QuarkNet Radio Telescope

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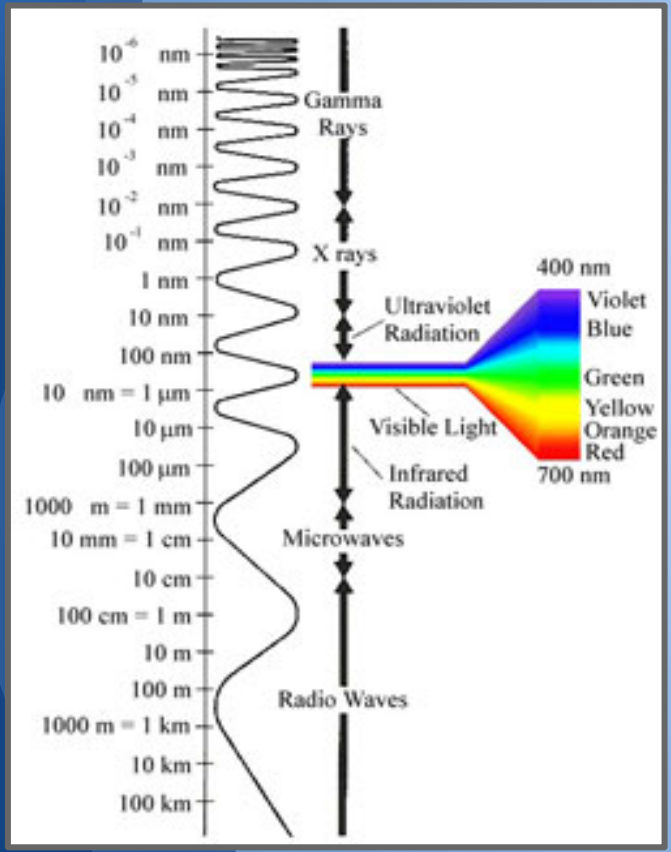
and Chris Stoughton

Goals

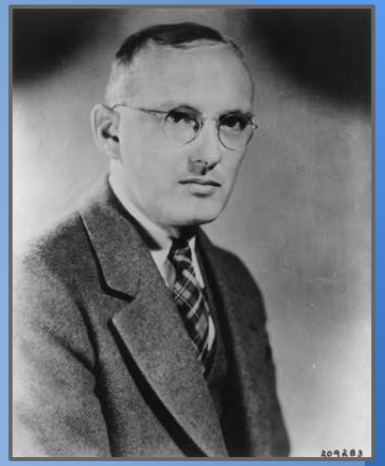
- Research and design a radio telescope
  - Assemble a working feed horn and antenna
  - Program necessary software
  - Obtain a signal
- Cater research and data to high schools so that they could build their own telescope
- Create a nationwide array of telescopes (using interferometry)

Radio Astronomy



- Radio Signal (3 kHz to 300 GHz)
- Astronomy using radio frequencies
- Examples of things we can observe:
  - Features invisible to the eye
  - Pulsars
  - Radio galaxies
  - Neutral hydrogen
  - And many more...

History of Radio Telescopes

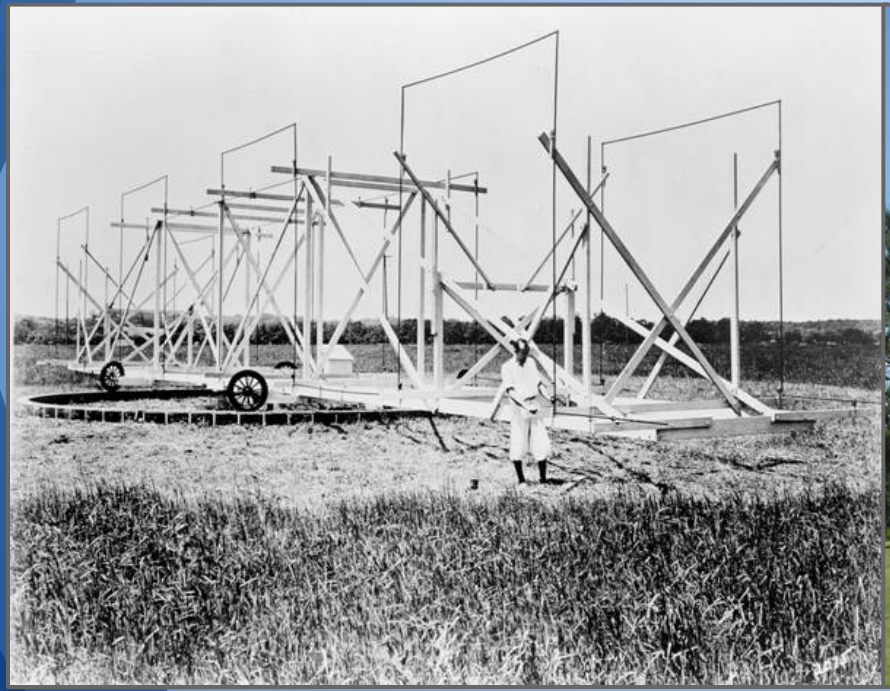


Karl Jansky (UW-Madison)

- Radio Engineer at Bell Labs
- Built receiver antenna (14.6λ)
- Formulated that radio static came from the Milky Way
- Flux density of radio sources (1 Jy=10^{-26} W m^{-2} Hz^{-1})

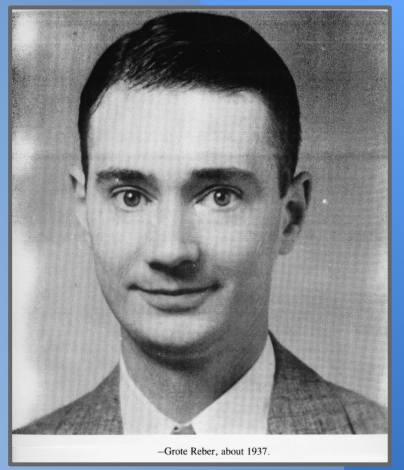
History of Radio Telescopes

Jansky's rotating telescope



Replica in Green Banks, West Virginia

History of Radio Telescopes


–Grote Reber, about 1937.

Grote Reber (IIT-Wheaton, IL)

- Inspired by Jansky
- Built modern-day radio telescope in his mother’s backyard (9 meters)
- Observed strong emissions across Milky Way
- Confirmed Jansky's formulation

History of Radio Telescopes

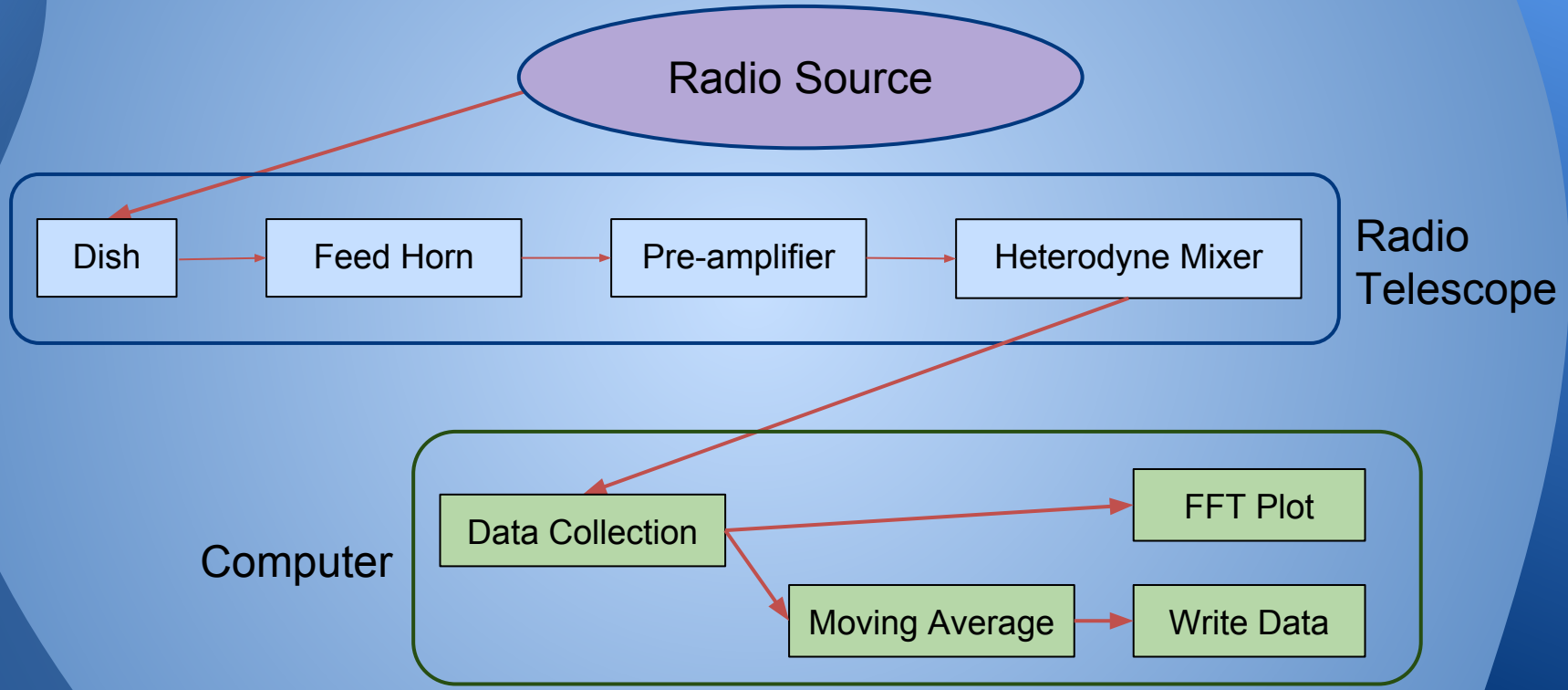
Reconstructed version of Reber's 9 meter dish in Green Banks, West Virginia

