PHYS 1401: Descriptive Astronomy   Summer 2016

Lab 01: Introduction to Stellarium

Introduction

Stellarium is a free, open-source planetarium program available for download. If you have your own computer, you should consider installing it. If you have your own copy installed, you can work on lab exercises at your own convenience, review or double-check your lab answers before quizzes, or just play around with it. The program can be downloaded at:

http://www.stellarium.org

This program is installed in the computer lab LSC 174, so you are free to use it any time the lab is open.

The advantages of using a computer-generated sky are numerous. First, and most obviously, it's never too cloudy to observe the sky on the screen! Another powerful advantage is time. We can examine the sky on any day, at any time: past, present, or future. We can watch the stars and planets move quickly across the night sky in a way that would not be possible outdoors, or even with a professional telescope. We can change our location, and see the sky from parts of the world we have never visited...or from other worlds entirely.

Objectives

- Become familiar with the Stellarium program and its user interface
- Define and distinguish between systems of astronomical coordinates
- Examine the position of the sun in the sky over the course of a year

Procedure

Launch the Stellarium program. When the program has loaded, your screen should show you located in a field of grass, facing south. You have two toolbars that you activate by moving the mouse over their locations. At the left edge of the window, towards the bottom, you will find a vertical toolbar with configuration windows for setting location, date, and viewing options. There is a horizontal toolbar along the bottom left edge as well. This has toggles for the most common viewing options, as well as time controls.

You can spend a few minutes clicking around, just to see what this button or that toggle does.
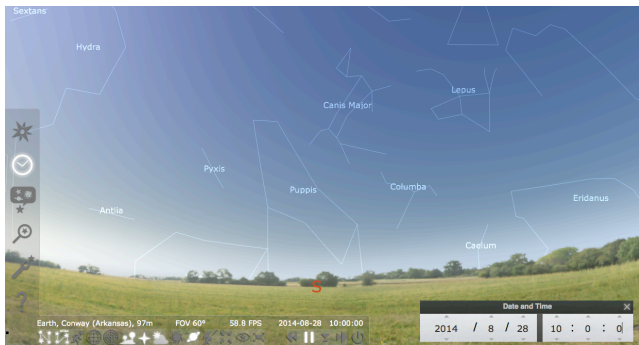
1. **Set your location:** Click on the Location Window icon (vertical toolbar, top icon). There are many ways to specify where you are, but start by doing the fastest thing. In the search box, start typing "Conway." By the time you are three letters in, you should see your location list has been whittled

down to just a few places, and you can select Conway, AR. Notice on the map that your red location arrow is correctly pointing to central Arkansas, and you can close the location window.

2. **Set your time:** Click on the Date/Time Window icon (vertical toolbar, second icon). It should initially display the current and correct date and time. Let's go ahead and see the eastern sky earlier this morning. Change the time to 6:00AM, and notice how dramatically your view changes. Go ahead and close the date/time window.

3. **Return to right now:** Activate the horizontal toolbar by mousing over it. The icons on the right end of the toolbar control the passage of time. Click on the "Set time to now" icon, or just type the number 8. You will notice that there are keystrokes which correspond to these toggles, and you will probably find a few that you use frequently—knowing a few keystrokes can be a real timesaver.

4. **Wander around:** Explore your landscape. You can navigate using the mouse or the arrow keys. Spin around, look up, look down.

Astronomical Coordinate Systems

There are several systems that can be used to locate objects in the sky. We will distinguish here between two coordinate systems: **azimuth/altitude (Az/Alt) and right ascension/declination (RA/DE)**. Either one of these systems is analogous to using x- and y-coordinates on a piece of graph paper. They are two dimensional systems, which means that they can tell you where to look in the sky to find an object, but not how far away that object is from the Earth.

5. **Turn and face north:** Toggle on the Azimuthal grid (command keystroke z), look up a bit, and examine the coordinate system. Azimuth is the angle measured in a horizontal circle, around your horizon. Due N = 0°. Head around the circle, and E = 90°, S = 180°, W = 270° and back to N = 360°. Altitude is the angle measured from the horizon (0°) to the zenith (90°, or directly overhead). Thus, any point in the sky that you can see can be specified by telling you which direction to face (az), and how high up to look (alt).

6. **Set your time for today:** (07/06/16), at 9:00PM (21:00). Locate the star Polaris, and record its az/alt coordinates (click on the star, and notice the information that appears in the top left of your screen). Pay attention to how these coordinates correspond to the star's location in the sky.

7. **Toggle between mounts:** Notice the difference between the equatorial and azimuthal mounts! The azimuthal mount parallels the az/alt coordinates. The equatorial mount makes no sense if you imagine you are outside looking at the sky with your naked eye, but makes sense if you imagine that you are looking through the eyepiece of a telescope. Many telescopes are mounted parallel to the celestial equator, which makes adjusting to find objects easy using RA/DE coordinates. Does changing the telescope mount change the actual location of the object?

