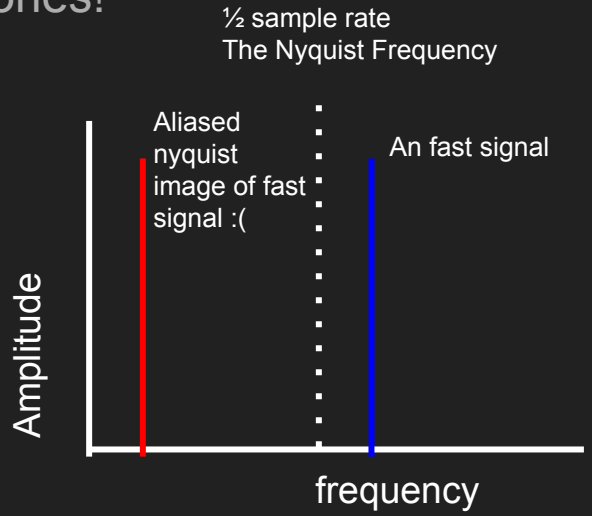
The Milky Way is <1Mhz wide.
The RTL-SDR can sample 1.8MHz, but not 200MHz.
Enter the humble Anti-aliasing filter

Reminder about Nyquist Sampling

ADC can only sample so fast!

Signals faster than ½ the sampling rate look like slow ones!



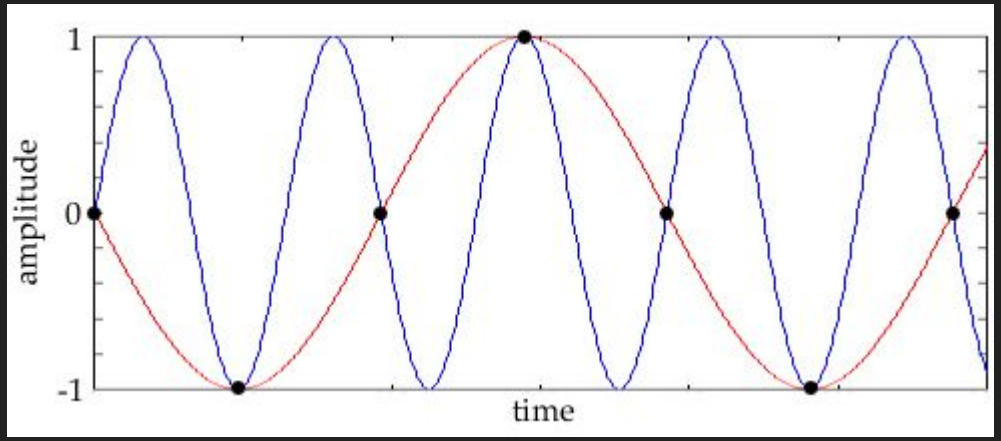


Fast Signal (blue) _looks_ identical to a Slow one (red). As far as the measurements (black dots) can tell.

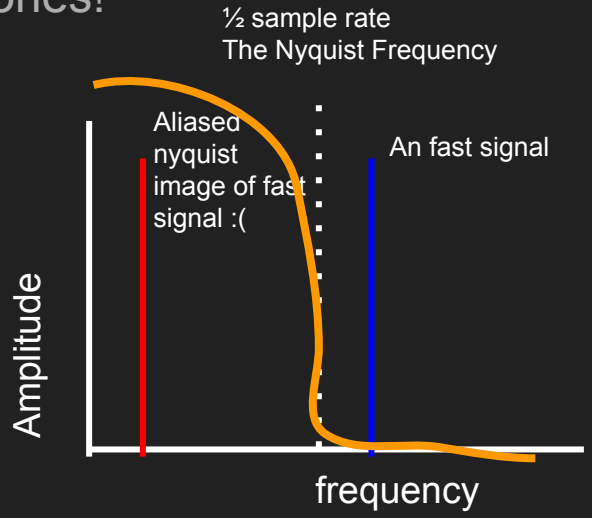
Reminder about Nyquist Sampling

ADC can only sample so fast!

Signals faster than ½ the sampling rate look like slow ones!



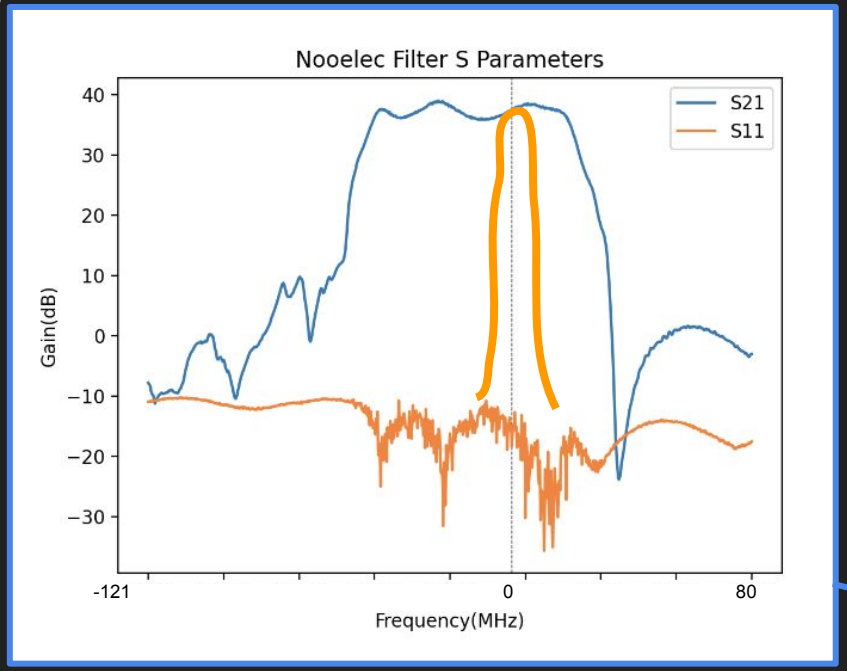
Fast Signal (blue) _looks_ identical to a Slow one (red). As far as the measurements (black dots) can tell.

