Due: Fri Oct 24 2014 12:00 PM EDT

Question 1

Instructions
Lab 3: The Galilean Revolution: Earth's Place in the Solar System

Read the lab before attending lab. You might find it easier to navigate if you expand only one or two sections at a time.

The following summary video is available to you in case you miss lab or want to review it when completing the lab:

Galilean Revolution (23:12)

You are permitted 100 submissions per question. Use some of these to save your work.

If you do not save your work periodically, you risk losing it when WebAssign times you out. WebAssign does this after a few hours for security reasons.

Do not open multiple copies of this assignment, or multiple WebAssign assignments, or you risk losing your answers upon saving or submitting.

Enter all calculated values to at least two significant digits.

Do not add units when entering numerical responses. WebAssign will not accept your response.

Do not use special characters when naming files. WebAssign will not accept your file.

IMPORTANT: Your instructor must submit observations for Lab 4 immediately. These observations take up to a week to complete, and you must have them to do Lab 4. Instructions for submitting these observations can be found in Lab 4, Procedure, Section B, Part 1.

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1. Question Details UNCAstro101L1 3.IL.001. [2026855]

LAB 3 — THE GALILEAN REVOLUTION: EARTH'S PLACE IN THE SOLAR SYSTEM

GOALS

In this lab, you will learn how to:

- Measure a moon's orbit around a planet.
- Use this information to measure the mass of the planet.
- Measure the phase and angular diameter of Venus.
- Use this information to distinguish between the geocentric and heliocentric models of the universe.

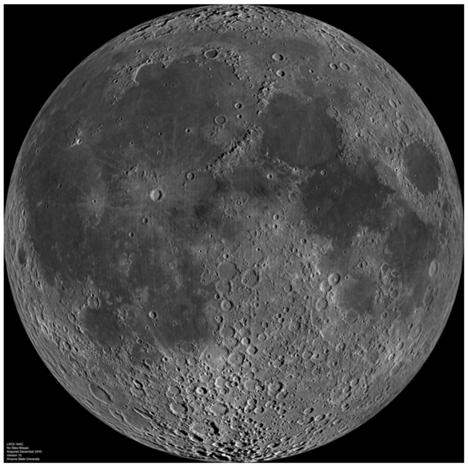
EQUIPMENT

Computer with Internet connection

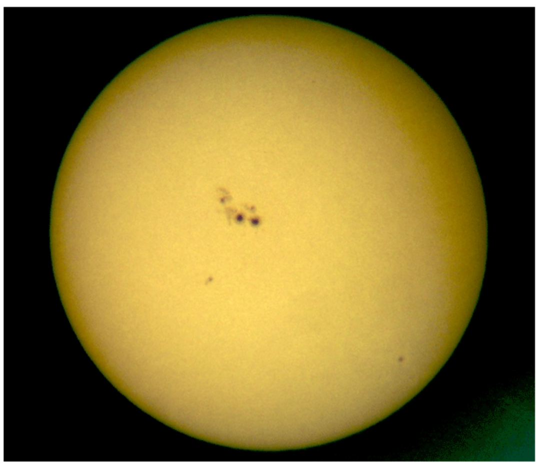
BACKGROUND: A. THE GALILEAN REVOLUTION

Galileo did not invent the telescope, but he was the first to point it to the heavens. Beginning in 1609, this led to four revolutionary discoveries.

He discovered craters and mountains on the moon.

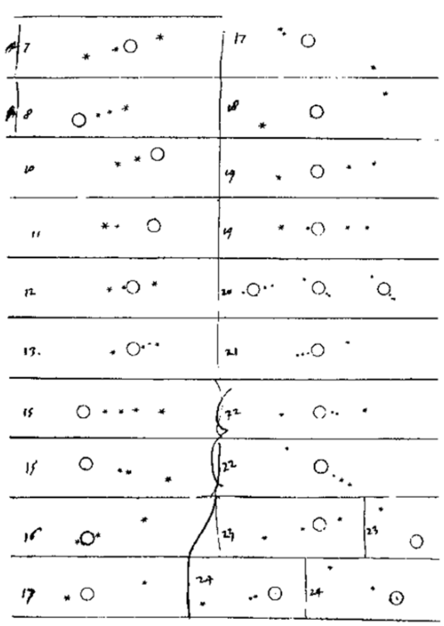


He discovered spots on the sun.



Both of these were revolutionary in that the Catholic Church had long ago adopted the Aristotelian idea that the moon and sun were "perfect" objects—spherical, perfectly smooth, and in the case of the sun, unblemished.

He discovered four moons orbiting Jupiter.

