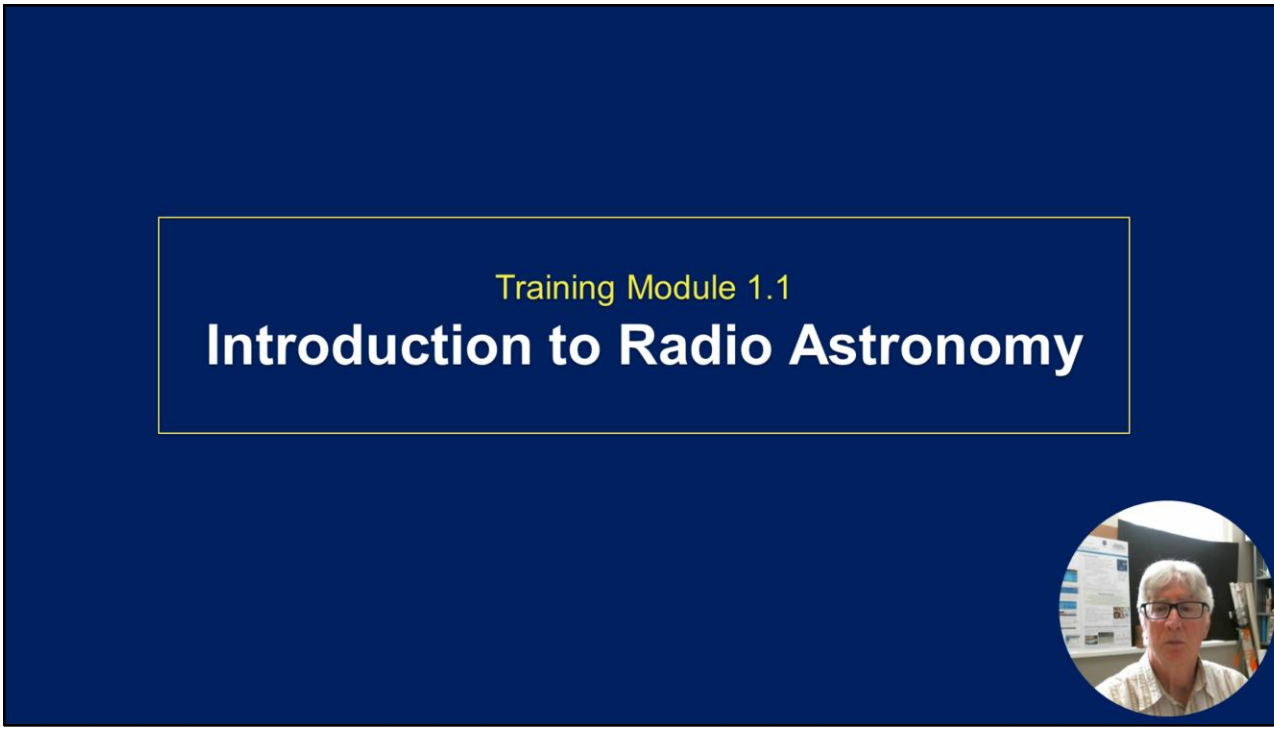
Welcome to The Radio JOVE Project Citizen Science Training Modules.

These training modules are a partnership between the SunRISE mission team and The Radio JOVE Project. We acknowledge contributors to these modules as well as our funding sources of support.



This is Training Module 1.1 – Introduction to Radio Astronomy

Prerequisites for Training Modules

1. High School Reading Comprehension and General Science
2. Scientific Notation
3. Electromagnetic Spectrum – Speed, Wavelength, and Frequency of Waves
4. Graphical Interpretation of Data
5. Basic structure of the atom
6. Thermal and non-thermal energy
7. Training Module 1.0

This is a list of prerequisites needed to be able to understand the material in this module.

Learning Objectives

1. Learn the origins of radio astronomy
2. Identify different parts of the radio spectrum
3. Understand the basic parts of Radio Telescopes
4. Learn why and how some objects emit radio waves

Brief summary of the learning objectives for this presentation.