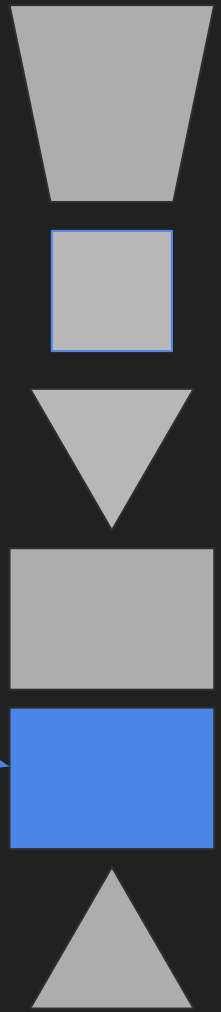


Anti-Aliasing Filter!
Only the slow enough to sample shall pass.

Anti-Aliasing Filter

f_sample wide





G Summary

$P_M(f) = G(f) P_T(f)$

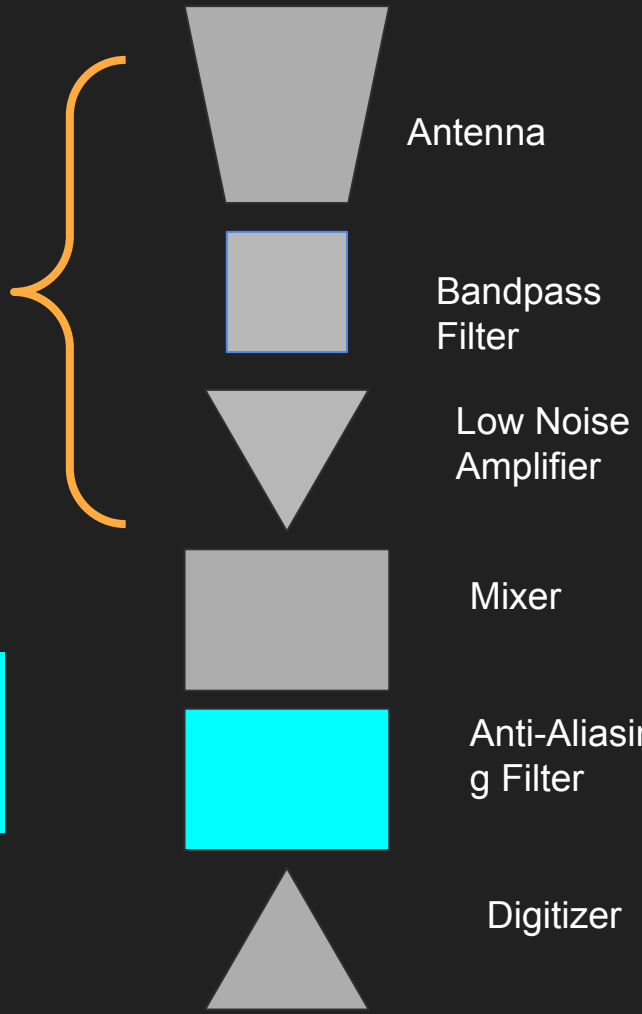
G_A

$G(f) = G_A(f) G_{anti}(f - f_{lo})$

Analog gains:
Depend on observed frequency. Vary on ~10MHz or greater scales. (can probably be modeled by a single number for the <1MHz 21cm tuning)

G_anti

Anti-aliasing Filter:
Applied at the “baseband”
Does not change with tuning.

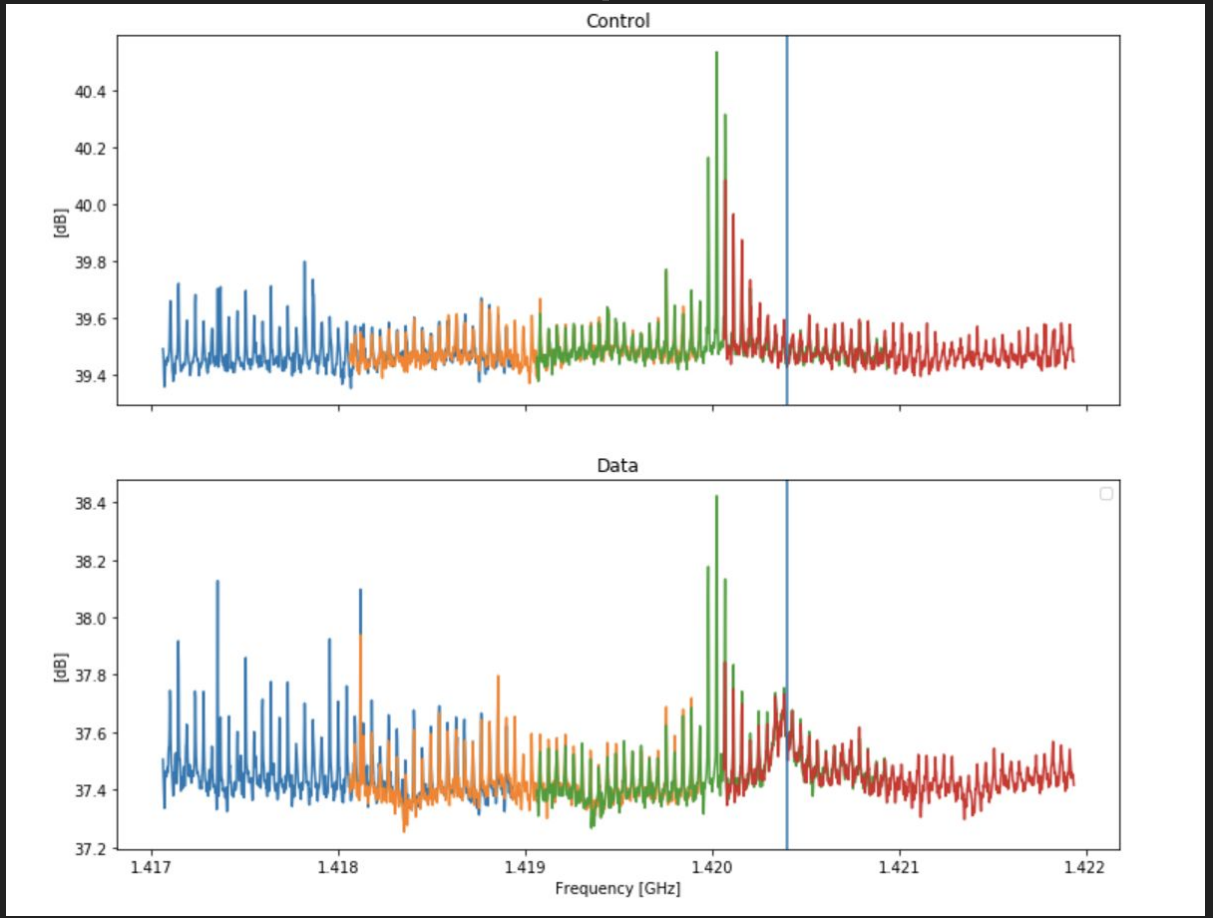


Apply bandpass cal in Jupyter

Run cells 4 and 5 in your jupyter notebook. What does your spectra look like now?