Large Radio Telescopes

Worlds Largest Radio Telescope
≅1000 feet Arecibo Observatory, Puerto Rico
≅3 football fields

Green Banks Radio Telescope
Green Banks, West Virginia
100 meter diameter

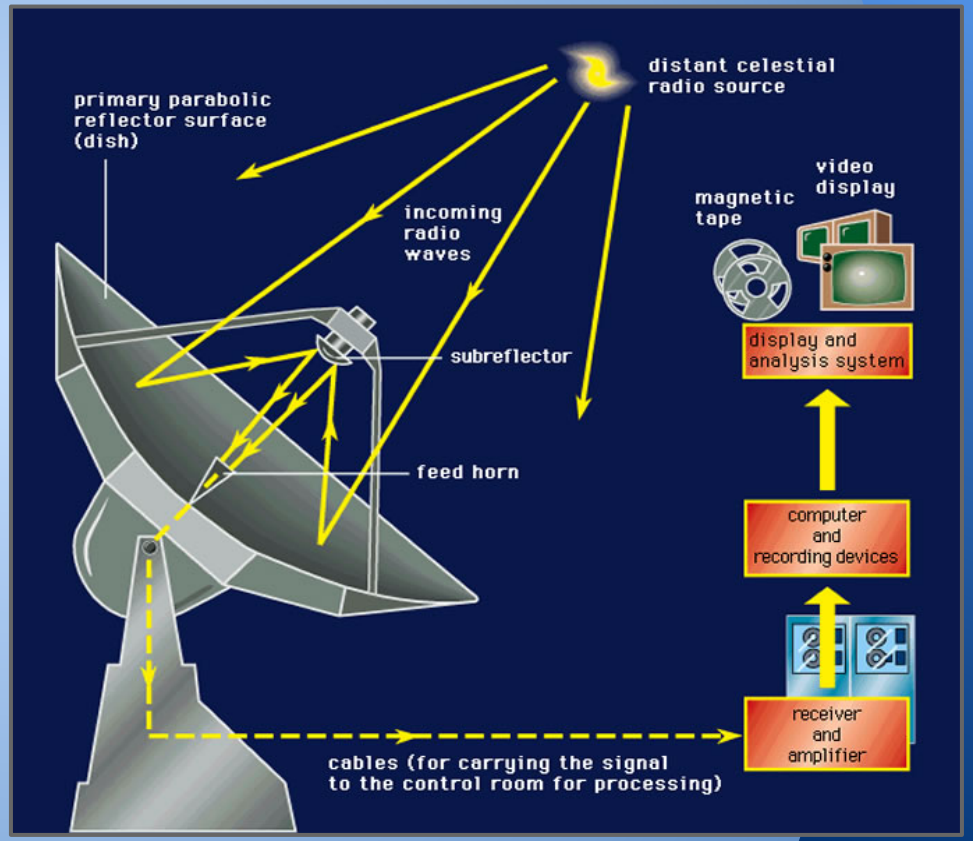
The Big Picture



Radio Telescope Basics

Parts of a Radio Telescope:

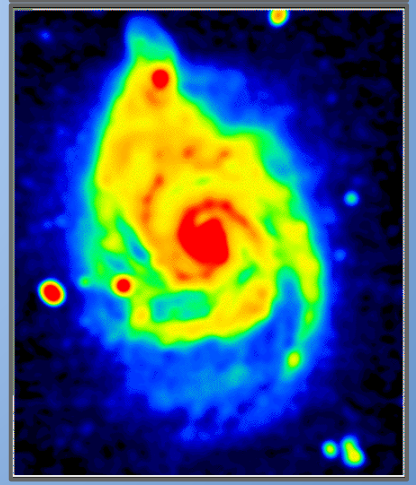
- **Parabolic Dish/Mount**
  - Collects and focuses radio waves
- **Feed Horn**
  - Receives radio waves
- **Pre-Amplifier**
  - Amplifies raw signal from feed horn
- **Heterodyne Receiver**
  - Turns analog signal into digital signal
- **Data Acquisition**
  - Receive and write data onto computer
- **Data Analysis**
  - Analyze power spectrum over time



Radio Sources

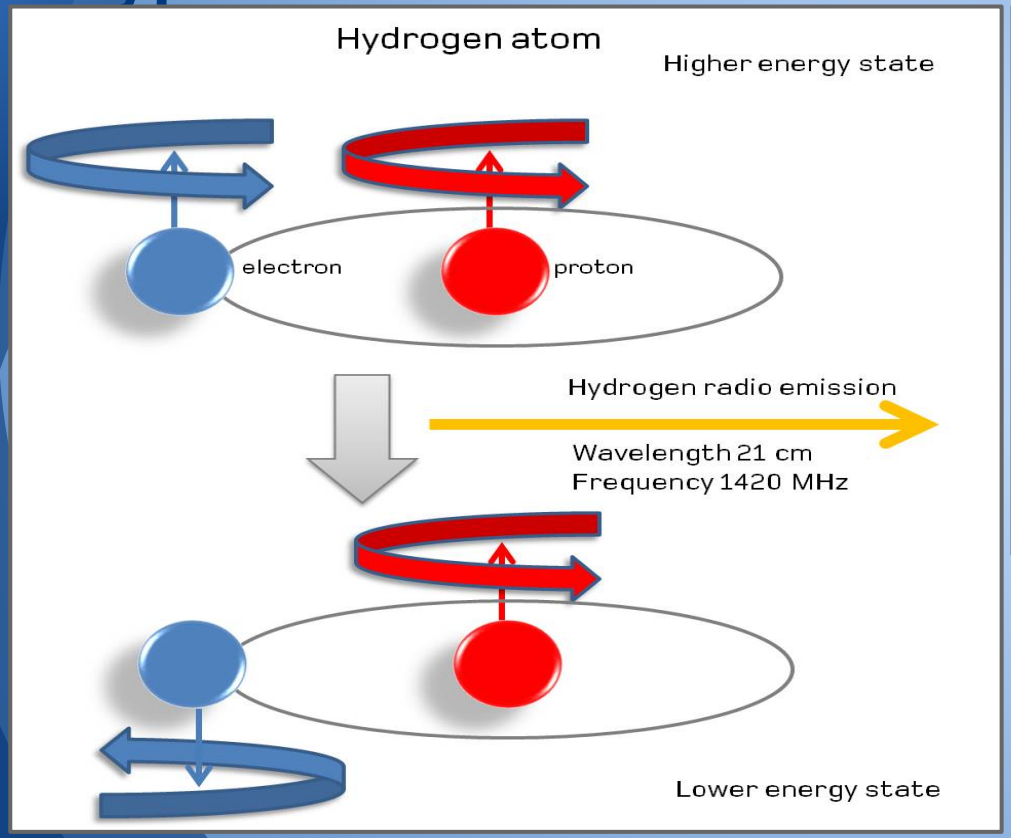
- Artificial sources
  - Radio stations
  - Aircraft communications
  - Signal generators
  - etc.
- Natural sources
  - Blackbody radiation
  - Synchrotron radiation
  - Neutral hydrogen emission

