



# JUPITER'S DISTANCE TO EARTH & ITS MOONS

**Important announcements:** *Due to the length of this lab, there will be no pre-lab quiz and because this lab involves a lot of calculations, it will be worth 50 points and will be due after 2 weeks, not one. There is a GOOD reason for the extended due date – PLEASE don't procrastinate. This is a sincere warning! The material we cover in this lab will be used in at least 2 more labs – the Sun & Moon – so take the time required to learn this material. Get help if needed. I realize this lab may be quite challenging for people uncomfortable with calculations. That's why you have 2 weeks – to ask questions and get assistance!*

*Bring a pencil to lab. You will probably need to erase while sketching. You will need a calculator and ruler for the homework part of this lab.*

*Purpose:* In this lab, you will make angular measurements of Jupiter and its moons to determine Jupiter's distance from Earth and the moons' distances from Jupiter. This lab is also related to an indoor lab where we will use a computer simulation to measure the same quantities that we are measuring "for real" in this activity. The results of that indoor lab will tell us the mass of Jupiter.

## **Introductory information**

Jupiter – king of the gods. Jupiter is the largest, and by far, the most massive planet in the solar system. You could fit 11 Earths across it, and more than 1000 Earths inside it! It has roughly the mass of 300 Earths. It rotates the fastest of all the planets and, because of that, has the most turbulent atmosphere of any planet. One of its storm systems, called The Great Red Spot, is twice the size of Earth and has lasted more than 300 years. We don't know how old it actually is because we've only been looking for 300 years!

Jupiter does not have a solid surface. Rather, as one sinks lower in the atmosphere, the pressure rises and the gas gets increasingly dense until it gradually turns liquid. There is no sharp boundary between the gas and liquid regions. At increasing depths, the liquid eventually turns solid from the enormous pressure of all of the mass above. It also has a collection of four large moons, called the Galilean satellites after their discoverer. Together, Jupiter and its moons are called the Jovian system. One of Jupiter's satellites (i.e. its moons), Ganymede, is larger than Mercury, while Callisto is about the same size as Mercury!

Tonight, you will reproduce historical observations, but will do them somewhat reversed from history. You will measure the angular size of Jupiter and the angular separation of the Galilean moons from Jupiter. After researching the actual size of Jupiter, you will determine several distances. You will also make both qualitative and quantitative assessments of the accuracy of your data, to help you begin to understand the limitations of various measuring techniques and tools.

For your information, historically, the distance to Jupiter was measured first, by understanding planetary orbits around the Sun. From that information, the physical size was computed using our method. We are doing the opposite: computing the distance after researching the physical size. The ideas are similar. See page **Error!**  
**Bookmark not defined..**

One interesting experiment, performed by Ole Roemer, determined that the Galilean moons weren't orbiting "on time" when Jupiter was on the other side of the Sun. He noticed they were getting to their predicted locations later than expected. Roemer correctly attributed this 1.4 hour-long delay to the finite speed of light. His is one of the first good estimates of the speed of light.

## *Jupiter Distances*

### **Directions**

- 1) To begin, do only a very rough polar alignment so we can quickly start on our first sketch of Jupiter.
- 2) Point the telescope at Jupiter and choose an appropriate eyepiece that allows the most magnified viewing of all visible moons (there will probably be four moons).
- 3) Make a good sketch of the moon system. Be very careful with the scale and the distances. Make sure the whole circle on the observation sheet represents the entire field of view, and that Jupiter's moons' distances and Jupiter's size are scaled appropriately.
- 4) In the notes section, note things like: the first moon is 4 Jupiter diameters away from Jupiter's CENTER, Jupiter is  $1/XX^{\text{th}}$  the size of the FOV. Note: Jupiter Diameters is how distances are reported in the computer Jupiter lab, on page **Error! Bookmark not defined.**. Rather than estimating distances from Jupiter's center, you can measure from the edge and use the fact that from Jupiter's center to its limb (edge) is half a Jupiter Diameter, by definition.
- 5) Label the NSEW directions on your sketch.
- 6) Label the moons 1, 2, 3, and 4. Moon 1 should be the closest and 4 the furthest. Later you will determine the names of these 4 moons.
- 7) By knowing the field of view of the eyepiece (from a previous lab) estimate, from your drawing and/or what you see in the eyepiece, the angular diameter of Jupiter. Include this estimate in the observation sheet's notes and in the table at the end of this lab. Similarly record your estimate the angular distances from the center of Jupiter to its moons in both locations. There is no penalty for incorrect guesses, as long as they are reasonable.
- 8) Get a signature on your observation sheet (or else you will receive no credit for it).
- 9) Adjust your polar alignment if you have time, just for practice. As this is not critical to the success of this lab, skip this step if you are running behind.
- 10) Using the drift-timing method that we used in the field-of-view lab, measure the time it takes Jupiter to drift across Jupiter's diameter. To do this align Jupiter with the westernmost edge of the FOV so that it is almost leaving the FOV, but not quite, and turn off the Right Ascension motor. Repeat this measurement for a total of 10 trials (or more, if you like). NOTE: if you think you made a mistake during one of the timings, cross out that datum and repeat the trial, so that you get 10 "good" measurements.
- 11) Estimate the uncertainty in the timing measurements by estimating your reaction time.
- 12) Again, use the drift method to compute the angular separation between the nearest edge of Jupiter to each of the visible four moons. Repeat each moon separation measurement five times. Do all 5 measurements for moon 1, then all 5 for moon 2, etc. In other words, don't do moon 1, then moon 2, then 3, then 4, then 1 again, then 2 again, etc.
- 13) Using your keen observational skills, try to identify the moons based on the following properties:
  - a. Io is yellow-orange and is usually (but not always) the closest satellite.
  - b. Europa is the second closest satellite to Jupiter (and therefore usually appears second closest – but not always), is the faintest, and is white in color.
  - c. Ganymede is (usually) next, is yellowish, and is the brightest and biggest.
  - d. Callisto is (usually) the farthest of the Galilean moons and is bluish-gray.
- 14) In the notes section of the observation sheet, write down how you identified each of the four moons. (Example: moon #2 is yellow-orange → Io.)
- 15) At the end of class (within the last 30 minutes), make another detailed sketch of the Jovian system, paying special attention to the moons' locations.

