Citizen Science Training Modules

The Radio JOVE Project

radiojove.gsfc.nasa.gov

A Partnership Between

SUNRISE GROUND RADIO LAB

NASA Partner

UNIVERSITY OF MICHIGAN

Welcome to The Radio JOVE Project Citizen Science Training Modules. I am Professor Chuck Higgins from Middle Tennessee State University and one of the leaders of The Radio JOVE Project.

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 1.2 – Radio Wave Propagation

Prerequisites for Training Modules

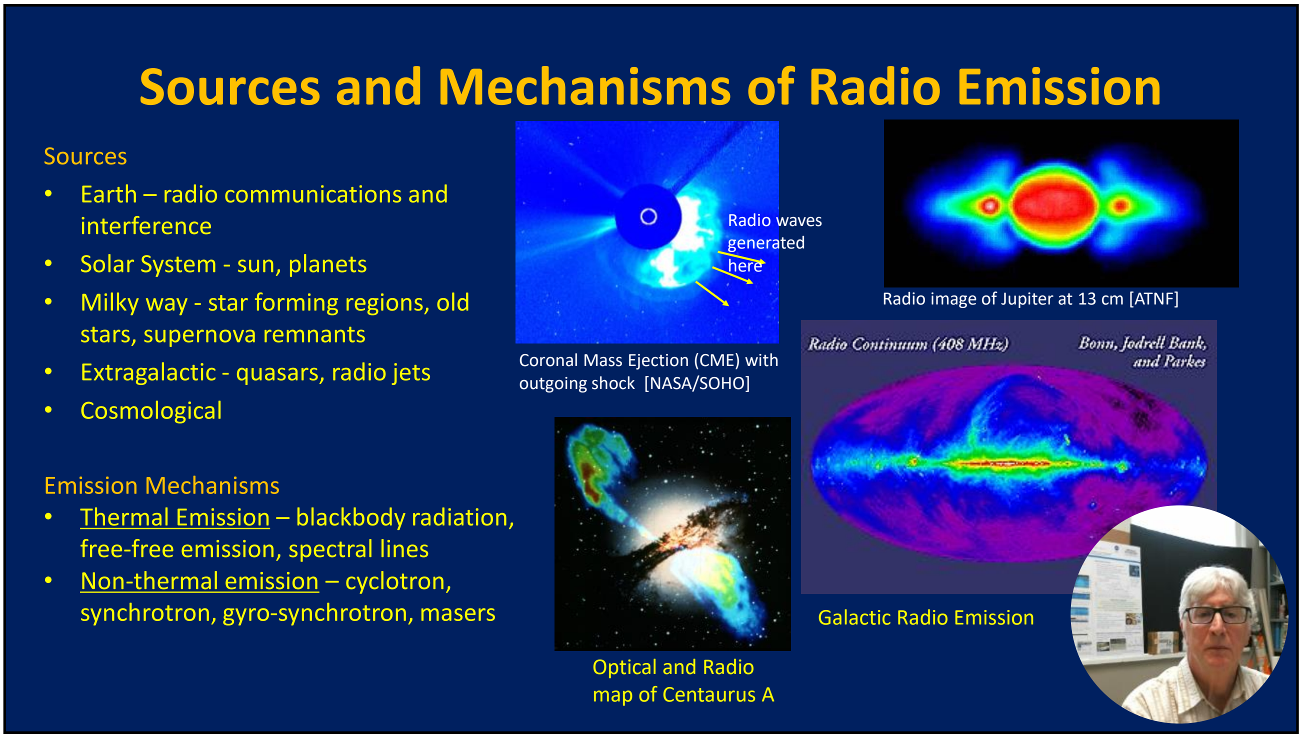
1. High School Reading Comprehension and General Science
2. Electromagnetic Spectrum
3. Speed, Wavelength, and Frequency of Waves
4. Graphical Interpretation of Data
5. Training Modules 1.0 and 1.1

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

Learning Objectives

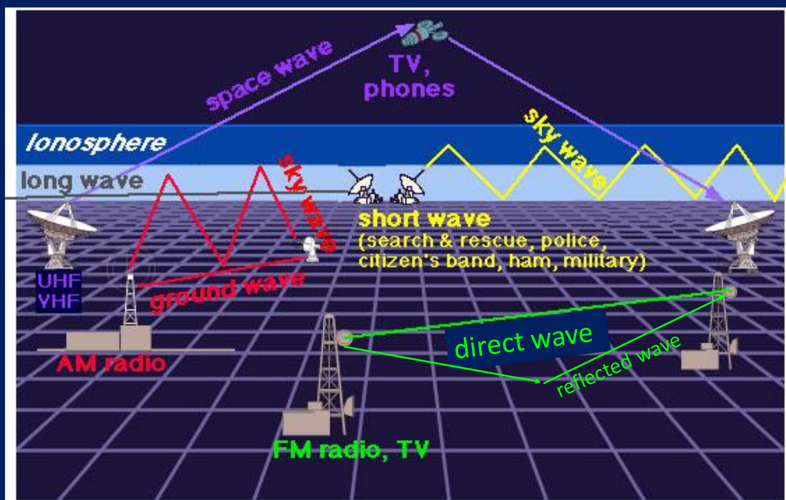
1. Radio wave emissions
2. Radio wave propagation
3. The Ionosphere
4. Ionospheric effects on radio waves

