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. Quiz

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

Estimated Time:

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

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 Activity Questions 1-4.
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 Page 1

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 ^{o} 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^o east and west and 30^o north and south. The total beam size is 70^o by 60^o. 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:** 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 study of Jupiter radio emissions and the radio telescope used.

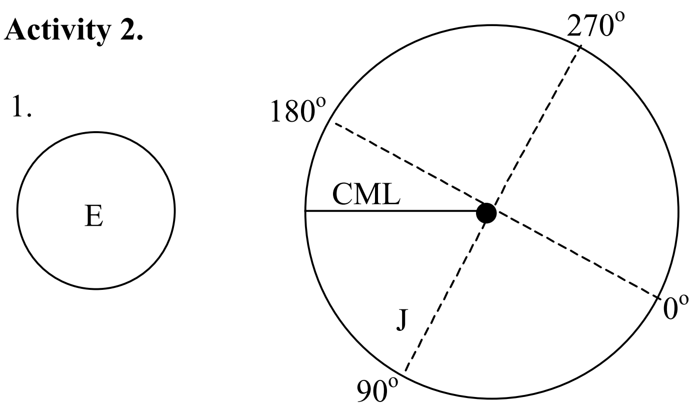
Teacher Page 2 **Answers to activities.**

Activity 1.

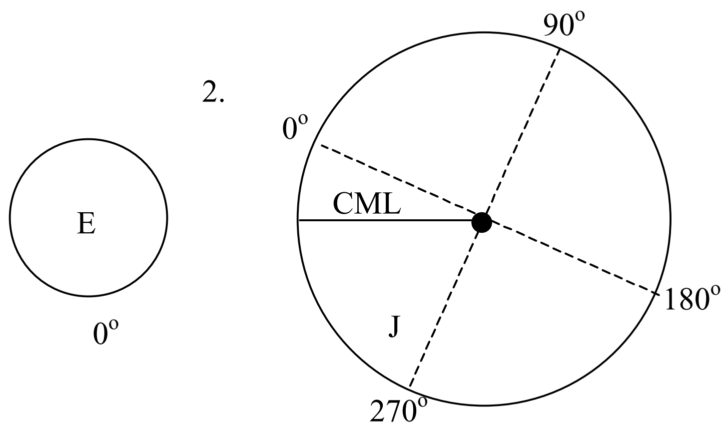
1. 180°
2. 250°
3. 280°

Activity 2.

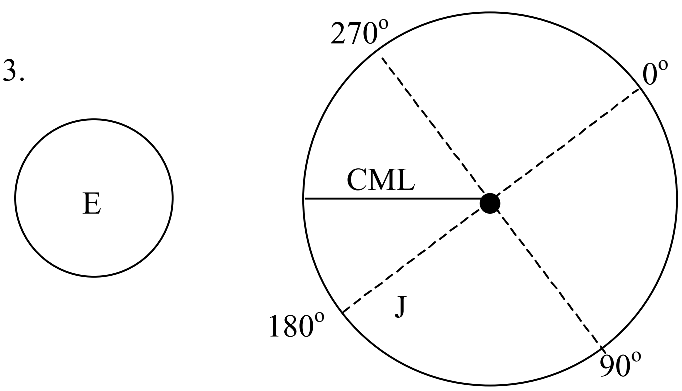
1.



2.



3.



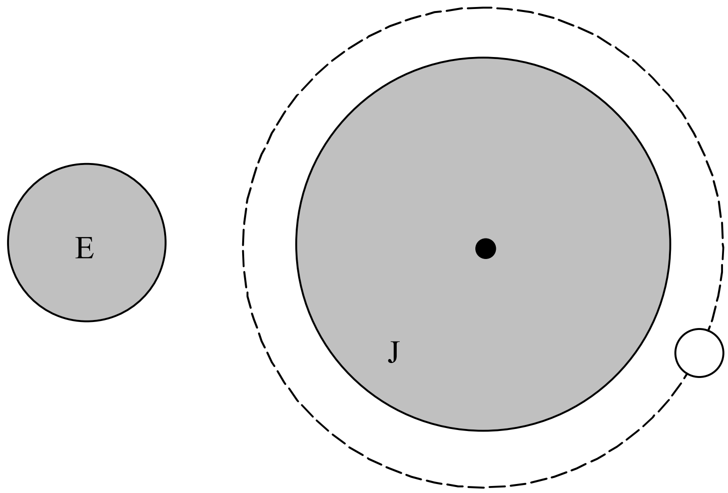
Teacher Page 3 **Answer to Activities**

Activity 3.

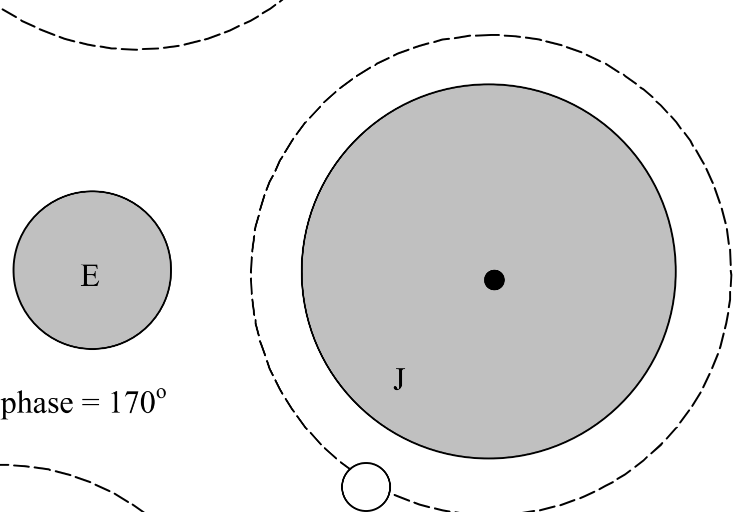
1. 30°
2. 100°
3. 300°

Activity 4.

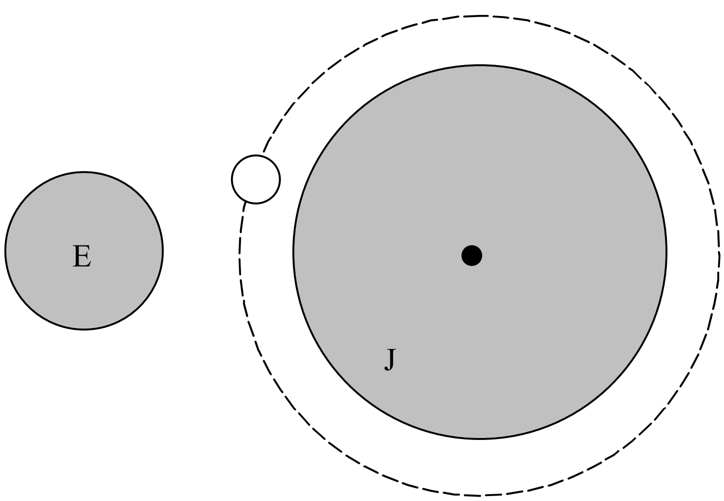
1. Io phase = 320°



2. Io phase = 230°



3. Io phase = 170°

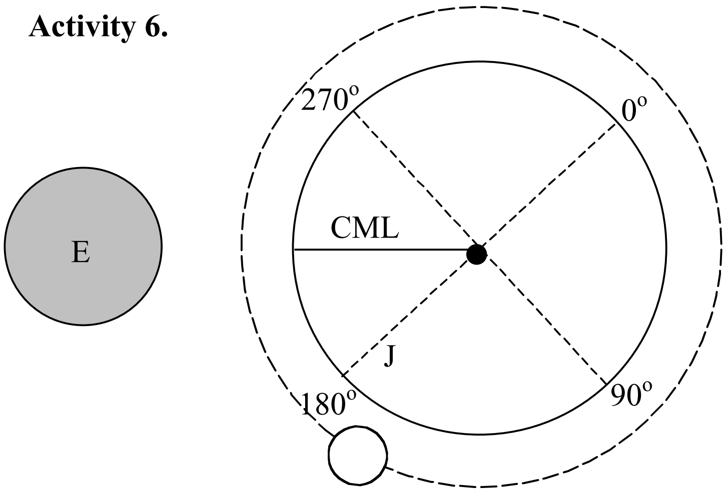


Teacher Page 4 **Answer to Activities**

Activity 5.