Why do we have a control spectra?

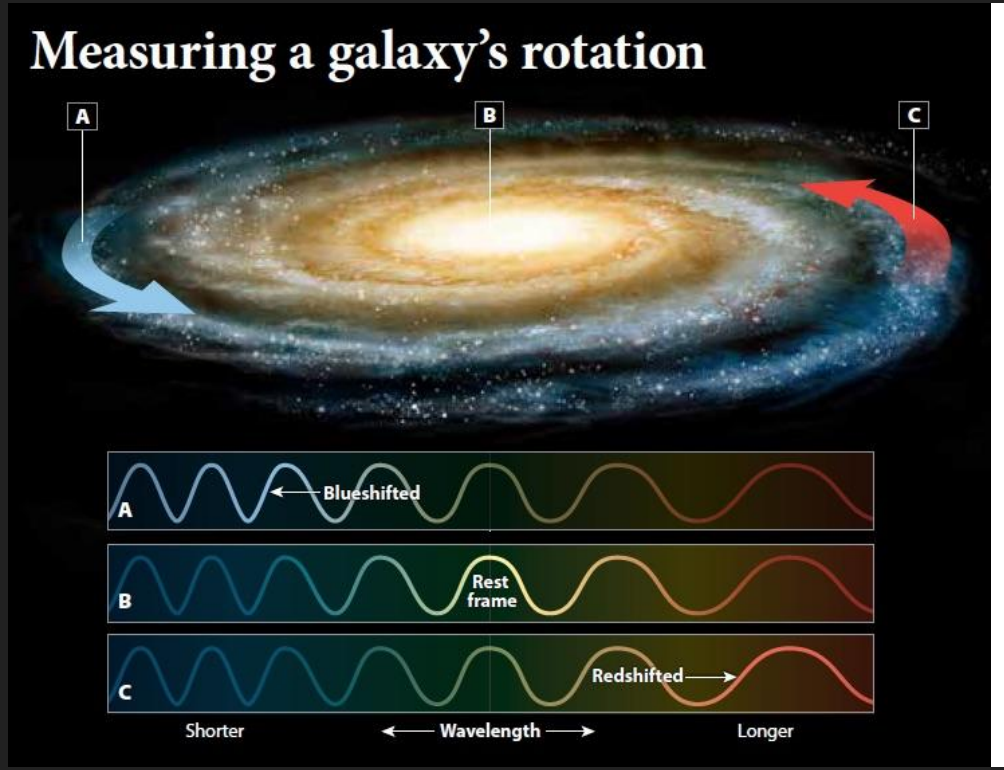
- What is in the control spectra?
- What is in the observation spectra?



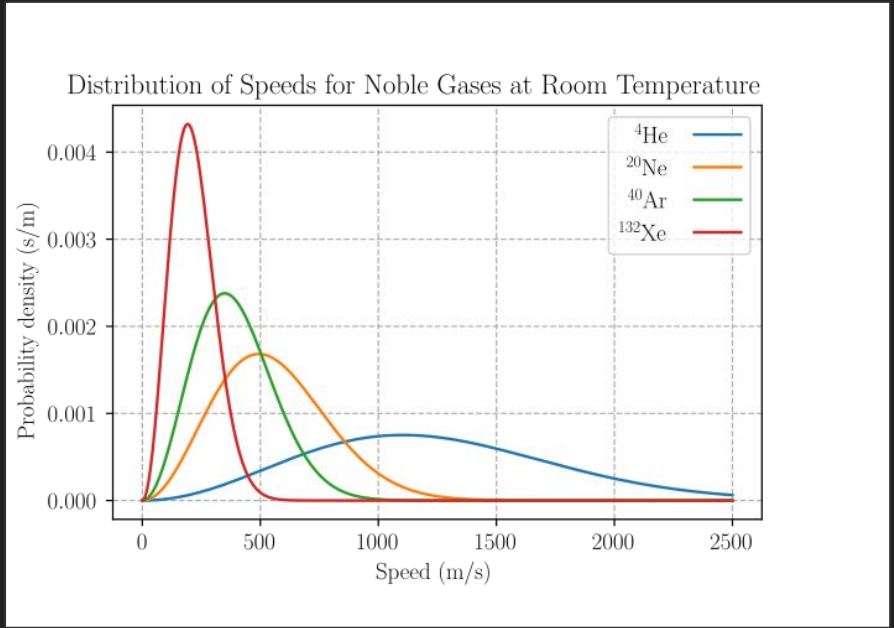
RFI vs Astronomical

- RFI = Radio Frequency Interference
- What are sources of RFI?
- What shape will RFI have in Frequency space?

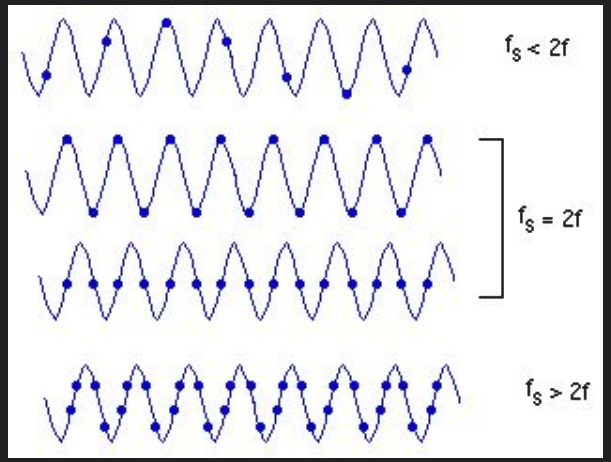
- What are astronomical sources?
- How will their shape be different?