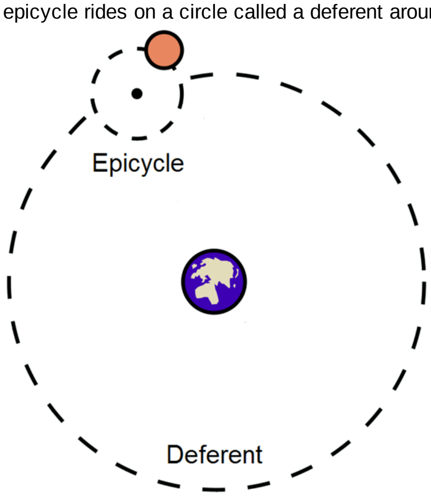


This was revolutionary in that it contradicted the geocentric model of the universe—the idea that Earth is at the center of the universe and everything orbits it. The geocentric model had also been long ago adopted as truth by the Catholic Church.

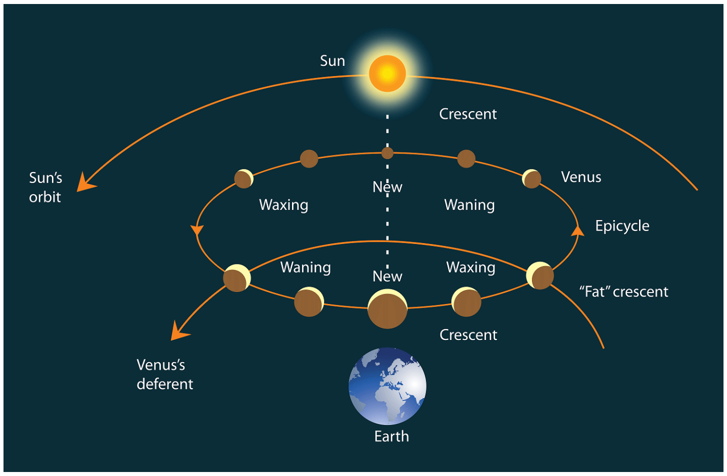
He discovered the phases of Venus.

Although lesser known than the discovery of Jupiter's moons, the discovery of Venus's phases is more significant, in that it not only contradicted the geocentric model of the universe, it confirmed a prediction of the heliocentric model of the universe—the idea that the sun, not Earth, is at the center.

In Aristotle's (and later Ptolemy's) geocentric model of the universe, Venus rides on a circle called an epicycle and the center of Venus's epicycle rides on a circle called a deferent around Earth.

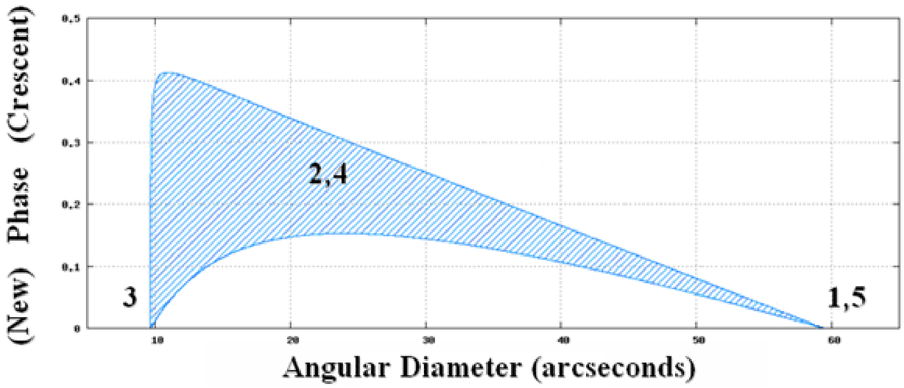


The center of Venus's epicycle is always on a line between Earth and the sun. Consequently, Venus never wanders too far from the sun in the sky, which is what is observed.

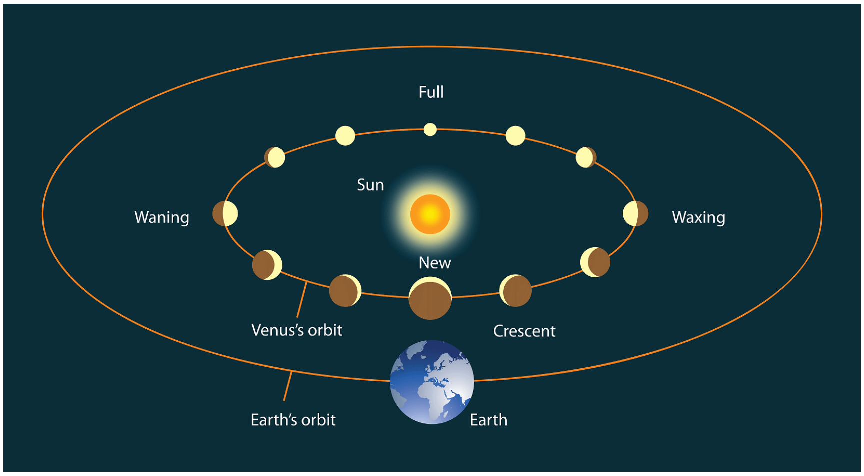


The geocentric model of the universe makes specific predictions about Venus's phases: (1) Venus's phase is new or very close to new when it is closest to Earth and consequently appears largest; (2) it transitions to crescent as it recedes from Earth and consequently appears smaller; (3) it transitions to new or very close to new again when it is farthest from Earth and consequently appears smallest; (4) it transitions to crescent again when it is approaching Earth and consequently appears larger; and (5) it transitions to new or very close to new again when it is closest to Earth and consequently appears largest.