This is a list of the learning objectives for this presentation. We first overview the sources of radio waves then we discuss how radio wave propagate through the air and in space. An important region for radio wave propagation is Earth's ionosphere. We will overview the ionosphere and discuss its effects on radio waves.



A brief review from last time, radio waves sources include many humanmade and natural radio emissions from Earth: radio stations, communications, lightning, and many types of radio interference. Radio astronomy sources of radio emission include solar system objects like the Sun and planets, many types of objects within the Milky Way, extragalactic sources like radio galaxies, 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. Frequencies in the HF radio band are associated with non-thermal processes. The four images here show radio emissions from an outgoing solar wind shock, a radio image of Jupiter, radio jets from galaxy Centaurus A, and a map of the radio emission from the Milky Way.

Modes of Propagation



Adapted from Windows to the Universe

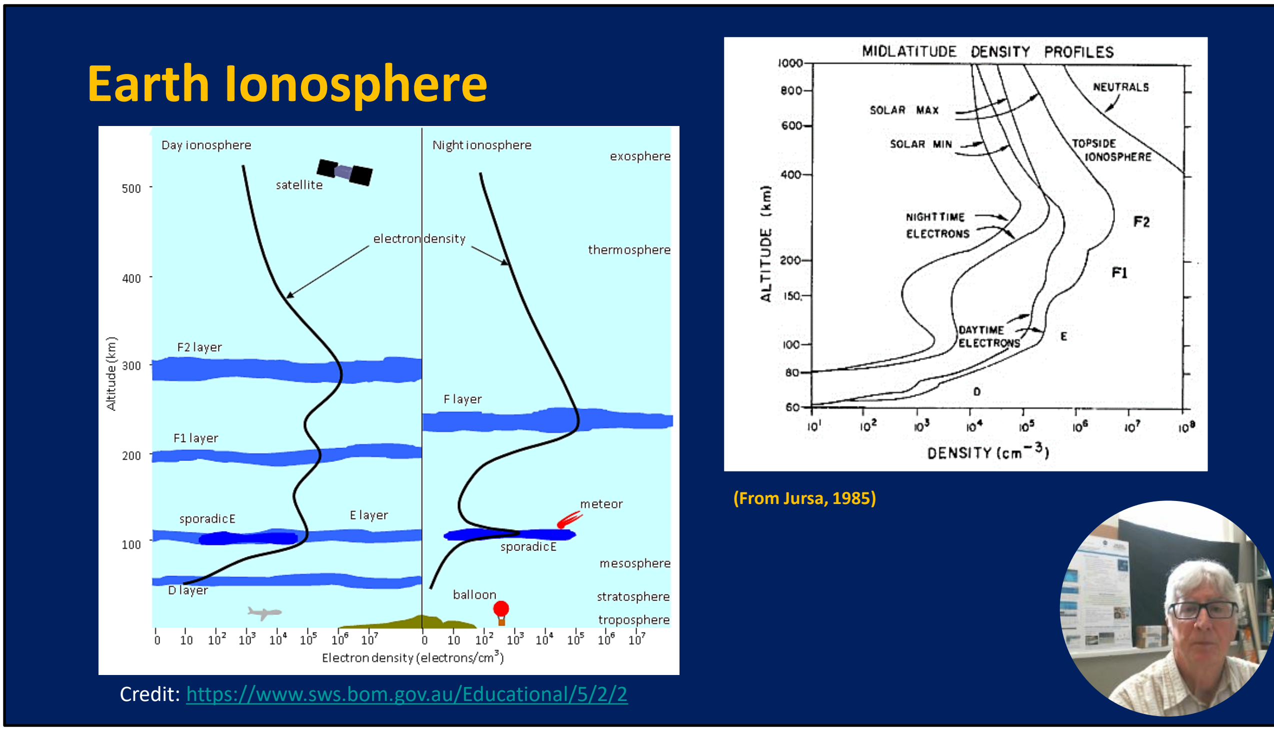
Radio Wave Propagation Modes

1. **Direct wave**
2. **Ground wave**
3. **Skywave**
4. **Space wave**

Radio waves propagate in several modes. Most of these modes are dependent on frequency and other factors like polarization, atmosphere absorption, and interference.

