Group Members: ________________

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The Galilean Satellites and the Mass of Jupiter

In 1610 Galileo Galilei was one of the first persons to point a telescope at Jupiter and observe that the planet has four bright moons. While there is evidence that others were observing Jupiter and its moons at the same time, Galileo was the first to report his observations and so we now call the four moons he discovered the Galilean moons of Jupiter. In today's lab you will be repeating measurements made by others after Newton derived Kepler's 3rd Law and showed how it could be used to determine the mass of the Sun or a planet. Newton's version of Kepler's 3rd Law tells us that the mass of Jupiter (plus the negligible mass of the moon in question) should be given by

$$Jupiter's\ mass = \frac{(semimajor\ axis)^3}{(period)^2}$$

where the mass will be in solar masses if the semimajor axis is in Astronomical Units and the period is in (Earth) years.

Instructions for collecting data

1. Start Stellarium. Look for the Stellarium icon and double click on it

2. You will need to stop time and get rid of the atmosphere. Move the cursor down to the lower left until a menu of icons appears. Stop the flow of time by clicking on the "play" button. Next, get rid of the atmosphere by clicking the "atmosphere" button that looks like a cloud with the Sun peeking out behind it.

3. Now you need to get rid of the horizon. Move the cursor over to the lower left side to get another icon menu to appear. Click on the "Sky and viewing options window". Select the "Landscaping" tab and in the "Options" section click the "Show ground" box off. You should now see a dark sky with no horizon. Close the "Sky and viewing options window".

4. Next, set the time to the nearest whole hour. From the left side icon menu, click the "Date/time window" and advance the seconds and minutes to the nearest whole hour. It doesn't matter which hour it is. DO NOT CLOSE THE "DATE/TIME WINDOW" AS YOU WILL USE IT THROUGHOUT THE LAB. Move the Date and Time window up to the top right corner so it is accessible but out of the way.

5. Move around the sky until you find Jupiter. While holding the left mouse button down, move your mouse around or slide your finger across the touchpad. Once you find Jupiter, left click on it to select it then center it by clicking the "Center on selected object" icon in the lower icon menu.

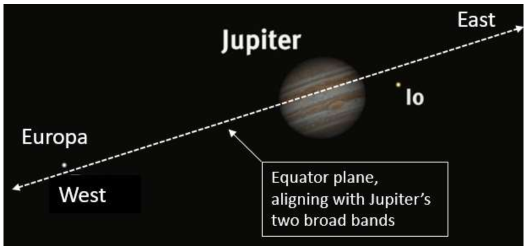
6. Zoom in on Jupiter until it is over a centimeter across and the moons are easily visible. If you have a mouse with a wheel, simply roll the wheel to zoom in. If you are using a touchpad, use the “CTRL”+up arrow or “Fn”+up arrow to zoom in.

7. Advance time by few hours and watch how Jupiter and its moons move on the screen to be sure that the screen size is proper. Choose the moon, either Io or Europa, to measure.

8. Measure the equatorial diameter of Jupiter to the nearest millimeter using a ruler. The two broad bands on Jupiter are parallel to the equator. (How big it shows up on your screen does not matter. It will be rescaled.) **Diameter of Jupiter: _________ (mm)**

9. Measure the position of your moon using a ruler. Place the zero on the moon and measure the distance to the center of Jupiter to the nearest millimeter.

10. Record the distance of your moon from the planet as the position of the moon in the table below next to 0 hrs. Note as the moon circulates around the Jupiter, it will appear on the east side (the right side of the equator plane of the Jupiter) and also on the west side (the left side of the equator plane of the Jupiter). Record a positive position for the east side and a negative position for the west side. The image here shows that Io is in the positive position while Europa is in the negative position.