1. CML = 10^{o}
   Io phase = 130^{o}
2. CML = 330^{o}
   Io phase = 255^{o}
3. CML = 90^{o}
   Io phase = 20^{o}

Activity 6.

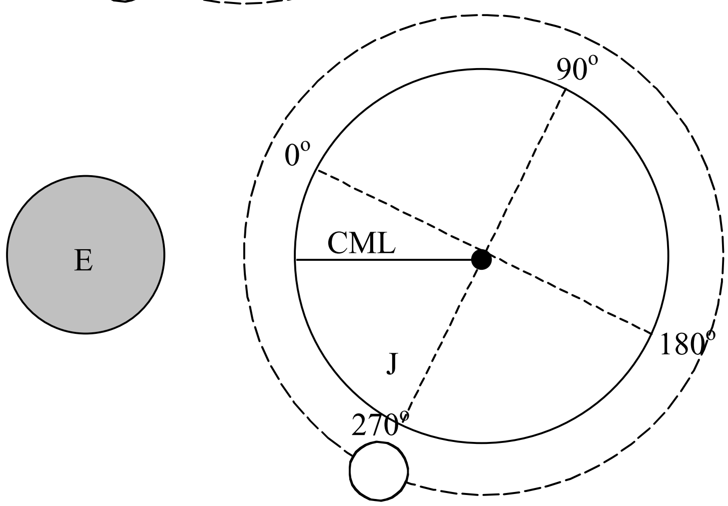


1.

CML = 225^{o}

Io phase = 240^{o}

(This is an Io-A storm.)

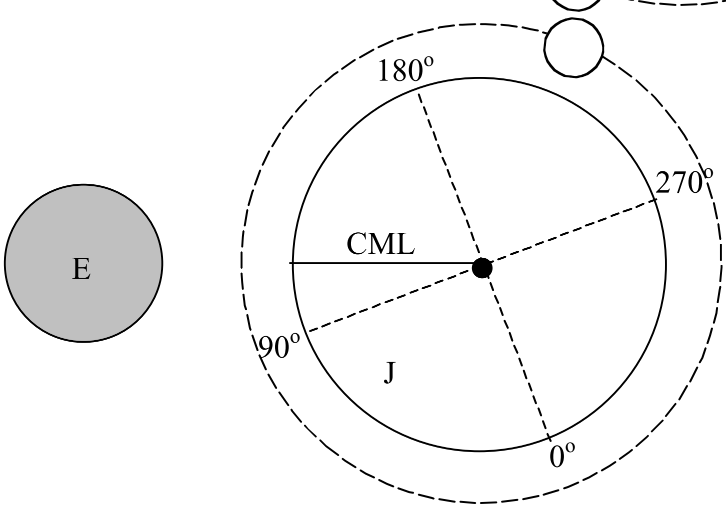


2.

CML = 330^{o}

Io phase = 250^{o}

(This is an Io-C storm.



3.

CML = 110^{o}

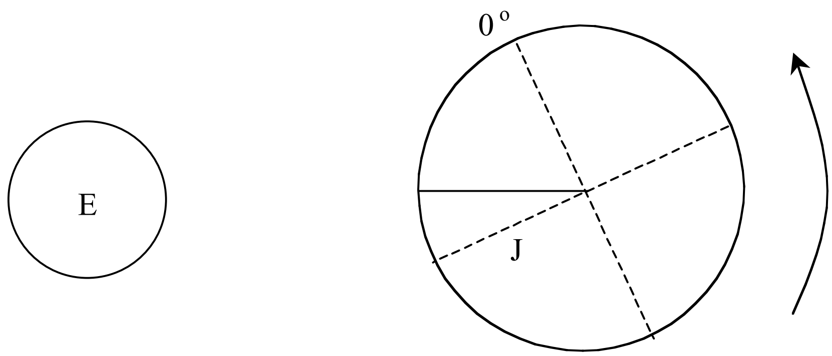
Io phase = 80^{o}

(This is an Io-B storm.)

<u>Teacher Page 5</u>
Io-B Storm Quiz

KEY

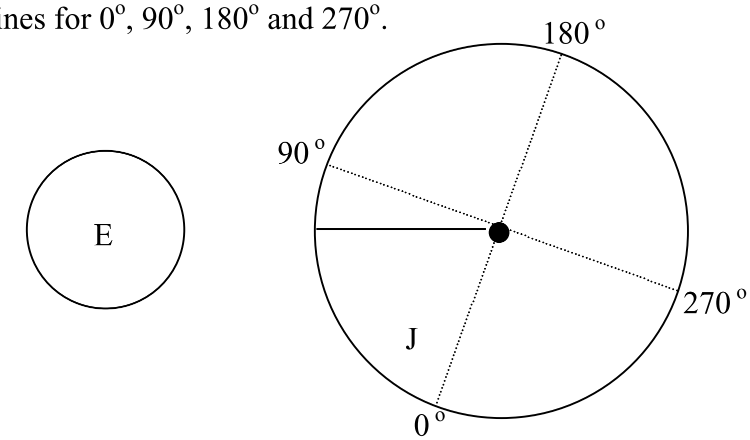
1. Draw in the CML and give the CML position shown in each of the following.



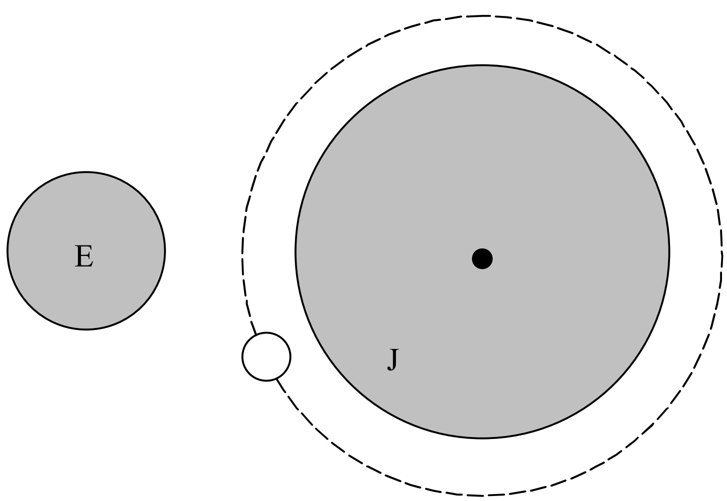
1. CML = 300°

2. Draw a diagram showing Earth and Jupiter illustrating the following CML positions. Label the CML and the meridian lines for 0°, 90°, 180° and 270°.