These phase and angular diameter transitions correspond to a curve in the following plot. The curve is thick because different versions of the geocentric model make slightly different predictions.

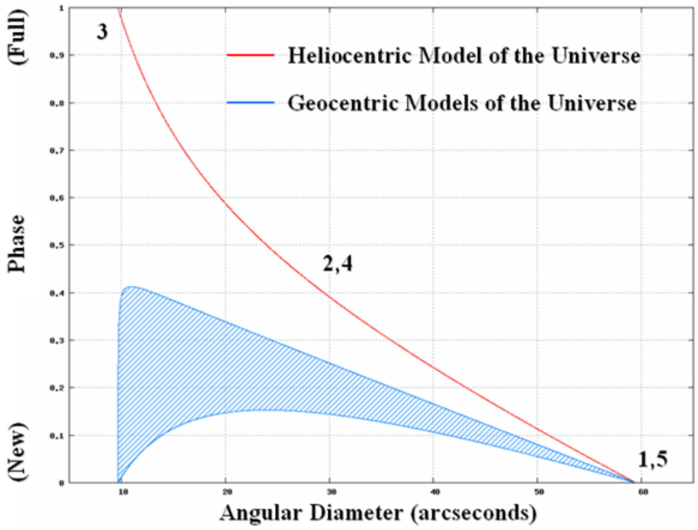


In the heliocentric model of the universe, Venus's orbit is interior to Earth's. Consequently, as in the geocentric model, Venus never wanders too far from the sun in the sky.



However, the heliocentric model of the universe makes very different predictions about Venus's phases: (1) Venus's phase is new or very close to new when it is closest to Earth and consequently appears largest; (2) it transitions to crescent and then quarter and then gibbous as it recedes from Earth and consequently appears smaller; (3) it transitions to full or very close to full when it is farthest from Earth and consequently appears smallest; (4) it transitions to gibbous and then quarter and then crescent again when it is approaching Earth and consequently appears larger; and (5) it transitions to new or very close to new again when it is closest to Earth and consequently appears largest.

These phase and angular diameter transitions correspond to the red curve in the following plot. Clearly, the predictions of the heliocentric model differ from those of the geocentric model.



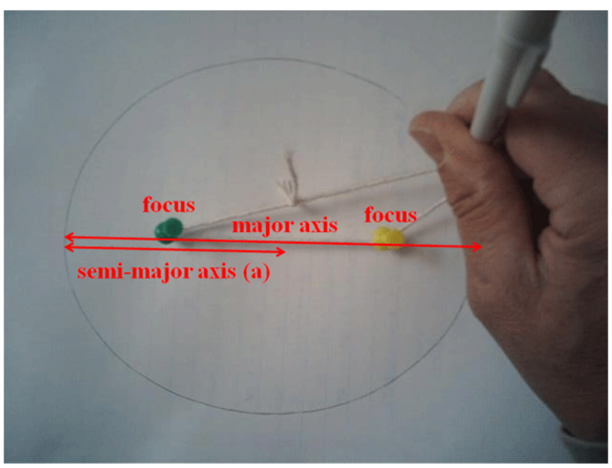
Here's a video of Venus in the geocentric model of the universe. It plays fast. Play it enough times to see all of the phase and angular diameter transitions.

Here's a video of Venus in the heliocentric model of the universe. Again, play it enough times to see all of the phase and angular diameter transitions.

In Section C of the procedure, you will measure Venus's phase and angular diameter at different times and then use this information to distinguish between the geocentric and heliocentric models of the universe.

BACKGROUND: B. ORBITS

Kepler showed that planets orbiting the sun and moons orbiting planets do not travel on circles, but on ellipses, with the central body at one of the two foci.



The long axis of an ellipse is called the **major axis**. Half of the major axis is called the **semi-major axis**, which is usually denoted ***a***.

Kepler also showed that the time that it takes for a planet to orbit the sun or for a moon to orbit a planet—the **orbital period**, which is usually denoted ***P***—is related to the semi-major axis in the following way.

$$P^2 = \text{constant} \times a^3,$$

where the value of the constant depends on the central body: All planets orbiting the sun have the same constant. All moons orbiting Jupiter share a different constant. The moon orbiting Earth has yet another constant.