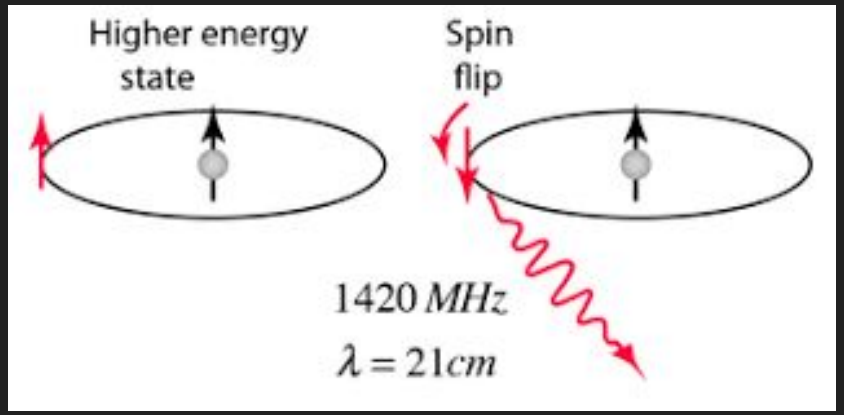


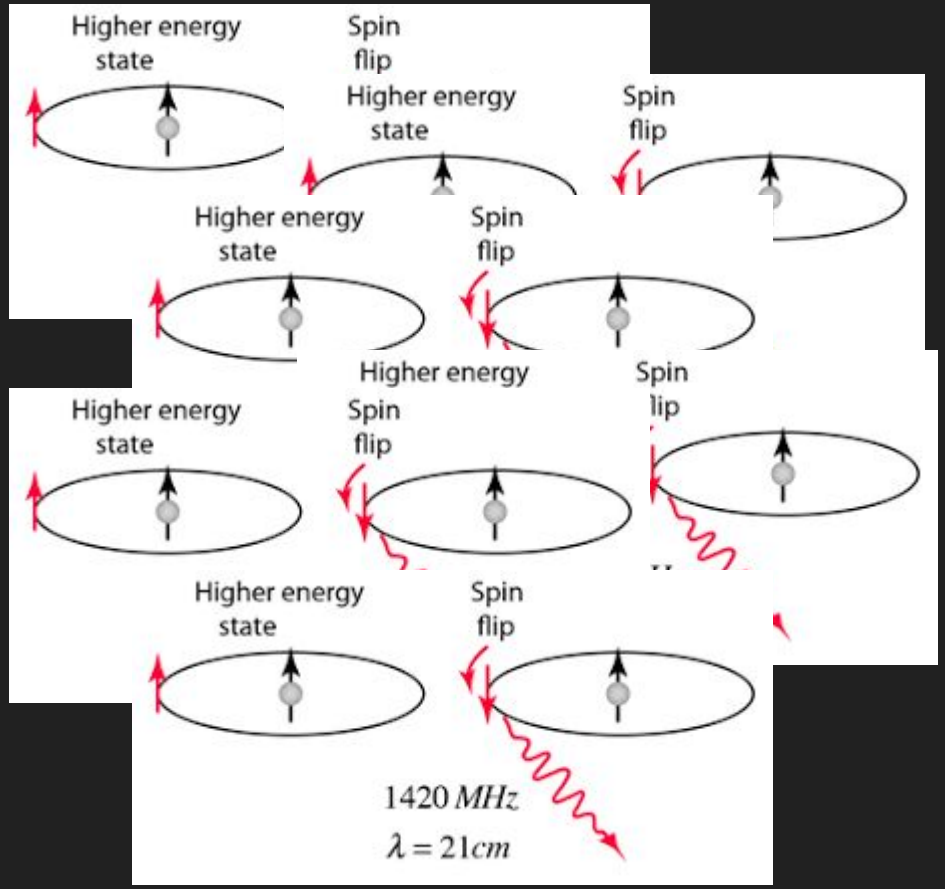
The Duality of Man (and hydrogen)



The Duality of Man (and hydrogen)

