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 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 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.

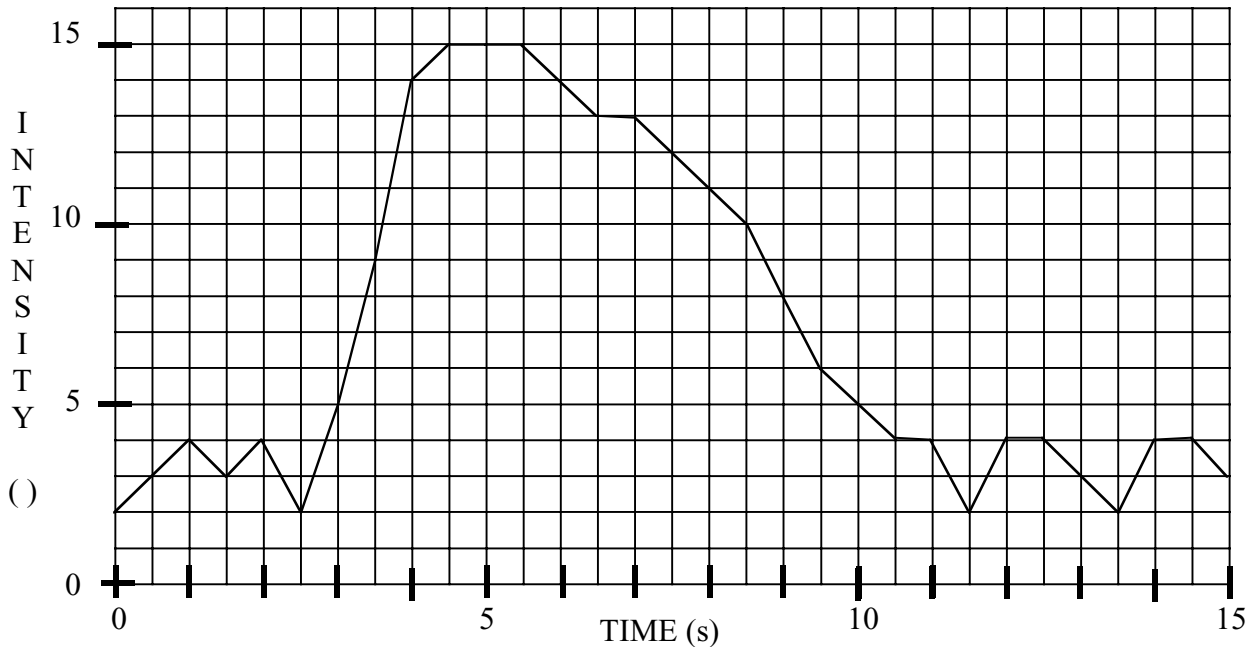**B. Ask the students what they think should be labeled on a graph.**
- Accurate scale markings with units of measurement.
- Title, axes (both X and Y) and, if the data are 3-dimensional, the Z axis.

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.

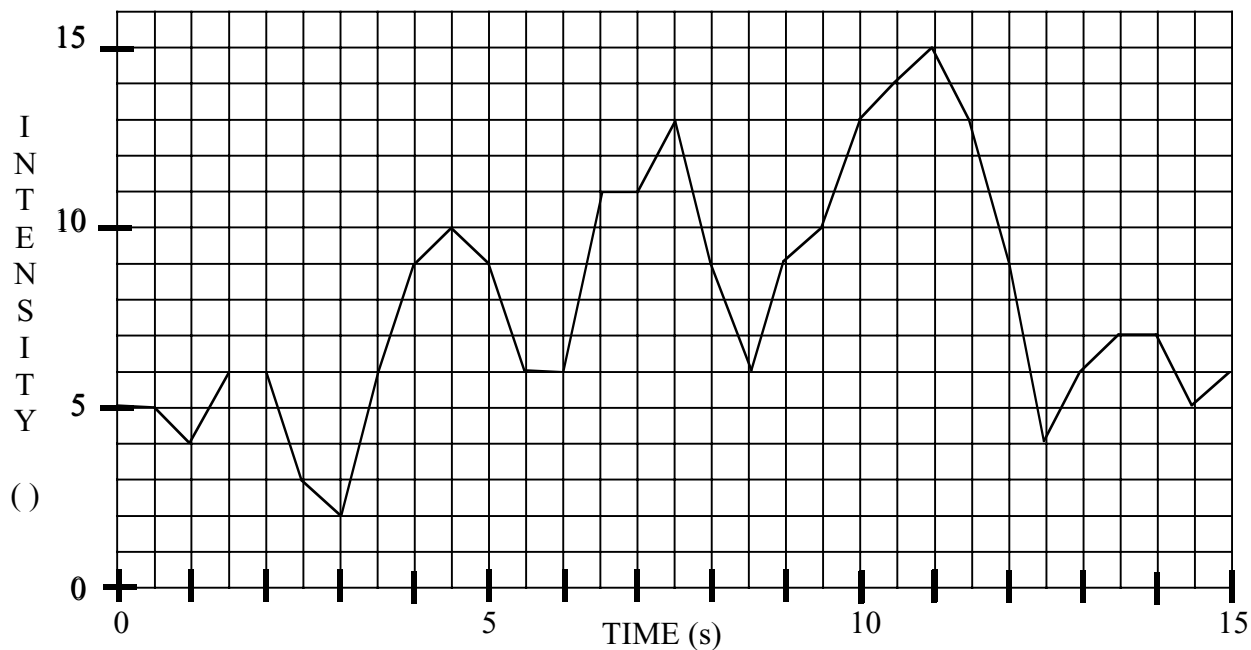| Time (s)	Intensity ( )		Time (s)	Intensity ( )		Time (s)	Intensity ( )
0.0	2						
0.5	3		5.5	15		10.5	4
1.0	4		6.0	14		11.0	4
1.5	3		6.5	13		11.5	2
2.0	4		7.0	13		12.0	4
2.5	2		7.5	12		12.5	4
3.0	5		8.0	11		13.0	3
3.5	9		8.5	10		13.5	2
4.0	14		9.0	8		14.0	4
4.5	15		9.5	6		14.5	4
5.0	15		10.0	5		15.0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

TEACHER PAGE 3

2.

