

The Effects of Earth's Upper Atmosphere on Radio Signals

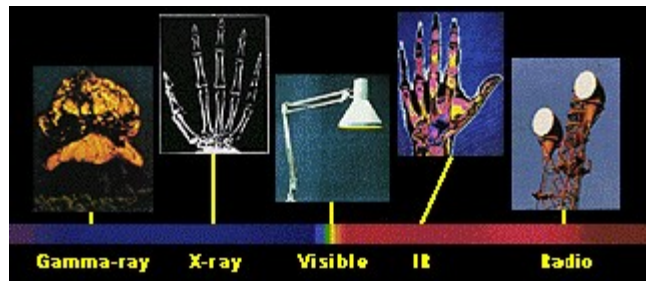


Image Credit: Imagine the Universe <http://imagine.gsfc.nasa.gov>

The electromagnetic spectrum consists of waves of many wavelengths ranging from very long wavelength radio waves to very short wavelength gamma rays. Visible light, consisting of short wavelength waves, is placed near the middle of this spectrum.

Visible light can pass through window glass, but a solid wall will absorb a portion of the light and reflect the remaining portions. Scientists would say that glass is transparent to visible light, but a wall is opaque.

Since the atmosphere is transparent to visible light (while absorbing some of the light), astronomers who use telescopes can see things from far away using visible light to form images.

Earth's atmosphere, however, acts an opaque barrier to much of the electromagnetic spectrum. The atmosphere absorbs most of the wavelengths shorter than ultraviolet, most of the wavelengths between infrared and microwaves, and most of the longest radio waves. For radio astronomers this leaves only short wave radio to penetrate the atmosphere and bring information about the universe to our Earth-bound instruments. The main frequency ranges allowed to pass through the atmosphere are referred to as the radio window. The radio window consists of frequencies from about 5 MHz (5 million hertz) to 30 GHz (30 billion hertz). The low-frequency end of the window is limited by signals being reflected by the ionosphere back into space, while the upper limit is caused by absorption of the radio waves by water vapor and carbon dioxide in the atmosphere. As atmospheric conditions change the radio window can expand or shrink. On clear days with perfect conditions signals as high as 300 GHz have been detected.