CML = 70°



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



3. Io phase = 110°

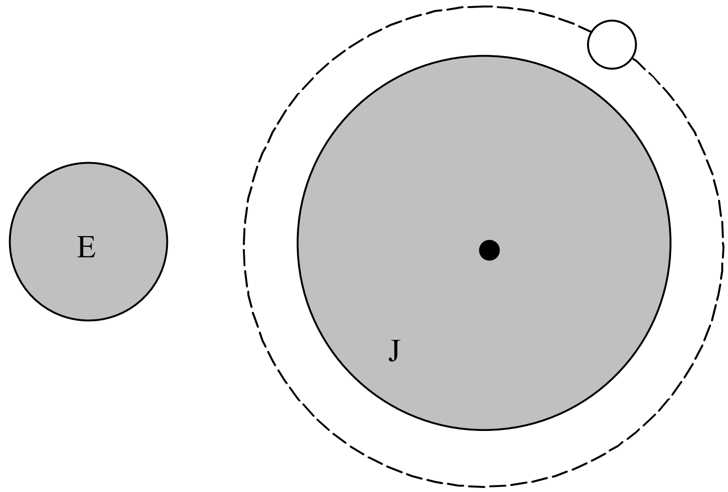
NOTE: Answers should be counted correct if they are within ±10° of the given answer.

KEY

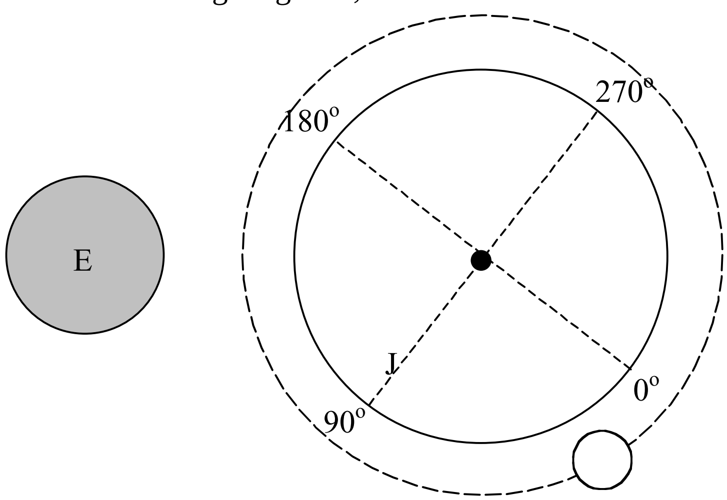
Teacher Page 6

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

Io phase = 60°



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



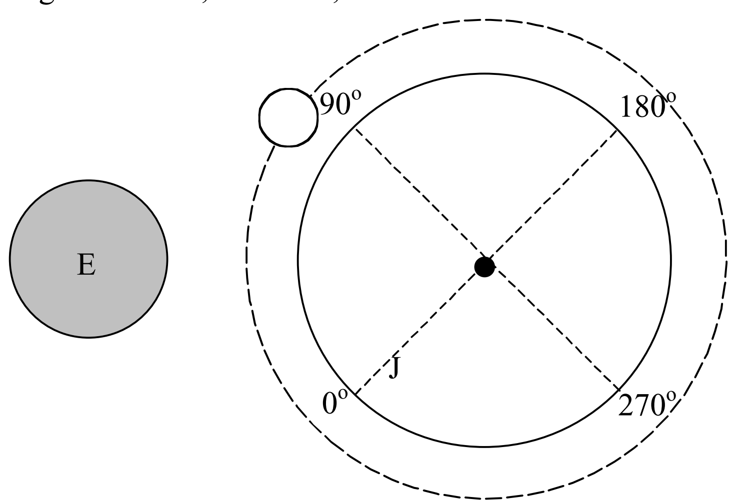
CML = 150°

Io phase = 300°

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

CML = 50°

Io phase = 140°



Resource Page 1

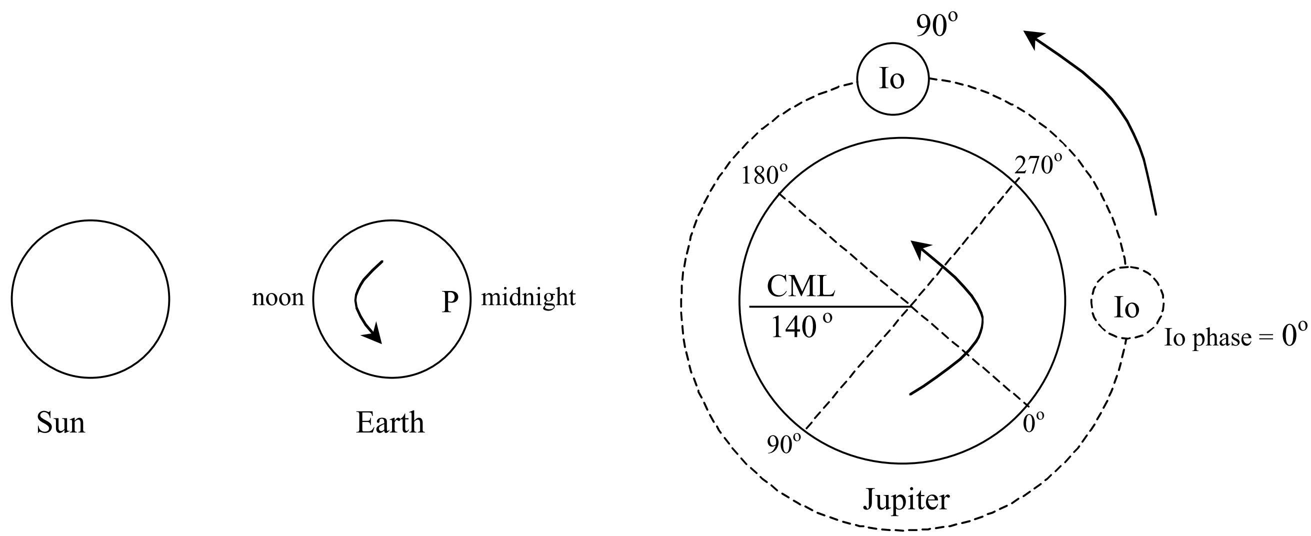
A Simplified Model for Predicting Jupiter Radio Storms

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^o and 180^o and the position of Io (called the **Io phase**) is between 80^o and 100^o. To simplify things for purposes of making a **mathematical model**, we will use a CML value of 140^o and an Io phase of 90^o.



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^o. The direction of **revolution** of Io is shown and Io is shown at a phase of about 90^o.

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

Resource Page 2

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^o
Io phase: 90^o
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:

$t_1 = 10\,x$ 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:

$t_2 = 42\,y$ 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:

$$t_1 = t_2$$

$$10\,x = 42\,y$$

$$x = 4.2\,y$$

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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)
y	**x**	**10 x**	**(10x)/24**
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^o, but can be anywhere from 100^o to 180^o. 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^o phase, but can be anywhere from 80^o to 100^o. 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