Time (s)	Intensity ( )		Time (s)	Intensity ( )		Time (s)	Intensity ( )
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.

TEACHER PAGE 4

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)?
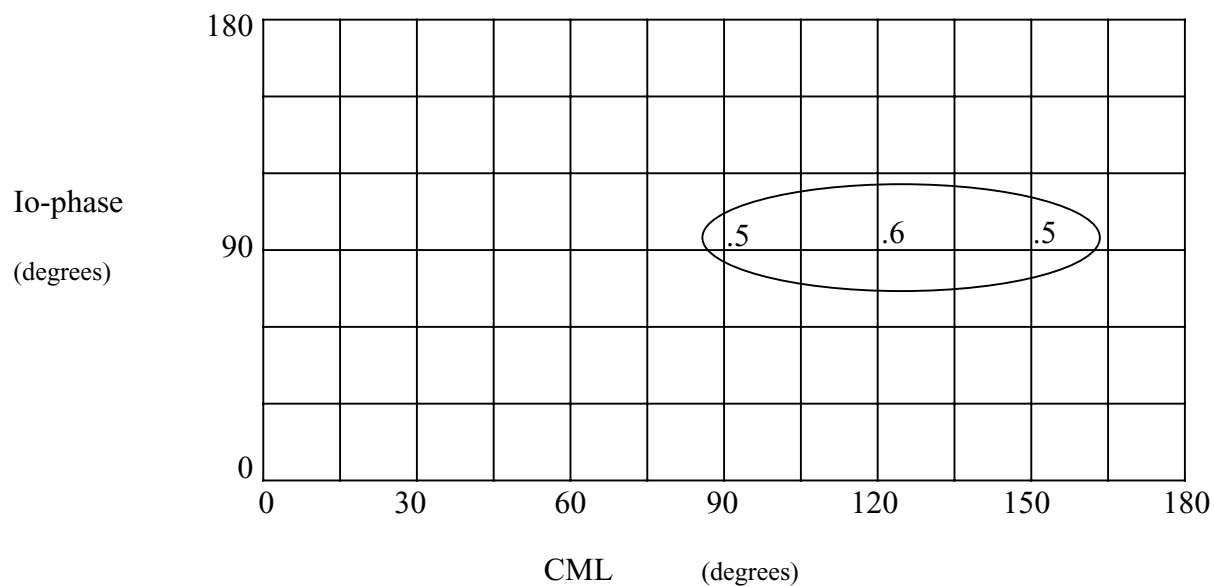**Ans: 5**

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).

TEACHER PAGE 5

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

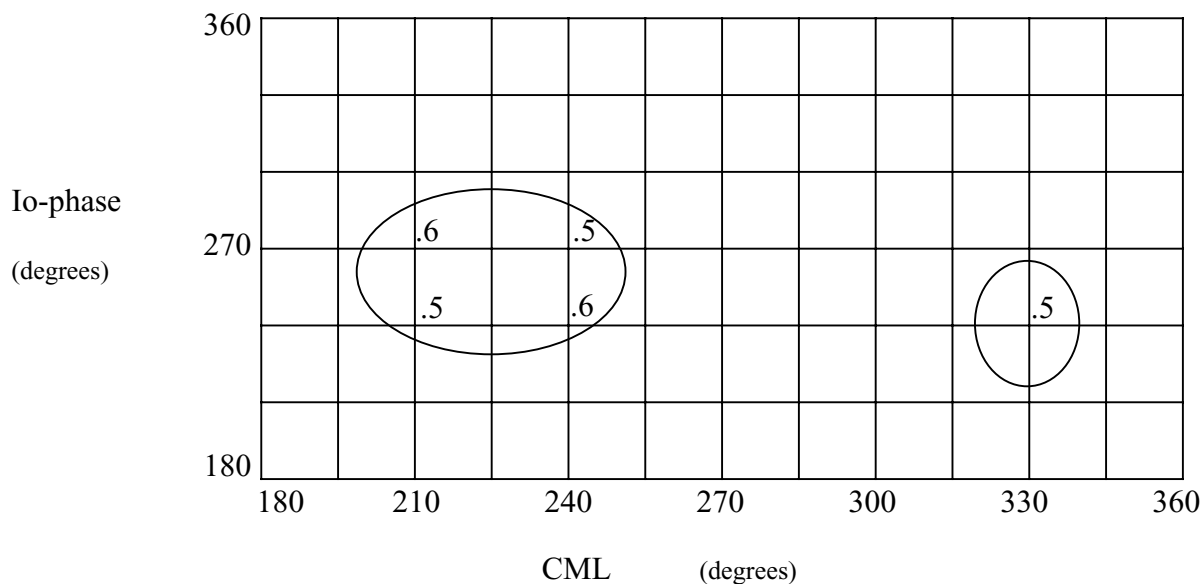| CML	Io-phase	Probability		CML	Io-phase	Probability		CML	Io-phase	Probability
(°)	(°)	( )		(°)	(°)	( )		(°)	(°)	( )
0	0	0		60	0	0		120	0	.1
0	30	0		60	30	0		120	30	.1
0	60	0		60	60	0		120	60	.1
0	90	0		60	90	0		120	90	.6
0	120	0		60	120	0		120	120	.1
0	150	0		60	150	0		120	150	.1
0	180	0		60	180	0	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

