RA Bootcamp 2023

Low-Frequency Cosmology (LoCo) Lab

Schedule (4-7pm)

3/20 Introduction

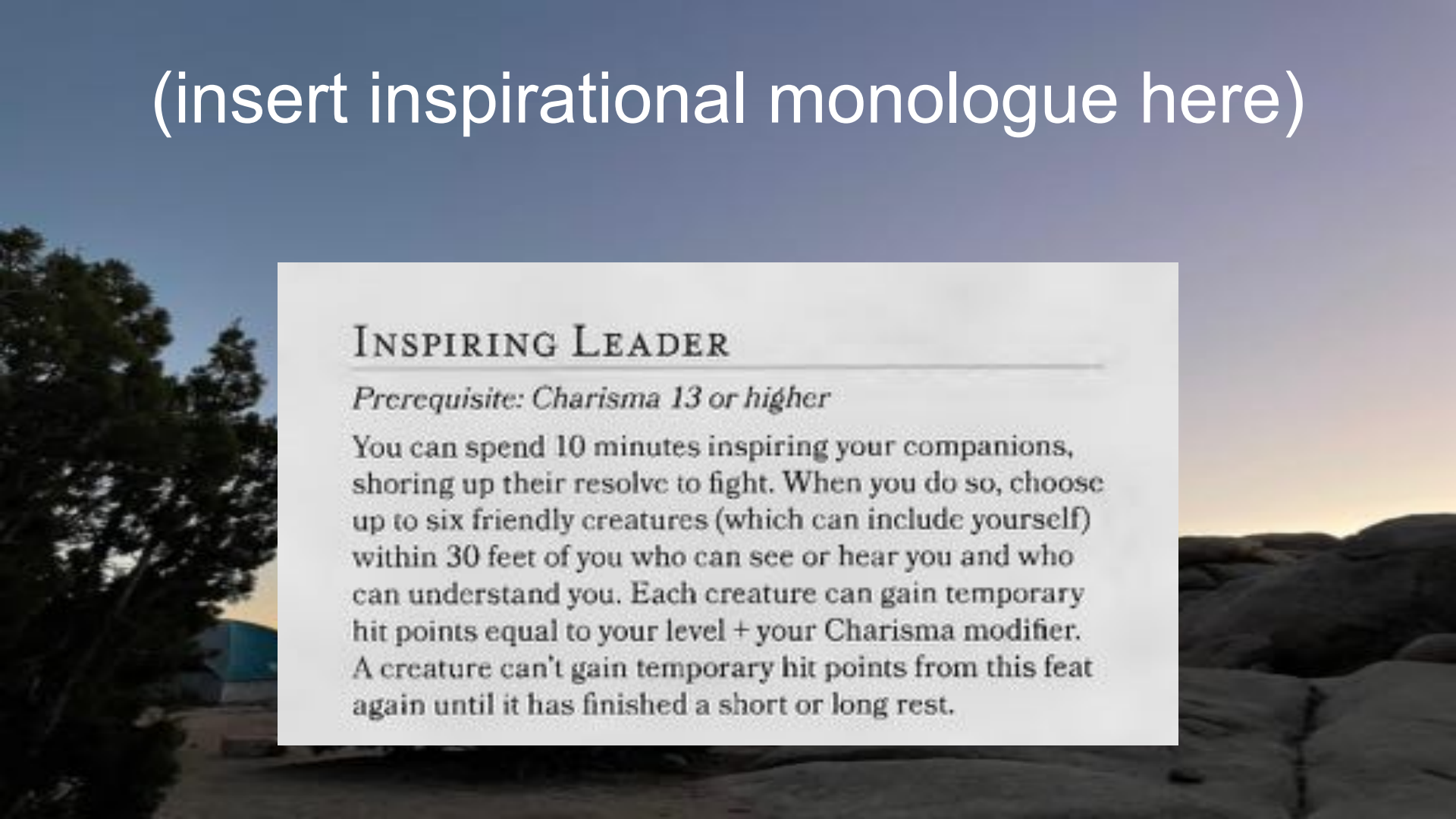
3/21 Intro to Jupyter and Fourier Transforms

3/22 Data pre-processing

3/23 Data analysis and results

3/24 Lab tours and more about LoCo!

(insert inspirational monologue here)



Inspiring Leader

Prerequisite: Charisma 13 or higher

You can spend 10 minutes inspiring your companions, shoring up their resolve to fight. When you do so, choose up to six friendly creatures (which can include yourself) within 30 feet of you who can see or hear you and who can understand you. Each creature can gain temporary hit points equal to your level + your Charisma modifier. A creature can't gain temporary hit points from this feat again until it has finished a short or long rest.

The LoCo Lab

Low-Frequency = Radio! (mostly) (depending on who you ask)

Cosmology = Origin and Evolution of the universe

Also we do lots of other stuff

THE WEDGE

Danny Jacobs

Assistant Professor ASU - Radio Cosmology and Cubesats 2017-current
Postdoc ASU & NSF Fellow 2011 - 2017
Phd UPenn 2009-2011
MS Montana State University - PI E1P Cubesat 2004-2009
BS New Mexico Tech 2000-2004


Danny, Karen, and Zoe:)

Prof. Judd Bowman

Professor, School Of Earth and Space Exploration

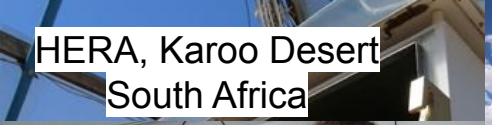
Chair **Beus Center for Cosmic Foundations**

Education

Ph.D. Physics, Massachusetts Institute of Technology 2007

B.S. Physics, Washington University in St. Louis 1998

B.S. Electrical Engineering, Washington University in St. Louis 1998


HERA, Karoo Desert South Africa

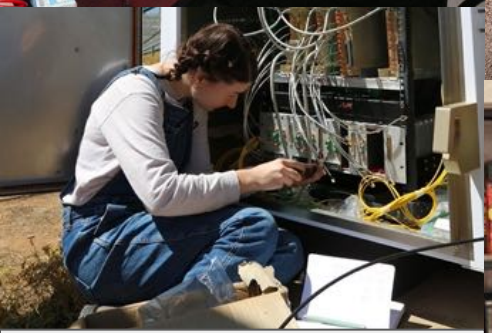



CHART Observing Trip, Painted Desert

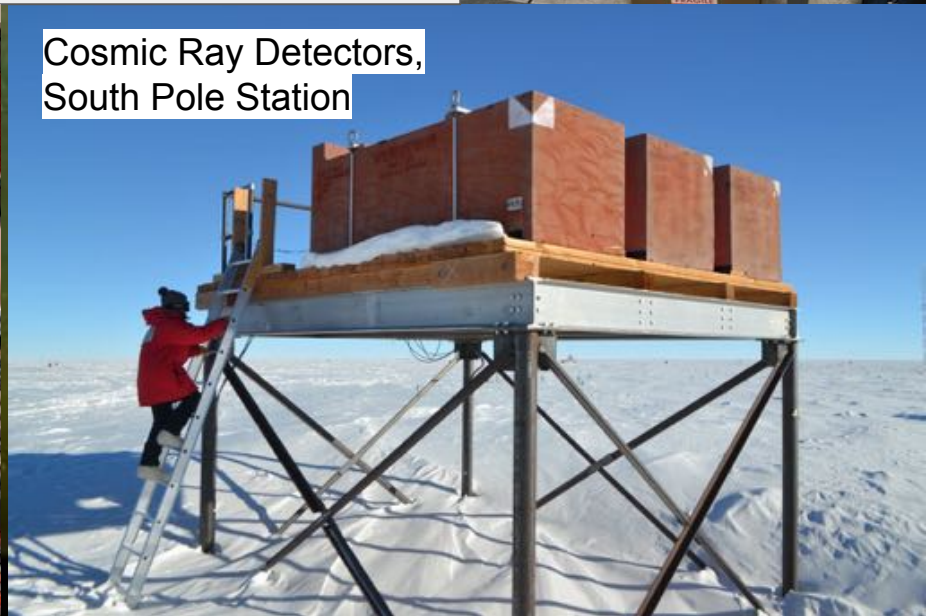
Libby

- 4th year PhD Candidate at ASU in Exploration Systems Design (Instrumentation)
- B.S in Astronomy & Astrophysics from UChicago

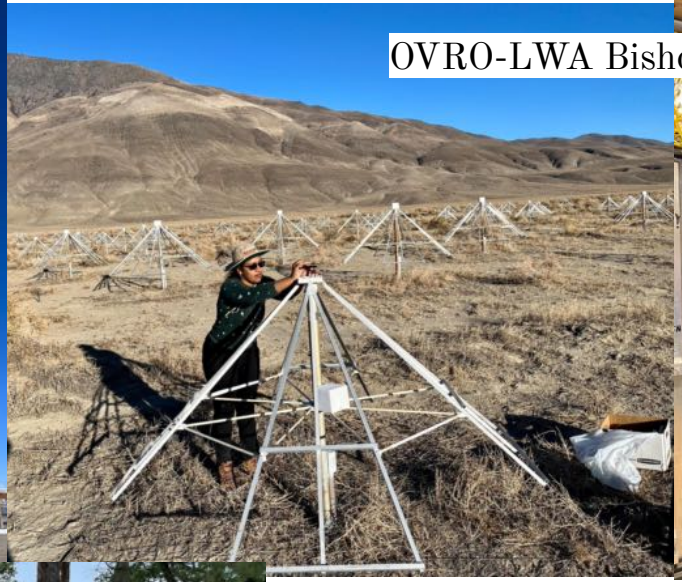

Goldstone Deep Space Communications Center

- Primarily work on instrumentation and signal processing
- Do cool stuff with cool equipment in cool places


Cat


Cosmic Ray Detectors, South Pole Station


VLA, Socorro NM


OVRO-LWA Bishop CA


40 m dish, Bishop CA


LANL, Los Alamos NM

Akshatha Vydula

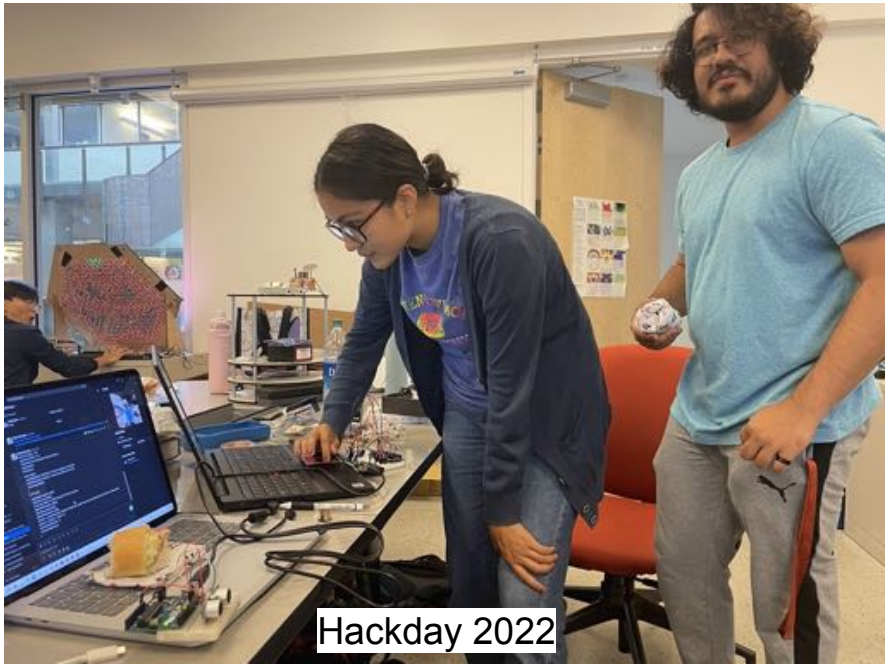
Ph.D. Candidate (Astrophysics)
B.E. Electronics Engineering,
RV College of Engineering, India.
Projects: EDGES, OVRO-LWA, VLA, ANDROMEDA
(Lunar neutron spectroscopy)
I work on stuff that are as small as neutrons to as large as the early Universe!
Contact: vydula@asu.edu


LoCo Outreach

Amy Zhao

PhD Candidate, Exploration Systems Design (Instrumentation)
B.S. Physics, Carnegie Mellon University
Projects: Lucy T2Cam, EDGES in Space

Arib



Hackday 2022

ASU Open Door


Day One

What is radio astronomy?

And why do I care?