### **For homework**

- 1) Rank the 10 Jupiter diameter drift times from shortest to longest in the space provided. We will assume that the experimental error is the difference between the middle-fast time and the middle-slow time. (If you took exactly 10 measurements, this would be the difference between #7 and #3.) This difference represents the error in the measurement technique as used in this activity. It tells you how precise you, these tools, and methods are when used together.

### *Jupiter Distances*

- II) A) Refer to page **Error! Bookmark not defined.** to compute the angular diameter of Jupiter based only on your drawings and FOV measurements. B) Similarly, compute the angular distances from each of the moons to the center of Jupiter.
- III) Use the drift timings to compute the angular diameter of Jupiter and the angular separations for the moons. When computing the drift-time angular separations, don't forget that your times probably went from the edge of Jupiter to the moon, but you want to determine the separation angle from the moon to the CENTER of Jupiter. So, add half of Jupiter's angular diameter to the moon drift-time angles.
- IV) Reliably identify the moons in your drawing by using any resources available to you, such as the internet (e.g. Java Jupiter at ShallowSky.com), Astronomy Magazine, Sky and Telescope magazine, or the CLEA Jupiter Moons computer software on the computers in MCS [Math] 8. Note: add 8 hours to Pacific Standard time to get Universal Time, but add only 7 hours if we're on Daylight Saving Time). If you say moon #1 is Io, #2 is Europa, etc, make sure that your research confirms this! Record the actual moon identifications in question 2, and try to figure out why you got any wrong, if you did (which is not unexpected).
- V) Research the actual equatorial diameter of Jupiter, in real units (e.g. kilometers or miles).

### **Determining Sizes/Separations from Distances or vice-versa**

Refer to the "Computing distances and linear sizes or separations using angles" on page **Error! Bookmark not defined.** to determine the distance from Earth to Jupiter. Use the same distance units (miles or km) for the distance as you used when researching Jupiter's true diameter. Convert Jupiter's distance into astronomical units (AUs) using the fact that 1 AU = 93 million miles = 150 million km. One AU is the average distance between the Earth and Sun. If Jupiter is 4 AUs away, then it is 4 times further from us than the Sun is from us.

Using the distance to Jupiter, compute the "true separation" of each of the moons from Jupiter's center. Do not report your answer in AU. For reference note that the distance from Earth to the Moon ranges between 363,000km to 406,000km, depending on the time of the month. It is unlikely that these distances are the "right" answers – in other words, they usually will not correspond to information you can look up in a textbook. A question in this assignment will ask why.

