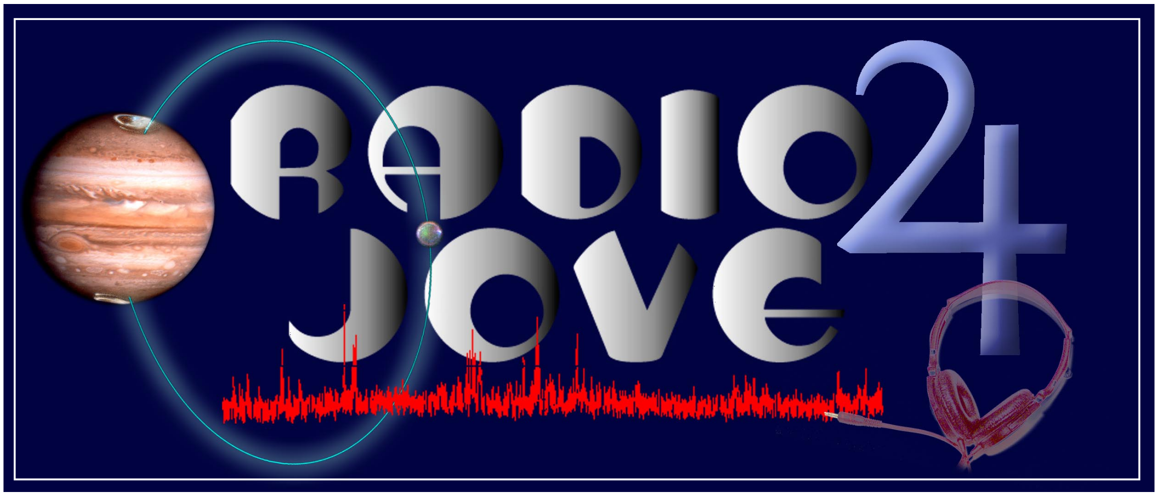

The Effects of Earth’s Upper Atmosphere on Radio Signals

Lesson #2

Lesson Plan:
The Effects of Earth's Upper Atmosphere on Radio Signals

Objective: The students will be able to identify concepts that guide scientific investigations, recognize and analyze alternative explanations and models by the end of this activity.

National Standards:

1. Content Standard B: Interactions of energy and matter
2. Content Standard A: Abilities necessary to do scientific inquiries

Course/Grade level: Physics/12

Materials:

1. Article: The Effects of Earth's Upper Atmosphere on Radio Signals
2. Discussion Questions: Student page
3. Activity one: AM radio, Aluminum screen (can be purchased at a home supply store such as Home Depot)
4. Resource page on scientific notation and standard form

Estimated Time: 60-90 minutes

20-30 minutes for completion of the reading
10-20 minutes for Activity One (Demonstration)
10-15 minutes for Activity Two
30 minutes for student questions and problems

Procedure:

1. **Engagement**: Introduction of the activity,
    A. Ask the students to compile a list of information, things they know about Earth's Ionosphere
    B. Ask the students to list what they know about radio waves. Some prompting may be necessary, such as: where do the radio signals come from that you listen to, what types of things give off radio waves.
    C. What causes your radio to lose a signal?

2. **Exploration**: Have the students read the article, stopping to discuss parts as needed. The reference article is broken into three categories, discussion after each section might be useful to ensure that the students have an understanding of each topic so that they will be able to incorporate all the information into completing the activities.

3. **Explanation**: After reading the article, complete the activities.

Activity One (Demonstration)

We can use the aluminum screens to mimic the effects of the ionosphere. To do this complete the following steps:

1.) Take the AM radio outside and tune in an AM station.
2.) Using the aluminum screen construct a small cage that you can place over the AM receiver. After placing the cage over the receiver observe how the station is weaker or disappears.
3.) Remove the cage and the station returns.

The screen acts as a solid or impenetrable object to the incoming radio waves. We can imagine the radio as an Earth based receiving station. The screen, like the ionosphere, reflects the low energy AM radio waves and they are not detectable by the radio.