Name of Moon: ____________________

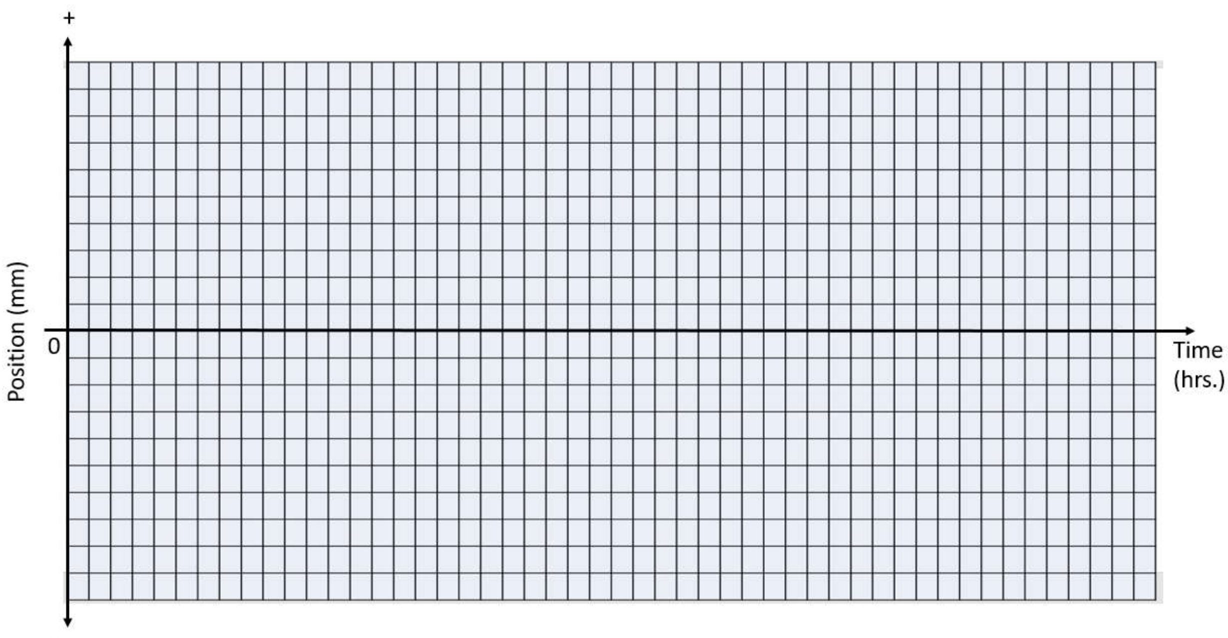
Time (hrs)	Position (mm)	Time (hrs)	Position (mm)	Time (hrs)	Position (mm)
0					

11. Advance time by 2 hours if you are doing Io or 4 hours if you are doing Europa. Repeat steps 9 & 10. Note, for Io, your time would be 0, 2, 4… always advancing by two hours. Similarly, for Europa, your time would be 0, 4, 8…. advancing by four hours. Pay attention to the positive and negative positions of the moon. If your moon is eclipsed, record the time but write "eclipsed" for the position. Measure until the table below is full.

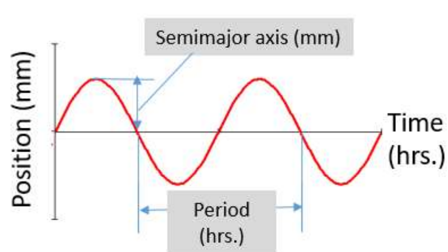
The reason that the moon swings first to one side of Jupiter then to the other side is because it is making approximately a circular orbit in the plane of our line of sight. It is actually staying about the same distance away from Jupiter the whole time. As a result, when the moon appears to be the furthest from Jupiter, we are actually measuring the radius while at other positions in its orbit the distance appears to be less than the radius due to the change in the line of sight.

Instructions for analyzing data to determine the mass of Jupiter

1. Great the position vs time graph based on your measurements



2. From your graph, determine the moon's period and the semimajor axis of the orbit. Meaning of your plot is shown on the right graph. Note that each horizontal box represents 2 hours for Io and 4 hours for Europa.



Now record the values below:

Period (hrs) = ____________

Semimajor axis (mm) = ____________

3. In order to use Kepler's 3rd Law you need to have your numbers in the correct units: years and AU.

First, convert the period from hours to years.

$$Period(hrs) \div 24 \left(\frac{hrs}{da}\right) \div 365.26 \left(\frac{days}{year}\right) = \underline{\hspace{4cm}} (yrs)$$

Second, convert your moons semimajor axis from mm to AU.

- Rescale your screen measurement to the right size using Jovian diameters (JD):

$$\frac{Semimajor\ axis\ (mm)}{Diameter\ of\ Jupiter(mm/JD)} = \underline{\hspace{4cm}} (JD)$$

- Convert Jovian diameters (JD) to AU:

$$Semimajor\ axis\ (JD) \times 0.0009558\ \frac{AU}{JD} = \underline{\hspace{4cm}} (AU)$$

4. Now calculate the mass of Jupiter using Newton's form of Kepler's 3rd Law.

$$\frac{[Semimajor\ axis\ (AU)]^3}{[Period(year)]^2} = \frac{\underline{\hspace{4cm}}}{\underline{\hspace{4cm}}} = \underline{\hspace{4cm}} (M_{Sun})$$

5. Convert this mass to Earth masses:

$$Jupiter\ Mass\ (M_{Sun})\ \underline{\hspace{3cm}} \times 332900\ (\frac{M_{Earth}}{M_{Sun}}) = \underline{\hspace{3cm}} (M_{Ear}\ \ )$$

6. The accepted value for the mass of Jupiter is 317.8 M_{Earth}. Find your percent error from this accepted value:

$$\%\ Error = \frac{Your\ Value - Accepted\ Value}{Accepted\ Value} \times 100\% = \underline{\hspace{3cm}}\ \%$$