

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





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

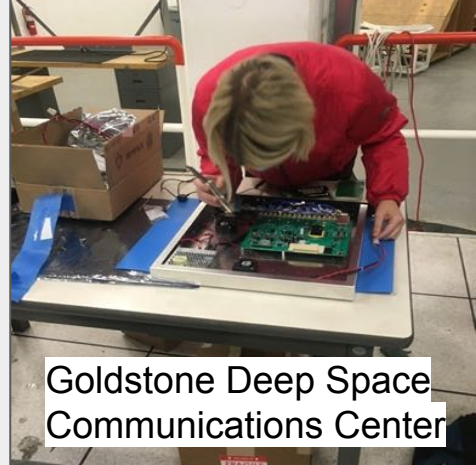


CHART
Observing Trip,
Painted Desert



Libby

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



Goldstone Deep Space
Communications Center

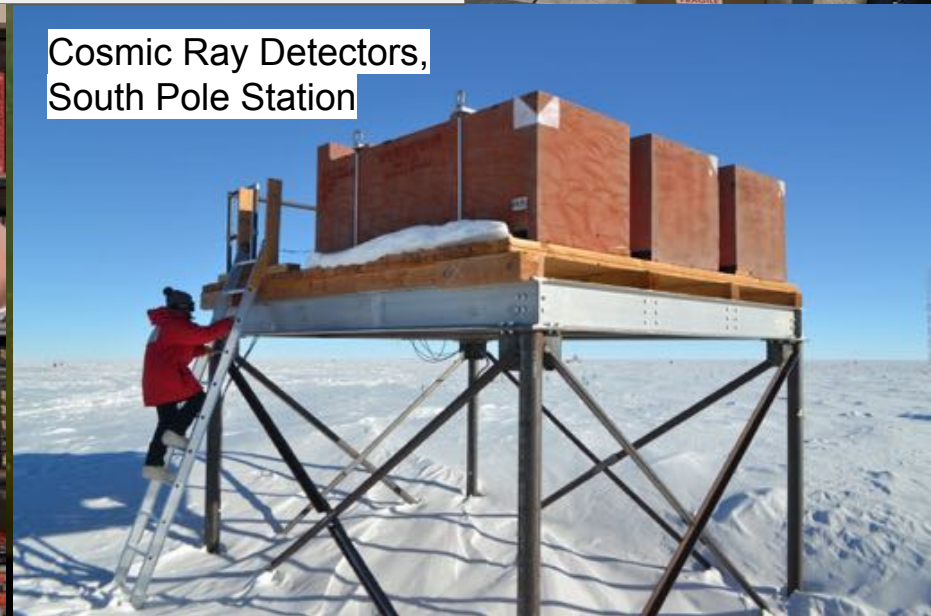


- Primarily work on instrumentation and signal processing
- Do cool stuff with cool equipment in cool places



Cat

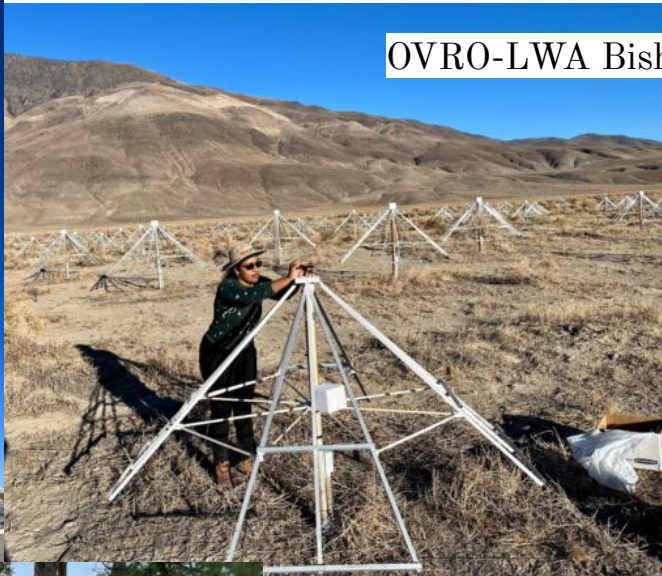
Cosmic Ray Detectors,
South Pole Station



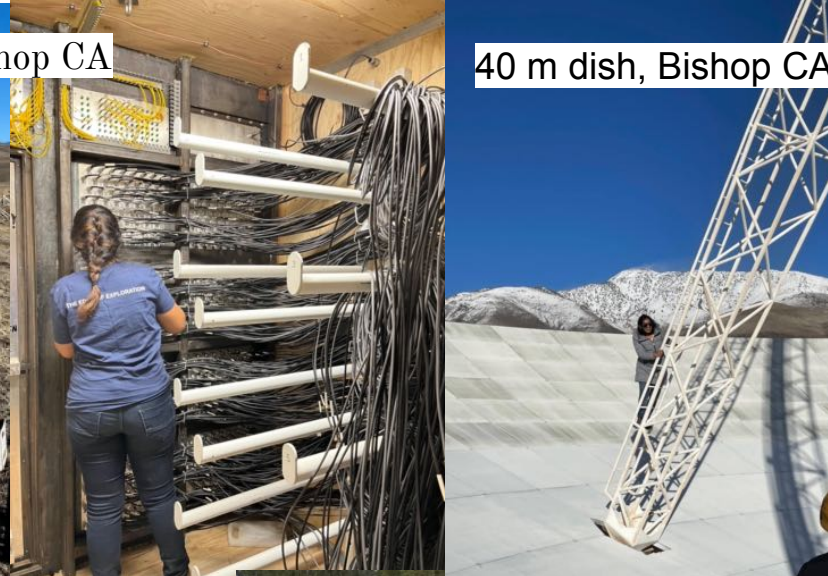
VLA, Socorro NM



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



Day One



What is radio astronomy?

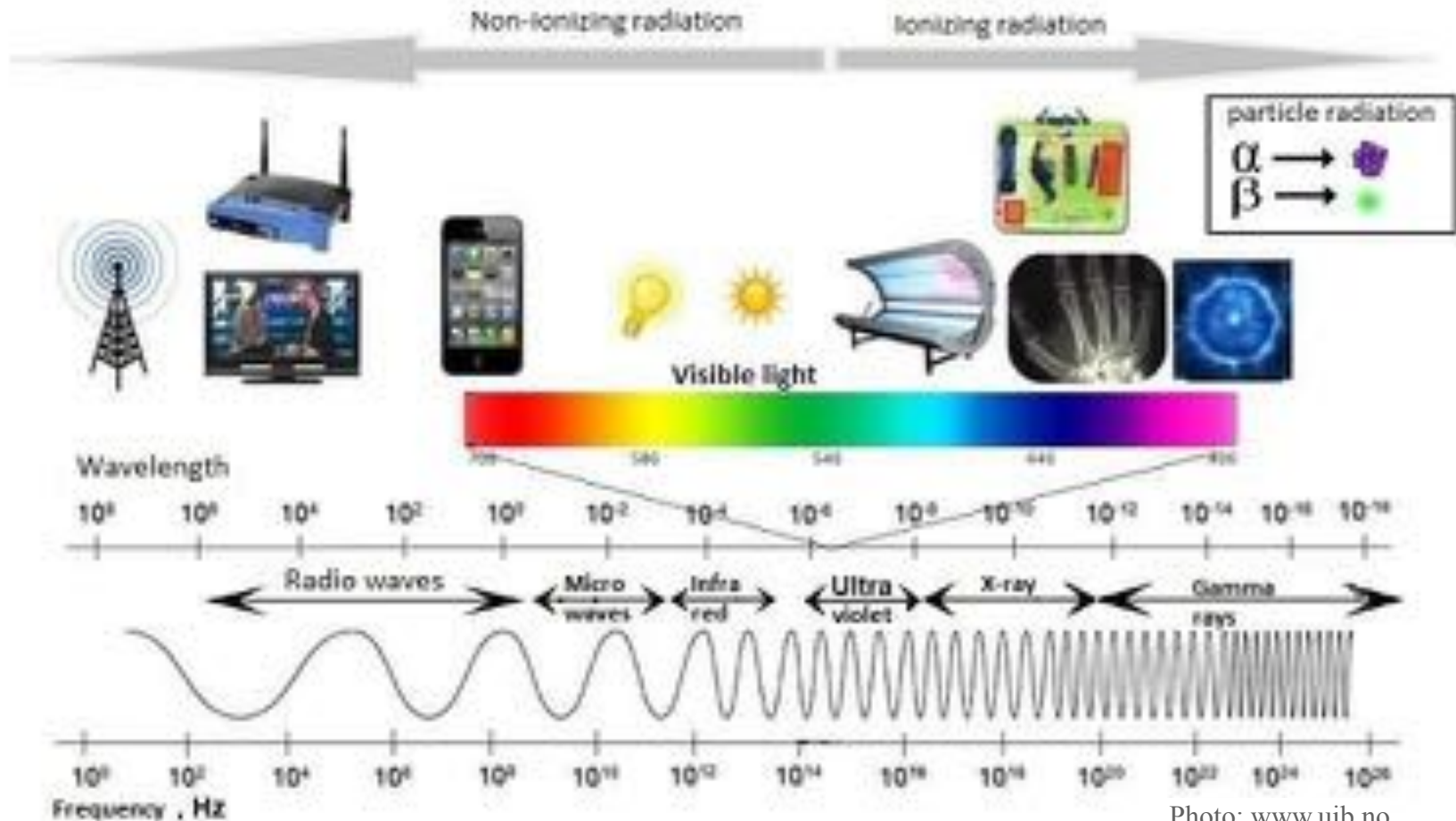
And why do I care?



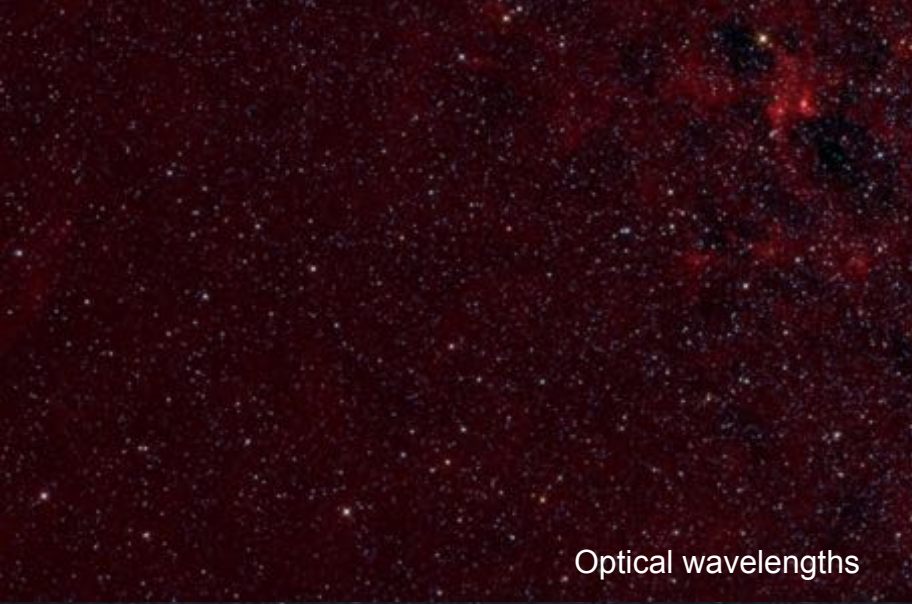
1. The electromagnetic spectrum



The electromagnetic spectrum





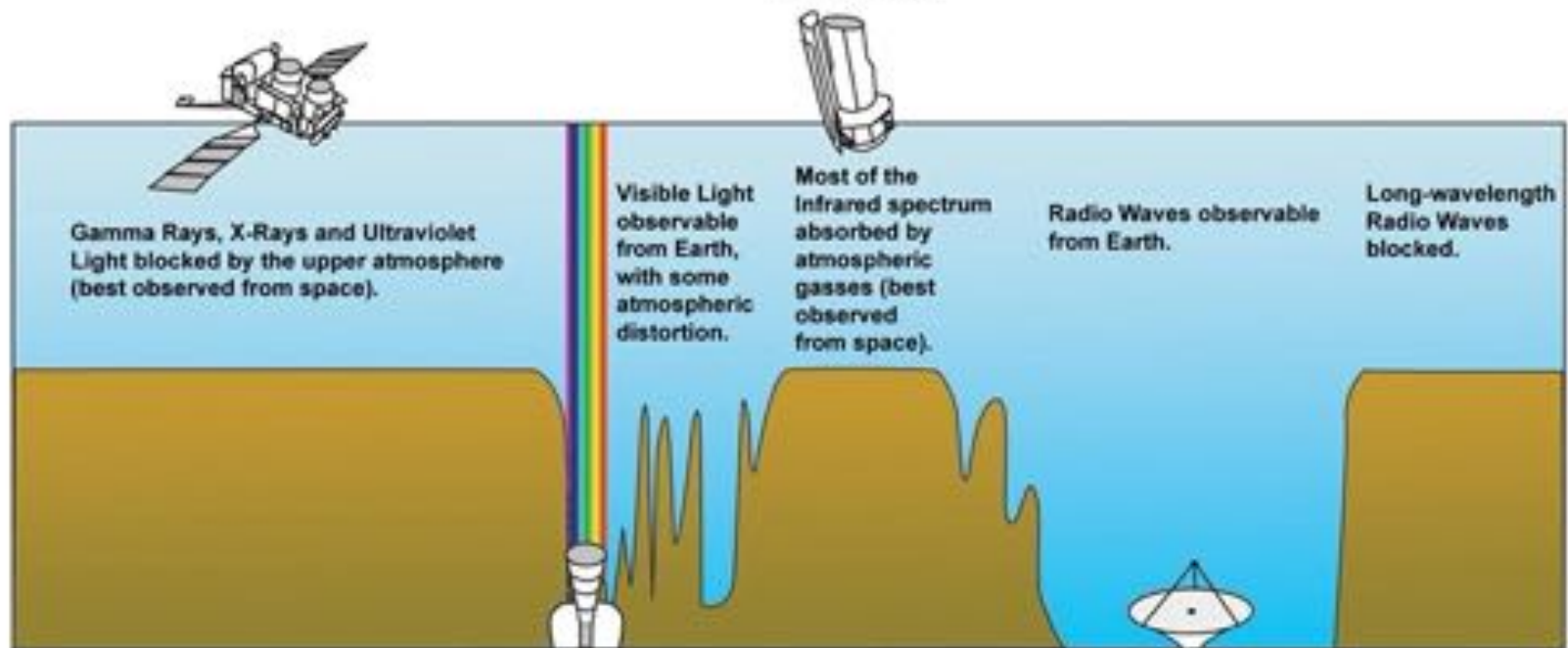
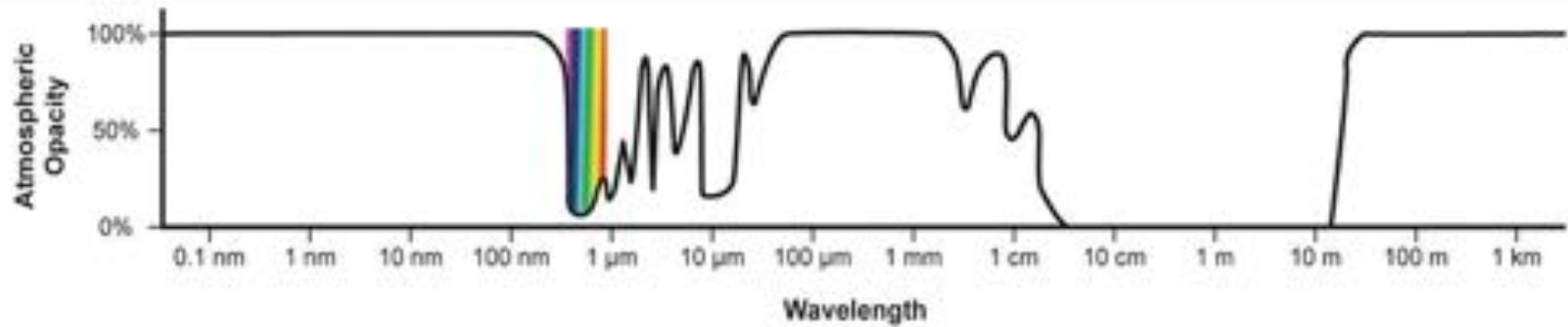