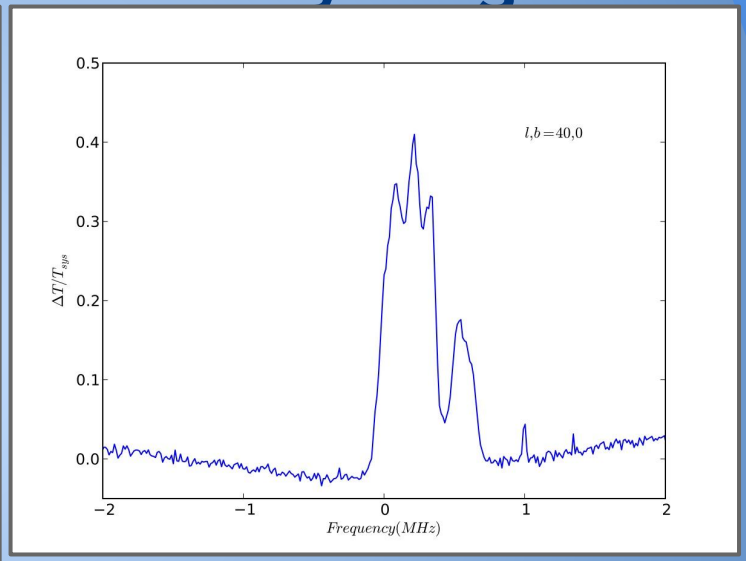
http://www.sparksbroadcast.com



http://lhsgems.org/IUTour.html

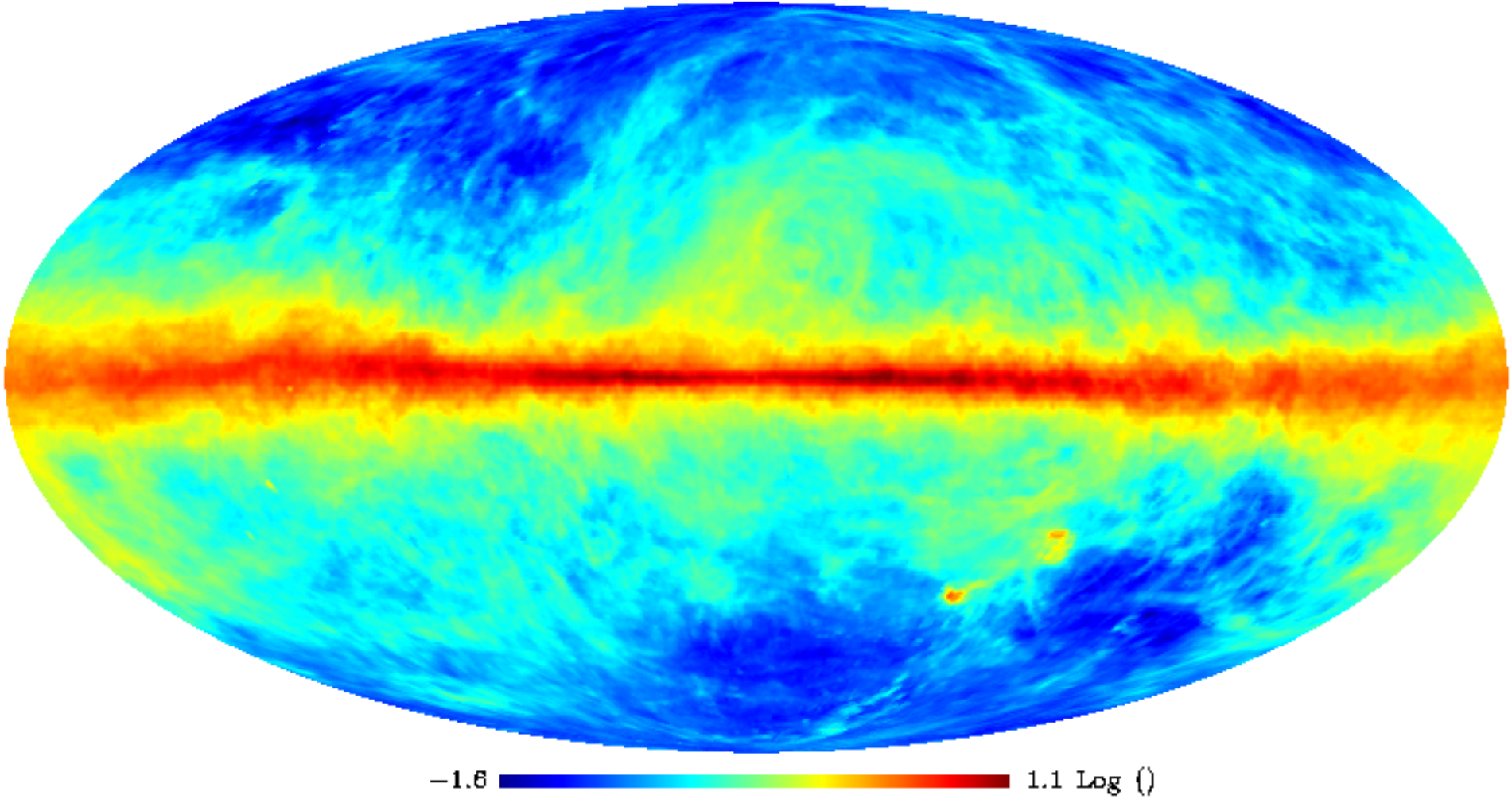
Hyperfine Transition of Neutral Hydrogen





Detect 21 cm radio emissions from clouds of neutral hydrogen across the galaxy

from the Leiden/Dwingeloo HI survey and the Instituto Argentino de Radioastronomia survey.



Dish → Feed Horn → Pre-amplifier → Heterodyne Mixer

Dish

- Parabolic Mesh surface (8 ft in diameter)
- Collects incoming radio waves
- Reflects radio waves into one point
- Bigger dish = Sharper resolution

The Feed Horn

- Receives the focused radio waves reflected from the dish
- Has an antenna inside
- Converts the radio signal into a weak electrical signal

Feed Horn Calculations

Given: $\lambda = 0.21106\ m$

$d = waveguide\ diameter = 0.1575\ m = 6.2\ in = .746\lambda$

Monopole Antenna Length: $L_a = \lambda/4$ $L_a = (0.211\ m)/4 = 0.05277\ m = 5.277\ cm$

(L_a = antenna length)

Low-Cut Wavelength: $\lambda_{LC} = 3.412r$ $\lambda_{LC} = 3.412(0.07874\ m) = 0.2687\ m$

(λ_{LC} = low cut wavelength, r = radius of cylinder)

Waveguide Length: $\lambda_g = 1/\sqrt{\left(\frac{1}{\lambda}\right)^2 - \left(\frac{1}{\lambda_{LC}}\right)^2}$ $\lambda_g = 1/\sqrt{\left(\frac{1}{(0.211\ m)}\right)^2 - \left(\frac{1}{(0.2687\ m)}\right)^2} = 0.3411\ m$

(λ_g = waveguide length, λ = wavelength, λ_{LC} = low cut wavelength)

Distance from antenna to back plate: $L_b = \lambda_g/4$ $L_b = (0.3411\ m)/4 = 0.0853\ m = 8.53\ cm$

(L_b = distance from antenna to back plate)

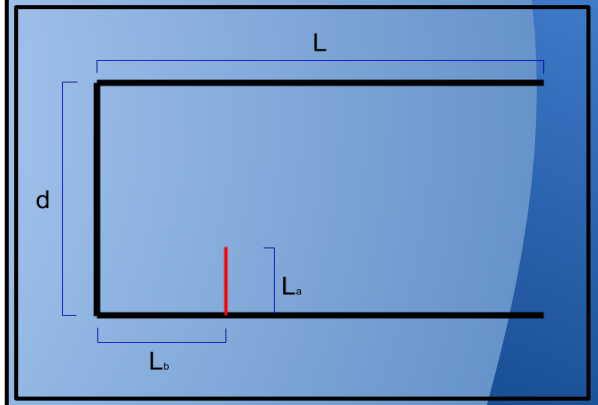
Length of Cylinder: $L = \frac{3}{4}\lambda_g$ $L = \frac{3}{4}(0.3411\ m) = 0.2558\ m\ = 25.58\ cm$

(L = length of cylinder)

3 dB Beamwidth: $BW_{3dB} \approx 66/d_\lambda\ degrees$ $BW_{3dB} \approx 66/(0.746\lambda)\ degrees = 88.46°$

(BW = beamwidth, d_λ = feed horn diameter in terms of λ)

Researched equations and calculated dimensions



Dish → **Feed Horn** → Pre-amplifier → Heterodyne Mixer

Feed Horn Construction

- Paint can
- Copper tube
- Solder, soldering iron, and glue
- Aluminum mounting brackets
- Coaxial (SMA) adapter mount
- Long (8ft) coaxial cable

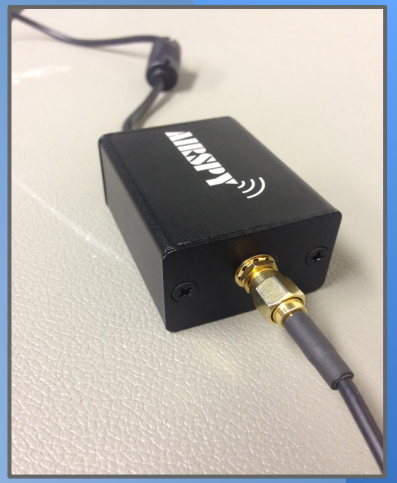
Dish → Feed Horn → **Pre-amplifier** → Heterodyne Mixer

LNA (Low Noise Amplifier)

- Attached to the feed horn
- Takes the weak signal from feed horn and adds 14.8 dB (Roughly 30 times stronger)
- Has a noise temperature of 50 Kelvin (very low)