Newton showed that the value of the constant depends on the mass of the central body.

$$P^2 = \left(\frac{4\pi^2}{GM}\right) \times a^3$$

(This assumes that the mass of the central body is significantly greater than the mass of the orbiting body.)

Now, consider the case of Earth orbiting the sun. Then P = 1 year, M = 1 solar mass, and a = 1 AU (astronomical unit = 1 sun-Earth distance). Hence:

$$(1\ \text{year})^2 = \left(\frac{4\pi^2}{G \times 1\ \text{solar mass}}\right) \times (1\ \text{AU})^3.$$

Dividing this equation into the previous equation yields:

$$\left(\frac{P}{1\ \text{year}}\right)^2 = \left(\frac{1\ \text{solar mass}}{M}\right) \times \left(\frac{a}{1\ \text{AU}}\right)^3.$$

Solving for the mass of the central body yields:

$$M = \left[\frac{(a/1\ \text{AU})^3}{(P/1\ \text{year})^2}\right]\ \text{solar masses}.$$

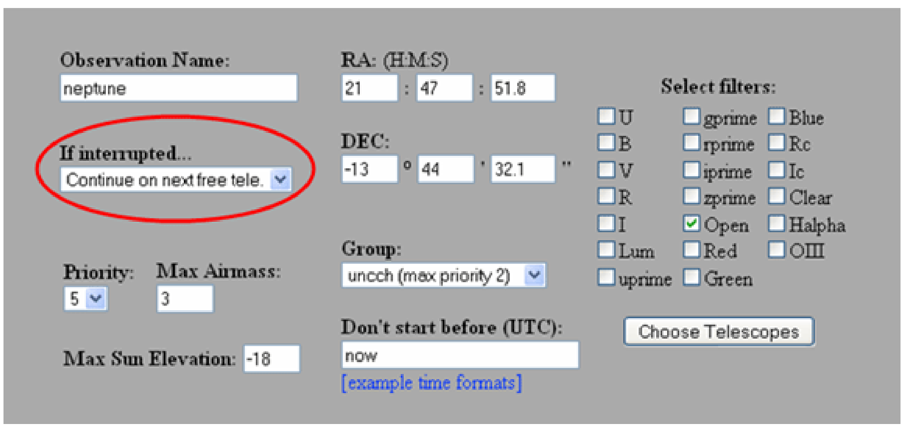
Hence, by measuring the semi-major axis of a moon's orbit around a planet in AU and its orbital period in years, you can measure the mass of the planet in solar masses. In Sections A and B of the procedure, you will measure the orbit of a moon around one of the four Jovian planets and then use this information to measure the mass of that planet.

PROCEDURE: A. MONITOR A PLANETARY SYSTEM WITH SKYNET - 1. How to Monitor a Planetary System with Skynet

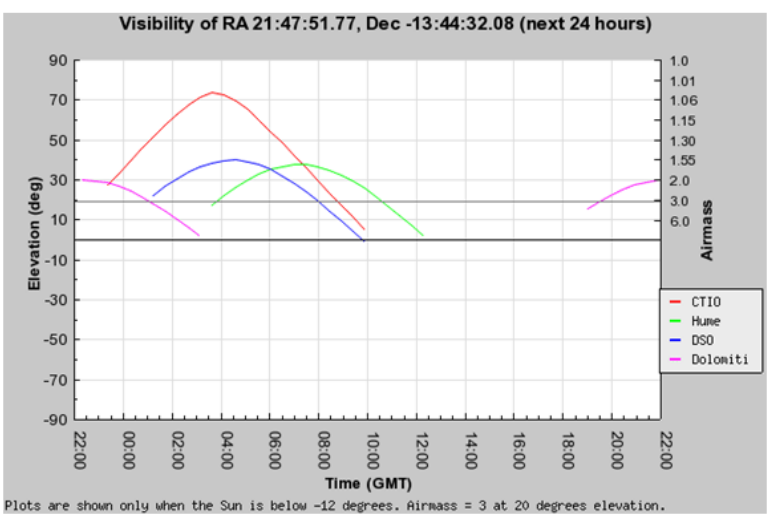
In this tutorial, you will learn how to monitor an object over an extended period of time.

Use Skynet to monitor an observable Jovian planetary system every clear night for two weeks. Select Jupiter, Saturn, Uranus, or Neptune.

Remember to change "If interrupted..." to "Continue on next free telescope" just in case the telescope that begins your observations goes offline during the next two weeks.



Confirm that the planetary system that you selected is indeed observable from CTIO or SSO this time of year.