TEACHER PAGE 6

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

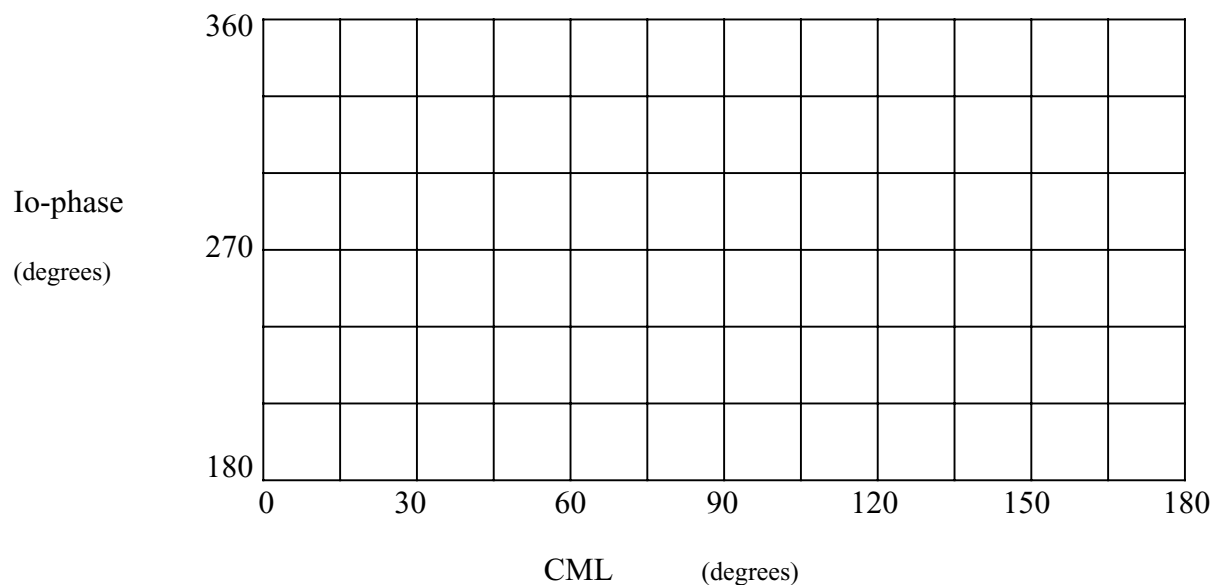| CML	Io-phase	Probability		CML	Io-phase	Probability		CML	Io-phase	Probability
(°)	(°)	( )		(°)	(°)	( )		(°)	(°)	( )
180	180	0		240	180	.1		300	180	0
180	210	0		240	210	.1		300	210	0
180	240	0		240	240	.6		300	240	0
180	270	0		240	270	.5		300	270	0
180	300	0		240	300	.1		300	300	0
180	330	0		240	330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

TEACHER PAGE 7

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.

TEACHER PAGE 8

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

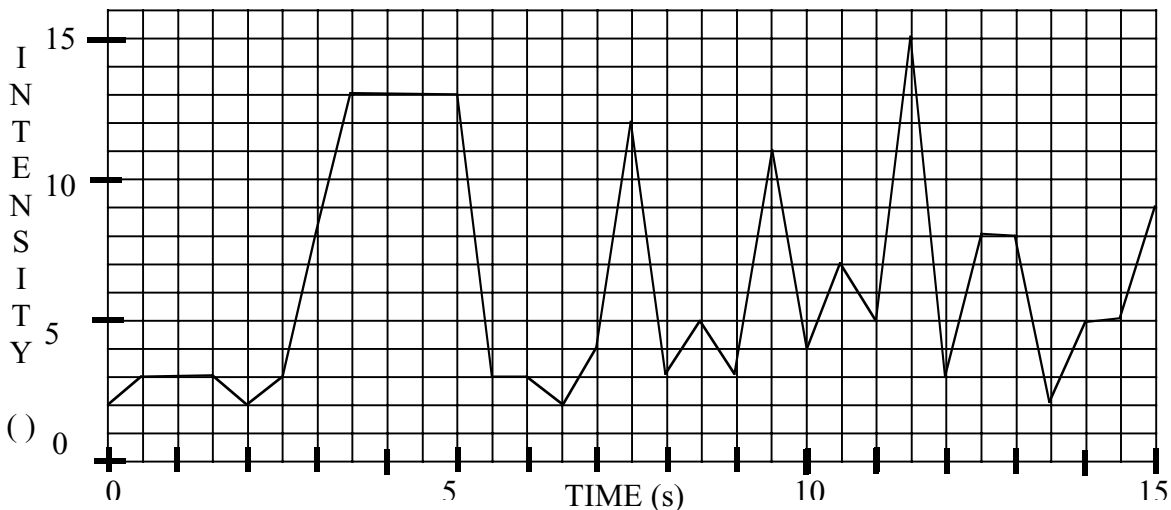1.   What is the origin of a graph? Explain using the words axes and coordinates.