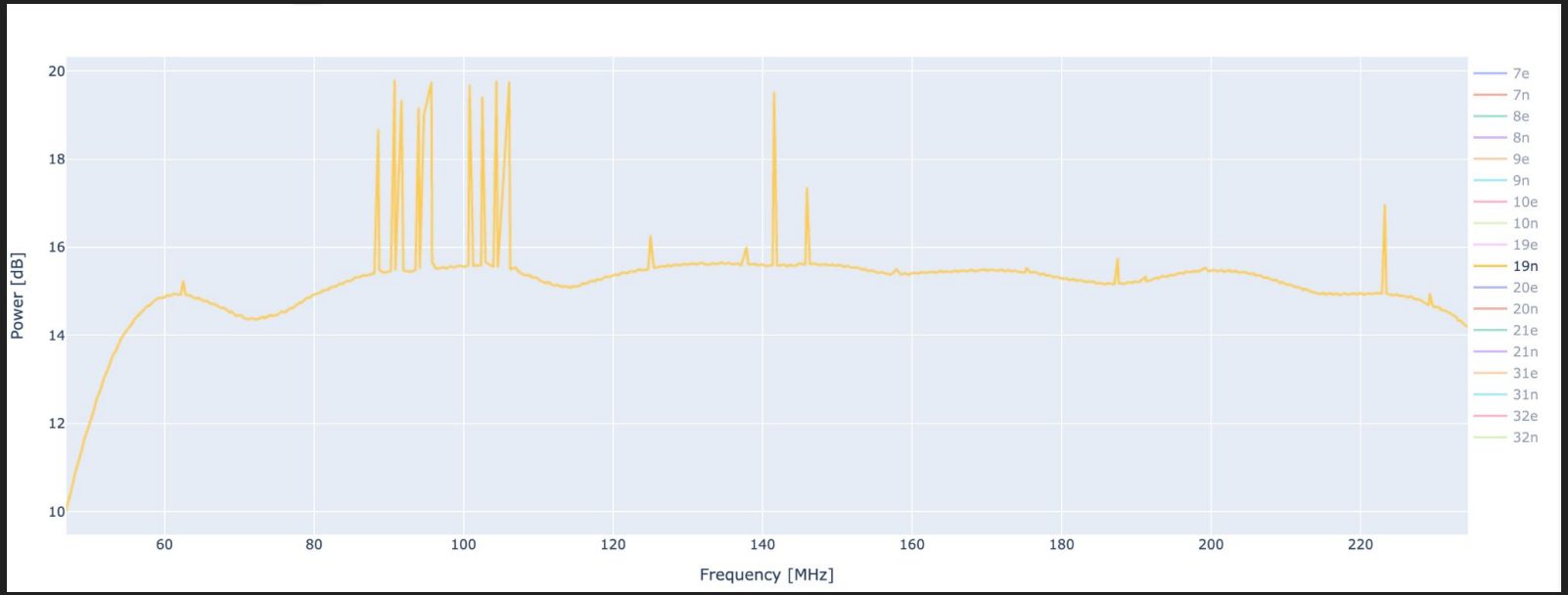




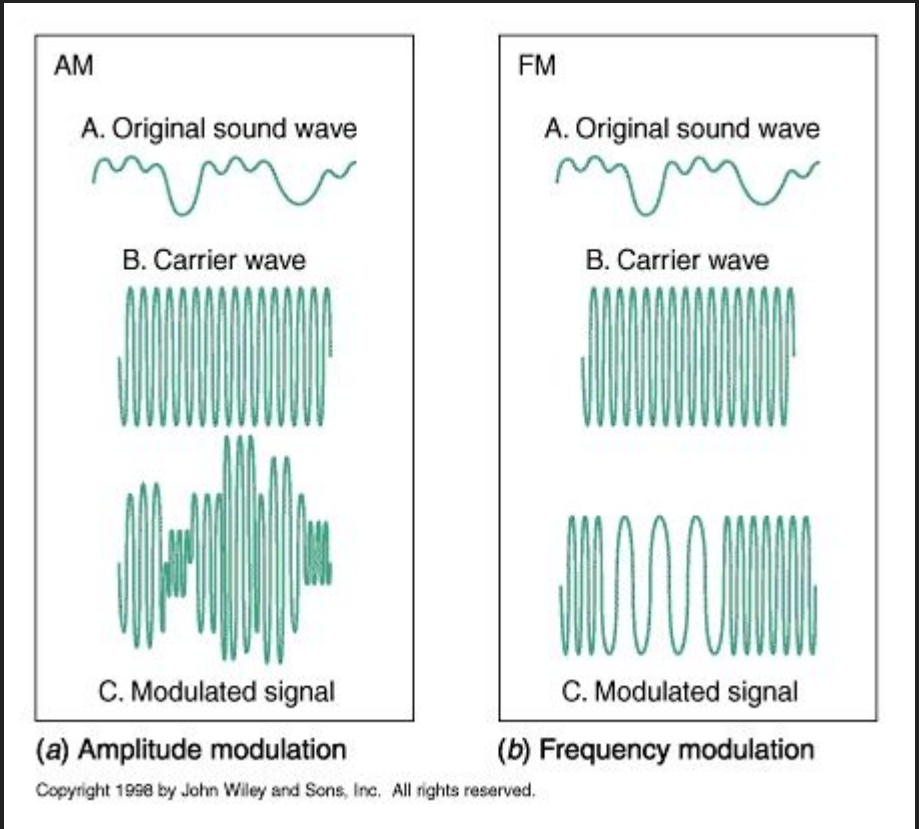


What does man-made interference look like?

