

# Radio JOVE Educational Activities and Lesson Plans



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#### Teacher Page: How the Activities / Lessons are Designed

The educational activities / lesson plans are designed to be stand-alone instructional packets that can be integrated into your curriculum. In doing this, we have tried to include the relevant background information and reference material for each individual topic.

#### The format of the Lesson Plan is broken down in the following way:

- **Objective:** What the writers see as the goal of the lesson
- National Standards: The correlations to the National Science Education Standards so that you will be better able to incorporate them into your daily teaching activities and plan.
- Course/Grade level: The target audience for the lesson. This is subject to the teachers' discretion, for that we know that across the United States there are great variations in the subject matter being taught and at which grade level courses are taught.
- **Materials**: A listing of the items found in the individual lesson, and any items that might need to be used for the activities included.
- Estimated Time: Our calculation on the time needed to work through the lesson; time can be changed to better suite your individual class and teaching style. Remember, this is our estimate.
- **Procedure:** We formatted our lessons into the 5 E's Plan, which is a Constructivist's approach to education. Attached below is a chart to better identify the five categories that we used in developing these lessons.

#### The various activities / lesson plans also have the following titled pages

- **Teacher Pages:** These pages include the lesson plan, discussion topics related to each lesson, examples with worked out calculations and answers, and the student page questions with answers.
- Resource/Reference Pages: Some of the Activities / Lessons have additional information or background information that we think could be useful to both the teacher and the student. These pages are separate from the student pages for the sole purpose that we understand that this is your classroom. We cannot assume that all students have the same background or ability level. Keeping these pages separate will allow you, the TEACHER, to either provide the material as part of the student pages, or to keep the information as a teacher resource. Either way, we have provided it so that hopefully, we will have reduced the number of surprises in doing the activities.
- **Student Pages**: These pages are to be given to the students. They have the articles to read as well as the questions and activities for the students to complete.
- Quiz / Additional Questions: At the end of each activity / lesson, we have included a few additional assessment questions. These can be given as either a stand-alone quiz or incorporated into one of your own assessments.

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#### Characteristics of a 5- E Lesson

The 5 Lesson components and the suggested activities for each are listed below

#### **Engagement:**

The activities in this section capture the students' attention, stimulate their thinking, and help them access prior knowledge.

- Demonstration; Teacher and/or student
- Reading from a current media source, science journal/book, or piece of literature
- Free write
- Analyzing a graphic organizer

#### **Exploration:**

In this section students are given time to think, plan, investigate, and organize collected information.

- Reading authentic resources to collect information
- For answers to open-ended questions, To make a decision
- Solve a problem, Construct a model, Investigation; design and/or perform

#### **Explanation:**

Students are now involved in an analysis of their exploration. Their understanding is clarified and modified because of reflective activities.

- Student analysis and explanation, Supporting ideas with evidence
- Structured questioning, Reading and discussion, Teacher explanation
- Thinking skills activities (comparing, classifying, abstracting, error analysis)

#### **Extension:**

This section gives students the opportunity to expand and solidify their understanding of the concept and/or apply it to real world situation.

- Problem solving, Decision-making
- Experimental inquiry
- Thinking skills activities (comparing, classifying, abstracting, error analysis)

#### **Evaluation:**

This performance-based activity helps students connect all the pieces of information involved in the lesson.

- Any of the above
- Development and implementation of scoring tool to measure student performance during activity, involvement of students will help students understand the teacher's expectations, and allow the students to set high standards for performance.

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# The Discovery of Jupiter Radio Waves

(How a Chance Discovery Opened up the Field of Jovian Radio Studies)

**Lesson #1** 

#### **Lesson Plan: The Discovery of Jupiter Radio Waves**

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

#### **National Standards:**

1. Content Standard A: Science as Inquiry

2. Content Standard G: History and Nature of Science

**Course/Grade level:** Earth/Space Science Course, Physics

Grade level: 8-12

#### **Materials**:

1. Article: The Discovery of Jupiter's Radio Emissions (How a Chance Discovery Opened up the Field of Jovian Radio Studies

2. Discussion Questions: Student page

**Estimated Time:** 30-45 minutes for completion of the reading and student questions

#### **Procedure:**

- 1. **Engagement**: Introduction of the activity,
  - A. Ask the students to compile a list of information, things they know about the planet Jupiter.
  - 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.
- 2. **Exploration:** Have the students read the article, stopping to discuss parts as needed.
- 3. **Explanation:** After reading the article, have the students complete the Discussion Questions.
- 4. **Extension:** Upon completion of the student questions, discuss any additional questions that the students might have derived from the reading, pulling out inferences that they might have made.
- 5. **Evaluation:** There is an additional question attached that is aimed at an understanding of the science involved in the article and at generating a connection to the Scientific Method used by the scientists.

#### **TEACHER PAGE 1:** Possible Ideas for Engagement Questions:

#### A. Things students may know about Jupiter

- Jupiter is one of the planets like Earth.
- Like Earth, Jupiter orbits the Sun.
- Jupiter is a lot bigger than Earth, and is the largest planet.
- Jupiter is farther from the Sun than Earth.
- Jupiter is completely covered in clouds.
- Like Earth, Jupiter has a moon. In fact it has many moons!

#### B. Things students may know about radio waves

- You need a radio receiver to pick up radio waves.
- Radio waves are electromagnetic waves like light, but have a different frequency.
- Radio stations send out radio waves that can be picked up by a radio receiver many miles away.
- Sometimes if there is lightning outside you can hear loud noises on the radio especially if you are listening to AM radio.
- Radio waves can travel very great distances through space.
- Satellites can send signals down to Earth using radio waves. Receiving these signals is what those TV dishes on the roof of houses are for.
- You can learn things about space by listening to radio waves with special radio receivers.
- Radio waves are transmitted by accelerating charges.

#### Student questions with answers

- 1. Which direction did the Mills Array radio beam point? Straight up
- 2. Did the scientists identify more than one source of radio waves in the article? yes
- 3. What types of radio wave sources were mentioned that came from nearby objects? Power lines, cars
- 4. What is the relationship of the change of position of Jupiter in the sky to the radio wave data the scientists obtained? The change of Jupiter's position in the sky matched the changes in the pattern of the radio data: 4 minutes earlier each night.
- 5. Why does the position of Jupiter appear to move? Jupiter orbits the Sun like Earth and because of this it will appear to move when we compare its position to stars in the sky
- 6. When identifying a new radio wave source, what do scientists first need to rule out as the source? Scientists first eliminate everything that they already know emits radio waves. Nearby things like cars and power lines and then more distant things like stars and galaxies are eliminated from the list.
- 7. How do scientists use patterns in their data to make predictions? Scientists try to match patterns found in their data with patterns that occur in nature. The time that they heard this strange emission matched the time that Jupiter appeared in that part of the sky.
- 8. What was the course of action taken by the scientists once they discovered that Jupiter emitted radio signals? Once scientists discovered that Jupiter emits strong radio waves they presented their discovery to other scientists.
- 9. What do you feel is the importance of the scientist s sharing their newly found discovery? More new things can be learned when many scientists, with many points of view, work on a common problem.
- 10. If you heard a sound that you could not identify, what is the method you would use to figure out what it is? Follow the scientific method to understand new and unknown ideas. What are the steps the scientists took in discovering radio waves from Jupiter, and how are they similar to the steps you would take? The scientists took the information that they knew from prior research, eliminated that as the cause, continued to gather other, new data with an unknown origin, hypothesized what might be the cause, tested the hypothesis, then shared the results for others to verify once they felt confident in their conclusion.

Quiz ANSWER KEY	Quiz	ANSWER KEY
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1. Explain how the use of the scientific method was involved in the discovery of Jupiter radio emissions? Be sure to elaborate on your knowledge of the scientific method and the actions taken by the scientists.

An important aspect of the article is that the scientists discovered the unknown radio emission by chance. They used the scientific method to identify and rule out various other radio sources. After repeated steps and continual observations, they were able to hypothesize that the source of the radio wave was not from Earth, nor was it from one of the previous observed objects from space. It is important to point out that before any hypothesis was made as to the source, the scientists had to make observations and conduct tests, which in turn had to be verified and changed many times. The scientists were able to verify their hypothesis by continuing their observations and showing that the emissions occurred only when Jupiter was at a location where it could be the radio source. Then they had sufficient confidence in their results to feel comfortable sharing their belief that the source of the radio emission was Jupiter.

# The Discovery of Jupiter Radio Waves

# (How a Chance Discovery Opened up the Field of Jovian Radio Studies)

By Dr. Leonard N. Garcia

Using a radio for astronomical research was still a relatively new idea when Bernard Burke and Kenneth Franklin of the Carnegie Institute in Washington D.C. discovered that the planet Jupiter was a strong source of radio waves.

In 1955 these two scientists were testing a new radio antenna called a Mills Cross Array which had been built a few miles outside of Washington D.C. The antenna was shaped like a gigantic "X" and covered 96 acres of land. Each leg of the X was over 2000 feet long and was made up of 64 dipole antennas. These dipole antennas were very similar to the dipole antennas used in the Radio Jove project. Each one looked like a wire stretched between two support poles with a connecting wire hanging down from the middle of it. [Actually the middle wire is a coaxial cable, which has a central wire, a layer of insulation around it, then another wire wound around the middle wire. The middle wire is connected to one half of the horizontally suspended wire and the outer wire is connected to the other half. This makes a Dipole .] The dipoles were connected such that the antennas acted like a single huge instrument. The array was designed to operate at a frequency of 22 megahertz (MHz). The direction from which radio waves could be picked up with the greatest sensitivity could be changed by changing the lengths of cable connecting the antennas. It so happened that Burke and Franklin had set the antenna direction to be nearly vertical. They left the array pointing in that direction and allowed the rotation of Earth to sweep the antenna across a path in the sky.

By this time astronomers knew of several sources of radio waves in the sky. One of them was the Crab Nebula in the constellation of Taurus. Burke and Franklin were going to use the Crab radio source to test how their antenna array was working. The tests seemed to go well but on a few of these occasions something appeared in their records that they could not identify. They thought at first it was some form of terrestrial interference. At these frequencies you can often get many different types of interference from very down-to-earth things such as car ignitions, power lines, etc. The first thing they noticed about this emission was that it appeared to occur at nearly the same time of night each time they heard it. After studying this interference over several more nights they realized that it didn't quite occur at exactly the same time.

It appeared to be occurring about 4 minutes earlier each night. This type of change with time is what they would expect from some celestial object since stars appear to rise 4 minutes earlier each night. So they knew it was very unlikely to be Earth-bound interference. Once they had several months of data they could track more precisely how

the timing of this interference changed. They found that it didn't quite move like the stars moved. This would eliminate any star, nebula or galaxy since they all appear to move across the sky at the same rate. Finally they realized that an object that happened to be near the Crab Nebula at the time they began hearing this interference was Jupiter. Jupiter, like Earth, orbits the Sun and its orbital motion would cause it to appear to move at a rate somewhat different from the background stars. The rate at which Jupiter moved matched the change with time of the strange interference found in the records. Finally on April 6, 1955 at a meeting of the American Astronomical Society, Burke and Franklin felt sufficiently confident about their results to announce their discovery of radio emission from Jupiter.

As news of this discovery spread other radio astronomers began pouring through their records to see if they had Jupiter emission in their data. One astronomer from Australia, C.A. Shain, found observations he had taken 5 years earlier that contained Jovian radio bursts that he hadn't recognized before. Very soon after radio emissions from Jupiter were discovered, scientists had a baseline of 5 years of data to work with! The data from long periods of monitoring Jupiter's radio behavior has proven vital for later discoveries.

#### Facts about the Mills Cross Array

- B. Y. Mills an Australian radio astronomer along with England's Martin Ryle developed this antenna design.
- Each leg of the array was made up of 64 pairs of unpainted wooden poles with wire stretched across their tops.
- The Mills Cross Array used by Burke and Franklin used more than 5 miles of wire.
- The radio instruments for the Array were originally housed in an Army surplus truck on site.

<b>Student Questions</b>		Name	
		Date	
	ions: Use the article you just read and the following questions. Use a separate	d the information from the class discussion to trate sheet of paper if needed.	
1.	Which direction did the Mills Array	radio beam point?	
	<del>_</del>	one source of radio waves in the article?	
3.	What types of radio wave sources w objects?	rere mentioned that came from nearby	
4.	What is the relationship of the change	ge of position of Jupiter in the sky to the radio	
5.	Why does the position of Jupiter app	pear to move?	
6.	When identifying a radio wave sour the source?	ce, what do scientists first need to rule out as	
7.	How do scientists use patterns in the	eir data to make predictions?	
8.	What was the course of action taken Jupiter emitted radio signals?	by the scientists once they discovered that	
9.	What do you feel is the importance discovery?	of the scientist's sharing their newly found	
10.	use to figure out what it is? What	not identify, what is the method you would are the steps the scientists took in discovering are they similar to the steps you would take?	

Quiz	Name	
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Explain how the use of the scientific method was involved in the discovery of		
Jupiter radio emissions? Be sure to elaborate on your knowledge of the scientific method and the actions taken by the scientists.		

1.



# The Effects of Earth's Upper Atmosphere on Radio Signals

#### **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:** 
$$N = 33300 \text{ e/cm}^3$$

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

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

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

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

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

Note: Where  $\sqrt{}$  means take the square root of the number

- 4. **Extension**: Upon completion of the student activities, assign <u>student</u> <u>questions</u>. 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 x  $10^8$  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  $\lambda$  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 =  $4 \times 10^8$  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?

$$c = \lambda f$$

$$3x10^8 = \lambda (500x10^3)$$

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

1.) If radio astronomers are studying 20 MHz radio signals from the Sun which is  $1.5 \times 10^{11}$  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.

 $\lambda = 100$  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?

 $\lambda = 15$  meters, spacing = 1.5 meters

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)

#### **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 <sup>9</sup>

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  $3 \times 10^8$  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 x 10<sup>7</sup> km
- Example 2: 923 million dollars becomes 923 x  $10^6$  dollars. In standard form =  $9.23 \times 10^8$  dollars
- Example 3: 3,478 seconds becomes 3.48 x 10<sup>3</sup> seconds. (Remember to round the numbers if necessary)
- Example 4: Approximate number of stars in the Milky Way galaxy:  $3 \times 10^{11}$  stars. We can write this as:  $300 \times 10^9$  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?]

#### Radio JOVE Educational Materials

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# The Effects of Earth's Upper Atmosphere on Radio Signals

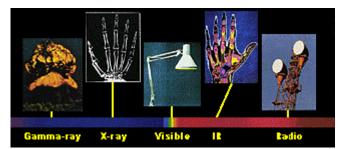


Image Credit: Imagine the Universe <a href="http://imagine.gsfc.nasa.gov">http://imagine.gsfc.nasa.gov</a>

The <u>electromagnetic spectrum</u> 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.

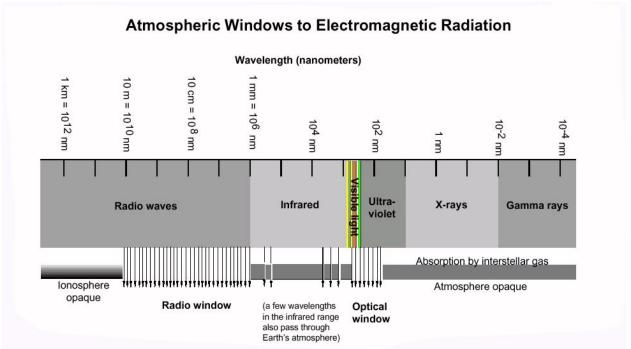


Image Credit: JPL http://www-b.jpl.nasa.gov/radioastronomy/

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.

Very High Frequency Waves Pass Through the Atmosphere

Higher Frequency
Waves Travel Further
Before Being Reflected

Ionosphere

Ionosphere

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

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

# 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:

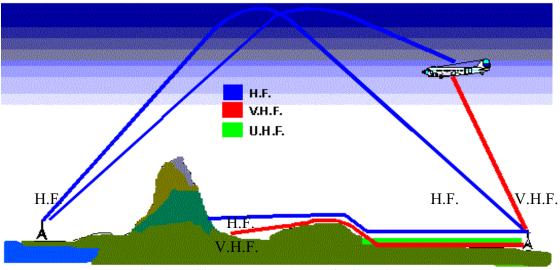
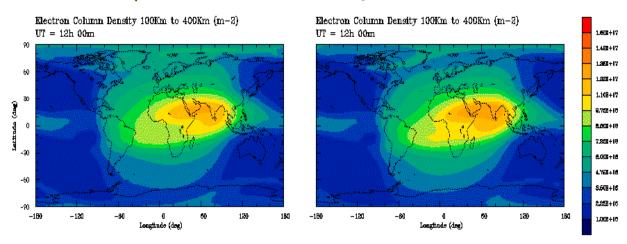


Image credit: http://www.voyager.co.nz/~elbate/propo2.htm

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:

$$f = 9x10^{-3} \sqrt{(N)}$$
 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,  $\sqrt{}$  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 1	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 x  $10^8$  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  $\lambda$  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:  $400,000 \text{ kilometers} = 4 \times 10^8 \text{ meters.}$ )

$$d = c \times t$$

$$4x10^{8}m = 3 \times 10^{8} \text{ m/s (t)}$$

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

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

$$c = \lambda f$$
  
3 x10<sup>8</sup> m/s =  $\lambda$  (500 x 10<sup>3</sup>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 is 1.5  $\times$  10<sup>11</sup> 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?

#### Radio JOVE Educational Materials

QUIZ	NAME
Use the	e 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?



# An Understanding of the Positions of the Planets and the Speed of Light

Lesson #3

### Lesson Plan: An Understanding of the Positions of the Planets and the Speed of Light

**Objective:** The students will be able to identify and understand the positions of the planets relative to Earth and Sun, then calculate distances and the time needed for radio signals to travel these distances by completing this activity.

#### **National Standards:**

- 1. Content Standard G: History and Nature of Science
- 2. Content Standard A: Science as Inquiry;
- 3. Content Standard B: Interactions of Energy and Matter

**Course/Grade level:** Earth/Space Science Course, Physics Grades: 9-12 NOTE: An understanding of scientific notation is recommended for this activity, the resource pages introduce the topic and can be included as student reference pages.