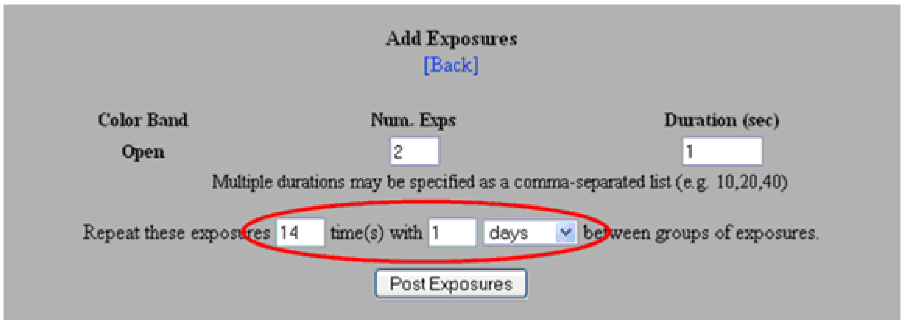
If it is not, select a different planetary system.

Select as many of PROMPT-1, 3, 4, 5, and 6 and PROMPT-SSO-1, 2, 3, and 4 as you can, but do not select PROMPT-2, 7, or 8.

Select filters and request exposure durations that will allow you to detect as many moons as possible without overly saturating the planet.

System	Filter	Exposure Duration (seconds)†
Jupiter	V	0.03
Saturn	Open	0.03
Uranus	Open	1
Neptune	Open	1

Request two exposures (just in case one disappoints) and below this request "Repeat these exposures 14 times with 1 day between groups of exposures".

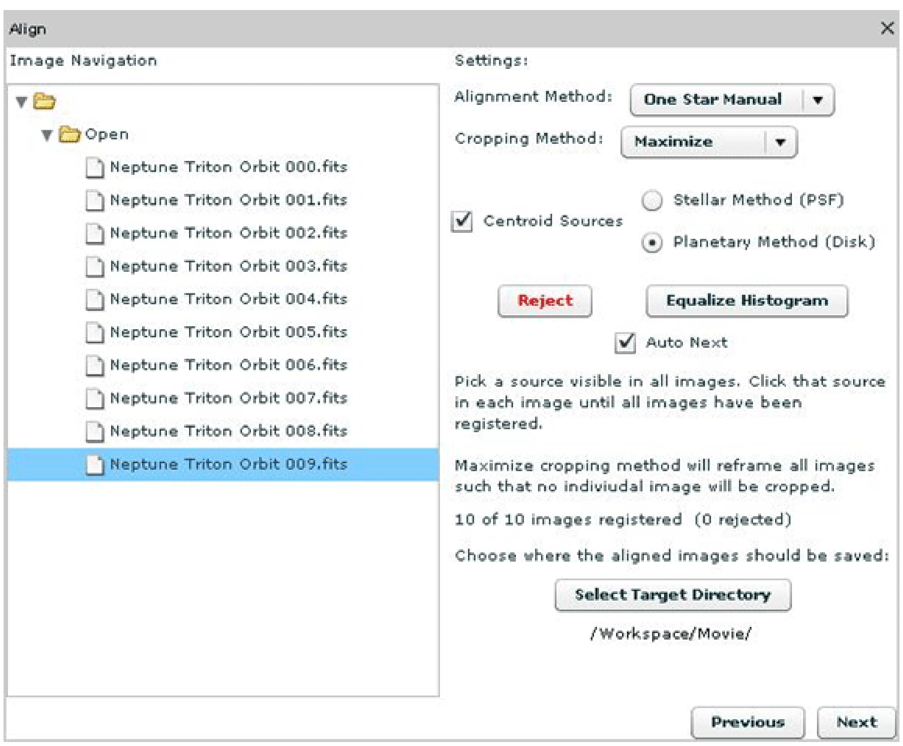


PROCEDURE: A. MONITOR A PLANETARY SYSTEM WITH SKYNET - 2. Make a Movie of the Moons Orbiting the Planet

In this tutorial, you will learn how to select and align images, which must be done before they can be made into a movie.

Select and align your images. Remember:

- If the planet is in the same general area in each of your images, feel free to change "Cropping Method" to "Intersection". Otherwise, use "Union".
- Since you will align by clicking on the planet, change "Stellar Method (PSF)" to "Planetary Method (Disk)".
- Select, or create and select, a target directory in your "Workspace", where your selected and aligned images can be saved.
- For each image, either select and align it by clicking on the planet or reject it by clicking the "Reject" button.



In this tutorial, you will learn how to turn selected and aligned images into a movie.

Turn your selected and aligned images into a movie. Remember:

If you want to see the moons orbit the planet, stop the movie. Select "ZScale" in the "Histogram" window and "Equalize Histogram" in the "Make Movie" window. Then play.

If you want to see the planet rotate, stop the movie. Select "MinMax" in the "Histogram" window and "Equalize Histogram" in the "Make Movie" window. (This is more impressive for Jupiter than it is for Saturn, Uranus, and Neptune).