Optical wavelengths



Optical + Radio

Manatee nebula



ELECTROMAGNETIC SPECTRUM

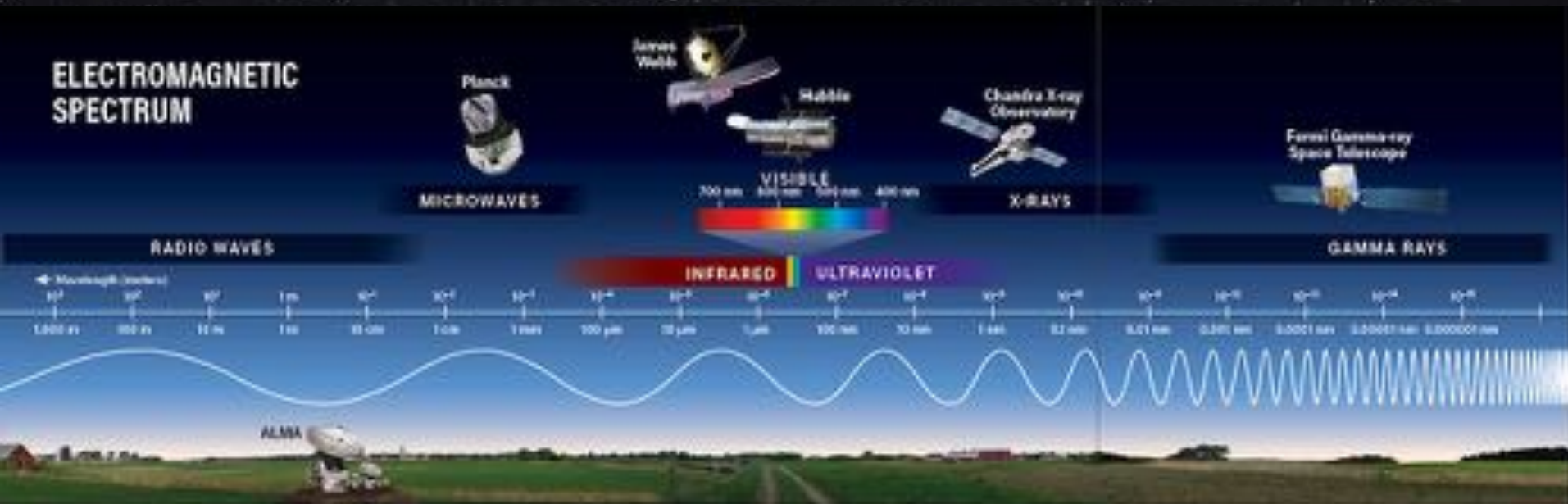


Image credit Astronomy: Roen Kelly

2. The Radio Spectrum

A map of the radio sky in galactic coordinates combining data from the Murchison and Parkes telescopes in Australia, the Very Large Array in New Mexico, Jodrell Bank Mill in the UK and the JFRSC in Effelsberg, Germany.
Compiled by: D. Jacobs, 2013 - Arizona State University, Low Frequency Cosmology

THE RADIO SPECTRUM



Abstract

1999, 2000, 2001, 2002, 2003, 2004, 2005, 2006, 2007, 2008, 2009, 2010, 2011, 2012, 2013, 2014, 2015, 2016, 2017, 2018, 2019, 2020, 2021, 2022, 2023, 2024, 2025, 2026, 2027, 2028, 2029, 2030, 2031, 2032, 2033, 2034, 2035, 2036, 2037, 2038, 2039, 2040, 2041, 2042, 2043, 2044, 2045, 2046, 2047, 2048, 2049, 2050, 2051, 2052, 2053, 2054, 2055, 2056, 2057, 2058, 2059, 2060, 2061, 2062, 2063, 2064, 2065, 2066, 2067, 2068, 2069, 2070, 2071, 2072, 2073, 2074, 2075, 2076, 2077, 2078, 2079, 2080, 2081, 2082, 2083, 2084, 2085, 2086, 2087, 2088, 2089, 2090, 2091, 2092, 2093, 2094, 2095, 2096, 2097, 2098, 2099, 2100, 2101, 2102, 2103, 2104, 2105, 2106, 2107, 2108, 2109, 2110, 2111, 2112, 2113, 2114, 2115, 2116, 2117, 2118, 2119, 2120, 2121, 2122, 2123, 2124, 2125, 2126, 2127, 2128, 2129, 2130, 2131, 2132, 2133, 2134, 2135, 2136, 2137, 2138, 2139, 2140, 2141, 2142, 2143, 2144, 2145, 2146, 2147, 2148, 2149, 2150, 2151, 2152, 2153, 2154, 2155, 2156, 2157, 2158, 2159, 2160, 2161, 2162, 2163, 2164, 2165, 2166, 2167, 2168, 2169, 2170, 2171, 2172, 2173, 2174, 2175, 2176, 2177, 2178, 2179, 2180, 2181, 2182, 2183, 2184, 2185, 2186, 2187, 2188, 2189, 2190, 2191, 2192, 2193, 2194, 2195, 2196, 2197, 2198, 2199, 2200, 2201, 2202, 2203, 2204, 2205, 2206, 2207, 2208, 2209, 2210, 2211, 2212, 2213, 2214, 2215, 2216, 2217, 2218, 2219, 2220, 2221, 2222, 2223, 2224, 2225, 2226, 2227, 2228, 2229, 2230, 2231, 2232, 2233, 2234, 2235, 2236, 2237, 2238, 2239, 2240, 2241, 2242, 2243, 2244, 2245, 2246, 2247, 2248, 2249, 2250, 2251, 2252, 2253, 2254, 2255, 2256, 2257, 2258, 2259, 2260, 2261, 2262, 2263, 2264, 2265, 2266, 2267, 2268, 2269, 2270, 2271, 2272, 2273, 2274, 2275, 2276, 2277, 2278, 2279, 2280, 2281, 2282, 2283, 2284, 2285, 2286, 2287, 2288, 2289, 2290, 2291, 2292, 2293, 2294, 2295, 2296, 2297, 2298, 2299, 2300, 2301, 2302, 2303, 2304, 2305, 2306, 2307, 2308, 2309, 2310, 2311, 2312, 2313, 2314, 2315, 2316, 2317, 2318, 2319, 2320, 2321, 2322, 2323, 2324, 2325, 2326, 2327, 2328, 2329, 2330, 2331, 2332, 2333, 2334, 2335, 2336, 2337, 2338, 2339, 2340, 2341, 2342, 2343, 2344, 2345, 2346, 2347, 2348, 2349, 2350, 2351, 2352, 2353, 2354, 2355, 2356, 2357, 2358, 2359, 2360, 2361, 2362, 2363, 2364, 2365, 2366, 2367, 2368, 2369, 2370, 2371, 2372, 2373, 2374, 2375, 2376, 2377, 2378, 2379, 2380, 2381, 2382, 2383, 2384, 2385, 2386, 2387, 2388, 2389, 2390, 2391, 2392, 2393, 2394, 2395, 2396, 2397, 2398, 2399, 2400, 2401, 2402, 2403, 2404, 2405, 2406, 2407, 2408, 2409, 2410, 2411, 2412, 2413, 2414, 2415, 2416, 2417, 2418, 2419, 2420, 2421, 2422, 2423, 2424, 2425, 2426, 2427, 2428, 2429, 2430, 2431, 2432, 2433, 2434, 2435, 2436, 2437, 2438, 2439, 2440, 2441, 2442, 2443, 2444, 2445, 2446, 2447, 2448, 2449, 2450, 2451, 2452, 2453, 2454, 2455, 2456, 2457, 2458, 2459, 2460, 2461, 2462, 2463, 2464, 2465, 2466, 2467, 2468, 2469, 2470, 2471, 2472, 2473, 2474, 2475, 2476, 2477, 2478, 2479, 2480, 2481, 2482, 2483, 2484, 2485, 2486, 2487, 2488, 2489, 2490, 2491, 2492, 2493, 2494, 2495, 2496, 2497, 2498, 2499, 2500, 2501, 2502, 2503, 2504, 2505, 2506, 2507, 2508, 2509, 2510, 2511, 2512, 2513, 2514, 2515, 2516, 2517, 2518, 2519, 2520, 2521, 2522, 2523, 2524, 2525, 2526, 2527, 2528, 2529, 2530, 2531, 2532, 2533, 2534, 2535, 2536, 2537, 2538, 2539, 2540, 2541, 2542, 2543, 2544, 2545, 2546, 2547, 2548, 2549, 2550, 2551, 2552, 2553, 2554, 2555, 2556, 2557, 2558, 2559, 2560, 2561, 2562, 2563, 2564, 2565, 2566, 2567, 2568, 2569, 2570, 2571, 2572, 2573, 2574, 2575, 2576, 2577, 2578, 2579, 2580, 2581, 2582, 2583, 2584, 2585, 2586, 2587, 2588, 2589, 2590, 2591, 2592, 2593, 2594, 2595, 2596, 2597, 2598, 2599, 2600, 2601, 2602, 2603, 2604, 2605, 2606, 2607, 2608, 2609, 2610, 2611, 2612, 2613, 2614, 2615, 2616, 2617, 2618, 2619, 2620, 2621, 2622, 2623, 2624, 2625, 2626, 2627, 2628, 2629, 2630, 2631, 2632, 2633, 2634, 2635, 2636, 2637, 2638, 2639, 2640, 2641, 2642, 2643, 2644, 2645, 2646, 2647, 2648, 2649, 2650, 2651, 2652, 2653, 2654, 2655, 2656, 2657, 2658, 2659, 2660, 2661, 2662, 2663, 2664, 2665, 2666, 2667, 2668, 2669, 2670, 2671, 2672, 2673, 2674, 2675, 2676, 2677, 2678, 2679, 2680, 26

[illegible]

TABLE 1

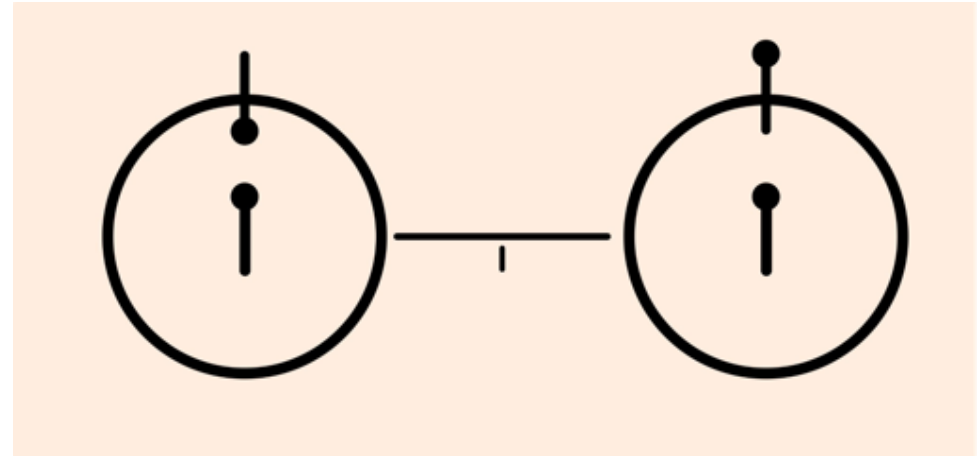
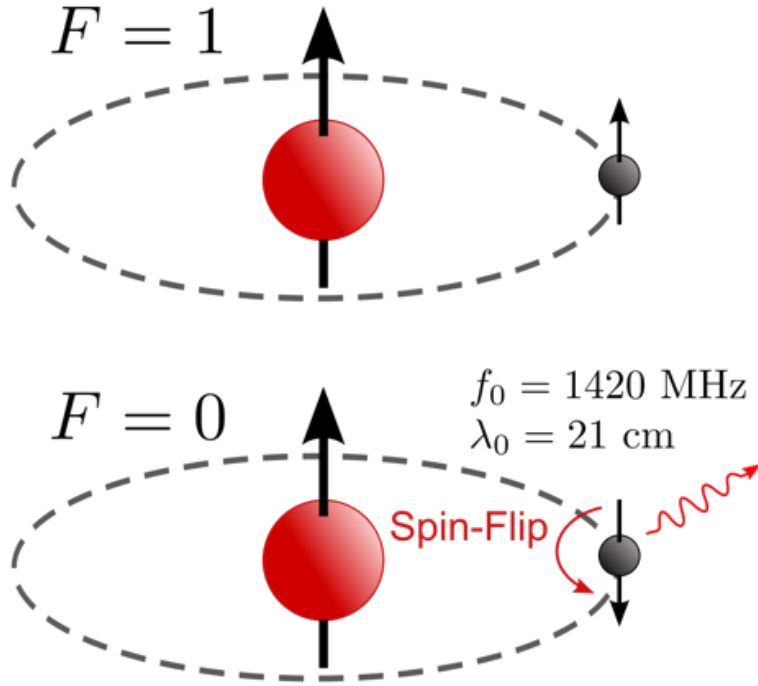
1000

 Springer Springer

A glowing blue arc, resembling a celestial body's limb or a ring, is centered on a black background. The arc is bright and slightly blurred, giving it a sense of depth. In the center of the arc, the text "21cm" is written in a white, sans-serif font.