#### **Materials:**

- 1. Article: How to Find Your Way Around the Sky
- 2. Discussion Questions: Student page
- 3. Making a Model: Activity page
- 4. Teacher/student resource pages (3)

#### **Estimated Time:**

60 minutes for completion of the reading and student questions 30 minutes for the Making a Model activity

#### Procedure:

- 1. **Engagement**: Introduction of the activity,
  - A. Engage the students in a discussion about the location and characteristics of the orbits of the planets.
  - B. Ask the students to discuss or list what they know about the speed of light. Some prompting may be necessary, such as: how fast is it, what travels at the speed of light.
  - C. Discussion of scientific notation may be needed, the included resource pages can be used as a guided practice.
- 2. **Exploration**: Have the students read the article, stopping to discuss parts as needed.
- 3. **Explanation**: After reading the article, have the students complete
  - A. Student calculations.
  - B. Activity: Making a Model (OPTIONAL).
- 4. **Extension**: Upon completion of the student questions, discuss any additional questions that the students might have derived from the reading, pulling out inferences that they might have made.
- 5. **Evaluation**: Additional questions are added for further assessment or testing.

Possible Ideas from the Engagement activities

- A. Engage the students in a discussion about the location and characteristics of the orbits of the planets.
  - All planets orbit the Sun.
  - The relative position and the simple ordering of the planets.
  - A discussion of Nicholas Copernicus and his early ideas of a heliocentric solar system (Sun centered) that changed the way the world viewed the solar system.
  - A discussion of Kepler and his plots and diagrams showing that all of the planets orbit the Sun and that the orbits are elliptical in nature.
- B. Ask the students to discuss or list what they know about the speed of light. Some prompting may be necessary, such as: how fast is it, what travels at the speed of light.
  - Conversions between hours, minutes and seconds.
  - The importance in keeping units constant in calculations.
  - Discussion that all forms of electromagnetic radiation travel at the speed of light.
- C. Discussion of scientific notation may be needed; the included resource pages can be used as a guided practice.
  - Review of <u>Scientific Notation</u> and <u>Standard Form</u>, tools for using large numbers (see Resource Page 3).

Use the following table for Problems 5-8.

Planet	Radius of orbit	Mean Distance (in AU)
Mercury	57,910,000 km	.39
Venus	108,200,000 km	.72
Earth	149,600,000 km	1.0
Mars	227,940,000 km	1.5
Jupiter	778,330,000 km	5.2
Saturn	1,429,400,000 km	9.6
Uranus	2,872,320,000 km	19.2
Neptune	4,502,960,000 km	30.1
Pluto	5,909,200,000 km	39.5

In the following problems, assume that the planets are aligned on the same side of the Sun (as close to one another as possible).

#### **Problems:**

- 1. How far does light travel in 20 seconds?  $6 \times 10^9$  m
- 2. How far does light travel in 30 minutes?  $5.4 \times 10^{11}$  m
- 3. How far does light travel in 4 hours?  $4.32 \times 10^{12} \text{ m}$
- 4. How far does light travel in 2 days?  $5.18 \times 10^{13} \text{ m}$
- 5. How long would it take radio waves to travel from Jupiter to Mars? 1.83 x 10<sup>3</sup> s (30.6 minutes)
- 6. How long would it take radio waves to travel from Jupiter to Venus? 2.23 x 10<sup>3</sup> s (37 minutes)
- 7. How long would it take radio waves to travel from Jupiter to Saturn?  $2.17 \times 10^3 \text{ s}$  (36 minutes)
- 8. How long would it take radio waves to travel from Mercury to Mars?  $5.6 \times 10^2 \text{ s}$  (9.4 minutes)
- 9. Find the signal travel time (to Earth) from Neptune when at opposition. **4.0 hours**
- 10. Find the signal travel time (to Earth) from Mars when at conjunction. **20.8 minutes**
- 11. Find the signal travel time (to Earth) from Pluto when at opposition.

  5.3 hours
- 12. If the signal travel time is 88 minutes, from what planet did the signal come? Is the planet at conjunction or opposition? **Saturn at conjunction**
- 13. If the signal travel time is 2.53 <u>hours</u>, from what planet did the signal come? Is the planet at conjunction or opposition? **Uranus at opposition**
- 14. Calculate the radius of orbit for Uranus in kilometers. **2,870,000,000 km**
- 15. Calculate the radius of orbit for Neptune in kilometers. **4.500,000,000 km**
- 16. Calculate the radius of orbit for Pluto in kilometers. **5,900,000,000 km**

#### **QUIZ ANSWER KEY**

QUIZ

Use the following table to answer questions 1-5.

Planet	Radius of orbit	Mean Distance (in AU)
Mercury	57,910,000 km	.39
Venus	108,200,000 km	.72
Earth	149,600,000 km	1.0
Mars	227,940,000 km	1.5
Jupiter	778,330,000 km	5.2

Speed of light = c = 300, 000, 000 meters per second =  $3 \times 10^8$  m/s

1. How long does it take sunlight to travel from the Sun to Earth?

$$d = 149,600,00 \text{ km} = 1.5 \text{ x } 10^8 \text{ km} = 1.5 \text{ x } 10^{11} \text{ m}$$
  
 $c = 3 \text{ x } 10^8 \text{ m/s}$ 

d = ct 
$$t = \frac{d}{c} = \frac{1.5 \times 10^{11}}{3 \times 10^8} = 5 \times 10^2 \text{ s} = 500 \text{ s} = 8 \text{ min } 20 \text{ s}$$

500 s

2. What do we call the position of Jupiter when it is closest to Earth?

opposition	
* *	

3. What is the shortest time it could take for radio signals to travel from Jupiter to Earth?

d = 778,330,000 km — 149,600,00 km = 7.78 x 1
$$^{\circ}$$
km — 1.5 x 1 $^{\circ}$ km = 6.28 x 10 $^{8}$  km = 6.28 x 10 $^{11}$  m

$$c = 3 \times 10^8 \text{ m/s}$$

d = ct 
$$t = \frac{d}{c} = \frac{6.28 \times 10^{11}}{3 \times 10^{8}} = 2.1 \times 10^{3} \text{ s} = 2100 \text{ s} = 35 \text{ min}$$

35 min

#### Radio JOVE Educational Materials

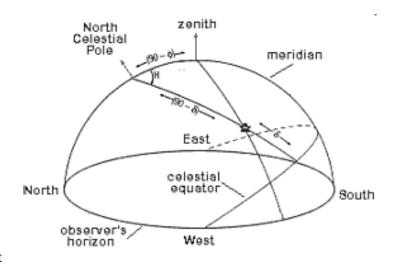
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# How to Find Your Way Around the Sky

## by Dr. Leonard N. Garcia

Figuring out when and where to observe Jupiter from this spinning, revolving planet can be difficult. The Earth revolves around the Sun with 8 other planets plus millions of comets, asteroids, moons and other even smaller bits of rock and ice. Together they are called the Solar System. The Earth also spins on its axis. We can explain most of the motion we see in the sky overhead from these two types of motion.

When we step outside we are aware of the sky above us and the ground beneath us. The Earth looks flat from our perspective. The sky on the other hand looks like a gigantic dome. The line where the sky appears to meet Earth we call our horizon. Everything that is below the horizon is blocked from view by Earth. Now imagine a line drawn from your feet through your head and pointing straight upwards. This line would point to your zenith, the point directly overhead.



**Above:** An illustration showing the horizon, local meridian and North Celestial Pole.

The rotation of Earth gives us our nights and days. It causes stars over the course of the night to appear to move across the sky and like the Sun rise in the east and set in the west. The imaginary line around which Earth spins is called the **axis**. This line points to a particular part of the sky which is very near a star called Polaris. Polaris is also known as the Pole Star since it is close to the **North Celestial Pole**. The Earth's spin axis is tilted about 23.5; from a perpendicular to the plane of Earth's orbit. It is Earth's revolution around the Sun in combination with the tilt of Earth's axis that gives us our seasons. It takes Earth one year to complete one orbit of the Sun. Over a few weeks we notice the constellations are setting earlier and new constellations are rising. This is all due to Earth's orbital motion.

If you now draw an arc which connects your zenith with the North Celestial Pole and extends down to the north and south points on the horizon you have drawn a line called your **local meridian**. Whenever a star or planet crosses your local meridian we say it is **transiting**. Often when we talk about the location of Jupiter we may say for example,

"Jupiter is at two hours before transit" meaning that two hours from now Jupiter will cross our local meridian.

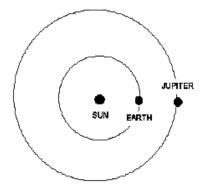
#### The Planets

The planets of the Solar System follow their own orbital paths around the Sun. For the planets closer to the Sun than Earth (the inner planets Mercury and Venus) it takes less than one year to orbit the Sun. For planets farther from the Sun than Earth (the outer planets) it takes more than a year. Jupiter, for example, takes 12 years to orbit the Sun once.

There are certain locations in the orbits of the planets that are important for an observer on Earth. The time when Earth is exactly between the Sun and an outer planet is called **opposition**. The time when the Sun is between Earth and an outer planet is called **conjunction**. For the inner planets conjunction occurs when the planet is between the Sun and Earth (inferior conjunction) or when the Sun is between the planet and Earth (superior conjunction).

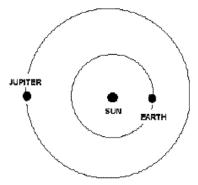
#### **Observing Jupiter Around Opposition**

The best nights to observe an outer planet is when it is at or near opposition. At this time the planet is above the horizon all night long. It is also at its shortest distance from Earth. When a planet is at opposition it transits your local meridian at midnight. When listening to Jupiter with the Radio JOVE equipment it is generally (but not always) better to observe Jupiter in the weeks prior to opposition. The reason for this is that radio interference is usually less the later in the night you observe. Therefore, you need to observe Jupiter in the night hours. The Sun and its effect on Earth's ionosphere make listening to Jupiter during daylight hours very difficult. A Jupiter observing "season" should be planned for the months before and after opposition. The farther from opposition Jupiter is, the fewer hours it will be high enough in the sky to observe with the Radio JOVE equipment while the Sun is still below the horizon.



**Left:** An illustration of Jupiter in opposition with the Sun.

**Right:** An illustration of Jupiter in conjunction with the Sun.



#### **Resource Page 1**

Radio waves, like all electromagnetic waves, travel at the speed of light — 300,000,000 meters per second (3 hundred million meters per second). So the speed of light, which is 3 followed by 8 zeroes, becomes  $3 \times 10^8$  meters per second. The standard symbol for the speed of light is  $\mathbf{c}$ , so we can write:

$$c = 3 \times 10^8 \text{ m/s}$$

Since radio waves travel at a constant speed, the distance traveled is given by:

distance = speed times time

or

d = c t

where

d = distance in meters t = time in seconds c = 3 x 10<sup>8</sup> meters per second

**Example Problem:** How far does a radio wave travel in 5 minutes?

 $t = 5 \text{ min} = 5(60 \text{sec/min}) = 300 \text{ s} = 3 \text{ x } 10^2 \text{ s}$   $c = 3 \text{ x } 10^8 \text{ m/s}$ d = ? m

d = c t  $d = (3 \times 10^8 \text{ m/s}) (3 \times 10^2 \text{ s})$   $d = (3 \times 3) \times 10^{8+2} \text{ m}$   $d = 9 \times 10^{10} \text{ m}$ 

RULE: to multiply,

MULTIPLY the numbers, ADD the powers of ten

If you know the distance and the speed (c), you can find the time it takes for radio waves to travel that distance using:

$$\mathbf{d} = \mathbf{c} \, \mathbf{t} \qquad \qquad \mathbf{t} = \frac{\mathbf{d}}{\mathbf{c}}$$

where

d = distance in meters (m) c = speed of light (3 x 10<sup>8</sup> m/s) t = time in seconds (s)

**Example Problem:** How long does it take radio waves to travel from Earth to the moon, a distance of 400,000 kilometers?

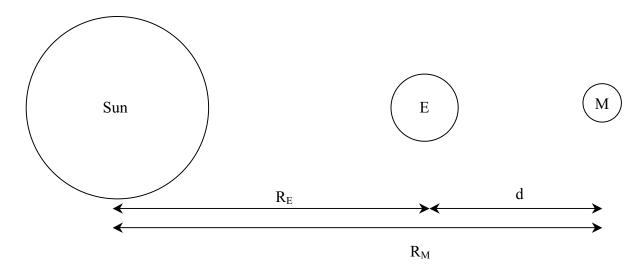
 $d = 400\ 000\ km = 400,000,000\ m = 4\ x\ 10^8\ m$   $c = 3\ x\ 10^8\ m/s$  t = ?  $t = \frac{d}{c}$   $t = \frac{4\ x\ 10^8\ m}{3\ x\ 10^8\ m/s}$   $t = 1.33\ x\ 10^0\ s \quad (NOTE:\ 10^0\ =\ 1)$   $t = 1.33\ s$ 

RULE: to divide,

DIVIDE the numbers and SUBTRACT the powers of ten. (Subtract the bottom power from the top)

**Example Problem:** How long does it take radio waves to travel from Mars to Earth when Earth and Mars are on the same side of the Sun?

radius of Mars' orbit  $R_{\rm M} = 227,\,940,000\,\,{\rm km} = 2.28\,\,{\rm x}\,\,10^8\,\,{\rm km} = 2.28\,\,{\rm x}\,\,10^{11}\,{\rm m}$  radius of Earth's orbit  $R_{\rm E} = 149,600,000\,\,{\rm km} = 1.50\,\,{\rm x}\,\,10^8\,\,{\rm km} = 1.50\,\,{\rm x}\,\,10^{11}\,{\rm m}$ 



$$d = R_M - R_E$$

$$d = 2.28 \times 10^{11} \text{ m} - 1.50 \times 10^{11} \text{ m}$$

$$d = 2.28 - 1.50 \times 10^{1} \text{ m}$$

$$d = .78 \times 10^{11} \text{ m}$$

$$d = 7.8 \times 10^{10} \,\mathrm{m}$$

RULE: to subtract,

IF the powers of ten are the same, SUBTRACT the numbers and the power of ten remains the SAME.

$$t = \frac{d}{c}$$

$$t = \frac{7.8 \times 10^{10} \text{ m}}{3 \times 10^8 \text{ m/s}}$$
 
$$t = 2.6 \times 10^{10-8} = 2.6 \times 10^2 \text{ s}$$
 
$$t = 260 \text{ s}$$
 (4 minutes 20 seconds)

A common unit of distance in astronomy is the <u>Astronomical Unit</u> (**AU**), which is defined as the distance from Earth to the Sun. ( $1 \text{ AU} = 1.5 \times 10^8 \text{ km}$ ) It is important to be able to convert between AU and kilometers. Below is an example of how to convert the distance from Mars to the Sun from kilometers to astronomical units.

$$R_{\rm M} = (2.28 \text{ x } 10^8 \text{ km}) \bullet \frac{1 \text{ AU}}{1.5 \text{ x } 10^8 \text{ km}} = 1.52 \text{ AU}$$

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 <sup>1</sup>
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 <sup>6</sup>
10,000,000	ten million	10 <sup>7</sup>
100,000,000	hundred million	10 <sup>8</sup>
1,000,000,000	billion	109

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  $3 \times 10^8$  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  $5.43 \times 10^7 \text{ km}$
- Example 2: 923 million dollars becomes 923 x  $10^6$  dollars. In standard form =  $9.23 \times 10^8$  dollars
- Example 3: 3,478 seconds becomes 3.48 x 10<sup>3</sup> seconds. (Remember to round the numbers if necessary)
- Example 4: Approximate number of stars in the Milky Way galaxy:  $3 \times 10^{11}$  stars. We can write this as:  $300 \times 10^9$  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?]

#### Radio JOVE Educational Materials

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#### **Student Page 1**

Use the following table for Problems 5-8.

Planet	Radius of orbit	Mean Distance (in AU)
Mercury	57,910,000 km	.39
Venus	108,200,000 km	.72
Earth	149,600,000 km	1.0
Mars	227,940,000 km	1.5
Jupiter	778,330,000 km	5.2
Saturn	1,429,400,000 km	9.6
Uranus		19.2
Neptune		30.1
Pluto		39.5

In the following problems, assume that the planets are on the same side of the Sun (as close to one another as possible).

#### **Problems:**

Answer each of the following questions, be sure to show all work needed in the calculations and include the units in the answer

- 1. How far does light travel in 20 seconds?
- 2. How far does light travel in 30 minutes?
- 3. How far does light travel in 4 hours?
- 4. How far does light travel in 2 days?
- 5. How long would it take radio waves to travel from Jupiter to Mars?
- 6. How long would it take radio waves to travel from Jupiter to Venus?
- 7. How long would it take radio waves to travel from Jupiter to Saturn?
- 8. How long would it take radio waves to travel from Mercury to Mars?
- 9. Find the signal travel (to Earth) time from Neptune when at opposition.
- 10. Find the signal travel time (to Earth) from Mars when at conjunction.
- 11. Find the signal travel time (to Earth) from Pluto when at opposition.
- 12. If the signal travel time is 88 minutes, what planet did the signal come? Is the planet at conjunction or opposition?
- 13. If the signal travel time is 2.53 <u>hours</u>, what planet did the signal come? Is the planet at conjunction or opposition?
- 14. Calculate the radius of orbit for Uranus in kilometers (km).
- 15. Calculate the radius of orbit for Neptune in kilometers (km).
- 16. Calculate the radius of orbit for Pluto in kilometers (km).

#### **Student Page 2**

#### Making a Model

Refer to the table of opposition dates of Jupiter. Did you notice a pattern? What is it and why?

Hint: It takes Jupiter 12 times as long to go once in its orbit around the Sun as it takes Earth.

Draw two concentric circles and let the inner smaller circle represent the orbit of Earth. The outer larger circle represents the orbit of Jupiter. The Sun can be a dot in the center. Place a coin or a pebble representing Earth on the circle you drew for Earth's orbit. Now place another coin or pebble on Jupiter's orbit where Jupiter would have to be when it is in opposition with Earth.

Where would Earth be in its orbit after 1 year? Where would Jupiter be? How much more does Earth have to travel in its orbit before Jupiter is again in opposition with Earth? Jupiter will be in conjunction on May 8, 2000. Try to make the same table for dates of Jupiter's conjunction from 1995 to 2010.

Opposition Dates of Jupiter 1995-2010				
June 1, 1995	October 23, 1999	March 4, 2004	July 9, 2008	
July 4, 1996	November 28, 2000	April 3, 2005	August 14, 2009	
August 9, 1997	January 1, 2002	May 4, 2006	September 21, 2010	
September 16, 1998	February 2, 2003	June 6, 2007		

Information Courtesy: NASA RP 1349 Twelve-Year Planetary Ephemeris 1995-2006 by Fred Espenak NASA/GSFC QUIZ

Name			

Use the following table to answer the questions. Show all your work.