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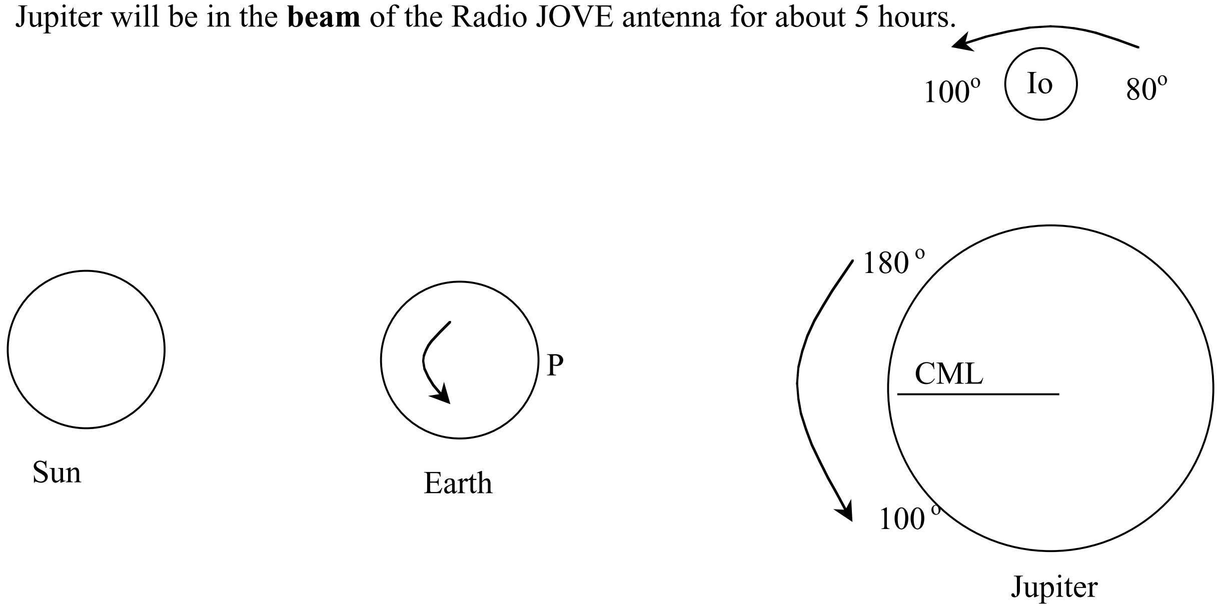
length of time can vary up to almost 12 hours. If the antenna is one like that used by Radio JOVE, then Jupiter must be within 2.5 hours of its highest elevation for the signal to be received. Jupiter will be in the **beam** of the Radio JOVE antenna for about 5 hours.



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.

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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^o east-west and 60^o north-south; in other words, Jupiter will be in the beam of the Radio JOVE double dipole antenna if Jupiter is within 35^o east or west and 30^o 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^o to 360^o (which is a return to 0^o).

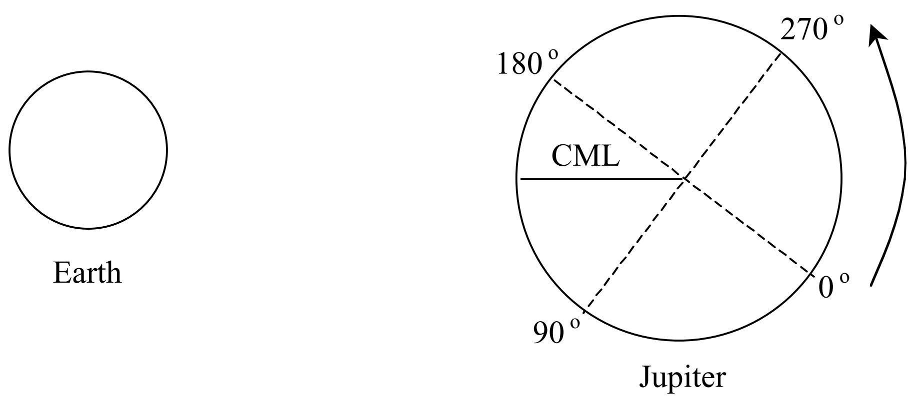

Diagram showing the CML. At this time, the CML is about 140^o.

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CML-Io phase plot a computer-generated 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.

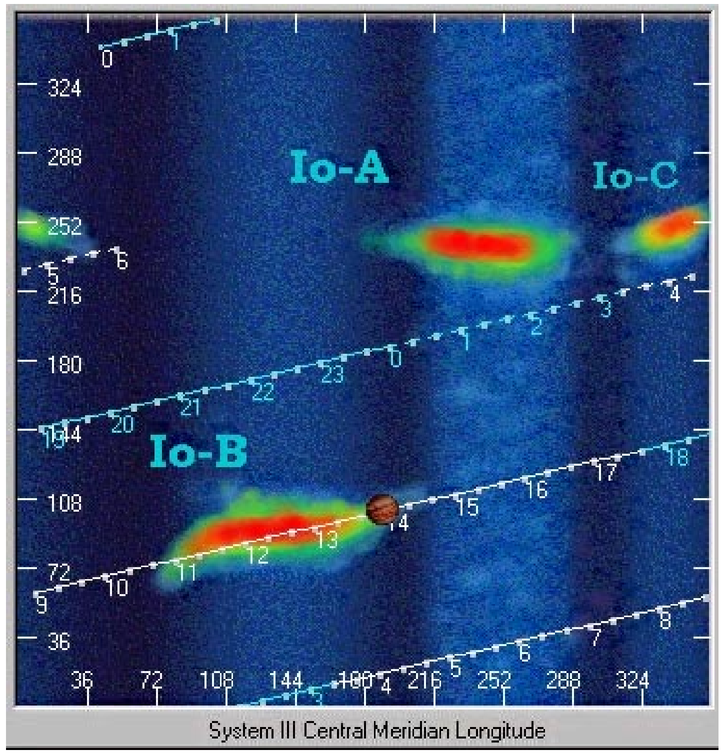

Image: Radio Jupiter Pro software

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.

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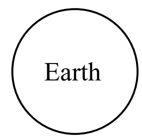
Io phase the position of Io relative to Jupiter as seen from Earth;



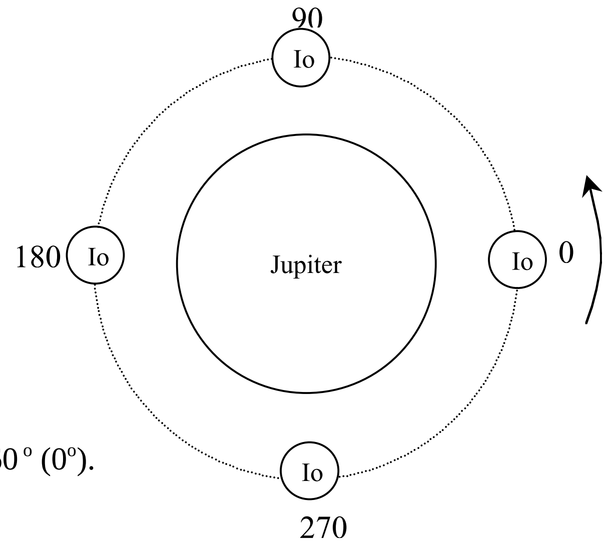


Diagram showing Io phases ranging from 0° to 360° (0°).

Io-A Storm storm probabilities are larger when 215° < CML < 255° and 220° < Io phase < 240°

Io-B storm storm probabilities are larger when 100° < CML < 180° and 80° < Io phase < 100°

Io-C Storm storm probabilities are larger when 320° < CML < 340° and 240° < Io phase < 260°

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.

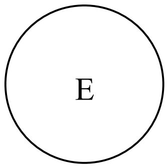
rotation the spinning of an object on its axis; Earth rotates once per day (24 hours), Jupiter rotates once every 10 hours.

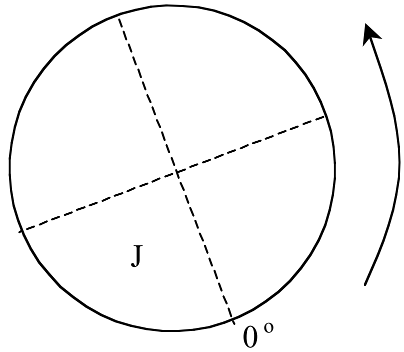
storm probabilities the probability of Jupiter radiating radio waves varies depending on the CML and the position of Io; for example, when Io-B alignment occurs, the storm probability is around 40%; that still means that over half the times that Io-B alignment occurs, no radio waves are detected!