> **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

Time (s)	Intensity ( )		Time (s)	Intensity ( )		Time (s)	Intensity ( )
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.

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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.
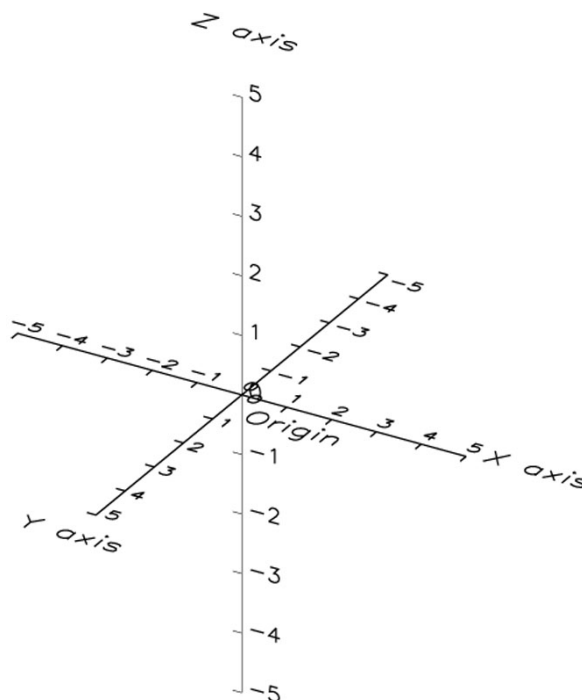
Image1

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 (s)	Intensity ( )		Time (s)	Intensity ( )		Time (s)	Intensity ( )
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.
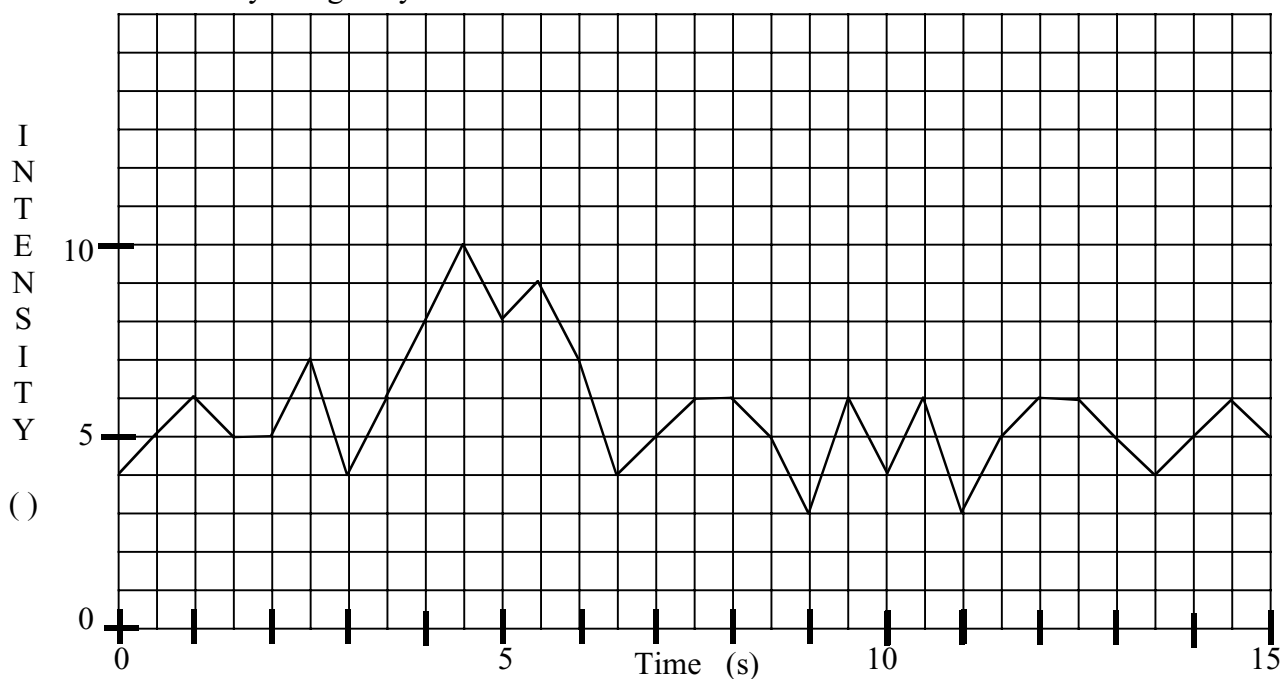
If we examine the x-y graph we can see that, while the intensity values jumped around quite a bit, there was a time during the 15-second interval where the value stayed higher than the rest of the time. That would be between times of about 4 seconds and 6 seconds. You could also see the high numbers 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.