Planet	Radius of orbit	Mean Distance (in AU)
Mercury	57,910,000 km	.39
Venus	108,200,000 km	.72
Earth	149,600,000 km	1.0
Mars	227,940,000 km	1.5
Jupiter	778,330,000 km	5.2

Speed of light = c = 300, 000, 000 meters per second =  $3 \times 10^8$  m/s

1. How long does it take sunlight to travel from the Sun to Earth?

2. What do we call the position of Jupiter when it is closest to Earth?

3. What is the shortest time it could take for radio signals to travel from Jupiter to Earth?



# Radio Waves and the Electromagnetic Spectrum

**Lesson #4** 

#### **Lesson Plan: Radio Waves and the Electromagnetic Spectrum**

**Objective**: Understand radio waves and how they relate to the electromagnetic spectrum. Determine wavelength, frequency, and speed of radio waves. Master these concepts by completing example problems.

#### National Standards:

- 1. Content Standard B: Motion and Forces, Structures and Properties of Matter
- 2. Content Standard D: Energy in the Earth System

**Course/Grade level:** Earth/Space Science Course, Physics Grade level: 9-12

#### Materials:

- 1. Reference material with sample problems
- 2. Student handout page with questions and problems
- 3. Resource page on scientific notation and standard form

Estimated Time: 30 - 45 minutes

#### **Procedure:**

- 1. **Engagement**: Introduction of the activity
  - A. Ask the students to identify where on the electromagnetic spectrum radio waves are located.
  - B. Ask the students to identify as many possible types of electromagnetic waves that they can. Can the students identify common uses of various wave types?
  - C. Discussion of scientific notation may be needed; the included resource pages can be used as a guided practice.
- 2. **Exploration**: Have the students read the reference material, stopping to discuss parts as needed.
- 3. **Explanation**: Work through the example problems with the students, then have the students complete the questions on the student page.
- 4. **Extension**: Upon completion of the student questions, discuss any additional questions that the students might have derived from the reading, pulling out inferences that they might have made about the relationship between wavelength and frequency.
- 5. **Evaluation**: Additional questions to assess the students understanding of the concepts of the activity.

#### **Teacher Page 1** Possible ideas from the engagement activities:

## A. Ask the students to identify where on the electromagnetic spectrum radio waves are located

- Radio waves are located at one end of the electromagnetic spectrum.
- Near microwaves.
- Have the longest wavelengths.

## B. Ask the students to identify as many possible types of Electromagnetic waves that they can. Can the students identify common uses of various wave types?

- Microwaves and their use cooking and heating food.
- Infrared waves for heat lamps.
- Ultraviolet waves and their relationship to sunburn and skin cancer.
- X-rays and their use in hospitals.
- Gamma Rays for nuclear explosions.

## C. Discussion of scientific notation may be needed; the included resource pages can be used as a guided practice.

• Review of <u>Scientific Notation</u> and <u>Standard Form</u>, tools for using large numbers (see Resource Page).

#### **Problems and Answers**

- 1. Find the wavelength of a radio wave with a frequency of 650 kHz.  $4.6 \times 10^2 \text{ m}$  (460 m)
- 2. Find the wavelength of a radio wave with a frequency of 1300 kHz. 2.3 x 10<sup>2</sup> m (230 m)
- 3. Find the wavelength of a radio wave with a frequency of 90 MHz. 3.3 m
- 4. Find the wavelength of a radio wave with a frequency of 101.5 MHz. 2.96 m
- 5. AM radio stations have frequencies from 540-1700 kHz.
  - a) Find the shortest wavelength AM radio signal.  $1.76 \times 10^2 \text{ m}$  (176 m)
  - b) Find the longest wavelength AM radio signal.  $5.56 \times 10^2 \text{ m}$  (556 m)
- 6. FM radio stations have frequencies from 88-108 MHz.
  - a) Find the longest wavelength FM radio signal. 3.4 m
  - b) Find the shortest wavelength FM radio signal. 2.8 m

The frequency range of Jupiter radio emissions that can be detected on Earth is approximately 8 MHz to 40 MHz.

- 7. Find the shortest wavelength Jupiter radio wave that can be detected on Earth.
  7.5 m
- 8. Find the longest wavelength Jupiter radio wave that can be detected on Earth. 37.5 m
- 9. Find the wavelength of the Jupiter radio wave that has a frequency of 20.1 MHz. **14.9m**
- 10. Explain the relationship between the wavelength and the frequency of the electromagnetic spectrum. Wavelength and frequency have an inverse relationship, meaning that as the frequency increases, the wavelength decreases, and vice versa.

## **Teacher Page 2 ANSWER KEY**

C	<b>Duiz</b>	Name

Answer each question completely.

1. If you double the frequency of a wave, what happens to the wavelength of the wave?

Answer: Wavelength is one-half (1/2) its original value because frequency and wavelength are inversely proportional ( $f \sim 1/\lambda$ ).

2. What is the frequency of a citizen's band (CB) radio which has a wavelength of 11.5 meters?

Answer: 26 MHz. (Use  $c = \lambda f$ )

3. What is the wavelength of electricity (power waves for buildings, lights, etc.)? The frequency of electrical waves is 60 Hz.

Answer: 5.0 x 10<sup>6</sup> meters or 5000 km!!!

(Note: the velocity of the wave is NOT the same thing as the current in a wire; current travels much, much slower.)

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 <sup>1</sup>
100	hundred	$10^2$
1,000	thousand	10 <sup>3</sup>
10,000	ten thousand	$10^4$
100,000	hundred thousand	10 <sup>5</sup>
1,000,000	million	10 <sup>6</sup>
10,000,000	ten million	10 <sup>7</sup>
100,000,000	hundred million	10 <sup>8</sup>
1,000,000,000	billion	10 <sup>9</sup>

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  $3 \times 10^8$  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:  $54311103 \text{ km becomes } 5.43 \times 10^7 \text{ km}$
- Example 2: 923 million dollars becomes 923 x  $10^6$  dollars. In standard form =  $9.23 \times 10^8$  dollars
- Example 3: 3,478 seconds becomes 3.48 x 10<sup>3</sup> seconds. (Remember to round the numbers if necessary)
- Example 4: Approximate number of stars in the Milky Way galaxy:  $3 \times 10^{11}$  stars. We can write this as:  $300 \times 10^9$  stars( non standard form) or 300 billion stars, then as 300,000,000,000 stars.

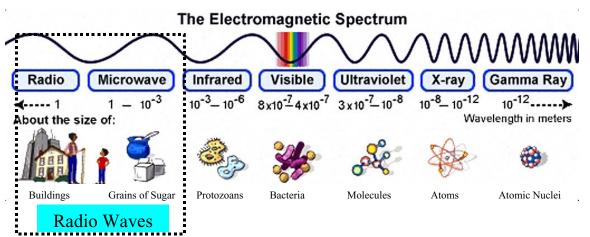
[Now do you see why scientific notation is so convenient?]

#### Radio JOVE Educational Materials

(Intentionally blank.)

### Wavelength and Frequency of Radio Waves

Radio waves are one part of the complete electromagnetic spectrum. As you can see from the figure below, there are many different types of waves and these waves are different because they have different properties.



Note: the units of measurement for wavelength in the diagram is meters (m)

Image credit: http://amazing-space.stsci.edu

One property to compare different kinds of waves is called the **wavelength**, or length of a wave. Wavelength is defined as the distance from one point on a wave to the corresponding point on the next wave. Since wavelength is a distance, the unit of wavelength is the meter (m). Radio waves have the longest wavelength compared to other types of waves (see figure).

Another property used to compare waves is the **frequency** of a wave, which is defined as the number of waves created per second. As the waves propagate away from the source, the frequency also represents the number of waves that will pass a point per second. The unit of frequency is one divided by time (1/seconds) and scientists have given this frequency unit the name of hertz (Hz). Radio waves have the lowest frequency compared to other types of waves. On your radio receivers, either in your car or at your home, the unit of measurement is also in Hz, but usually in one of two variations, kHz and MHz (kilohertz, thousands of hertz and megahertz, millions of Hertz respectively). These variations are used to help identify the length of the wave, by using simple metric prefixes.

The speed of a wave can be measured, and what scientists have discovered is that the speed of all types of electromagnetic waves is the same. Scientists call this speed the speed of light because visible light is the most familiar kind of wave to humans [that is what we see!]. The speed of light is measured to be 300,000,000 m/s, which can also be written as,  $3 \times 10^8 \text{ m/s}$  (approximately 186,000 miles per second!).

Frequency, wavelength and speed are related by the equation:

$$c = \lambda f$$

where c is the speed of light  $(3 \times 10^8 \text{ m/s})$ ,

 $\lambda$  (lambda) is the wavelength in meters (m),

and f is the frequency in Hertz (Hz).

From this equation we can see that a long wavelength will have a low frequency while a short wavelength will have a high frequency since the product of these two quantities is constant (that is, the product equals the speed of light).

In this diagram, the distance (d) indicated represents the distance the waves travel in 1 second.

#1

d (distance traveled in 1 second)

#2

Wave #1 has 5 complete waves passing by in one second, while Wave #2 has 10 waves passing by in the same time. If you were to watch Wave #1 pass a point, the frequency would be 5 waves per second or 5 Hz. Wave #2 would have a frequency of 10 hertz. Wave #1 has half the frequency of Wave #2 and two times the wavelength. For both waves, the product of the wavelength and frequency are the same.

**Example problem:** Find the wavelength of a radio wave with a frequency of 900 kHz.

$$f = 900 \text{ kHz} = 900 \text{ x } 10^3 \text{ Hz} = 9 \text{ x } 10^5 \text{ Hz}$$

$$c = 3 \text{ x } 10^8 \text{ m/s}$$

$$\lambda = ?$$

$$c = \lambda \text{ f (Solve for } \lambda)$$

$$1. \quad \frac{1}{f} c = \lambda \text{ f } \frac{1}{f}$$

$$4. \quad \lambda = .33 \text{ x } 10^3 = 3.3 \text{ x } 10^2 \text{ m (330 m)}$$

	nt Page	Name
Pro	oblems	Date
	swer each of the following questiculations and include the units in	ions. Be sure to show all work needed in the the answer
1.	Find the wavelength of a radio w	vave with a frequency of 650 kHz.
2.	Find the wavelength of a radio w	vave with a frequency of 1300 kHz.
3.	Find the wavelength of a radio w	vave with a frequency of 90 MHz.
4.	Find the wavelength of a radio w	vave with a frequency of 101.5 MHz.
5.	AM radio stations have frequence a. Find the shortest waveler	
	b. Find the longest wavelen	gth AM radio signal.
6.	FM radio stations have frequence a. Find the longest wavelen	
	b. Find the shortest waveler	ngth FM radio signal.
MF	Hz to 40 MHz.	emissions that can be detected on Earth is 8
MF	Hz to 40 MHz.	o emissions that can be detected on Earth is 8 biter radio wave that can be detected on Earth.
MF	Iz to 40 MHz.  Find the shortest wavelength Jup	
MF 7.	Find the shortest wavelength Jup  Find the longest wavelength Jup	piter radio wave that can be detected on Earth.

Quiz	Name
Answer each question comple	etely.
1. If you double the frequency of the wave?	y of a wave, what happens to the wavelength
2. What is the frequency of a a wavelength of 11.5 meters?	citizen's band (CB) radio which has
3. What is the wavelength of lights, etc.)? The frequency o	electricity (power waves for buildings, f electrical waves is 60 Hz.



## A Simplified Model for Predicting Jupiter Radio Storms

**Lesson #5** 

## Lesson Plan: A Simplified Model for Predicting Jupiter Radio Storms

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

#### **National Standards:**

1. Content Standard A: Science as Inquiry

2. Content Standard B: Interactions of Energy and Matter;

**Course/Grade level:** Physics Grade level: 10-12

#### **Materials:**

1. Resource Article

2. Sample questions and explanations

3. Discussion Questions: Student pages

4. Ouiz

#### **Estimated Time:**

45-60 minutes for completion of the reading 20-30 minutes for each activity

**NOTE:** Additional References can be obtained by preceding this activity with the Lesson Plan:

#### Discovery of Jupiter Radio Waves,

The article provides an insight as to the beginnings of the studying of Jupiter Radio emissions and the radio telescope used

#### **Procedure:**

- 1. **Engagement**: Introduction of the activity,
  - A. Ask the students to compile a list of information identifying similarities between Jupiter and Earth.
  - B. Ask the students to identify the Galilean moons and the closest Galilean moon to the planet Jupiter (Io), and give some of its characteristics.
  - C. Ask the students to list what they know about radio telescopes. Some prompting may be necessary, such as: How do radio telescopes differ from a normal (optical) telescope?
- 2. **Exploration:** Have the students read the resource material, stopping to discuss parts as needed.
- 3. **Explanation:** After reading the article, have the students complete the <u>Activity Questions 1-4.</u>
- 4. **Extension:** Activity Questions 5 & 6 are designed to have the students extend the information and skills from the previous Activities. Upon completion of the Activity Questions, discuss any additional questions that the students might have derived from the reading, pulling out inferences that they might have made from the modeling exercises
- 5. **Evaluation:** Have the students take the quiz to assess their understanding of the concepts they have just learned. Answers are provided in the teacher pages.

**Teacher Resources:** Possible Ideas from Engagement Questions:

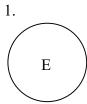
- A. Ask the students to compile a list of information identifying similarities between Jupiter and Earth.
  - Like Earth, Jupiter orbits the Sun.
  - Like Earth, Jupiter rotates on its axis.
  - Like Earth, Jupiter has a magnetic field (tipped 10 ° like Earth's).
  - Earth has a moon, Jupiter has many moons.
- B. Ask the students to identify the Galilean moons and the closest Galilean moon to the planet Jupiter, and identify and of its characteristics.
  - The Galilean moons are Io, Europa, Ganymede, and Callisto.
  - The closest Galilean moon to Jupiter is Io.
  - Io is approximately the same size as our moon.
  - Io is the only other body in the solar system, besides Earth, known to be volcanically active.
- C. Ask the students to list what they know about radio telescopes. Some prompting may be necessary, such as: How do radio telescopes differ from a normal (optical) telescope.
  - The Radio JOVE double dipole antenna sees a fairly large part of the sky from the local meridian line directly overhead the beam extends 35 east and west and 30° north and south. The total beam size is 70° by 60°. Jupiter signals can be received any time Jupiter is in the beam and transmitting. Optical telescopes see a much narrower portion of the sky. Optical telescopes give us an image. Radio telescopes usually tell us the strength of the radio signal.
  - **NOTE:** <u>Additional References</u> can be obtained by preceding this activity with the **Lesson Plan: Discovery of Jupiter Radio Waves**. The article provides an insight as to the beginnings of the study of Jupiter radio emissions and the radio telescope used.

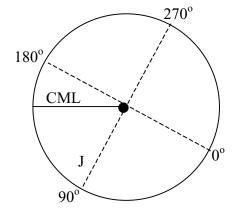
#### Answers to activities.

#### Activity 1.

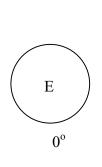
- 1. 180°
- 2. 250°
- 3. 280°

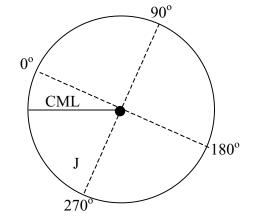
#### Activity 2.



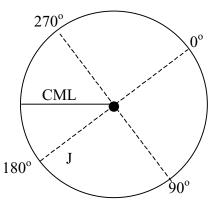


2.





3. Е



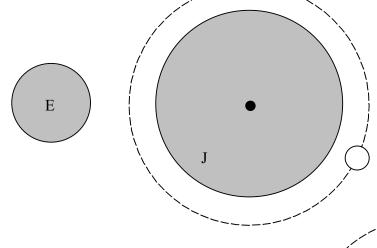
#### **Answer to Activities**

1. Io phase =  $320^{\circ}$ 

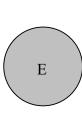
#### Activity 3.

- 1. 30°
- 2. 100° 3. 300°

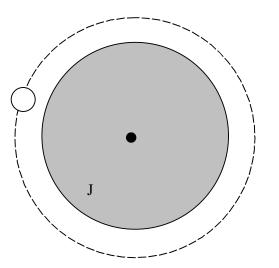
#### Activity 4.



2. Io phase =  $230^{\circ}$ 



3. Io phase =  $170^{\circ}$ 



E

#### **Answer to Activities**

#### Activity 5.

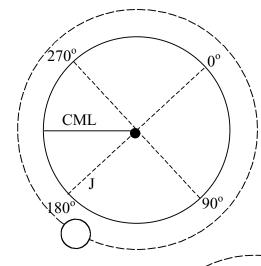
1. 
$$CML = 10^{\circ}$$
  
Io phase =  $130^{\circ}$ 

2. 
$$CML = 330^{\circ}$$
  
Io phase =  $255^{\circ}$ 

3. 
$$CML = 90^{\circ}$$
  
Io phase =  $20^{\circ}$ 

Activity 6.



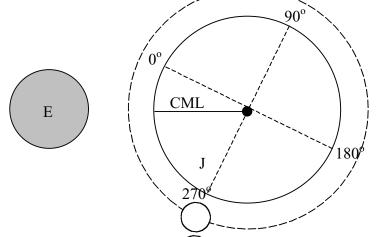


1.

$$CML = 225^{\circ}$$

Io phase 
$$= 240^{\circ}$$

(This is an Io-A storm.)



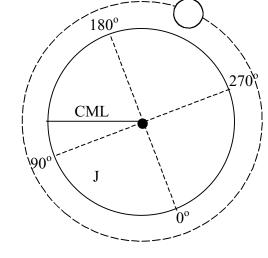
2.

$$CML = 330^{\circ}$$

Io phase 
$$= 250^{\circ}$$

(This is an Io-C storm.





3.

$$CML = 110^{\circ}$$

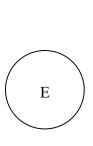
Io phase 
$$= 80^{\circ}$$

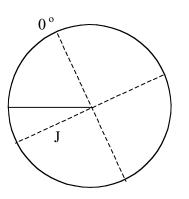
(This is an Io-B storm.)