Activity 1. **Name**______________________________

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

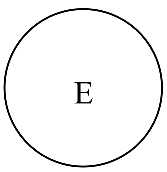
Example.

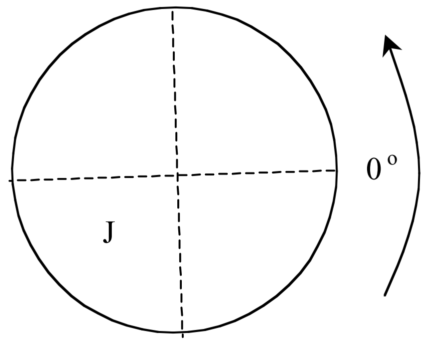




CML = __105°____

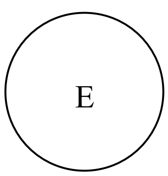
1.

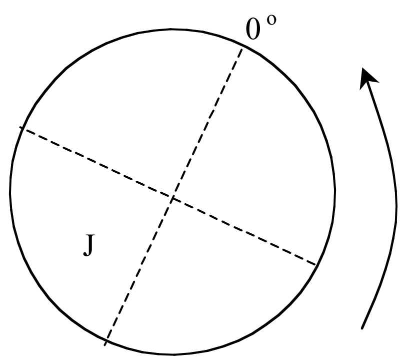




1. CML = ______

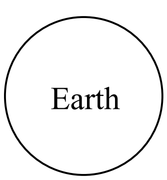
2.

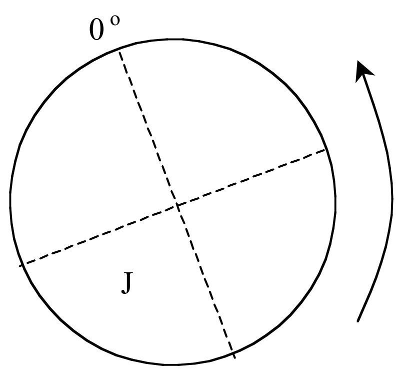




2. CML = ______

3.





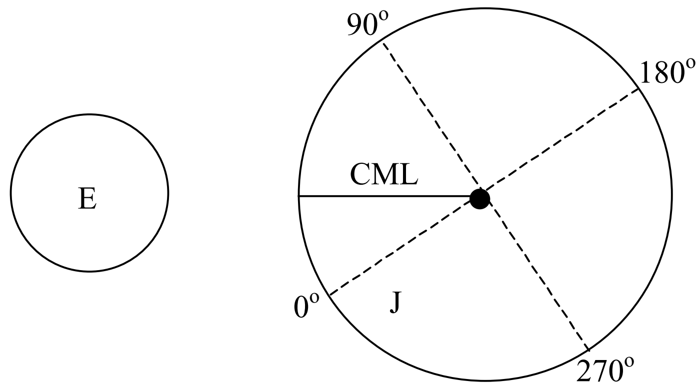
3. CML = ______

Activity 2. Name______________________________

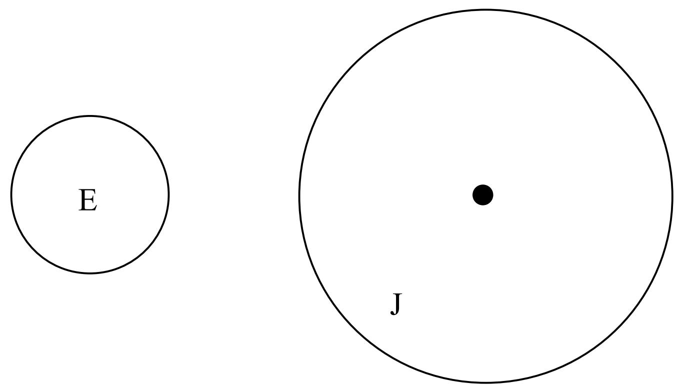
Draw a diagram showing Earth and Jupiter illustrating the following CML positions. Label the CML and the meridian lines for 0^o, 90^o, 180^o and 270^o.

Example.

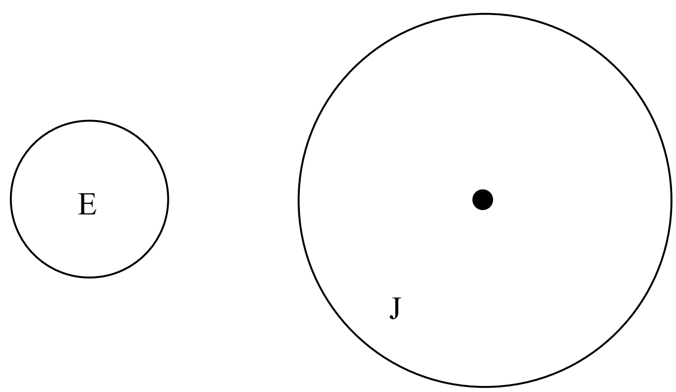
CML = 30^o



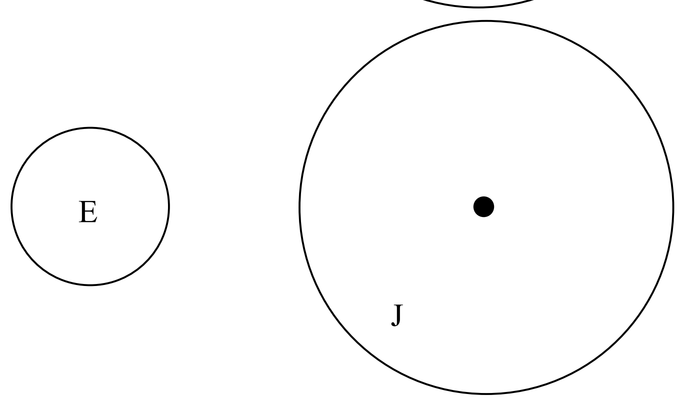
1. CML = 150^o



2. CML = 340^o



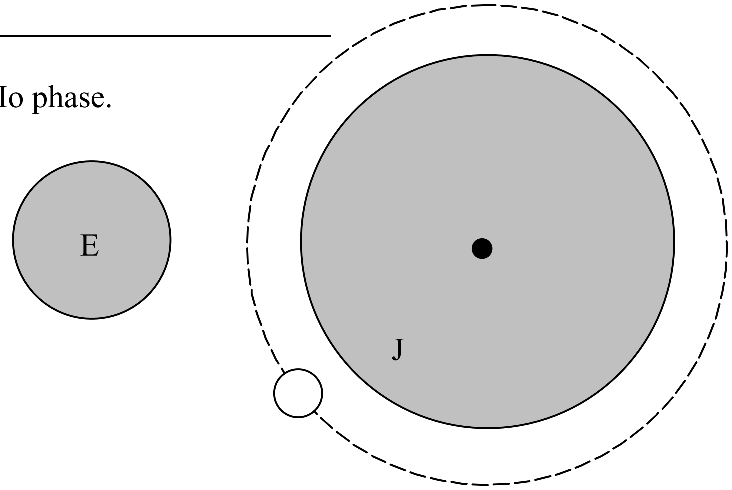
3. CML = 220^o



Activity 3. **Name**______________________________

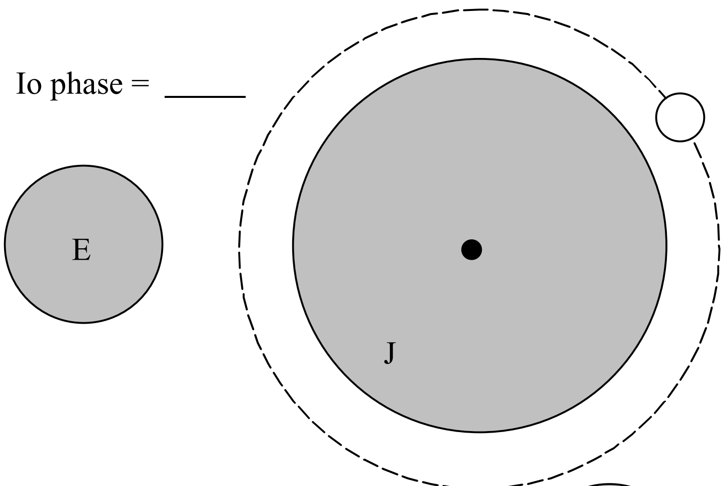
Using the following diagrams, give the Io phase.