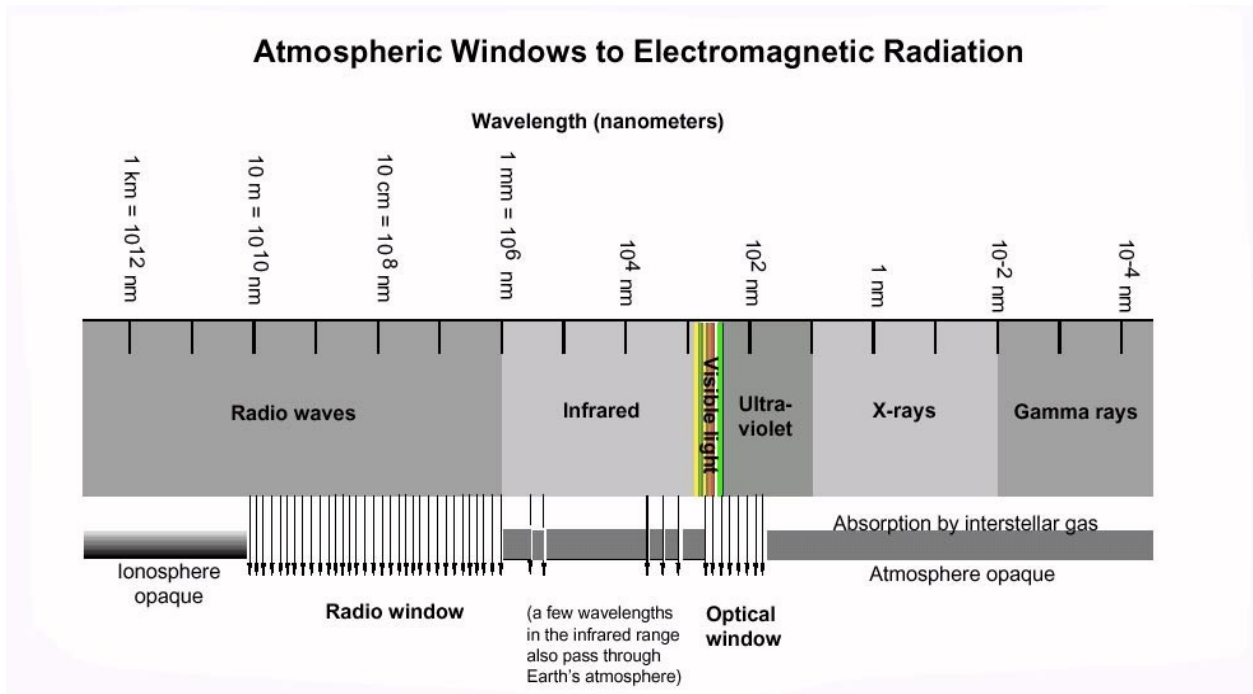


Image Credit: JPL <http://www-b.jpl.nasa.gov/radioastronomy/>

It is the effects of the ionosphere on the lower end of the radio spectrum that we will investigate in this exercise.

The Ionosphere

The ionized part of Earth's atmosphere is known as the ionosphere. Ultraviolet light from the Sun collides with atoms in this region knocking electrons loose. This creates ions, or atoms with missing electrons. This is what gives the Ionosphere its name and it is the free electrons that cause the reflection and absorption of radio waves.

How does this affect our observations of Jupiter?

When the Sun is overhead during the day, most of the ionosphere is ionized due to the large amount of ultraviolet light coming from the Sun. As radio waves enter Earth's atmosphere from space some of the waves are absorbed by the electrons in the ionosphere while others pass through and are detectable to ground based observers. The frequency of each of these waves is what determines whether or not it is absorbed or able to pass through the atmosphere. Low frequency radio waves do not travel very far through the atmosphere and are absorbed or reflected rather quickly. Higher frequency waves are able to pass through the atmosphere entirely and reach the ground.

This process also works in reverse for radio waves produced on Earth. The high frequency waves pass through the ionosphere and escape into space while the low frequency waves reflect off the ionosphere and essentially "skip" around Earth.

The diagram below will help illustrate the movement of radio waves on Earth:

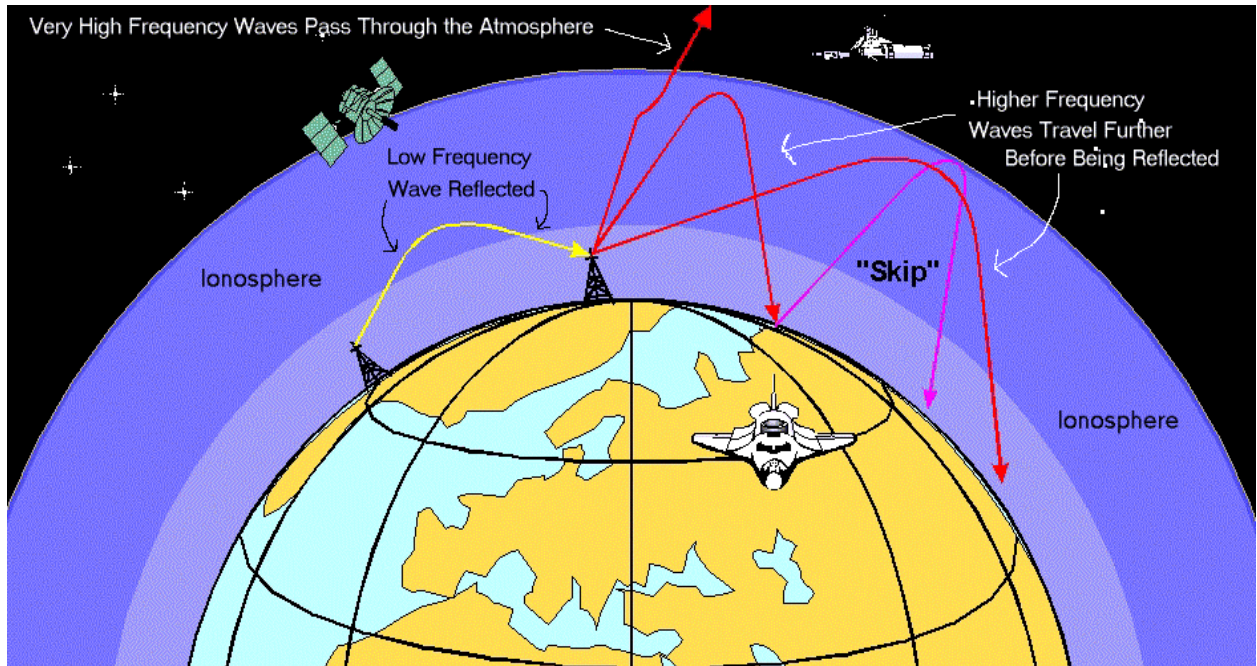


Image credit: <http://www.voyager.co.nz/~elbate/propo.htm>

What's all this talk about high frequency and low frequency radio waves? What types of things fall in each range?

Astronomical radio sources emit over a wide range of frequencies. Jupiter for example emits radio waves from about 10 kHz up to about 300 GHz. This emission is broken into several groupings. The lowest is the kilometric emission that ranges from 10 kHz up to 1000 kHz. Other frequency groups include hectometric (1000 kHz to 3 MHz), decametric (3 MHz to 40 MHz), and decimetric (100 MHz to 300 GHz). It is the decametric emissions that we are receiving with Radio Jove. The Radio Jove receiver is tuned to a frequency of 20.1 MHz.

Radio waves produced on Earth are mostly manmade and are often at one specific frequency. In fact, this is one way astronomers can distinguish a signal created on Earth apart from an astronomical signal. If they are able to tune their receivers to a slightly higher or lower frequency and the signal disappears it is most likely an Earth-based signal.

Radio waves fall into three main categories with a variety of uses. Listed below you will find a breakdown of the three main types of radio waves:

HF (High Frequency: 3 to 30MHz)

Long Range communications - Shipping, Aircraft, World Broadcast Communications, Radio Amateurs.

Use involves reflecting the signal off the ionosphere back down to waiting receiving stations. Prone to atmospheric changes causing fading and noise.

Range from 500 to thousands of Kilometers.

VHF (Very High Frequency: 30 - 300 MHz)

Medium range communications - Fleet vehicles, mobile, coastal shipping and air to tower communications.

Range 70-100km (aircraft several hundred km).

UHF (Ultra High Frequency: 300-3000 MHz)

This is the domain of such things as Police handheld radios, cell-phones, T.V., and spacecraft to ground communications. In the high UHF range the signal can "bounce" off buildings and reflect until a receiver detects it.

The diagram below will help illustrate the movement of the three main types of radio waves on Earth:

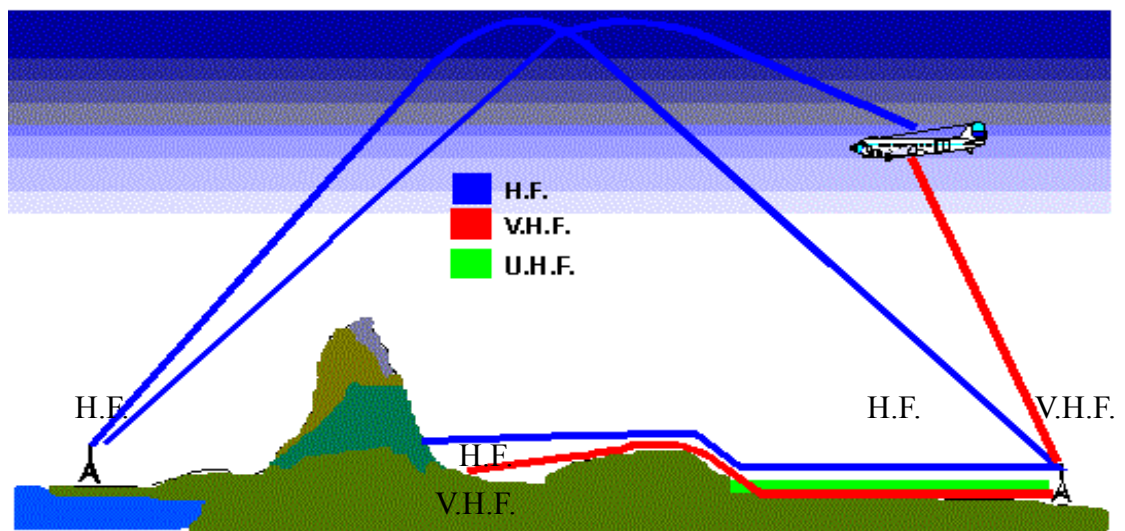
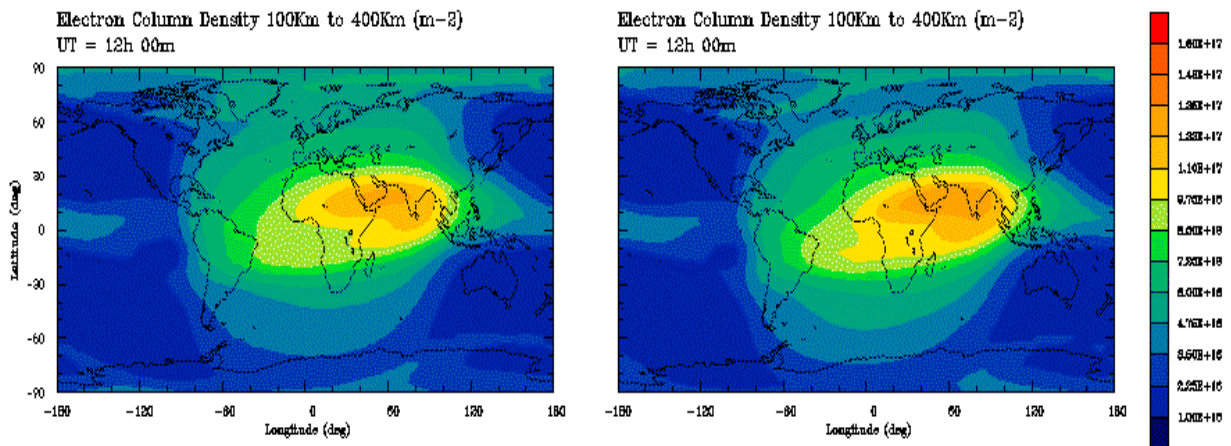


Image credit: <http://www.voyager.co.nz/~elbate/propo2.htm>

Below are images comparing the ionospheric conditions during a typical day with that of a day containing an ionospheric storm. An ionospheric storm is caused by a coronal mass ejection from the Sun that strikes Earth's atmosphere. These mass ejections contain large amounts of particles that smash into the ionosphere and knock electrons loose from atoms. As discussed above the loose electrons reflect radio waves from astronomical sources back into space. The addition of loose electrons as a result of a coronal mass ejection makes observations and communications difficult. The dark blue and purple areas are the areas where the number of loose electrons is low. In these areas there are few electrons to reflect radio waves and thus lower frequency waves are able to reach the ground. As can be seen from the images the night time and early morning hours are best for observations due to the fact that the Sun is not in the sky and its ultraviolet light is not reaching the atmosphere at this time.