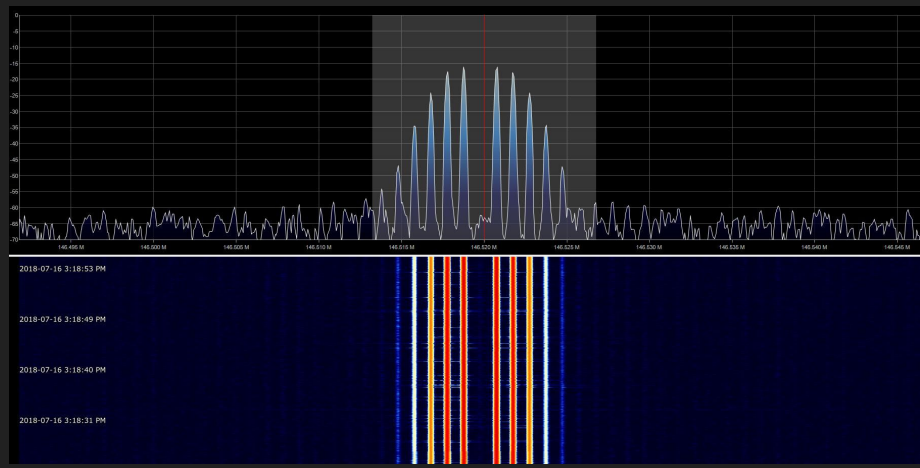
- Example case: FM Radio



Time Domain



Frequency Domain

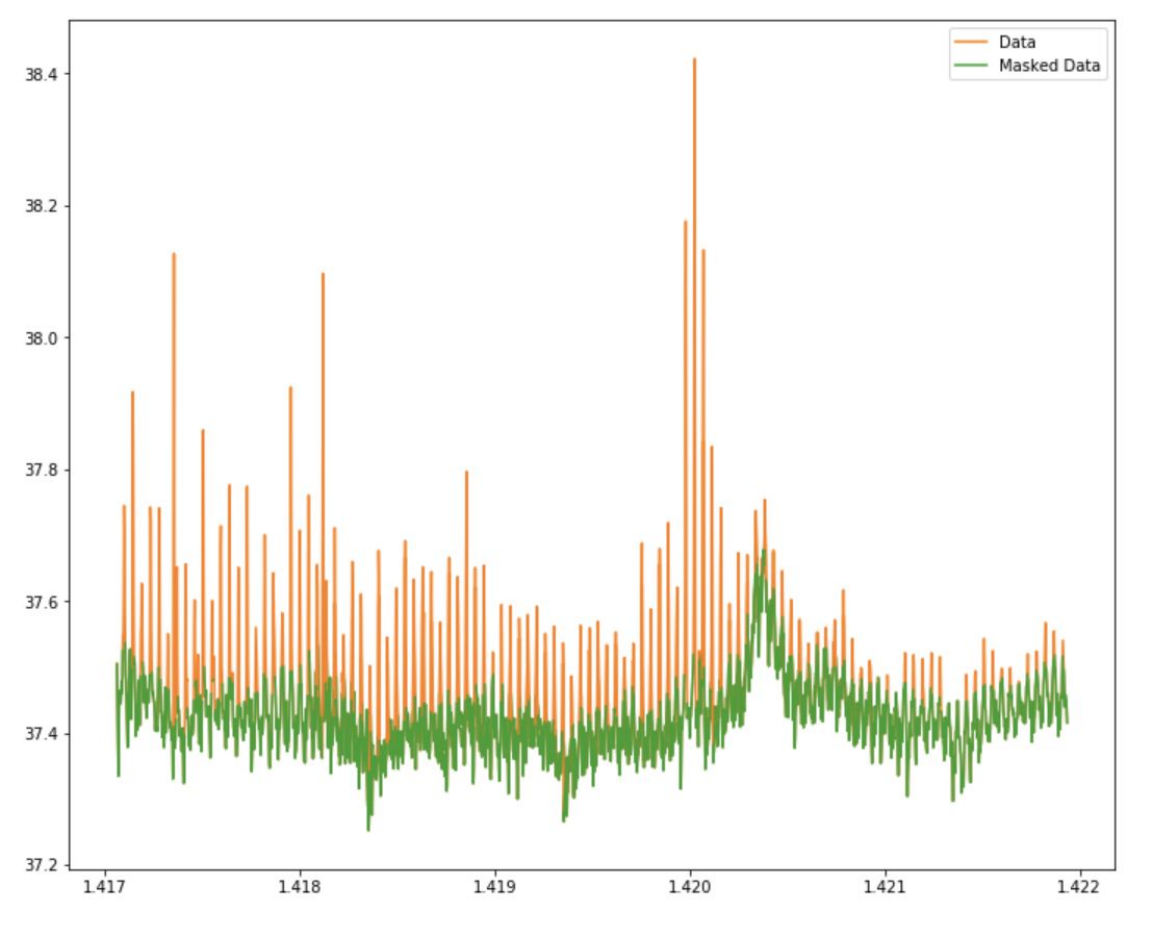


https://commons.wikimedia.org/wiki/File:Waterfall_FM.jpg

Sharp Edges!

Flagging out RFI

- Run cells 6, 7, 8 in your notebook
- How do we flag, and what are the downsides of this?
- What does a flagged spectrum look like?

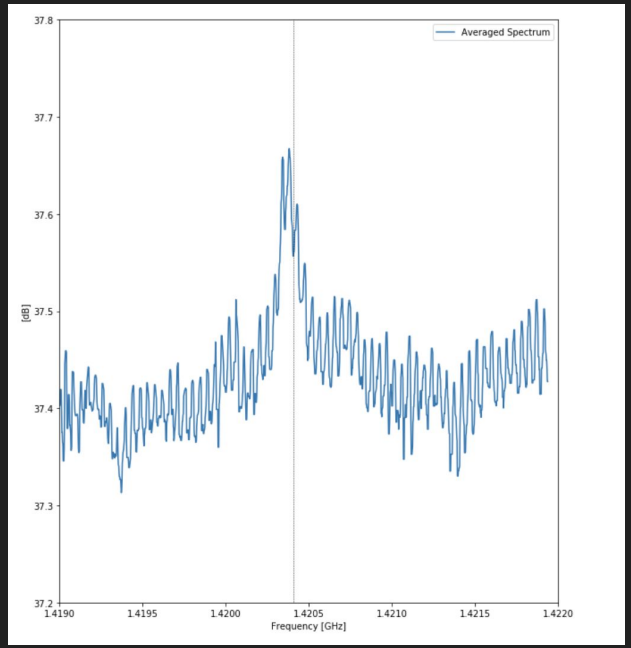


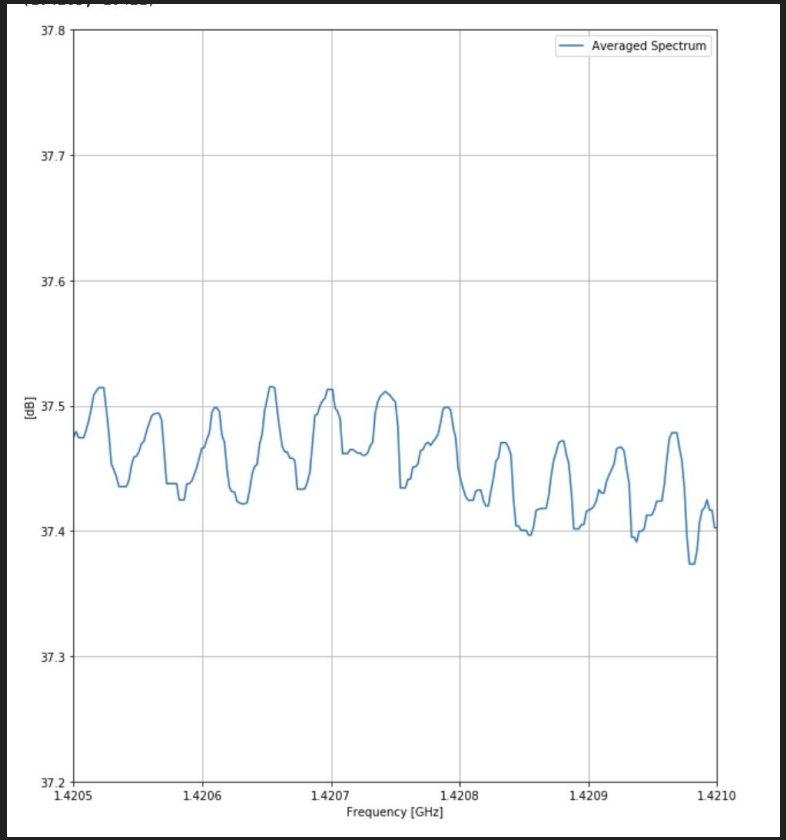
How does your data look now?

Run cells 9-12

What's that ripple? Find it's period!