## *Jupiter Distances*

### *Questions*

- 1) [1/2 pt] What map number (in your sky atlas) is Jupiter on today? What constellation is it in?
- 2) [1 pt] Did you correctly identify the moons during the lab class? If not, why might you have misidentified the moons that you didn't get correct? [Don't forget, moon #1 may not be Io, moon #2 may not be Europa, etc.] What was your source of the moons' positions?
- 3) [1.5 pts] A) How does the experimental error (fast-middle datum minus slow-middle datum) for Jupiter's drift time compare to your reaction time. (Are they close, or very different?) B) Why might they be the same? C) Why might they be different?
- 4) [1 pt] When measuring the moons' separation from Jupiter, why did we measure the moons five trials at a time, instead of doing the first trial for all 5 moons, then the second trial, etc.?
- 5) [1 pt] Did you notice any changes in the moons' positions between the beginning of class and the end of class? Which moon did/should have appeared to move the most during the 2-3 hour time interval? Least? Justify your choices.
- 6) [2 pt] The human eye is capable of resolving objects (i.e. detecting something as more than a dot) that have angular sizes of one approximately arcminute or larger. A) Given this theoretical limitation, could you theoretically see Jupiter as something that appears larger than a dot with your unaided eye (i.e. without a telescope/binoculars)? (i.e. is Jupiter more than 1' in diameter?) B) Could you theoretically see the moons' separation from Jupiter? [Note, this question does not ask if you can theoretically distinguish the moons from dots – it asks about the separation.] C) For both of the above questions, answer one of the following questions:
  - a. If you could theoretically see this, why didn't you actually see it?
  - b. If you could not theoretically see it, give another (completely different) reason why it would be difficult/impossible to see? (If you did see it, your eyes are better than mine.)
- 7) [1.5 pts] If you were very careful scientists, then you would measure the same drift times in the 40mm eyepiece as you would in any other eyepiece. Why doesn't the drift time depend on which eyepiece you use?
- 8) [2 pts] The moon separations you compute at the end of the worksheet should not be the same as the orbital distances from Jupiter to each moon. Why not?
- 9) [4 pts **extra credit**] According to your research, what are the actual orbital distances for each of the moons? Should your calculated distances be greater than, less than, or equal to the values you researched? Why? Were your distances greater, less, or equal to the researched values? If there is a discrepancy between what you think they should be and what they actually are, to what do you attribute this discrepancy?

### **What to submit:**

- 1) [10.5 pts] The answers to the above questions
- 2) [33 pts] The following 2 page worksheet
- 3) The work you did for the computations on the following worksheet. If you omit your calculations work, you cannot receive partial credit for incorrect answers.
- 4) [3 pts] At least two sketches of Jupiter and each sketch must contain:
  - a. [1/2 pt] Estimates of Jupiter diameters from moons to Jupiter, and size of Jupiter compared to the entire FOV. See Direction (4) above.
  - b. [1/2 pt] moons labeled 1-4
  - c. [1/2 pt] tentatively named moons
  - d. [1.5 pts] correctly identified moons according to research
  - e. [1/2 pt] research source cited

**Data tables and analysis for Jovian System**

Complete the top part of this during lab. After finishing that, I strongly suggest you work on the rest in class, time permitting.

[1/2 pt] Ask your instructor for the following (or determine it on your own with a good polar alignment!):  
Jupiter RA today \_\_\_\_\_ Jupiter declination today \_\_\_\_\_

[1.5 pts] Estimate of Jupiter diameter \_\_\_\_\_ arcminutes  
Estimate of angular separation (in arcminutes) between Jupiter and 4 moons  
#1 \_\_\_\_\_ #2 \_\_\_\_\_ #3 \_\_\_\_\_ #4 \_\_\_\_\_  
These are educated guesses – not calculations

[4 pts] 10 trials of Jupiter’s drift time across its diameter (measured in decimal seconds: e.g. 4.34 sec)  
#1 \_\_\_\_\_ #2 \_\_\_\_\_ #3 \_\_\_\_\_ #4 \_\_\_\_\_ #5 \_\_\_\_\_  
#6 \_\_\_\_\_ #7 \_\_\_\_\_ #8 \_\_\_\_\_ #9 \_\_\_\_\_ #10 \_\_\_\_\_

[1/2 pt] Average \_\_\_\_\_ seconds [compute after class]

[4 pts] Moon timings:  
Moon 1: #1 \_\_\_\_\_ #2 \_\_\_\_\_ #3 \_\_\_\_\_ #4 \_\_\_\_\_ #5 \_\_\_\_\_ avg: \_\_\_\_\_  
Moon 2: #1 \_\_\_\_\_ #2 \_\_\_\_\_ #3 \_\_\_\_\_ #4 \_\_\_\_\_ #5 \_\_\_\_\_ avg: \_\_\_\_\_  
Moon 3: #1 \_\_\_\_\_ #2 \_\_\_\_\_ #3 \_\_\_\_\_ #4 \_\_\_\_\_ #5 \_\_\_\_\_ avg: \_\_\_\_\_  
Moon 4: #1 \_\_\_\_\_ #2 \_\_\_\_\_ #3 \_\_\_\_\_ #4 \_\_\_\_\_ #5 \_\_\_\_\_ avg: \_\_\_\_\_