## **Teacher Page 5 Io-B Storm Quiz**

KEY

1. Draw in the CML and give the CML position shown in each of the following.



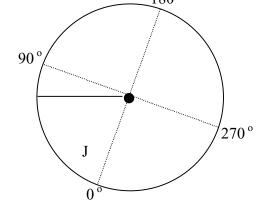


1. 
$$CML = 300^{\circ}$$

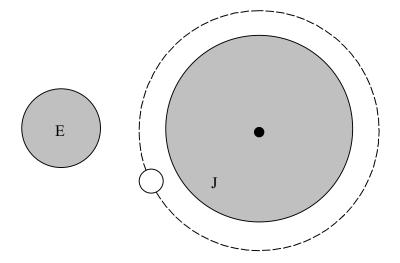
2. Draw a diagram showing Earth and Jupiter illustrating the following CML positions. Label the CML and the meridian lines for  $0^{\circ}$ ,  $90^{\circ}$ ,  $180^{\circ}$  and  $270^{\circ}$ .







3. Using the following diagrams, give the Io phase.



3. Io phase =  $110^{\circ}$ 

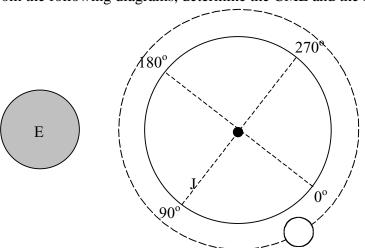
NOTE: Answers should be counted correct if they are within  $\pm 10^{\circ}$  of the given answer.

4. Draw a diagram showing Earth, Jupiter and Io illustrating the following Io phases.



Io phase =  $60^{\circ}$ 

5. From the following diagrams, determine the CML and the Io phase.



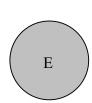
 $CML = 150^{o}$ 

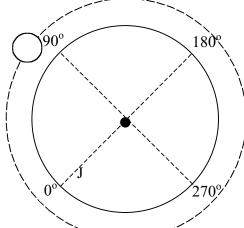
Io phase  $= 300^{\circ}$ 

6. For the following, draw in the meridian longitudes of 0°, 900 180°, 270° and the CML. Draw Io in the indicated phase.

 $CML = 50^{\circ}$ 

Io phase =  $140^{\circ}$ 





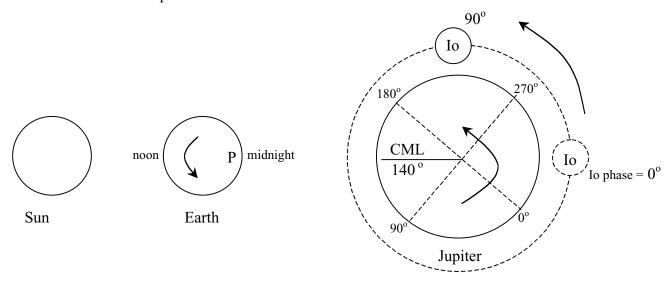
### A Simplified Model for Predicting Jupiter Radio Storms

#### **Historical Background**

After many observations of **Jupiter** using radio telescopes, it was determined that Jupiter had a higher probability of emitting strong radio signals if certain conditions existed. These conditions included:

- 1. Jupiter's orientation relative to Earth as it rotates on it axis and
- 2. the position of **Io** relative to Jupiter and Earth as it orbits Jupiter.

There are smaller **storm probabilities** that are not related to the position of Io, but radio storms are most probable in situations that include a favorable position of Io. One type of Io-related storm is called an **Io-B storm**. In an Io-B storm, the central meridian longitude (**CML**) of Jupiter is between 100° and 180° and the position of Io (called the **Io phase**) is between 80° and 100°. To simplify things for purposes of making a **mathematical model**, we will use a CML value of 140° and an Io phase of 90°.



Above is a diagram of Io-B storm conditions. This view is looking down from above showing the positions of the Sun, Earth, Jupiter and Io. Earth's direction of rotation is shown and P marks the position of an observer. The position of the Sun indicates that it is **local midnight** for the observer. Jupiter is at its highest **elevation** in the sky. The **rotation** of Jupiter is shown and the CML is indicated and is about 140°. The direction of **revolution** of Io is shown and Io is shown at a phase of about 90°.

If everything were aligned as shown in the diagram <u>and</u> Jupiter emitted radio waves, that would be an Io-B storm.

#### A Mathematical Model for Jupiter Storm Prediction

A question to consider is the following:

When will be the next occurrence of an Io-B alignment?

We will require exactly the alignment shown in the diagram:

Jupiter CML position: 140°
Io phase: 90°

Jupiter elevation as seen by the observer: maximum

(Notice an Io-B storm could occur when the alignment is merely close to this.)

To create a mathematical model to answer the question, we will need some values associated with the rotation of Jupiter, revolution of Io and the rotation of Earth. To simplify the mathematics in this model, we will use approximations for some of the numbers. The following table gives these values and the approximations we will use.

Quantity	Value	Approximation
Rotation of Earth	24 hours	24 hours
Rotation of Jupiter	9.925 hours	10 hours
Revolution of Io	42.459 hours	42 hours

The CML will next be in the correct position in 10 hours, but Io will be out of position at that time. An equation that expresses when the CML position will be correct is:

$$t_1 = 10 \text{ x}$$
 where  $t_1$  is the time of the future alignments (in hours) and x is the number of rotations of Jupiter (x must be an **integer**)

Similarly, Io will next be in position in 42 hours, but the CML may not be in the correct position. An equation that gives the times of alignment of Io is:

$$t_2 = 42 \text{ y}$$
 where  $t_2$  is the time of the future alignments (in hours) and y is the number of revolutions of Io (y must be an integer)

Io-B alignment will occur when these two times are the same:

$$t_1 = t_2$$

$$10 x = 42 y$$

$$x = 4.2 y$$

Notice that the condition that x must be an integer will only be met for certain values of y. The smallest value of y that will give an integer value for x is y = 5. Any multiple of 5 will also give an integer value for x. The following table shows the values of y, x, the number of hours and the number of days until the next alignments.

Number of revolutions of Io	Number of rotations of Jupiter	Number of hours until next alignment	Number of rotations of Earth (days)
Tevolutions of 10	X	10 x	$\frac{\text{Cartif (days)}}{(10x)/24}$
<u>y</u>			ì
5	21	210	8.75
10	42	420	17.5
15	63	630	26.25
20	84	840	35
25	105	1050	43.75
30	126	1260	52.5
35	147	1470	61.25
40	168	1680	70

The last column indicates that the next Io-B alignment will occur 8.75 days after the first alignment. But 8.75 days after the first alignment the local time for observer P will be around 6 PM, which is before dark and Jupiter will have just risen. Jupiter storms are very difficult to observe while the Sun is up.

At the next alignment, 17.5 days after the first, it will be local noon for observer P and Jupiter will not be visible to that observer. Notice that an Io-B storm could be observed by someone on the opposite side of Earth from P.

In order to have Jupiter be high in the sky for observer P, we apply the condition that the number of rotations of Earth, that is the number of days, must also be an integer. We can see that the next Io-B alignment that can be observed from position P on Earth will occur 35 days after the first alignment. The Io-B alignment will repeat every 35 days for observer P.

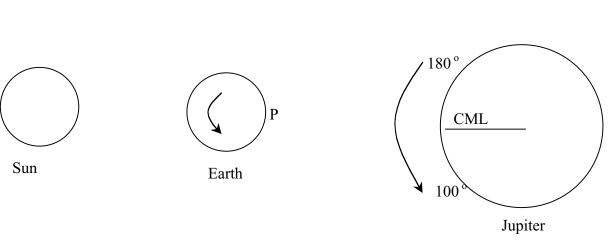
It turns out that Io-B storms occur more often than every 35 days for a given observation point on Earth. This is because the conditions for an Io-B storm are not as strict as those applied in the model.

The CML does not have to be exactly 140°, but can be anywhere from 100° to 180°. The CML will be in this range for 2.2 hours of each rotation of Jupiter..

Io does not have to be exactly at 90° phase, but can be anywhere from 80° to 100°. Io will be in that range for 2.3 hours of each revolution of Io.

Jupiter does not have to be at its highest elevation as seen from Earth. If the **antenna** of the telescope can be pointed, Jupiter only has to be above the horizon. The length of time that Jupiter is above the horizon depends on the **hour angle** of Jupiter when the Sun sets and this

length of time can vary up to almost 12 hours. If the antenna is one like that used by Radio JOVE, then Jupiter must be within 2.5 hours of its highest elevation for the signal to be received. Jupiter will be in the **beam** of the Radio JOVE antenna for about 5 hours.



So what is required for an Io-B storm to be observed is that all three quantities, Jupiter CML position, Io phase and Jupiter elevation as seen by the observer, must overlap. The result is that Io-B storms are predicted for a particular viewing location substantially more often than every 35 days. In fact, due to the complex interaction and motions of Earth, Jupiter, and Io, there is a 7-day periodicity.

So how can we determine exactly when to expect to be able to observe the next Io-B storm from our location? To get this time exact requires removing the approximations stated earlier. Removing those approximations makes the equations more difficult to solve. Also a couple of other things must be considered.

- 1. Because of the motions of Earth and Jupiter in their orbits, Jupiter rises earlier each night, so 24 hours is not the right time to use for Jupiter's return to highest elevation.
- 2. For half of the year Jupiter is in the same general direction as the Sun. Since the Sun is a strong radio source (much stronger than Jupiter), Jupiter radio storms cannot be observed during this part of the year even though the Io-B alignment occurs. The lack of ability to observe Jupiter during the day is more related to its relative weakness and inability to penetrate the Sun-enhanced Ionosphere than to being drowned out by the stronger solar source. Further references can be found in the activity The Effects of Earth's Upper Atmosphere on Radio Signals".

There are other alignments, called **Io-A** and **Io-C**, that also can provide radio storms. Because of the unavoidable complexity of actual Jupiter storm prediction, computers are used to generate a plot, called a **CML-Io phase plot**, which can be used to predict Jupiter radio storms.

Io

100°

80°

## Glossary

antenna

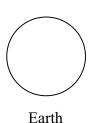
used by a radio telescope to detect radio waves; Radio JOVE uses a double dipole antenna array although a single dipole could be used but would have less sensitivity; more advanced telescopes use large dish antennas that can be pointed to a particular spot in the sky and are very sensitive.

beam

the area of the sky where the antenna can detect radio waves; the Radio JOVE antenna, set up so the dipoles are aligned east-west, has a beam width of  $70^{\circ}$  east-west and  $60^{\circ}$  north-south; in other words, Jupiter will be in the beam of the Radio JOVE double dipole antenna if Jupiter is within  $35^{\circ}$  east or west and  $30^{\circ}$  north and south of straight overhead; a dish antenna would have a very small beam width, but this limitation is offset by the ability to point it accurately.

**CML** 

Central Meridian Longitude; the meridian of longitude on Jupiter that is in the direction of the observer (usually on Earth) at a given time; since Jupiter rotates once every 10 hours, the CML is constantly changing from  $0^{\circ}$  to  $360^{\circ}$  (which is a return to  $0^{\circ}$ ).



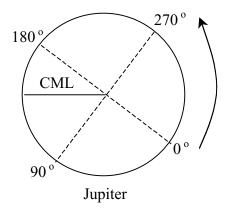


Diagram showing the CML. At this time, the CML is about 140°.

#### **CML-Io phase plot**

a computergenerated graph showing the relationship between the CML, Io phase and time; Jupiter storm alignments are indicated on the plot; used for planning Jupiter storm observations.

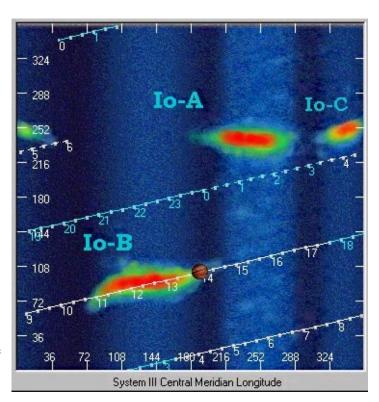


Image: Radio Jupiter Pro software

**elevation** the angle of a planet (or any object in the sky) above the horizon; the elevation changes as Earth rotates, reaching its maximum value when the planet is due south of the observer (or north in the southern hemisphere).

#### hour angle

a way of expressing the position of an object in the sky; an hour angle of —2 means that the planet will reach maximum elevation (due south of the observer) in 2 hours; an hour angle of +1 means that the planet was at maximum elevation 1 hour ago; in each hour of time, the planet moves 15° in the sky.

#### Io

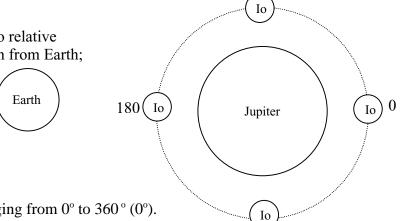
the closest moon to Jupiter; the smallest of the Galilean moons and the fourth largest of all the moons; has many active sulfur volcanoes; ionized sulfur atoms contribute the electrons that spiral down Jupiter's magnetic field lines and give off radio waves.

#### 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.

Io phase the position of Io relative

to Jupiter as seen from Earth;



90

270

Diagram showing Io phases ranging from 0° to 360° (0°).

**Io-A Storm** storm probabilities are larger when  $215^{\circ} < \text{CML} < 255^{\circ}$  and  $220^{\circ} < \text{Io phase} < 240^{\circ}$ 

**Io-B storm** storm probabilities are larger when  $100^{\circ} < \text{CML} < 180^{\circ}$  and

 $80^{\circ} < \text{Io phase} < 100^{\circ}$ 

**Io-C Storm** storm probabilities are larger when  $320^{\circ} < \text{CML} < 340^{\circ}$  and

 $240^{\circ}$  < Io phase <  $260^{\circ}$ 

integer a positive or negative whole number (or zero); in the model developed here,

positive integers are used.

**Jupiter** fifth planet from the Sun; largest planet; has a strong magnetic field; emits radio

waves and many other types of electromagnetic radiation.

**local midnight** occurs when the Sun is on the opposite side of Earth from the observer;

(i.e. the Sun is 180° in longitude away from the observer's position)

mathematical model using equations to describe a physical situation to help understand

how things are related

**revolution** the motion of an object in orbit around another; planets revolve around the Sun,

moons revolve around planets.

rotation the spinning of an object on its axis; Earth rotates once per day (24 hours), Jupiter

rotates once every 10 hours.

**storm probabilities** the probability of Jupiter radiating radio waves varies depending on the

CML and the position of Io; for example, when Io-B alignment occurs, the storm probability is around 40%; that still means that over half the times

that Io-B alignment occurs, no radio waves are detected!

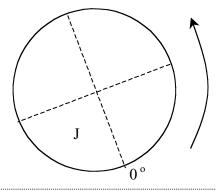
#### Activity 1.

Name\_\_\_\_\_

Draw in the CML and give the CML position relative to Earth shown in each of the following.

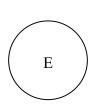
Example.

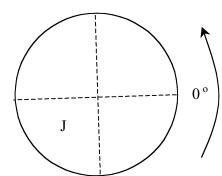




 $CML = \underline{105^{o}}$ 

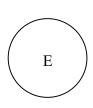
1.

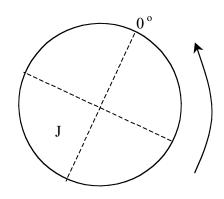




1. CML = \_\_\_\_

2.

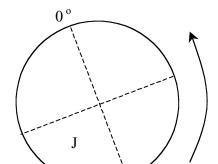




2. CML = \_\_\_\_

3.





3. CML = \_\_\_\_\_

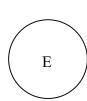
#### Activity 2.

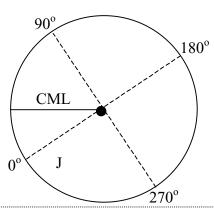
Name\_\_\_\_

Draw a diagram showing Earth and Jupiter illustrating the following CML positions. Label the CML and the meridian lines for  $0^{\circ}$ ,  $90^{\circ}$ ,  $180^{\circ}$  and  $270^{\circ}$ .

Example.

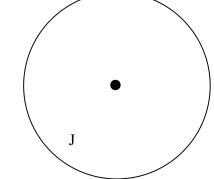
 $CML = 30^{\circ}$ 





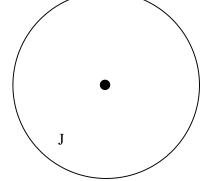
1.  $CML = 150^{\circ}$ 





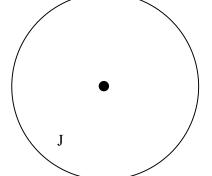
2.  $CML = 340^{\circ}$ 

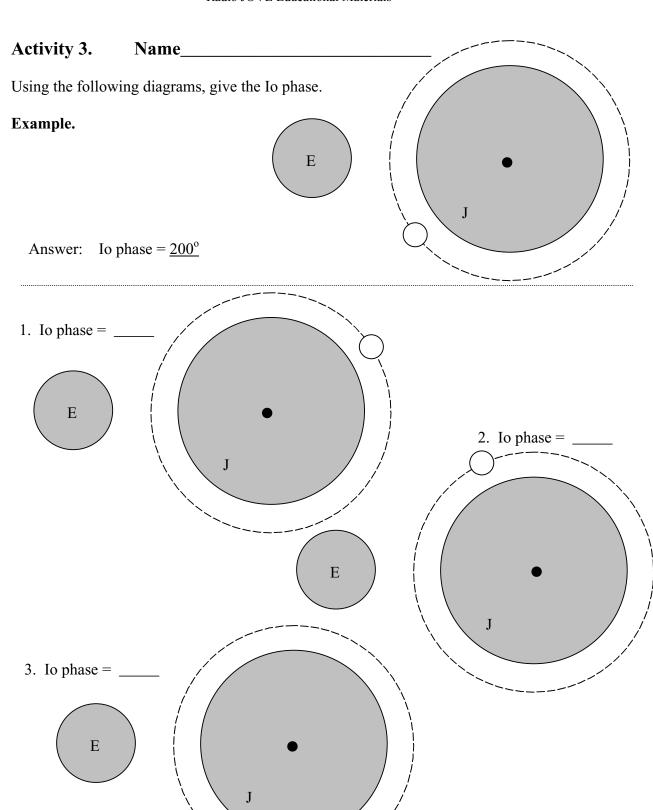




3.  $CML = 220^{\circ}$ 







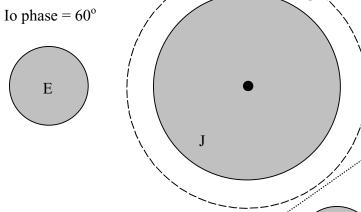
Е

#### Activity 4.

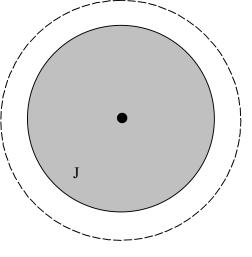
Name\_\_\_\_\_

Draw a diagram showing Earth, Jupiter and Io illustrating the following Io phases.