21cm

Neutral Hydrogen and the 21cm line



Voyager Spacecraft

Cosmology

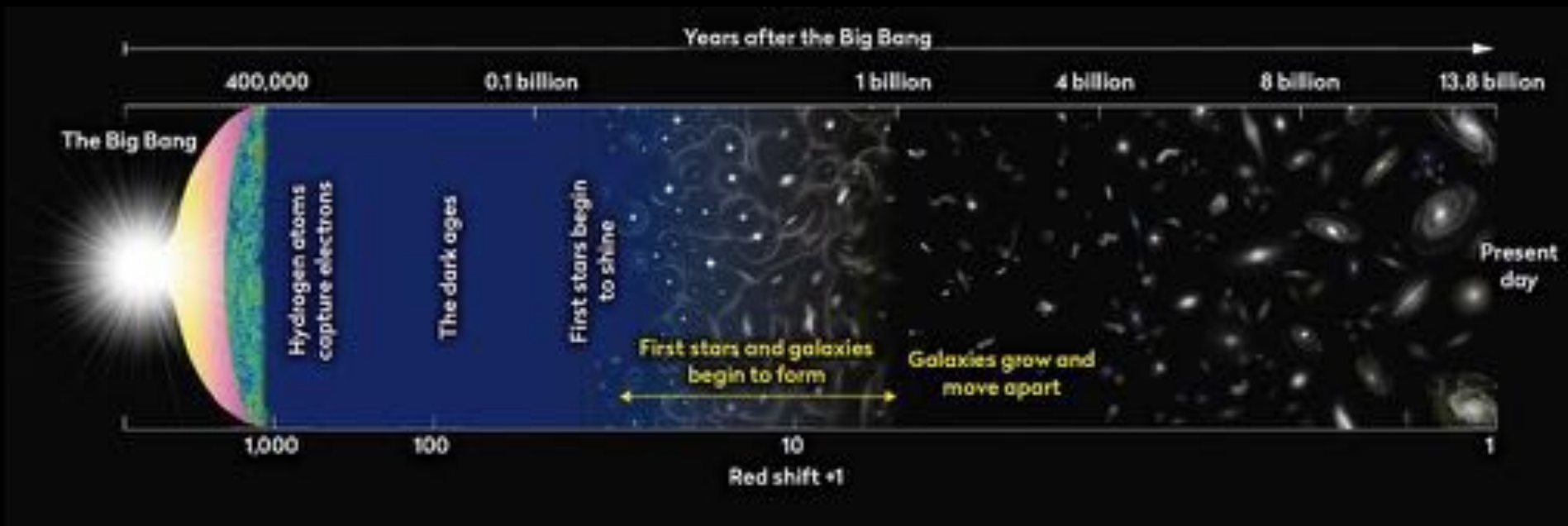
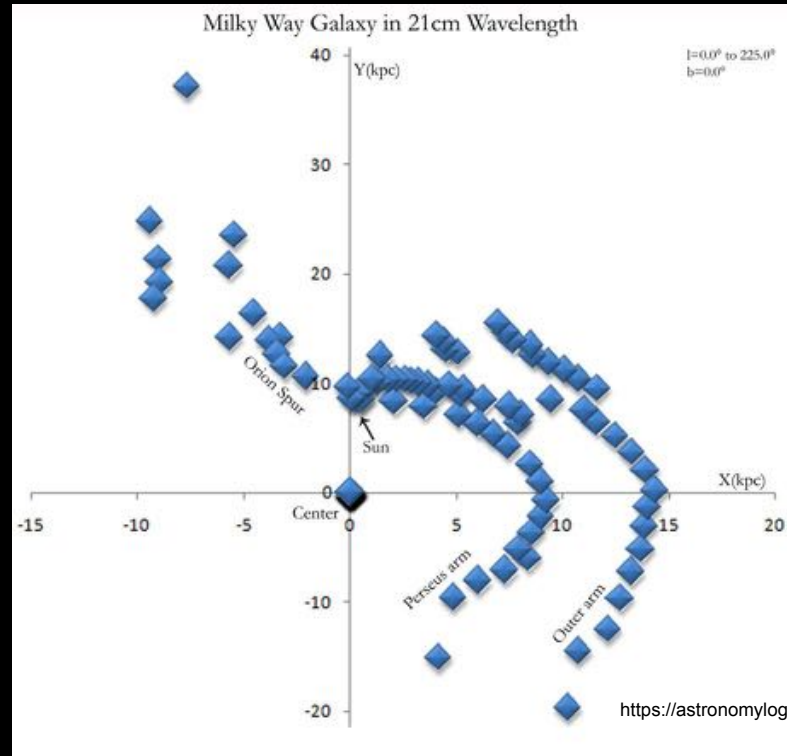
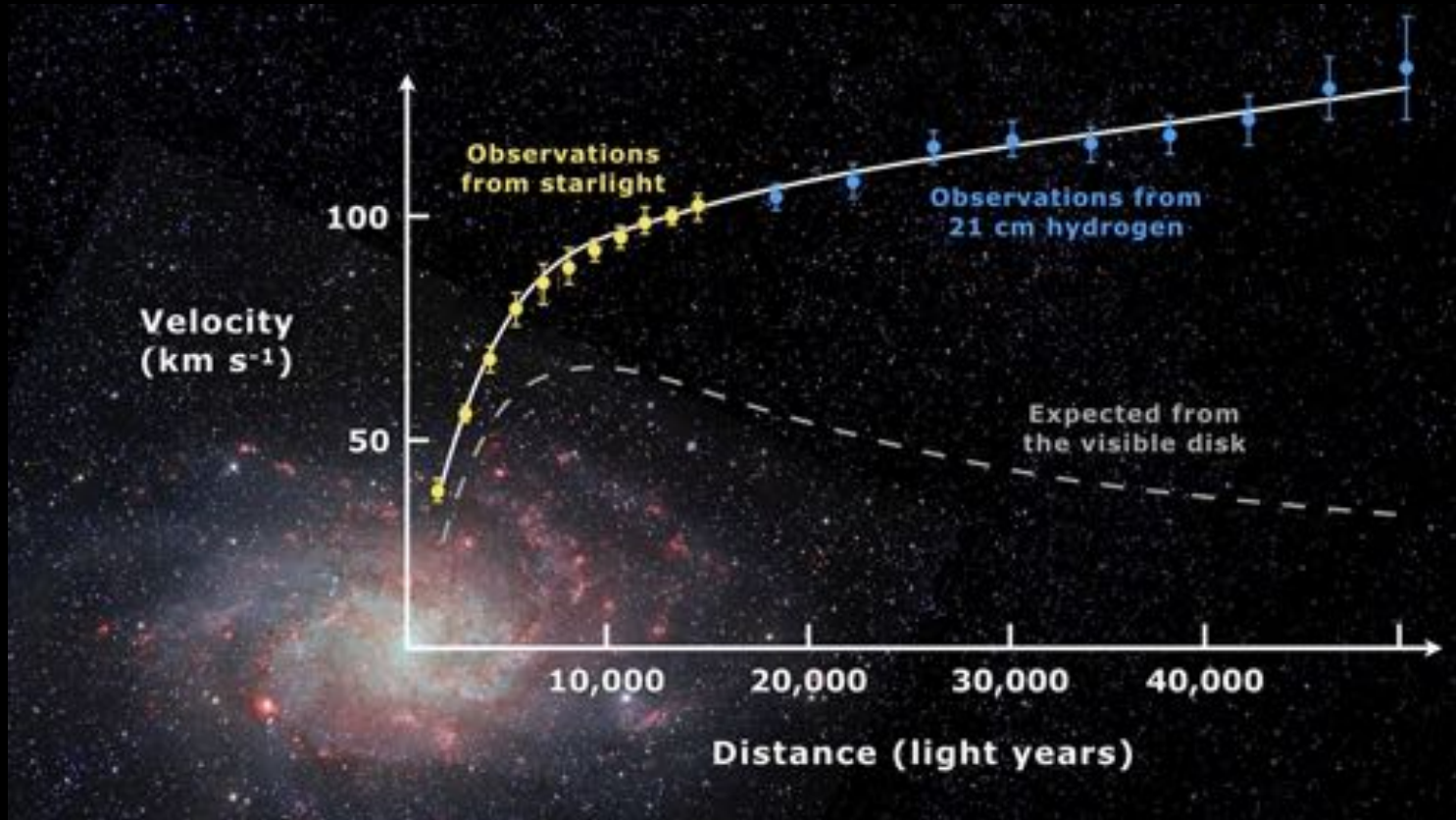


Image credit: ALMA

Milky Way Dynamics



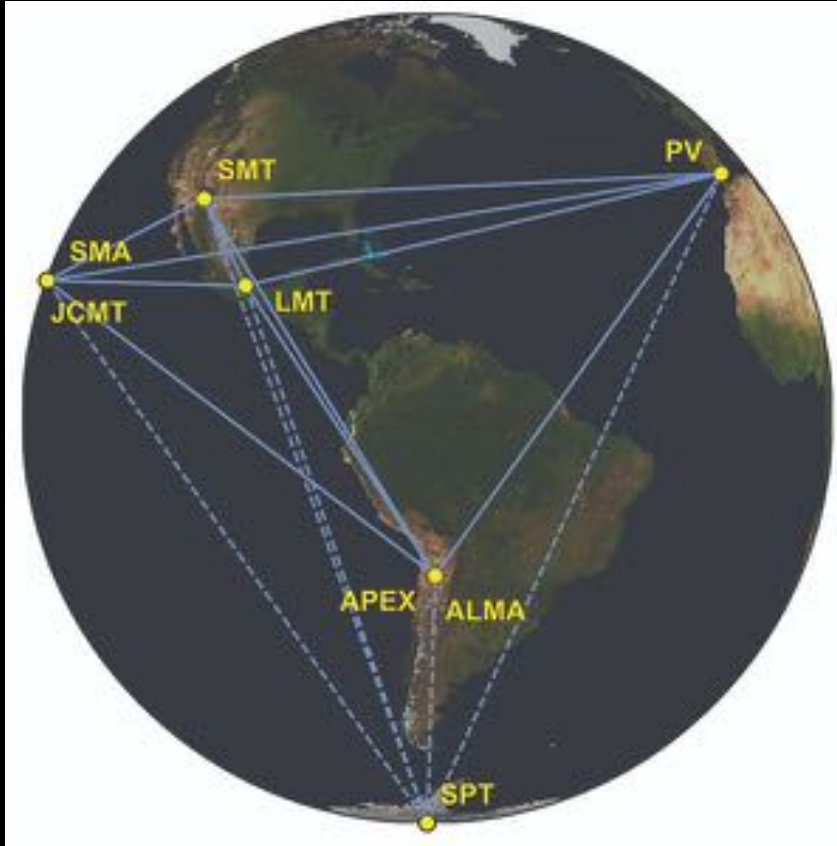
Evidence for Dark matter



A satellite photograph of Earth at night, showing the curvature of the planet and the glowing lights of cities and continents. The text "Other Stuff" is centered over the image.

Other Stuff

Event Horizon Telescope



Event Horizon Telescope collaboration

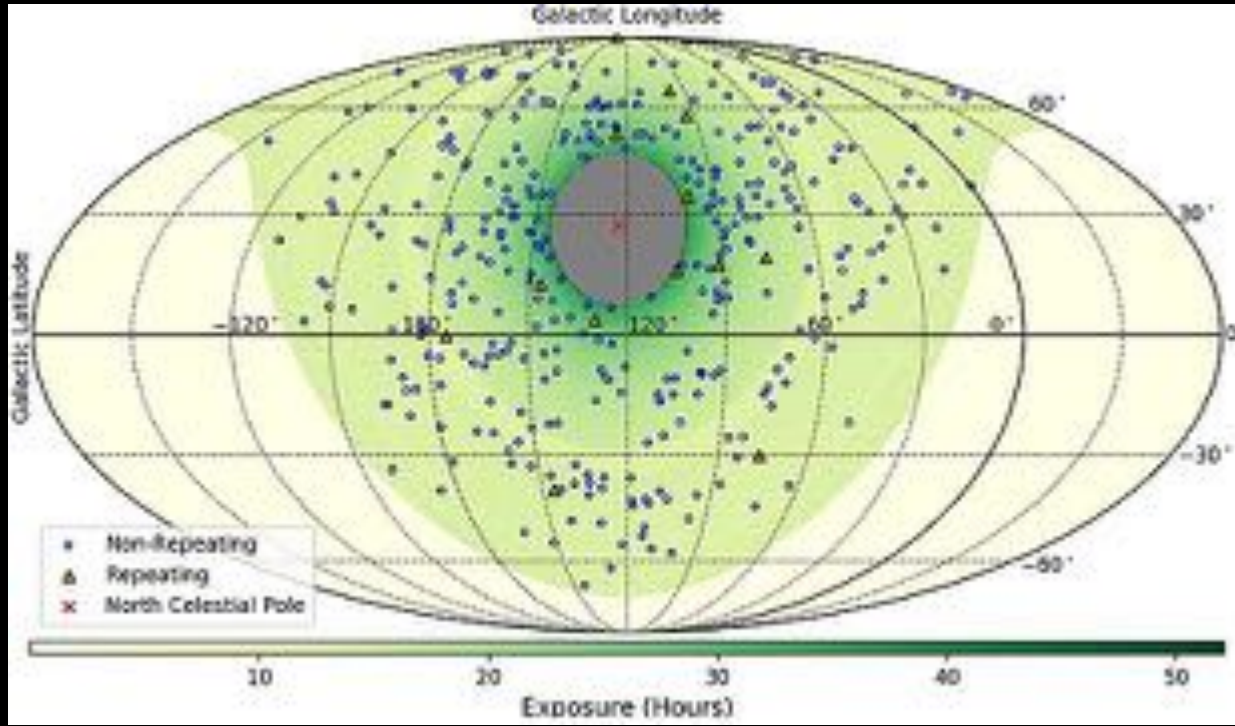
Pulsars



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

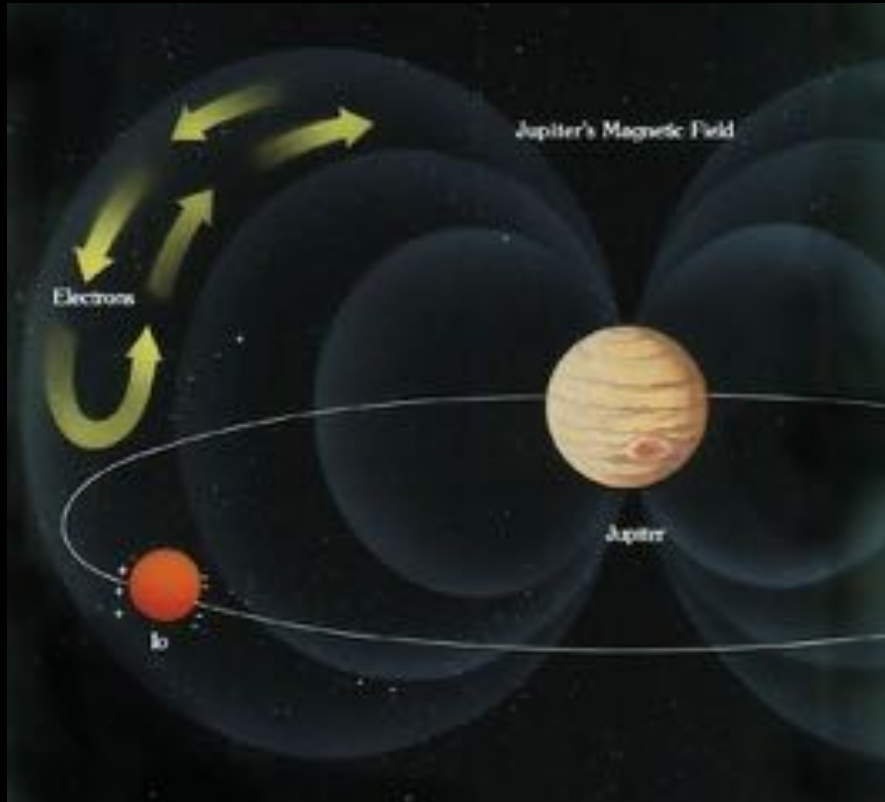


- **Fast radio bursts** are intense bursts of radio emission that have durations of milliseconds and exhibit the characteristic dispersion sweep of pulsars
- Most do not repeat



Image credit: Chime Collaboration

Solar System Astronomy



[Image credit](#)

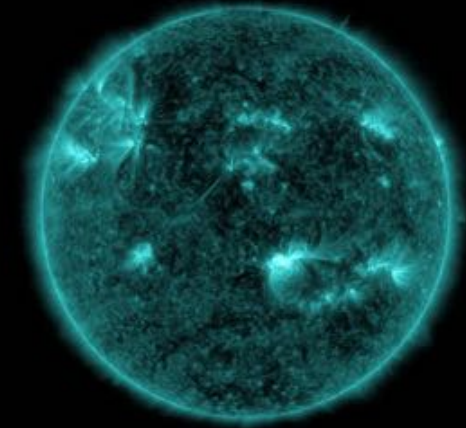


Image Credit: NASA's Goddard Space Flight Center/SDO

Cosmic Microwave Background

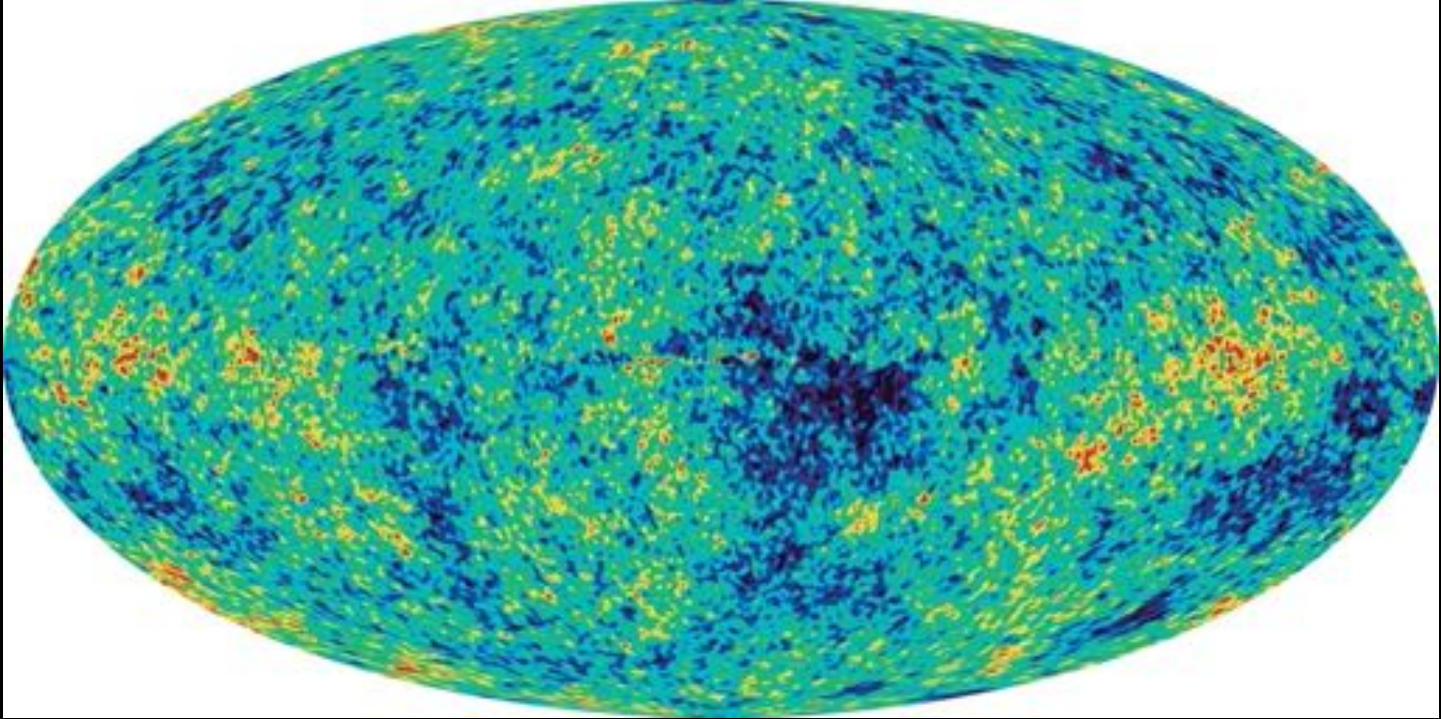
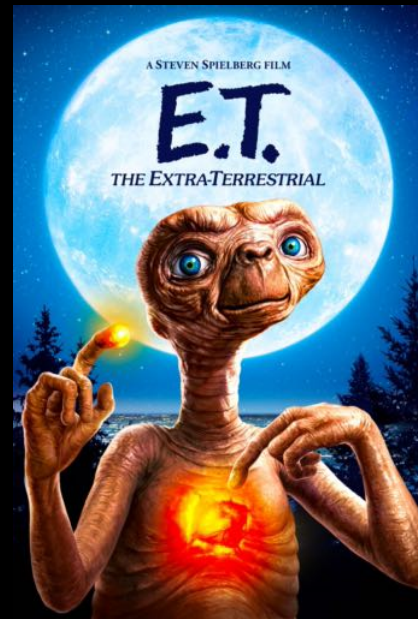