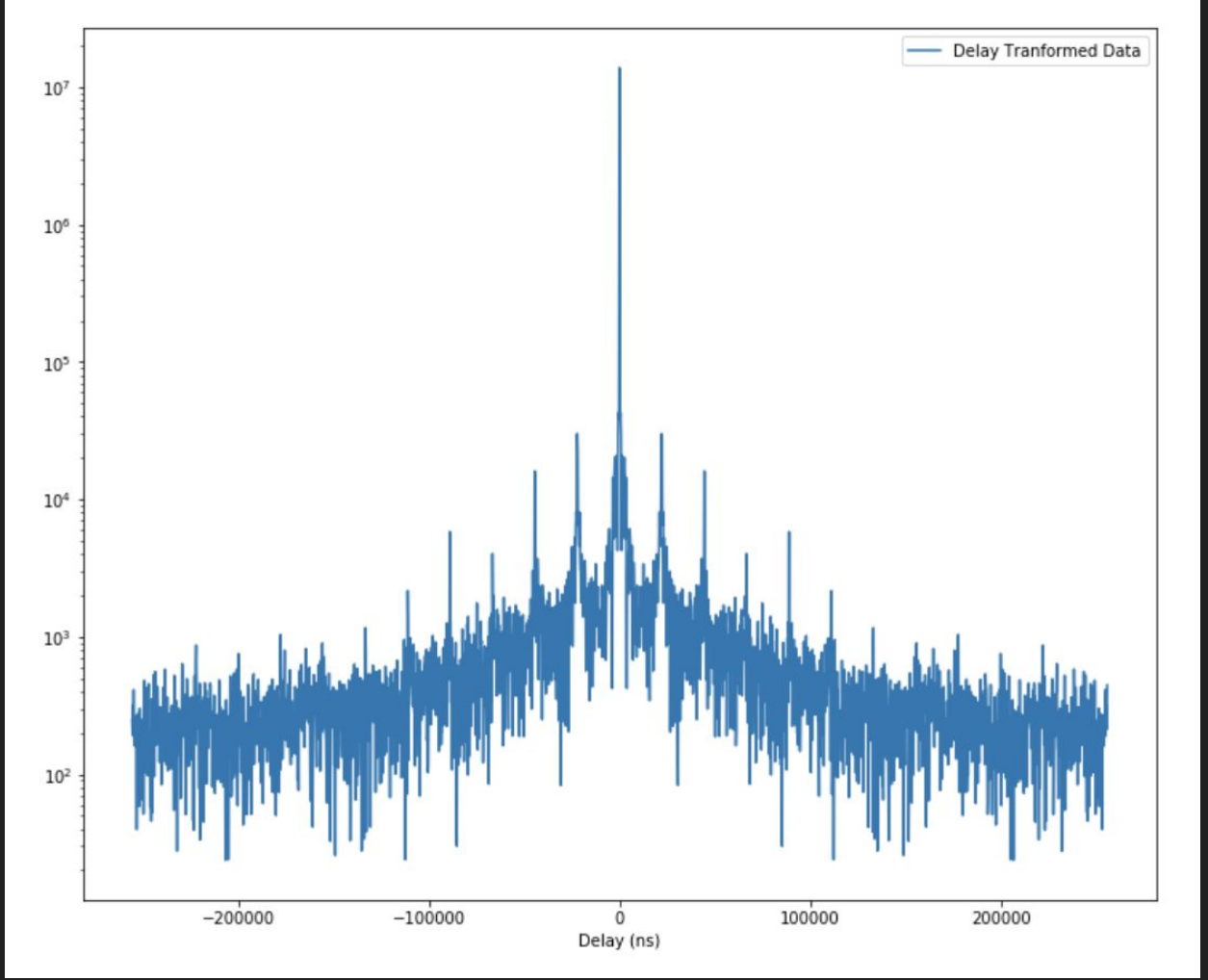
Break into Danny special on Delay Space



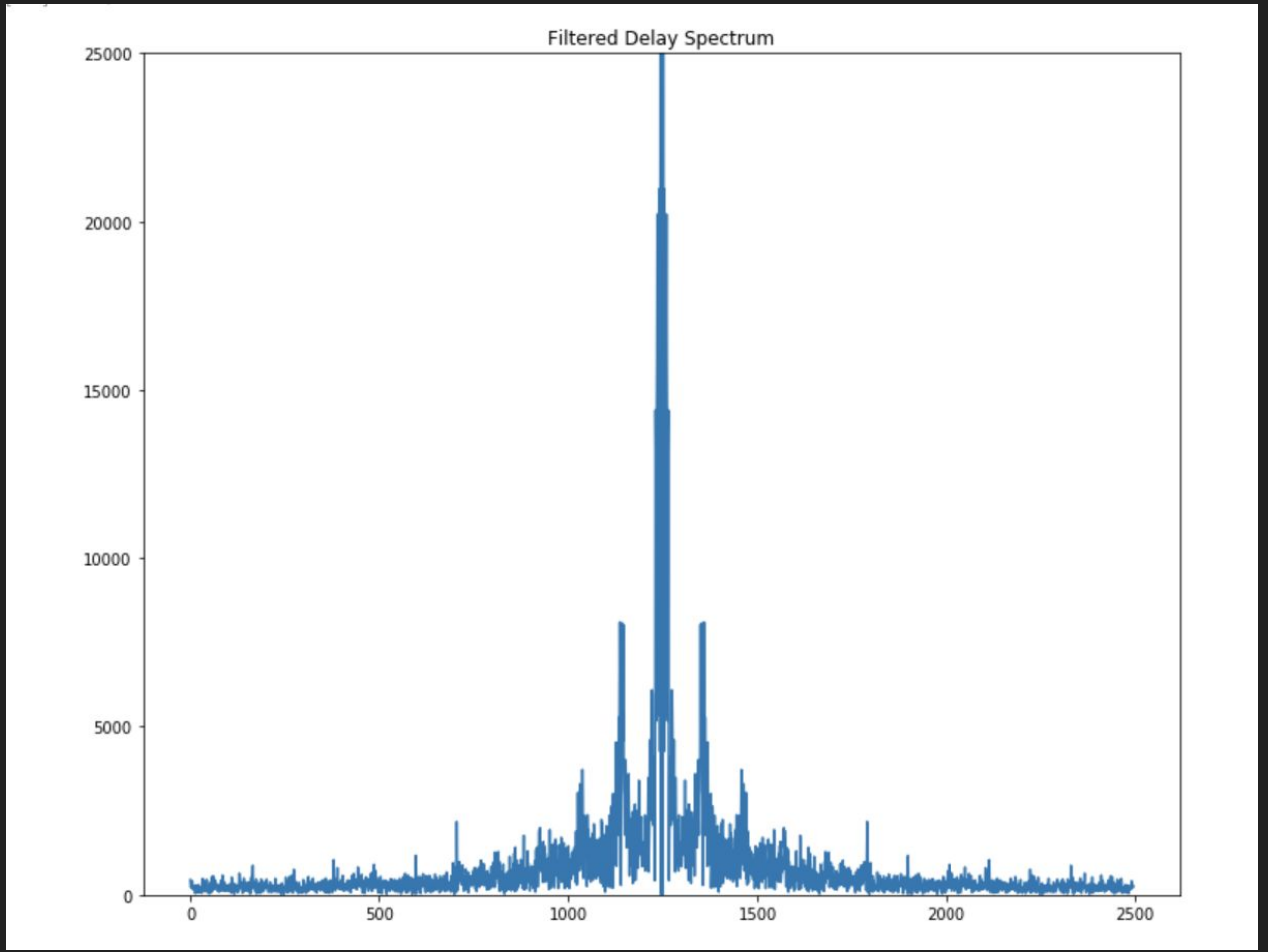


Run cell 13

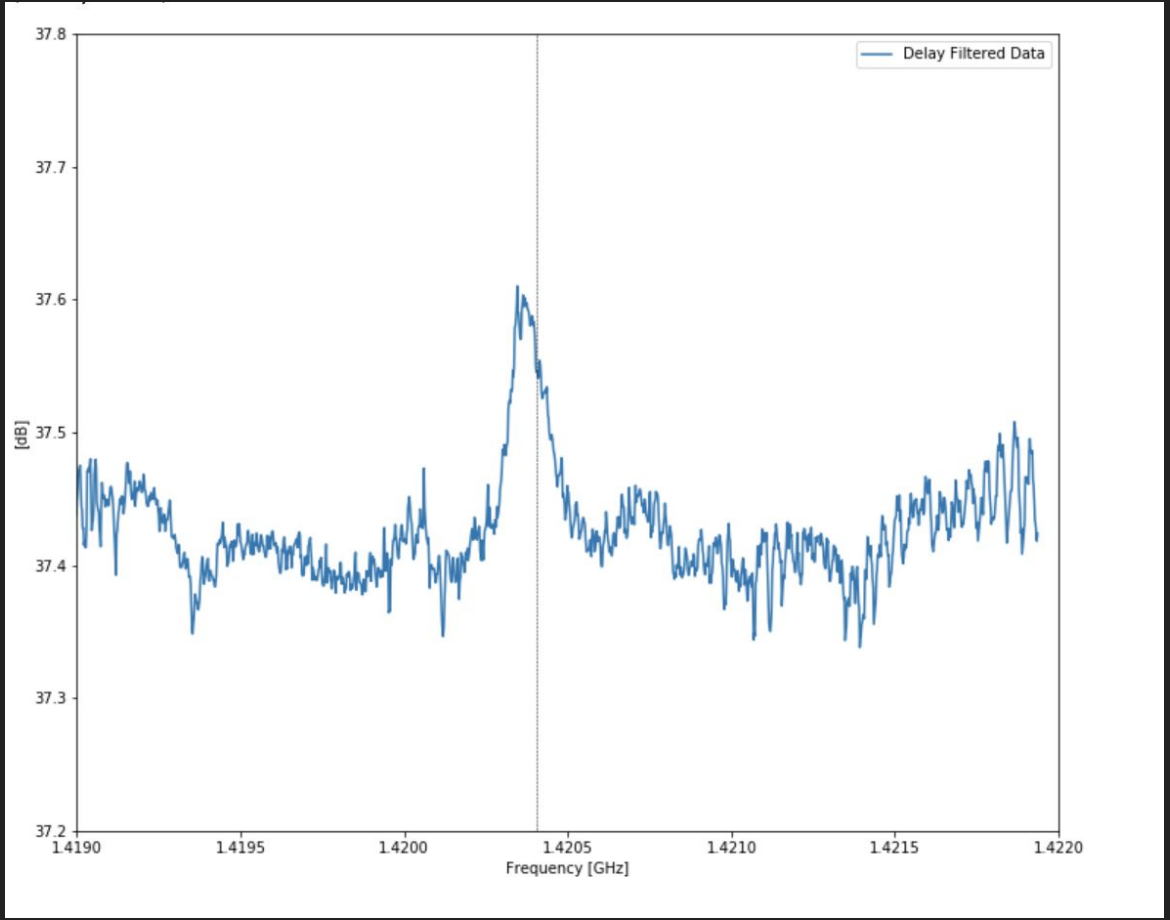
What is delay space?