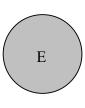
Example.

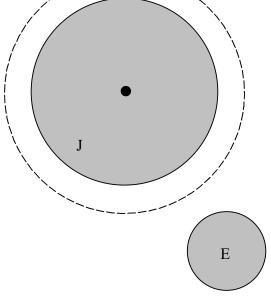


1. Io phase =  $320^{\circ}$ 

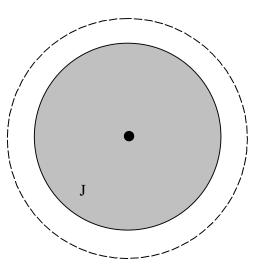


2. Io phase =  $230^{\circ}$ 





3. Io phase =  $170^{\circ}$ 



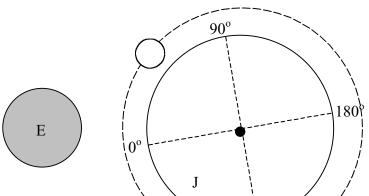
270°

180°

#### Activity 5.

#### Name\_

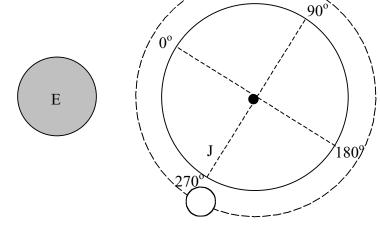
From the following diagrams, determine the CML and the Io phase. Use the skills you learned in activities 1 - 4 to complete this section.



1.

CML = \_\_\_\_

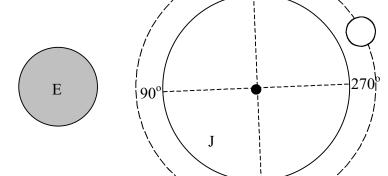
Io phase = \_\_\_\_\_



2.

CML = \_\_\_\_

Io phase = \_\_\_\_\_



3.

CML =

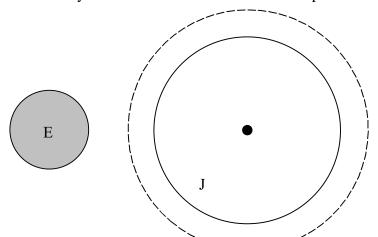
Io phase = \_\_\_\_\_

## Activity 6.

## Name\_

For the following, draw in the meridian longitudes of  $0^{\circ}$ ,  $90^{\circ}$ ,  $180^{\circ}$ ,  $270^{\circ}$  and the CML. Draw Io in the indicated phase.

Use the skills you learned in activities 1 - 4 to complete this section.

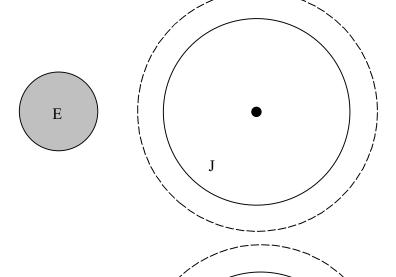


1.

 $CML = 225^{\circ}$ 

Io phase  $= 240^{\circ}$ 

(This is an Io-A storm.)

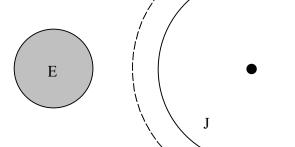


2.

 $CML = 340^{\circ}$ 

Io phase  $= 250^{\circ}$ 

(This is an Io-C storm.)



3.

 $CML = 110^{\circ}$ 

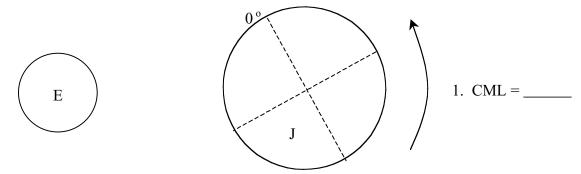
Io phase  $= 80^{\circ}$ 

(This is an Io-B storm.)

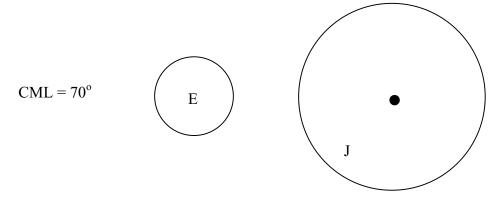
## **Io-B Storm Quiz**

Name \_\_\_\_\_

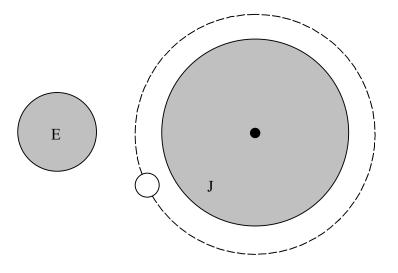
1. Draw in the CML and give the CML position shown in each of the following.



2. Draw a diagram showing Earth and Jupiter illustrating the following CML positions. Label the CML and the meridian lines for  $0^{\circ}$ ,  $90^{\circ}$ ,  $180^{\circ}$  and  $270^{\circ}$ .



3. Using the following diagrams, give the Io phase.



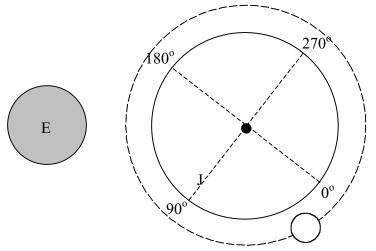
3. Io phase = \_\_\_\_\_

4. Draw a diagram showing Earth, Jupiter and Io illustrating the following Io phases.

Quiz pg. 2

Io phase =  $60^{\circ}$ 

5. From the following diagrams, determine the CML and the Io phase.



CML = \_\_\_\_

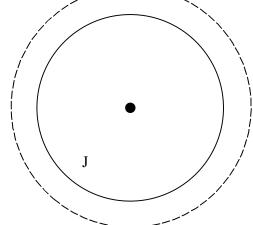
Io phase = \_\_\_\_

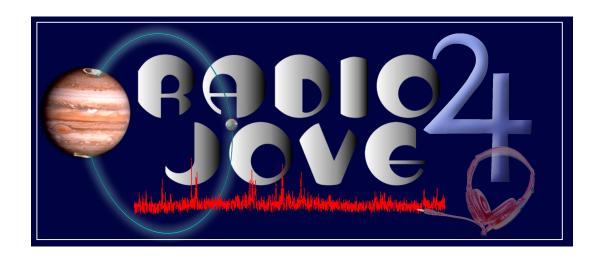
6. For the following, draw in the meridian longitudes of 0°, 90° 180°, 270° and the CML. Draw Io in the indicated phase.

$$CML = 50^{\circ}$$

Io phase 
$$= 140^{\circ}$$







# **Graphing Jupiter Radio Signals**

**Lesson #6** 

## **Lesson Plan:** Graphing Jupiter Radio Signals

**Objective:** The students will be able to identify questions and concepts in the ability to construct accurate graphs, recognize and analyze alternative explanations and models by the end of this activity.

#### **National Standards:**

1. Content Standard A: Science as Inquiry

2. Content Standard G: History and Nature of Science

**Course/Grade level:** Earth/Space Science Course, Physics / 9-12

#### Materials:

1. Reference material on graphing Radio Jove data

2. Discussion Questions: Student page

**Estimated Time:** 120 minutes for completion of the reading and student questions

#### **Procedure:**

1. **Engagement**: Introduction of the activity,

- A. Ask the students to explain the importance of graphing data.
- B. Ask the students what they think should be labeled on a graph.
- 2. **Exploration:** Have the students read the article, stopping to discuss parts as needed.
- 3. **Explanation:** After reading the reference material, have the students complete the Discussion Ouestions.
- 4. **Extension:** Upon completion of the student questions, discuss any additional questions that the students might have derived from the reading, pulling out inferences that they might have made.
- 5. **Evaluation:** There are additional questions attached that are aimed at an understanding of the fundamentals of graphing and at generating a connection to the graphing tools needed to further develop an understanding of Project Radio JOVE.

#### **TEACHER PAGE 1:** Possible Ideas from Engagement Questions

#### A. Ask the students to explain the importance of graphing data.

- Graphs are a way to organize numbers.
- Graphs can show relationships between numbers.
- Graphs can provide a visual interpretation of number patterns that cannot be seen in the numbers themselves.

#### B. Ask the students what they think should be labeled on a graph.

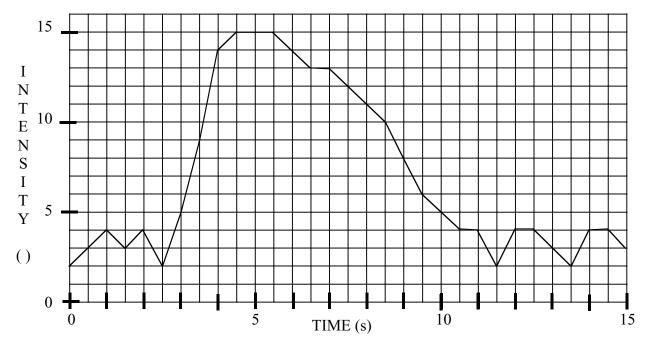
- Accurate scale markings with units of measurement.
- Title, axes (both X and Y) and, if the data are 3-dimensional, the Z axis.

## **Teacher Page 2: Answers to Student Questions**

Plot the following radio data. Be sure to label the axes and indicate the scale for each.

1.

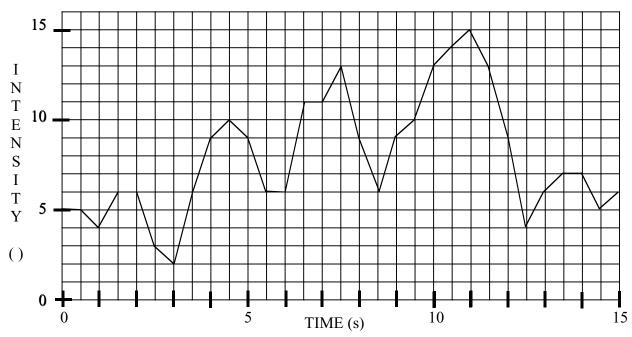
Time	Intensity	Time	Intensity	Time	Intensity
(s)	( )	(s)	( )	(s)	( )
0.0	2				
0.5	3	5.5	15	10.5	4
1.0	4	6.0	14	11.0	4
1.5	3	6.5	13	11.5	2
2.0	4	7.0	13	12.0	4
2.5	2	7.5	12	12.5	4
3.0	5	8.0	11	13.0	3
3.5	9	8.5	10	13.5	2
4.0	14	9.0	8	14.0	4
4.5	15	9.5	6	14.5	4
5.0	15	10.0	5	15.0	3



If the data above were plotted correctly, you should see some small changes in intensity for the first couple of seconds followed by a quick increase in intensity with a peak at 15 followed by a slow decrease in intensity. Projecting a shark fin shaped feature in the data for about 9 seconds. The end of the data looks similar to the beginning. The shark fin shaped data is typical of what a radio burst from the Sun would look like with your Radio JOVE equipment

2.

Time	Intensity	Time	Intensity	Time	Intensity
(s)	( )	(s)	( )	(s)	( )
0.0	5				
0.5	5	5.5	6	10.5	14
1.0	4	6.0	6	11.0	15
1.5	6	6.5	11	11.5	13
2.0	6	7.0	11	12.0	9
2.5	3	7.5	13	12.5	4
3.0	2	8.0	9	13.0	6
3.5	6	8.5	6	13.5	7
4.0	9	9.0	9	14.0	7
4.5	10	9.5	10	14.5	5
5.0	9	10.0	13	15.0	6



If the above data was plotted correctly, you should see 3 strong peaks in the middle of the graph. These 3 peaks look similar to Jupiter storm activity as seen with the Radio JOVE equipment. These storms however, generally last between 15 minutes to 1 hour.

#### The following questions refer to Image 2 (in the reading):

3. What would be the time difference between sections if you started at 00:00:00UT and ended at 00:08:00UT?

#### Ans 2 min.

4. What would be the time difference between sections if you started at 00:12:00UT and ended at 00:36:00UT?

Ans: 6 min.

5. If the difference between the starting time and first division were 5 minutes, what would be the total amount of time from start to end of the graph?

Ans: 20 min.

6. Let us say that instead of having 4 equal sections, you have 5. What would be the time difference between sections if you started at 04:21:00UT and ended at 04:56:00UT?

Ans: 7 min.

#### The following questions refer to the section on Sample Rate and Average:

7. If you set the sample period to 100 ms and the average to 20, then you will plot a sample every how many seconds?

Ans: 2 sec.

8. If you set the sample period to 10 ms and the average to 1, then you will plot a sample every how many milliseconds?

Ans: 10 ms.

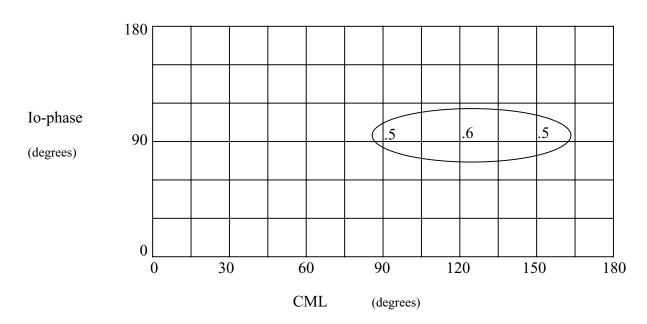
9. If you set your sample rate to 10 samples/sec. To what would you need to set your average in order to plot 2 times a second (500 ms)?

Ans: 5

The following page shows a quarter of the CML-Io phase plane. Plot the following data by putting the probability value at the appropriate spot of the CML-Io phase plane. When all of the points are plotted, put a circle around the group of high probability values (probability >.4).

## 10. The lower left quadrant of the CML-Io phase plane

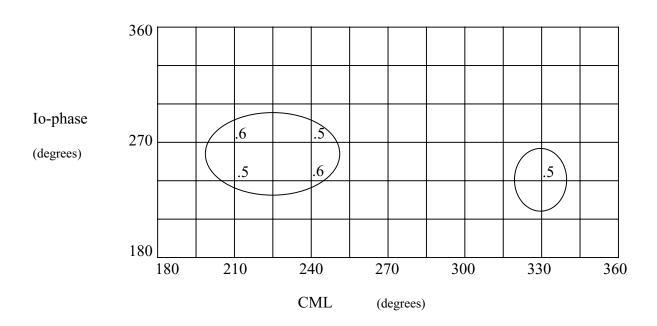
CML	Io-phase	Probability	CML	Io-phase	Probability	CML	Io-phase	Probability
(°)	(°)	( )	(°)	(°)	( )	(°)	(°)	( )
0	0	0	60	0	0	120	0	.1
0	30	0	60	30	0	120	30	.1
0	60	0	60	60	0	120	60	.1
0	90	0	60	90	0	120	90	.6
0	120	0	60	120	0	120	120	.1
0	150	0	60	150	0	120	150	.1
0	180	0	60	180	0	120	180	.1
30	0	0	90	0	.1	150	0	.1
30	30	0	90	30	.1	150	30	.1
30	60	0	90	60	.1	150	60	.1
30	90	0	90	90	.5	150	90	.5
30	120	0	90	120	.1	150	120	.1
30	150	0	90	150	.1	150	150	.1
30	180	0	90	180	.1	150	180	.1



The high probability area of this plot is called the Io-B storm. When the CML and the phase of Io have values in this region, the probability of a storm is great.

## 11. The upper right quadrant of the CML-Io phase plane

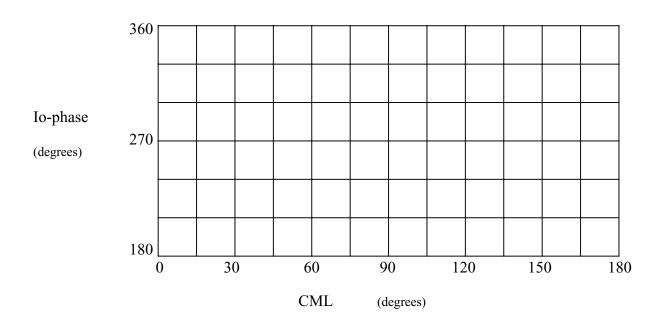
CML	Io-phase	Probability	CML	Io-phase	Probability	CML	Io-phase	Probability
(°)	(°)	( )	(°)	(°)	( )	(°)	(°)	( )
180	180	0	240	180	.1	300	180	0
180	210	0	240	210	.1	300	210	0
180	240	0	240	240	.6	300	240	0
180	270	0	240	270	.5	300	270	0
180	300	0	240	300	.1	300	300	0
180	330	0	240	330	.1	300	330	0
180	360	0	240	360	.1	300	360	0
210	180	.1	270	180	0	330	180	.1
210	210	.1	270	210	0	330	210	.1
210	240	.5	270	240	0	330	240	.5
210	270	.6	270	270	0	330	270	.1
210	300	.1	270	300	0	330	300	.1
210	330	.1	270	330	0	330	330	.1
210	360	.1	270	360	0	330	360	.1



There are two Jupiter storm regions in this quadrant. The larger one, to the left, is called Io-A; the smaller area to the right is called Io-C.

## 12. The upper left quadrant of the CML-Io phase plane

CML	Io-phase	Probability	CML	Io-phase	Probability	CML	Io-phase	Probability
(°)	(°)	( )	(°)	(°)	( )	(°)	(°)	( )
0	180	0	60	180	0	120	180	.1
0	210	0	60	210	0	120	210	.1
0	240	0	60	240	0	120	240	.1
0	270	0	60	270	0	120	270	.1
0	300	0	60	300	0	120	300	.1
0	330	0	60	330	0	120	330	.1
0	360	0	60	360	0	120	360	.1
30	180	0	90	180	.1	150	180	.1
30	210	0	90	210	.1	150	210	.1
30	240	0	90	240	.1	150	240	.1
30	270	0	90	270	.1	150	270	.1
30	300	0	90	300	.1	150	300	.1
30	330	0	90	330	.1	150	330	.1
30	360	0	90	360	.1	150	360	.1



As can be seen by scanning the table and by looking at the graph, there are no Jupiter storm regions in this quadrant.