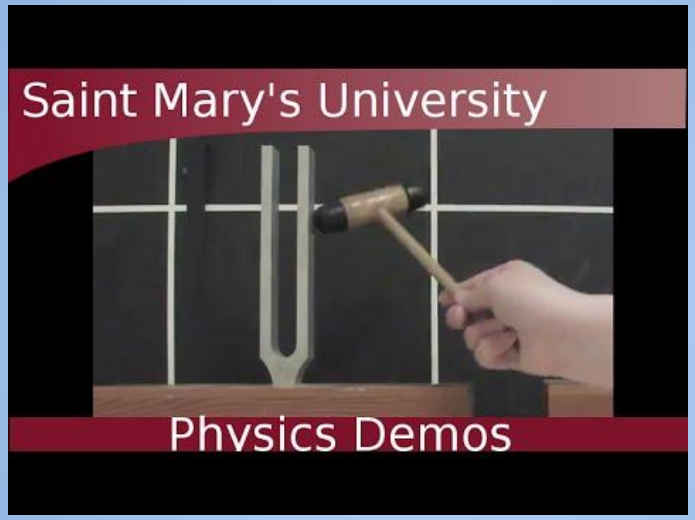
Dish → Feed Horn → Pre-amplifier → **Heterodyne Mixer**

Heterodyne Mixer (Airspy)



- Converts high frequency analog signal to a low frequency wave digital output
- Connected via USB to computer
- Relays the signal to a computer readable format (data collection system)
- Mixes and then digitizes

Beat Frequency

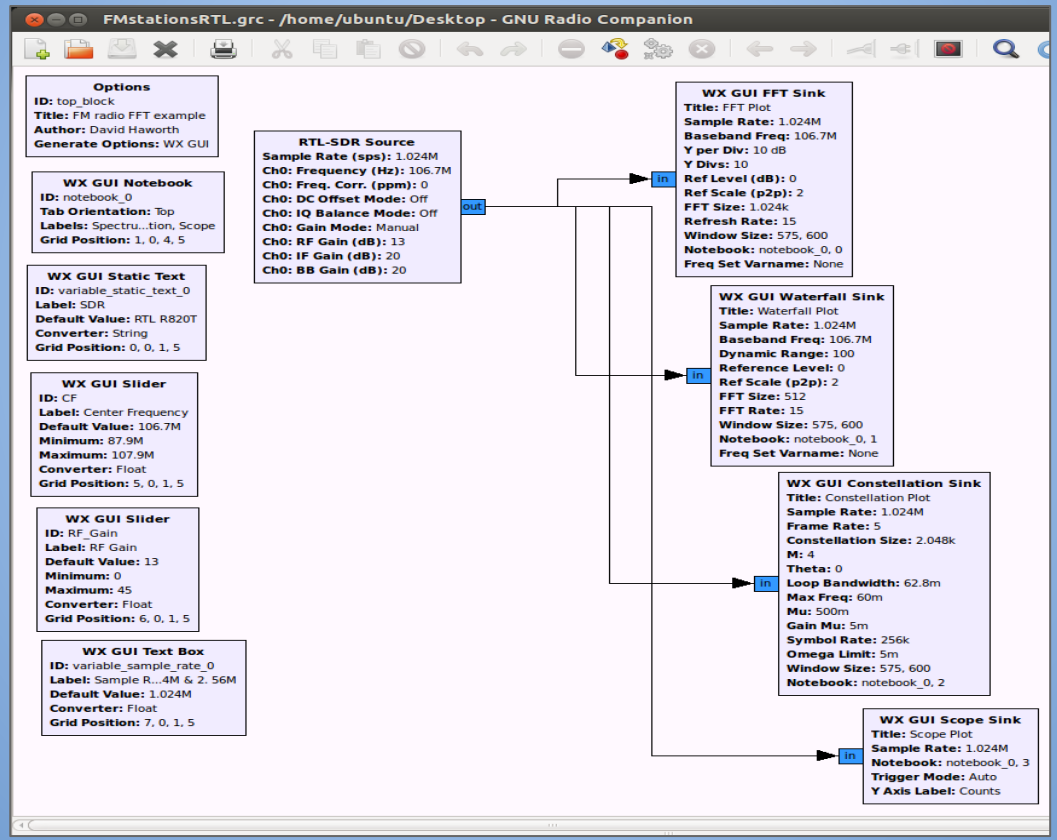


Airspy gets an incoming frequency and creates a frequency similar to it thus making a beat frequency

GNUradio

- GNUradio is a user friendly interface that allows users to create flowcharts to develop programs
- Free Software Development Toolkit
- Implements SDR (Software Defined Radio)
- Uses code blocks to operate
- Open Source

GNUradio Flowchart

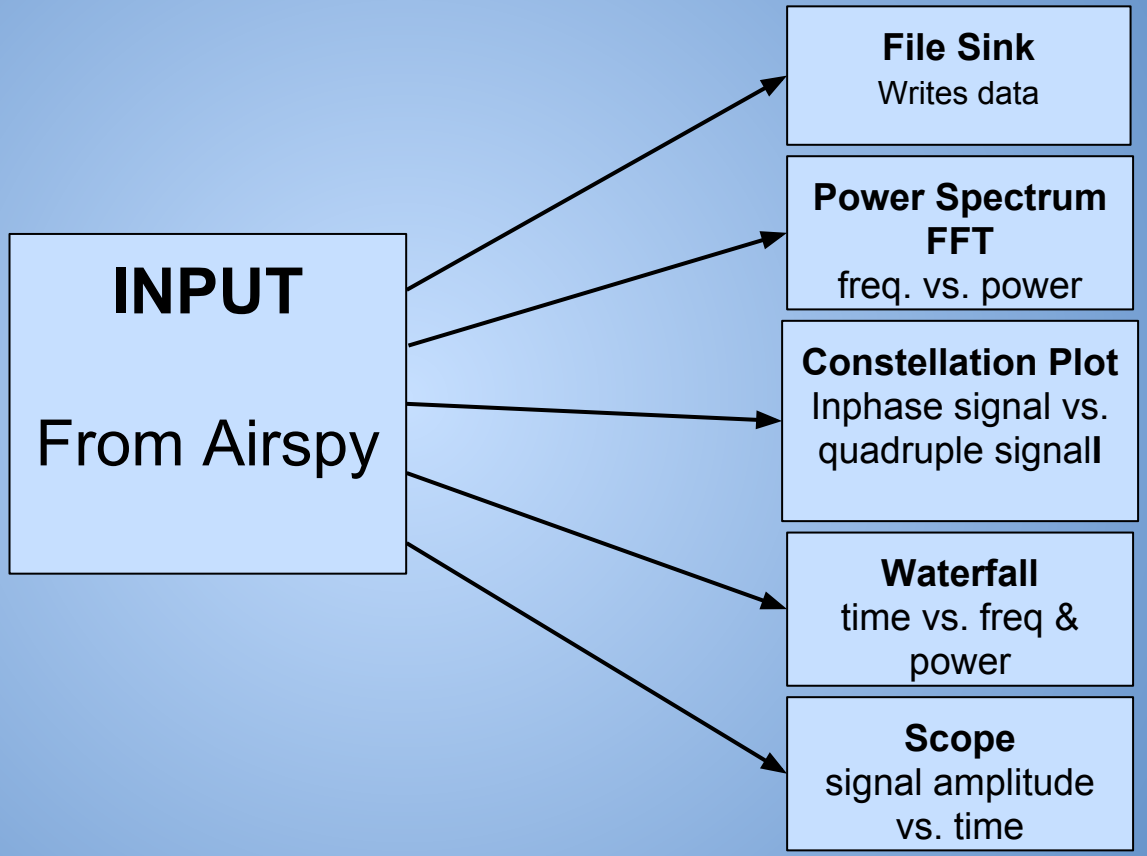


GNUradio Simplified Flowchart

Options
Control Panel

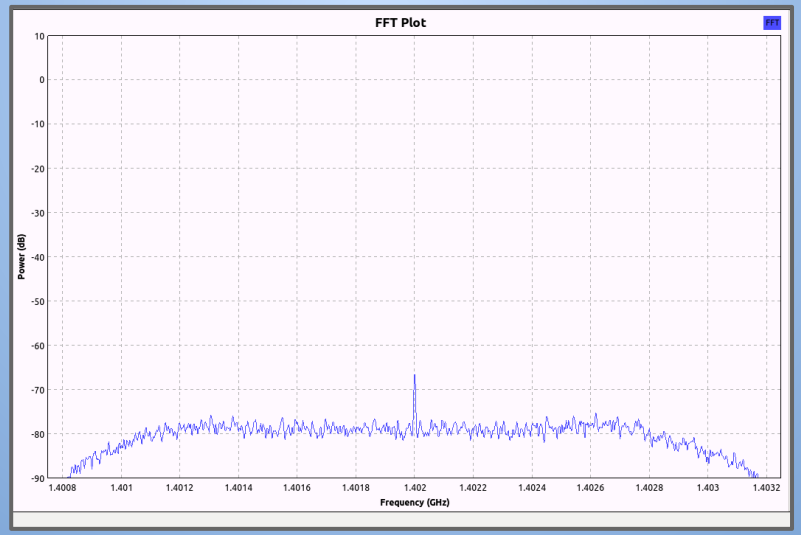
Static
variables to be kept constant

Slider
variables you can change



Power Spectrum Graph

- Uses the fast fourier transform (FFT)
- Plots frequency vs. power (strength of signal)
- Used to identify and analyze signals and noise levels

