NAME: ____________________ SECTION: ______ DATE: __________

B.3 Jupiter's Moons

I. Introduction

Galileo Galilei was the first to record seeing moons surrounding Jupiter. The four moons he observed are now known as the Galilean moons. They are, in order of increasing orbital distance, Io, Europa, Ganymede, and Callisto. Although the moons follow elliptic orbits, they appear to move in a linear, rather than circular fashion about Jupiter. This is due to the fact that the plane of the moons' orbits lies nearly in the ecliptic plane. Recall that the *ecliptic plane is the plane which is described by the path which the Sun follows through the sky and that most of the planets' orbits lie within or very near this plane.*

Because of this projected view of circular motion onto a line, the observed distance from Jupiter when plotted should appear as a sine curve. The period of this sine curve is period of the Moon's orbit. By measuring the period of the orbit and the semi-major axis from a graph, you can use Kepler's third law

$$P^2 = \frac{a^3}{M_{\text{Jupiter}}} \tag{B.15}$$

to calculate the mass of Jupiter.

In this lab you will simulate an actual set of observations on the Galilean moons using a computer program rather than making actual observations. Using the program allows us to accurately simulate making observations that a modern astronomer would make using a CCD camera to obtain images through a telescope.

The program will allow you to make a series of observations. On some "nights" it will be cloudy and you will not be able to obtain any data for that night. Using your data set you will be able to find the orbital periods for each of the Galilean moons and then be able to calculate Jupiter's mass using Kepler's third law.

II. Reference

- *21$^{\text{st}}$ Century Astronomy*, Chapter 3, pp. 76 – 77, 81 – 82 (Kepler's 3$^{\text{rd}}$ law).
- CLEA Jupiter's Moons lab manual

III. Materials Used

- CLEA Jupiter's Moons program
- calculator

IV. Observations

The observations you will be making will be simulated observations using the CLEA program. You will do the following things in this observation:

- measure the apparent positions of the Galilean moons relative to Jupiter for a number of days (different lab groups will be given different periods of time over which to make the observations)
- plot the apparent positions of each moon versus time on graph paper, and draw a best fit sine curve through the data

- use your graphs to determine the semimajor axis and period of each moon
- use the values from your graphs to determine an average mass for Jupiter

Observation

1. Start the Jupiter program by double-clicking on the Clea_jup icon.
2. Log in to the program by entering all the group members' names into the appropriate places after selecting **Log In** from the **File** menu.
3. Select **Run** from the **File** menu. Enter the start date and time given to your group by the instructor. You can use the default observation interval or you can set it by selecting **File** → **Preferences** → **Timing** and changing it to your preferred value. Setting it to a shorter time interval may be useful.
4. The observation field can be displayed at different levels of magnification. You can change it by clicking on the **100X**, **200X**, **300X**, and **400X** buttons at the bottom of the screen. To improve the accuracy of your measurement, you should use the largest possible magnification which allows you to make your measurement.
5. In order to measure the observed distance of the moons from Jupiter, move the mouse pointer until the tip is centered on each moon. Hold down the left mouse button and the cursor will change to a cross-hair. Center the moon in the cross-hair and information about the moon will appear in the lower right corner of the screen. The information will include the name of the moon, the x and y pixel location on the screen, and the perpendicular distance (in units of Jupiter's diameter) from the Earth-Jupiter line of sight as well as an E or W to signify whether it's east or west of Jupiter. Record this information using **Record Observations**. Be sure to enter a "E" or "W" to signify the position of the moon relative to Jupiter.
6. Once you have recorded the data for each of the moons on that date, continue making observations on consecutive observation intervals by clicking on the **Next** button. You need to observe for at least 18 observation intervals.
7. After completing your observations, you should save your data. The data can be saved using **File** → **Data** → **Save**. A copy of your data should be turned in with your lab. You can do this by using **Data** → **Print** → **Data Table**.
8. You now need to analyze your data. This can be done using the program. Select **File** → **Data** → **Analyze**.
9. Choose **Select** → **Moon** and select one of the moons to analyze. Start with Ganymede.
10. Choose **Plot** → **Fit Sine Curve** → **Set Initial Parameters**. You need to set 3 parameters to help the program fit the data: t-zero, period, and amplitude (in units of Jupiter diameters). T-zero is the time when the sine wave first starts a cycle, the period is the time it takes the moon to orbit Jupiter, and the amplitude is the semimajor axis of the orbit. An example graph showing these quantities appears in Fig. B.7 below. You will need to estimate values of these quantities from your data.
11. Adjust the values for the three quantities using the scrollbars to obtain a best fit. Note you may need to reset the initial values if they were not close because the scrollbars have a limited range of adjustment. Once you have found your best fit, print that page by choosing **Plot** → **Print Current Display**.
12. Repeat the above procedure for the next 3 moons.

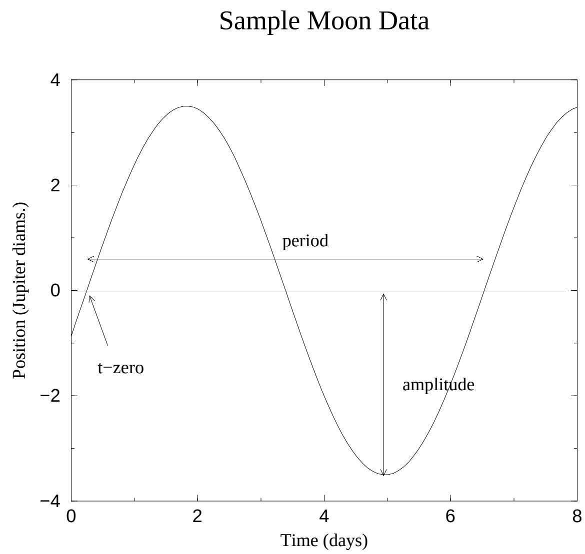

Figure B.7: Sample graph of data for a moon.

V. Questions

1. Please fill in the following table using your data and actual values.

Table B.7: Values of orbital quantities for Jupiter's moons.

Moon	**Measured period (days)**	**Actual period (days)**	**Measured semimajor axis (Jup. diams.)**	**Actual semimajor axis (Jup. diams.)**
Io		1.769		2.949
Europa		3.551		4.692
Ganymede		7.155		7.483
Callisto		16.689		13.169

2. Using Eq. B.15, calculate a mass for Jupiter from each moon's data. Note you will need to convert the values in your table above to AU (astronomical units) and years for the semimajor axis and period respectively.

$$\text{Jupiter's diameter} = 9.53 \times 10^{-4}\ \text{AU}. \tag{B.16}$$

Fill in the following table with your data. Also recall that the mass you calculate for Jupiter will be given in terms of the mass of the Sun. Once you have calculated the average in terms of the Sun's mass, convert that to kilograms ($M_{\odot} = 1.99 \times 10^{30}$ kg) and find the percent error in your measurement. The actual mass of Jupiter is 1.90×10^{27} kg.

Table B.8: Value of Jupiter's mass.

Moon	**Measured period (years)**	**Measured semimajor axis (AU)**	**Jupiter's mass (Sun's mass)**
Io			
Europa			
Ganymede			
Callisto			

Average mass of Jupiter ($M_\odot$) =

Average mass of Jupiter (kg) =

percent error of Jupiter's mass measurement =

3. If you did not change the observation interval, you may have had trouble analyzing the data for Io. Why? How would you change the time interval to make your analysis simpler?

VI. Credit

To receive credit for this lab, you must turn in all of the data from your observations, copies of your graphs for each of the moons, the calculated values from Tables B.7 and B.8 as well as your answers to the above questions.