Repeat #1 so the moons can be seen orbiting the planet. In the "Make Movie" window, select either the "avi" or "mov" file format and save your movie by clicking "Download Movie". Check your saved movie by playing it with other software on your computer.

Question: Upload your final avi or mov movie. (Submit a file with a maximum size of 8 MB. 5 points.)

Choose File No file chosen

PROCEDURE: B. ORBIT AND MASS DETERMINATION - 1. Measure the Angular and Physical Diameters of the Planet

Question: Which planet did you observe in Section A of the procedure? (1 point)

- Jupiter
- Saturn
- Uranus
- Neptune

Identify the sharpest looking image of your images. Open it in Afterglow, **select the "Histogram" window, and select "MinMax". Zoom in until the planet fills your window.**

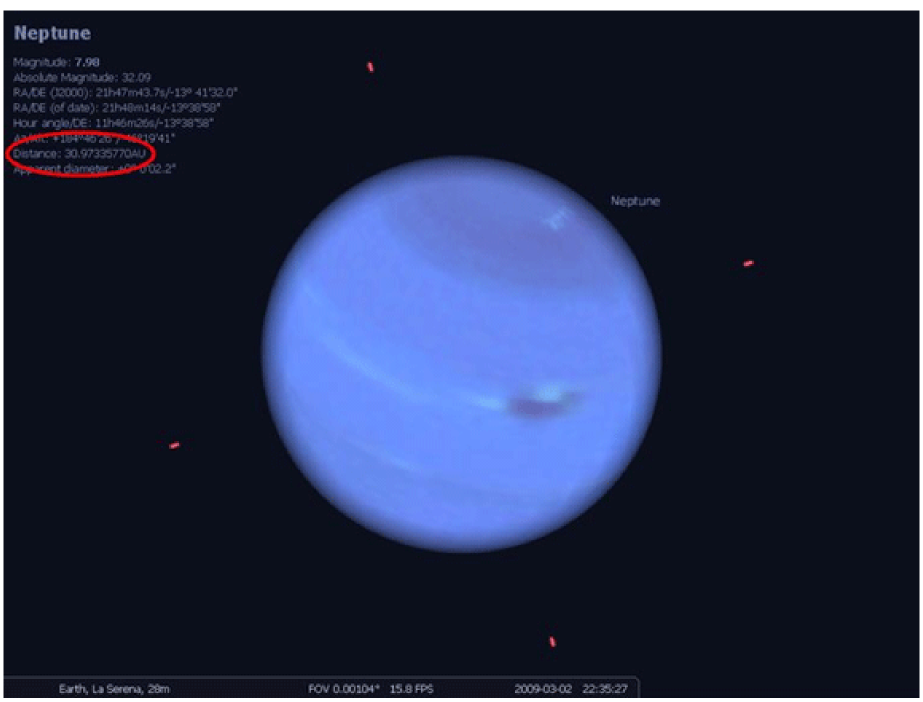
Question: Measure the angular diameter (θ) of the planet to the nearest 0.1 arcseconds. If your planet is Saturn, measure the angular diameter of its rings. (2 points)

[ ] arcseconds

Note: This value should be larger than the true value due to atmospheric blurring and possibly due to difficulty knowing which shade of gray best marks the edge of the planet.

Question: Use Stellarium to find the distance to the planet when Skynet took your image, in AU. (2 points)

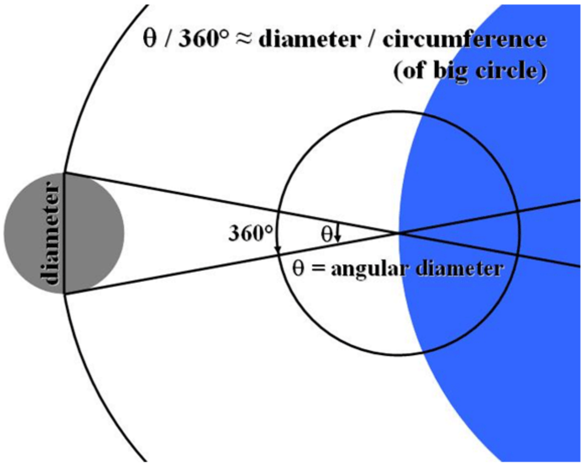
[ ] AU



Note: In Lab 4, you will learn how to measure distances to solar system objects directly using parallax, instead of having to look

them up in Stellarium. But this will do for now.

Once the angular diameter of the planet and the distance to the planet are known, the physical diameter of the planet can be determined.