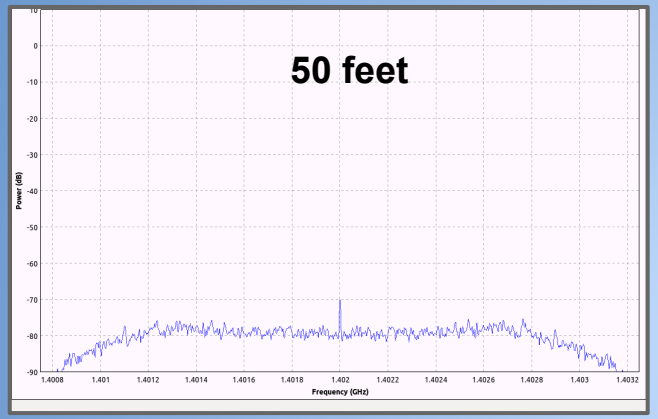


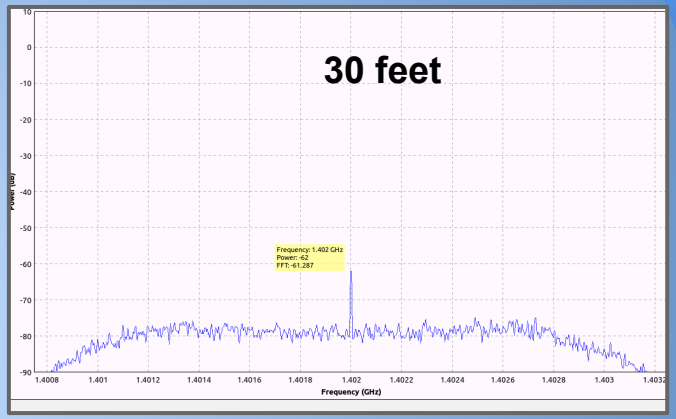
Theoretical Results

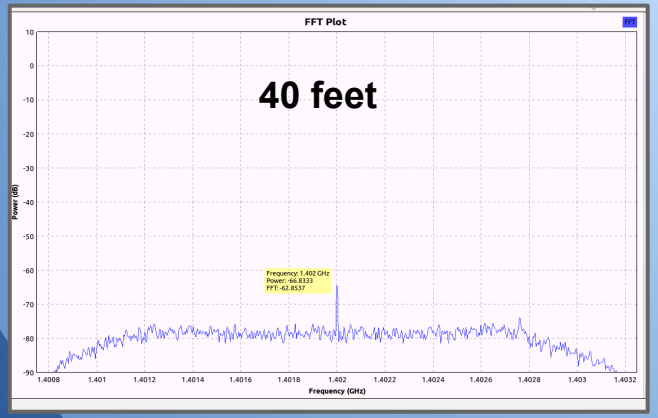
- Point at source with uniform radio wave emission (the Sun):
  - Ambient noise increases
- Point at a signal generator with antenna:
  - Peak shows up at designated frequency
- Point at hydrogen clouds:
  - See peak around 1.402 GHz

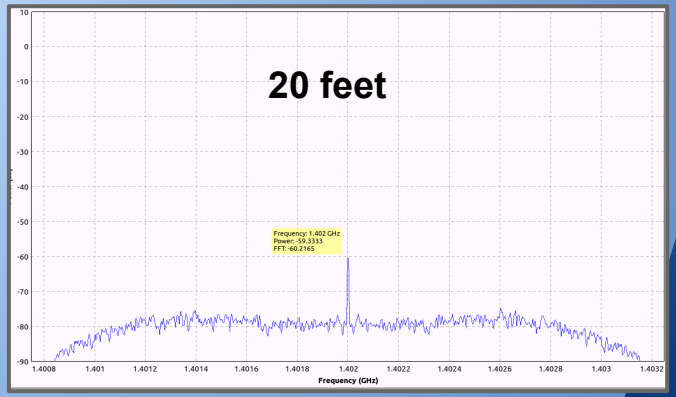
Temporary Site Location

Data Collection P(d)