Image credit: Wilkinson Microwave Anisotropy Probe

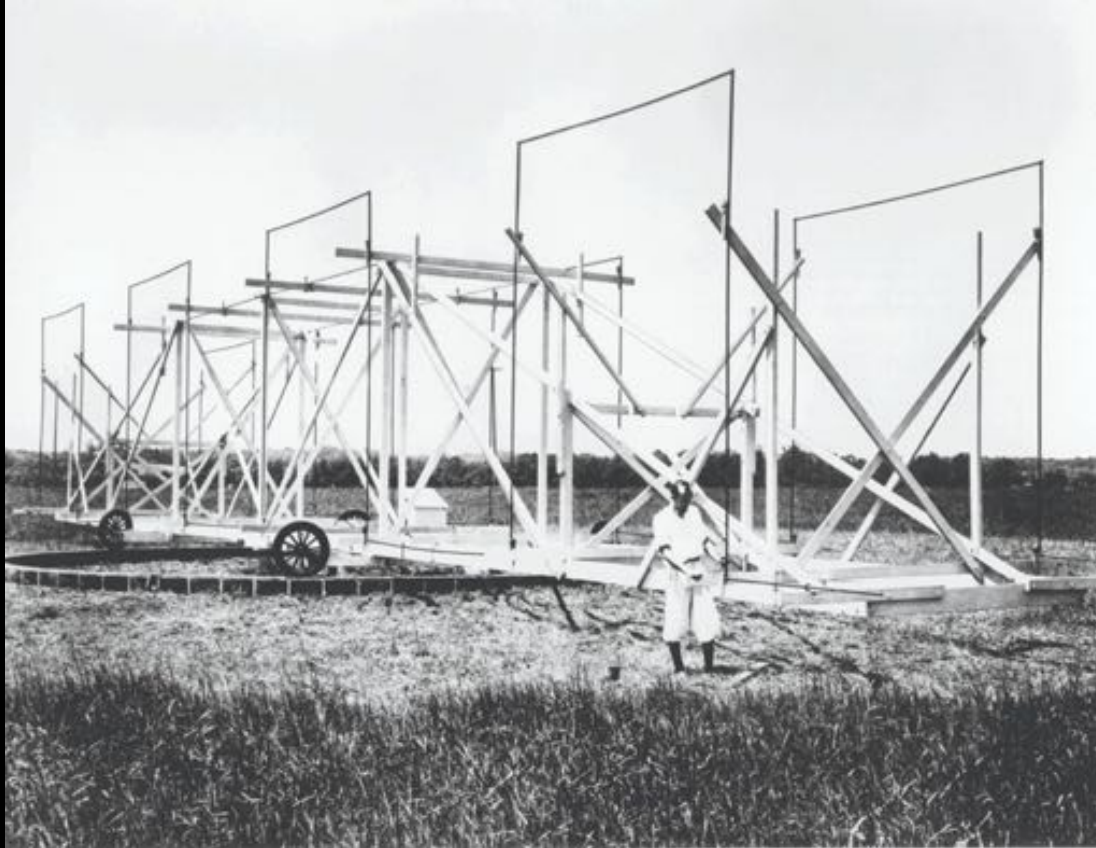
SETI/ET





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 $7\frac{1}{2}$ 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° .

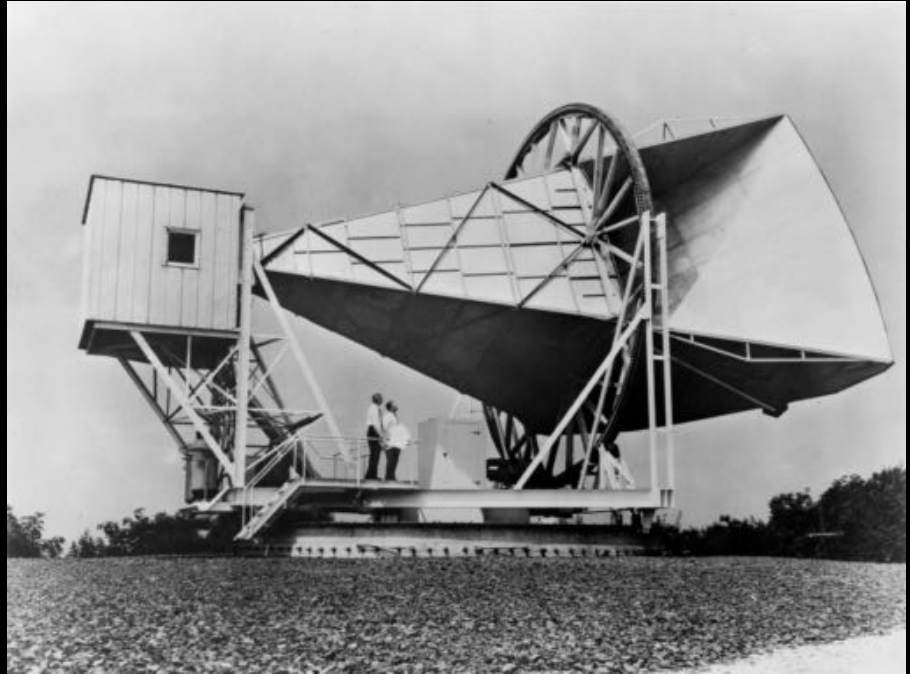
The angular distribution of the radio stars, unlike that of the general background radiation, shows no concentration in the galactic plane; this result suggests either that they are at distances small compared with the dimensions of the galaxy, or that they are situated outside the galaxy. Whilst there 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

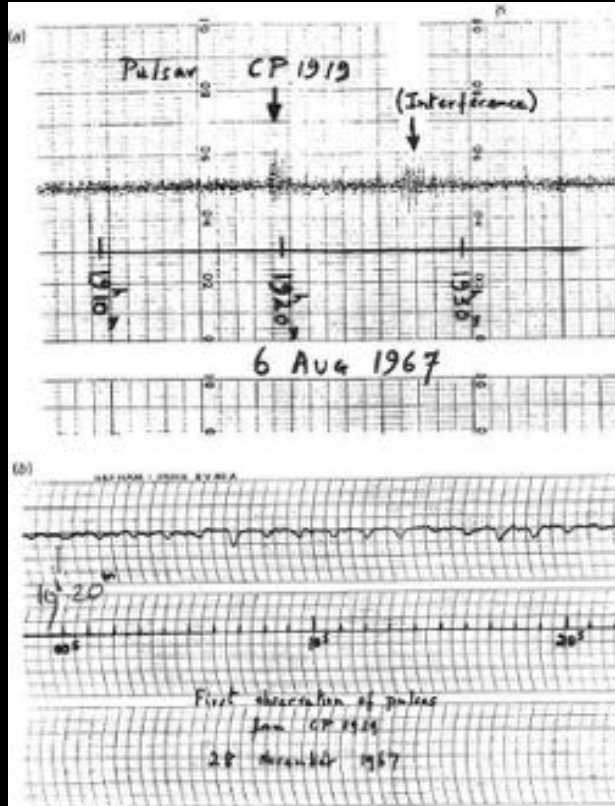


- In 1951, first measurement of the 21-cm signal from Neutral Hydrogen
- Predictions doubted detectability of the line

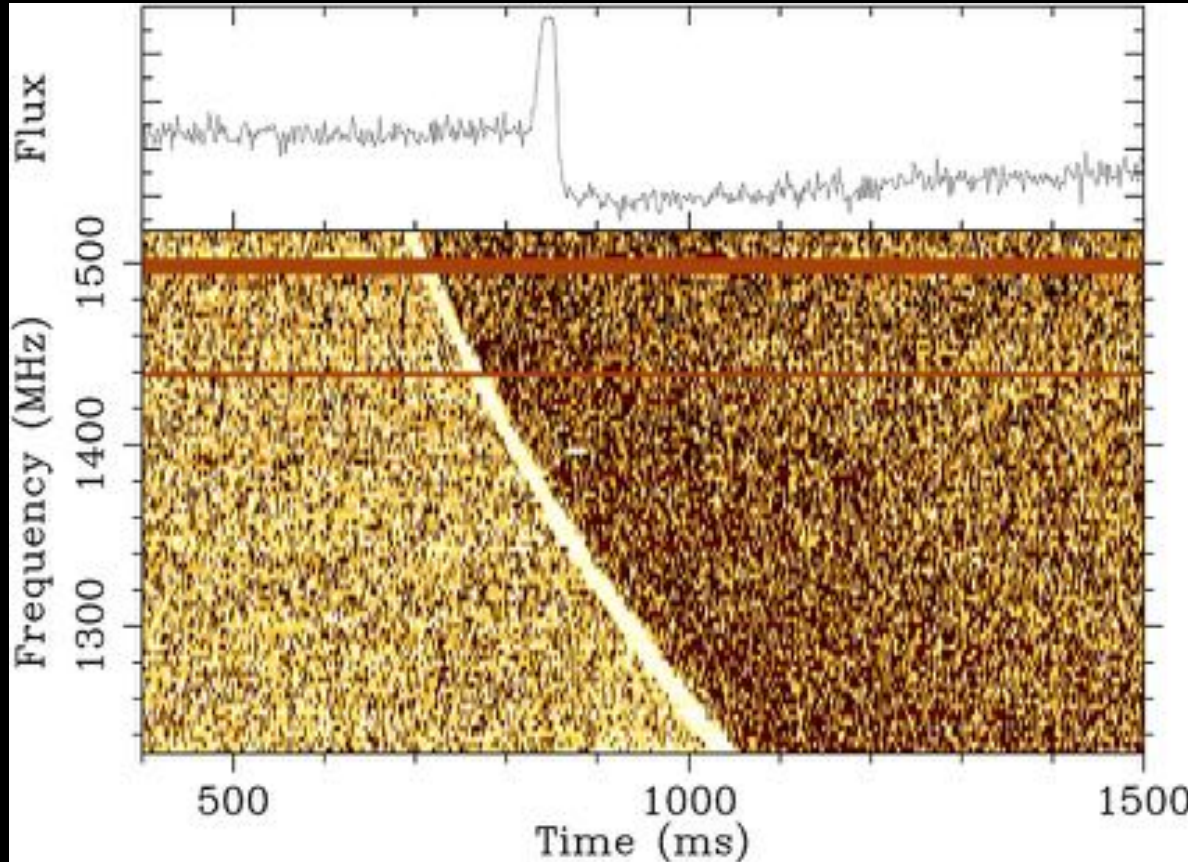
NRAO-Green Bank May 22, 2001

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

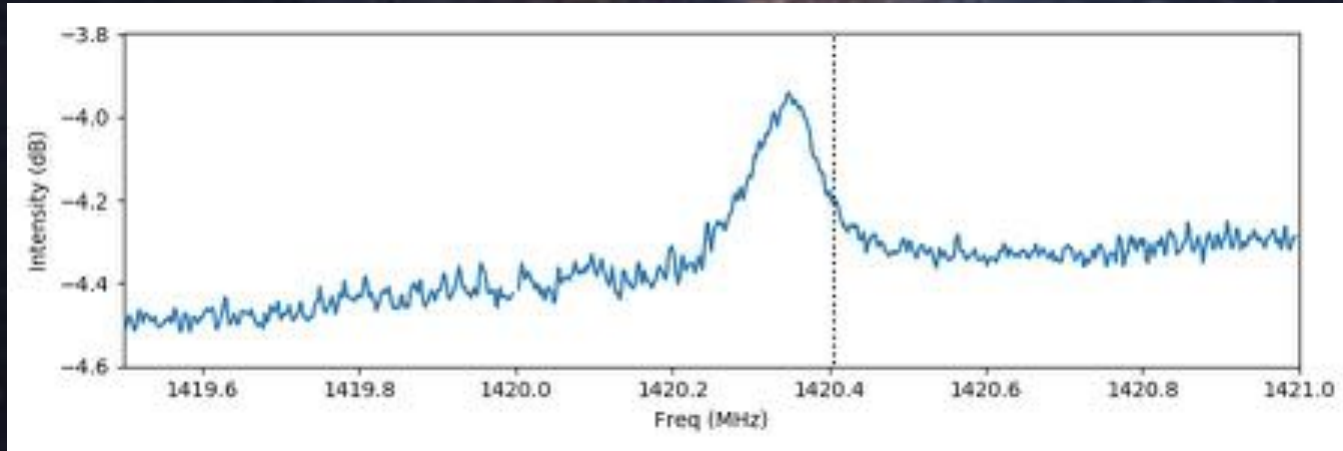
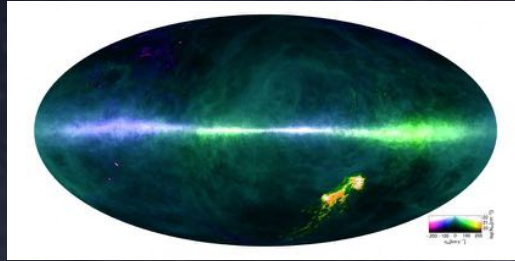


- Mysterious interference by signals called perytons was first detected in 1998 "within 5km" of the Parkes Observatory
- Lorimer and student David Narkevic in 2007 recorded the first FRB at the Parkes Radio Telescope