NASA Image ID: PIA03654

1. The electromagnetic spectrum

NASA Image ID: iss050e066094

The electromagnetic spectrum

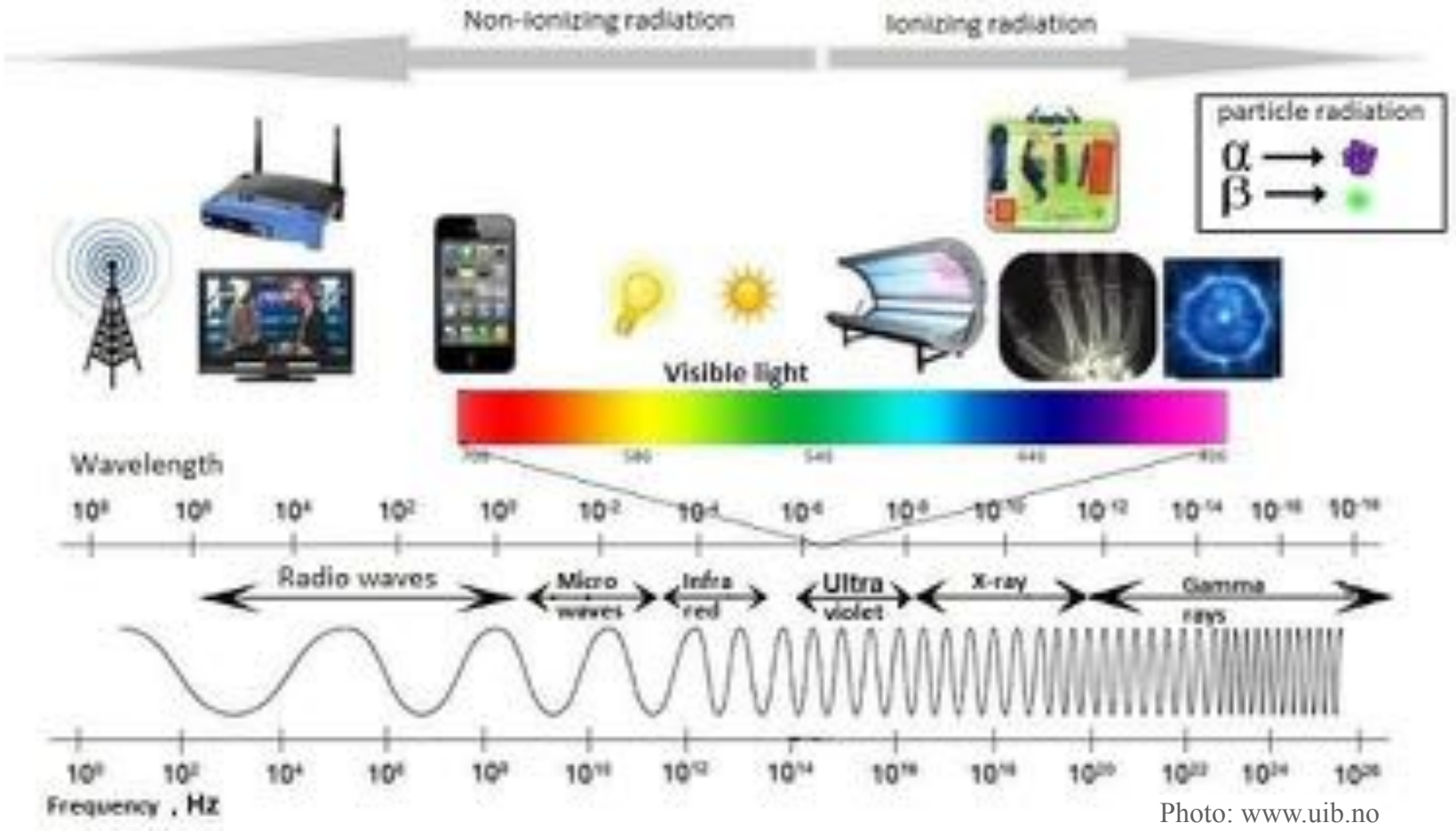


Photo: www.uib.no

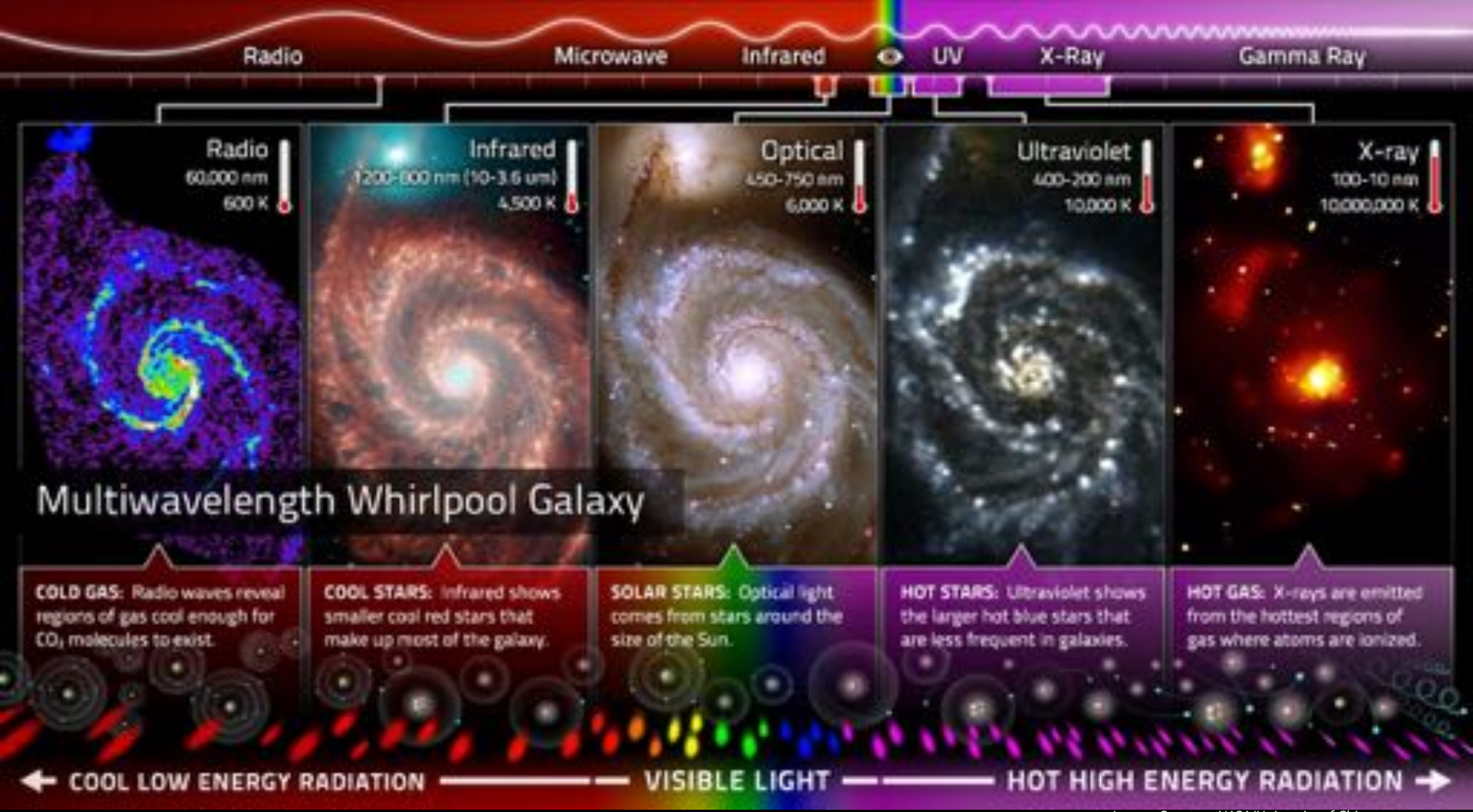
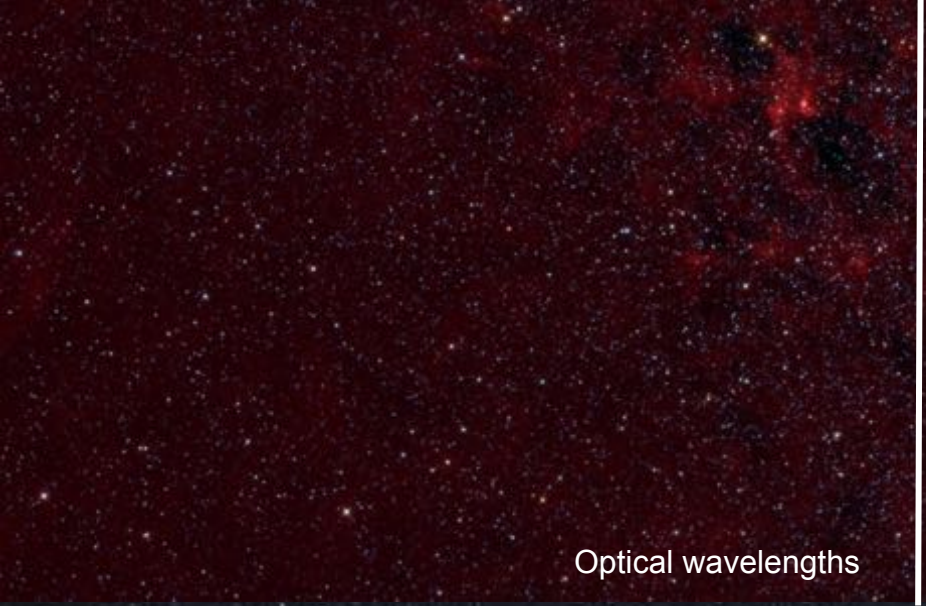
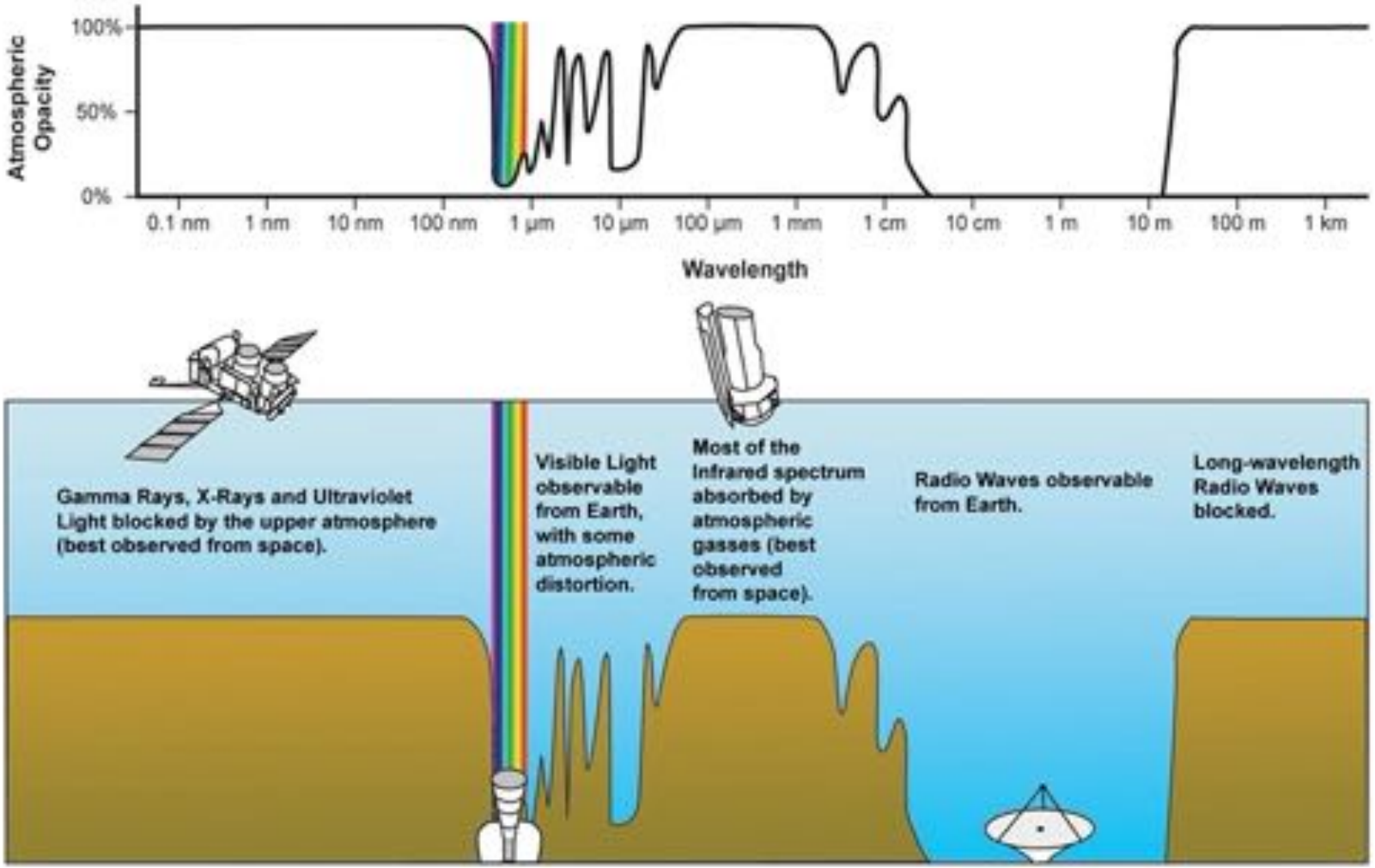


Image: Courtesy NASA/University of Chicago.



Manatee nebula

https://public.nrao.edu/radio-astronomy/the-science-of-radio-astronomy


Atmospheric Opacity
100%
50%
0%
0.1 nm
1 nm
10 nm
100 nm
1 µm
10 µm
100 µm
1 mm
1 cm
10 cm
1 m
10 m
100 m
1 km
Wavelength
Gamma Rays, X-Rays and Ultraviolet Light blocked by the upper atmosphere (best observed from space).
Visible Light observable from Earth, with some atmospheric distortion.
Most of the Infrared spectrum absorbed by atmospheric gasses (best observed from space).
Radio Waves observable from Earth.
Long-wavelength Radio Waves blocked.

Source: NASA

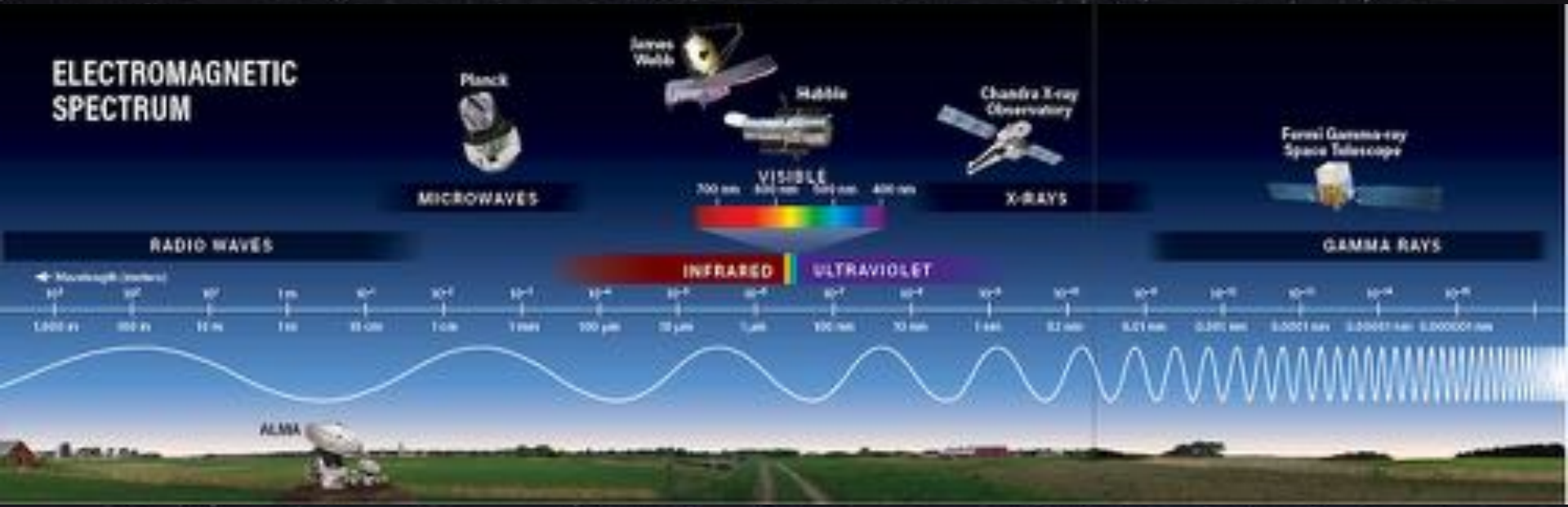
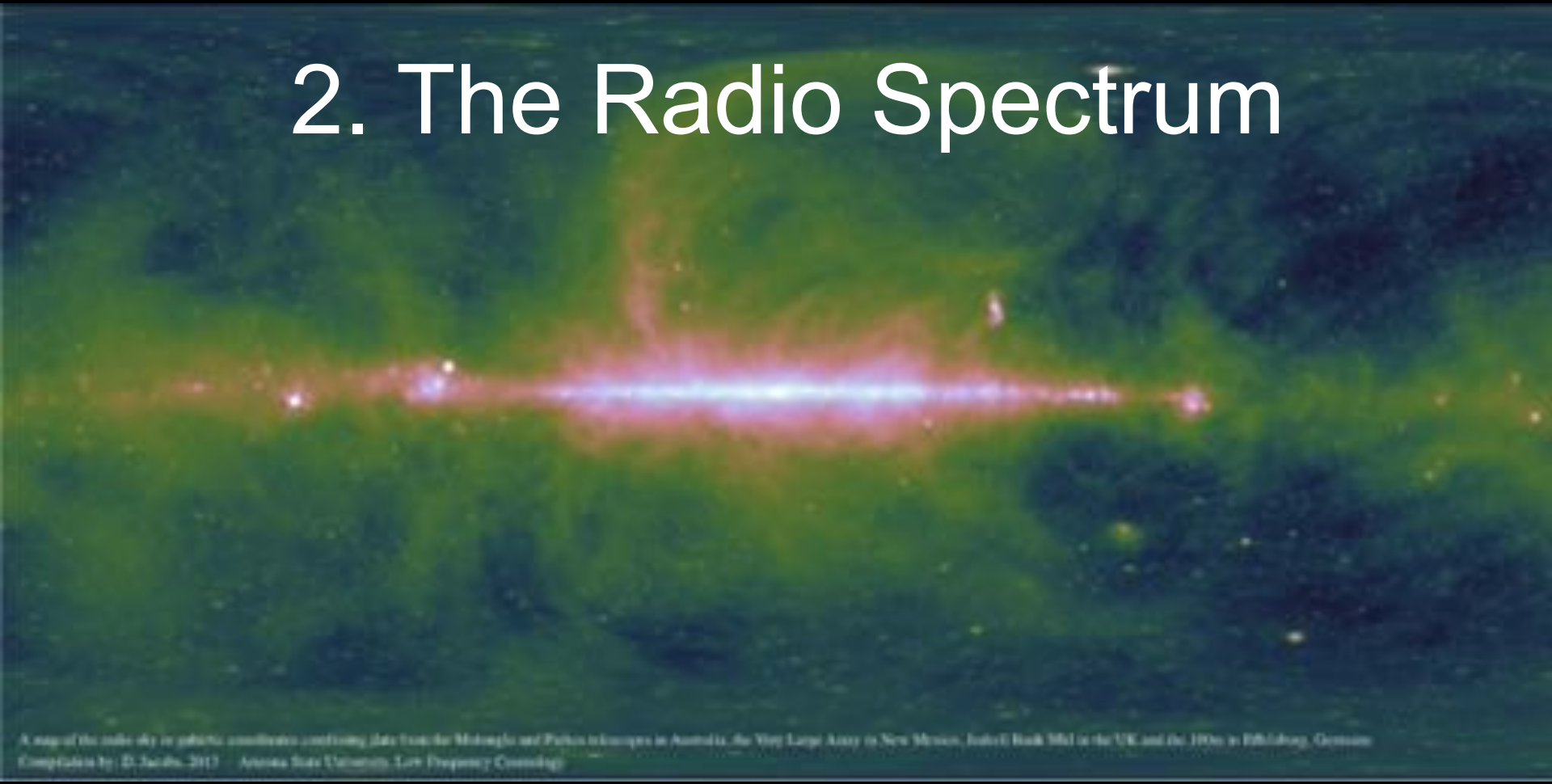