Image 2
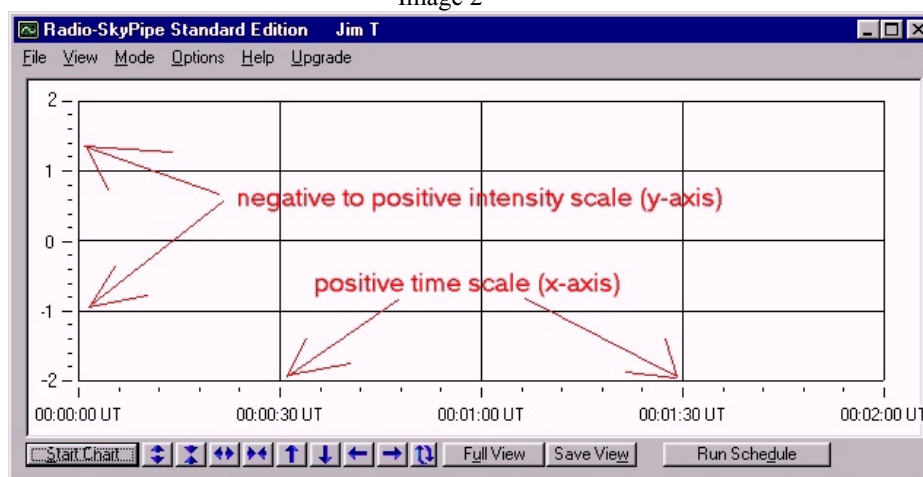
Radio-SkyPipe

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.**

Image 3
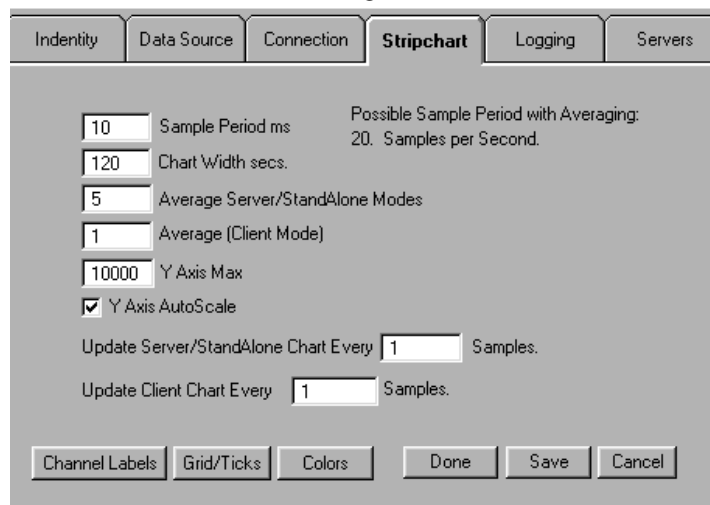
Radio-SkyPipe Stripchart Dialog Box showing sample period, average, update chart, and more

Sample period
The difference in time between each recorded data point is known as thesample 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.
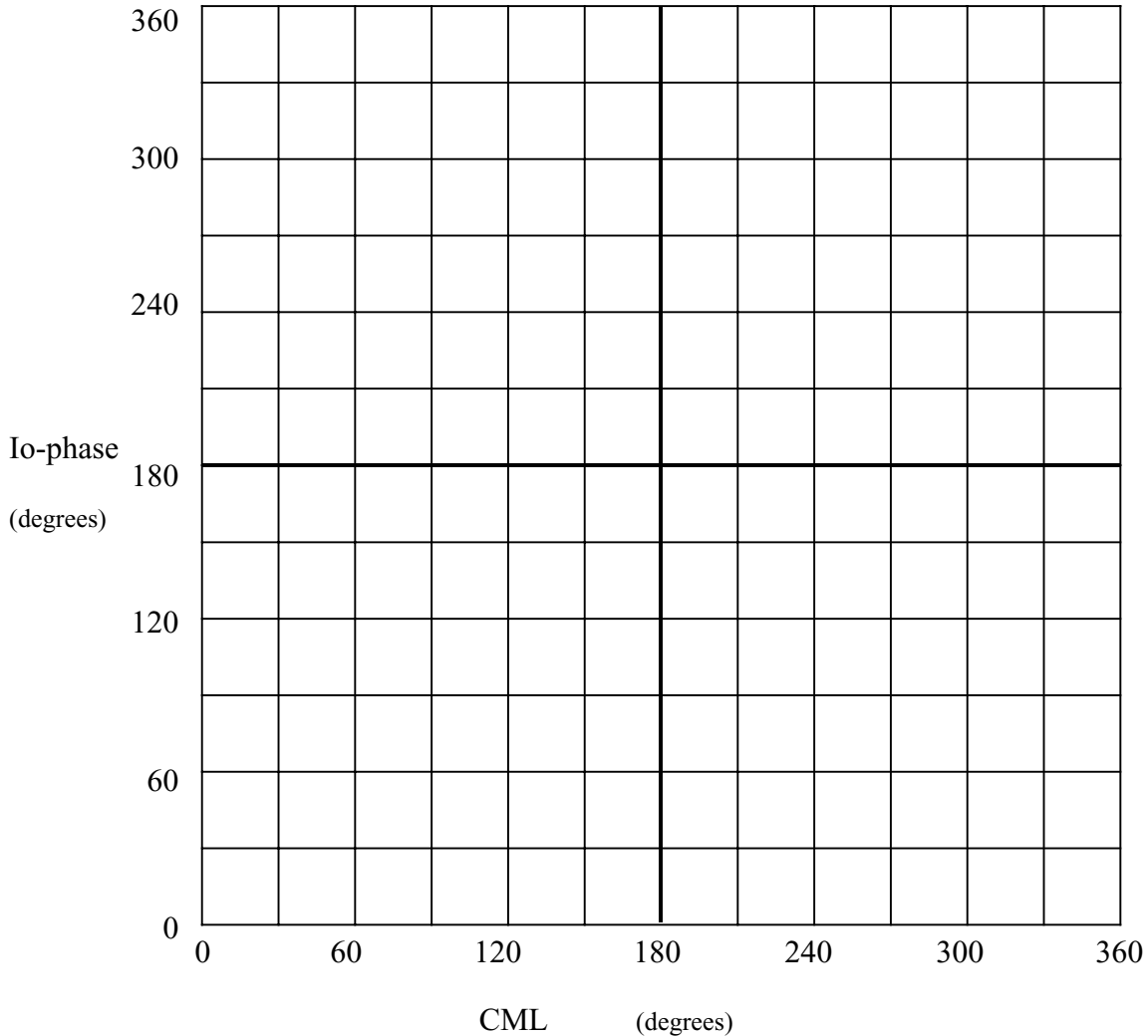
As Jupiter rotates, the CML changes from 0° to 360° (0°) in about 10 hours. As Io orbits Jupiter, the Io phase changes from 0° to 360° (0°) in about 42 hours. Observations over several years have yielded probability values for Jupiter storms for every CML-Io phase combination. The probability is computed 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
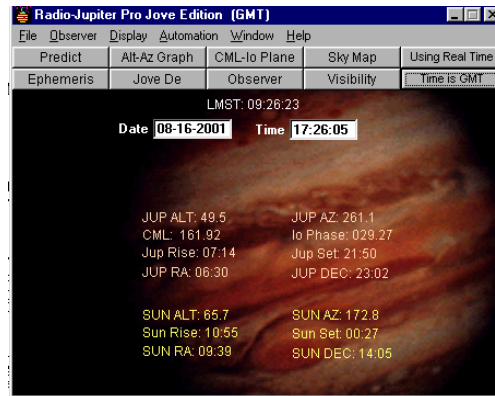