[1 pt] Estimate of the uncertainty in the timings based on reaction time, etc: \_\_\_\_\_ seconds

----- Everything below this line can be done as homework -----

[1/2 pt] Ranked times above for Jupiter’s diameter  
Fastest #1 \_\_\_\_\_ #2 \_\_\_\_\_ #3 \_\_\_\_\_ #4 \_\_\_\_\_ #5 \_\_\_\_\_  
#6 \_\_\_\_\_ #7 \_\_\_\_\_ #8 \_\_\_\_\_ #9 \_\_\_\_\_ #10 \_\_\_\_\_ Slowest

[1/2 pt] Middle fast \_\_\_\_\_ Middle slow \_\_\_\_\_ Experimental error \_\_\_\_\_

**Image scale preliminary calculations (See “For Homework”, step II, above)**

[1/2 pt] Size of FOV circle on observation sheet: \_\_\_\_\_ cm  
[1/2 pt] Angular size of FOV \_\_\_\_\_ (include angular units!)  
[1 pt] Image scale \_\_\_\_\_ (e.g. 5 cm per arcminute or 1 arcminute per 0.2 cm)  
[1 pt] Size of Jupiter on observation sheet: \_\_\_\_\_ cm

**Show work** (written neatly and clearly) for ALL of the following calculations on your own paper, **not** on this sheet! Report only your final answers on this sheet.

[1 pt] Angular diameter of Jupiter determined using drawing \_\_\_\_\_ (include units)  
[1 pt] Angular diameter of Jupiter determined using drift timing average \_\_\_\_\_  
[1/2 pt] From the above data, determine your best guess for the angular diameter \_\_\_\_\_  
[1/2 pt] Was your estimate [top of this page] close? \_\_\_\_\_

*Jupiter Distances*

[2 pts] Ruler distance from center of Jupiter to moon #1 on observation sheet: \_\_\_\_\_ cm

Drawing method: Angular separation of moon #1 \_\_\_\_\_ (include units)

Drift time method: (don't forget to add Jupiter's radius!) Ang sep of moon #1 \_\_\_\_\_

Determine your best guess for the separation and convert this angle to radians \_\_\_\_\_

Was your estimate close? \_\_\_\_\_

[2 pts] Ruler distance from center of Jupiter to moon #2 on observation sheet: \_\_\_\_\_ cm

Drawing method: Angular separation of moon #2 \_\_\_\_\_ (include units)

Drift time method: (don't forget to add Jupiter's radius!) Ang sep of moon #2 \_\_\_\_\_

Determine your best guess for the separation and convert this angle to radians \_\_\_\_\_

Was your estimate close? \_\_\_\_\_

[2 pts] Ruler distance from center of Jupiter to moon #3 on observation sheet: \_\_\_\_\_ cm

Drawing method: Angular separation of moon #3 \_\_\_\_\_ (include units)

Drift time method: (don't forget to add Jupiter's radius!) Ang sep of moon #3 \_\_\_\_\_

Determine your best guess for the separation and convert this angle to radians \_\_\_\_\_

Was your estimate close? \_\_\_\_\_

[2 pts] Ruler distance from center of Jupiter to moon #4 on observation sheet: \_\_\_\_\_ cm

Drawing method: Angular separation of moon #4 \_\_\_\_\_ (include units)

Drift time method: (don't forget to add Jupiter's radius!) Ang sep of moon #4 \_\_\_\_\_

Determine your best guess for the separation and convert this angle to radians \_\_\_\_\_

Was your estimate close? \_\_\_\_\_

RESEARCH: Actual diameter of Jupiter \_\_\_\_\_ (include units).

[1 pt] Source of research \_\_\_\_\_

[1 pt] Computed distance to Jupiter \_\_\_\_\_ (miles or km – indicate which)

[1/2 pt] Convert distance to AU: \_\_\_\_\_

Based on your angular separations and the distance to Jupiter, compute the “true separation” between each moon and Jupiter’s center. The following answers should be generated from you data, not based on research.

[1 pt] True separation from moon #1 \_\_\_\_\_ (include units – probably miles or km)

[1 pt] True separation from moon #2 \_\_\_\_\_ (include units)

[1 pt] True separation from moon #3 \_\_\_\_\_ (include units)

[1 pt] True separation from moon #4 \_\_\_\_\_ (include units)

Note: your answers for the moon separations will almost assuredly not match what you find if you look up the “right” answers. There’s a good reason for that... Your distance to Jupiter should be reasonably close, however. Of course, the distance from Earth to Jupiter varies as the Earth and Jupiter go around the Sun.

*Phew! All done. I bet your brain is pretty full.*