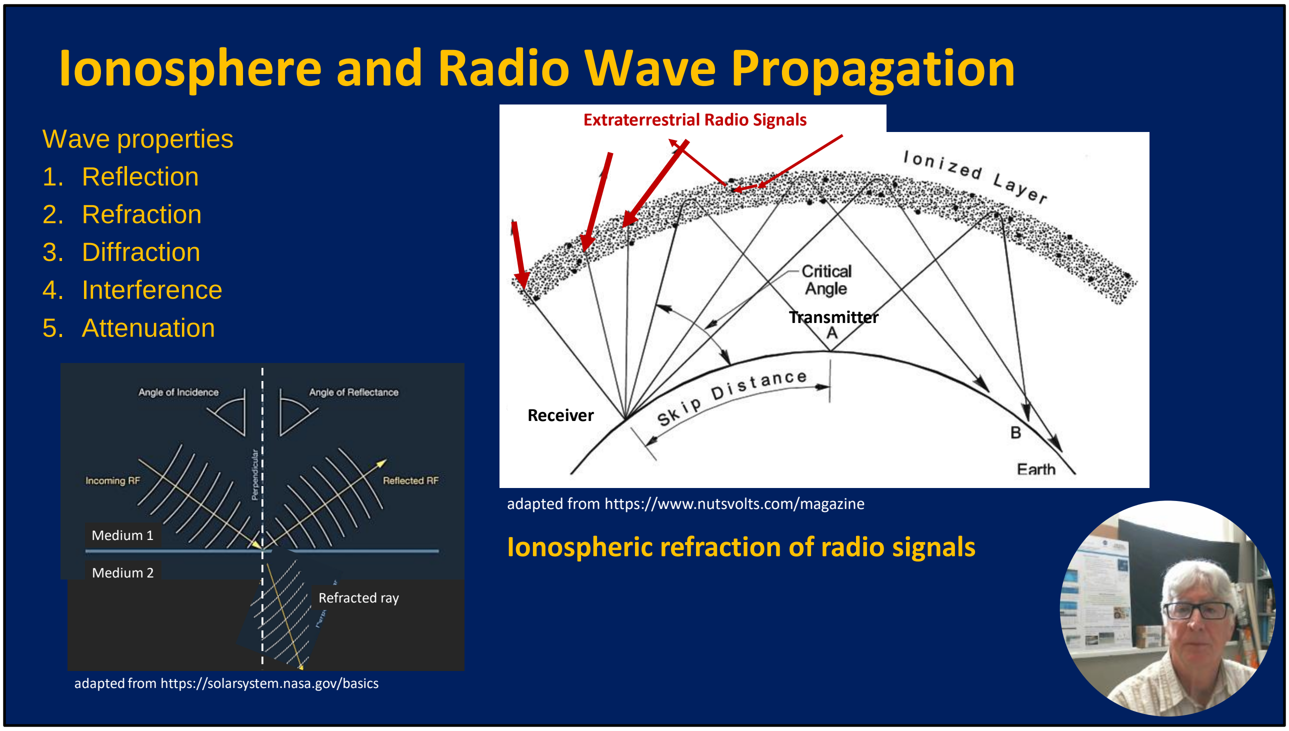
1. Line of sight or a direct wave or sometimes called a space wave – a direct path between a transmitter and receiver (or a reflected wave off the ground)
2. Ground wave or surface wave – uses the conductivity of the Earth to allow propagation of radio waves – works well over saltwater oceans
3. Skywave – radio waves refracted by the ionosphere, the electrically charged layer of the upper atmosphere
4. Space waves – in this context, these are radio waves that pass through the ionosphere to communicate with satellites (uplink/downlink).

We are interested in extraterrestrial or astronomical radio signals and how they travel to the Earth.



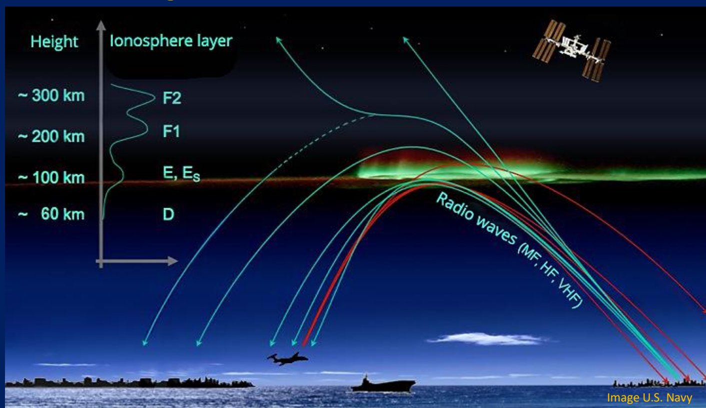
This diagram shows the various layers of the ionosphere, the electrically charged regions of the upper atmosphere. The atoms in these layers become ionized into electrons and ions by the solar ultraviolet light. The important ionized layers are the D, E, and F layers. Note that the D layer only occurs in the daytime, and the F layer splits into two layers, F1 and F2. The F1 and F2 layers have the highest electron density, and these layers are important for skywave communications, refracting and absorbing radio waves in different ways.