Quiet Ionosphere UT = 12h 00m Ionospheric Storm UT = 12h 00m



The density of electrons (how many electrons there are per every cubic centimeter) is represented by the varying colors. Bands of high density that appear at high latitudes during the storm but disappear rapidly as it subsides are due to the high velocity particles smashing into the atoms in the atmosphere and knocking electrons free. These same high velocity particles produce the auroral lights. We can use these maps and the varying colors to find the lowest frequency that is detectable from the ground. The lowest frequency detectable, known as the critical frequency, is related to the density of electrons by the equation:

$$f = 9 \times 10^{-3} \sqrt{N} \text{ (N) Hz.}$$

In this equation f is the critical frequency in hertz (Hz) and N is the electron density in number of electrons per cubic centimeter, $\sqrt{\quad}$ means to take the square root of the electron density. In the maps above, the electron density ranges from 33300 electrons/cm³ (dark blue, dark gray-black) to 249,750 electrons/cm³ (green, gray) to 552,780 electrons/cm³ (red, gray in the center).

Student Page

Name _____

Date _____

Reference Material

The speed of all electromagnetic waves (the speed of light, or c) is 300,000,000 meters per second (3×10^8 m/s). The distance traveled (d) by an electromagnetic wave in time (t) is given by the equation: $d = c t$.

The frequency and wavelength of an electromagnetic wave are related by the equation: $c = f \lambda$ where f is the frequency of the wave in hertz, c is the speed of light in meters per second, and λ is the wavelength in meters.

Example 1. How long would it take a radio wave to travel to Earth from the moon?

The moon is 400,000 kilometers from Earth.

(Note: 400,000 kilometers = 4×10^8 meters.)

$$d = c \times t$$

$$4 \times 10^8 \text{ m} = 3 \times 10^8 \text{ m/s} (t)$$

$$t = 1.33 \text{ seconds}$$

Example 2. What is the wavelength of a radio wave with a frequency of 500 kHz?

$$c = f \lambda$$

$$3 \times 10^8 \text{ m/s} = (500 \times 10^3 \text{ s}) \lambda$$

$$\lambda = 600 \text{ m}$$

Directions: Answer the following questions with detail and be sure to include all work done for all calculations.

- 1.) If radio astronomers are studying 20 MHz radio signals from the Sun which is 1.5×10^{11} meters away from Earth, how long did take for the radio signals to reach Earth?
- 2.) 3 MHz is the lowest frequency that will pass through the ionosphere. Calculate the wavelength of these waves.
- 3.) A general rule is that spacing on the order of 1/10 of a wavelength will seem solid to a radio wave. What size would the spacing in our mesh screen have to be in order to block the 20 MHz solar radio waves discussed in problem 1?
- 4.) As shown above, the ionosphere can act as a solid object to radio waves. Using this idea do you think it is possible to build a radio dish that is not solid? If so, what are the benefits and advantages of a mesh dish?
- 5.) If spacing of 1/10 of a wavelength seem solid to electromagnetic waves would imperfections in a solid radio dish (holes or nicks) of this size matter? Radio studies deal with waves ranging from about 100 m to 1 mm. If we built a solid dish for each of these extremes (100 m and 1 mm) how small could the imperfections in our antenna be?

QUIZ:NAME _____

Use the information in the article to answer the questions.

1. It was discussed in the article that radio signals from Jupiter range from 10 KHz to 300 GHz (large bandwidth) and man-made signals are very short in bandwidth. What is a common technique used to distinguish a man-made signal from a Jovian signal?

2. Where do coronal mass ejections come from and what effect do they have on Earth's ionosphere and on man-made signals?

3. What sources of radio waves besides man-made signals do you think are produced on Earth?

4. What is critical frequency and does a higher electron density increase or decrease the critical frequency?