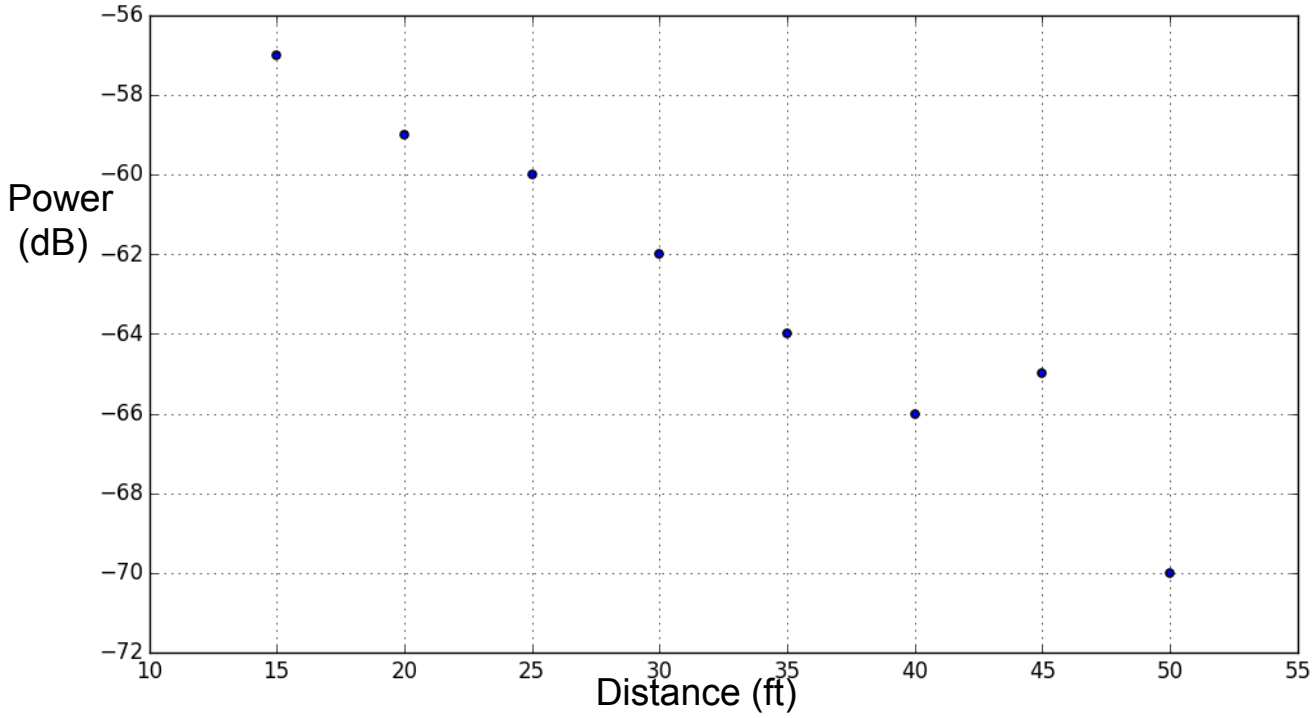




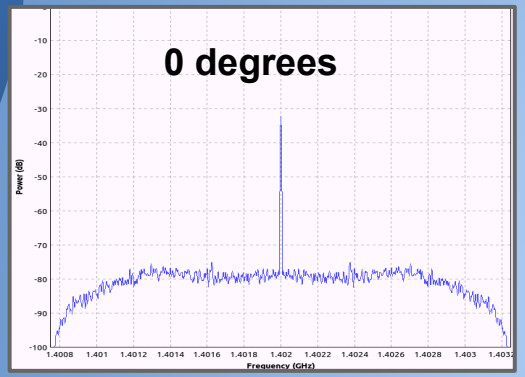


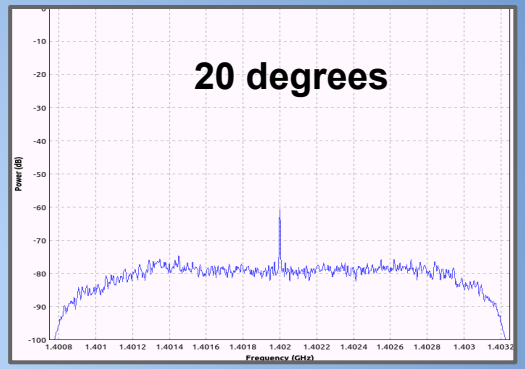


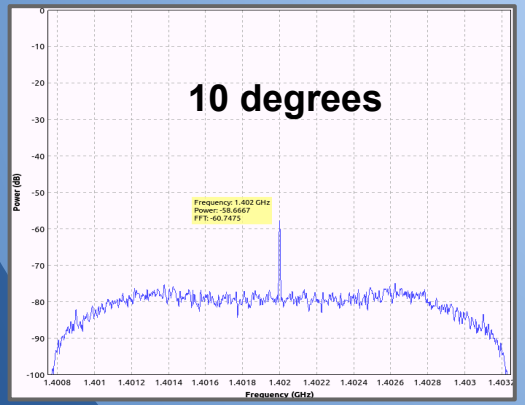
Distance Vs. Power Plot

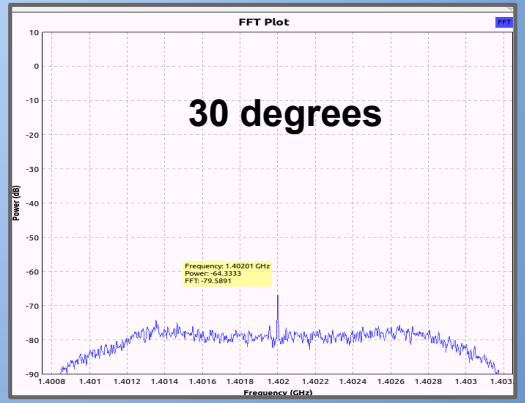


Data Collection P(θ)