#### The following questions refer to Image 5 (in the reading):

**13.** Would an Io phase of 80 degrees and Jupiter CML of 140 degrees give a high probability of receiving radio emission from Jupiter? If so, is it Io-A, B, or C related?

Ans: yes, Io-B

14. Answer the same set of questions for Io phase of 250 degrees and Jupiter CML of 100 degrees.

Ans: no

How about an Io phase of 250 degrees and Jupiter CML of 340 degrees?

Ans: yes, Io-C

15. What would have been a good time to listen to Jupiter? (give start and stop time)

Ans: start at 11:00UT, end at 14:00UT

16. Based on the time line track, how long does it take for Jupiter to rotate once?

Ans: about 9.5 hrs.

17. Does Io take more or less than one Earth day to go around Jupiter?

Ans: more

18. Do you expect to receive Io-A, Io-B or Io-C emission on September 16, 2000? Why or why not?

Ans: Io-B because the time line passes through the combinations of Jupiter CML and Io phase for the Io-B source.

## **ANSWER KEY**

Quiz

1. What is the origin of a graph? Explain using the words axes and coordinates.

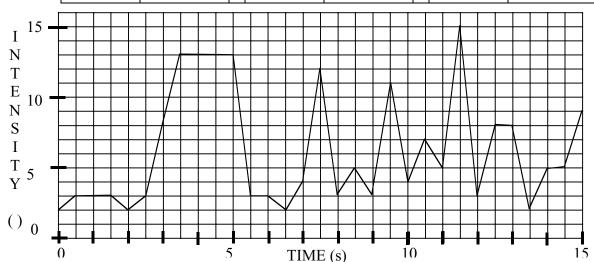
The origin is the point on a graph where the coordinates are all zero and where the axes cross each other.

2. What technique used in plotting points on a graph can get rid of some random fluctuations in the data and reduce your data file?

Averaging eliminates random points by giving the mean value of a set of data points. Thus by averaging points together, your data file is reduced.

3. Plot the following radio data. Be sure to label the axes and indicate the scale for each

<u>are 101 eac.</u>					
Time	Intensity	Time	Intensity	Time	Intensity
(s)	( )	(s)	( )	(s)	( )
0.0	2				
0.5	3	5.5	3	10.5	7
1.0	3	6.0	3	11.0	5
1.5	3	6.5	2	11.5	15
2.0	2	7.0	4	12.0	3
2.5	3	7.5	12	12.5	8
3.0	8	8.0	3	13.0	8
3.5	13	8.5	5	13.5	2
4.0	13	9.0	3	14.0	4
4.5	13	9.5	11	14.5	4
5.0	13	10.0	4	15.0	9



Above is a series of spikes and plateaus simulating manmade interference. October 2001 <a href="http://radiojove.gsfc.nasa.gov">http://radiojove.gsfc.nasa.gov</a>

#### Radio JOVE Educational Materials

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## A Quick Introduction to Graphing

When displaying data taken through scientific investigation, it is often appropriate to display the data visually as a graph. Graphs are very useful in not only displaying data, but also useful in finding trends and fluctuations in scientific data to pick out significant features.

Radio-SkyPipe and Radio-JupiterPro are very useful software packages used to predict and display data obtained with the Radio JOVE radio telescope. In this tutorial we will use both Radio-SkyPipe and Radio-JupiterPro to help explain features of a graph and to do some helpful exercises.

#### **Background to Graphing**

A graph is usually created as a two-dimensional (2-d) or three-dimensional (3-d) plot depending on the type of data you are trying to plot. A 2-d plot is usually displayed as an x-y graph, and a 3-d plot is displayed as an x-y-z graph. A point plotted on a 2-d plot consists of a data point having two coordinates and on a 3-d plot consists of a data point having three coordinates (a coordinate is a specific value either x, y or z, identifying the position of the point) on a spatial grid. A 3-d graph can reveal more information since you are adding another value for each data point. The x, y, and z represent the coordinate axes and they are each at 90 degree angles to each other, each going from negative infinity to positive infinity. The point where all three coordinates are zero is called the origin. Extending from the origin along each axis (x, y, and z) are marks with regularly increasing values that extend in the positive and negative directions along each axis. This is the scale.

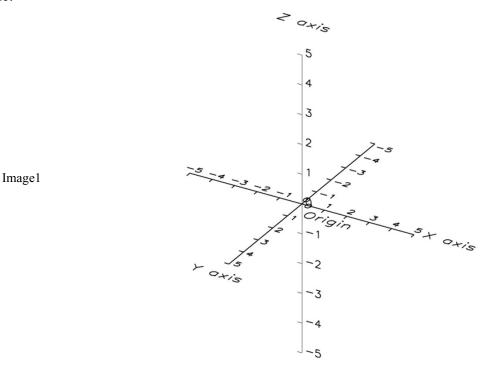


Image credit: Robert Candey NASA/GSFC

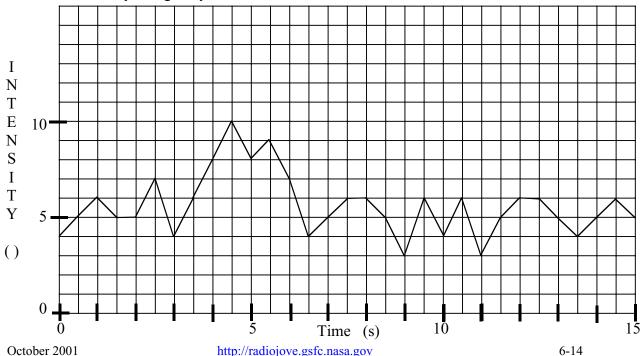
# **Graphing Jupiter Radio Signals**

## Why Draw a Graph?

Jupiter radio data consists of a series of intensity values indicating the strength of the radio signal taken at particular times. Each time has an intensity associated with it. The following table is a sample of Jupiter radio data. The time values are given in seconds with data being taken every half second; the intensity values in this case do not have a unit specified. What we are looking for here is any change in the intensity that looks significant, so the units are not important.. Intensity can be measured in decibels, or volts as measured by a voltmeter.

Time	Intensity	Time	Intensity	Time	Intensity
(s)	( )	(s)	( )	(s)	( )
0.0	4				
0.5	5	5.5	9	10.5	6
1.0	6	6.0	7	11.0	3
1.5	5	6.5	4	11.5	5
2.0	5	7.0	5	12.0	6
2.5	7	7.5	6	12.5	6
3.0	4	8.0	6	13.0	5
3.5	6	8.5	5	13.5	4
4.0	8	9.0	3	14.0	5
4.5	10	9.5	6	14.5	6
5.0	8	10.0	4	15.0	5

As you look at the intensity values, it is obvious that the value does not stay constant. But how does it change? Is there any pattern? What is going on? A graph can help answer these questions. Below is a 2-dimensional plot of these data with time along the x-axis and intensity along the y-axis.



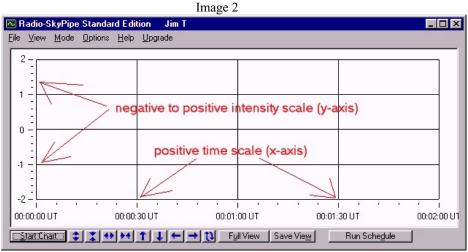
If we examine the x-y graph we can see that, while the intensity values jumped around quite a bit, there was a time during the 15-second interval where the value stayed higher than the rest of the time. That would be between times of about 4 seconds and 6 seconds. You could also see the high numbers in the table, but with the graph can you can more easily see that there is only one period of higher than average values.

Drawing a graph can make it easier to interpret data.

## **Basics to Graphing Using Radio-Sky Pipe**

#### Radio-SkyPipe

Now that we know how to draw, understand, and plot a graph we now want to understand the graphing used by Radio-SkyPipe. Radio-SkyPipe is Radio JOVE's central program for plotting data from your RJ telescope. The Radio JOVE data we want to display are relatively simple; there is an intensity value and a time marker associated with each data point. Consequently this is what Radio-SkyPipe plots for us, relative intensity (on the y-axis) vs. time (on the x-axis). Radio-SkyPipe is set up to accept negative intensity values which may occur if the gain (volume) on your receiver is set low enough. So the y-axis goes from negative values to 0 to positive values. Since time is always positive, the x-axis is always positive.



Radio-SkyPipe

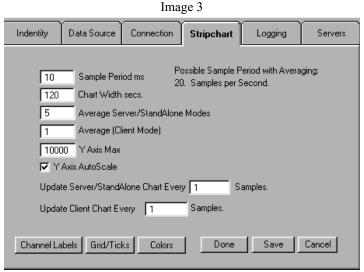
Let's first look at the x-axis, or the time scale axis. Notice in Image 2 that the total time from left to right is 2 minutes. You also see three large vertical divisions of the time axis in between the left-most and right-most times which as a result divide your time into 4 **equal** sections. If you divide the total time (from start to end in graph) by the number of equal sections in your graph, you get the time difference between each section. For the example above, the total time is 2 minutes (120 seconds) and there are 4 equal parts. So if you divide 120 seconds by 4 you get 30 seconds between each division. You can see above that the starting time is 00:00:00UT (hh:mm:ssUT) and the next division is

00:00:30UT and the one after that is 00:01:00UT and so on as you keep adding 30 seconds to each division.

Notice that each section is further subdivided into 5 parts by the small tick marks. These tick marks are used to help you obtain a more exact time for a feature in the data. So in the graph above, each small tick mark represents 6 seconds. Notice that there are also 4 sections and 5 subdivisions for each section on the intensity scale (y-axis) and thus the same type of calculations done above for time can be used for intensity as well.

#### Sample rate

When you are collecting data using Radio-SkyPipe there is a limit to the rate at which you can collect the data which is dependent on the processor speed of your computer. The number of samples Radio-SkyPipe collects per second is known as the sample rate (samples/sec.). The sample rate is displayed on Radio-SkyPipe while the chart is running but the sample rate is dependent on the value you choose for the sample period.



Radio-SkyPipe Stripchart Dialog Box showing sample period, average, update chart, and more

#### Sample period

The difference in time between each recorded data point is known as the sample period. In Radio-SkyPipe, this difference in time is measured in milliseconds (ms). There are 1000 ms in one second, so if you set the sample period to 1 ms, then the sample rate would be 1000 samples/sec. (that's a lot!). Setting the sample period to 10 ms makes the sample rate 100 samples/sec., setting the sample period to 100 ms makes the sample rate 10 samples/sec. So to get the sample rate from the sample period, you divide 1000 by the sample period. So how often would you receive a data point (sample rate) if you set the sample period to 2000 ms? For most Radio JOVE observations, it is sufficient to set your sample period to 100 ms (thus a sample rate of 10 samples/sec.).

#### Average

In observing long duration activity, scientific data is often averaged in order to smooth out any random fluctuations in the data and also to reduce the amount of data you need to store. Mathematically, the average of a set of data points is the sum of the data points values divided by the number of data points. For example if you have 5 data points with values 6,8, 12, 9, and 10, then the average would be (6+8+12+9+10)/5 which would be 9. In Radio-SkyPipe you can set the number of samples you wish to average to get each data point. So if you set this number to 5, then you would be averaging 5 samples and plotting the average value of those 5 samples. The sample period and average determine the number of actual data points displayed on Radio-SkyPipe. If you set the sample period to 200 ms and the averaging to 5, then Radio-SkyPipe will plot a point every second (5\*200 ms = 1000 ms = 1 sec.). With averaging you lose detailed information but you can better see longer duration trends.

#### **Update Chart**

This allows the user to set the number of samples between updates of the chart. So let's say you set your sample rate to 200 ms and set the update chart value to 5. Then SkyPipe will update the graph each second (200 ms \* 5 = 1000ms = 1 sec.). This option does not affect the data displayed, just the rate at which it is displayed on your screen.

The previous material on 2-d plots should prepare you for the following section on graphing on the CML-Io Phase Plane and Radio-JupiterPro, which involves some 3-dimensional graphing on a 2-dimensional surface.

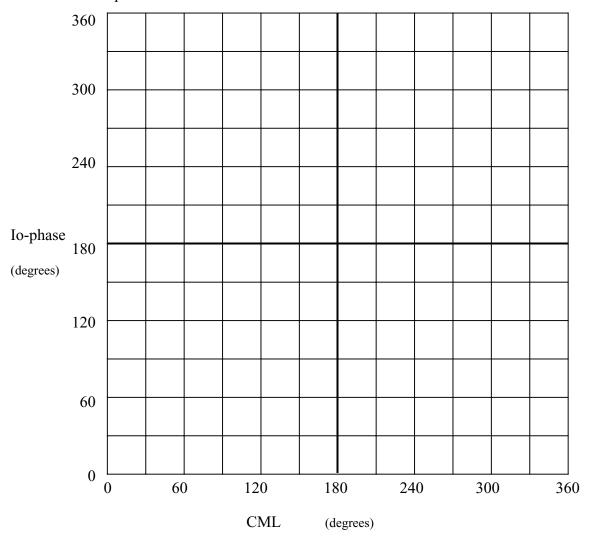
## Graphing on the CML-Io Phase Plane

Early radio astronomers noticed that Jupiter did not give off radio waves all of the time. When Jupiter did emit radio waves, that was called a "Jupiter storm". At first, astronomers did not know when to expect a Jupiter storm. After many observations, it was determined that Jupiter had a higher probability of having a storm when certain parts of Jupiter were facing towards Earth. Since there are lines of latitude and longitude defined for Jupiter just like Earth, the part of Jupiter facing Earth could be identified by its longitude. This is the definition of the Central Meridian Longitude, or CML. As Jupiter rotates on its axis, the CML constantly changes. As Jupiter passes overhead as seen from Earth, radio astronomers observe whether there is a storm or not and add their observations to the large body of data accumulated over the past years. The result is that astronomers can now predict when Jupiter is more likely to have a storm observable from Earth based on the CML. When the CML is right for a high probability of a storm that does not mean that a storm is guaranteed to occur. Even when the CML is right, a Jupiter storm occurs only part of the time for reasons not completely understood.

As astronomers continued to make their observations, it was discovered that another condition contributed to the probability of a storm: the position of the moon Io. As Io orbits Jupiter as the innermost Galilean moon, its position seemed to play a role in Jupiter storms. When Io was in the right position and the CML was right, the probability of a Jupiter storm rose dramatically. These times became the best times to observe Jupiter storms, although regular observations continue to add to the data already gathered.

#### The CML-Io Phase Plane

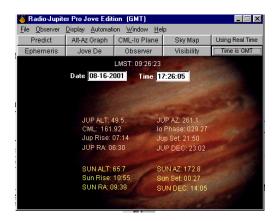
A convenient way to display the data radio astronomers have gathered is on a graph. This graph involves three quantities: the CML, the phase of Io and the probability of a Jupiter storm. Since this graph involves three dimensions and we don't have three-dimensional paper, we are going to graph it in two-dimensions using a method called contour plotting similar to maps of Earth showing hills and valleys. Below is shown the CML-Io Phase plane.



As Jupiter rotates, the CML changes from  $0^{\circ}$  to  $360^{\circ}$  ( $0^{\circ}$ ) in about 10 hours. As Io orbits Jupiter, the Io phase changes from  $0^{\circ}$  to  $360^{\circ}$  ( $0^{\circ}$ ) in about 42 hours. Observations over several years have yielded probability values for Jupiter storms for every CML-Io phase combination. The probability is computed simply by dividing the total amount of time that storms were received for a particular range of CML and Io phase by the total time listening for the same range. Thus, the probabilities range from 0 to 1. A probability of .4 or more is considered high.

## **Basics of Graphing Using Radio-JupiterPro**

#### Image 4



Radio-JupiterPro Software

#### Radio-JupiterPro

Radio-JupiterPro is a multi-functional program, which offers Jupiter storm predictions and related information on probabilities and positions of Jupiter and the Sun. A very useful graph in displaying the probability of receiving emission from Jupiter is the CML-Io Phase Plane diagram, which we now discuss.

#### **CML-Io Phase Plane Graph**

As noted previously, when astronomers first started making radio observations of Jupiter they noticed that over many hours of observing there was a higher probability of receiving emission when certain longitudes (CML) of Jupiter were facing the observer, in our case, Earth. After further studies were done, scientists discovered that Jupiter's moon, Io, greatly increases storm probabilities when it was in a certain phase (position angle of Io in its orbit around Jupiter, with respect to the observer). These three factors, CML, Io phase, and probability of receiving emission are the three axes for the CML-Io Phase Plane graph.

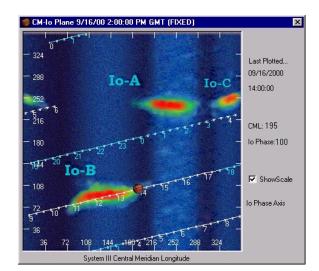


Image 5

CML-Io Phase Plane

As you can see from the graph above, the CML of Jupiter is on the x-axis, the Io phase is on the y-axis, and the probability is on the z-axis which is represented by a color scale. The darker colors are lower probability and the lighter colors display higher probability of receiving emission (red being the highest). Along the x (Jupiter longitude) and y (Io phase) axes the units are degrees. The color scale of the z-axis has no units because it is just a probability and goes from blue (low probability) to red (high probability). You can see in the above graph three high probability sources of emission simply labeled Io-A, Io-B, and Io-C that occur when particular longitudes of Jupiter are facing the observer and Io is in a particular phase. The three sources are labeled as "Io storms" because they are so dependent on the phase of Jupiter's moon Io.

There is one other feature plotted on the graph above, which we now cover briefly. You can see a set of parallel lines slanting across the graph with time markers (in UT) displayed along the lines. This is the time line trace for a specific day as Jupiter CML and Io phase change with time. The time line trace depends on the day for which the plot was made. For example in the day above (September 16, 2000) you see a 0 (time marker) at the top left corner, this spot marks the Jupiter CML and Io phase when that day started (about 40° and 345° respectively). Since the Io phase is almost 360 degrees when the day starts, as time goes by, it reaches 360° and jumps back down to the bottom of the graph because 360 degrees is the same as 0 degrees, then it begins increasing from 0°. You can see on the time line a little picture of Jupiter at 14:00 UT. This little picture just displays where along the track, the Jupiter CML and Io phase are for the particular time for which the graph was plotted. You also may notice that the track goes right through an Io-B source. This would have been a good day to observe Jupiter with Radio JOVE because from the graph, there was a high probability of receiving an Io-B emission.