You can try various material to investigate what other materials might have similar effects on the strength of the radio signal.

Activity Two:

Students will need to refer to the Ionosphere map section of the article. Use these values to calculate the critical frequency for the dark blue, green and red areas on the maps. Students can find an explanation in the article under the picture; here are the calculations for the teacher.

dark blue = 1.6 MHz green = 4.5 MHz red = 6.7 MHz

Solving the problems:

Dark blue: $N = 33300 \text{ e/cm}^3$

$f = (9 \times 10^{-3})(\sqrt{33300}) = 1.6$ MHz

Green: $N = 249750 \text{ e/cm}^3$

$f = (9 \times 10^{-3})(\sqrt{249750}) = 4.5$ MHz

Red: $N = 552780 \text{ e/cm}^3$

$f = (9 \times 10^{-3})(\sqrt{552780}) = 6.7$ MHz

Note: Where √ means take the square root of the number

4. **Extension**: Upon completion of the student activities, assign student questions. Discuss any additional questions that the students might have derived from the reading, pulling out inferences that they might have made between the readings and the activities.

5. **Evaluation**: Additional questions are given that can be used as an assessment.

TEACHER PAGE 1: Questions and Problems with Answers

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: $c = \lambda f$ 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.)

$$d = c\ t$$
$$4 \times 10^8 = 3 \times 10^8\ t$$
$$t = 1.33 \text{ seconds}$$

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

$$c = \lambda f$$
$$3\text{x}10^8 = \lambda\ (500\text{x}10^3)$$
$$\lambda = 600 \text{ m}$$

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 does it take for the radio signals to reach Earth?

t = 500 seconds

2.) 3 MHz is the lowest frequency that will pass through the ionosphere. Calculate the wavelength of these waves.

λ = **100 meters**

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?

λ = 15 meters, spacing = 1.5 meters

Teacher Page 2

4.) As shown above, the ionosphere and metal screens 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?

Lightweight, saves building costs, not much gathers inside (rain, snow, leaves, etc.), in cases of large antennas a mesh can allow sunlight to reach the ground below and help prevent erosion of soil by allowing growth of grass and plant life.

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?

Imperfections would matter in a solid dish.

10 meters and .1mm (or .0001m)

Teacher Page 3

Quiz Answer Key

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 (a 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?

   Tuning away from a specific frequency on the receiver. If the signal goes away, it is probably man-made, if the signal remains, it might be from Jupiter. The Radio JOVE receiver can be tuned over a range, and thus this technique can be used to detect solar or Jovian activity.

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

   Coronal mass ejections are bubbles of plasma emitted from the Sun's corona. They cause an increased amount of charged particles (ions) in the Earth's ionosphere. As a result, they make observations and communications difficult because the ionosphere becomes opaque.

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

   Any type of electrical discharge, such as lightning will emit radio waves.

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

   Critical frequency is the lowest frequency that can propagate through an ionized gas and it depends on the detectable through a medium and is dependent on the electron density of the medium. If the electron density increases, the critical frequency increases (as shown by the equation $f=(9 \times 10^{-3})(\sqrt{(N)})$).

Resource Page

In scientific notation, powers of ten are used to represent the zeroes in large numbers. The following table shows how this is done.

Number	Name	Power of ten
1	one	10^0
10	ten	10^1
100	hundred	10^2
1,000	thousand	10^3
10,000	ten thousand	10^4
100,000	hundred thousand	10^5
1,000,000	million	10^6
10,000,000	ten million	10^7
100,000,000	hundred million	10^8
1,000,000,000	billion	10^9

If you examine the first and last columns, you can see that the power of ten is the same as the number of zeroes in the number. So the speed of light, which is 3 followed by 8 zeroes, becomes 3×10^8 meters per second.

Also in these activities, we will be working with large numbers that have several non-zero digits. In this case, the power of ten indicates how many places to move the decimal to the right rather than the number of zeroes to add. We will also round off the values so that there are only three nonzero digits with one digit to the left of the decimal. This is called **standard form**.