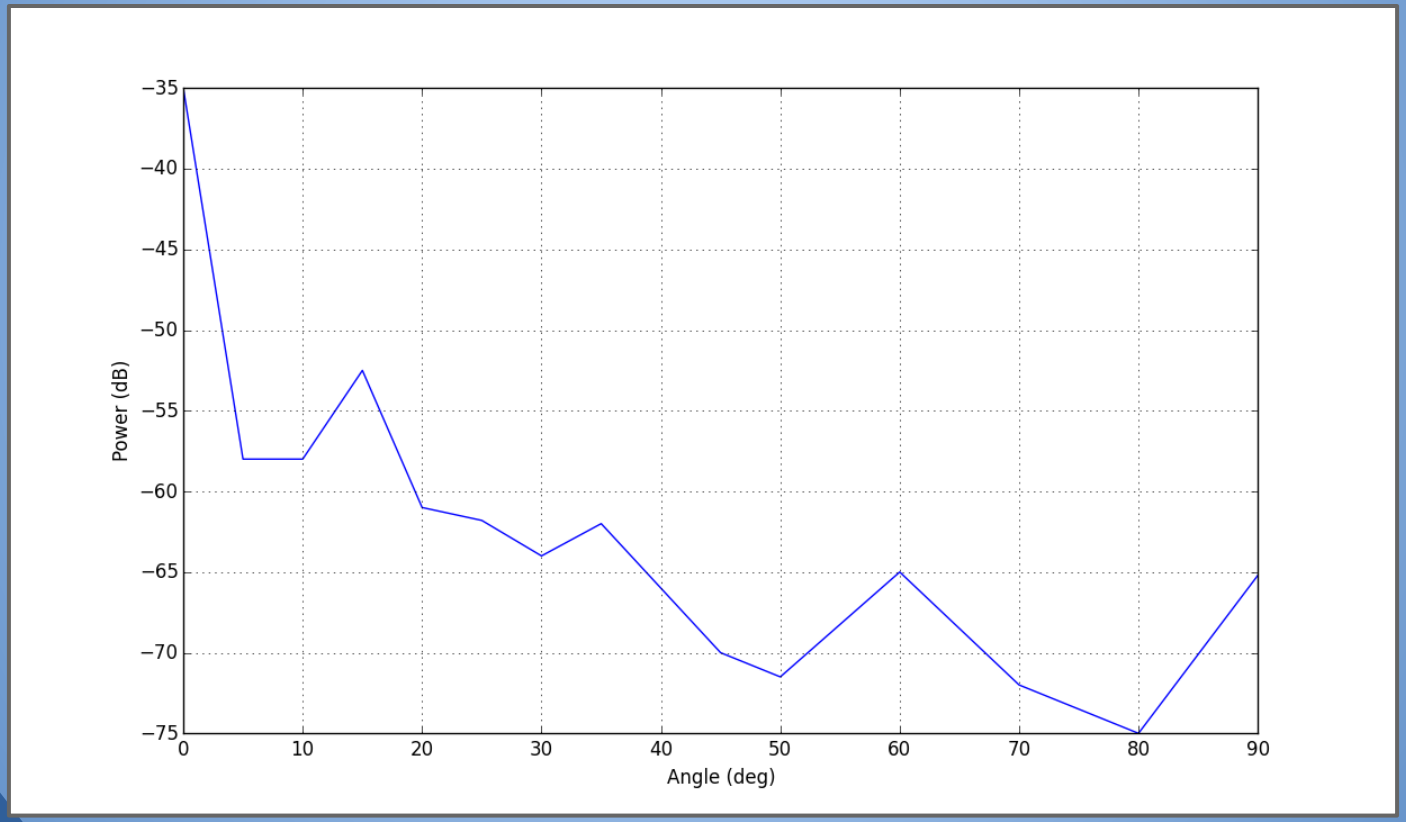




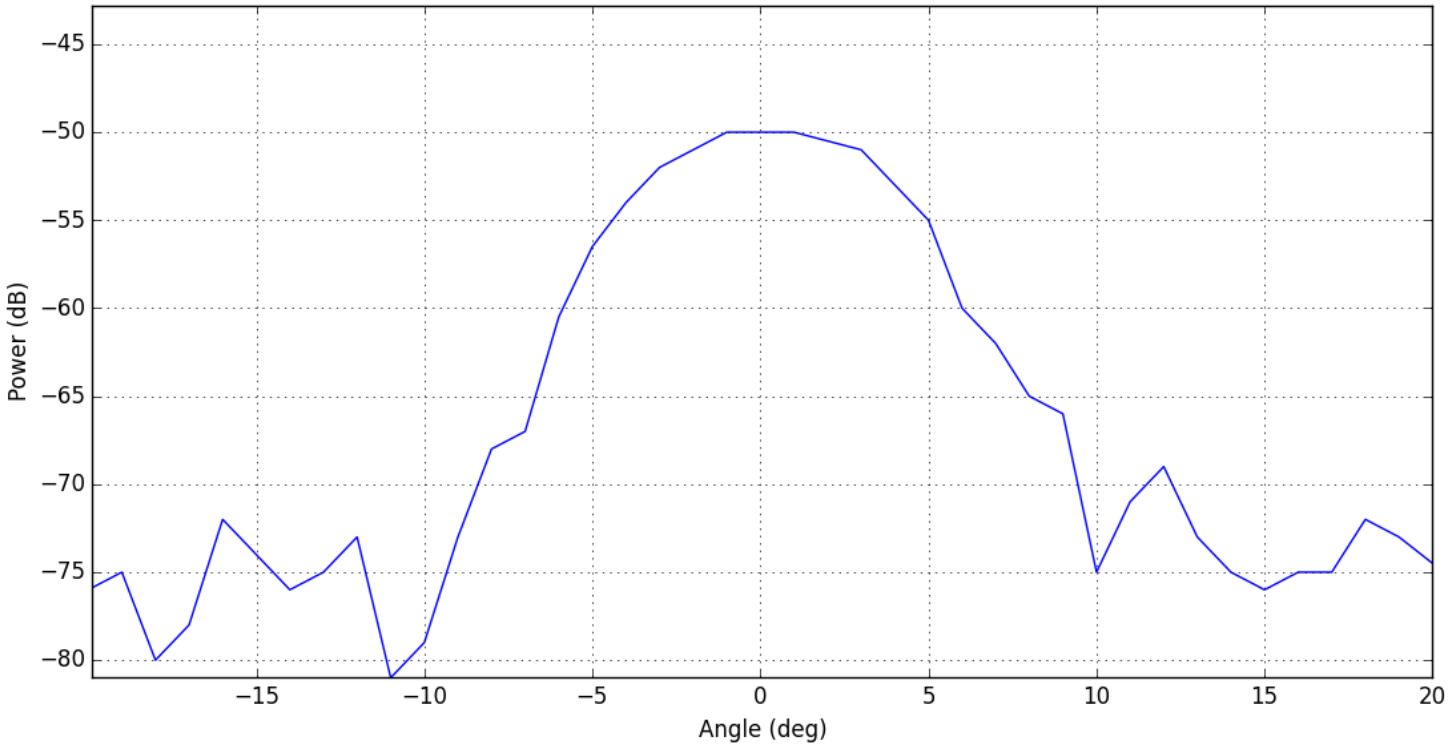




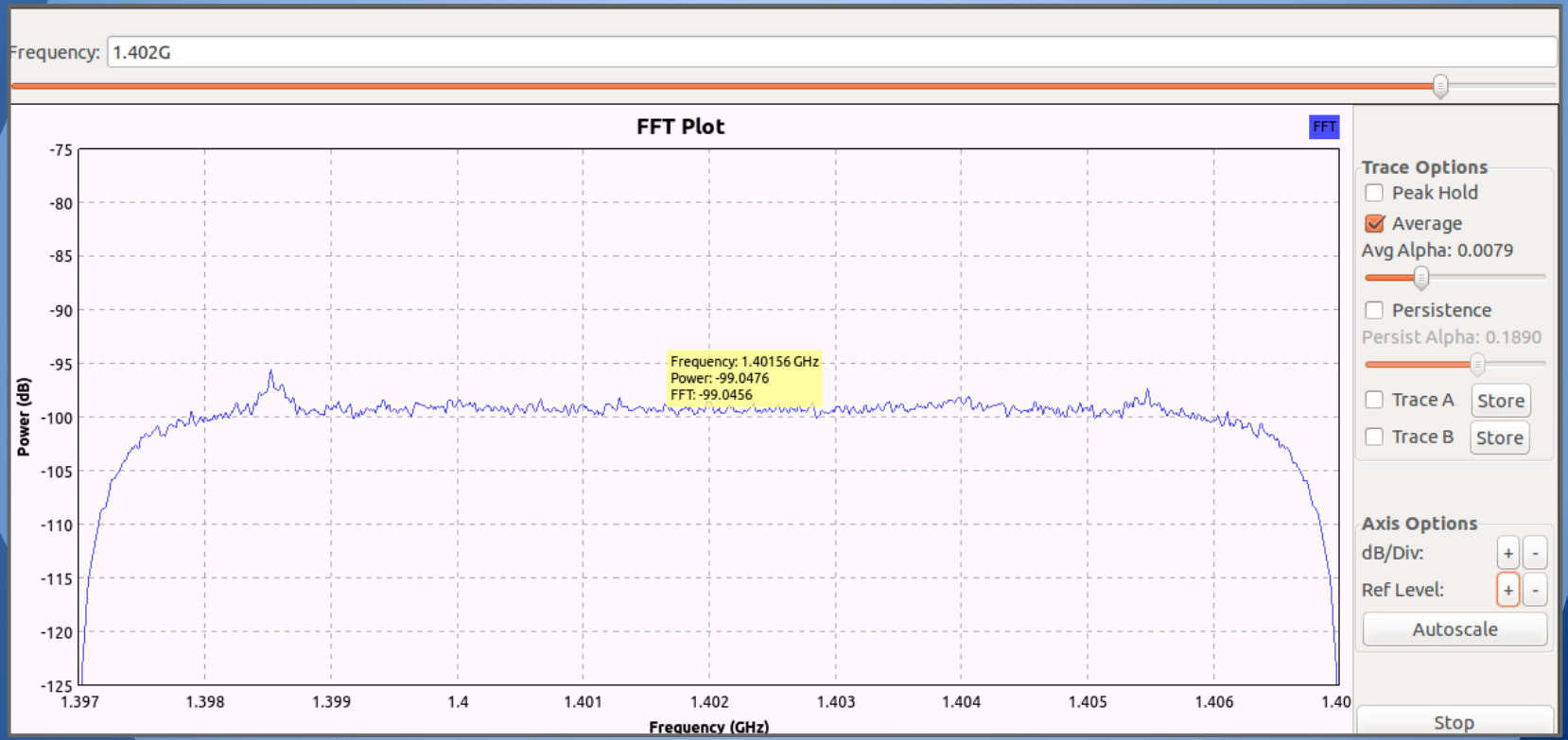
Initial Radiation Pattern



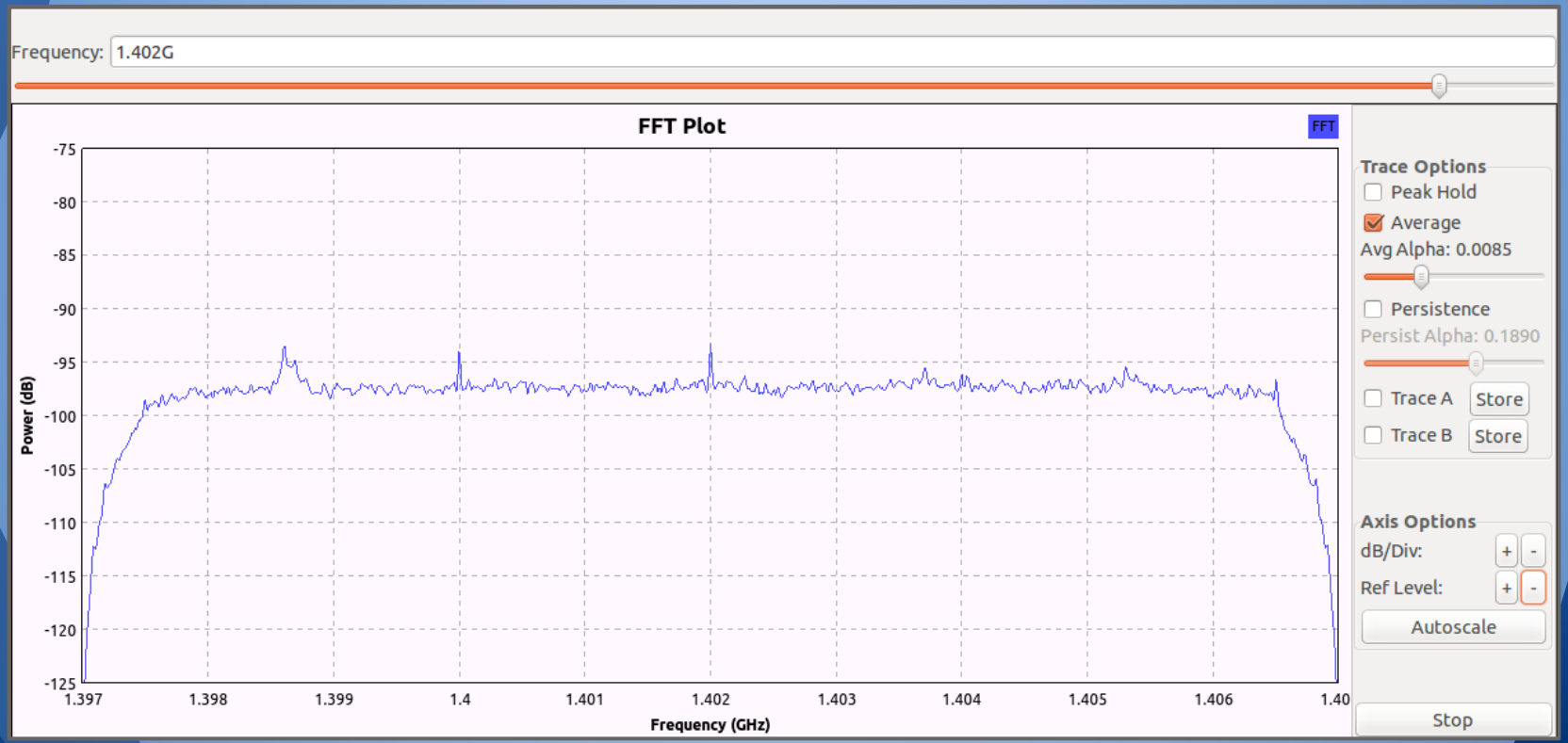
Better Radiation Pattern



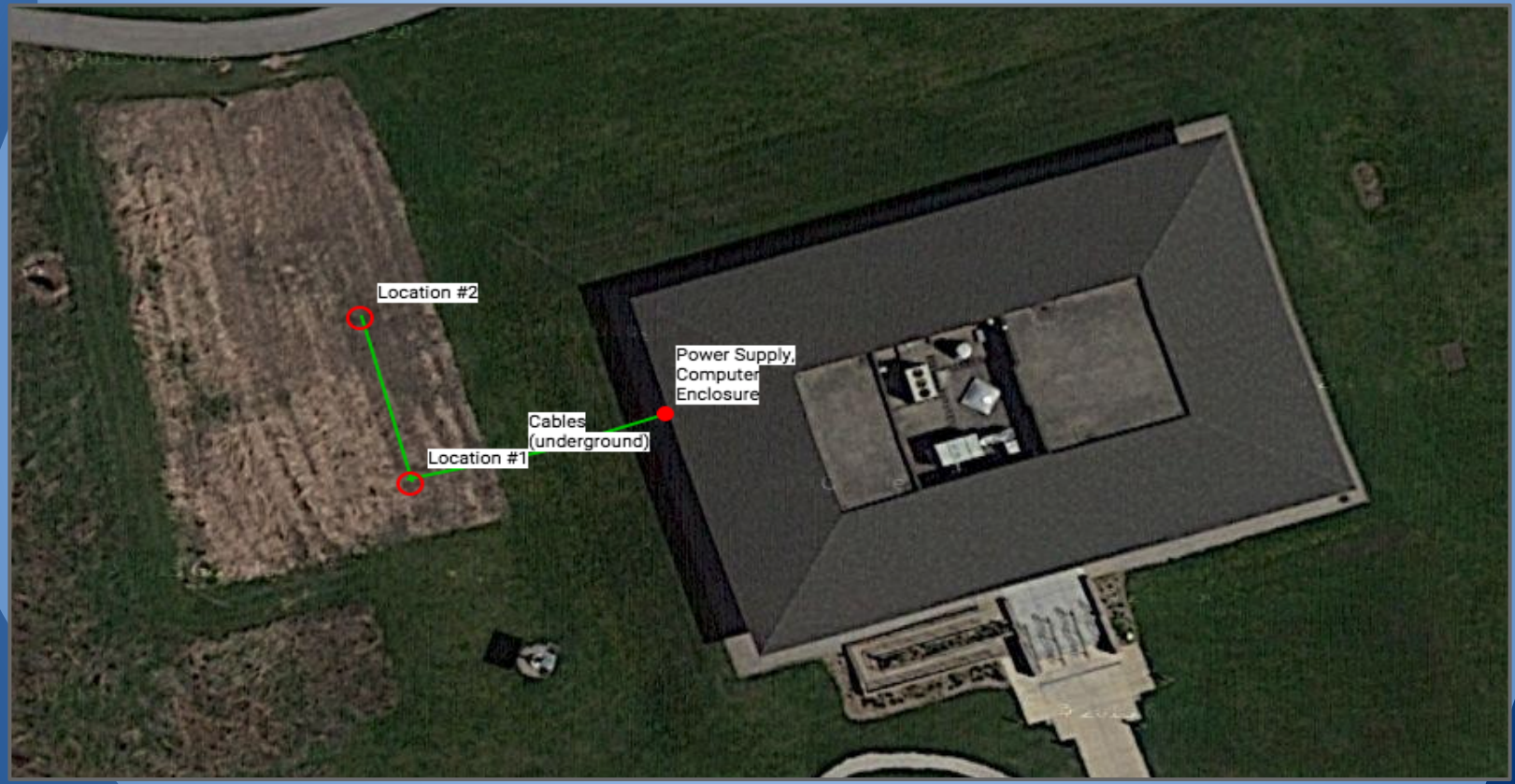
Results: Away from Sun



Results: Towards Sun



Lederman Science Center (Permanent)



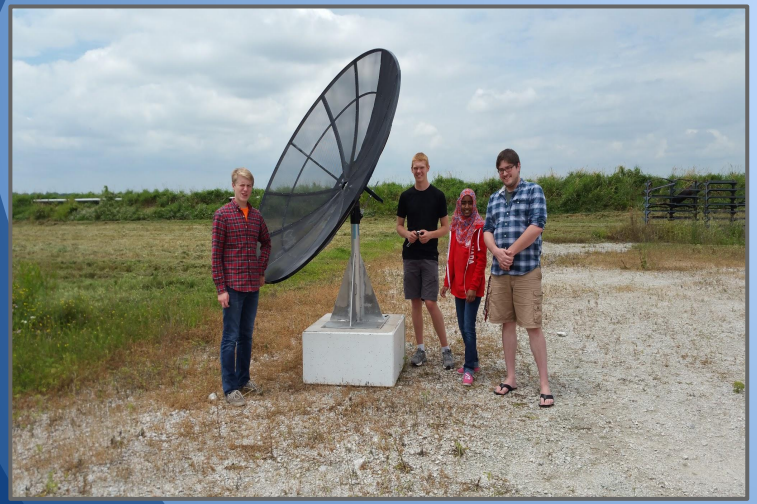
Interferometry

- Many radio telescopes operating in sync with each other
- Greatly increases overall resolution
- A distant goal for the QRT

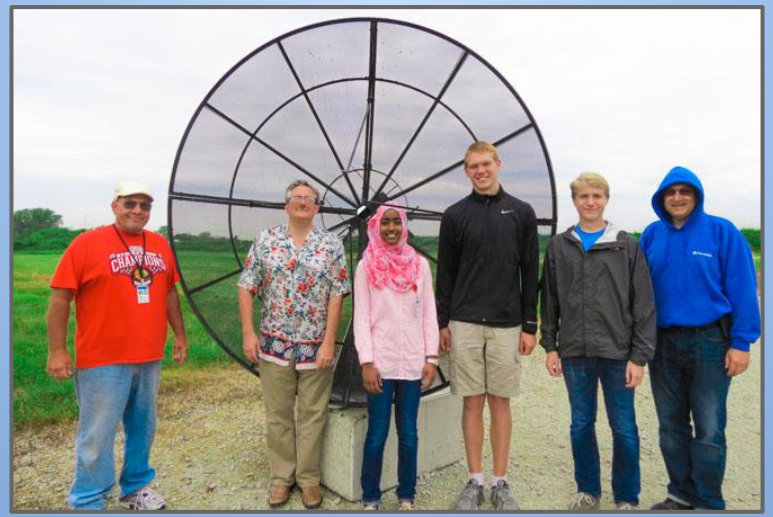
Atacama Large Millimeter Array (ALMA)

Project Management

Tasks	Status	Problems/Errors/To Do	Solutions
GNU Radio GUI	Complete	Spectrum Graph working-other three graphs not showing %CPU Increasing/Decreasin	Change settings/Tinker with sample, sinks-FFT. Fix CPU- Test with Throttle on Mac/Dell??
Test GNU Radio and AirSpy on artificial source	Complete	met Sten on 14th floor, two peaks showing- controlling the center frequency??	
GNU Radio and DA	Complete	Install GNURadio onto server	
Engineer Pole Support	Complete	Talking with electrical people/make mount sketch	LNA model number: ZX60-P33ULN+
Feed Horn	Complete	Buy/Make? Research-Jake, Write paper on design- Coffee Can??	
Install Dish (telescope)/Build	Complete	Read installation guide online	
String Wires	Complete	Create basic map w/location of dish and conduit, Find safe	
Basic Tests (on astronomical objects)	Complete		
PYEPHEM	Complete		
Previous Measurements	Complete		
8-Hour Scan	In Progress		
BASICS:		**Links**	
Background Information on Radio Telescope	Complete	http://www.tek2000.com/cgi-bin/web.cgi?command=productcategory&header_id=Sate	Dish Specifications
Python-up to Battleship	Complete	http://www.w1ghz.org/antbook/chap4.pdf	Parabolic Dishe and Feedhorn Design
Get GNURadio on laptops	Complete	http://www.tvrosat.com/phpBB-3.0/phpBB3/viewtopic.php?f=146&t=1252	Installation guide