Early History of Radio Astronomy

1930s

- 1932 Karl Jansky, extraterrestrial “hiss” (MW at 20 MHz)
- 1938 Grote Reber, maps the Galaxy at 160 MHz (non-thermal emission) [“Controversial” paper published in 1940]

1940s

- 1942 Hey and Southwood - intense solar radio interference
- 1944 Oort, van de Hulst predict the 21-cm line of H
- 1945 end of WWII – radio telescopes built in Holland, England, and Australia (Interferometers)
- Radar reflections off the Moon
- Cygnus A and Cassiopeia A radio sources identified
- 1949 optical and radio sources identified

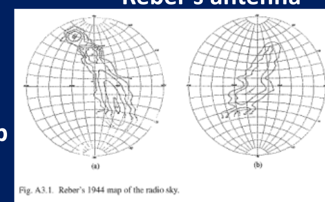
1950s

- Synchrotron mechanism proposed
- 1951 Ewen and Purcell find the 21-cm line of H
- 1955 Radio emission from Jupiter discovered
- Radar studies of planets and the 1st satellite

Jansky’s antenna

Reber’s antenna

Reber’s radio sky map

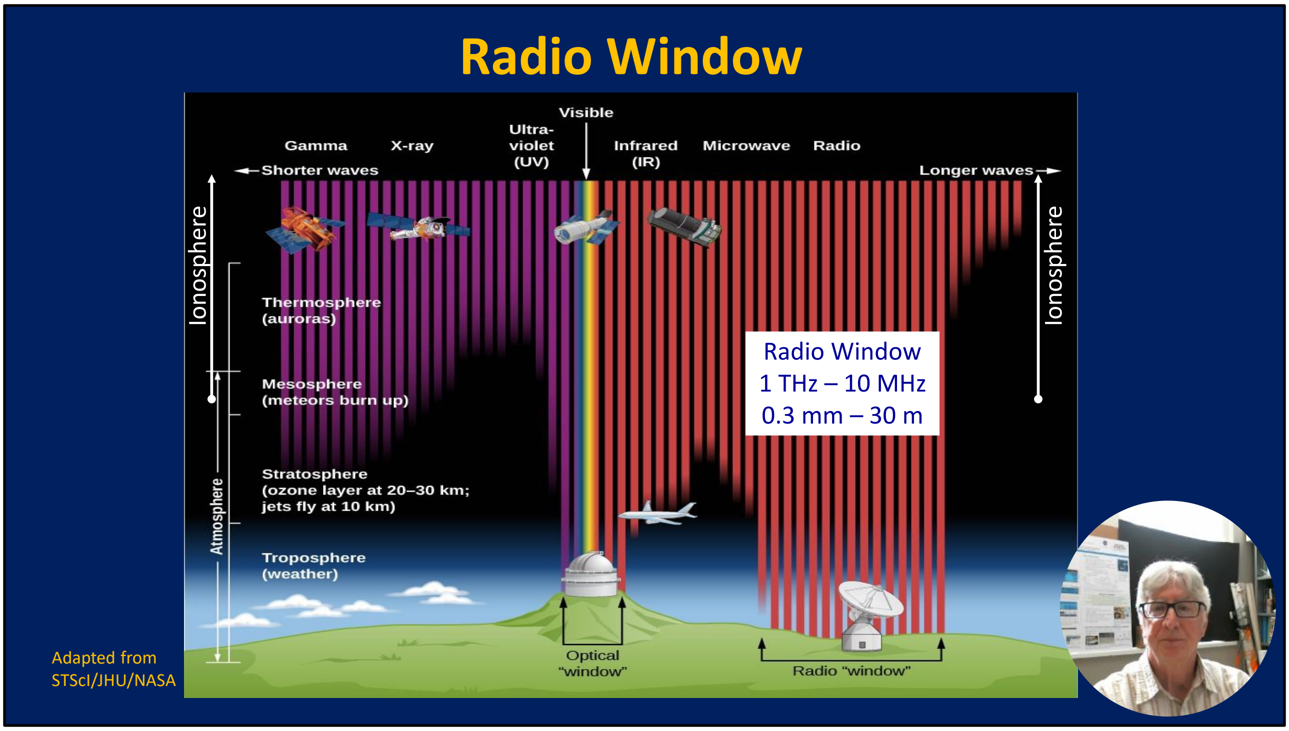


1960s

- Quasars discovered
- SETI begins
- Interstellar molecular lines
- 1965 Cosmic microwave background
- 1967 Pulsars discovered