Radio-JupiterPro Software

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
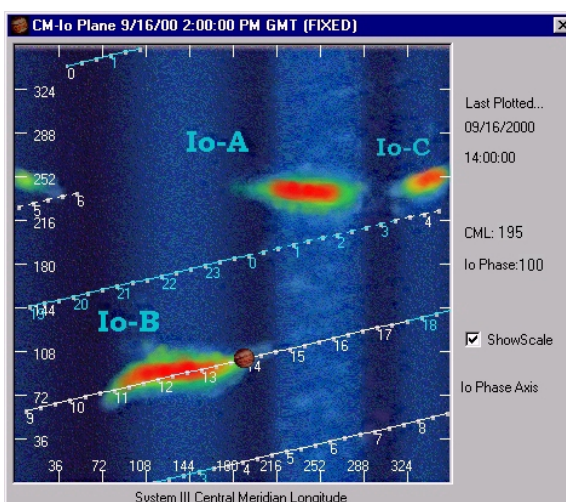
As you can see from the graph above, the CML of Jupiter is on the x-axis, the Io phase is on the y-axis, and the probability is on the z-axis which is represented by a color scale. The darker colors are lower probability and the lighter colors display higher probability of receiving emission (red being 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
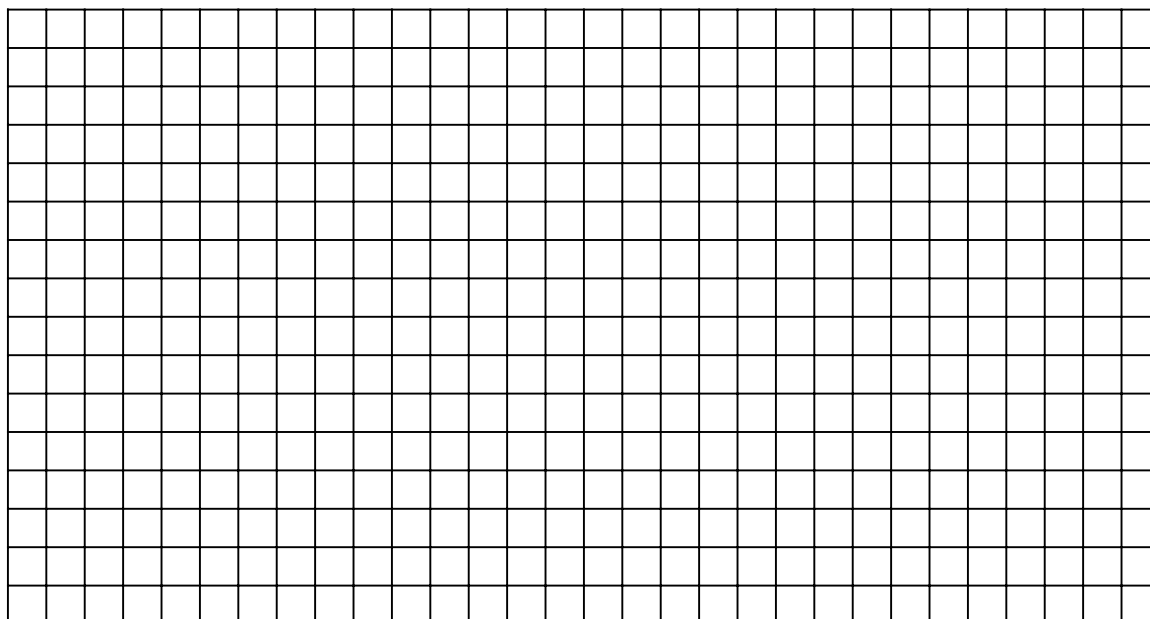The Radio-SkyPipe graph and the CML-Io Phase Plane graph are two essential graphing tools in displaying and predicting Jupiter radio emissions. From these graphs it is easy to see why scientists use graphing techniques to display their data. Graphs say a lot in a concise format. As long as you understand what the different parts of a graph are, the results can be understood and appreciated.