Do GNURadio tutorials-understand basics	Complete	http://www.sbrac.org/files/budget_radio_telescope.pdf	21 cm Radio Telescope for the Cost-Conscious
Sketch of Tornado Shelter/Outback	Complete	http://www.stargazing.net/david/GNUradio/RTLFMstations.html	GNU radio Airspy
Photoshop of Dish/Lederman Center	Complete	http://www.qsl.net/va3iul/Antenna/Antenna%20Types%20and%20Antenna%20Pattern	Descriptions and specs on antenna types
Measurement/Outback Placement Sketch	Complete	http://caltopo.com/m/3D1H	Editable Version of Outback Sketch (NEED TO ZOOM IN TO SEE)
Engineer Pole Support Sketch	Complete	http://www.packratvhf.com/Article_9/Dish_Not.pdf	3 Feedhorn Types
Clean the Tornado Shelter	Complete	http://www.w1ghz.org/antbook/chap6-3.pdf	
Set up table/chairs in tornado shelter	Complete	http://www.vk4adc.com/web/index.php/microwave-projects/62-antennas/139-coffee-ca	Coffee can feed instructions
Status Meeting Monday	Complete	http://www.ijetae.com/files/Volume4Issue5/IJETAE_0514_107.pdf	Important formulas for coffee can (or conical) dimentions
Build Feedhorn	Complete	http://caltopo.com/m/4R2T	Updated Sketch of Outback (cables/measurements included)
GNUradio (average block, threshold block, CF)	Complete	http://caltopo.com/m/383J	Lederman science center diagram
Schedule Lectures/Talks with Scientists (Saniya)	Complete	http://rhodesmill.org/pyephem/quick.html	Pyephem refrence guide
Find feed horn materials	Complete	http://www.reeve.com/Documents/RadioScience/CelestialRadioSources.pdf	Prominant Radio Sources
Get GNURadio on server computer	Complete	https://github.com/airspy/host/wiki/Troubleshooting	
		http://seclab.skku.edu/wp-content/uploads/2015/02/gnuplot-freq-commands.pdf	GNUPlot manual
		http://matplotlib.org/Matplotlib.pdf	Matplotlib manual
		http://alma.mtk.nao.ac.jp/e/aboutalma/more/system.html	Interferometry Explanation



YOU CAN BUILD ONE TOO….



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