Image credit *Astronomy*: Roen Kelly

2. The Radio Spectrum

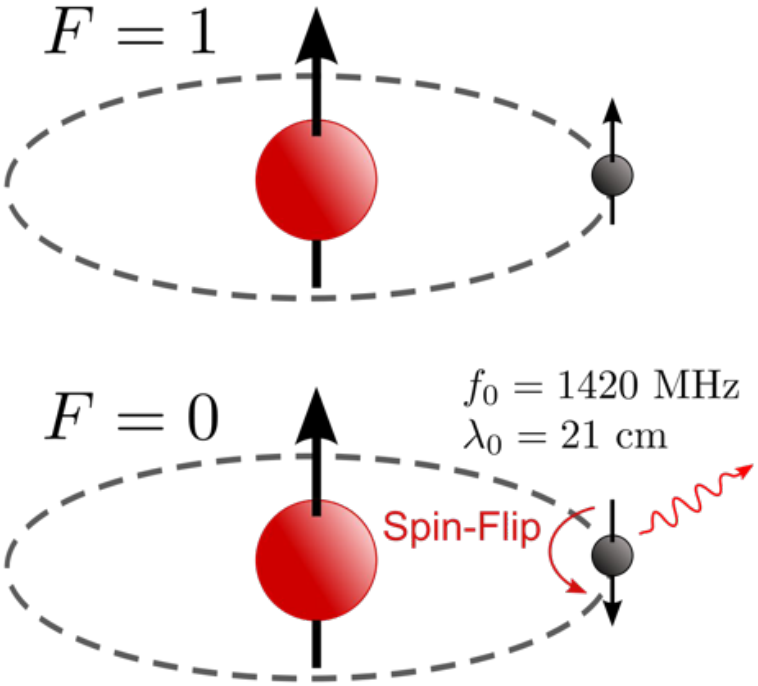


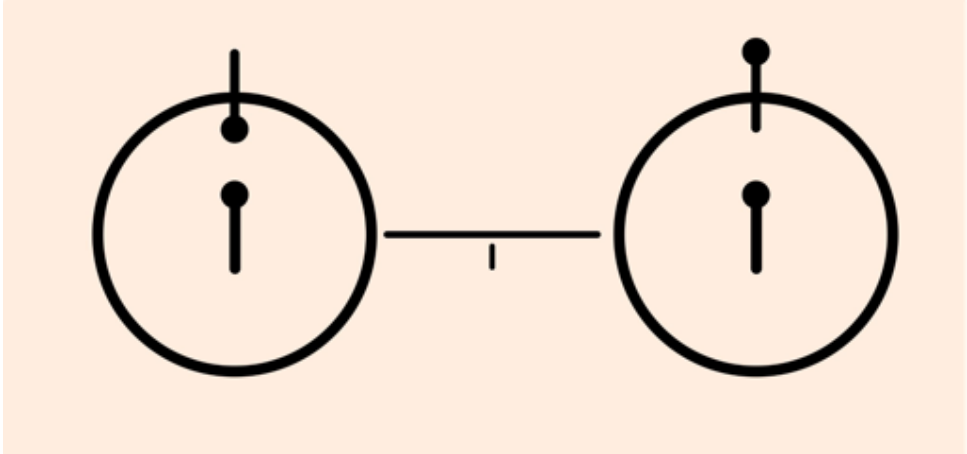
UNITED STATES FREQUENCY ALLOCATIONS

THE RADIO SPECTRUM


21cm

Neutral Hydrogen and the 21cm line





Voyager Spacecraft

Cosmology

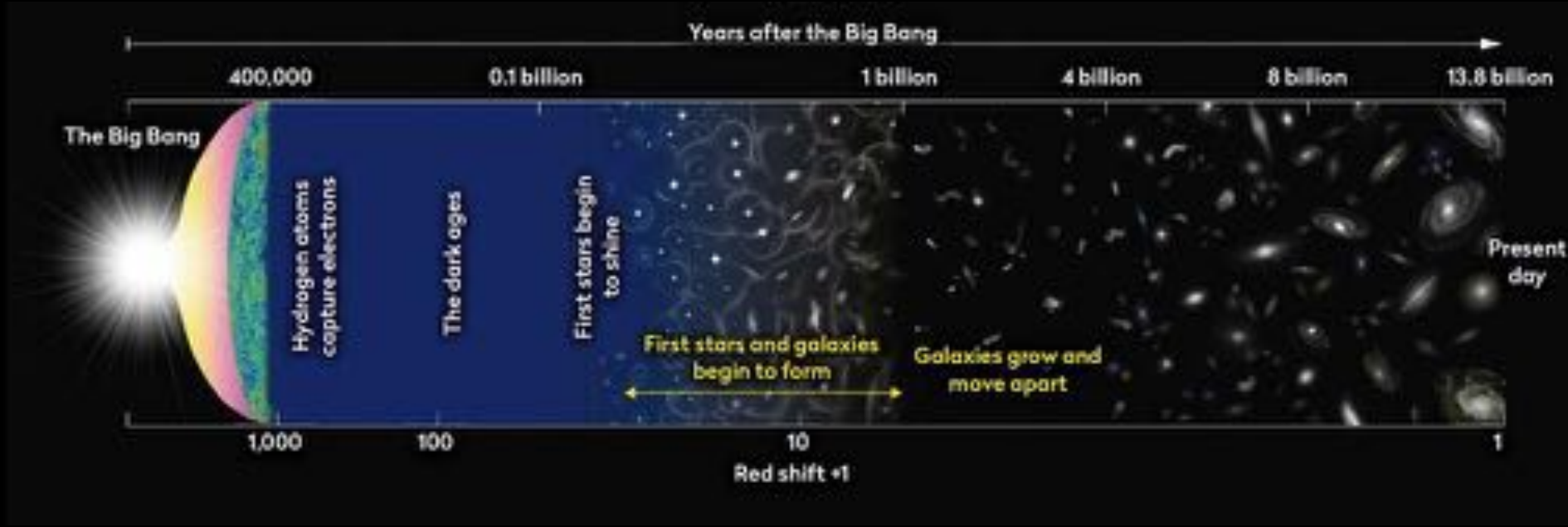
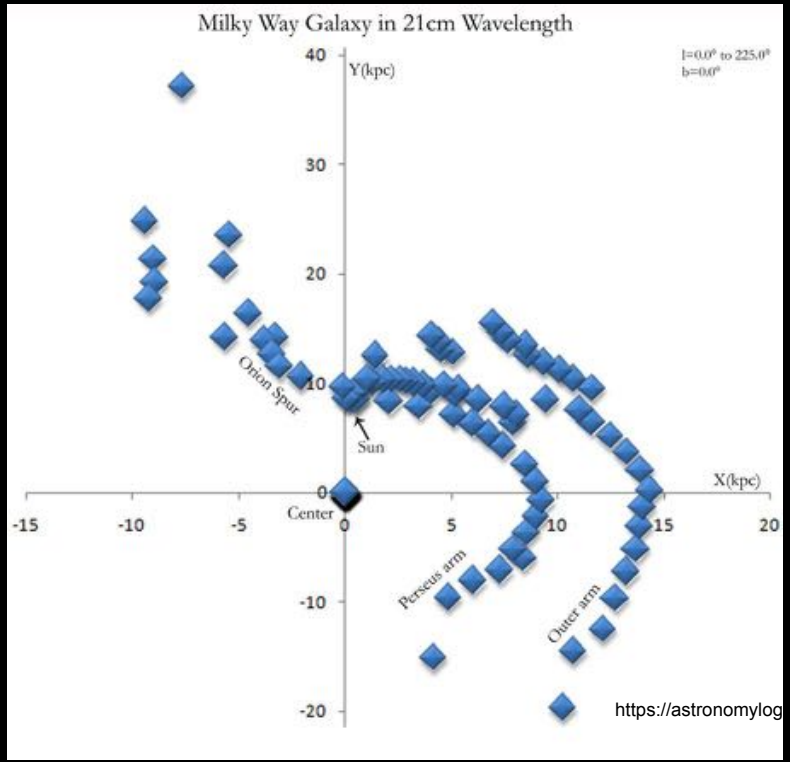
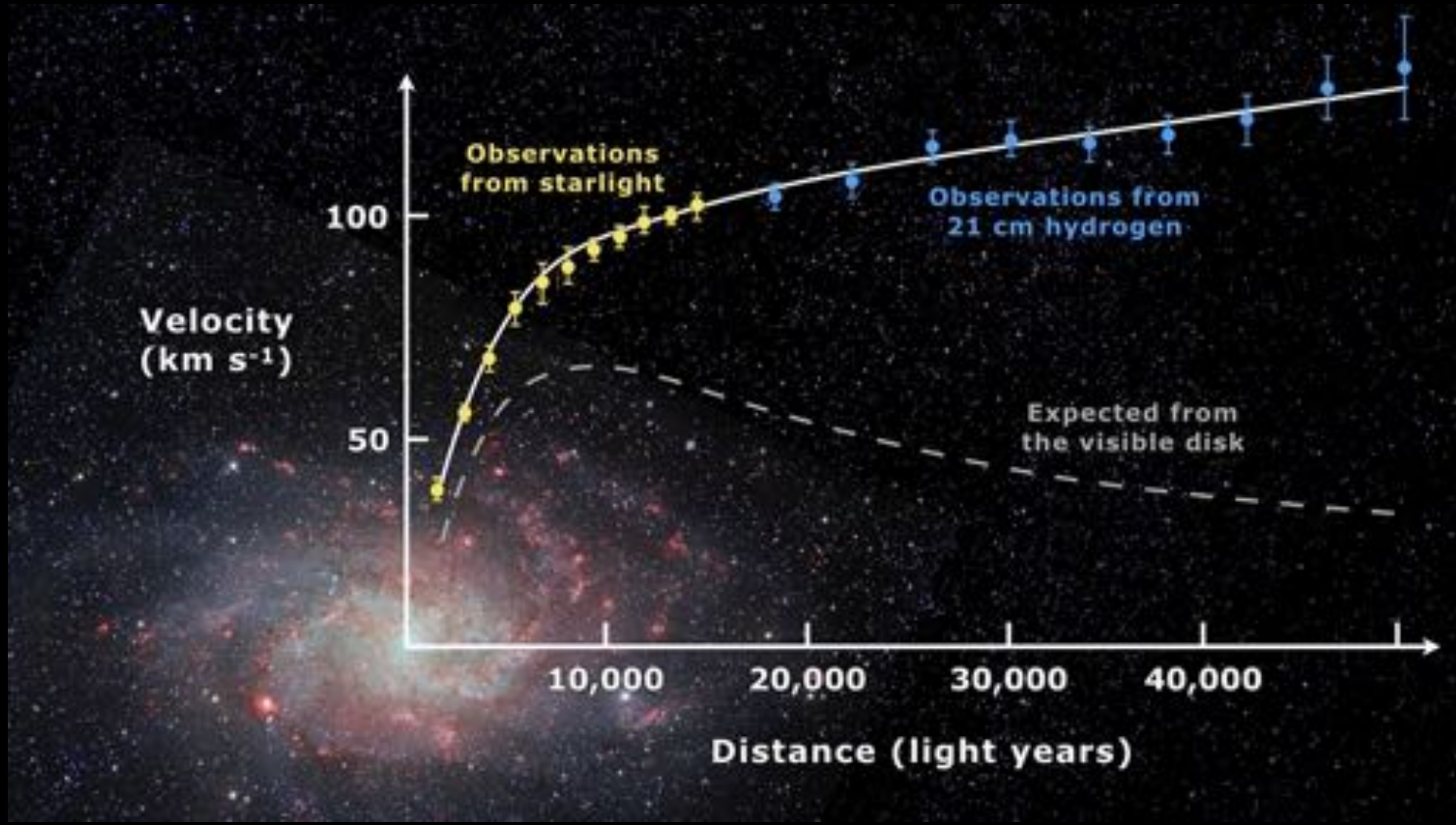


Image credit: *ALMA*

Milky Way Dynamics



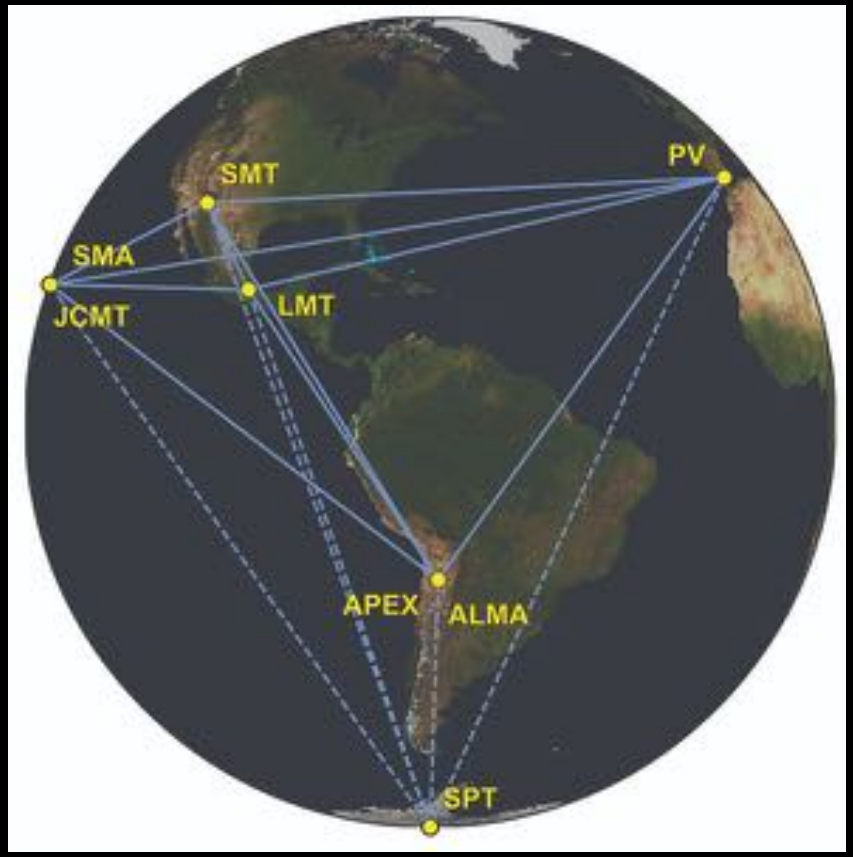
Evidence for Dark matter



https://academic.oup.com/mnras/article/311/2/441/965167?login=true


Other Stuff

Event Horizon Telescope



Event Horizon Telescope collaboration

Pulsars

Image credit: Joeri van Leeuwen, License: CC-BY-AS

- Rotating Neutron Stars, beam along the magnetic axis
- Pulses at regular intervals that typically range from milliseconds to seconds

Fast Radio Bursts

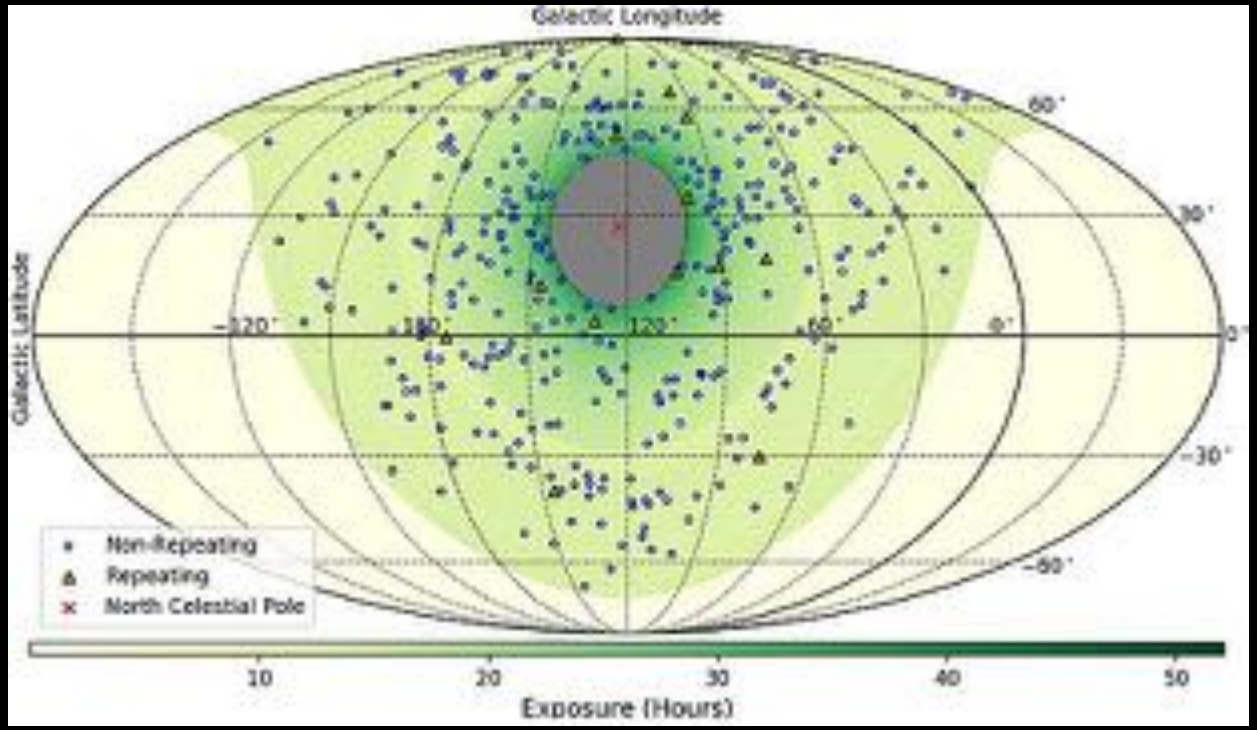


Image credit: Chime Collaboration

- **Fast radio bursts** are intense bursts of radio emission that have durations of milliseconds and exhibit the characteristic dispersion sweep of pulsars
- Most do not repeat