The physical diameter of the planet as a fraction of the circumference of the big circle is the same as the angular diameter of the planet as a fraction of 360°:

$$\frac{\textbf{diameter}}{\textbf{circumference}} = \frac{\theta}{360°}$$

Since circumference = 2π × radius and the radius of the big circle is the distance to the planet:

$$\frac{\textbf{diameter}}{2\pi \times \textbf{distance}} = \frac{\theta}{360°}$$

Solving for the physical diameter of the planet yields:

$$\textbf{diameter} = 2\pi \times \textbf{distance} \times \frac{\theta}{360°}$$

Question: Use this equation to calculate the physical diameter of your planet in AU. You will need to convert θ to degrees first. (3 points)

[ ] AU

Show your work for both of these calculations.

Note: Since in AU, this should be a very small number.

Note: This value should be larger than the true value by the same factor that your measurement of the planet's angular diameter (θ) is larger than its true value. These factors will cancel out in Section B.4 of the procedure and consequently will not affect your measurement of the planet's mass.

⊞ PROCEDURE: B. ORBIT AND MASS DETERMINATION - 2. Measure the Orbit of a Moon

Next you are going to measure the orbit of one of your planet's moons:

- If your planet is Jupiter, you will measure the orbit of Ganymede.
- If your planet is Saturn, you will measure the orbit of Titan.
- If your planet is Uranus, you will measure the orbit of Oberon.
- If your planet is Neptune, you will measure the orbit of Triton.

For each of your successful observations:

- Select the better of the two images.
- For that image, select the information window and record the system (not universal) date and time that the image was taken in Data Table 1 below. Also record the Julian date that the image was taken in Data Table 1, to the nearest 0.1 days.
- Adjust the max value and zoom in/out until you can easily see the moons. Use Stellarium to identify which one is Ganymede, Titan, Oberon, or Triton. (If the moon is too close to the planet to see, or so far from the planet that it is off the image, skip this observation.)
- Measure the angular separation between the center of the planet and the center of the moon. Record it to the nearest 0.1 arcseconds in Data Table 1 below.

Question: Which moon did you measure? (1 point)

- Ganymede
- Titan
- Oberon
- Triton

Data Table 1: Planetary Moons (10 points)
Note: Angular separations must be measured in arcseconds, not arcminutes.

System Date	System Time	Julian Date (days)	Angular Separation (arcseconds)

Sign your name to attest to the fact that you collected these data yourself:

PROCEDURE: B. ORBIT AND MASS DETERMINATION - 3. Measure the Mass of the Planet

Go to this website and select "Moon". In this tutorial, you will learn how to graph your data and measure an orbit's semi-major axis in arcseconds and period in days.

Make a graph of angular separation vs. Julian date and adjust the semi-major axis (*a*), the orbital period (*P*), and the phase and tilt

of the orbit until the curve best matches your data.

Note: Google the orbital period of your moon to check your result. If you are way off, try again.

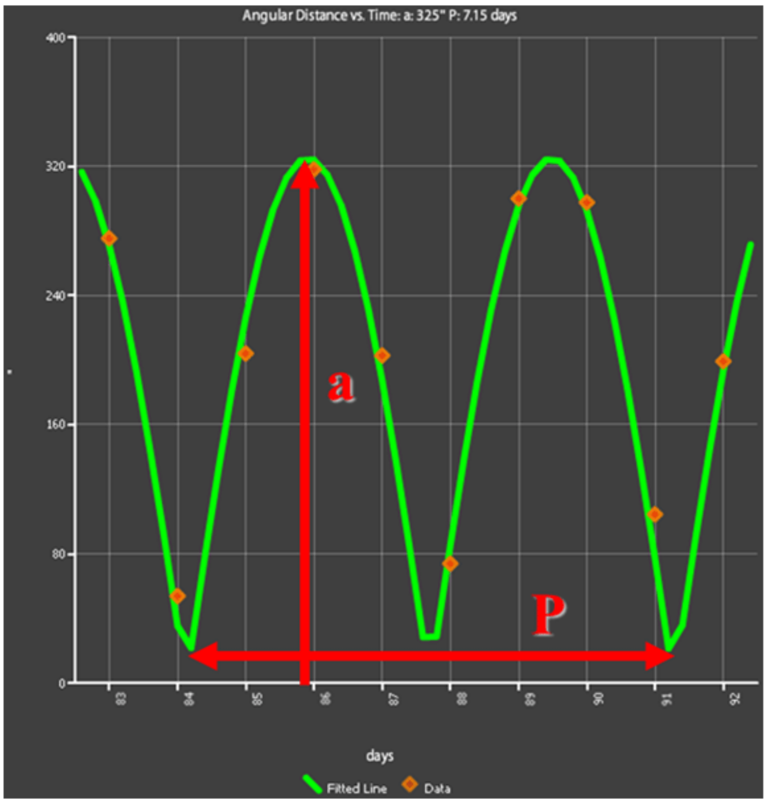
Note: Jupiter, Saturn, and currently Uranus have small orbital tilts, meaning that you are viewing them close to edge on. Neptune currently has a large orbital tilt, meaning that you are viewing it close to face on. If you are way off, try again.