Example.

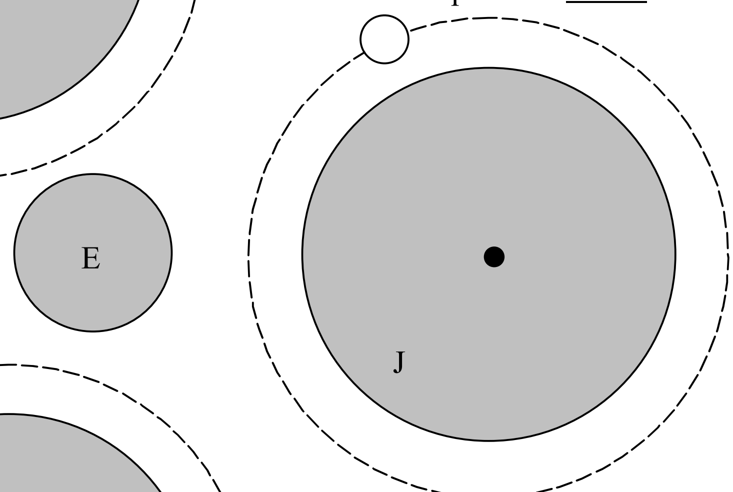


Answer: Io phase = <u>200^{o}</u>

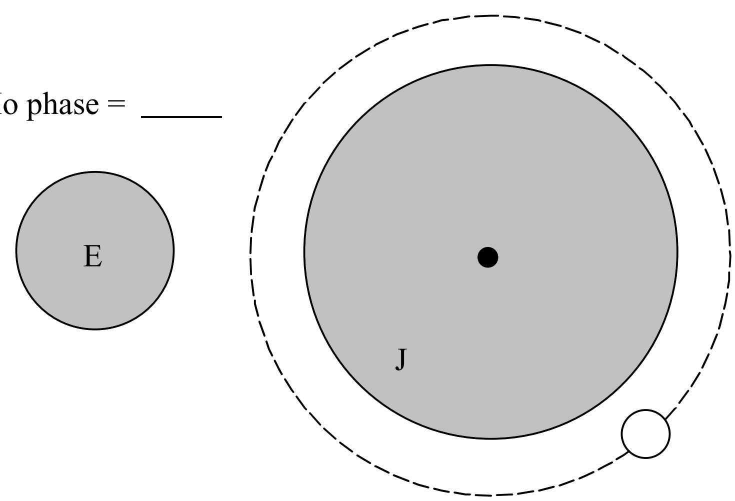
1. Io phase = _____



2. Io phase = _____



3. Io phase = _____

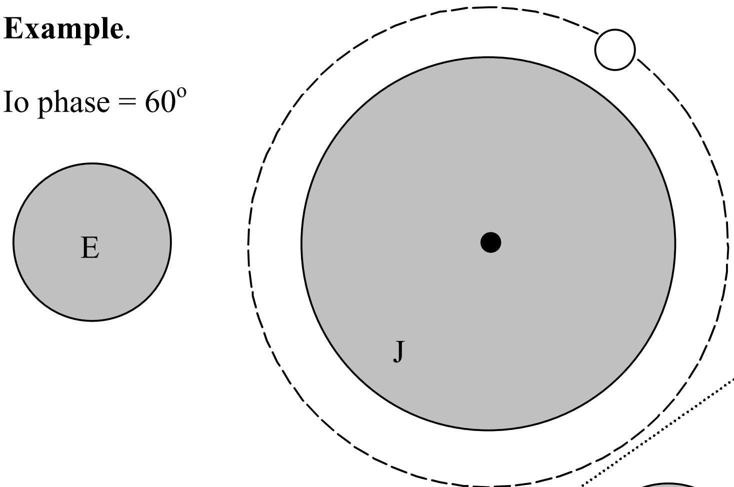


Activity 4. **Name**____________________________

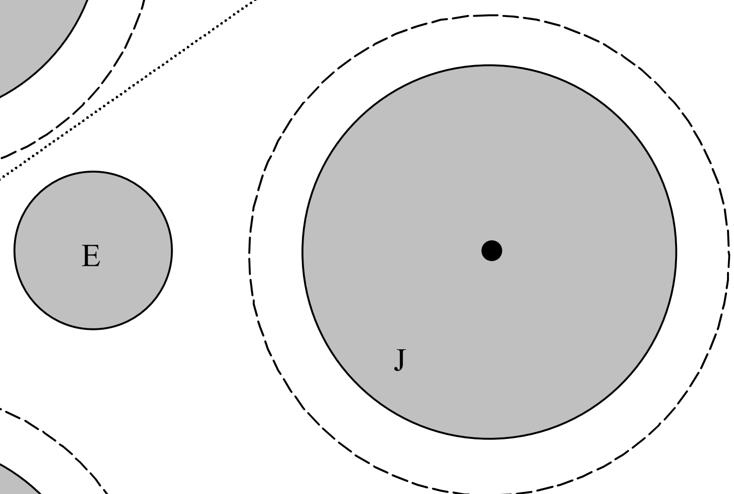
Draw a diagram showing Earth, Jupiter and Io illustrating the following Io phases.

Example.