#### Conclusion

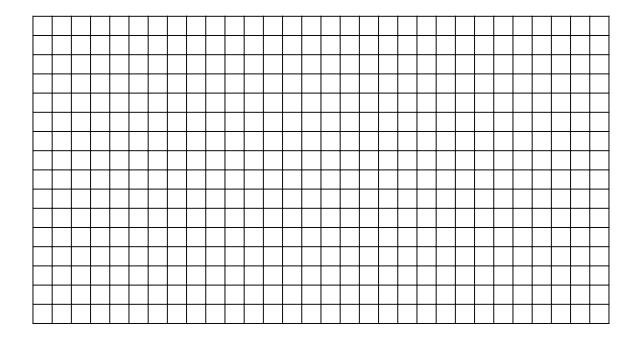
The Radio-SkyPipe graph and the CML-Io Phase Plane graph are two essential graphing tools in displaying and predicting Jupiter radio emissions. From these graphs it is easy to see why scientists use graphing techniques to display their data. Graphs say a lot in a concise format. As long as you understand what the different parts of a graph are, the results can be understood and appreciated.

Name

Plot the following radio data. Be sure to label the axes and indicate the scale for each.

1

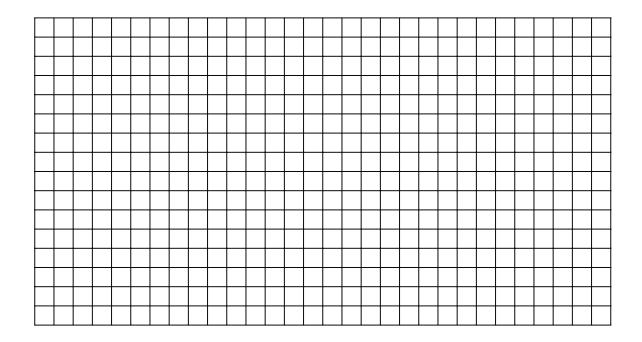
Time	Intensity	Time	Intensity	Time	Intensity
(s)	( )	(s)	( )	(s)	( )
0.0	2				
0.5	3	5.5	15	10.5	4
1.0	4	6.0	14	11.0	4
1.5	3	6.5	13	11.5	2
2.0	4	7.0	13	12.0	4
2.5	2	7.5	12	12.5	4
3.0	5	8.0	11	13.0	3
3.5	9	8.5	10	13.5	2
4.0	14	9.0	8	14.0	4
4.5	15	9.5	6	14.5	4
5.0	15	10.0	5	15.0	3



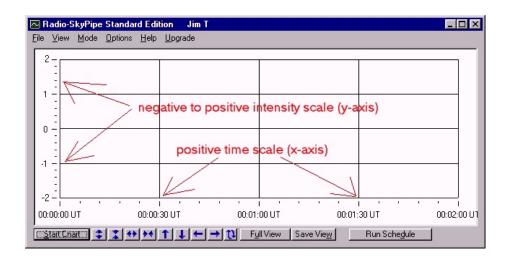
If the data above were plotted correctly, you should see some small changes in intensity for the first couple of seconds followed by a quick increase in intensity with a peak at 15 followed by a slow decrease in intensity. Projecting a shark fin shaped feature in the data for about 9 seconds. The end of the data looks similar to the beginning. The shark fin shaped data are typical of what a radio burst from the Sun would look like with your Radio JOVE equipment

2.

Time	Intensity	Time	Intensity	Time	Intensity
(s)	( )	(s)	( )	(s)	( )
0.0	5				
0.5	5	5.5	6	10.5	14
1.0	4	6.0	6	11.0	15
1.5	6	6.5	11	11.5	13
2.0	6	7.0	11	12.0	9
2.5	3	7.5	13	12.5	4
3.0	2	8.0	9	13.0	6
3.5	6	8.5	6	13.5	7
4.0	9	9.0	9	14.0	7
4.5	10	9.5	10	14.5	5
5.0	9	10.0	13	15.0	6



If the above data were plotted correctly, you should see 3 strong peaks in the middle of the graph. These 3 peaks look similar to Jupiter storm activity as seen with the Radio JOVE equipment. These storms however, generally last between 15 minutes and 1 hour.



3.	What would be the time difference between sections in the above graph if you
	started at 00:00:00UT and ended at 00:08:00UT?

4.	What would be the time difference between sections in the above graph if you
	started at 00:12:00UT and ended at 00:36:00UT?

- 5. In the above graph, if the difference between the starting time and first division was 5 minutes, what would be the total amount of time from start to end of the graph?
- 6. Let us say that instead of having 4 equal sections, you have 5. What would be the time difference between sections if you started at 04:21:00UT and ended at 04:56:00UT?

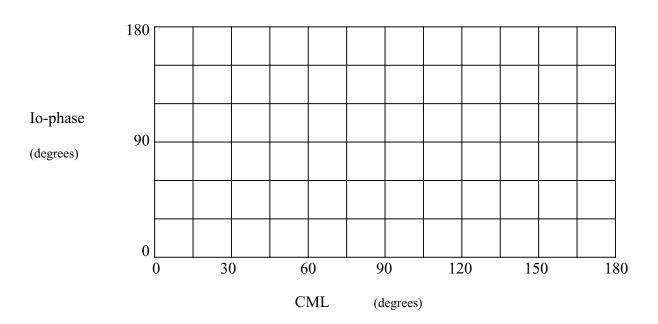
The following questions refer to the section on Sample Rate and Average:

7.	If you set the sample period to 100 ms and the average to 20, then you will plot a sample every how many seconds?
8.	If you set the sample period to 10 ms and the average to 1, then you will plot a sample
0.	every how many milliseconds?
9.	If you set your sample rate to 10 samples/sec. What would you need to set your average in order to plot 2 times a second (500 ms)?

The following shows a quarter of the CML-Io phase plane. Plot the following data by putting the probability value at the appropriate spot of the CML-Io phase plane. When all of the points are plotted, put a circle around the group high probability values (probability >.4).

#### 10. The lower left quadrant of the CML-Io phase plane

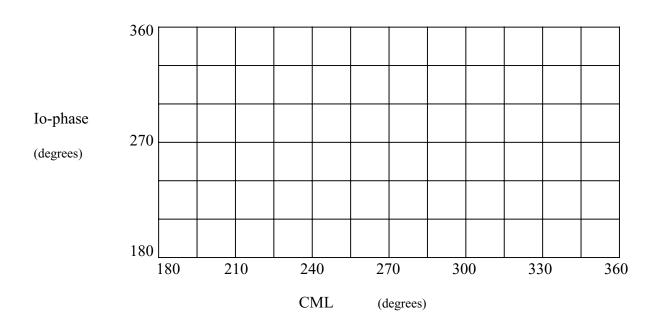
CML	Io-phase	Probability	CML	Io-phase	Probability	CML	Io-phase	Probability
(°)	(°)	( )	(°)	(°)	( )	(°)	(°)	( )
0	0	0	60	0	0	120	0	.1
0	30	0	60	30	0	120	30	.1
0	60	0	60	60	0	120	60	.1
0	90	0	60	90	0	120	90	.6
0	120	0	60	120	0	120	120	.1
0	150	0	60	150	0	120	150	.1
0	180	0	60	180	0	120	180	.1
30	0	0	90	0	.1	150	0	.1
30	30	0	90	30	.1	150	30	.1
30	60	0	90	60	.1	150	60	.1
30	90	0	90	90	.5	150	90	.5
30	120	0	90	120	.1	150	120	.1
30	150	0	90	150	.1	150	150	.1
30	180	0	90	180	.1	150	180	.1



The high probability area of this plot is called the Io-B storm. When the CML and the phase of Io have values in this region, the probability of a storm is great.

## 11. The upper right quadrant of the CML-Io phase plane

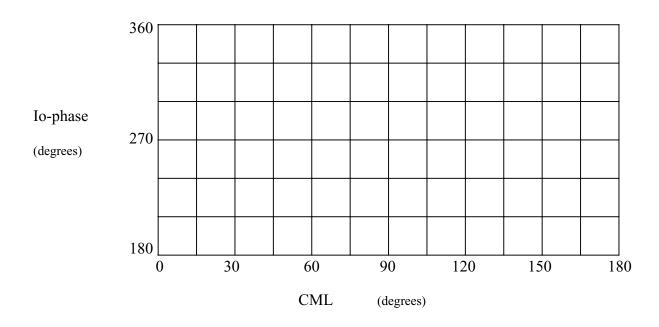
CML	Io-phase	Probability	CML	Io-phase	Probability	CML	Io-phase	Probability
(°)	(°)	( )	(°)	(°)	( )	(°)	(°)	( )
180	180	0	240	180	.1	300	180	0
180	210	0	240	210	.1	300	210	0
180	240	0	240	240	.6	300	240	0
180	270	0	240	270	.5	300	270	0
180	300	0	240	300	.1	300	300	0
180	330	0	240	330	.1	300	330	0
180	360	0	240	360	.1	300	360	0
210	180	.1	270	180	0	330	180	.1
210	210	.1	270	210	0	330	210	.1
210	240	.5	270	240	0	330	240	.5
210	270	.6	270	270	0	330	270	.1
210	300	.1	270	300	0	330	300	.1
210	330	.1	270	330	0	330	330	.1
210	360	.1	270	360	0	330	360	.1



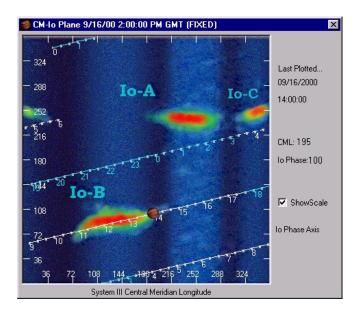
There are two Jupiter storm regions in this quadrant. The larger one, to the left, is called Io-A; the smaller area to the right is called Io-C.

## 12. The upper left quadrant of the CML-Io phase plane

CML	Io-phase	Probability	CML	Io-phase	Probability	CML	Io-phase	Probability
(°)	(°)	( )	(°)	(°)	( )	(°)	(°)	( )
0	180	0	60	180	0	120	180	.1
0	210	0	60	210	0	120	210	.1
0	240	0	60	240	0	120	240	.1
0	270	0	60	270	0	120	270	.1
0	300	0	60	300	0	120	300	.1
0	330	0	60	330	0	120	330	.1
0	360	0	60	360	0	120	360	.1
30	180	0	90	180	.1	150	180	.1
30	210	0	90	210	.1	150	210	.1
30	240	0	90	240	.1	150	240	.1
30	270	0	90	270	.1	150	270	.1
30	300	0	90	300	.1	150	300	.1
30	330	0	90	330	.1	150	330	.1
30	360	0	90	360	.1	150	360	.1



As can be seen by scanning the table and by looking at the graph, there are no Jupiter storm regions in this quadrant.



13. Based on the graph above, would an Io phase of 80 degrees and Jupiter CML of 140 degrees give a high probability of receiving radio emission from Jupiter? If so, is it Io-A, B, or C related?

14. Based on the graph above, would an Io phase of 250 degrees and Jupiter CML of 100 degrees give a high probability of receiving radio emission from Jupiter? How about an Io phase of 250 degrees and Jupiter CML of 340 degrees?

15. Based on the above graph, what would have been a good time to listen to Jupiter? (give start and stop times)

16. Based on the time line track, how long does it take for Jupiter to rotate once?

17. Does Io take more or less than one day to go around Jupiter?

18. Based on the graph above, do you expect to receive Io-A, Io-B or Io-C emission on September 16, 2000? Why or why not?

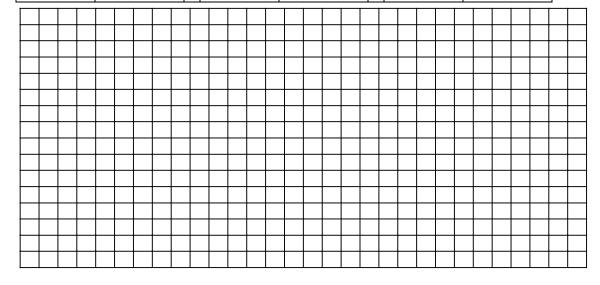
<b>QUIZ</b>	Name
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1. What is the origin of a graph? Explain using the words axes and coordinates.

2. What technique used in plotting points on a graph can get rid of some random fluctuations in the data and reduce the size of your data file?

3. Plot the following radio data. Be sure to label the axes and indicate the scale for each.

the scale for each.										
Time	Intensity	Time	Intensity	Time	Intensity					
(s)	( )	(s)	( )	(s)	( )					
0.0	2									
0.5	3	5.5	3	10.5	7					
1.0	3	6.0	3	11.0	5					
1.5	3	6.5	2	11.5	15					
2.0	2	7.0	4	12.0	3					
2.5	3	7.5	12	12.5	8					
3.0	8	8.0	3	13.0	8					
3.5	13	8.5	5	13.5	2					
4.0	13	9.0	3	14.0	4					
4.5	13	9.5	11	14.5	4					
5.0	13	10.0	4	15.0	9					





# **Radio JOVE Data Analysis**

Lesson #7

## **Lesson Plan: Radio JOVE Data Analysis**

**Objective**: Understand the characteristics of the data that is collected using the Radio JOVE antenna/receiver system. Using calibrations for the equipment, one can determine a proper measure of the peak intensity of the output, identify the duration of the solar or Jovian radio activity, and calculate the approximate total power emitted by the source. Master these concepts by completing example problems.

#### **National Standards:**

- 1. Content Standard B: Motion and Forces, Structures and Properties of Matter
- 2. Content Standard D: Energy in the Earth System

**Course/Grade level:** Physics, AP Physics / Grade 12

#### Materials:

- 1. Reference material with sample problems
- 2. Student handout page with questions and problems

**Estimated Time:** 45 - 75 minutes for completion of the reading, sample problems, and questions.

#### **Procedure:**

- 1. **Engagement**: Introduction of the activity
  - A. Ask the students to identify where natural radio waves might come from
  - B. Discuss how radio waves might be generated. Discuss interaction of charged particles in magnetic fields.
  - C. Discussion of how energy is released and power emitted.
- 2. **Exploration**: Have the students read the reference material, stopping to discuss parts as needed.
- 3. **Explanation**: Work through the example problems with the students, and then have the students complete the questions on the student page.
- 4. **Extension**: Upon completion of the student questions, discuss any additional questions that the students might have derived from the reading.
- 5. **Evaluation**: Additional questions to assess the students understanding of the concepts of the activity.

#### **Teacher Page 1**

Possible Ideas from the Engagement activities

#### A. Ask the students to identify where natural radio waves might come from

- Lightning.
- Earth aurorae.
- Earth's magnetosphere.
- Other planetary magnetospheres.
- The Sun.

# B. Discuss how radio waves might be generated. Discuss interaction of charged particles and magnetic fields.

- Accelerating charged particles in a magnetic field causes energy to be released.
- Accelerated particles can give off photons of energy in all parts of the spectrum. Natural radio emission is long wavelength and low energy.
- Generated by radio stations, i.e., transmitters [these are man-made signals].

#### C. Discussion of energy released and power emitted.

• Energy and power are calculated by comparing the signal strength to known power sources for comparison. This is called calibration, and we use this to calculate the energy collected by the radio telescope.

# Problems and Answers What is the total power of a Jupiter storm?

Using the figures above for the Jupiter radio storm on December 1, 1999, we can approximate the maximum power emitted during the storm. If we assume that the radio emissions from a Jupiter storm are sent out uniformly in all directions, then the radio energy that we receive on Earth is only a small fraction of the total power emitted by Jupiter. Let's calculate the total power!

1. Calculate the approximate total duration of the Jupiter storm using the time axis (i.e., find the approximate beginning and ending time of the Jupiter burst).

A: about 00:03:50

2. Use a ruler and draw horizontal lines to determine the galactic background intensity and the peak Jupiter burst intensity in db. An alternative is to use the calibration curve in the figure below. Just find the intensity number value on the abscissa and then the corresponding intensity in decibels on the ordinate.

GB = 25 db

Peak Jupiter burst: 18 db

## **Teacher Page 2**

3. Use the flux density curve to determine the flux density for the Jupiter burst on December 1, 1999. Remember that the decibel level used is the signal ABOVE the galactic background baseline level.

A: 
$$S = 1.21 \times 10^{-20} \text{ W/(m}^2 \text{ Hz)}$$

- 4. What is the surface area over which this power is spread? If Jupiter is at opposition, the planets are at their smallest distance (Use Jupiter = 5.2 AU from the Sun).
  - a. The Earth-Jupiter distance (in astronomical units, AU) is:

$$D_{EJ} = 5.2 \text{ AU} - 1.0 \text{ AU} = 4.2 \text{ AU}$$

b. Convert this distance to meters.

$$D_{EJ} = 4.2 \text{ AU} (1.5 \text{ x } 10^{11} \text{ m} / 1 \text{ AU}) = 6.3 \text{ x } 10^{11} \text{ m}$$

5. The radio signals will travel outward at the same rate (the speed of light), filling a sphere centered at the storm. The surface of a sphere of this radius is:

$$A = 4\pi r^2 = 4\pi (6.3 \times 10^{11})^2 = 5.0 \times 10^{24} \text{ m}^2$$

6. For every watt radiated by Jupiter, there will be (1/area) number of watts on each square meter at Earth. Since we received flux in W/(m² Hz) at our antenna, the power emitted from Jupiter in a 1 Hz bandwidth is called the spectral power, w. The spectral power (w) is simply the power per unit frequency and can be computed easily.

w = Flux density x Area

$$w = S \cdot A$$
  
 $w = (1.21 \text{ x} 10^{-20} \text{ W}/(\text{m}^2 \text{ Hz}))(5.0 \text{ x} 10^{24} \text{ m}^2)$ 

$$w = 6.05 \times 10^4 \text{ W/Hz}$$

7. Your answer for #6 shows how many watts of power Jupiter emitted for each Hertz of bandwidth. During a typical Jupiter storm, radio waves are emitted over a frequency range of about 10 MHz (a 10 MHz bandwidth). Assuming that there is equal power per hertz across the entire bandwidth, the total power (W) of this solar burst is:

$$W_{total power} = (6.1 \times 10^4 \text{ W/Hz})(10 \times 10^6 \text{ Hz})$$

$$\mathbf{W}_{\text{total power}} = 6.1 \times 10^{11} \, \mathbf{W}$$

**Total Power = 610 billion watts!** 

[Note: This large power output is actually larger than the power in the solar radio example. The reason is due to our simplifying assumption about Jupiter emitting equally in all directions.]