Save your graph as a png file.

Question: Upload your png graph. (10 points)

Choose File No file chosen

The orbit's semi-major axis and period are reflected in the fitted curve as follows.



The maximum angular separation between the moon and the planet is the semi-major axis of the moon's orbit.

Question: Record the semi-major axis, *a*, in arcseconds. (2 points)

arcseconds

The time between peaks is the time it takes for the moon to move from one side of the planet to the other. This is half of the moon's orbital period. The time between two peaks is the moon's orbital period.

Question: Record the orbital period, *P*, in days. (2 points)

days

Next, use your measurement of the planet's angular diameter in arcseconds and your calculation of the planet's physical diameter in AU from Section B.1 of the procedure to convert your measurement of the moon's orbital semi-major axis from arcseconds to AU.

$$\boldsymbol{a} \textbf{ in AU} = (\boldsymbol{a} \textbf{ in arcseconds}) \times \left(\frac{\textbf{diameter in AU}}{\boldsymbol{\theta} \textbf{ in arcseconds}} \right)$$

Question: Calculate *a* in AU. (2 points)

AU

Show your work.

Note: Since in AU, this should be a very small number.

Question: Convert your measurement of the moon's orbital period from days to years. (2 points)

years

Show your work.

Note: Since in years, this should be a very small number.

By Newton's form of Kepler's third law, the mass of the planet must then be:

$$M = \left[\frac{(a/1\ \text{AU})^3}{(P/1\ \text{year})^2} \right] \textbf{ solar masses}$$

Question: Calculate the mass of the planet. (2 points)

solar masses

Show your work.

Question: Finally, convert the planet's mass to Earth masses: 1 solar mass = 333,000 Earth masses. (2 points)

Earth masses

Show your work.

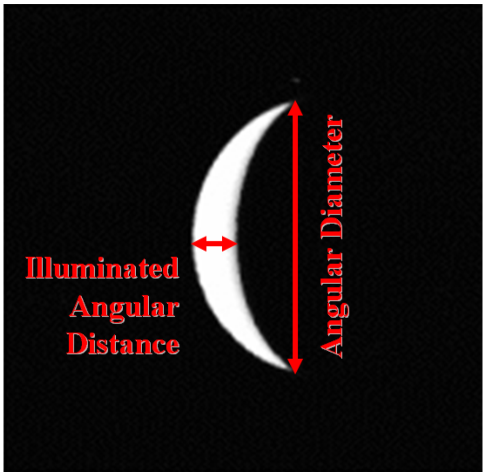
Question: Google the true mass of your planet in Earth masses and compute your percent error. (3 points)

%

Question: Discuss significant sources of error. (3 points)

PROCEDURE: C. VENUSIAN PHASES

Venus's angular diameter and illuminated angular distance are defined as follows.



Use Afterglow **to measure the angular diameter and illuminated angular distance of Venus (1) in your image from Lab 1, if you got one of Venus, and (2) in archival images (in Afterglow, go to "File", "Open Image(s)", "Sample Images", "Astro 101 lab", "Lab 3 - Galilean Revolution", "Venus"). Record these to the nearest 0.1 arcseconds in Data Table 2 below.**

Note: For each image, select the "Histogram" window and select "MinMax". Zoom in until Venus fills your window!

Venus's phase is given by:

$$\text{phase} = \frac{\text{illuminated angular distance}}{\text{angular diameter}}.$$

Compute Venus's phase for each image and record this to two decimal places in Data Table 2 below.

Data Table 2: Venusian Phases (10 points)

Note 1: Illuminated angular distances should be smaller than angular diameters.

Note 2: Phases should be between 0 and 1.

Image	Illuminated Angular Distance (arcseconds)	Angular Diameter (arcseconds)	Phase
1			
2			
3			
4			
5			
6			
7			
8			

Sign your name to attest to the fact that you collected these data yourself:

Go to this website and select "Venus".

Make a graph of Venus's phase vs. angular diameter. Save it as a png file.

Question: Upload your png graph. (5 points)

Choose File No file chosen

Question: Are your measurements more consistent with the geocentric model of the universe or the heliocentric model of the universe?

Why? (3 points)

Discuss significant sources of error. (2 points)

Assignment Details

Name (AID): **Lab 3: Galilean Revolution (T) (2586554)**
Submissions Allowed: **100**
Category: **Homework**
Code:
Locked: **Yes**
Author: **Reichart, Daniel (reichart@physics.unc.edu)**
Last Saved: **Jun 19, 2013 05:31 PM EDT**
Permission: **Protected**
Randomization: **Assignment**
Which graded: **Last**

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Response
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Question Part Score
Solution
Mark
Help/Hints
Response