Solar System Astronomy

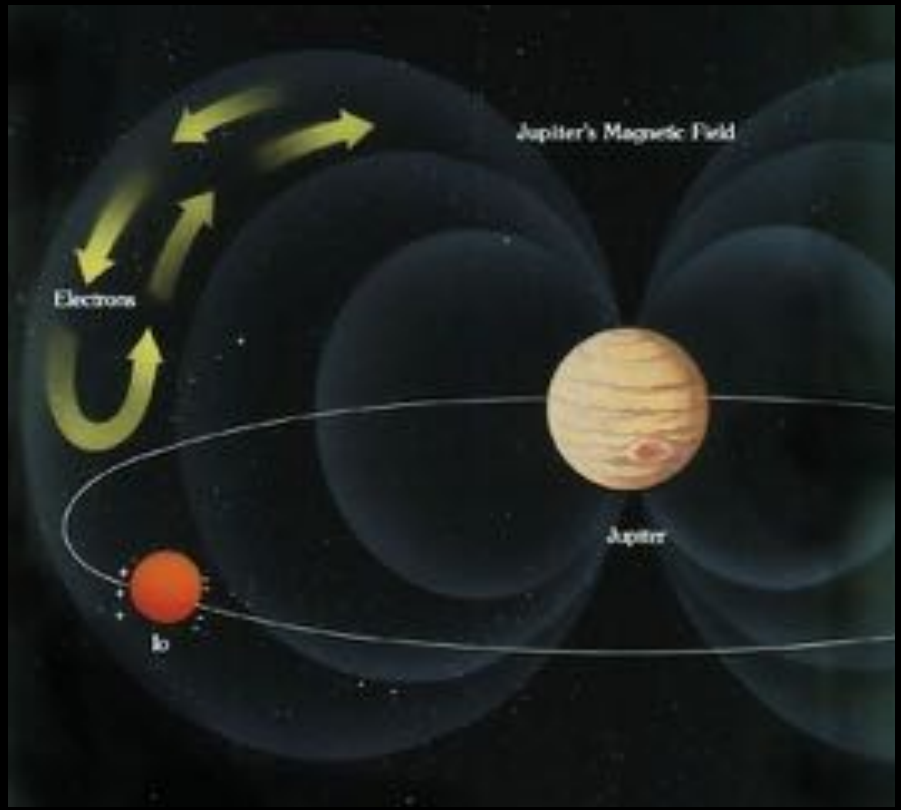


Image credit

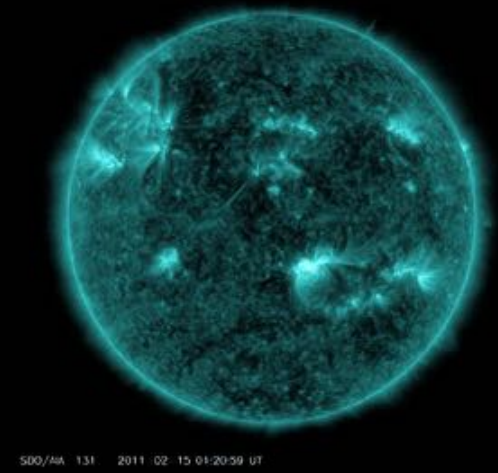


Image Credit: NASA's Goddard Space Flight Center/SDO

Cosmic Microwave Background

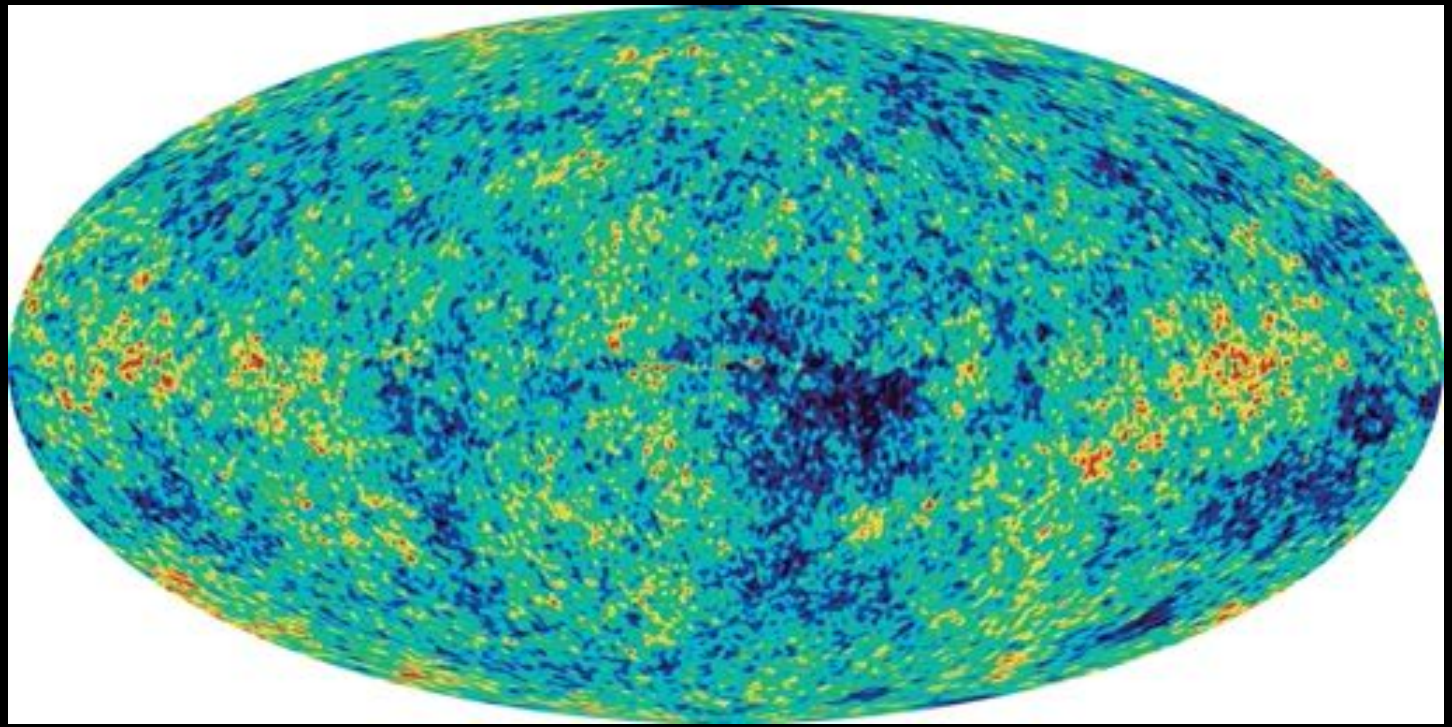
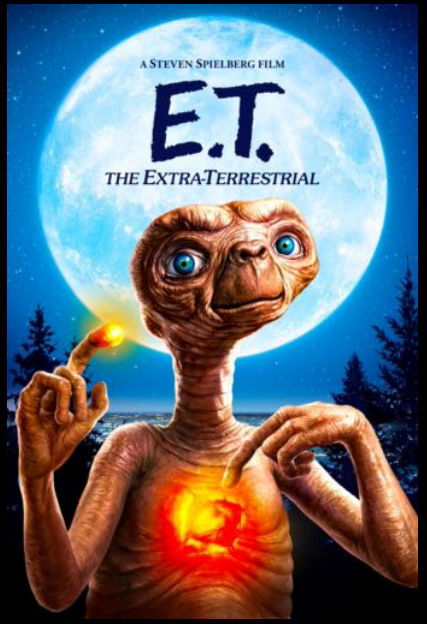


Image credit: Wilkinson Microwave Anisotropy Probe

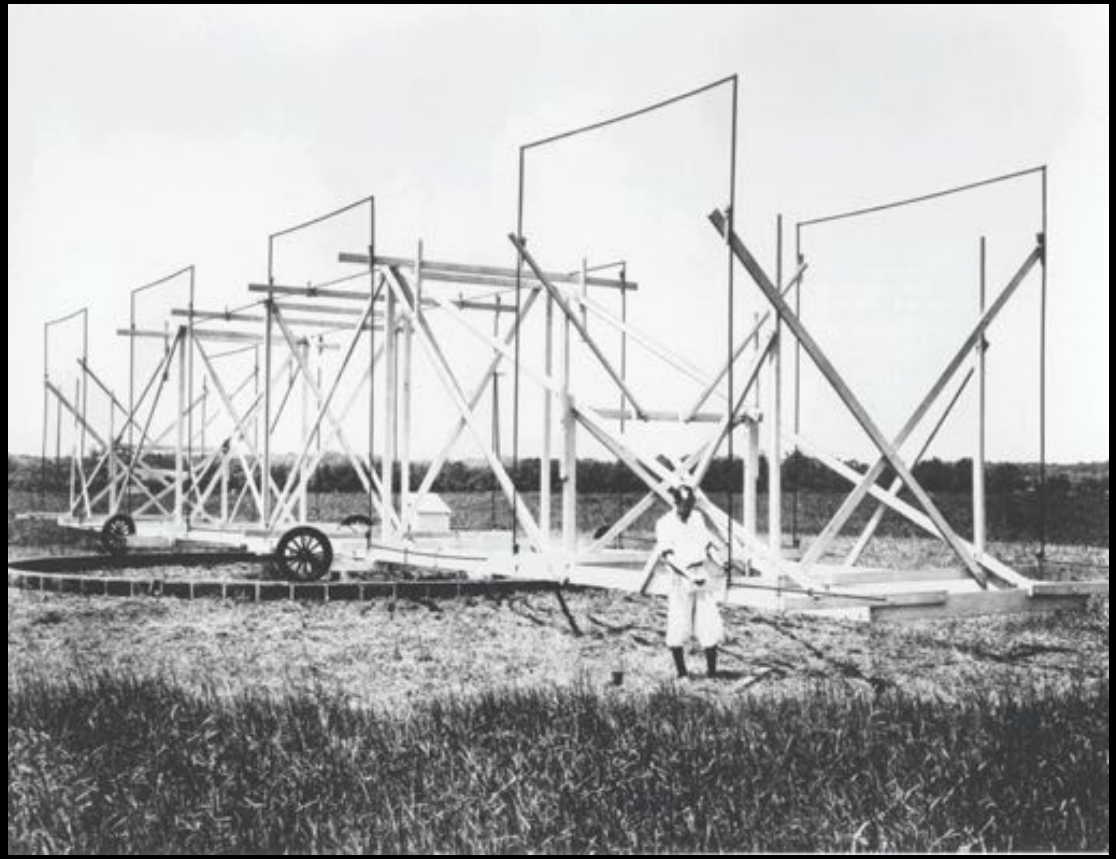
SETI/ET


NRAO
SETI
INSTITUTE
Karl G. Jansky Very Large Array
NRAO Very Large Array and
SETI Institute Collaboration


A STEVEN SPIELBERG FILM
E.T.
THE EXTRA-TERRESTRIAL

A Brief History of Radio Astronomy

Bell Labs, circa 1933



- “Jansky’s Merry Go Round”
- Built for identifying sources of static for overseas radio communication
- Found a source of static that moved throughout the day- the center of the Milky Way!

Reber’s backyard, circa 1937

- Inspired by Jansky, Reber applied for jobs at Bell Labs and with astronomical observatories to study cosmic radio waves, but none of them were hiring at the time
- So he built his own!
- First surveys of Radio Waves

Ryle Interferometer

A PRELIMINARY SURVEY OF THE RADIO STARS IN THE NORTHERN HEMISPHERE

M. Ryle, F. G. Smith and B. Elsmore

(Received 1950 August 25)

Summary

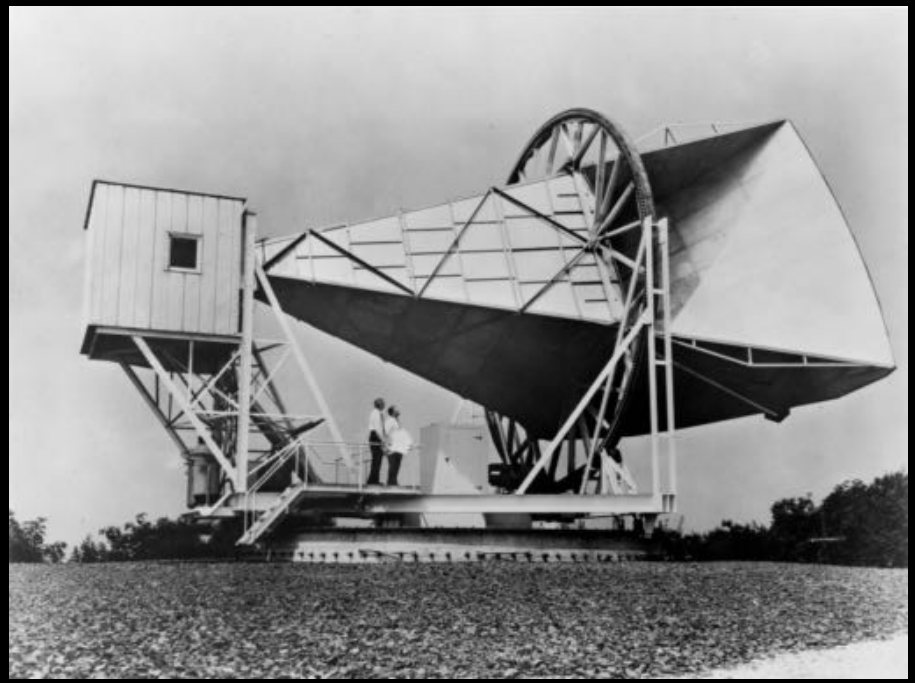
Observations with an interferometer of large resolving power have made it possible to locate 50 discrete sources of radio waves or " radio stars " in the Northern Hemisphere ; their positions and intensities (which cover a range of 7½ in apparent magnitude) are given. The positions of the more intense radio stars can be determined with an accuracy of about 5 minutes of arc, but most of them can only be located to within 1°.

The angular distribution of the radio stars, unlike that of the general background radiation, shows no concentration in the galactic plane; this result suggests either that they are at distances small compared with the dimensions of the galaxy, or that they are situated outside the galaxy. Whilst there is evidence that a few of the weakest radio stars represent the total " background " radiation of some of the nearest extra-galactic nebulae, it is concluded that the majority of the radio stars must be situated within the galaxy. Estimates of the relative intensities of the radio stars and of the background radiation have suggested that they are distributed throughout the galaxy with an average population density comparable with that of visual stars.

Attempts to identify the radio stars with various types of visual body have been unsuccessful; it is therefore concluded that the radio star represents a hitherto unobserved type of stellar body, distributed widely throughout the galaxy, and one which is equally numerous in other spiral nebulae.

Penzias and Wilson

- Built for commercial use
- “Background noise” of uniform origin
- Originally attributed to pigeon poop
- Cosmic Microwave Background, foundational support of “Big Bang” theory



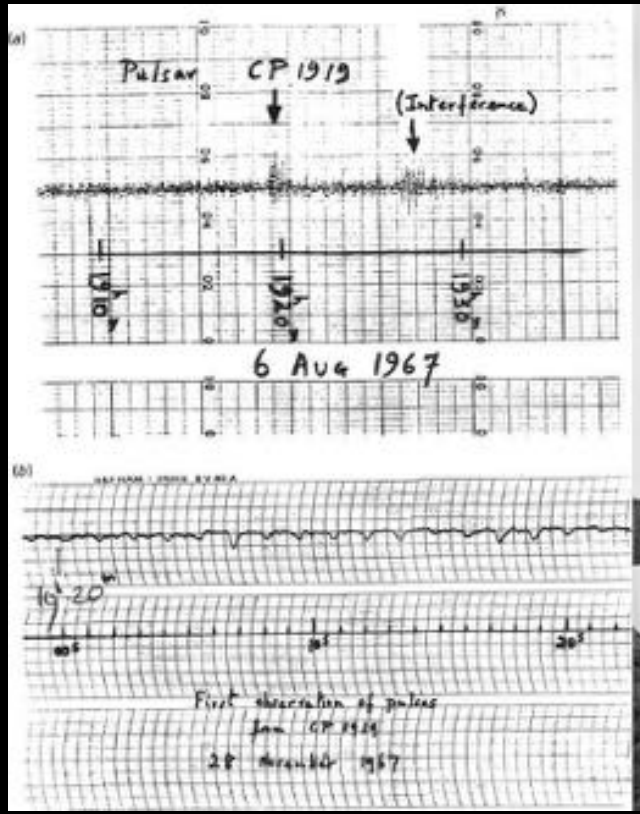
Ewen & Purcell

NRAO-Green Bank May 22, 2001

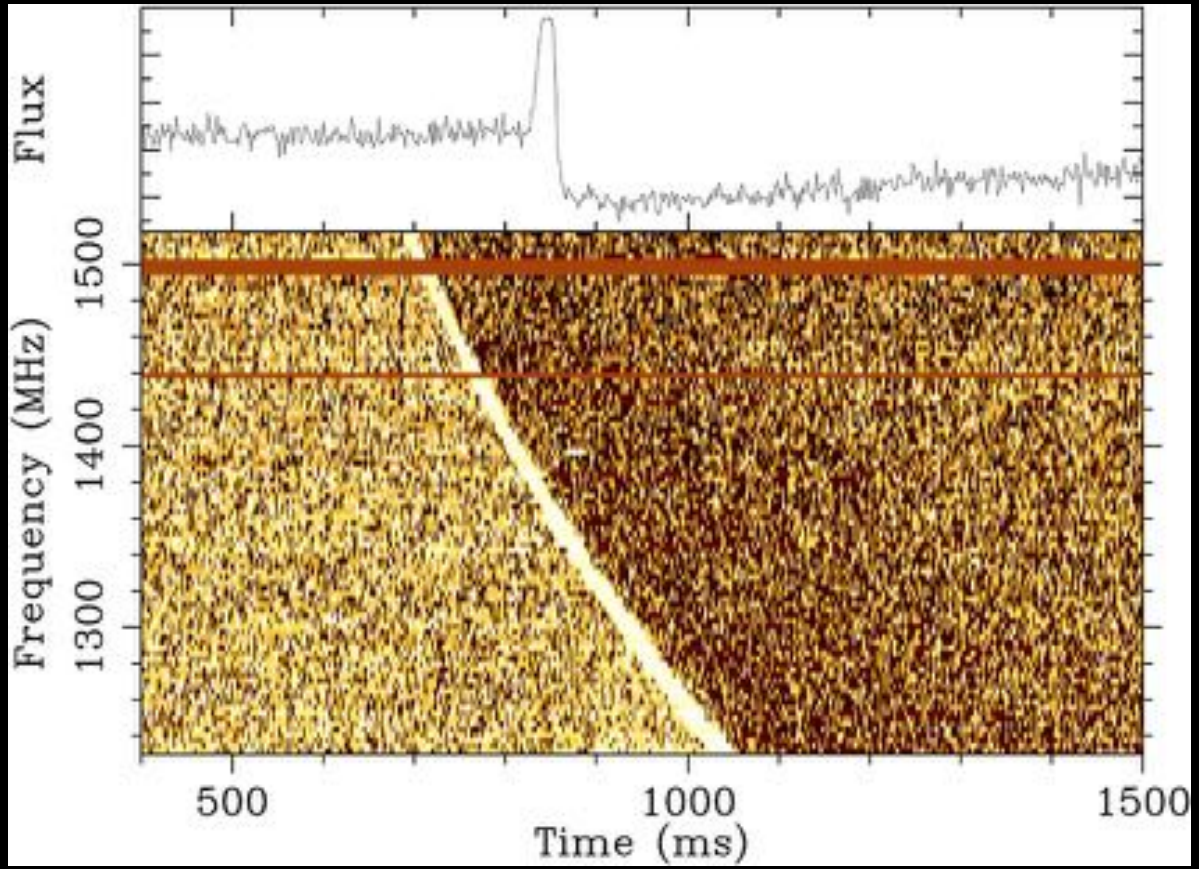
- In 1951, first measurement of the 21-cm signal from Neutral Hydrogen
- Predictions doubted detectability of the line

Jocelyn Bell

- In 1967, Bell noticed a strange signal in her radio data
- Bell and her college advisor D. Hewish labeled the signal LGM for Little Green Men.
- When more were found, it was concluded that the source was astronomical