Student Page 1   **Name** _____

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

1.

Time (s)	Intensity ( )		Time (s)	Intensity ( )		Time (s)	Intensity ( )
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

Student Page 2

2.

Time (s)	Intensity ( )		Time (s)	Intensity ( )		Time (s)	Intensity ( )
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.

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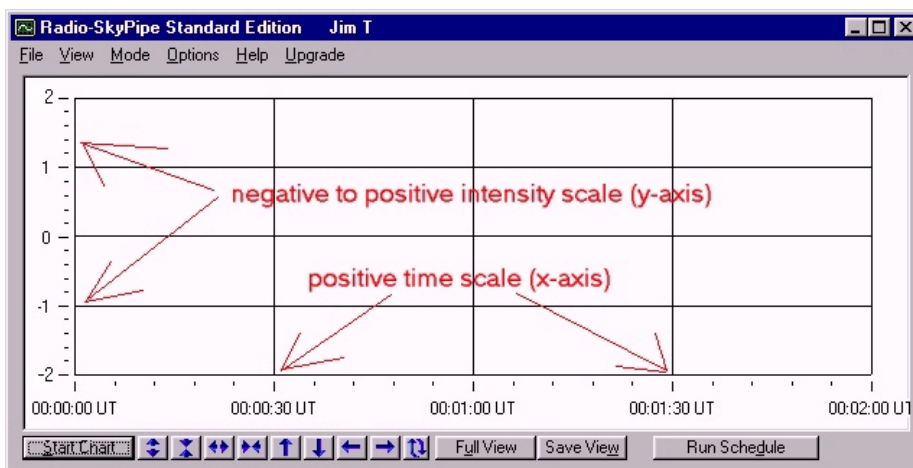
3. What would be the time difference between sections in the above graph if you started at 00:00:00UT and ended at 00:08:00UT?

_____

_____

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?

_____

_____

Student Page 4

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 every how many milliseconds?

    _____

    _____

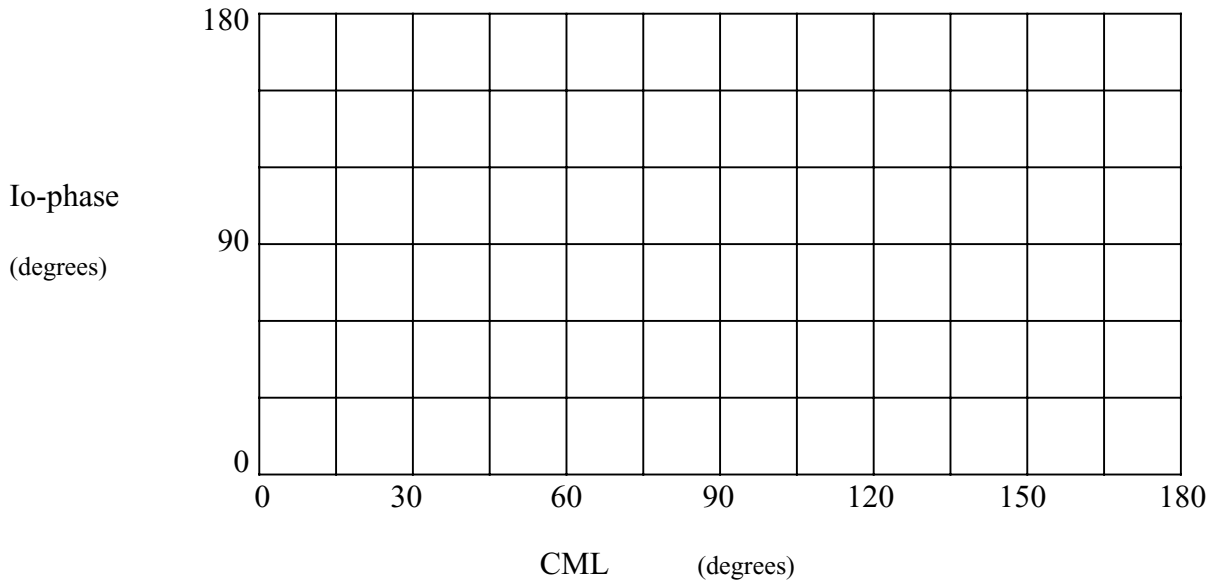
9. If you set your sample rate to 10 samples/sec. What would you need to set your average in order to plot 2 times a second (500 ms)?

    _____

    _____

Student Page 5

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

Io-phase

(degrees)