1970s, 1980s, 1990s, 2000s
Increased technology and large arrays

A brief list of major events in the early history of radio astronomy. Using the research on electromagnetic radiation from Maxwell, Hertz, Tesla, and others, the radio began in the 1890s by Italian inventor Guglielmo Marconi with his work on the wireless telegraph. Karl Jansky, in 1932, first measured an “extraterrestrial” radio signal with a radio telescope. Soon after Jansky’s discovery, Grote Reber built his own radio telescope in his backyard and first mapped the Galaxy at 160 MHz. One might consider Reber the first citizen scientist radio astronomer! Many other early discoveries are listed here, with an incredible growth of radio astronomy after World War II. In 2019, radio astronomers used new technology and 5-8 radio telescopes around the world to make the first image of a supermassive black hole, located in the galaxy M87.



The Radio Window – visible light waves and most radio waves easily pass through Earth's atmosphere making optical and radio astronomy accessible for ground-based telescopes. The atmosphere is transparent to these waves. Higher energy gamma rays, x-rays, and ultraviolet light are blocked by the atmosphere, that is, the atmosphere is opaque to this radiation. Most mid-infrared and shorter wavelength radio waves are absorbed by atmospheric water, oxygen, and carbon dioxide, so observations must take place in the upper atmosphere or in space. The longer wavelength radio waves are absorbed or refracted back into space by Earth's ionosphere, the plasma layer existing above about 50 km and labeled on each side of the figure.

Radio Bands

<u>Some Radio Bands</u>

Extremely Low Frequency (ELF) to Low Frequency (LF): 3 Hz – 300 kHz

Medium Frequency (MF): 300 Hz – 3 MHz
- AM bands (0.5-1.7 MHz), emergency distress signals

HF: 3-30 MHz, decameter
- Shortwave radios, CBs

VHF: 30-300 MHz meterwave (TV/FM)

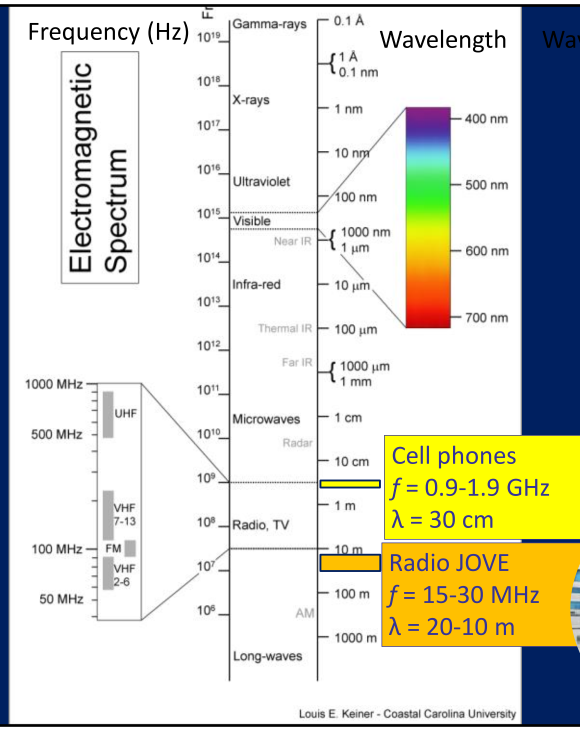
UHF: 300-3000 MHz decimeter
- (phones, LAN, cable TV, microwave ovens, GPS)

Microwave: 1000-30,000 MHz

SHF: microwave (3 - 30 GHz) radars

EHF: millimeter (30 - 300 GHz)

Infrared: sub-millimeter (300 - 700 GHz)