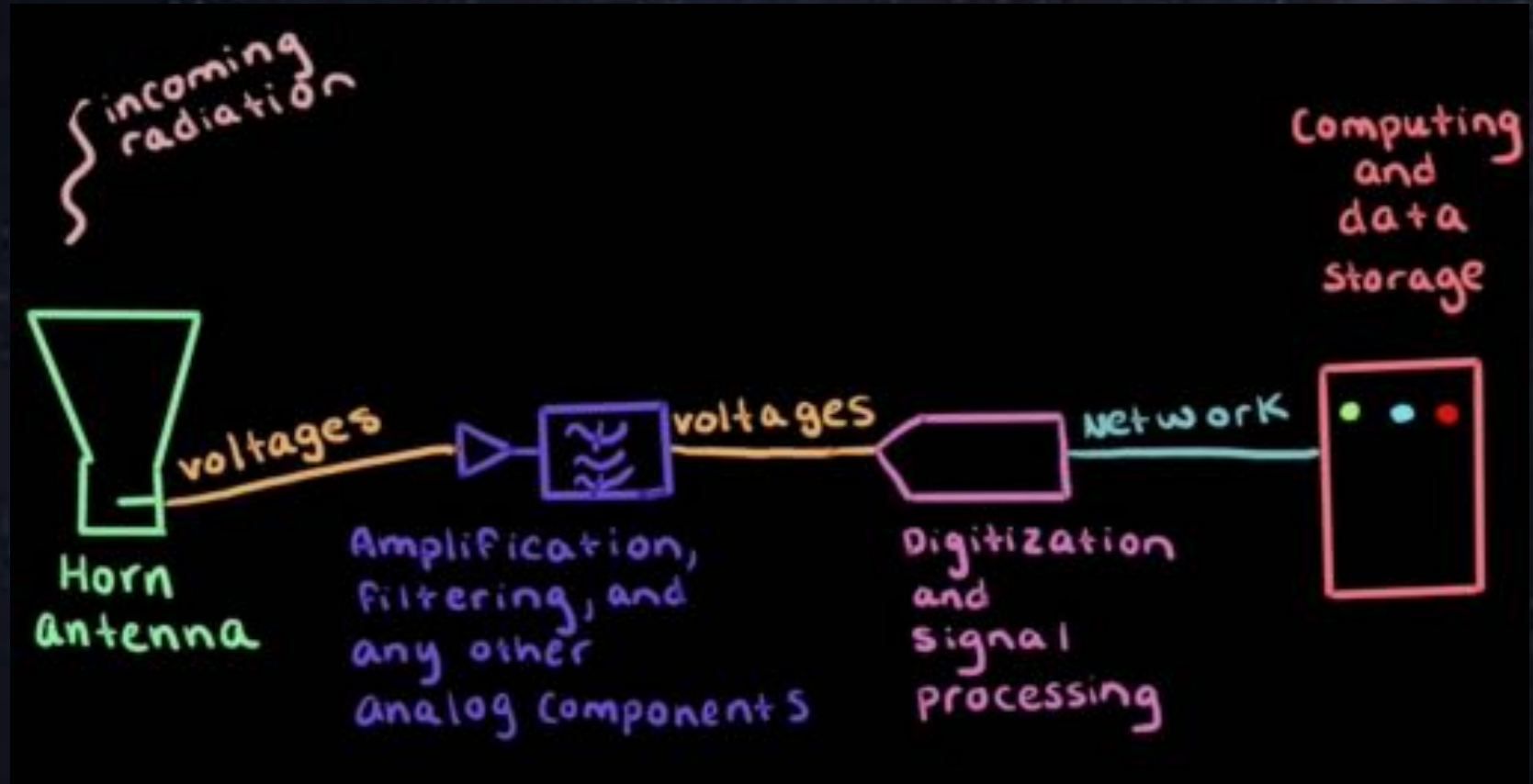


Parts of a telescope and Signal Processing

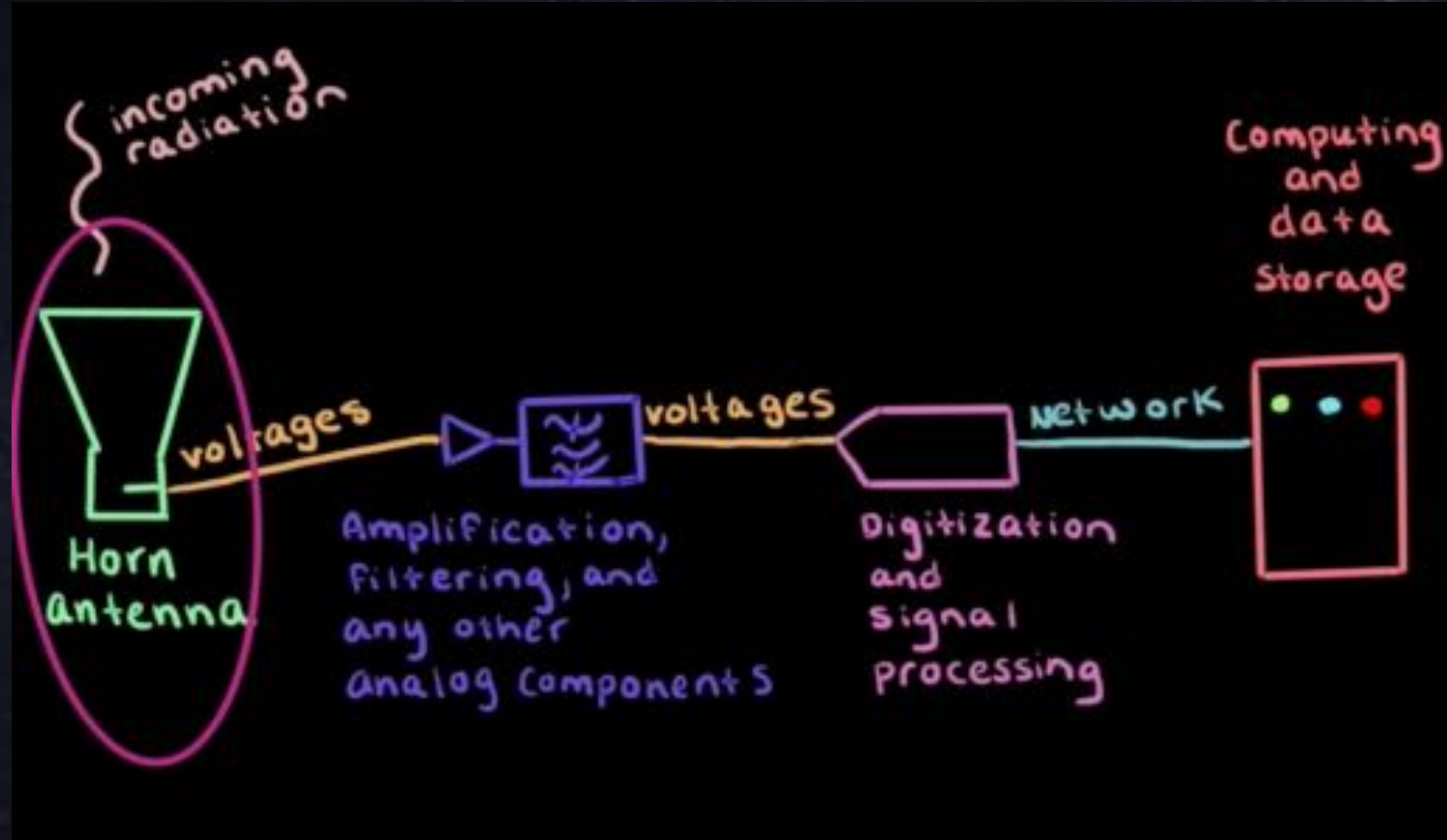
How do I get from radiation in the sky to a spectrum?



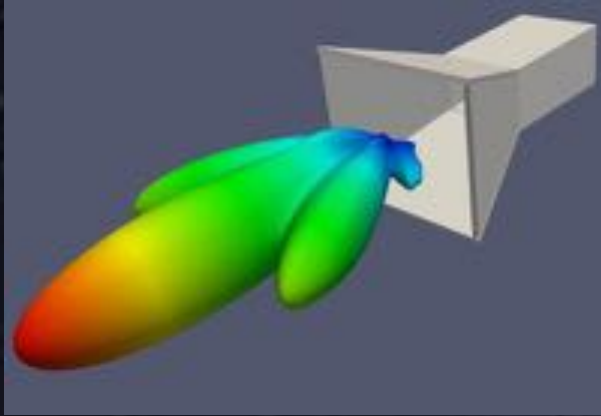
Parts of a radio telescope



Antenna



Horn Antenna

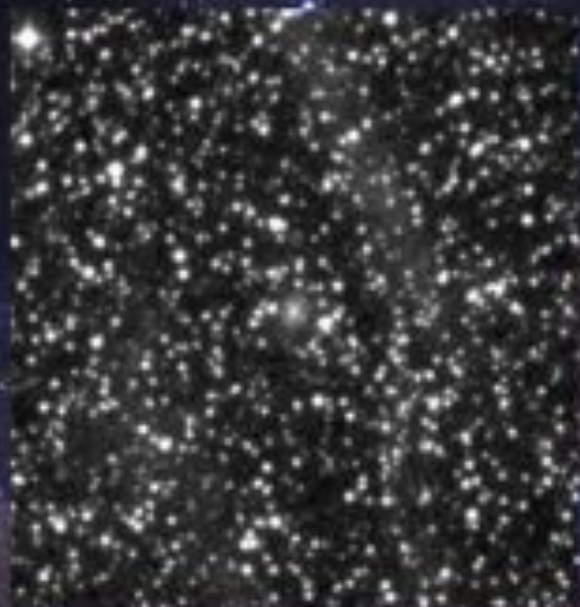


<https://www.everythingrf.com/search/waveguide-horn-antennas>



Reber Dish

Palomar 200"



But there are many kinds....

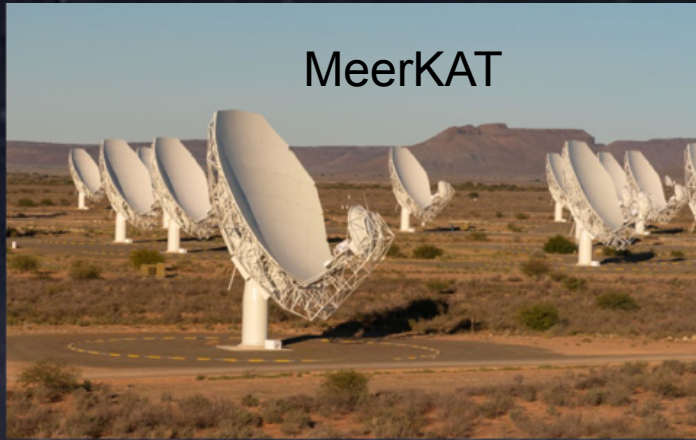


Bigger dish = Better Resolution
Drift scan vs. Pointable antennas



Interferometers!

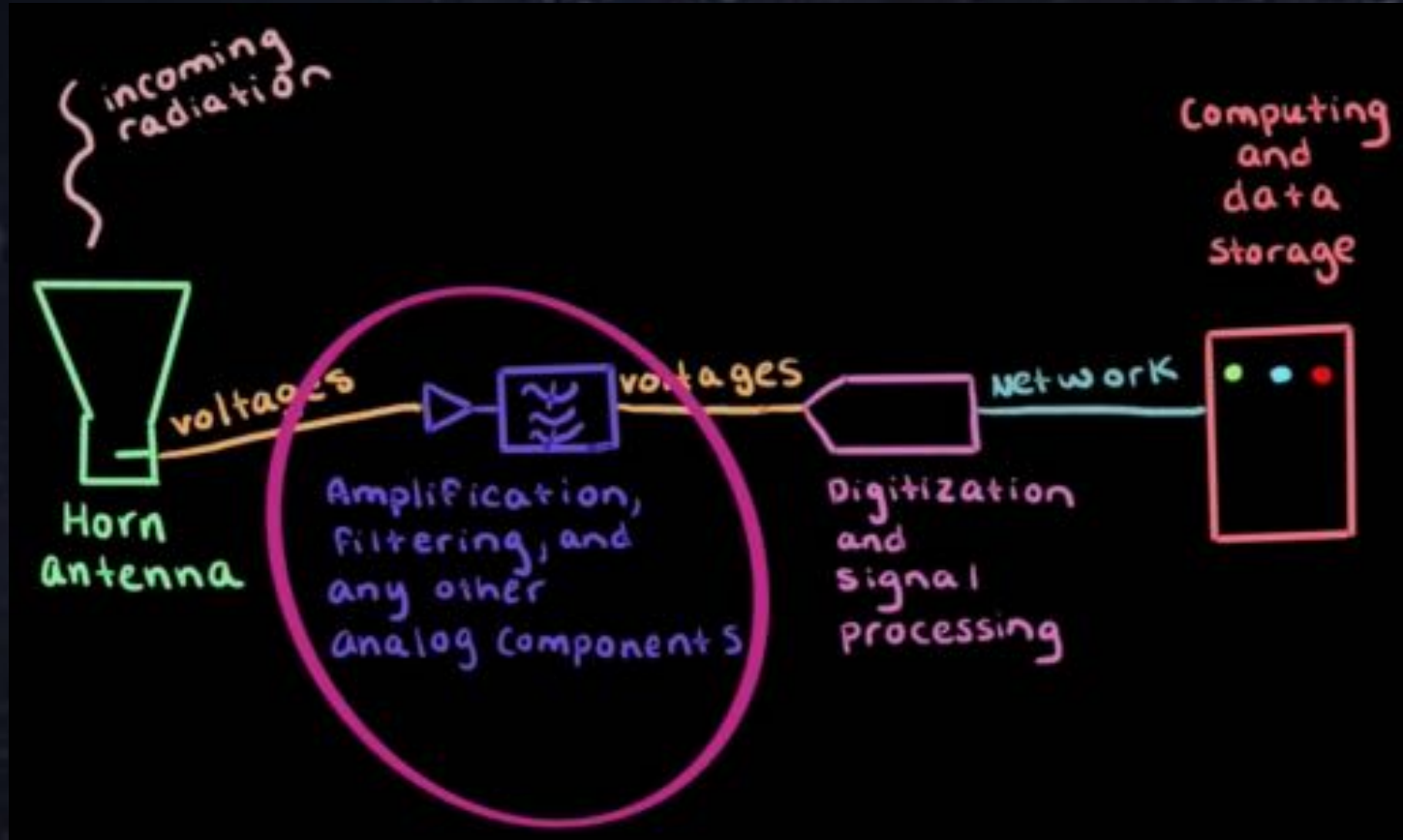
MeerKAT



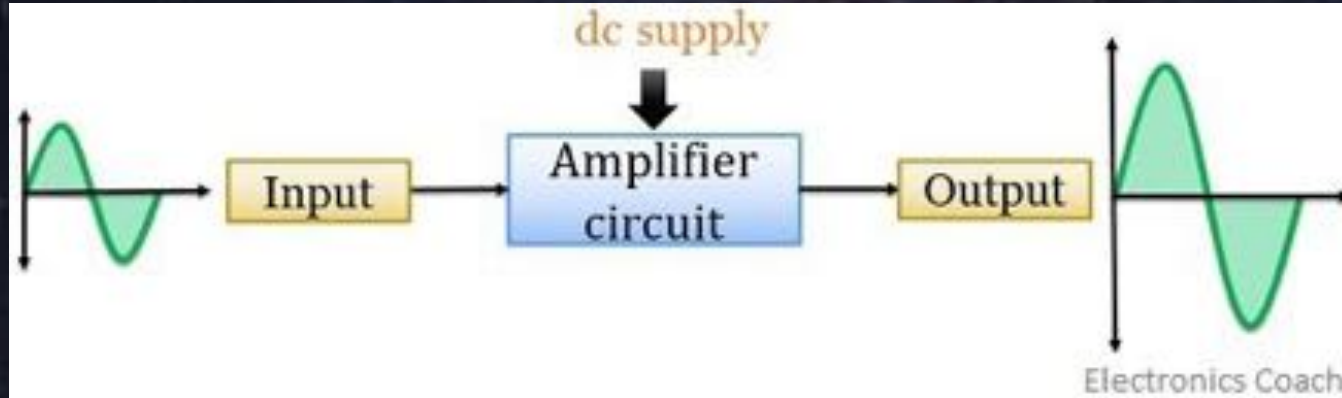
HERA



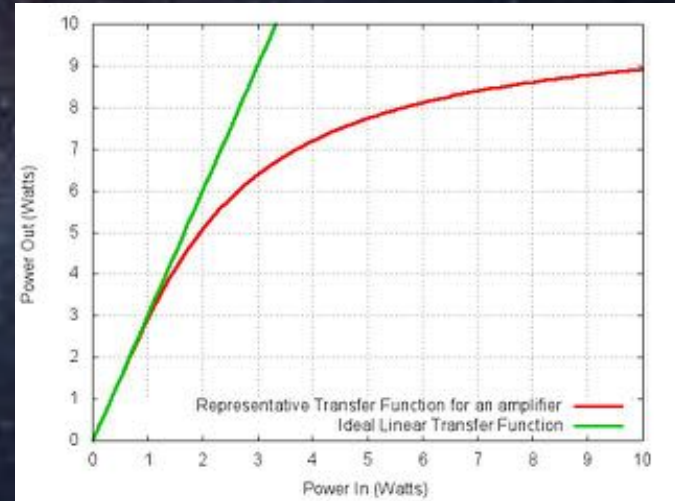
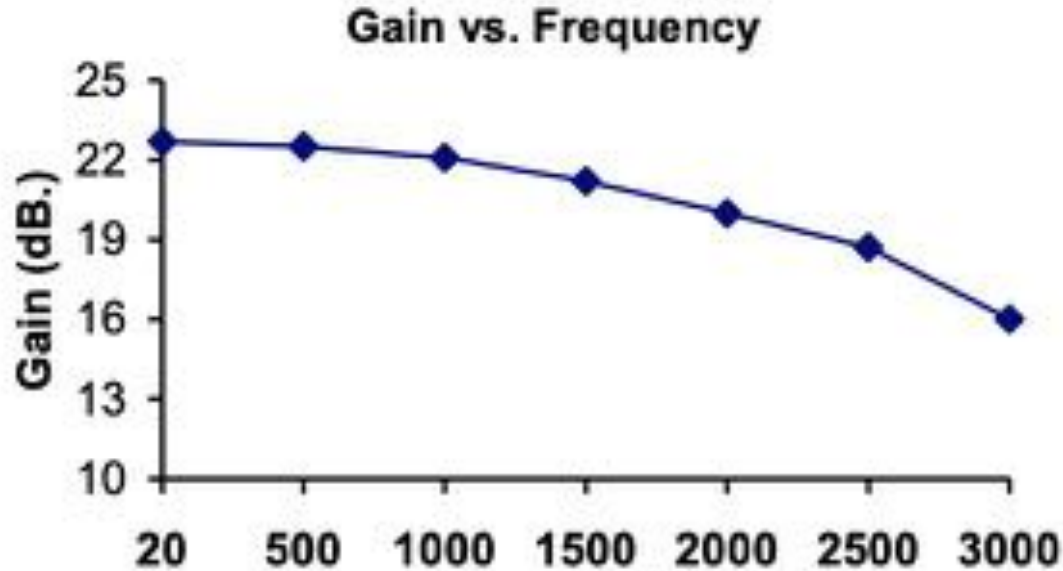
Analog Components