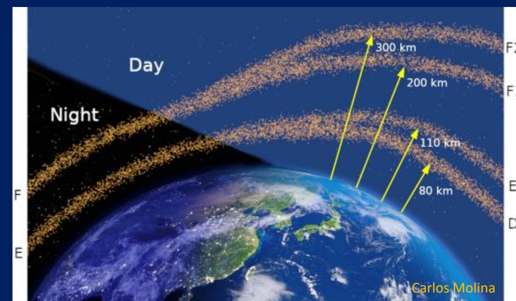
Not only is the ionosphere variable over the night/day, it also depends on the latitude, the seasons, and is impacted by the solar cycle and solar activity as seen in the figure on the right.



Radio waves, like any waves, undergo reflection, refraction, diffraction, interference, and attenuation. From basic optics, the angle of incidence equals the angle of reflection, and the angle of refraction can be determined by Snell's Law. Radio waves propagating through the ionosphere undergo refraction and depend on the frequency, the angle, the ionosphere density, among other things. The figure on the right shows signals from transmitter A refracted by the ionosphere to the receiver. Extraterrestrial radio signals, like solar radio emissions, are also refracted by the ionosphere and depending on the frequency, angles, etc., can be detected by the receiving antenna.

Ionosphere and Radio Wave Propagation





Nighttime and Daytime Ionosphere

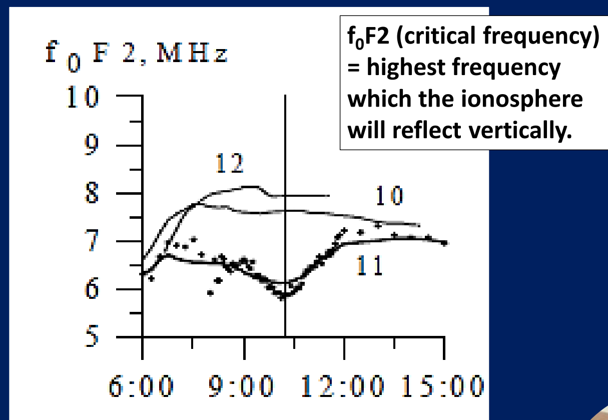
Radio Wave Bands
Medium Frequency MF (0.3 – 3 MHz) refracted
High Frequency HF (3 – 30 MHz) partially refracted/transmitted
Very High Frequency VHF (30 – 300 MHz) transmitted

Another depiction of the nighttime and daytime ionosphere on the right. The figure on the left shows how radio waves of different frequency propagation near the ionosphere. Depending on the frequency, HF radio waves are partially refracted/transmitted. Extraterrestrial signals must propagate through the ionosphere to reach ground-based radio telescopes.

Solar Eclipses and the Ionosphere

Centre National d'Etudes Spatiales (CNES)

Satellite image of the lunar shadow on Earth's atmosphere.



Afraimovich et al., 2002

A graph of the critical frequency during the August 11, 1999, total solar eclipse showing changes in the ionosphere caused by the lunar shadow.

The satellite image shows the lunar shadow on Earth's atmosphere creating a momentary nighttime. Radio wave propagation studies can help determine how a solar eclipse changes the electron density in the ionosphere. The f0F2 parameter is the critical frequency of the F2 layer of the ionosphere indicating the limiting frequency at or above which a wave component penetrates through this ionospheric layer. The critical frequency is associated with the electron density, and the data show the UT time variation of the f0F2 ionospheric parameter during the August 11, 1999, total solar eclipse (from Fig 3a from Afraimovich et al., 2002). Reference data were taken on August 10 and August 12, 1999, and the vertical line shows the onset of totality during the eclipse. Therefore, solar eclipses can be used to study the ionosphere.

Resources

Introduction to Radio Wave Propagation
https://www.sws.bom.gov.au/Educational/5/2/2

Basics of Radio Wave Propagation
https://www.qsl.net/va3iul/Antenna/Basics_of_Radio_Wave_Propagation.pdf

Understanding HF Propagation
https://www.youtube.com/watch?v=7Y_RTdPs3NI

NRAO Radio Astronomy
https://public.nrao.edu/radio-astronomy/

This is a short list of good resources on radio wave propagation.

Thank you for watching!

Now you are ready to learn about solar radio emissions …

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