180

90

0

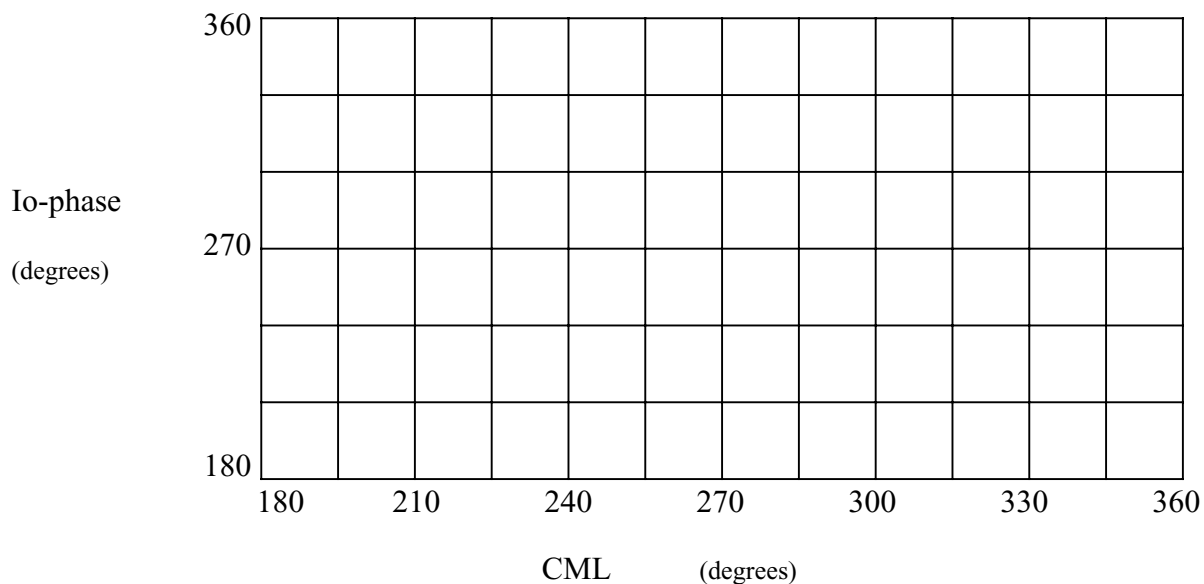0   30   60   90   120   150   180

CML   (degrees)

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.

Student Page 6

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

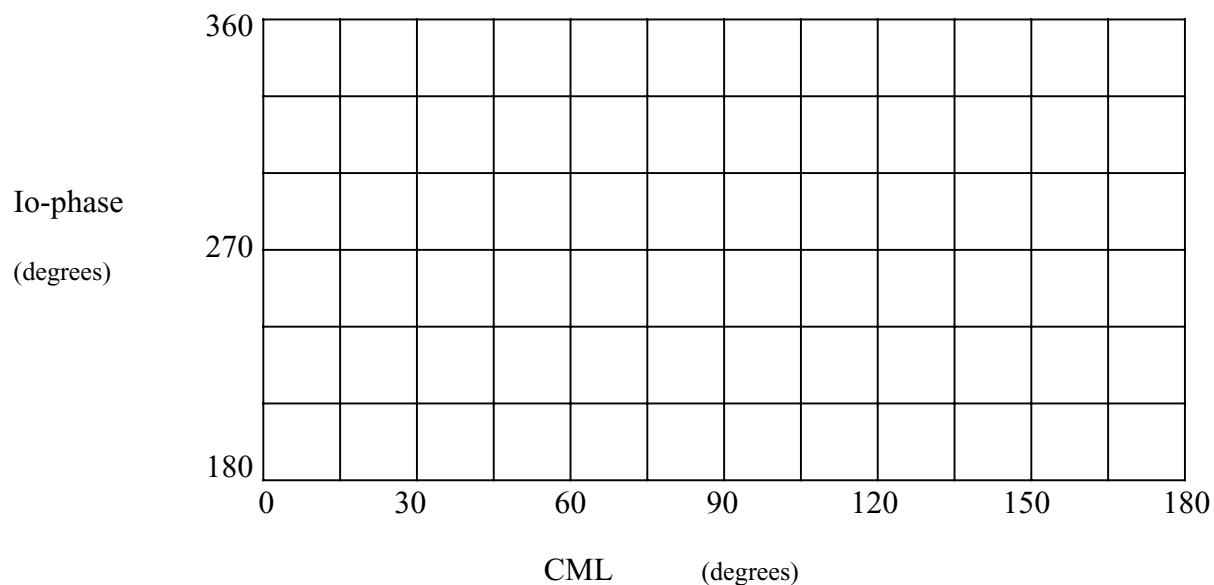

Io-phase

(degrees)

CML   (degrees)

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.

Student Page 7

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.

Student Page 8
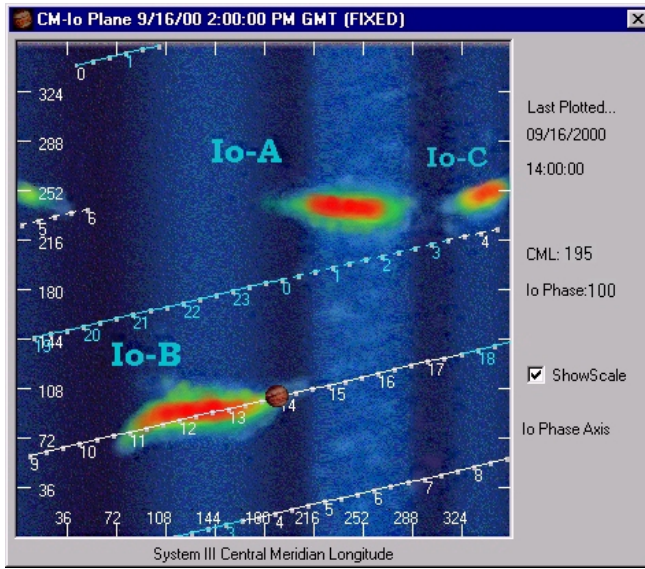
13. Based on the graph above, would an Io phase of 80 degrees and Jupiter CML of 140 degrees give a high probability of receiving radio emission from Jupiter? If so, is it Io-A, B, or C related?

_____

_____

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?

_____

_____

QUIZ   Name_____

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.

Time (s)	Intensity ( )		Time (s)	Intensity ( )		Time (s)	Intensity ( )
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