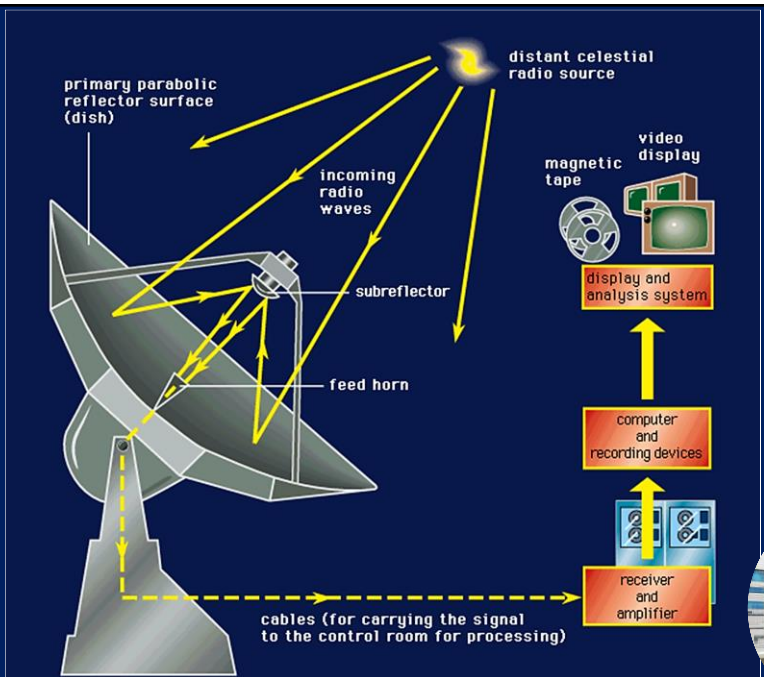
Wavelength

The electromagnetic spectrum is shown here. The radio spectrum ranges from about 1 Hz to several terahertz (THz), and there are many designated radio bands and sub-bands based on frequency and/or wavelength. Several bands and their applications are highlighted here. Based on the radio "window", most radio astronomy is conducted between 10 MHz and 1 THz. At the upper end of the radio frequency spectrum, the bands are considered as microwave or infrared radiation. Bands with frequencies less than the microwave region are High Frequency (HF) bands, down to 3 MHz, below the radio cutoff by the ionosphere. For illustration, cell phones and the Radio JOVE frequencies are show here.

Radio Telescopes

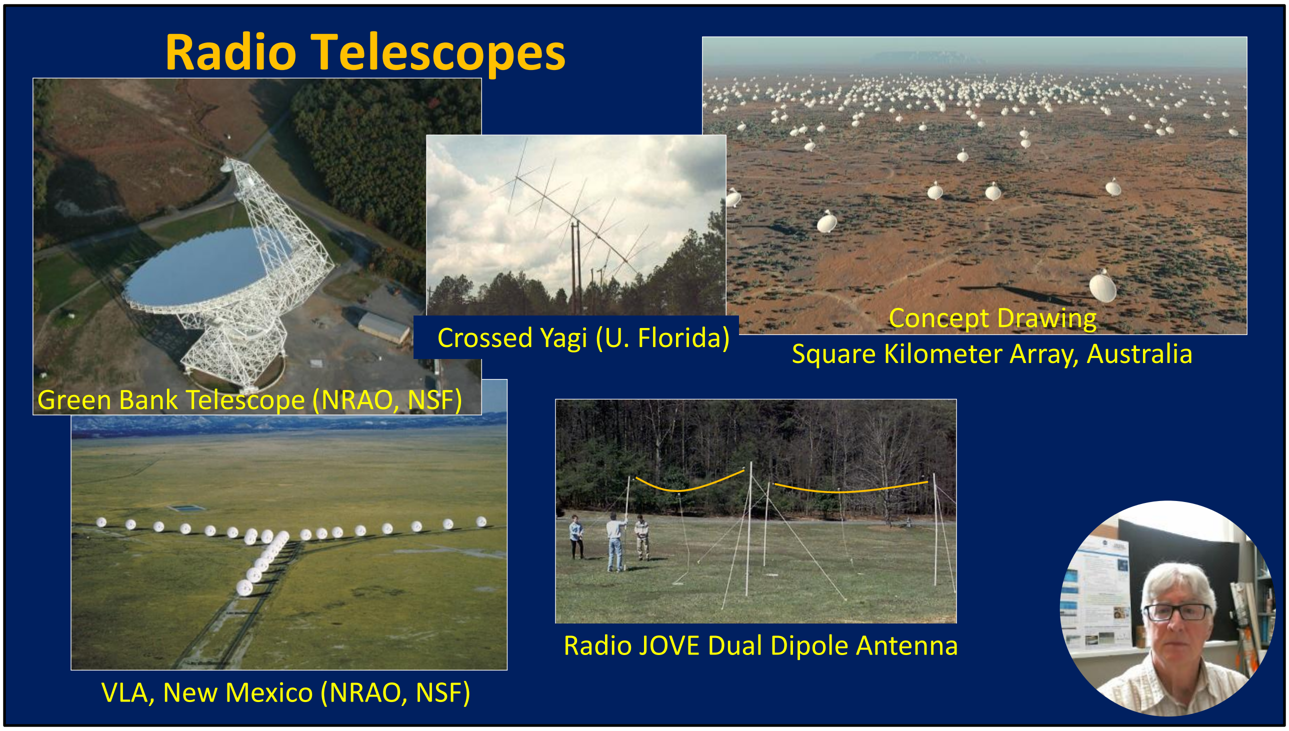
Basic Parts of a Radio Telescope

- Antenna
- Receiver
- Recorder (pen strip chart, magnetic tape, computer)