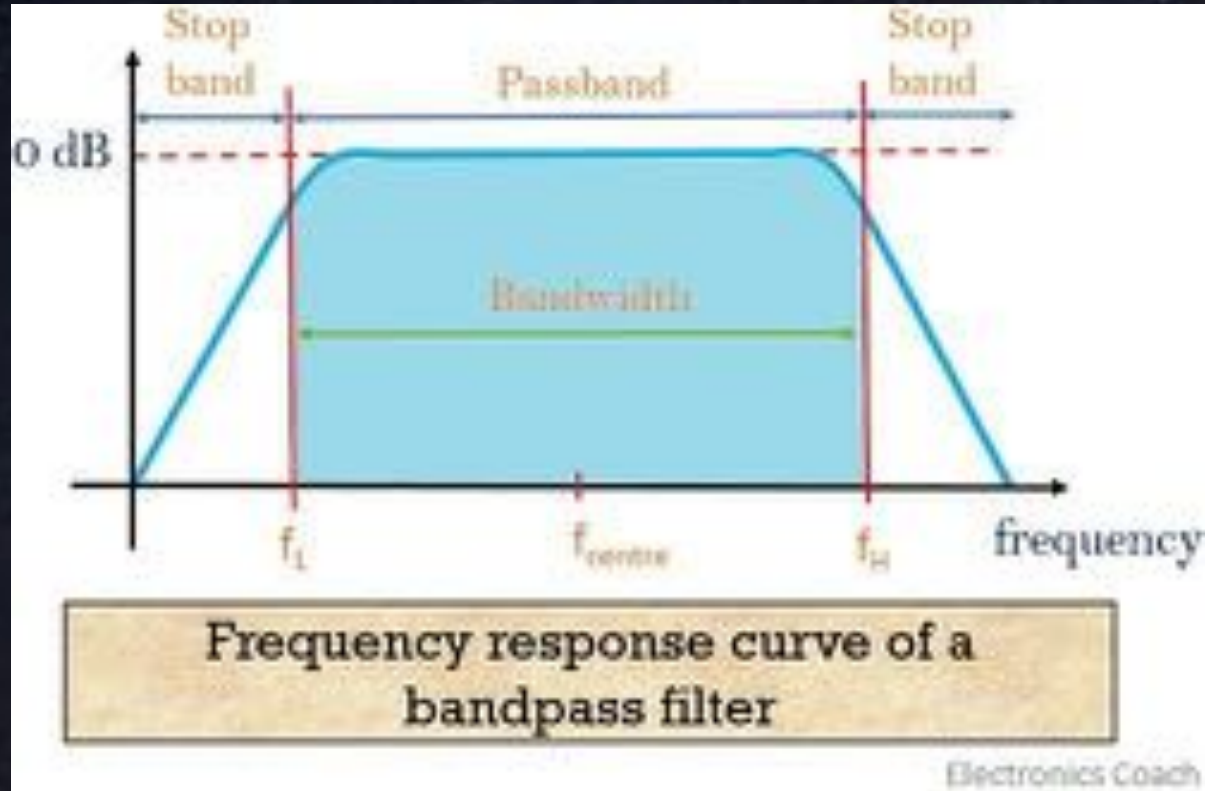
Amplification



Amplifier response curve



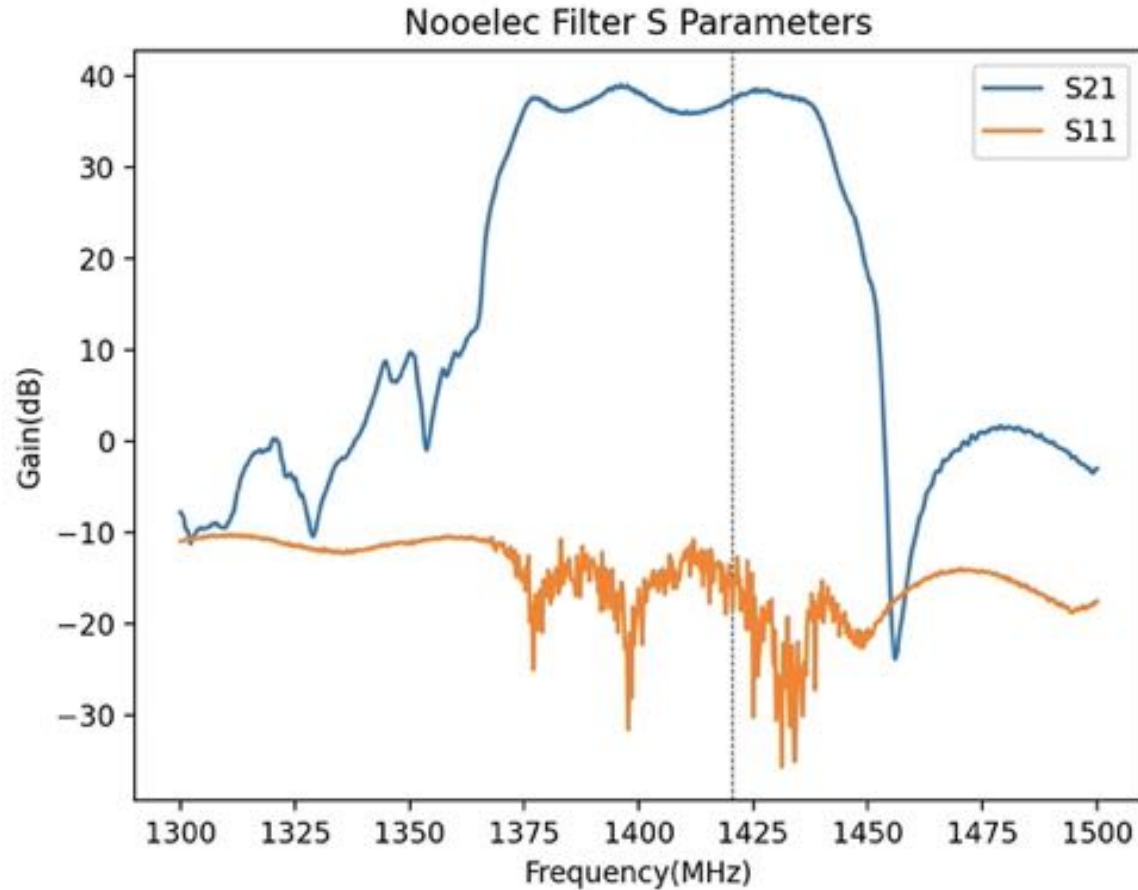
Filtering



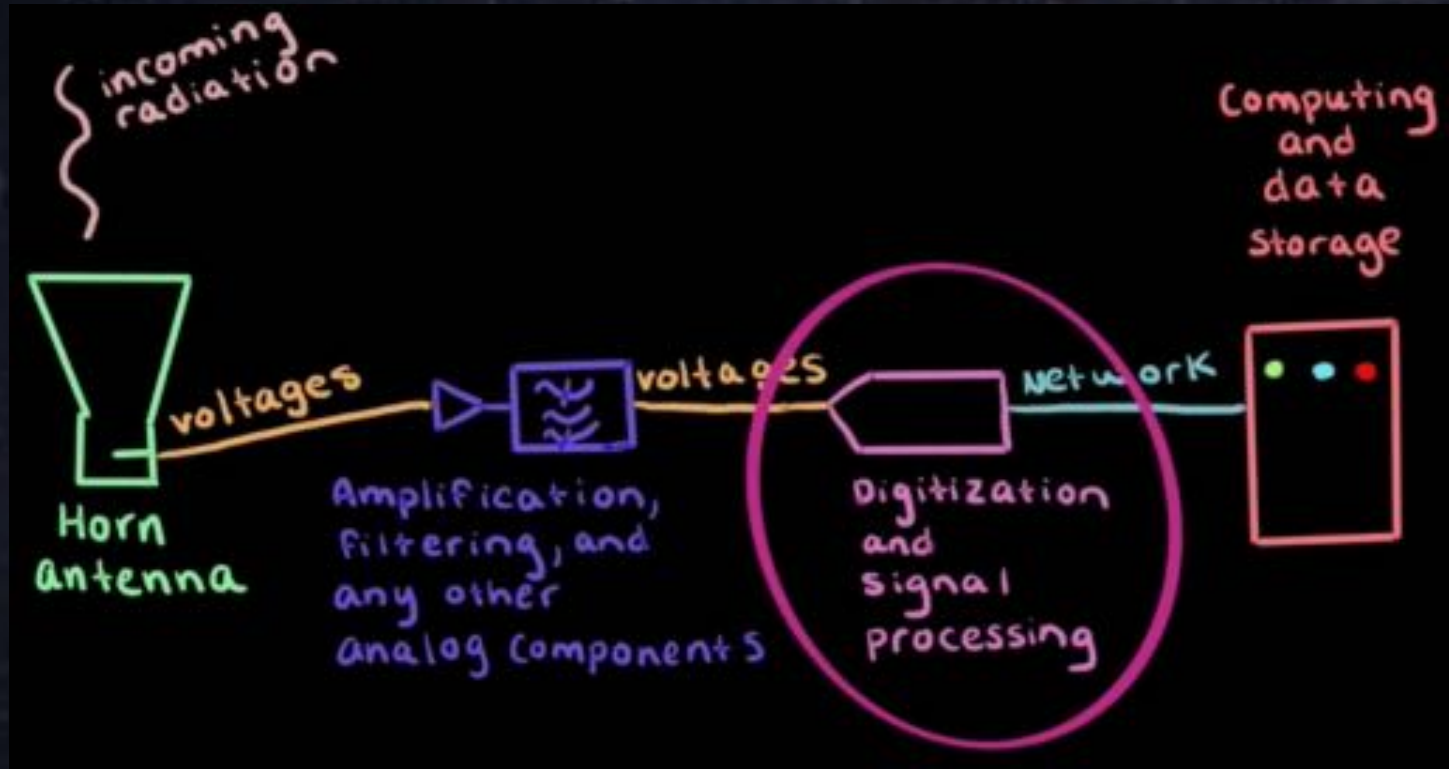


<https://www.noelec.com/store/sawbird-h1-barebones.html>

Nooelec Passband



Digitization and Signal Processing



SDR

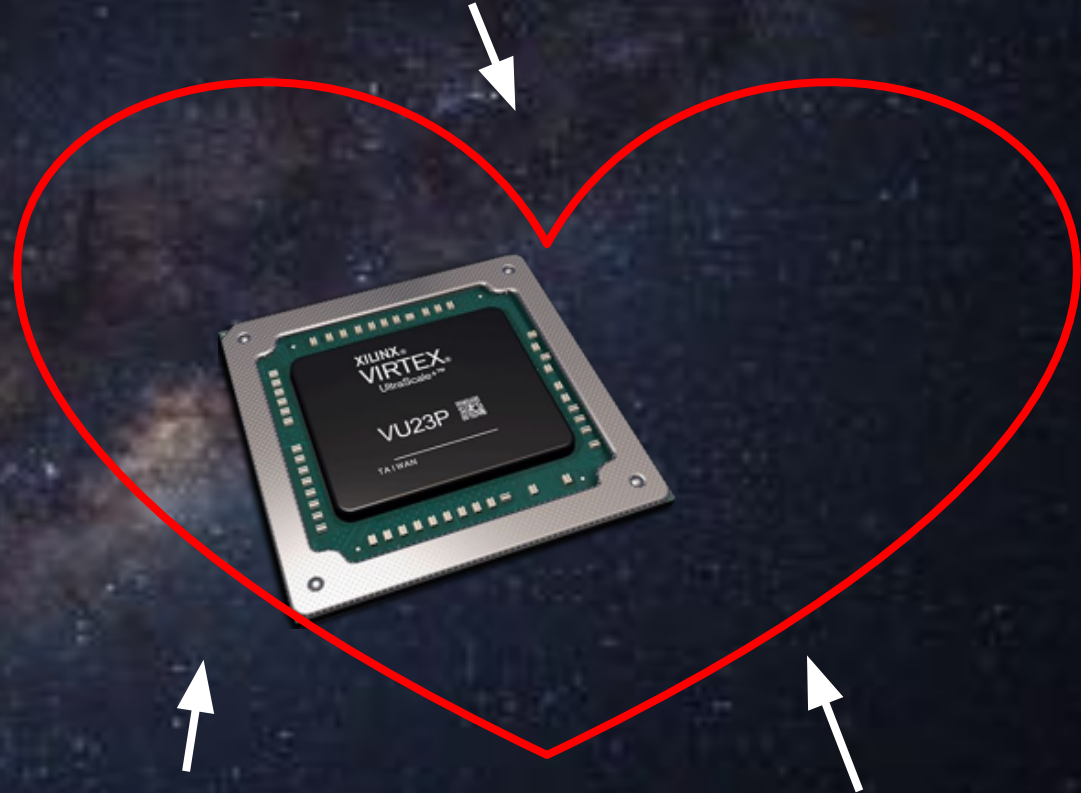


Software defined radios implement traditional radio components entirely in software.

There are other options...



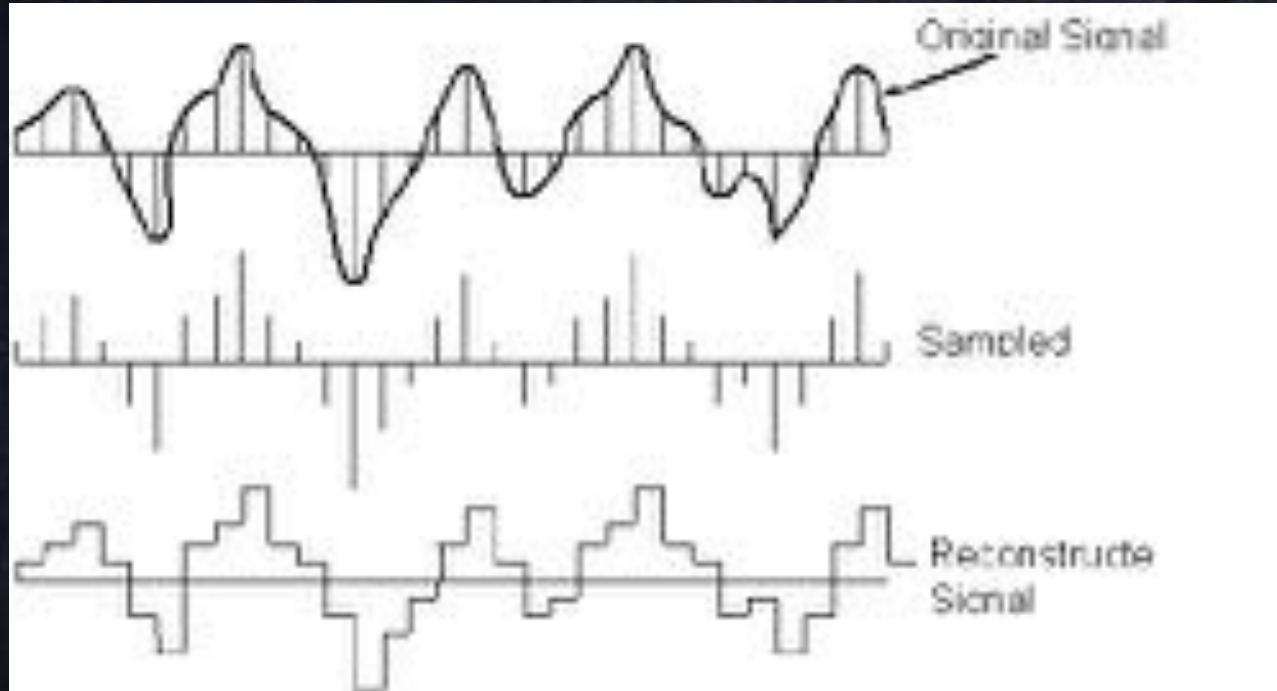
Make tons of \$\$\$!!!