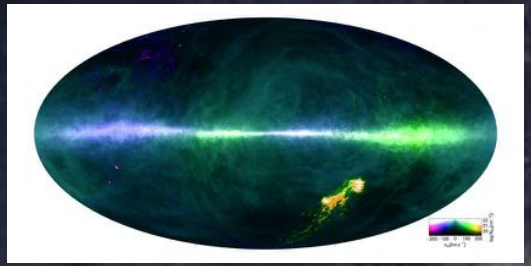
Lorimer Burst/Parkes Observatory

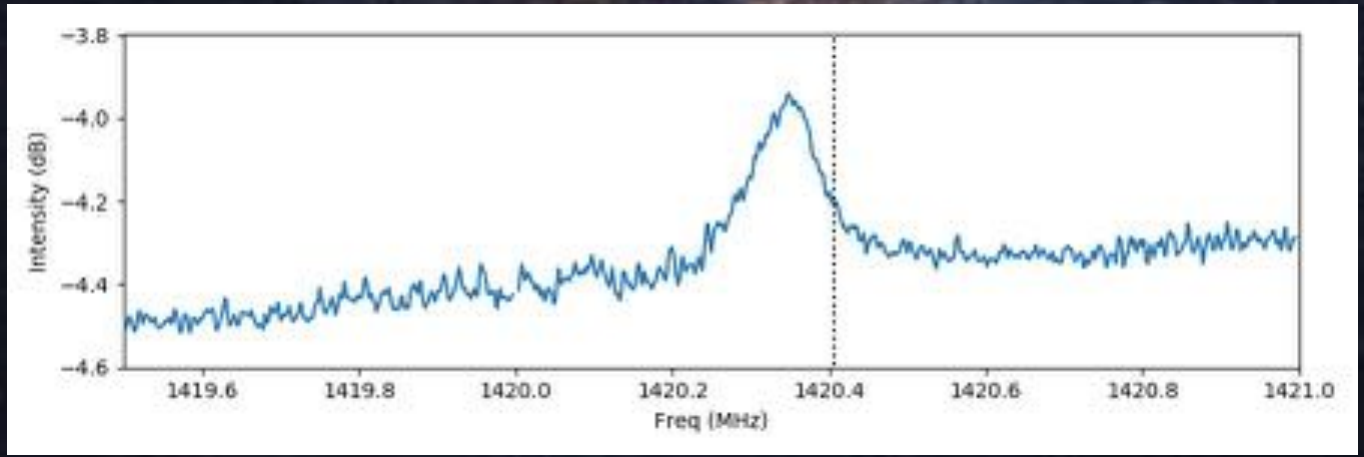


- Mysterious interference by signals called perytons was first detected in 1998 "within 5km" of the Parkes Observatory
- Lorimer and student David Narkevic in 2007 recorded the first FRB at the Parkes Radio Telescope

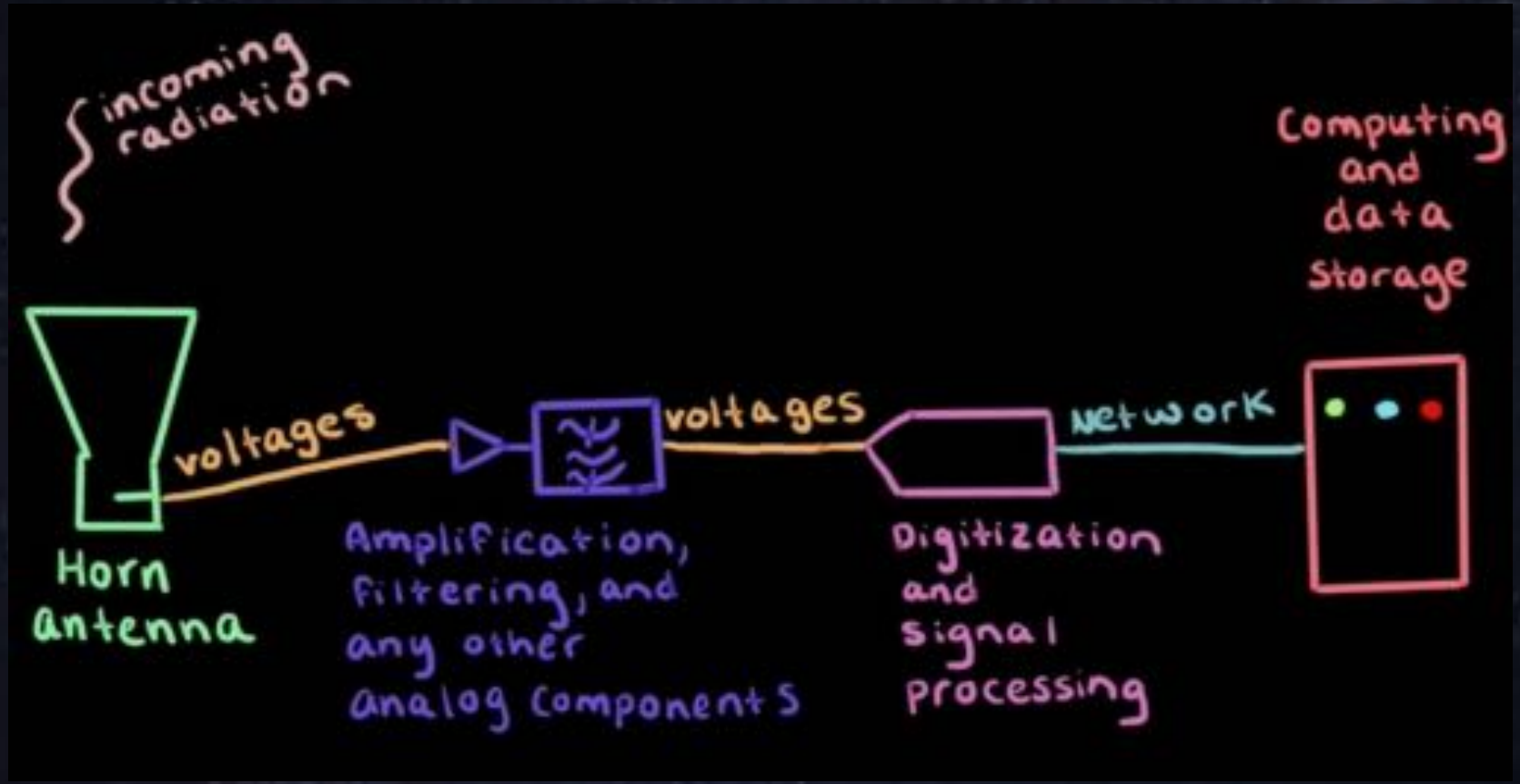
Parts of a telescope and Signal Processing

How do I get from radiation in the sky to a spectrum?

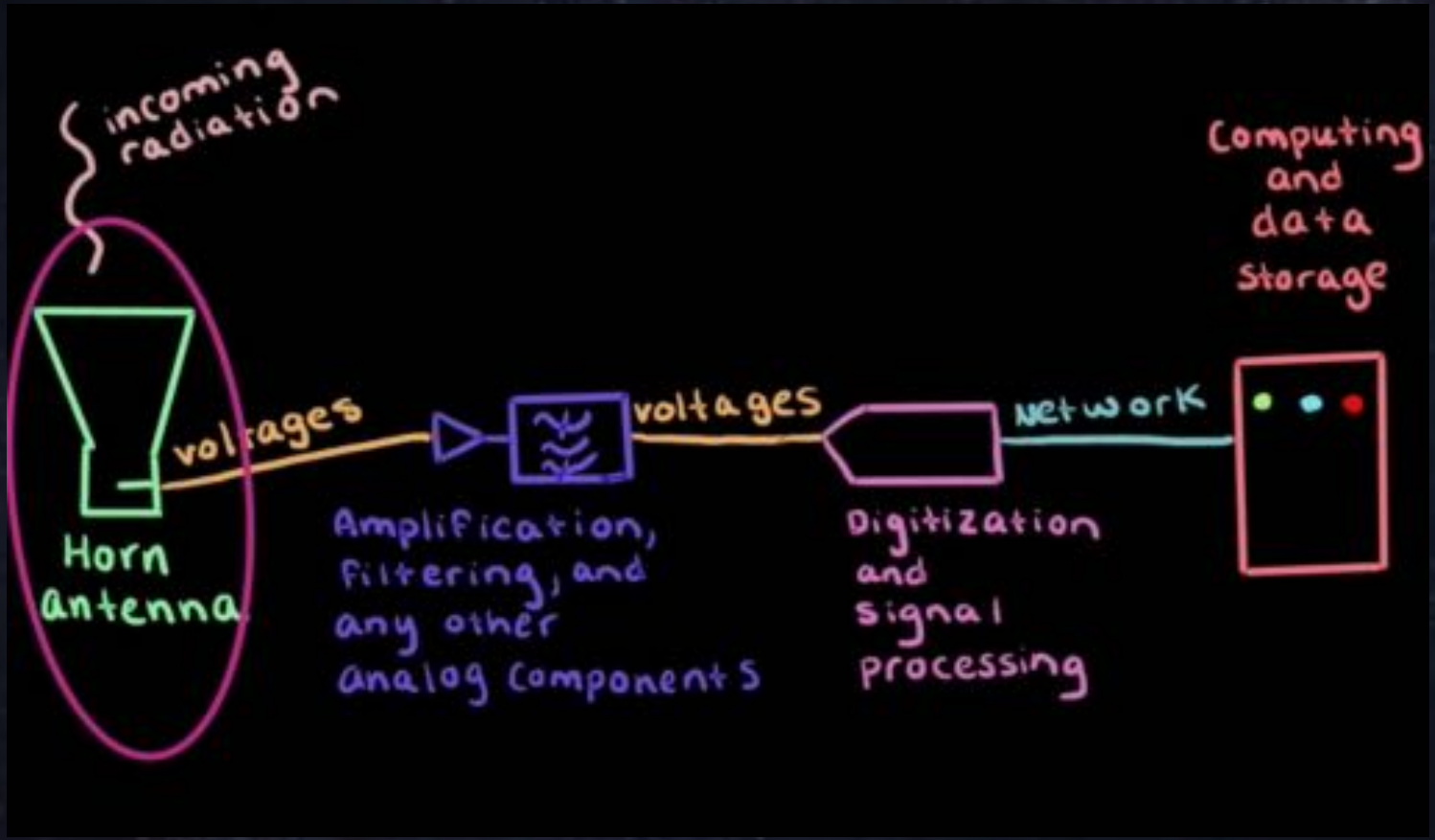




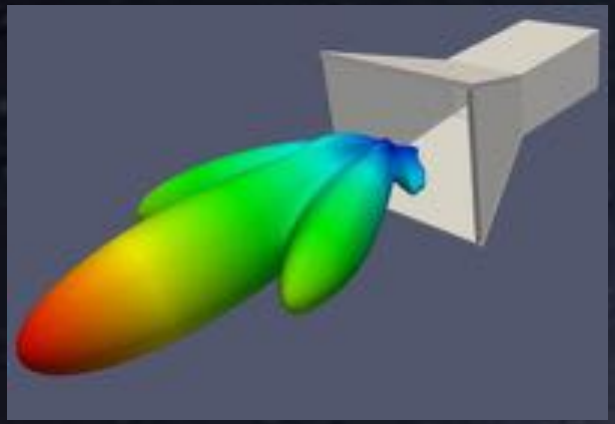
Parts of a radio telescope



Antenna


incoming radiation
Horn antenna
voltages
Amplification, filtering, and any other analog components
voltages
Digitization and signal processing
network
Computing and data storage

Horn Antenna



https://www.everythingrf.com/search/waveguide-horn-antennas

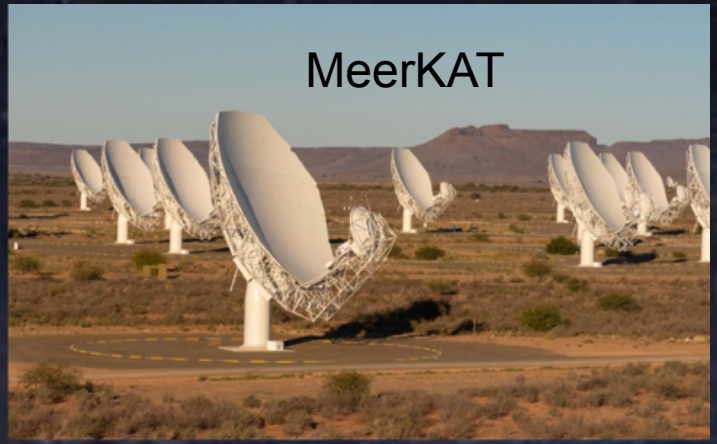
Reber Dish

Palomar 200″

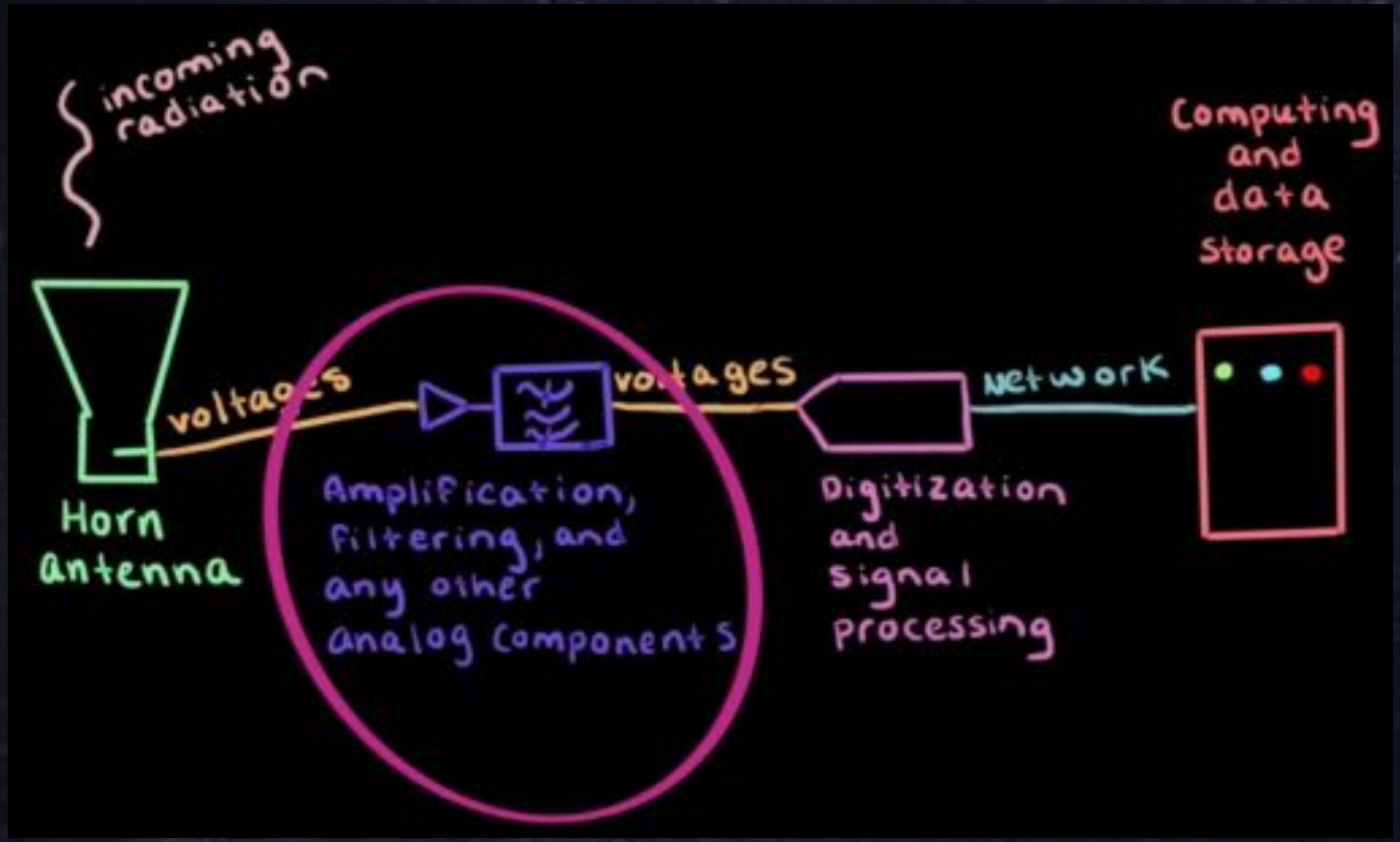
But there are many kinds….

Bigger dish = Better Resolution
Drift scan vs. Pointable antennas

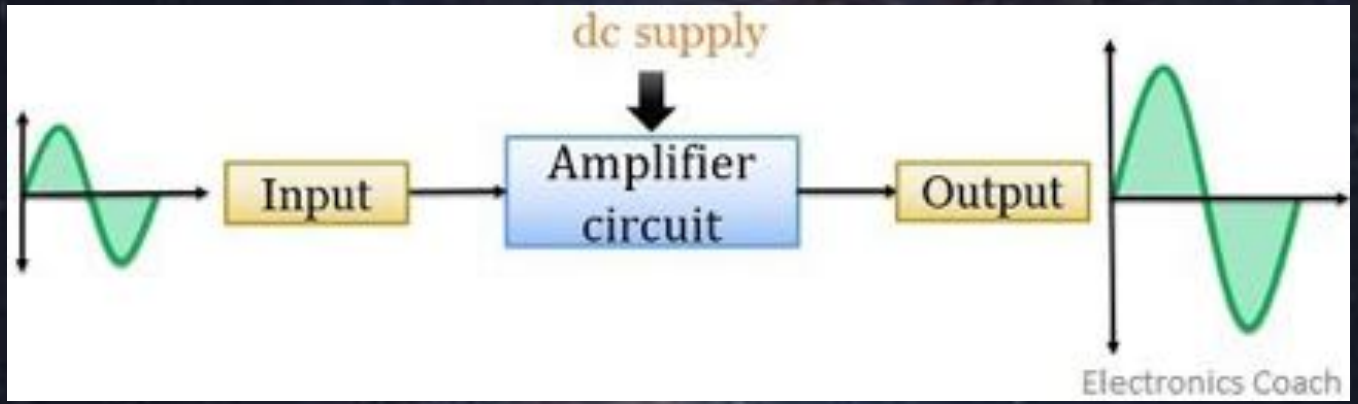
Interferometers!