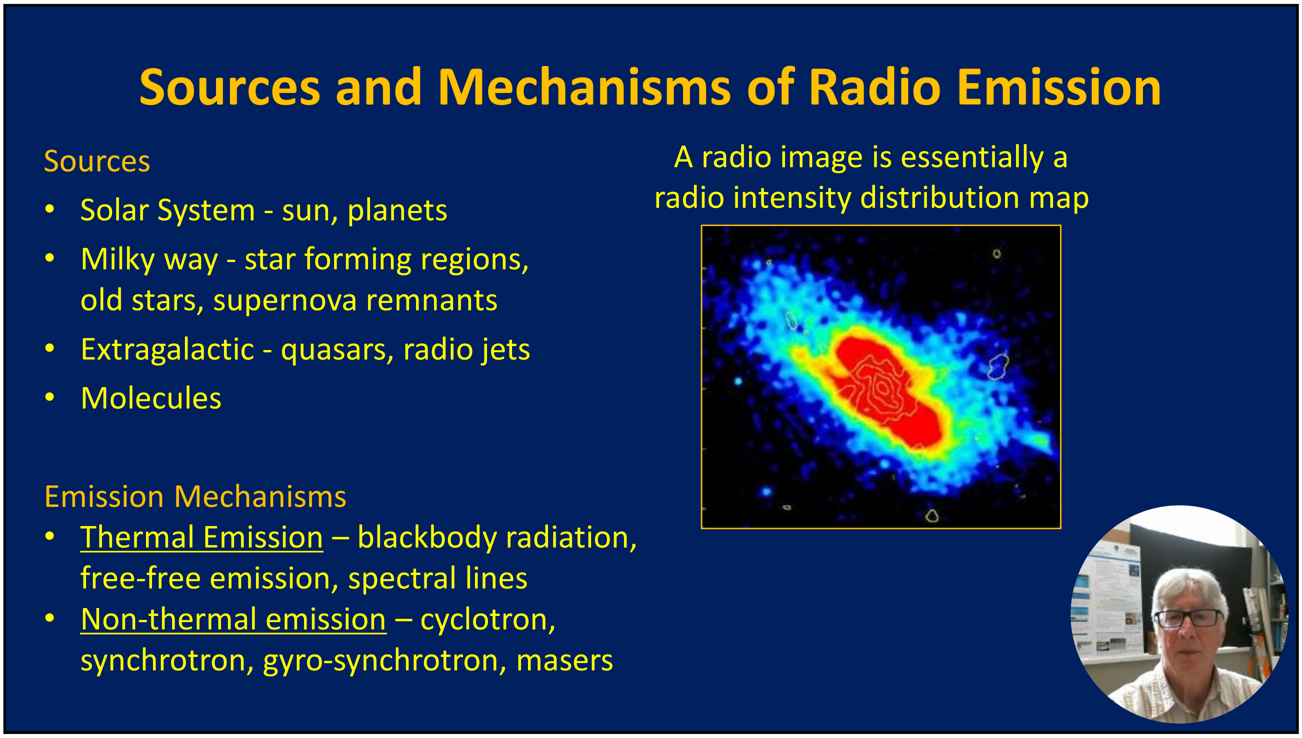


Credit: https://www.britannica.com

Radio astronomy, of course, requires a radio telescope. A radio telescope consists of three basic parts: (1) the antenna to collect the radio waves, (2) the receiver to amplify and filter the signals, and (3) a recorder to record the signals for analysis.



Because radio wavelengths used in radio astronomy have a large range of wavelengths, 0.3 mm to 30 m, radio telescope antennas have many different shapes and sizes. Shorter wavelength radio signals use large radio dishes to collect and focus the radio waves much like an optical telescope mirror. Basic optics tells us that the resolution of the images produced are inversely proportional to the wavelength of light collected. Thus, making radio images with good resolution requires very large dishes or large arrays of dishes. However, as the wavelengths get longer to meters or tens of meters, dishes become impractical and antennas like a Yagi or a dipole are required.