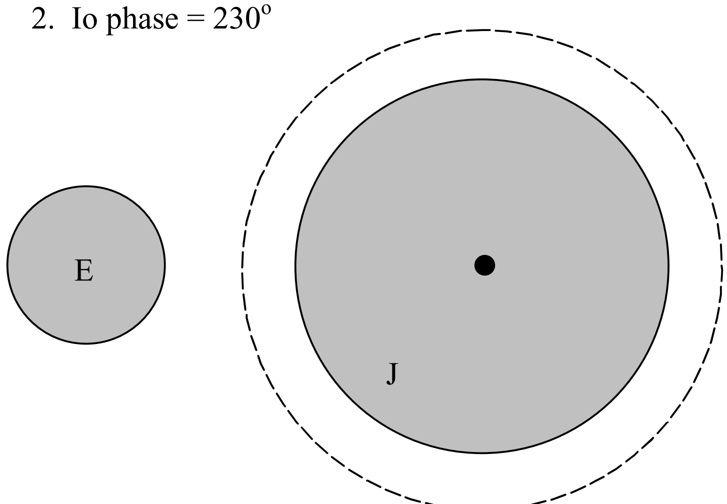
Io phase = 60°



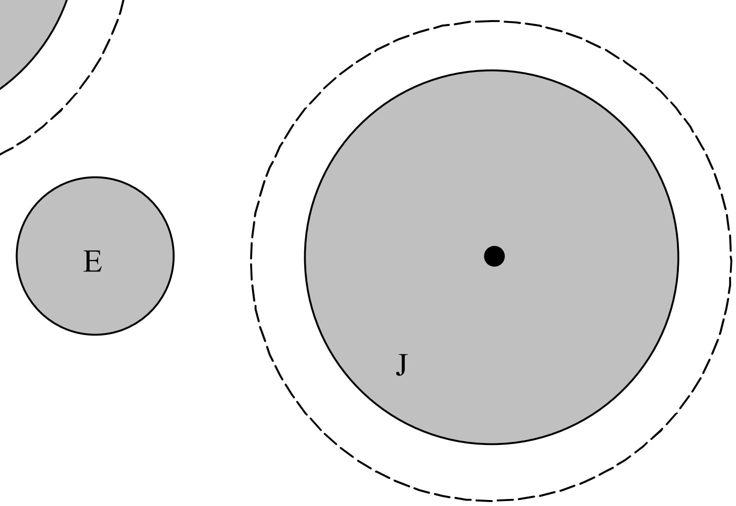
1. Io phase = 320°



2. Io phase = 230°

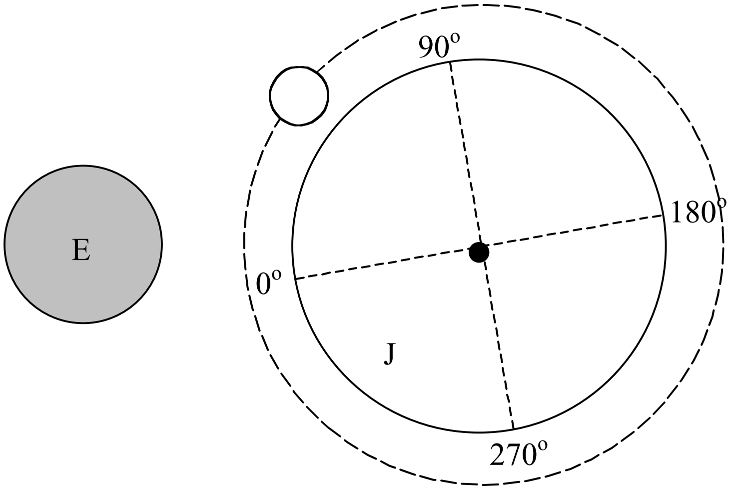


3. Io phase = 170°

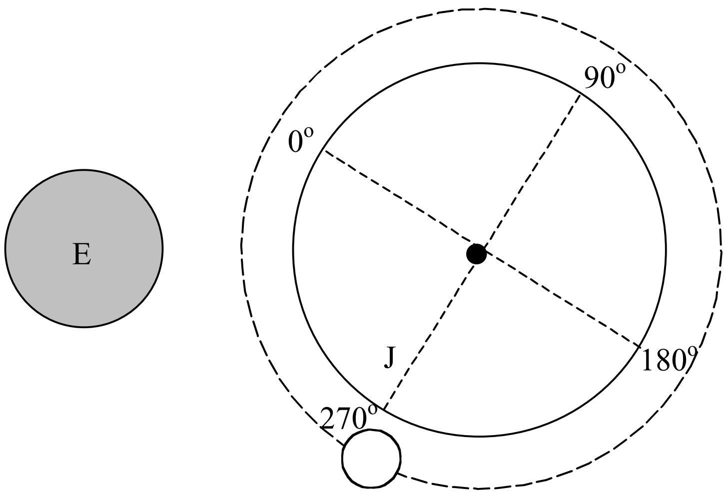


Activity 5. **Name**______________________________

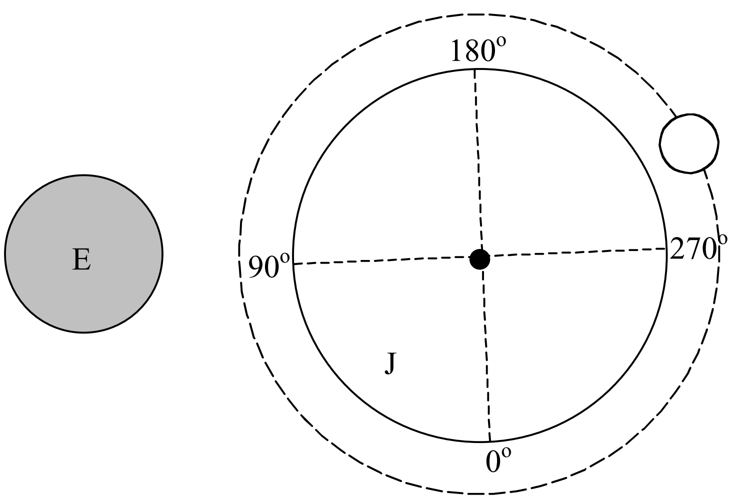
From the following diagrams, determine the CML and the Io phase.
Use the skills you learned in activities 1 - 4 to complete this section.



1.
CML = _______________
Io phase = _______________



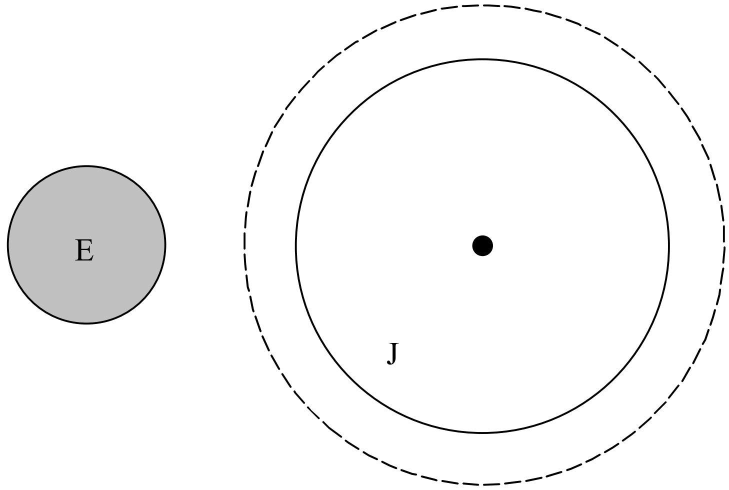
2.
CML = _______________
Io phase = _______________



3.
CML = _______________
Io phase = _______________

Activity 6. **Name**______________________________

For the following, draw in the meridian longitudes of 0^o, 90^o, 180^o, 270^o and the CML.
Draw Io in the indicated phase.
Use the skills you learned in activities 1 - 4 to complete this section.

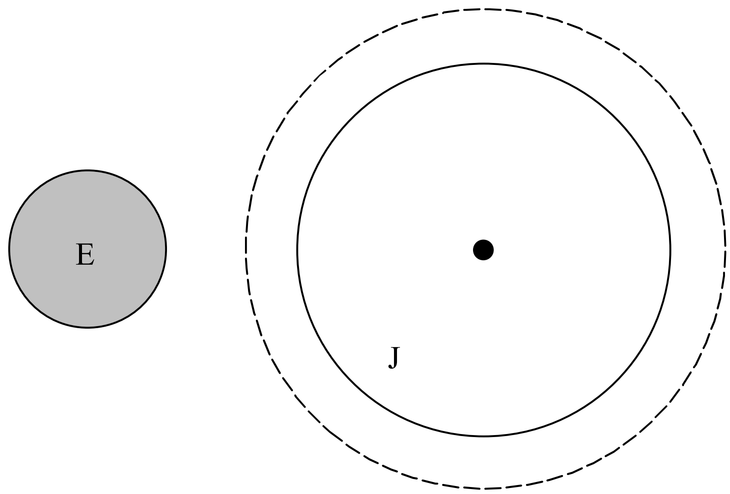


1.