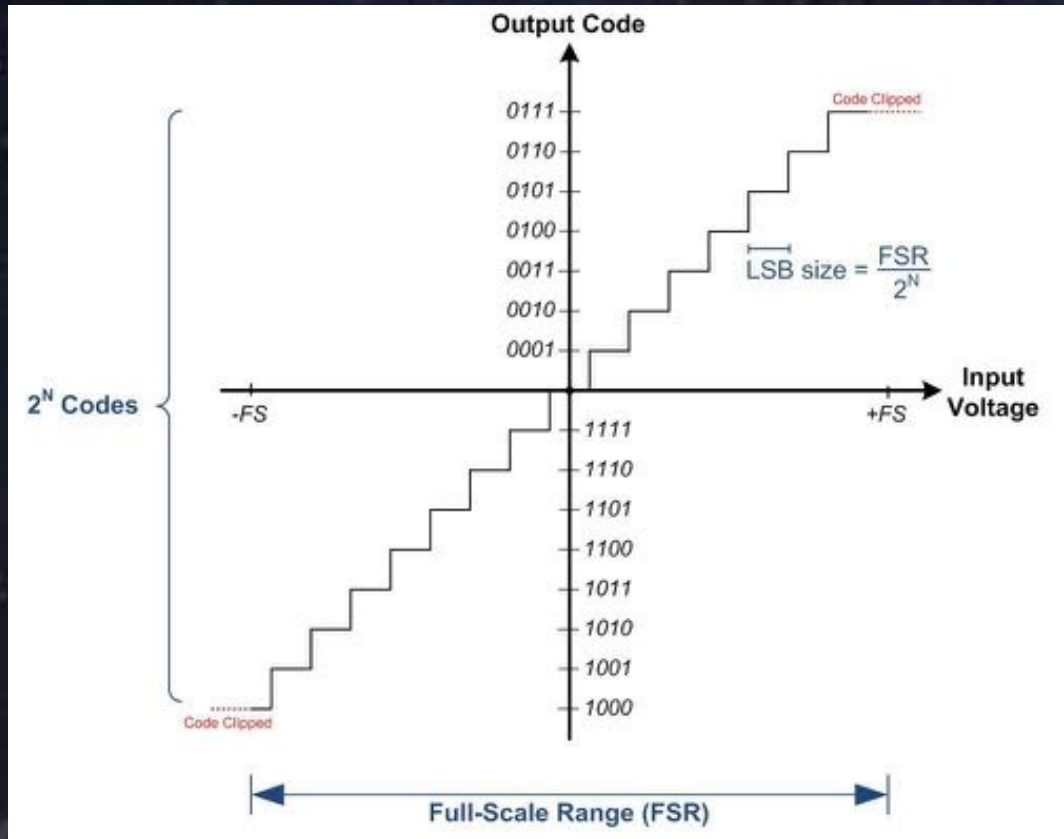
Write your own firmware !!!

Flexible AND Fast !!!

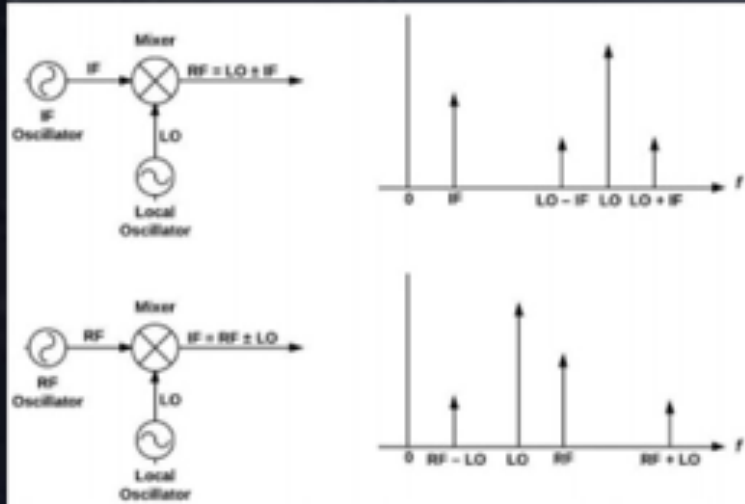
Analog to Digital Conversion



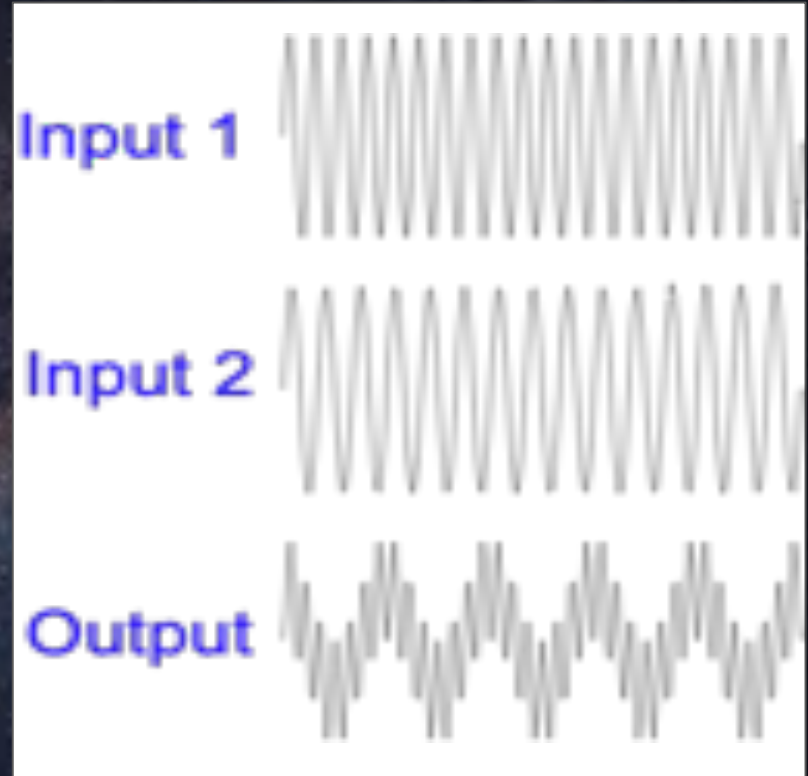
Analog to Digital Conversion



Mixing/Tuning

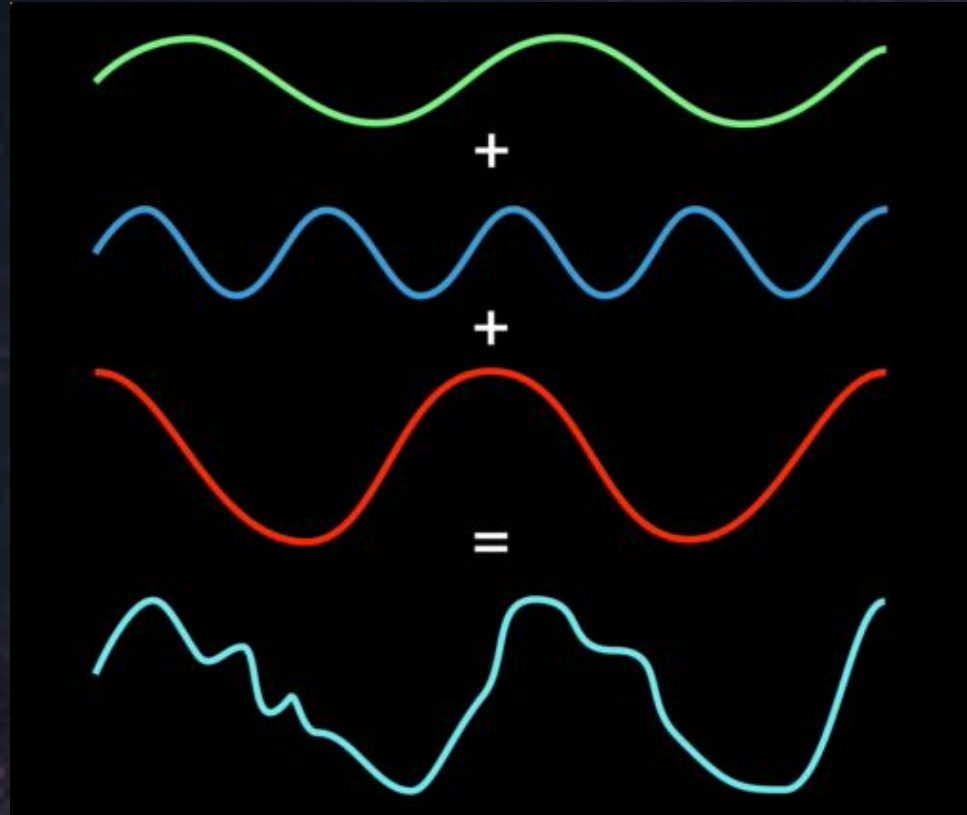


<https://coppermountaintech.com/rf-mixer-characterization/>



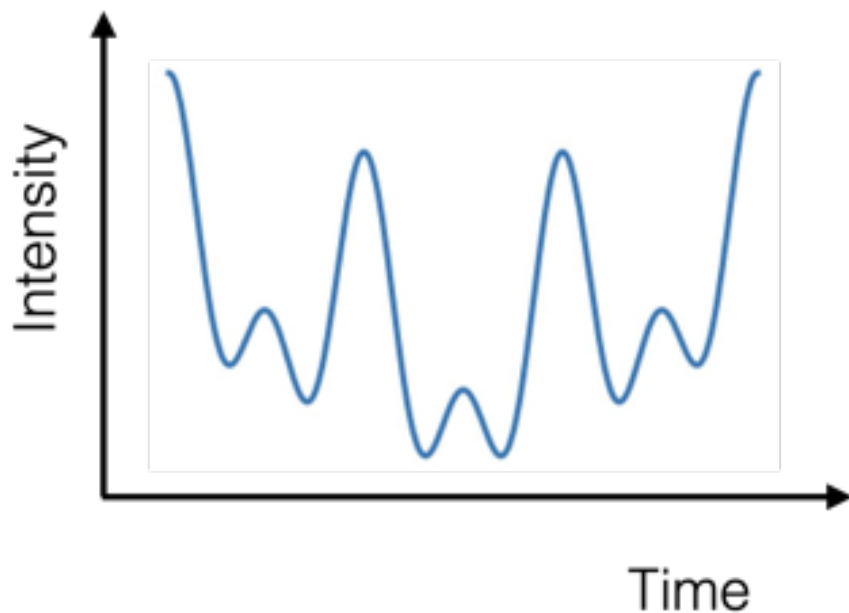
<https://academo.org/demos/wave-interference-beat-frequency/>

Fourier Decomposition

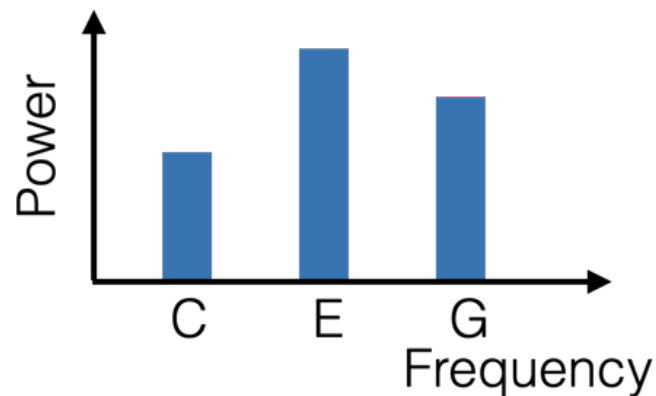
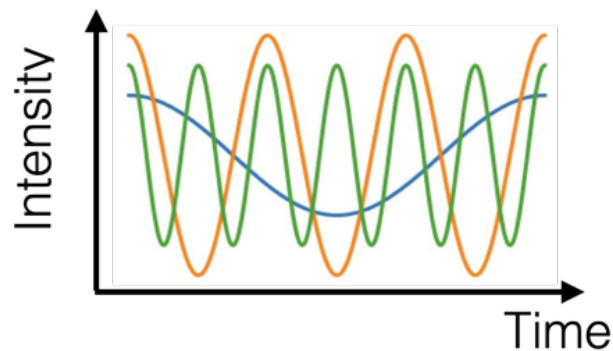
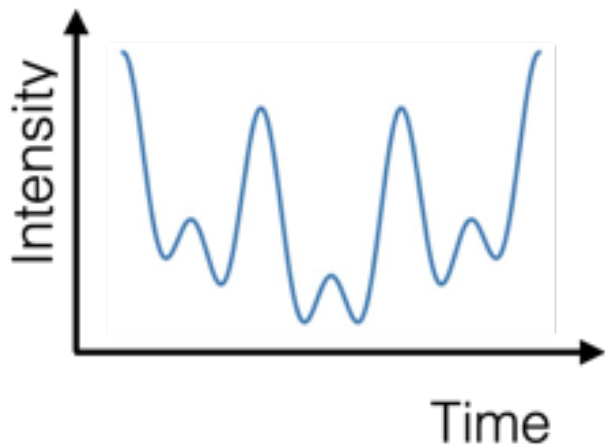


