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.

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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

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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: $S = 1.21 \text{ x}10^{-20}$ W/(m^2 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 AU — 1.0 AU = 4.2 AU
   b. Convert this distance to meters.
   D_{EJ} = 4.2 AU (1.5 x 10^{11} m / 1 AU) = 6.3 x 10^{11} 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:

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

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/(m^2 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

$$w = S \cdot A$$

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

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

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:

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

$$W_{\text{total power}} = 6.1 \text{ x } 10^{11} \text{ W}$$

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.]

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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 $x10^{-20}$ W/(m^2 Hz) when the Earth-Jupiter distance was 4.5 AU, what would be the total power?
(8.7 $x10^{11}$ W)

2. If the flux density of a storm were found to be 1.35 $x10^{-20}$ W/(m^2 Hz) when the Earth-Jupiter distance was 4.8 AU, what would be the total power?
(8.8 $x10^{11}$ W)

3. If the flux density of a storm were found to be 1.44 $x10^{-20}$ W/(m^2 Hz) when the Earth-Jupiter distance was 4.4 AU, what would be the total power?
(7.8 $x10^{11}$ W)

Answer KEY QUIZ

1. Why do we subtract the galactic background to calculate the intensity of a solar or 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^2. 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.

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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.

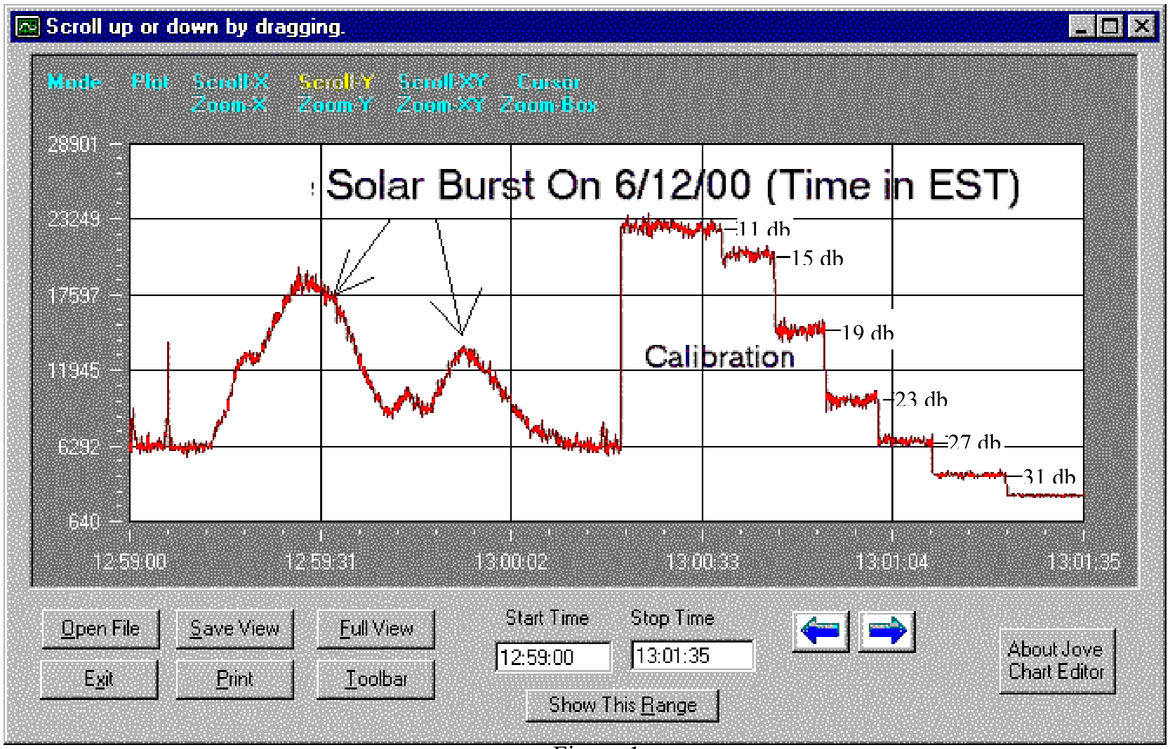

Figure 1

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

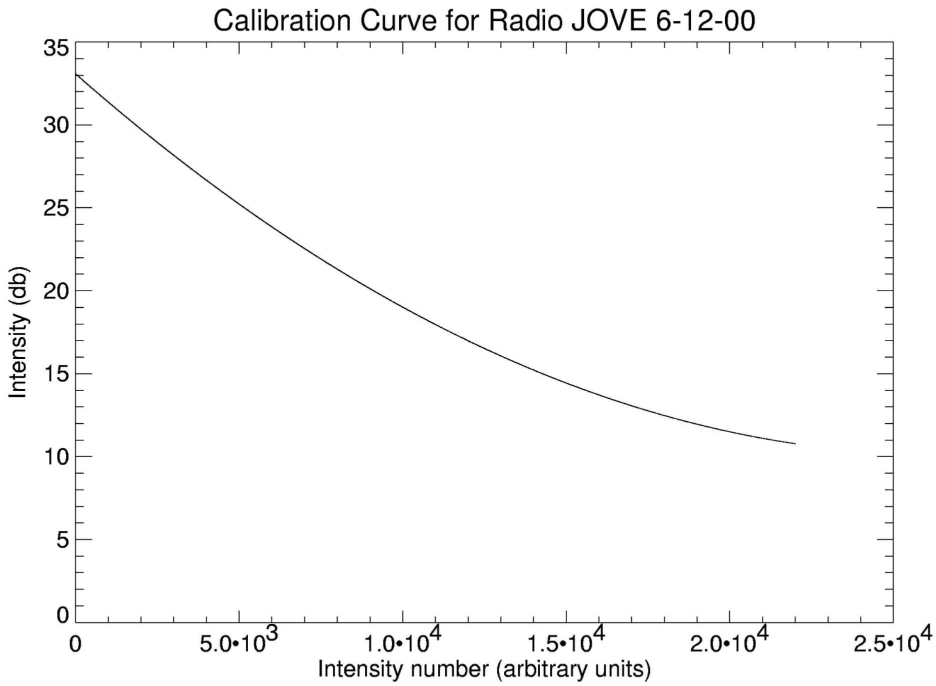

Figure 2

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 m^2), 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:

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

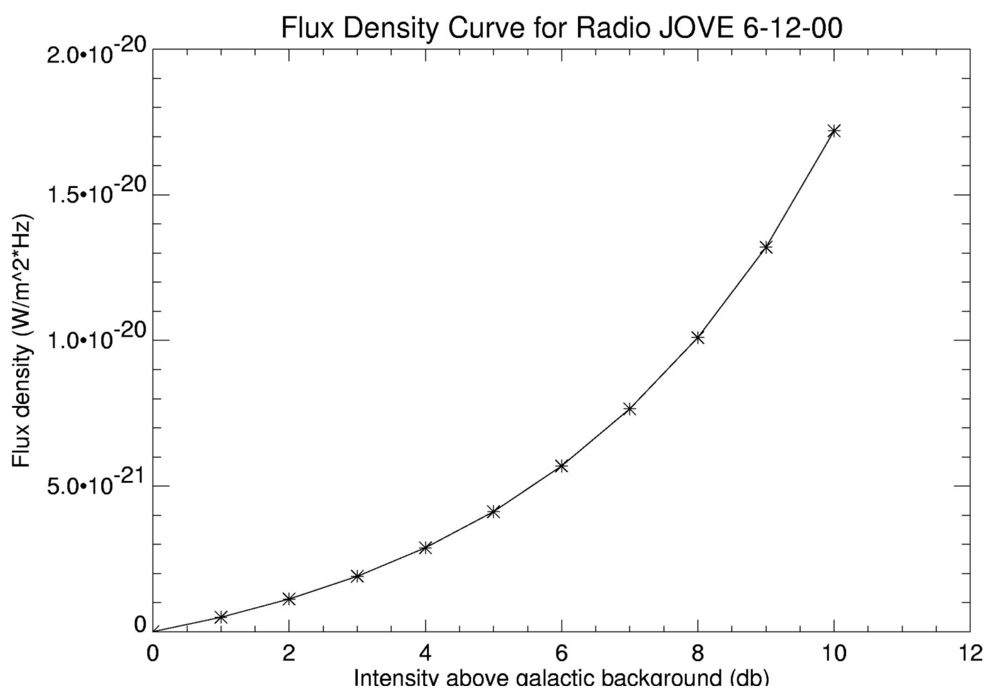

Figure 3

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.