Example 1: 54311103 km becomes 5.43×10^7 km

Example 2: 923 million dollars becomes 923×10^6 dollars.
In standard form = 9.23×10^8 dollars

Example 3: 3,478 seconds becomes 3.48×10^3 seconds.
(Remember to round the numbers if necessary)

Example 4: Approximate number of stars in the Milky Way galaxy: 3×10^{11} stars.
We can write this as: 300×10^9 stars (non standard form) or 300 billion stars, then as 300,000,000,000 stars.

[Now do you see why scientific notation is so convenient?]

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The Effects of Earth's Upper Atmosphere on Radio Signals

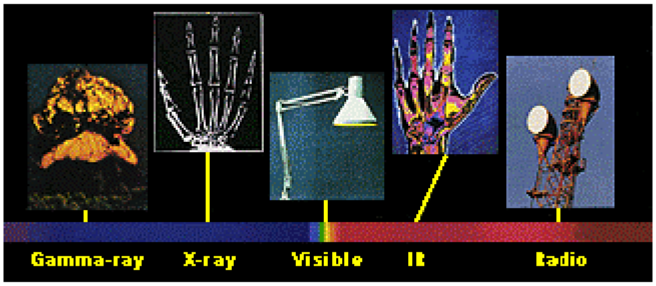


Image Credit: Imagine the Universe http://imagine.gsfc.nasa.gov

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.

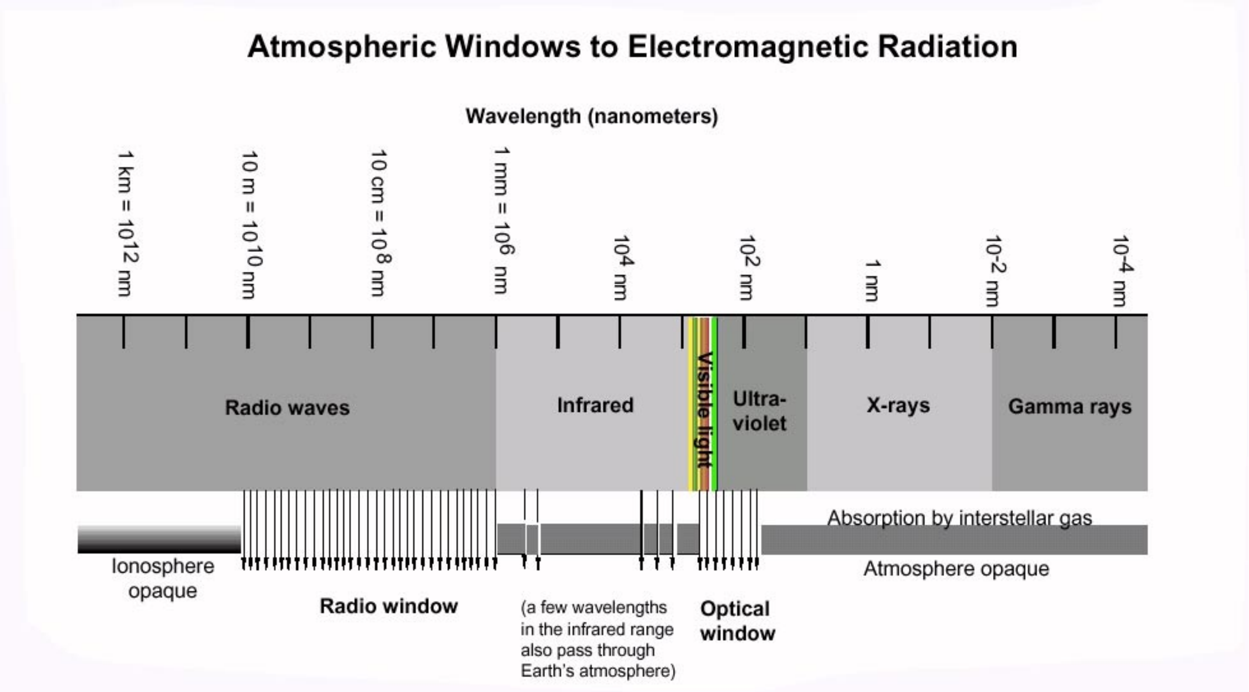


Image Credit: JPL http://www-b.jpl.nasa.gov/radioastronomy/

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:

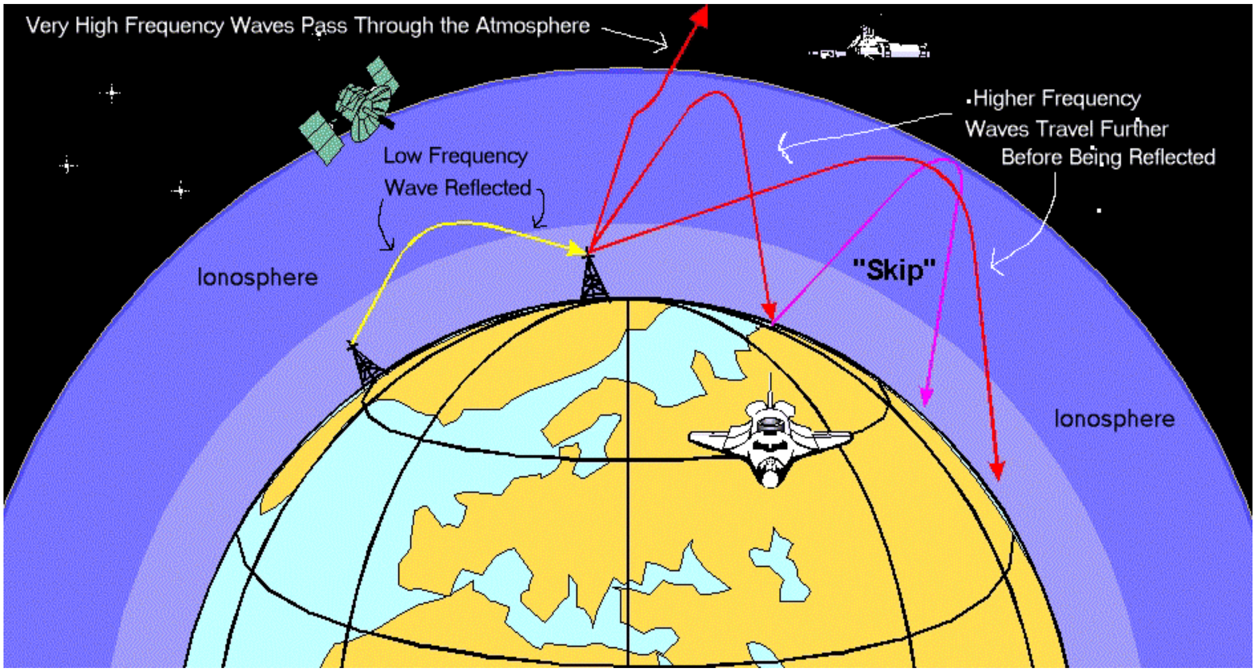


Image credit: http://www.voyager.co.nz/~elbate/propo.htm

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:

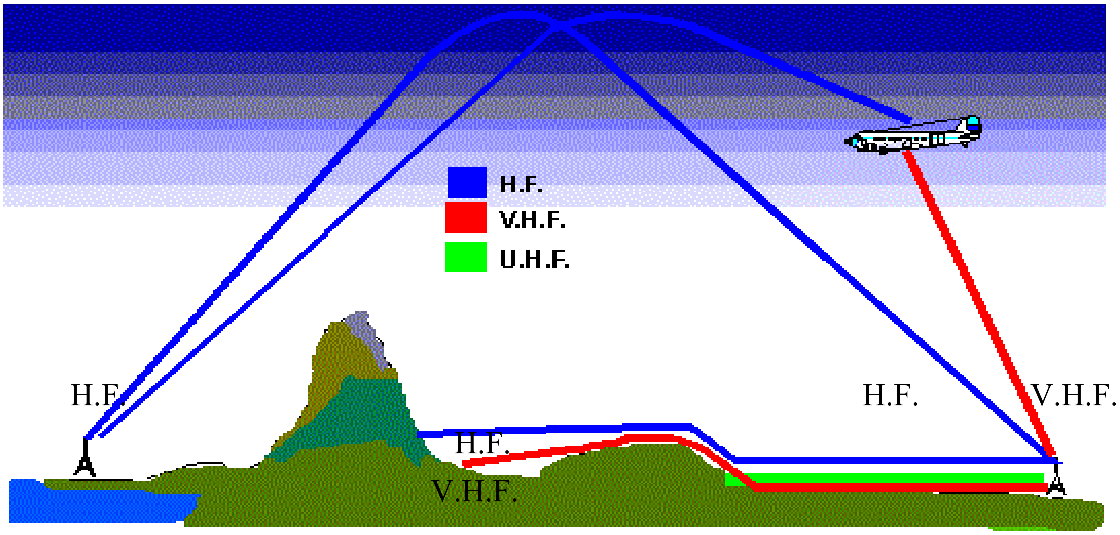
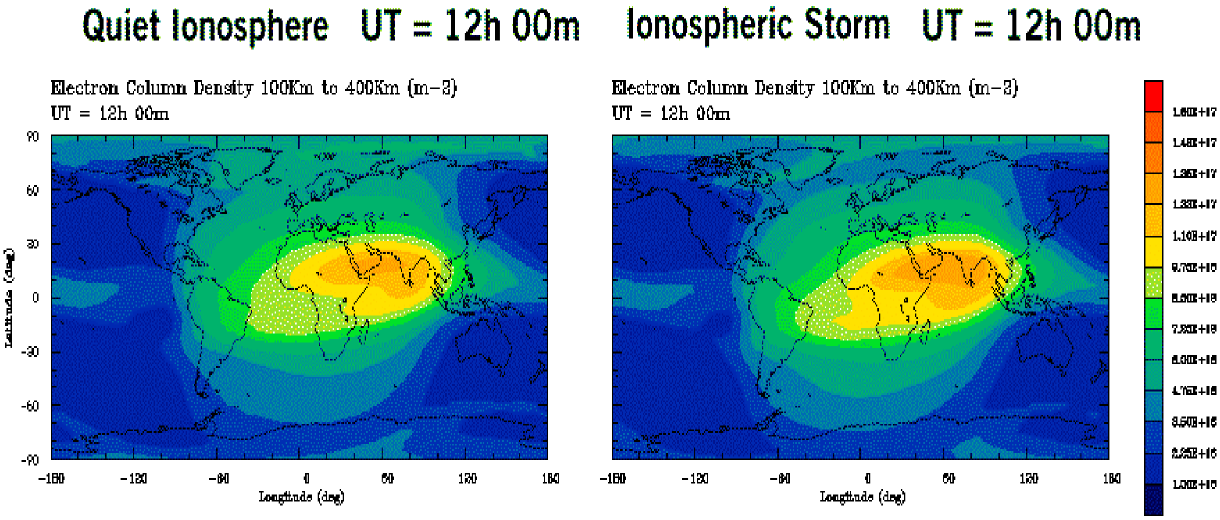


Image credit: http://www.voyager.co.nz/~elbate/propo2.htm

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:

$$f = 9x10^{-3} \sqrt{(N)} \text{ Hz.}$$

In this equation f is the critical frequency in hertz (Hz) and N is the electron density in number of electrons per cubic centimeter, √ means to take the square root of the electron density. In the maps above, the electron density ranges from 33300 electrons/cm^3 (dark blue, dark gray-black) to 249,750 electrons/cm^3 (green, gray) to 552,780 electrons/cm^3 (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: $d = c\,t$.
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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.)

$$d = c \times t$$
$$4\times10^8\text{m} = 3 \times 10^8 \text{ m/s } (t)$$
$$t = 1.33 \text{ seconds}$$

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

$$c = \lambda f$$
$$3 \times10^8 \text{ m/s} = \lambda\,(500 \times 10^3\text{s})$$
$$\lambda = 600 \text{ m}$$

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 is1.5×10^{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?

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

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

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

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