Analog Components

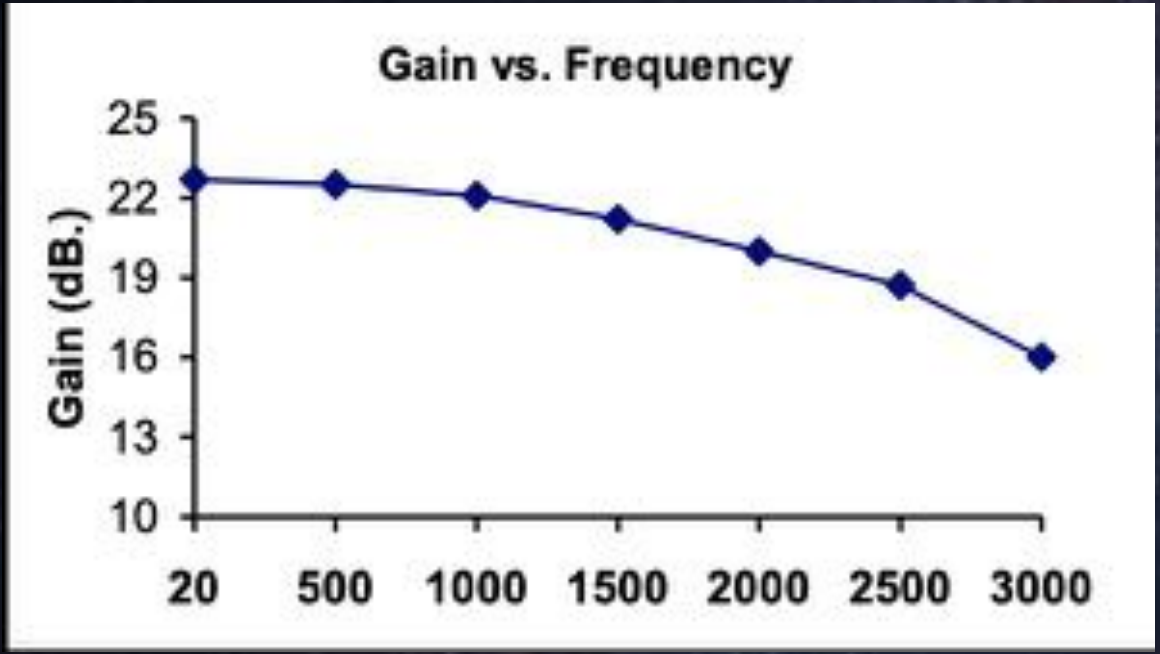


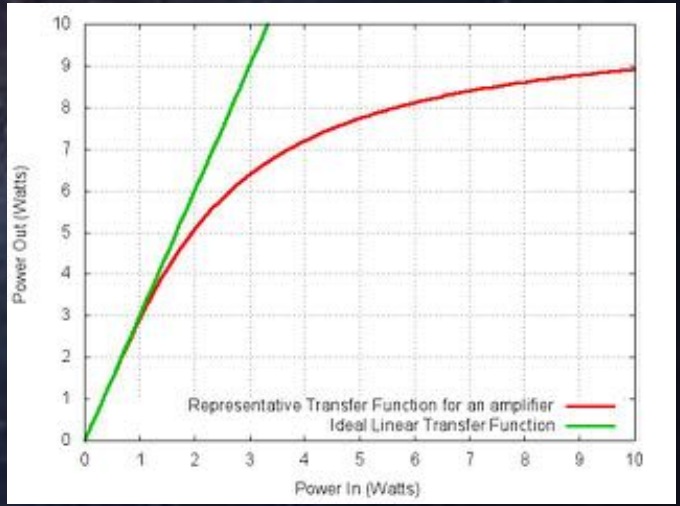
Amplification



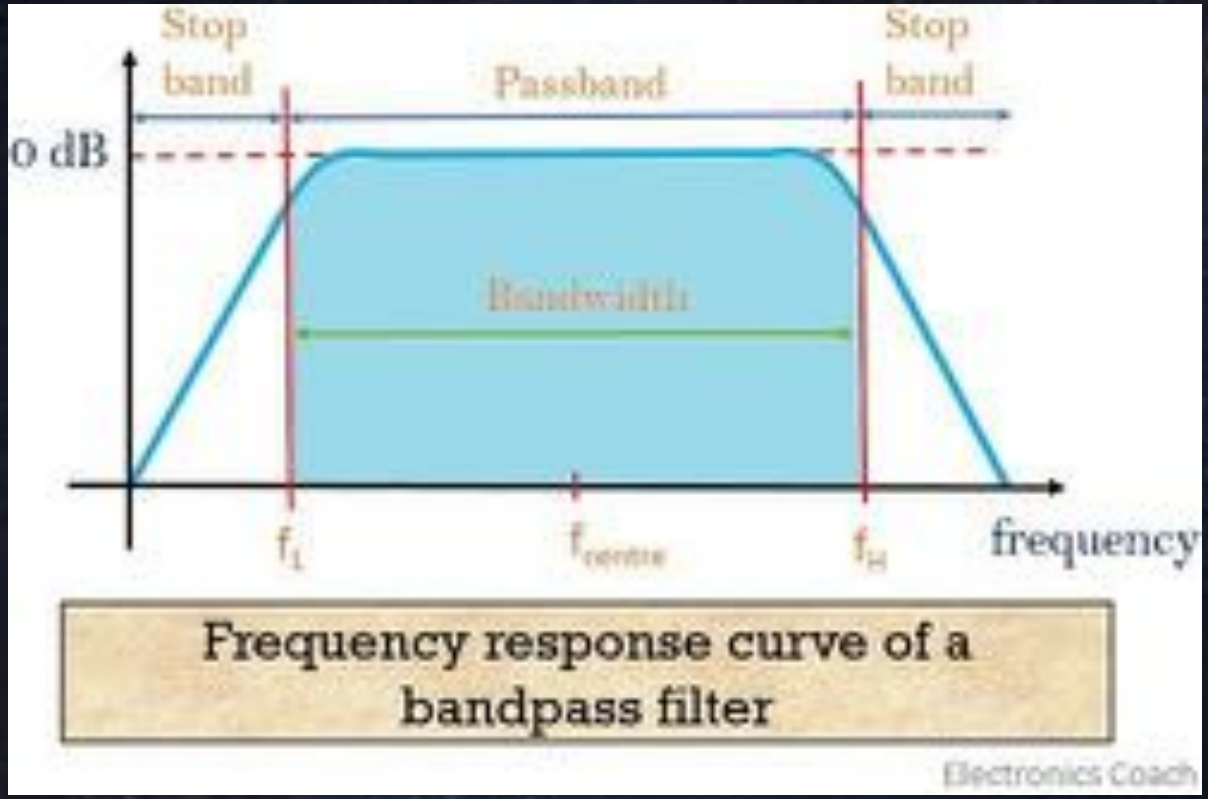
https://electronicscoach.com/amplifier-in-electronics.html

Amplifier response curve





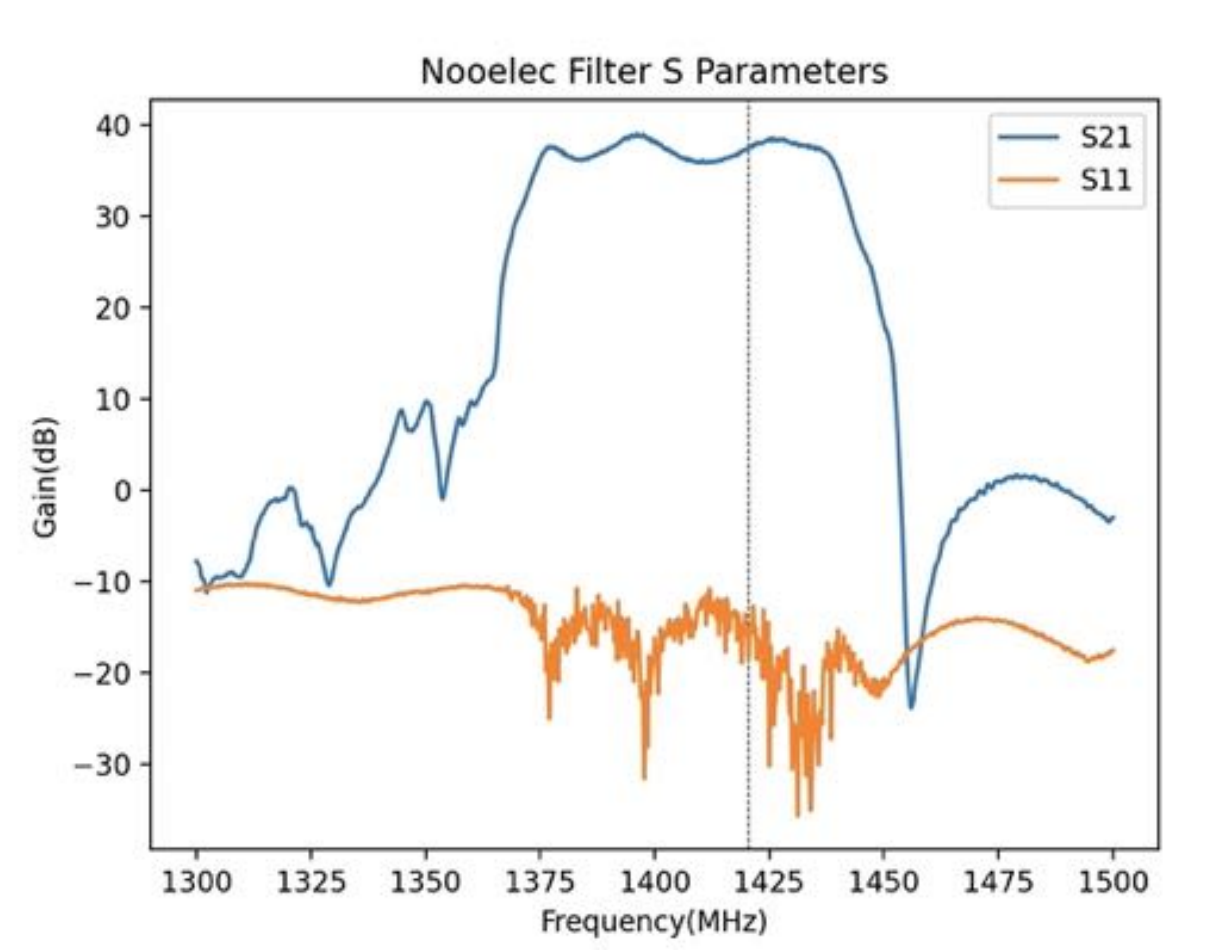
Filtering



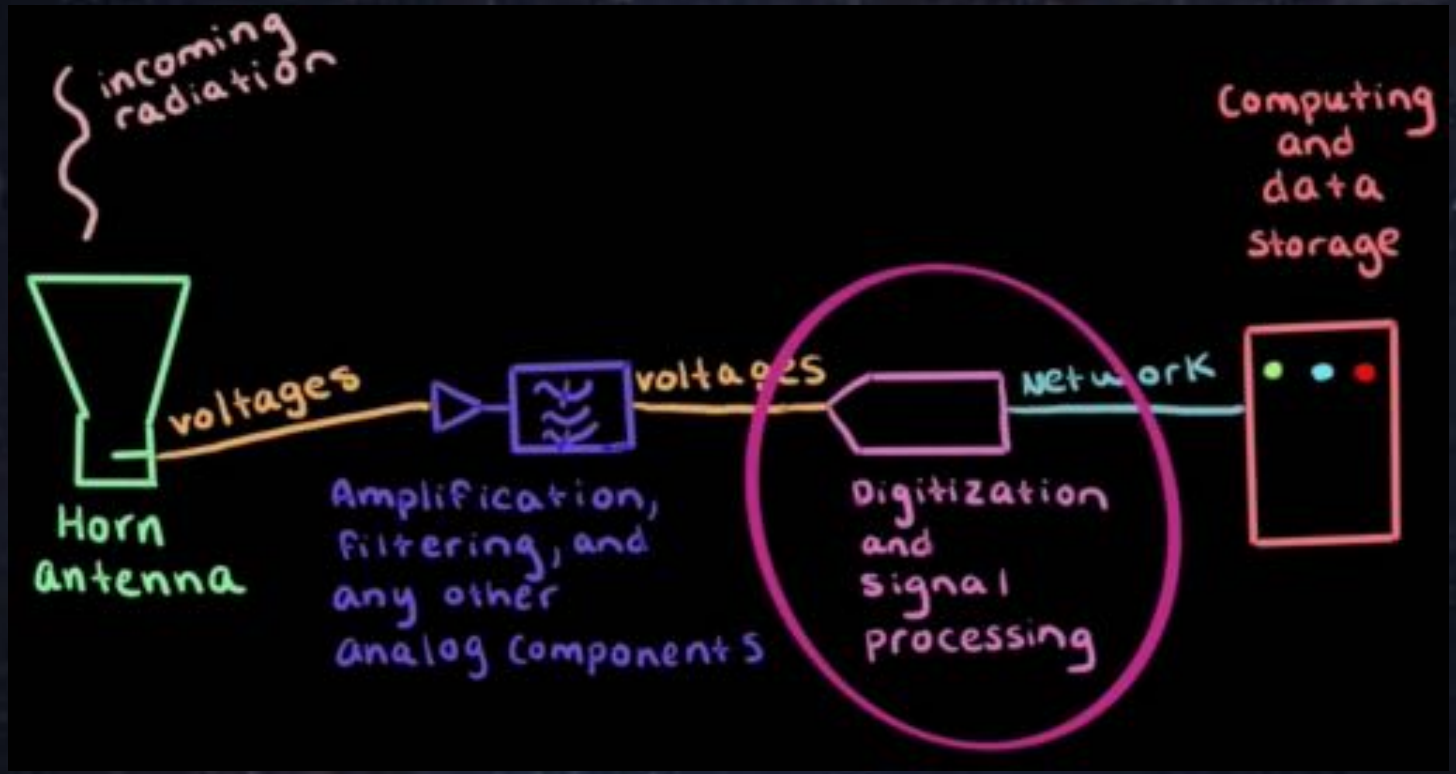
https://electronicscoach.com/bandpass-filter.html/frequency-response-curve-of-bandpass-filter

https://www.nooelec.com/store/sawbird-h1-barebones.html

Nooelec Passband



Digitization and Signal Processing

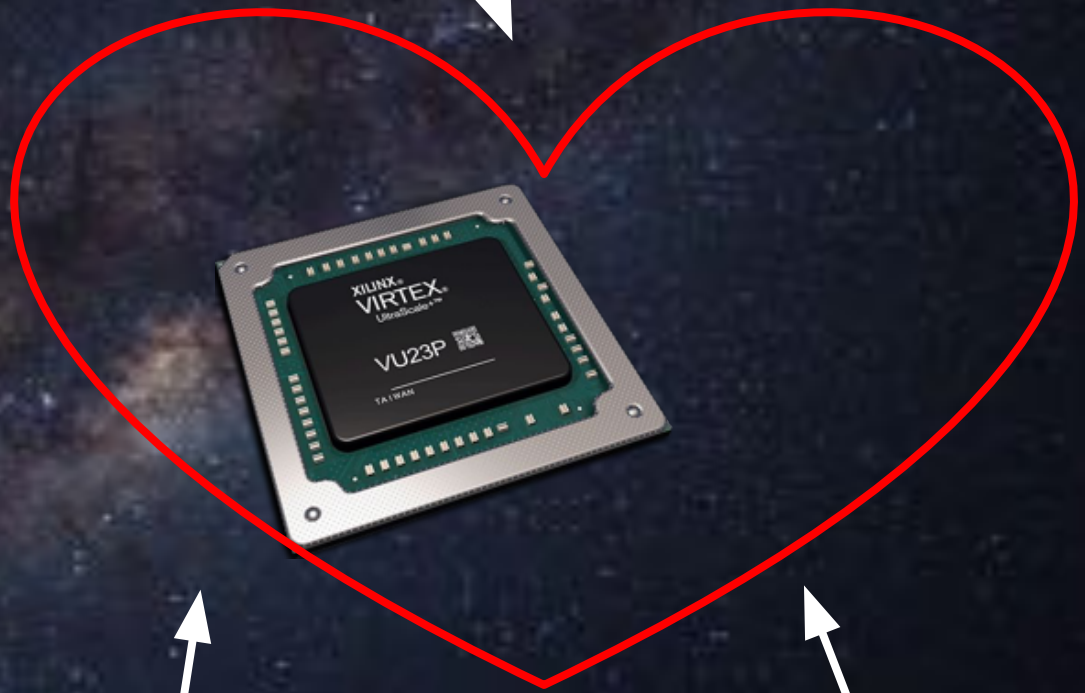


SDR

Software defined radios implement traditional radio components entirely in software.

There are other options…

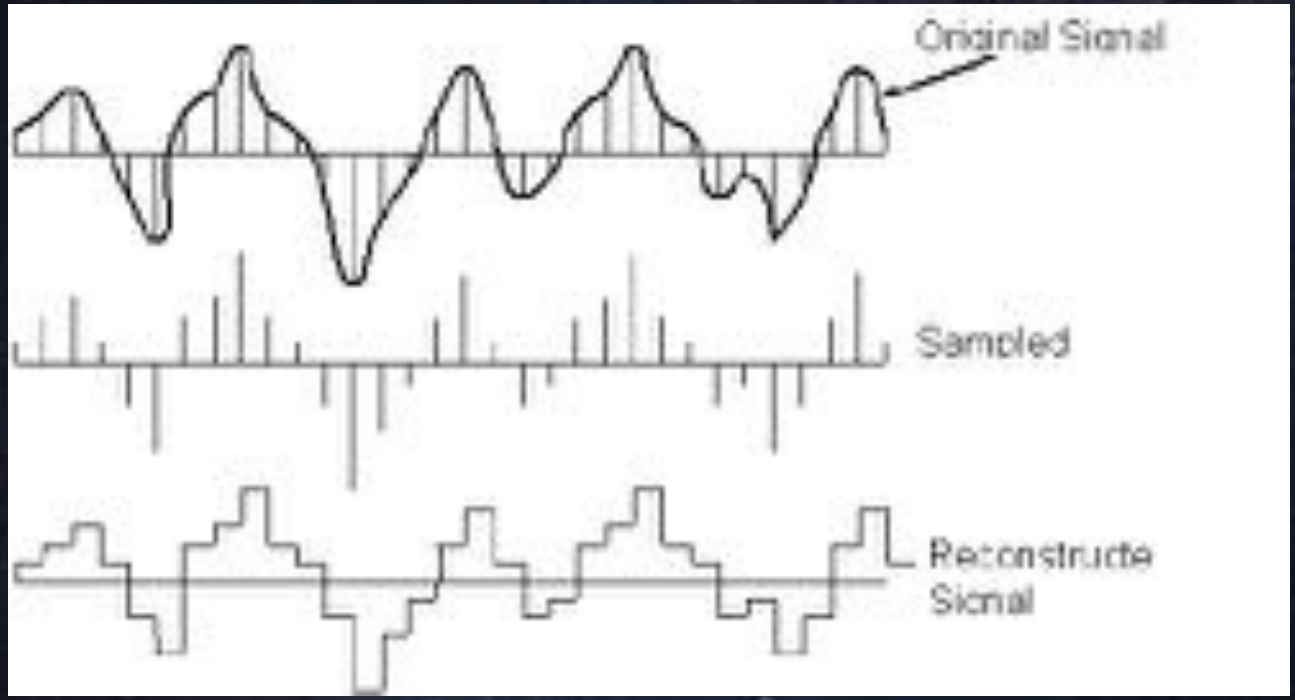
Make tons of $$$!!!