CML = 225^o

Io phase = 240^o

(This is an Io-A storm.)

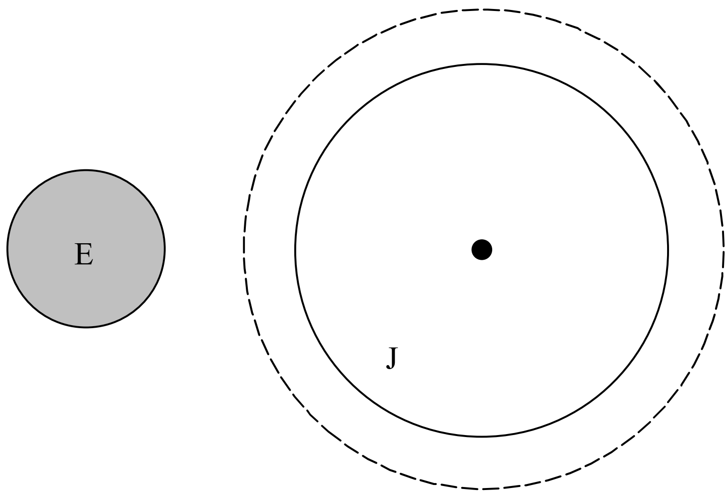


2.

CML = 340^o

Io phase = 250^o

(This is an Io-C storm.)



3.

CML = 110^o

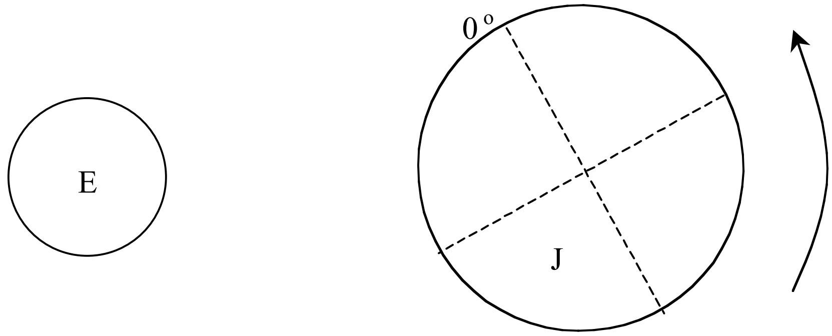
Io phase = 80^o

(This is an Io-B storm.)

Io-B Storm Quiz

Name ___________________________

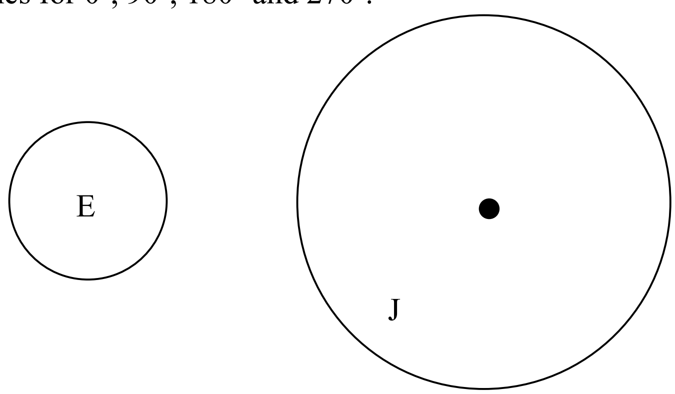
1. Draw in the CML and give the CML position shown in each of the following.



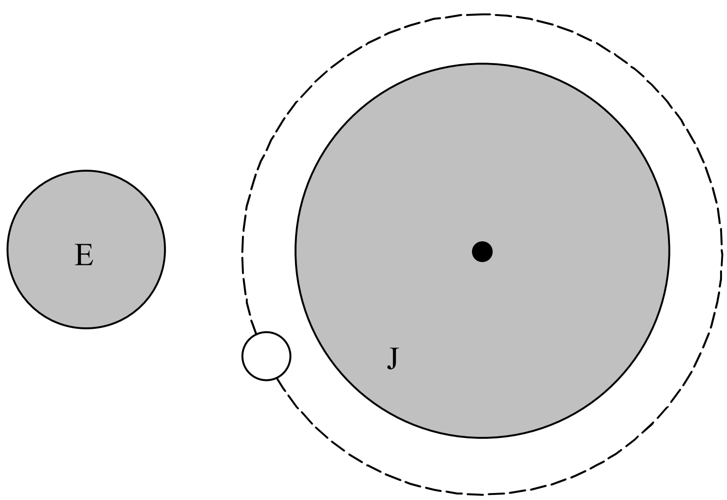
1. CML = ______

2. Draw a diagram showing Earth and Jupiter illustrating the following CML positions. Label the CML and the meridian lines for 0º, 90º, 180º and 270º.

CML = 70º



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

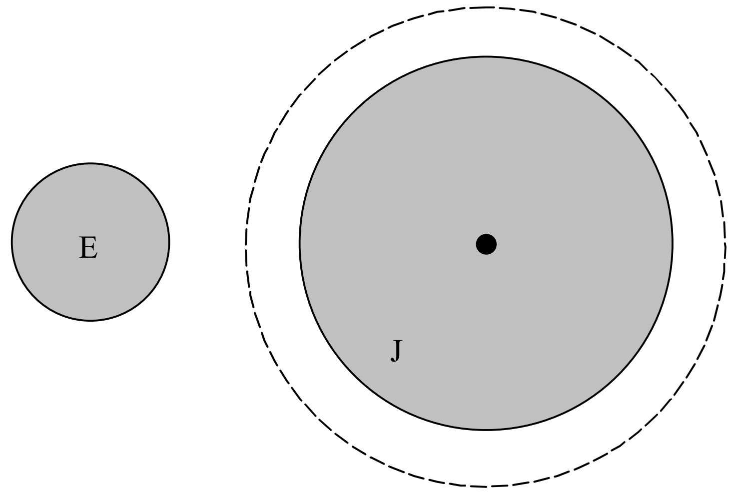


3. Io phase = _____

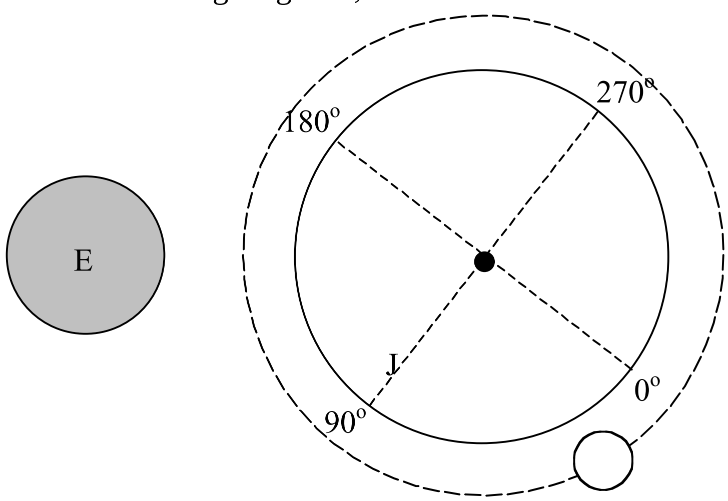
Quiz
pg. 2

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

Io phase = 60^o



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^o, 90^o 180^o, 270^o and the CML.
Draw Io in the indicated phase.

CML = 50^o

Io phase = 140^o