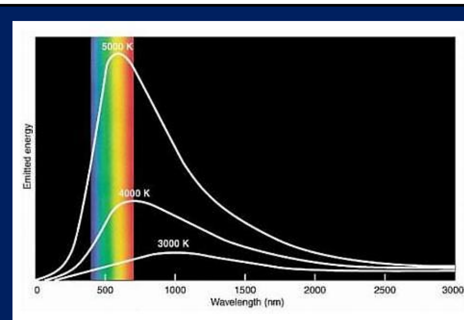


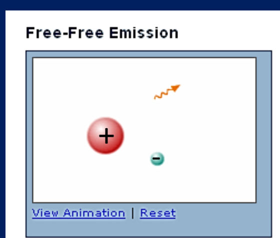
Radio astronomy sources of radio emission include solar system objects like the Sun and planets, many types of objects within the Milky Way like star formation regions, pulsars, supernova remnants, extragalactic sources like radio galaxies, quasars, and cosmological signals from the beginnings of the universe. Radio emission is generated in two categories, thermal emission due to the temperature of the object, and non-thermal emission from charged particle motion. Radio "images" are made by associating radio intensities with a color to make a spatial map of the radio source.

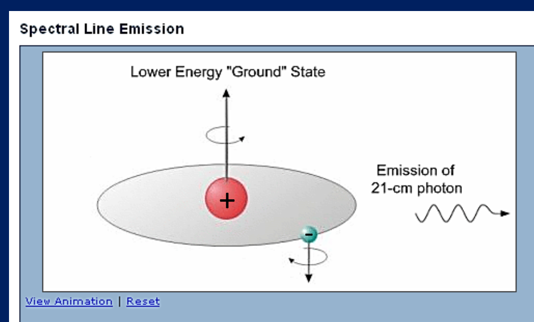
Mechanisms of Radio Emission

Thermal Emission

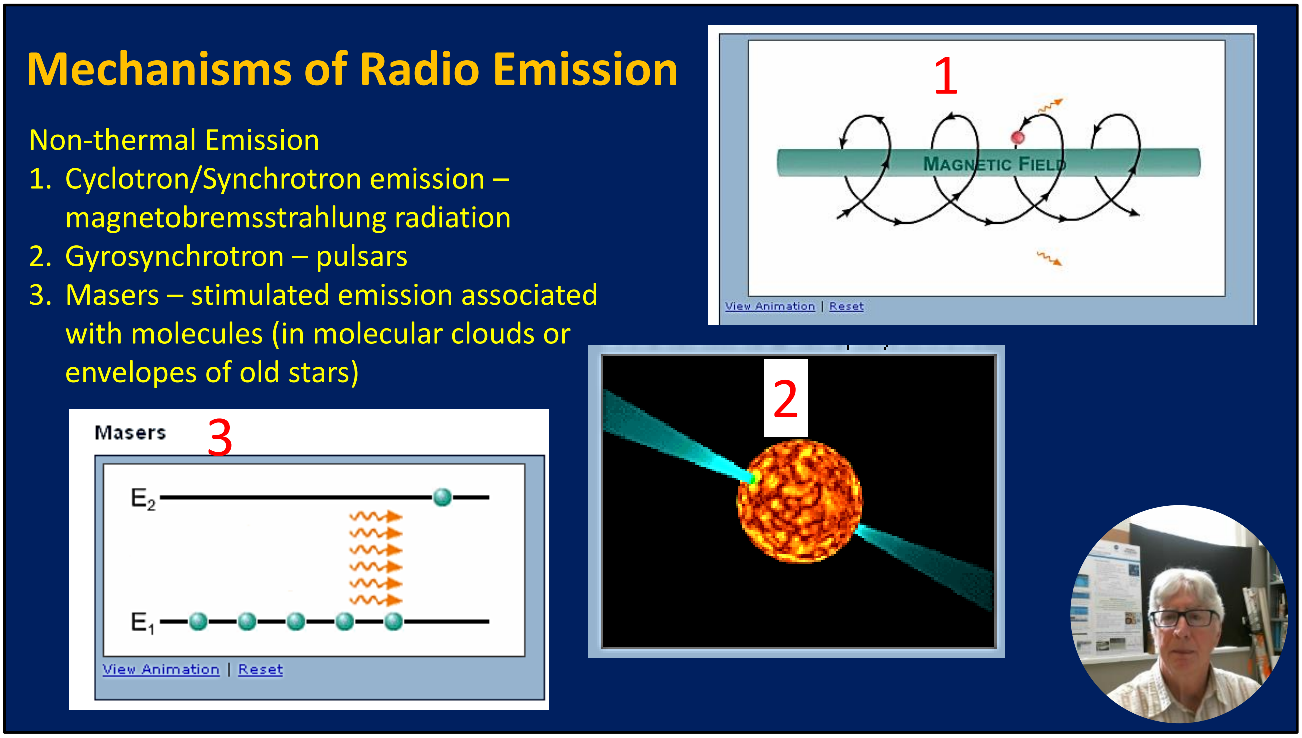
1. Thermal Emission – blackbody radiation
2. Free-free emission – thermal ‘bremsstrahlung’ radiation (for local thermodynamic equilibrium)
3. Spectral Line Emission – i.e., 21 cm line of Hydrogen