# Teacher Page 3

## **Jupiter Radio Data Problems**

(Assume a 10 MHz bandwidth for the Jupiter emissions.)

1. If the flux density of a storm were found to be  $1.52 \times 10^{-20} \text{ W/(m}^2 \text{ Hz)}$  when the Earth-Jupiter distance was 4.5 AU, what would be the total power?

 $(8.7 \times 10^{11} \text{ W})$ 

2. If the flux density of a storm were found to be  $1.35 \times 10^{-20} \text{ W/(m}^2 \text{ Hz)}$  when the Earth-Jupiter distance was 4.8 AU, what would be the total power?

 $(8.8 \times 10^{11} \text{ W})$ 

3. If the flux density of a storm were found to be  $1.44 \times 10^{-20} \text{ W/(m}^2 \text{ Hz})$  when the Earth-Jupiter distance was 4.4 AU, what would be the total power?

 $(7.8 \times 10^{11} \text{ W})$ 

**Answer KEY QUIZ** 

Why do we subtract the galactic background to calculate the intensity of a solar or 1. Jupiter radio burst? [Note that this technique is valid for all types of telescope systems.]

To properly calculate the intensity of a radio burst we must remove any other sources of radio noise. The telescope captures Jupiter + the galactic background, so if we want to find the strength of a Jupiter burst we must subtract the contribution caused by the Galaxy.

2. Explain the usefulness of adding a calibration to an observation record? [Hint: Think about how we calculate the absolute power of a burst.]

A calibration is absolutely necessary to calculate the strength of any recorded signal. A calibration signal represents a known (standard) source of energy to compare with incoming radio signals. Without a calibration, the observer can only judge the relative intensity of two signals, and would have no way of comparing signals accurately with other observers. Simply stated, a calibration signal is necessary to accurately compute the power of a received signal.

3. Flux density is a measure of how much energy is received per unit time on a certain area for a given set of frequencies (bandwidth). How would the FLUX of a solar burst differ if two people measured the same burst with the same equipment, but one person was five (5) times farther away from the Sun than Earth (say, on Jupiter's moon Europa)? [Hint: how does flux change with distance?]

Flux is proportional to 1/area, or 1/distance<sup>2</sup>. Thus a person twice (2x) as far away will receive  $1/2^2$ , or 1/4 the energy with the same sized telescope. For an observer five (5x) times farther away, the energy received is 1/25, or 25 times weaker.

### Radio JOVE Educational Materials

(Intentionally blank.)

# **Basics of Radio Emission and Radio JOVE Data Analysis**

#### **Sources of Radio Signals**

Radio signals can be created naturally any time charged particles are accelerated. On Earth, lightning is an example of a natural radio source. As charged particles accelerate in a lightning bolt, radio signals are created that can be received by radio and television receivers. If you have ever heard static as the result of nearby thunderstorms, you have heard the natural radio signal produced by lightning.

On Jupiter, radio signals are created as charged particles are accelerated in Jupiter's powerful magnetic field. Sources of charged particles near Jupiter come from the solar wind and the innermost Jovian moon, Io. Io is volcanically active and this results in a cloud of sulfur, sodium, and other atoms being shot into space. Ultraviolet light from the Sun has enough energy to remove electrons from these atoms and the electrons then move toward Jupiter under the influence of the dominant force, electromagnetism. Since Jupiter has a strong magnetic field, the electrons move along the magnetic field lines and spiral their way down toward Jupiter's poles. This is similar to the way auroras are formed near the poles on Earth.

The frequency of the radio waves emitted depends on many local parameters in the Jovian magnetosphere, namely the strength of the magnetic field and the density of the plasma. Because the field strength and plasma density varies around Jupiter, the planet can emit a wide range of frequencies of radio waves. The upper limit of frequency for Jupiter radio signals is the spiraling frequency of the most energetic electrons that can be held by Jupiter's magnetic field (which is related to the maximum magnetic field above the cloud tops) — about 40 MHz. The lowest frequency that can be detected on Earth from Jupiter is determined by the lowest frequency that can penetrate Earth's ionosphere and reach the surface — about 8 MHz. Therefore, the signals that can be detected on Earth range in frequency from about 8 MHz to 40 MHz. Jupiter emits radio signals at even higher frequencies, however, as high as 300 gigahertz (GHz), but the process by which this radiation is emitted is different. One needs a large radio dish to receive these signals.

#### Radio JOVE Data Output

The output of the Radio JOVE antenna and receiver is usually collected by a tape recorder or a computer. Using Radio Skypipe software, the data can be collected directly from the receiver to your computer through a sound card (or played back to the computer later from a tape). The output looks like the Figure 1 below which has been marked to show the features.

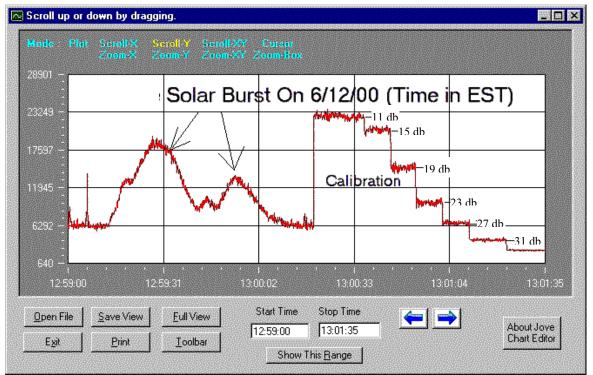


Figure 1

Notice the axes of the graph. Eastern Standard Time (EST) is plotted on the abscissa (horizontal or x-axis), and an arbitrary intensity unit is plotted on the ordinate (vertical or y-axis). Because each antenna system setup is different, a calibration must be completed to convert the data into a real intensity unit. This unit is a decibel (db) named after Alexander Graham Bell, and was first defined as a way to measure sound levels. For a radio antenna, however, decibels are related to the ratio of two noise intensities, one that is measured and one that is a reference. Decibel markings made from a calibrated noise source connected to the receiver are shown in Figure 1.

On the left side of Figure 1 we see two solar bursts corresponding to the two broad peaks in the output. Also notice the trace of data just before and after the solar burst. The relatively flat sections of data represent the baseline of the data. This baseline can be thought of as a zero point for the data, but in reality your antenna system is collecting radio signals from other sources as well. This other source is the Milky Way galaxy. This constant galactic radio signal comes from all directions in space and is very weak compared to solar or Jovian radio bursts. Therefore the baseline is often called the galactic background (GB).

Using the intensity-time data (Figure 1) we can make some interesting calculations.

1. Calculate the approximate total duration of the solar bursts using the time axis (i.e., find the approximate beginning and ending time of the solar burst). The answer for this example is:

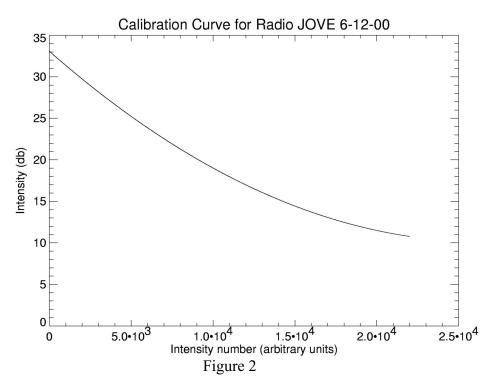
Burst End Time = 13:00:10 Burst Start Time: 12:59:12

Burst Duration = end time — start time = 00:00:58, or 58 seconds

2. Use a ruler and draw horizontal lines on the graph above to determine the galactic background intensity and the peak solar burst intensity in db. An alternative is to use the calibration curve in Figure 2 below. Just find the intensity number value on the abscissa and then the corresponding intensity in decibels on the ordinate. Note that the calibration curve is just a best-fit curve of the calibration db levels and the stripchart recorder output levels [shown on the data graph above]. Creating a curve simplifies the process of converting the data to real units.

For this example:

Galactic Background level: 27 db Peak Solar Burst level: 17 db



3. Determine the intensity of the source (the Sun) above the galactic background. For our example:

Source intensity above the galactic background:

Intensity = Galactic background — Solar Burst

= 27 db - 17 db = 10 db

#### What is the Total Power of a Solar Burst?

If we assume that the radio emissions from the Sun are sent out uniformly in all directions, then the radio energy that we receive on Earth is only a small fraction of the total power emitted by the Sun. Because the radio emissions are sometimes beamed in narrow angles, our calculation is an upper limit to the total power of each burst. However,

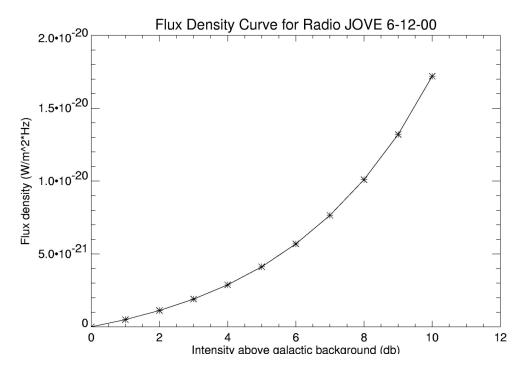
the true complex nature of each type of radio burst is unknown and scientists are still learning how these radio bursts are created and how they propagate in space.

The double dipole antenna of the Radio JOVE receiver has an effective area of about 128 square meters (128 m²), so the solar radio signal that falls within this area is the signal that is sent to the receiver. The receiver indicates the presence of a solar burst by showing a signal level that is above the galactic background level. Using these values, the effective area of the antenna, and several other parameters of the radio telescope used, the flux density (S) can be calculated. For simplicity in the calculation, the flux density curve is given below. Note that the curve is non-linear because the decibel is a logarithmic unit.

The flux density is simply the total power in watts landing on each square meter of antenna for each 1 Hz of frequency bandwidth. The units are the watt (W) or power per unit area (square meters,  $m^2$ ) per hertz (Hz). So this quantity represents the power of the radio emissions measured at Earth per unit area per frequency unit. [Note: A unit of flux density called the Jansky was named in honor of Karl Jansky, a pioneer of radio astronomy. The definition of the Jansky is:  $1 J = 10^{-26} W/(m^2 Hz)$ .].

Use the flux density curve Figure 3 to determine the flux density for the solar burst on June 12, 2000. Remember that the decibel level used is the signal ABOVE the galactic background baseline level. For a 10 db signal peak, the answer is:

$$S = 1.7 \times 10^{-20} \text{ W/(m}^2 \text{ Hz)}$$



Now this power started out at the Sun and we assume it has spread evenly outward as an expanding spherical surface. The next question is, what is the surface area over which this power is spread.

The Earth-Sun distance (in astronomical units, AU) is 1.0 AU.

$$D_{ES} = 1.0 \text{ AU} (1.5 \text{ x } 10^{11} \text{ m} / 1 \text{ AU}) = 1.5 \text{ x } 10^{11} \text{ m}$$

The radio signals will travel outward at the same rate (the speed of light), filling a sphere centered at the storm. The surface of a sphere of this radius is:

$$A = 4\pi r^2 = 4\pi (1.5 \text{ x } 10^{11})^2 = 2.8 \text{ x} 10^{23} \text{ m}^2$$

For every watt radiated by the Sun, there will be (1/area) number of watts on each square meter at Earth. Since we received flux in W/(m² Hz) at our antenna, the power emitted from the Sun in a 1 Hz bandwidth is called the spectral power, w. The spectral power (w) is simply the power per bandwidth (Watts/frequency) and can be computed easily.

$$w = Flux density x Area$$
  
 $w = S \cdot A$   
 $w = (1.7 \times 10^{-20} \text{ W/(m}^2 \text{ Hz}))(2.8 \times 10^{23} \text{ m}^2)$   
 $w = 4.8 \times 10^3 \text{ W/Hz}$ 

So the Sun emitted 4800 watts of power for each hertz of bandwidth over which it emitted radio waves. During a typical solar burst, radio waves are emitted over a frequency range of about 1 MHz (a 1 MHz bandwidth). Assuming that there is equal power per hertz across the entire bandwidth, the total power (W) of this solar burst is:

$$W_{\text{total power}} = (4.8 \text{ x } 10^3 \text{ W/Hz})(1 \text{x} 10^6 \text{ Hz})$$
  
 $W_{\text{total power}} = 4.8 \text{ x } 10^9 \text{ W}$ 

This is a power output of about 5 billion watts! This is much more power than can be put out by the largest power plant in the world. This amount of power would be enough to power a large city during the storm.

# Resource Page 1

#### **Jupiter Radio Storm Data Analysis**

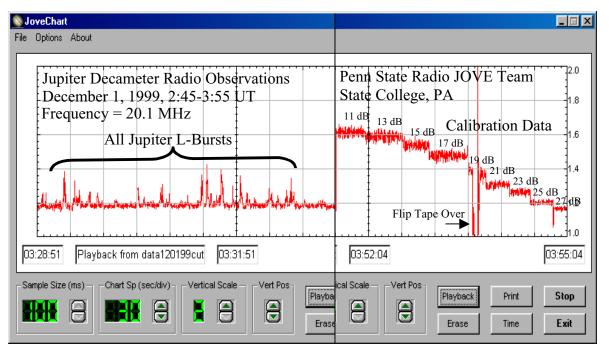


Figure 4

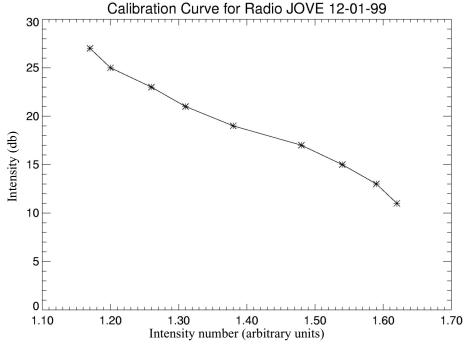
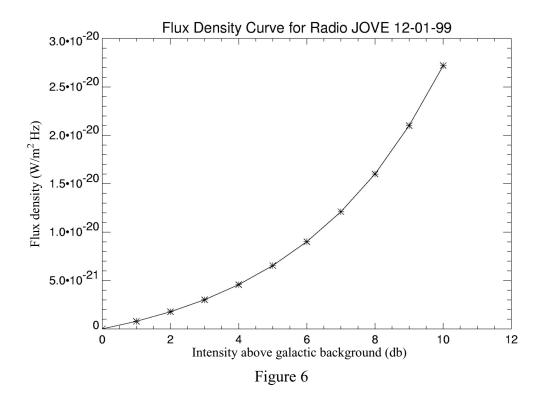


Figure 5

# **Resource Page 2**



Stude	nt Page 1	NAME
What	is the total power of a Jupite	r storm?
approx emission energy	simate the maximum power emons from a Jupiter storm are se	er radio storm on December 1, 1999, we can litted during the storm. If we assume that the radio nt out uniformly in all directions, then the radio ly a small fraction of the total power emitted by r!
1.		al duration of the Jupiter storm using the time axis ginning and ending time of the Jupiter burst).
		Ans:
2.	background intensity and the to use the calibration curve Fi	al lines on Figure 4 to determine the galactic peak Jupiter burst intensity in db. An alternative is gure 5. Just find the intensity number value on the onding intensity in decibels on the ordinate.
		Ans:
		Ans:
3.	•	gure 6) to determine the flux density for the Jupiter temember that the decibel level used is the signal and baseline level.
		Ans:
4.	opposition, the planets are at the Sun).	which this power is spread? If Jupiter is at their smallest distance (Use Jupiter = 5.2 AU from ance (in astronomical units, AU) is:  Ans:
	b. Convert this distance	
		Ans:
5.	<del>-</del>	outward at the same rate (the speed of light), filling a The surface of a sphere of this radius is:
		Ans:

# **Student Page 2**

For every watt radiated by Jupiter, there will be (1/area) nu square meter at Earth. Since we received flux in W/(m² Hz) power emitted from Jupiter in a 1 Hz bandwidth is called the spectral power (w) is simply the power per bandwidth Calculate the spectral power.	) at our antenna, the ne spectral power, w.
	Ans:
Your answer for #6 shows how many watts of power Jupiter Hertz of bandwidth. During a typical Jupiter storm, radio va a frequency range of about 10 MHz (a 10 MHz bandwidth) spectral power is isotropic, that is that there is equal power entire bandwidth, the total power (W) of this solar burst is:	waves are emitted over  . Assuming the above per hertz across the
Jupiter Radio Data Problems	Ans:
sume a 10 MHz bandwidth for the Jupiter emissions.)	
If the flux density of a storm were found to be $1.52 \times 10^{-20}$ Earth-Jupiter distance was 4.5 AU, what would be the total	
	Ans:
If the flux density of a storm were found to be $1.35 \times 10^{-20}$ Earth-Jupiter distance was 4.8 AU, what would be the total	
	Ans:
If the flux density of a storm were found to be $1.44 \times 10^{-20}$	$W/(m^2 Hz)$ when the
Earth-Jupiter distance was 4.4 AU, what would be the total	
	power emitted from Jupiter in a 1 Hz bandwidth is called the spectral power (w) is simply the power per bandwidth Calculate the spectral power.  Your answer for #6 shows how many watts of power Jupite Hertz of bandwidth. During a typical Jupiter storm, radio of a frequency range of about 10 MHz (a 10 MHz bandwidth) spectral power is isotropic, that is that there is equal power entire bandwidth, the total power (W) of this solar burst is:  Jupiter Radio Data Problems  ssume a 10 MHz bandwidth for the Jupiter emissions.)  If the flux density of a storm were found to be 1.52 x 10 <sup>-20</sup> Earth-Jupiter distance was 4.5 AU, what would be the total Earth-Jupiter distance was 4.8 AU, what would be the total

QUIZ Name	
1. Why do we subtract the galactic background to calculate the intensity Jupiter radio burst? [Note that this technique is valid for all types of telescop	
2. Explain the usefulness of adding a calibration to an observation recor [Hint: Think about how we calculate the absolute power of a burst.]	<sup>-</sup> d.
3. Flux density is a measure of how much energy is received per unit tir certain area for a given set of frequencies (bandwidth). How would the FLUX burst differ if two people measured the same burst with the same equipment, person was five (5) times farther away from the Sun than Earth (say, on Jupi Europa)? [Hint: how does flux change with distance?]	X of a solar but one