Fourier Transform

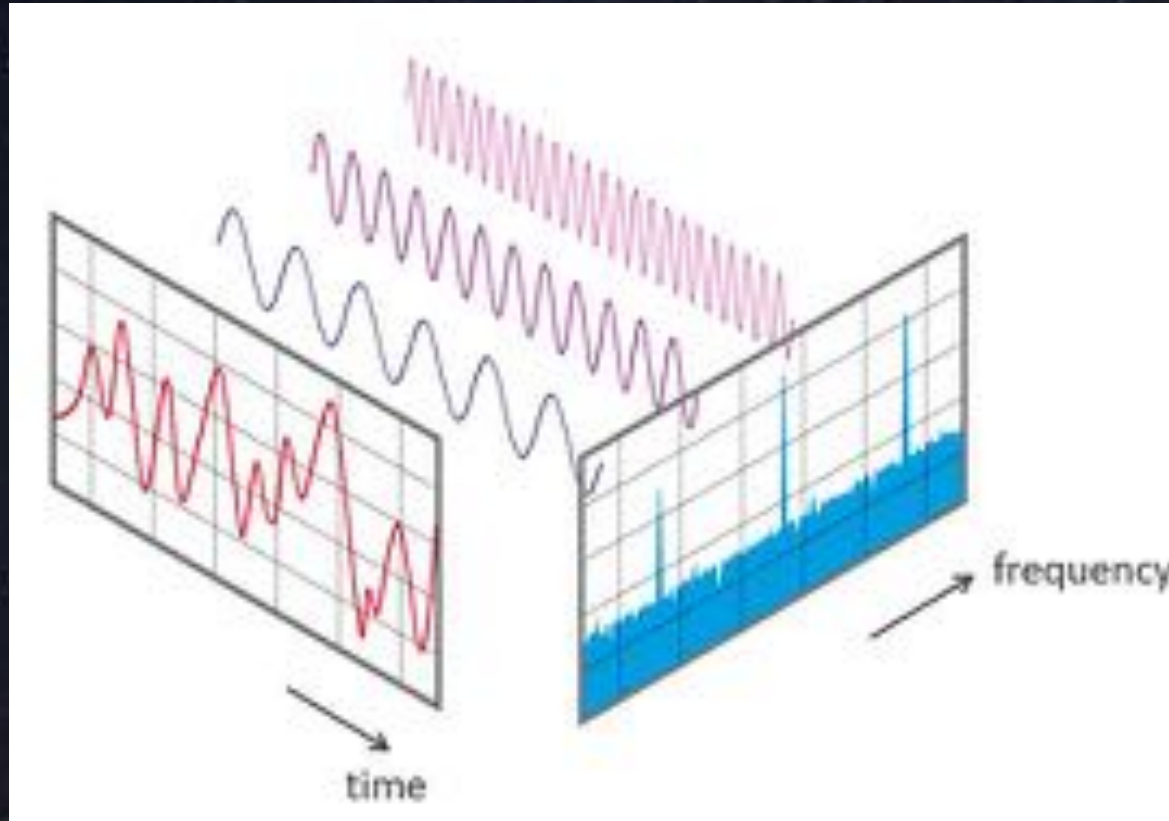
Complicated Sound Wave



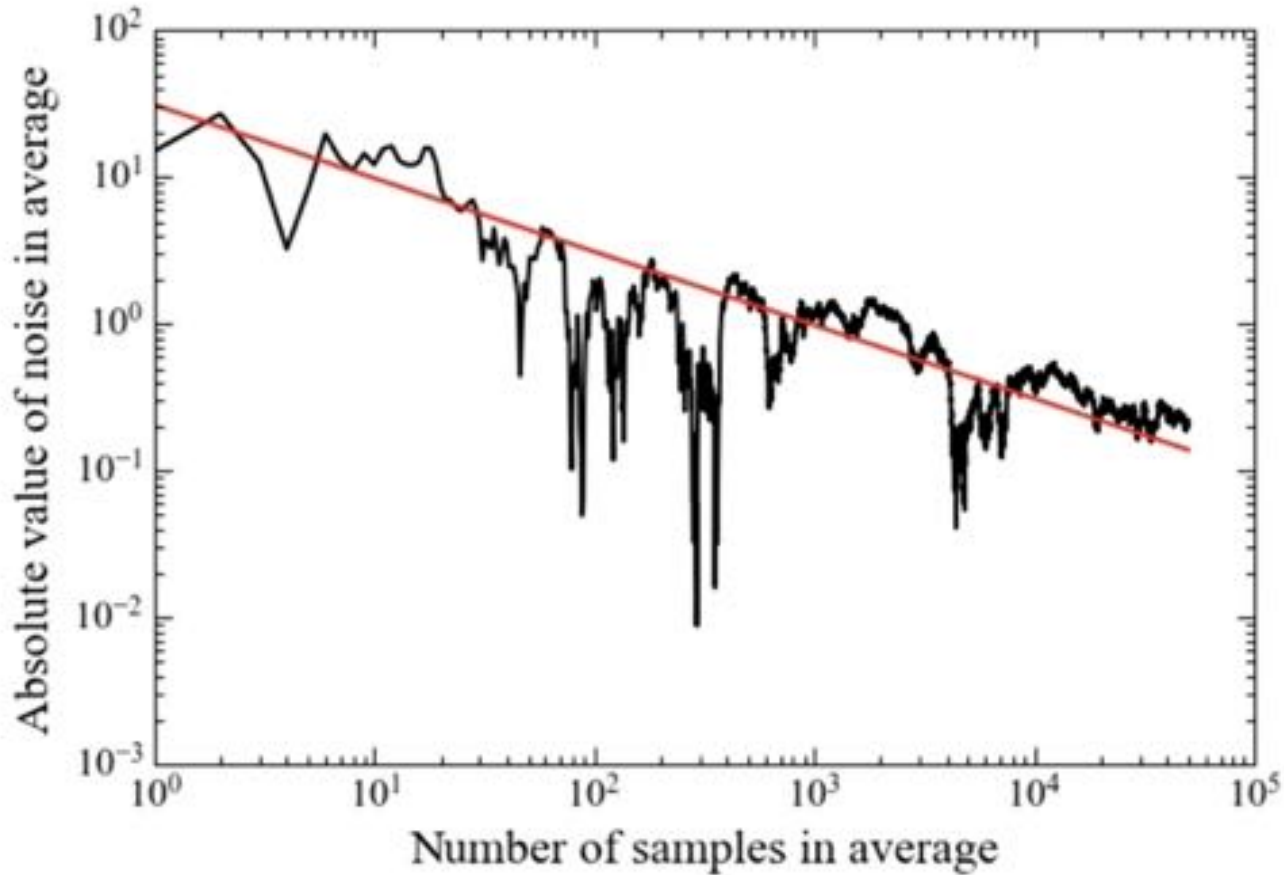
Fourier Transform



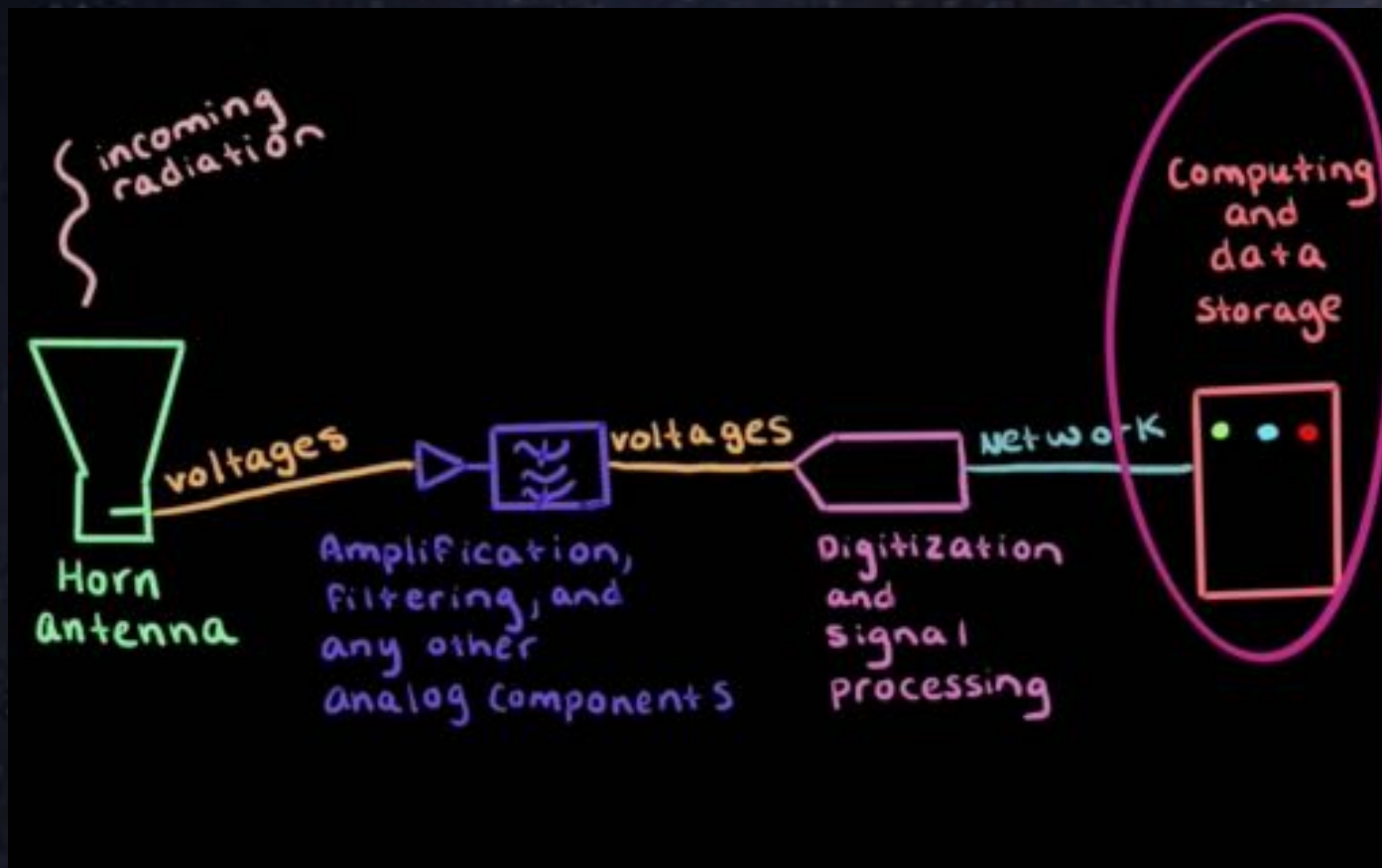
Fourier Transform to Spectra



Integration

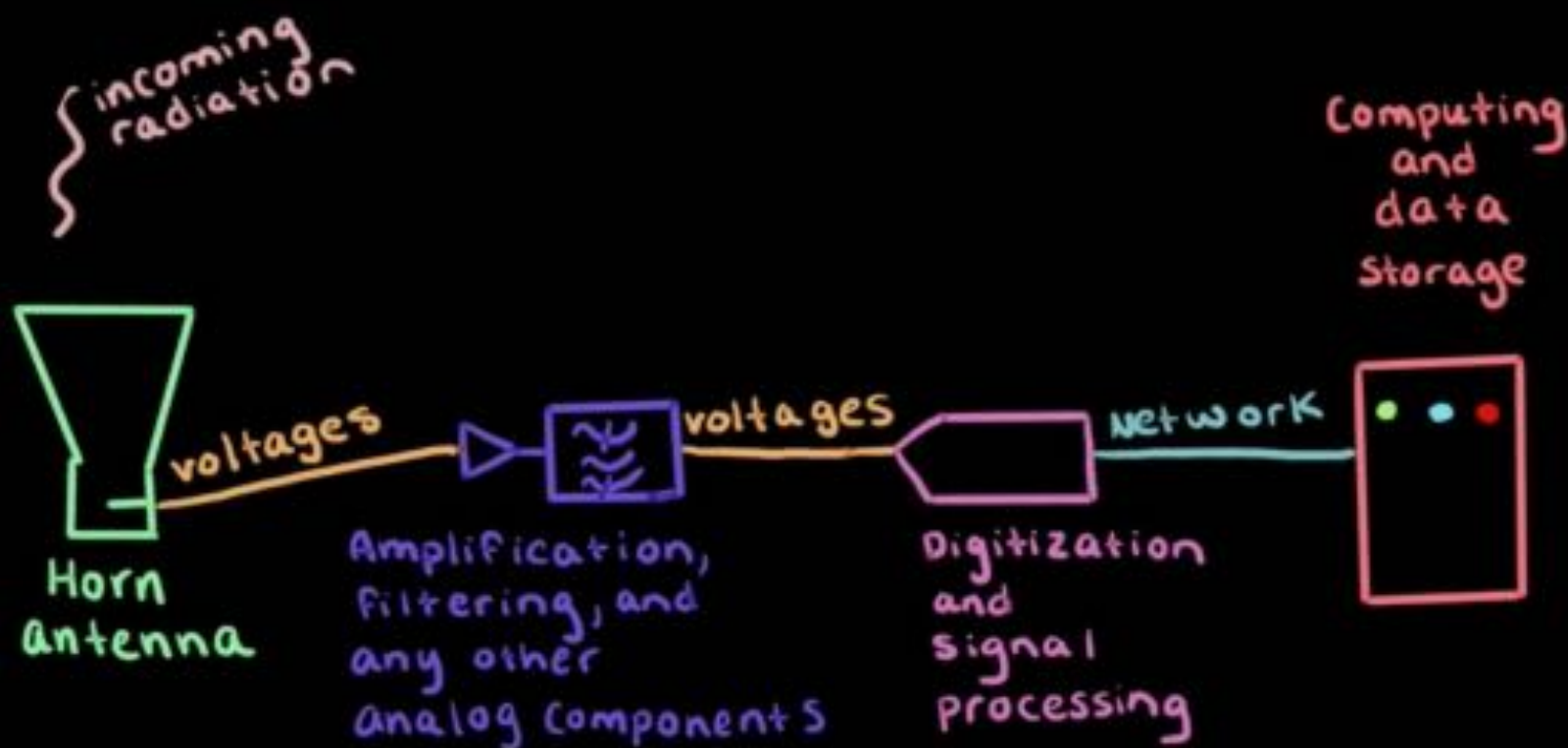


Computing and Data Storage



Computing and Data Storage





Sort into groups for enterprise accounts



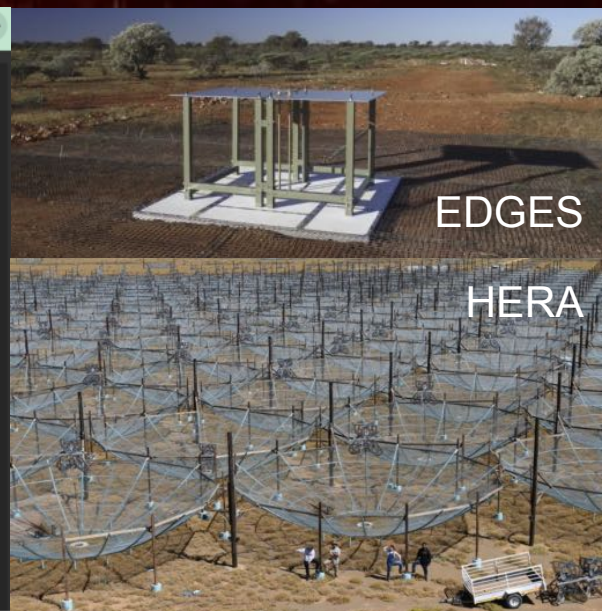
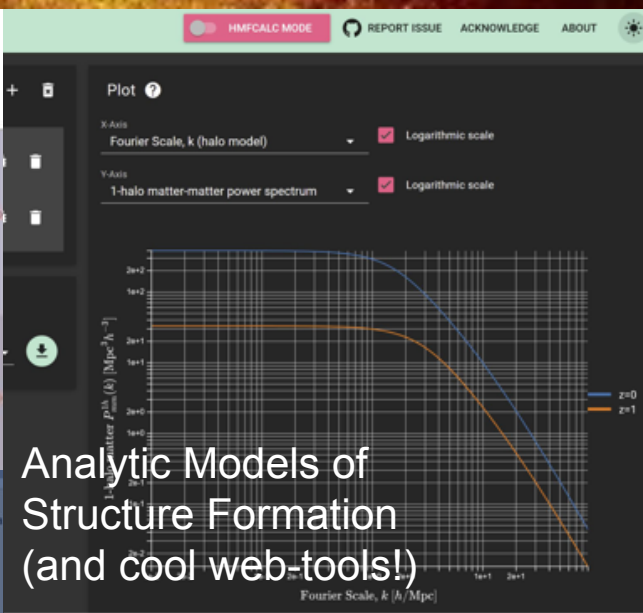
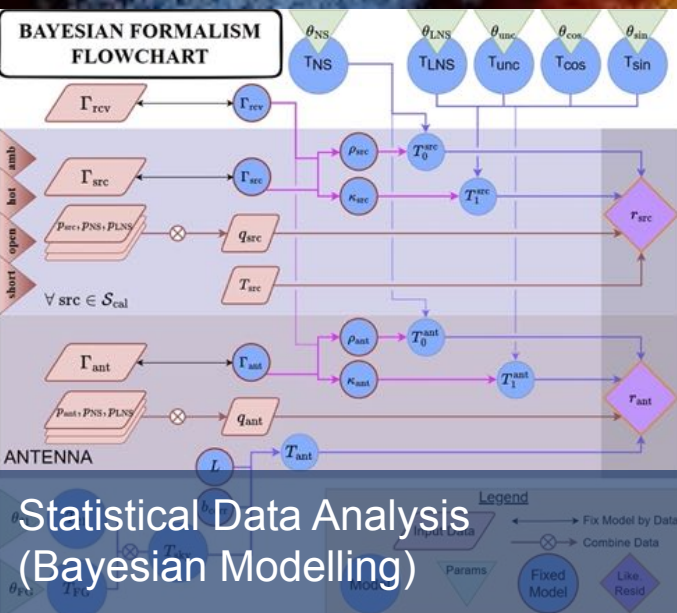
Backup Slides

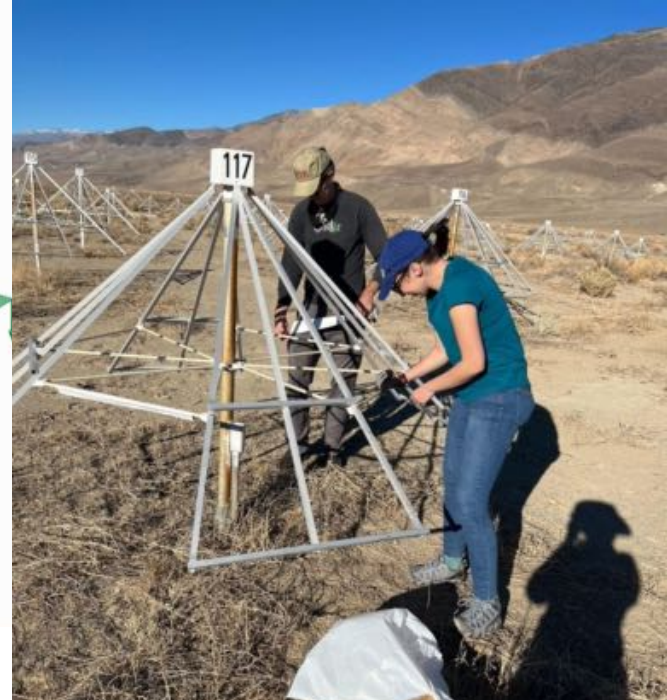
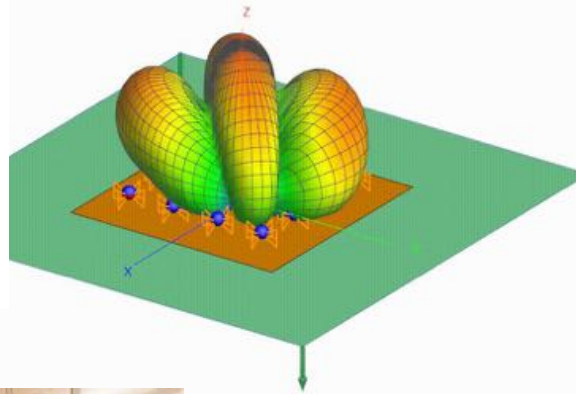
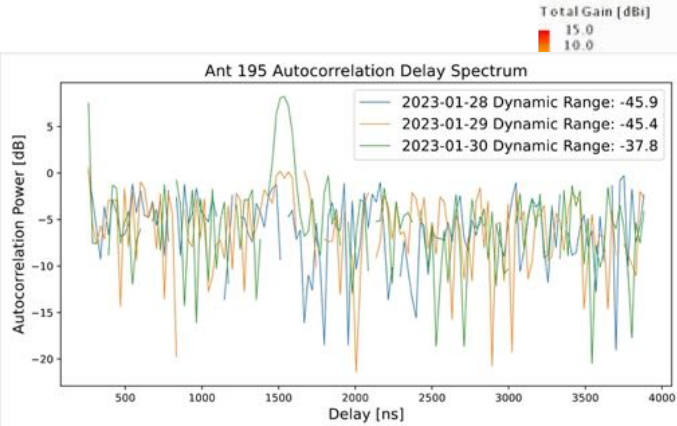


Cosmological
Simulations

Steven Murray

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





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