Thermal radio emission occurs by three different mechanisms. Hot objects emit electromagnetic waves as blackbody radiation; however, unless the object’s temperature is extremely hot, little radio emission is generated by this process. More thermal emission occurs in low density plasmas from electron-ion particle interactions in free-free emission. Called bremsstrahlung, or braking radiation, it is caused when a particle emits energy in the form of electromagnetic radiation at the expense of its kinetic energy during the electron-ion interaction. Finally, thermal radio waves can be generated by atomic processes like spectral line emission. Spectral line emission occurs when the electrons of excited atoms change energy levels emitting energy as they return to the ground state. The most famous radio wave spectral line is the 21 cm line from atomic hydrogen caused by a small “spin-flip” energy difference between the nucleus and the electron.



Non-thermal radio emission is a very important process, particularly gyromagnetic processes. Gyromagnetic emissions involve moving charged particles in magnetic fields like planetary or solar magnetic fields. Depending on the energy of the moving charge, cyclotron or synchrotron radio emission results. Pulsar radio emissions result from a gyrosynchrotron process, where a rotation neutron star emits radio waves from the plasma near the intense magnetic poles. Finally, radio emission is also generated by a microwave laser-like process, a maser, from molecular clouds and some planetary and solar magnetospheres.

Resources

1. Basics of Space Flight - https://solarsystem.nasa.gov/basics/
   i. Chapter 2: Reference Systems - https://solarsystem.nasa.gov/basics/chapter2-1
   ii. Chapter 6: Electromagnetics - https://solarsystem.nasa.gov/basics/chapter6-1

2. Atacama Large Millimeter/submillimeter Array (ALMA) - https://www.almaobservatory.org
   ALMA Radio Astronomy Manual https://www.eso.org/public/archives/education/pdf/edu_0072.pdf

3. The National Radio Astronomy Observatory (NRAO) - https://public.nrao.edu
   i. The Science of Radio Astronomy - https://public.nrao.edu/radio-astronomy/the-science-of-radio-astronomy
   ii. What are radio telescopes - https://public.nrao.edu/telescopes/radio-telescopes

4. Goldstone-Apple Valley Radio Telescope (GAVRT) - https://gavrt.lewiscenter.org
   Basics of Radio Astronomy - https://www2.jpl.nasa.gov/radioastronomy/radioastronomy_all.pdf

5. Society of Amateur Radio Astronomers (SARA) - https://radio-astronomy.org
   i. Introduction to Radio Astronomy (41 min video) - https://www.radio-astronomy.org/node/240
   ii. Getting Started in Radio Astronomy - https://www.radio-astronomy.org/getting-started
   iii. Beginner Booklet - https://www.radio-astronomy.org/pdf/sara-beginner-booklet.pdf

6. Commonwealth Scientific and Industrial Research Organisation (CSIRO) - Australia's National Science Agency
   What is radio astronomy? - https://www.csiro.au/en/research/technology-space/astronomy-space/What-i

This is a short list of good resources on radio astronomy.

Thanks for watching!

Next, Radio Wave Propagation …

Thank you for watching. Next, we will learn about radio wave propagation.