Run Cells 14 -16

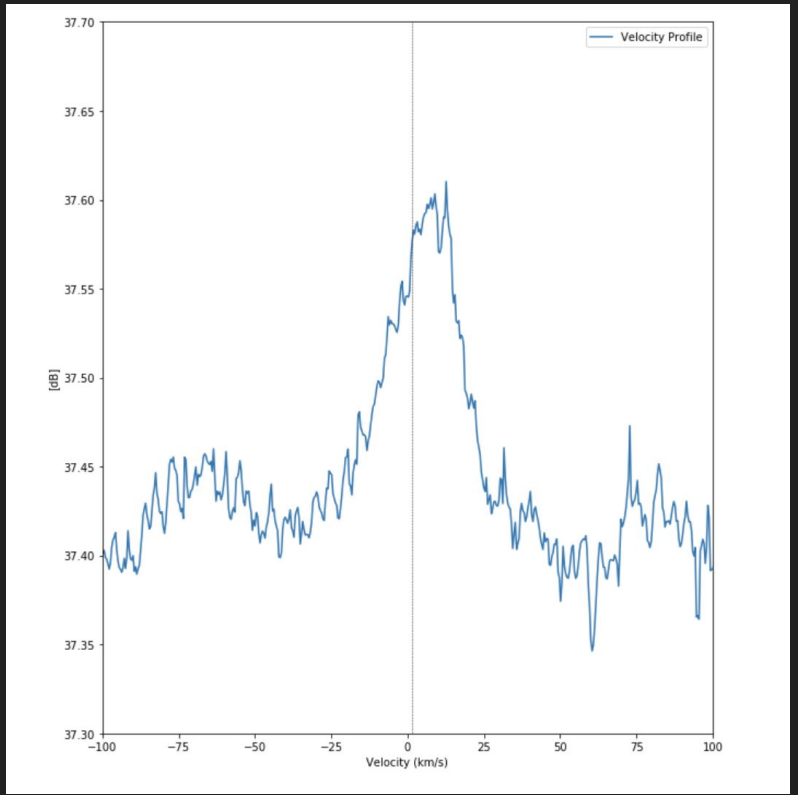


Run Cell 17-18



Frequency to Velocity

- Run cell 19 in your notebook.
- Pretty! What does it mean?



Final results tomorrow! Science is hard.