Write your own firmware !!!

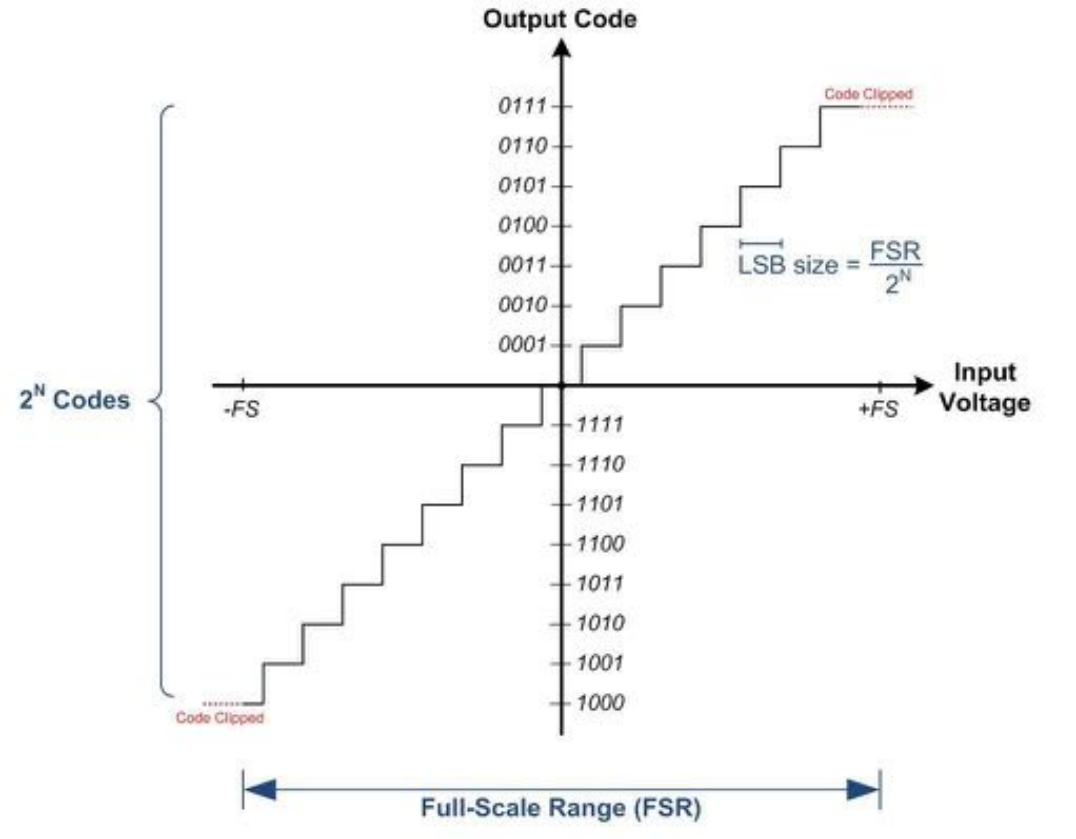
Flexible AND Fast !!!

Analog to Digital Conversion

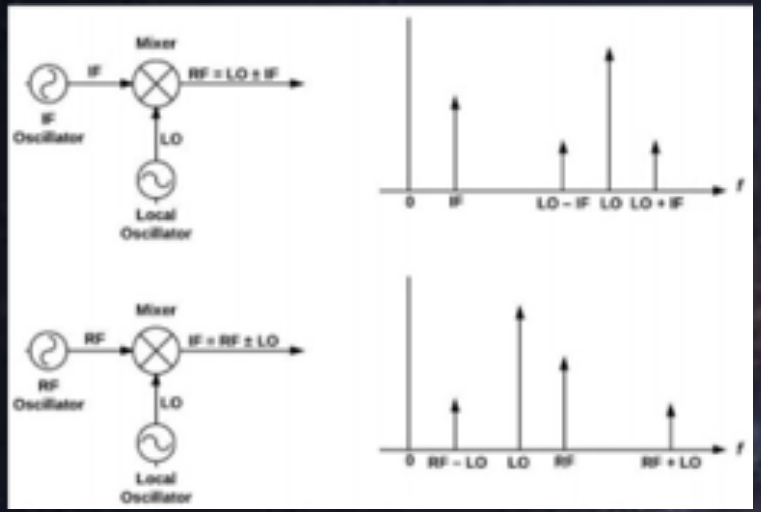


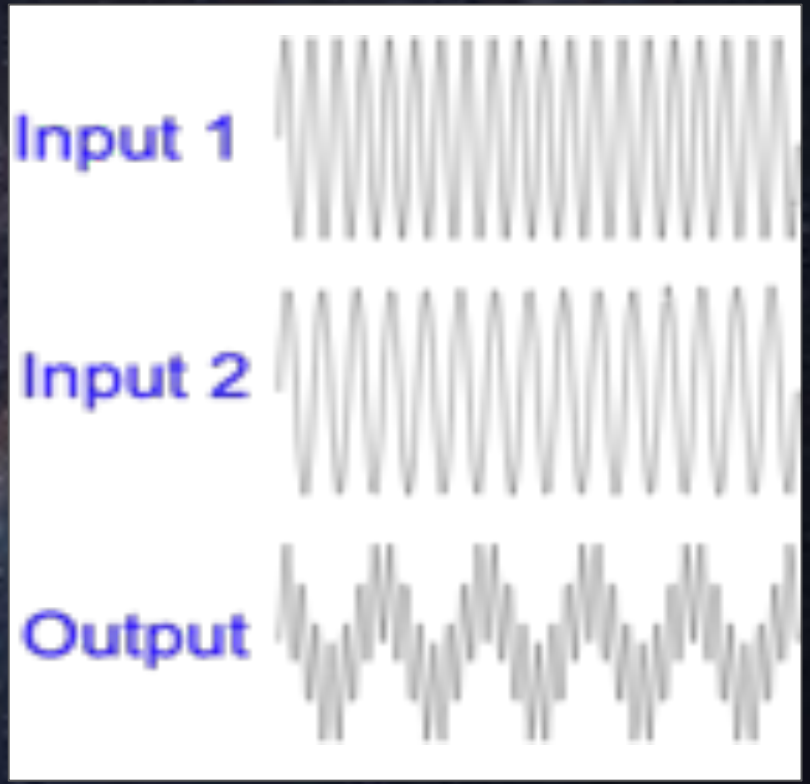
http://www.azimadli.com/vibman/analogtodigitalconversion.html

Analog to Digital Conversion



Mixing/Tuning

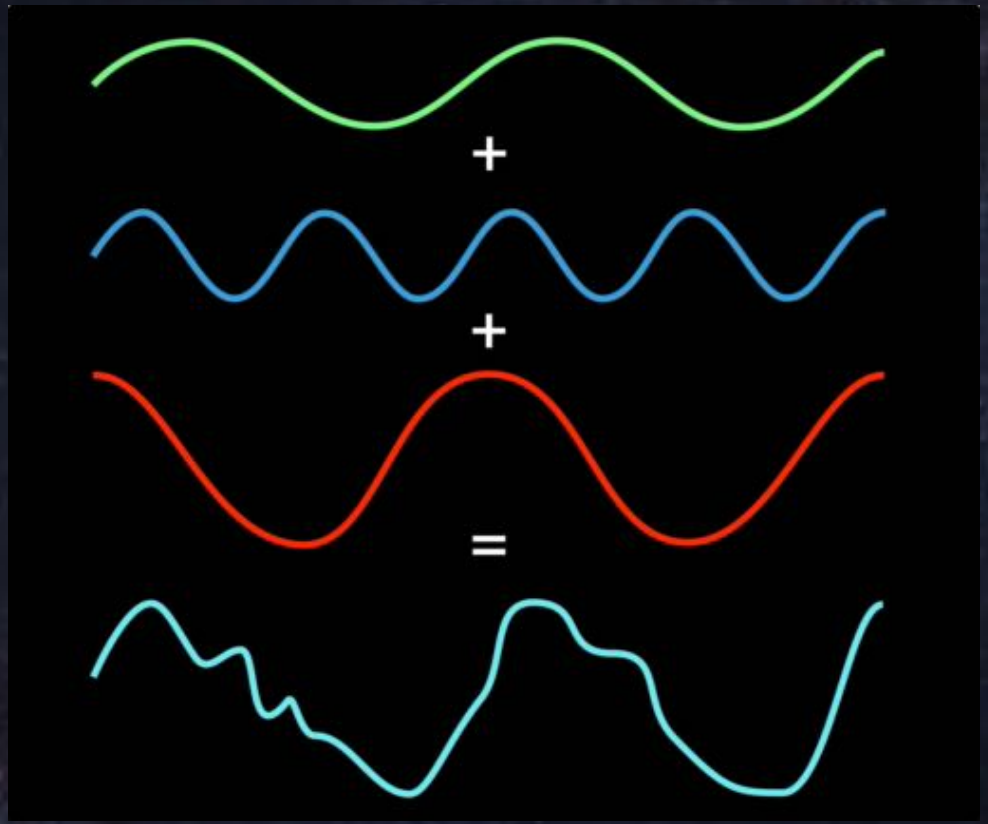




https://coppermountaintech.com/rf-mixer-characterization/

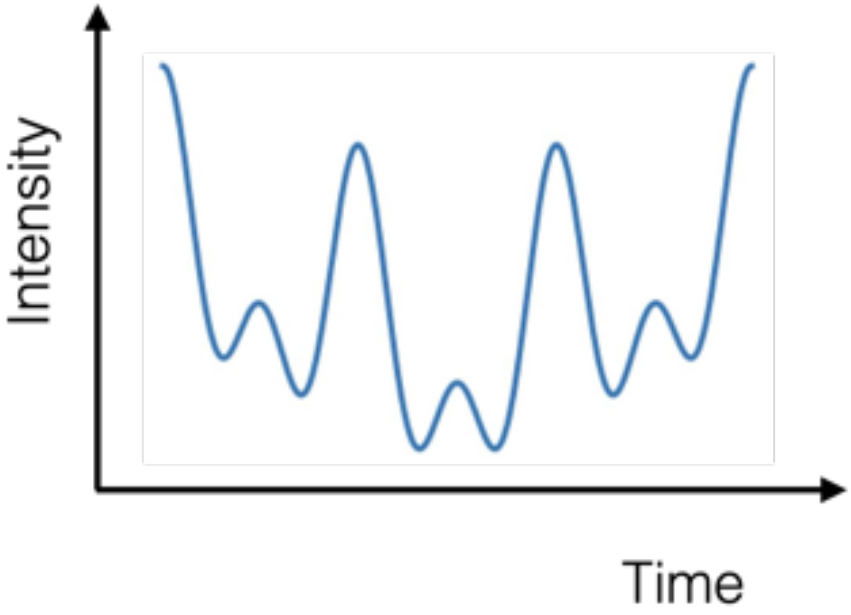
https://academo.org/demos/wave-interference-beat-frequency/