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

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:

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

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 $W/(m^2 \text{ Hz})$ 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.

$$w = \text{Flux density x Area}$$

$$w = S \cdot A$$

$$w = (1.7 \times 10^{-20} \text{ W}/(\text{m}^2 \text{ Hz}))(2.8 \times 10^{23} \text{ m}^2)$$

$$w = 4.8 \times 10^3 \text{ W/Hz}$$

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:

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

$$W_{\text{total power}} = 4.8 \times 10^9 \text{ W}$$

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

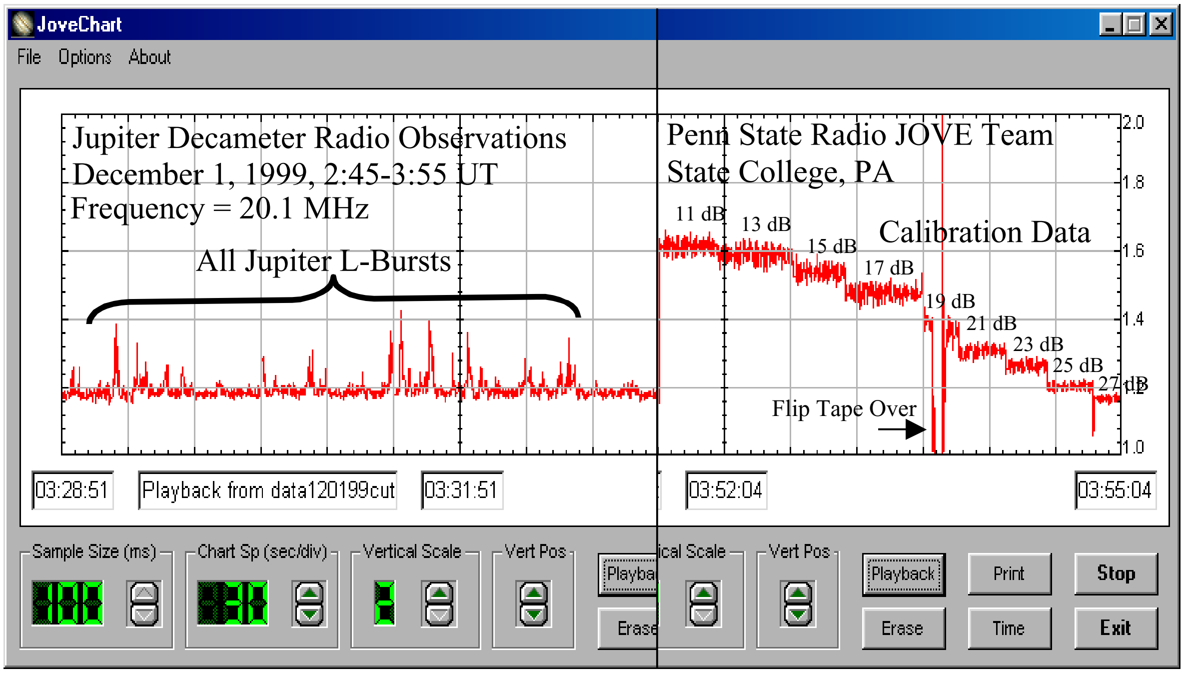

Figure 4

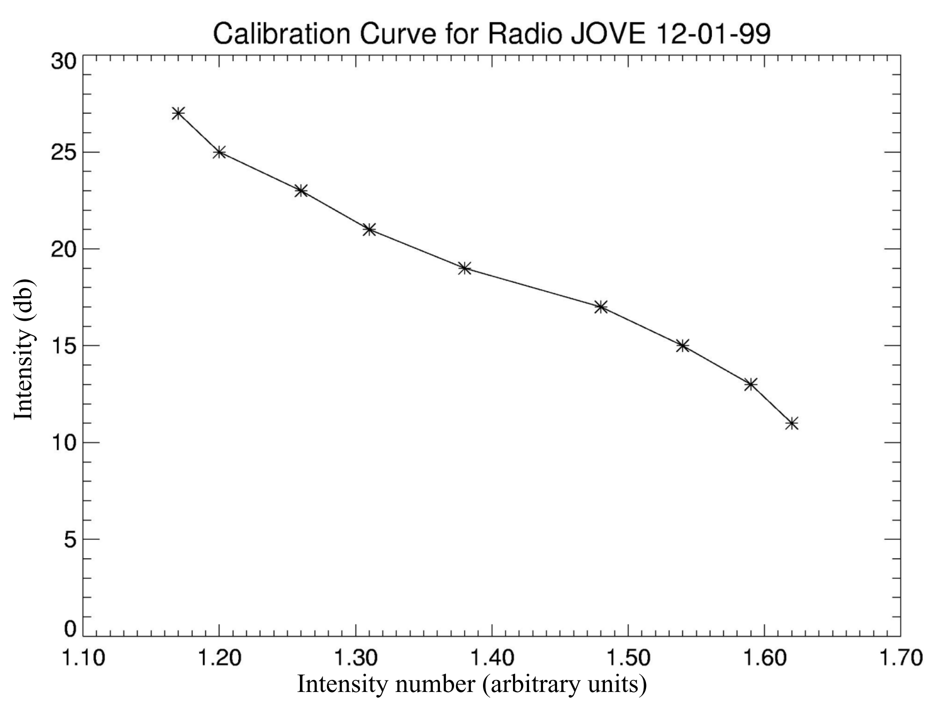

Figure 5

Resource Page 2

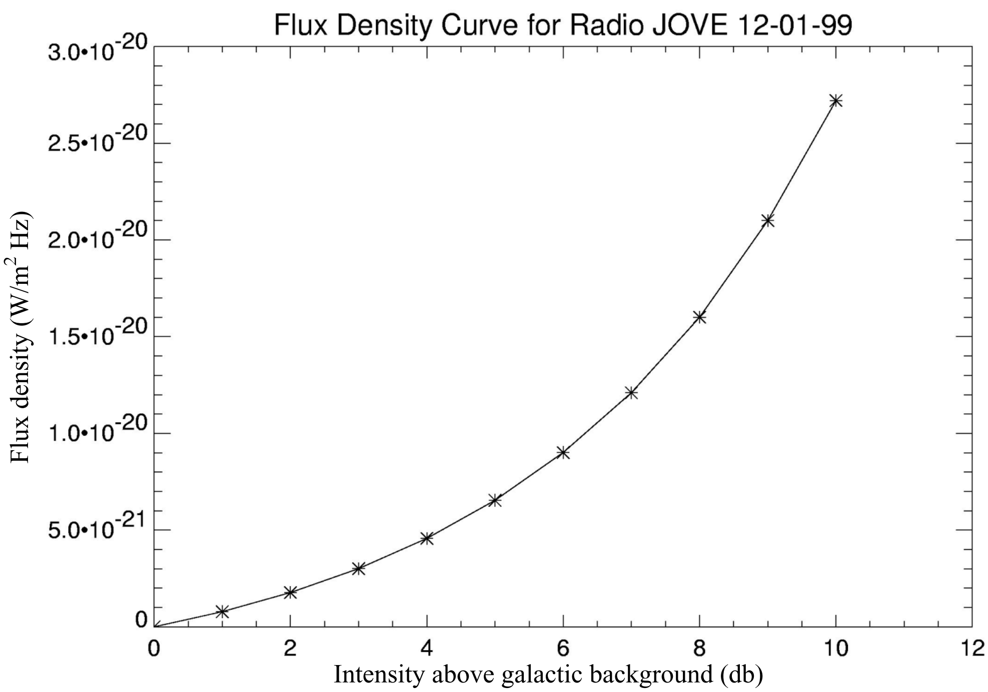

Figure 6

Student Page 1 **NAME ________________________________**

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).

   Ans: _____________

2. Use a ruler and draw horizontal lines on Figure 4 to determine the galactic background intensity and the peak Jupiter burst intensity in db. An alternative is to use the calibration curve Figure 5. Just find the intensity number value on the abscissa and then the corresponding intensity in decibels on the ordinate.

   Ans: _____________
   Ans: _____________

3. Use the flux density curve (Figure 6) 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.

   Ans: _____________

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:
      Ans: _____________
   b. Convert this distance to meters.
      Ans: _____________

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:

   Ans: _____________

Student Page 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/(m^2 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 bandwidth (Watts/frequency). Calculate the spectral power.

Ans: _____________

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 the above spectral power is isotropic, that is that there is equal power per hertz across the entire bandwidth, the total power (W) of this solar burst is:

Ans: _____________

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 x 10^{-20} W/(m^2 Hz) when the Earth-Jupiter distance was 4.5 AU, what would be the total power?

Ans: _____________

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

Ans: _____________

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

Ans: _____________

QUIZ **Name __________________________**

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

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

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?]