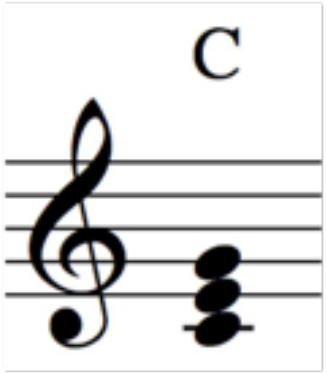
Fourier Decomposition



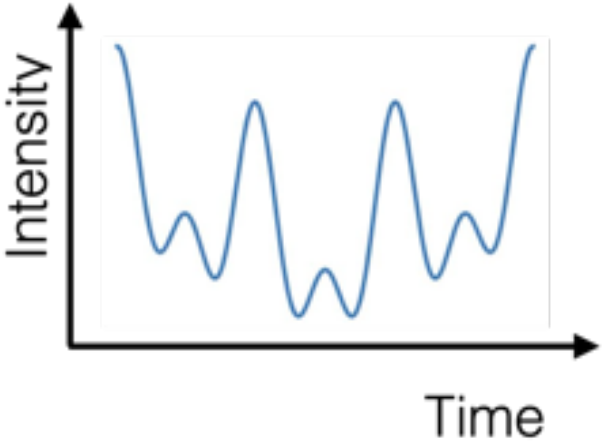
Fourier Transform

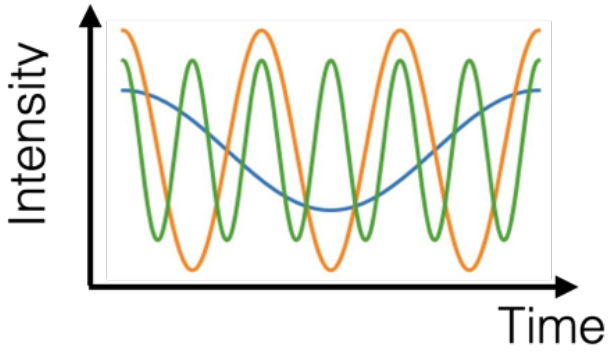
Complicated Sound Wave

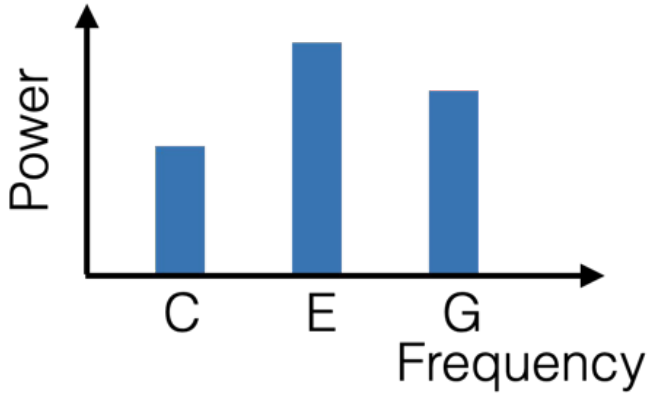




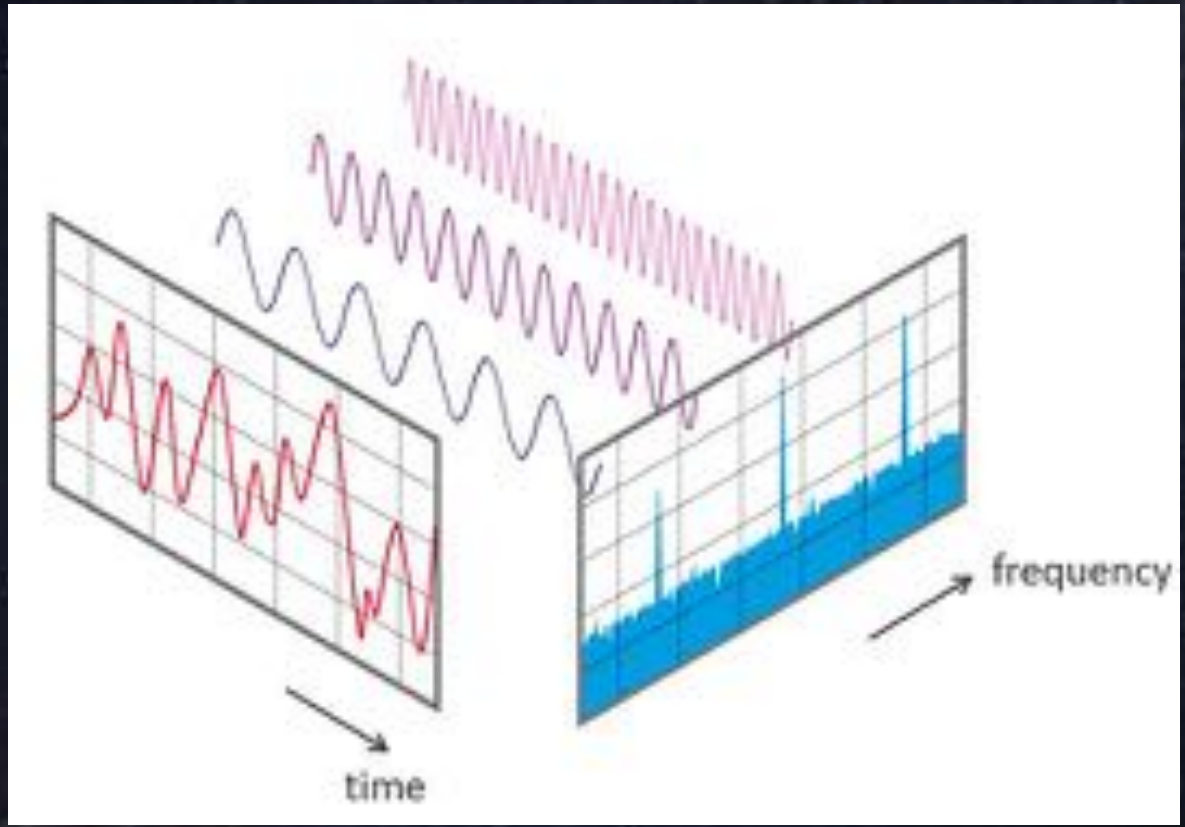
Fourier Transform





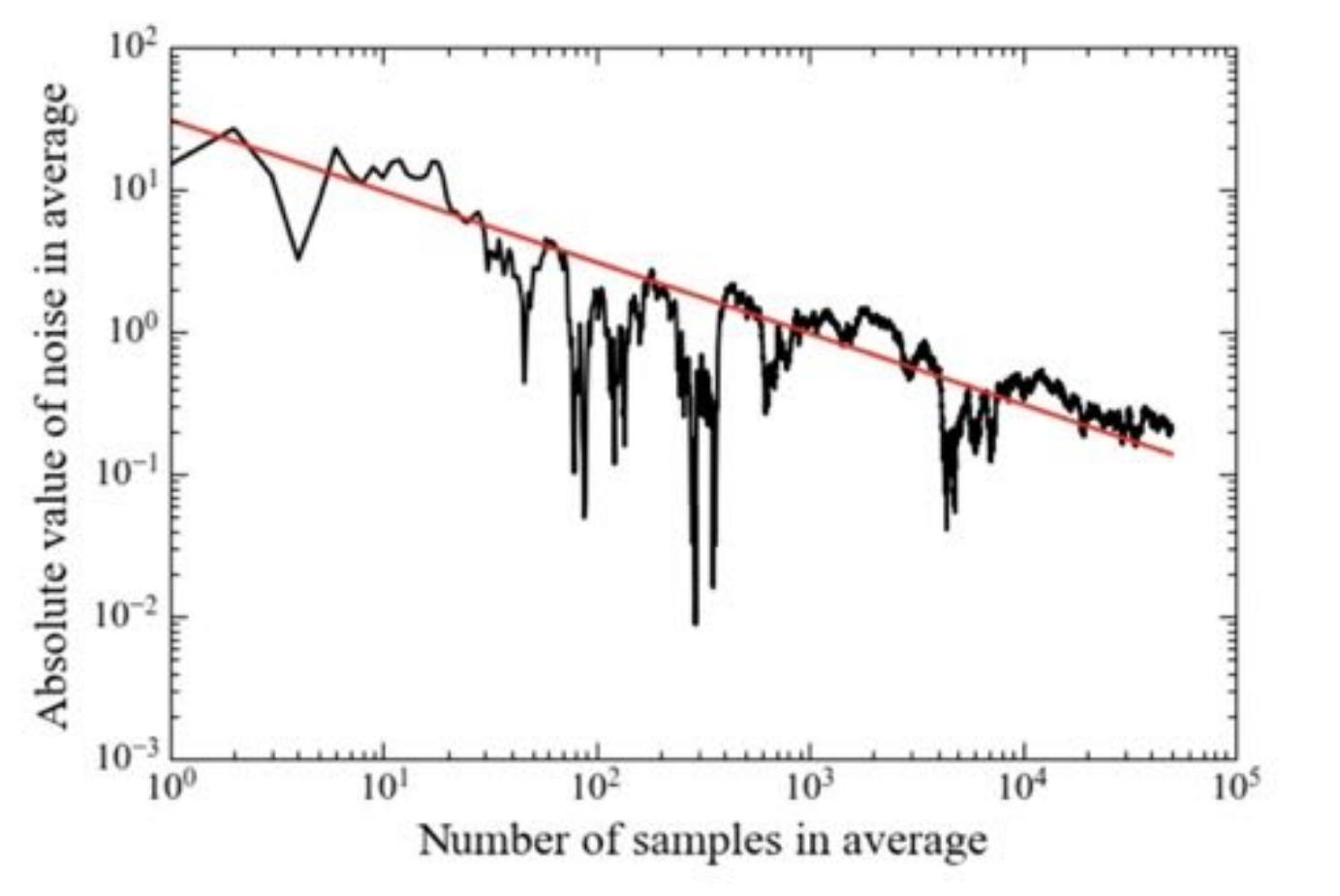


Fourier Transform to Spectra



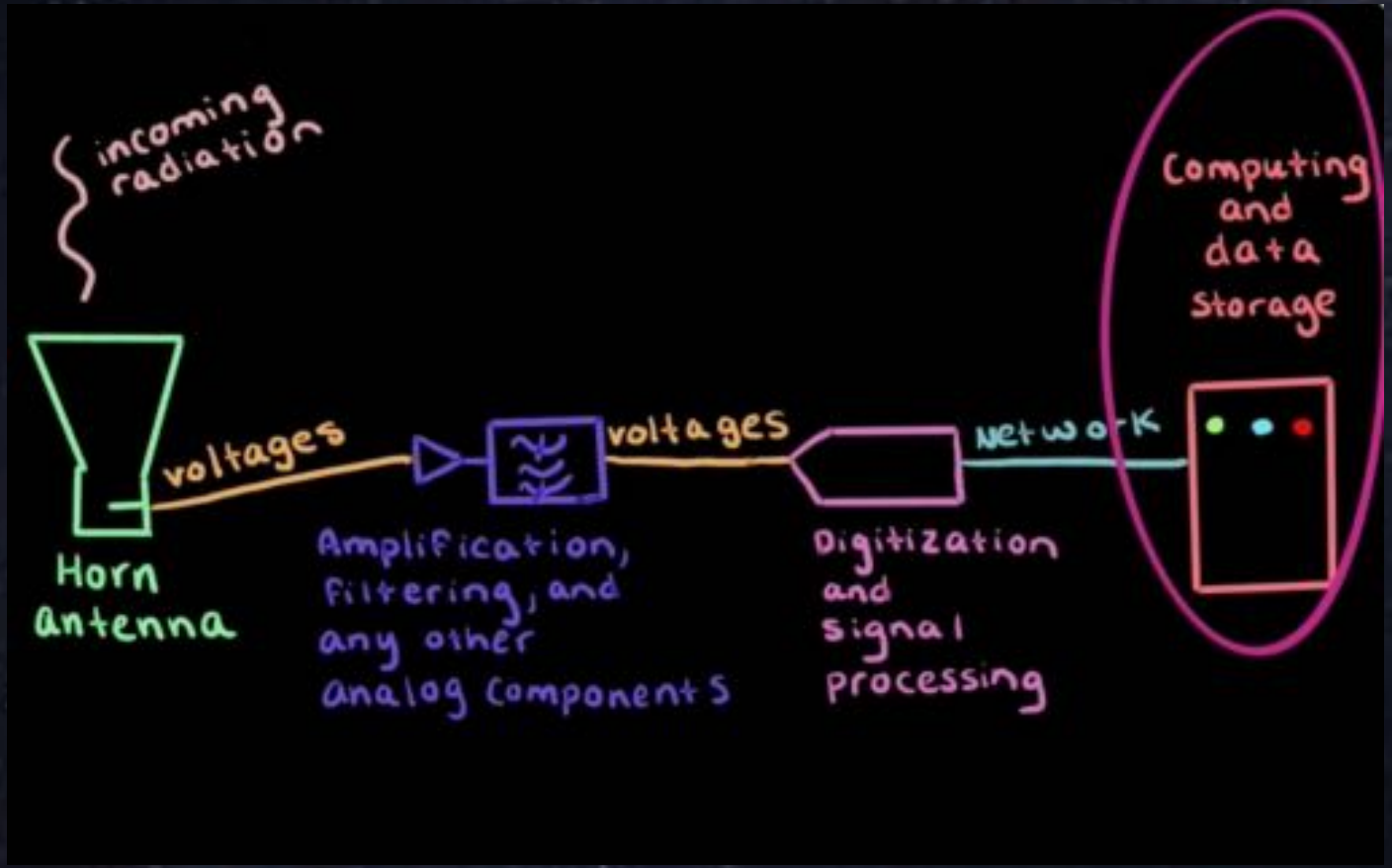
https://www.nti-audio.com/en/support/know-how/fast-fourier-transform-fft

Integration

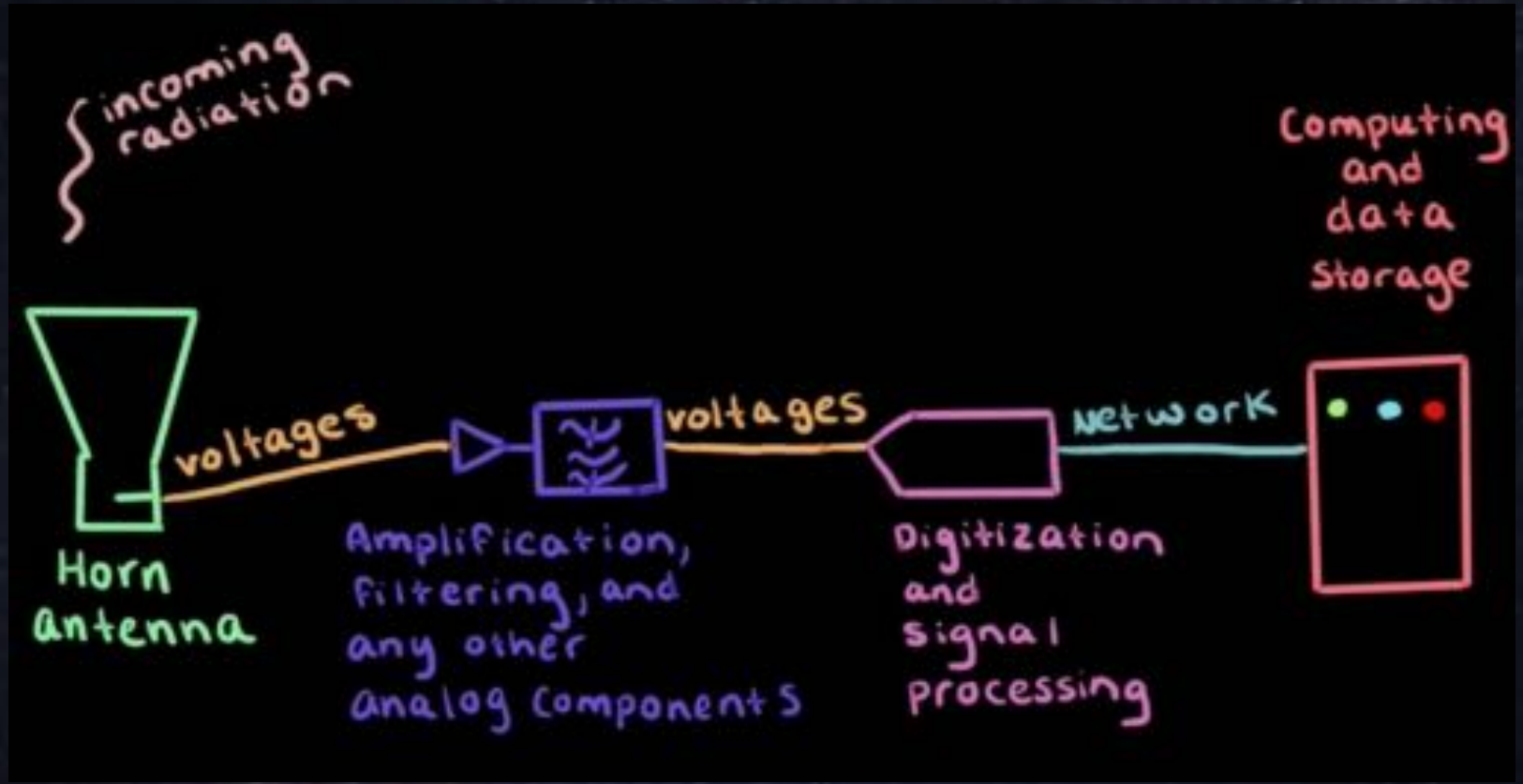


https://github.com/HERA-Team/CHAMP_Bootcamp/blob/main/Lessons/RadioAstronomyIntro/NoiseStatistics.ipynb

Computing and Data Storage



Computing and Data Storage


incoming radiation
Computing and data storage
voltages
voltages
network
Horn antenna
Amplification, filtering, and any other analog components
Digitization and signal processing

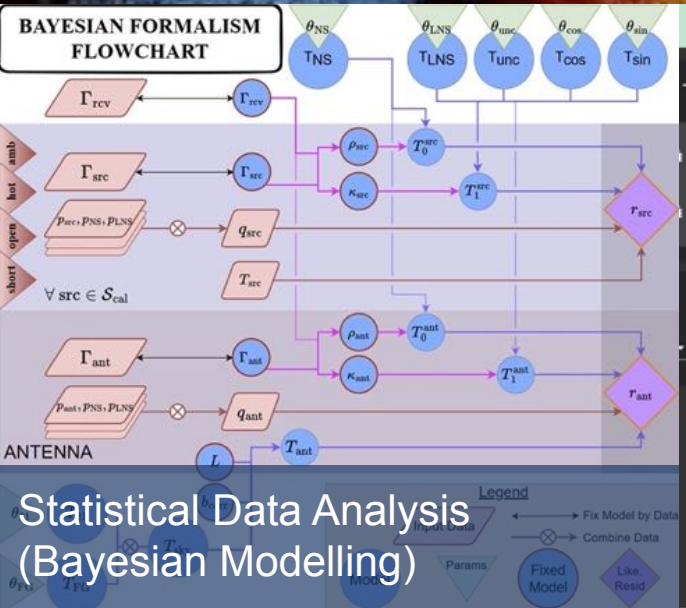
Sort into groups for enterprise accounts

Backup Slides

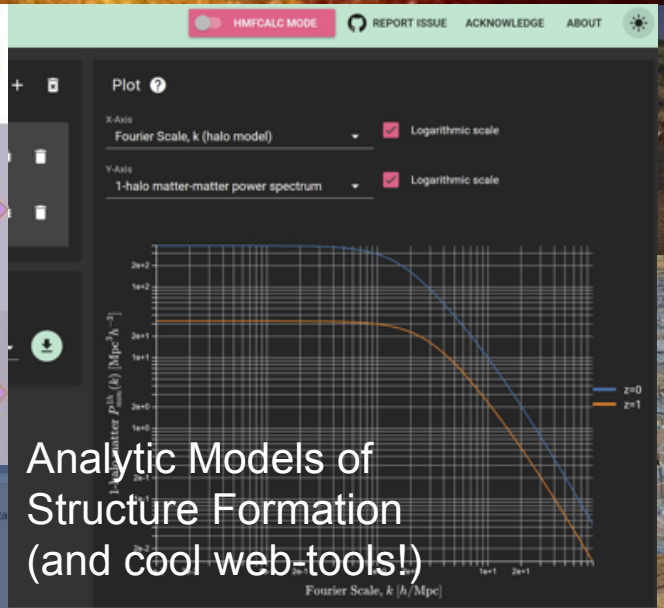
Cosmological Simulations

Steven Murray

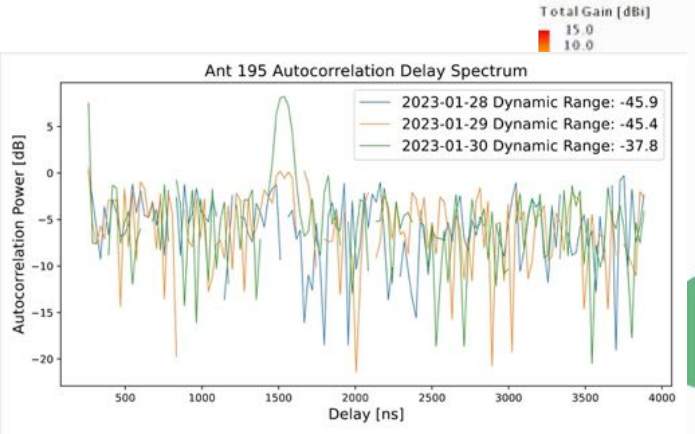
https://steven-g-murray.netlify.app/

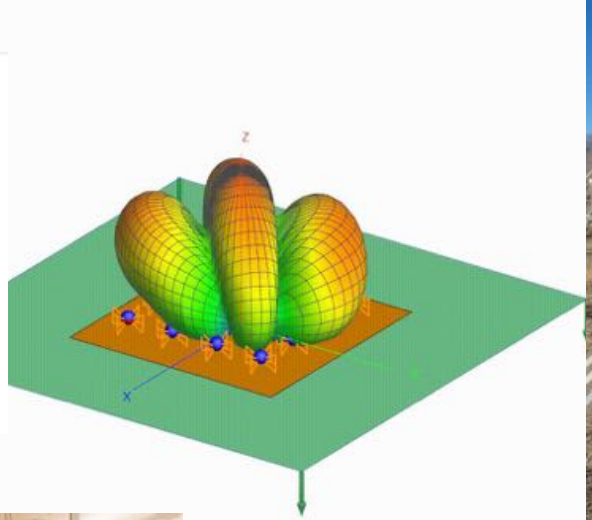


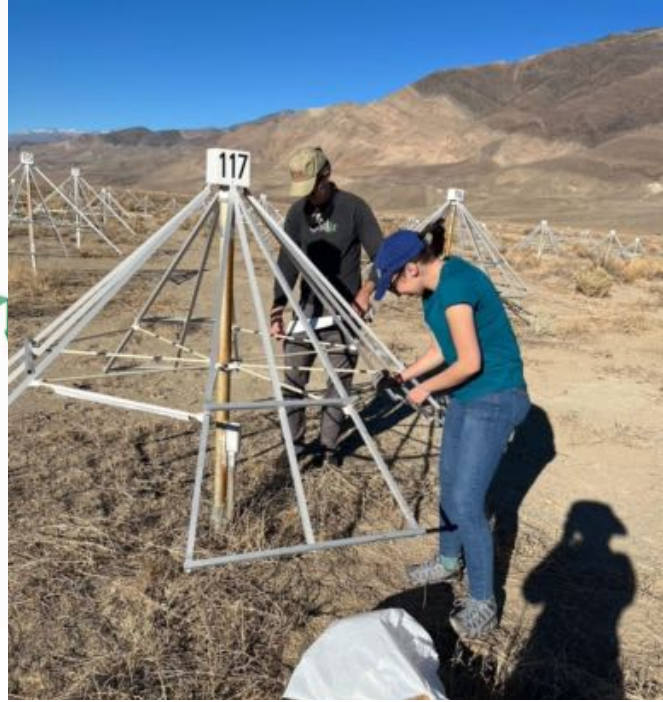
Statistical Data Analysis (Bayesian Modelling)



Analytic Models of Structure Formation (and cool web-tools!)







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