8. **Toggle between grids:** Turn off the az/alt coordinates (z), and toggle on the equatorial grid (command keystroke e). You are now looking at the right ascension/declination coordinate system. Record these coordinates for Polaris, and notice that RA is not given in degrees. *Always use the J2000 coordinates for RA/DE.*
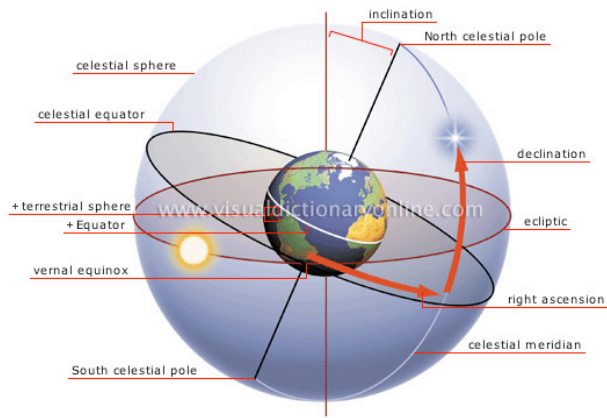
9. **Set the day and time:** Change the date to today (07/06/16), at 9:00PM (21:00). Locate the bright star Acturus in the western sky. Record both its Az/Alt coordinates and RA/DE. Move forward in time to 10/01/16 at the same time, and record the positions. Note that even if the star dips below your viewing horizon (alt < 0°), its position is still displayed. Continue to advance in three month increments for an entire year. Construct a table in your lab notebook to record your data (do not try to fill in this example table, there is simply not enough room).

Date	Azimuth and Altitude		Right Ascension and Declination	
	Az	Alt	RA	DE
07/06/16				
10/06/16				
01/06/16				
04/06/16				

10. **Change your location:** Return to the original date (07/06/16) and time (21:00). Remain centered on the star Arcturus, but change your observation location. Pick any place you like: New York, Chicago, Paris…literally anywhere. Note your location, and record one more time the Az/Alt and RA/DE coordinates for the star. For the location you chose, is Arcturus visible above the horizon?

11. **Really change your location**: First, return to your default location (Conway, AR). In the Location window, notice that you are not limited to staying here on Earth! Go to Mars. Yes, Mars. The program will preserve your latitude and longitude, and place you in the equivalent location on whatever planet you select. Have the RA/DE coordinates of Arcturus changed? Where in the Martian sky does Arcturus appear?

12. **Wow, what does that mean?** You have just demonstrated the difference between the coordinate systems! Notice that Az/Alt depends entirely on where you are located, and RA/DE does not. Relating this back to question 07, if you were an astronomer here in Arkansas who needed to tell a colleague at Kitt Peak (in Arizona) about a sky object, how would you choose to communicate its location?

Sunrise and Sunset

We all know that the sun rises in the east and sets in the west, right? Let's examine the position and time of the rising and setting sun over the course of the year, and see how true that is. Toggle back to **Az/Alt** (z) coordinates for this exercise.

13. **Find the rising sun:** Set your date for 09/21/16, and find the rising sun. Guess at the time, then refine your time until the sun has an altitude of 0°. Adjust the time in seconds to get as close as you can, but because you cannot adjust time in smaller than 1 second increments, understand that you will probably not be able to obtain an altitude of precisely 0°0'0". Get as close as you can, and record the time and both azimuth and altitude coordinates.

14. **Find the setting sun:** Without changing the date, advance the time to sunset. The setting sun will again have an alt = 0°. Record the time and Az/Alt coordinates.

15. **Change the date and repeat:** Record the sunrise and sunset times and coordinates again on 12/21/16, 03/21/17, and 06/21/17. You should construct a table in your notebook so that you can compare these data easily. (This example is nowhere near large enough to record your observations.)

Date	Sunrise			Sunset		
	Time	Az	Alt	Time	Az	Alt
09/21						
12/21						
03/21						
06/21						

16. **Does the sun rise due east (az = 90°) every day?** Set due west (az = 270°)? On which day does the sun rise farthest to the north (smallest azimuth, or north of east)? On which day does it rise furthest south (greatest azimuth, or south of east)?

17. **Why look at the sun on those days in particular?** Why not four other random days chosen three months apart? Note the significance of each of these particular dates. See Figure 0.10 (page 10) of your textbook.

18. **Correlate the data to the dates:** What is significant about the specific dates we selected? For example, note what is similar in your data about 03/21 and 09/21, and what it means (and what about 06/21 and 12/21?).

19. **Compare to Arcturus:** Why didn't we use the same set of dates for our observations of Arcturus?

Make sure that you are recording everything you do in your lab notebook. When you take your quiz in class next week, you will be allowed to use your notebook, a calculator, and clicker, but no additional resources.

Lab 02: Determining the Solar and Sidereal Days

Introduction

Some of our most basic knowledge of astronomy is based on observing the sun and its position in the sky. Unfortunately, some of things we "know" are not entirely correct! One common misconception is that the sun is directly overhead at noon. Whether or not the sun is straight overhead depends on where you are on the globe, what time of year it is, and what you mean by "noon."

Similarly, we all know that one day is 24 hours long. Our entire calendar is based on this fact! However, the measurement of the rotation rate of any object must be done with respect to some reference point. When we measure the time it takes for the Earth to complete one full rotation, it turns out that it makes a difference whether we measure it with respect to the sun or with respect to a distant star.

Objectives

- Improve your ability to navigate Stellarium fluently
- Clearly define the concept of solar noon
- Examine the position of the sun in the sky over the course of a year
- Compare the position of the sun at the same time in different global locations
- Observe the lengths of solar and sidereal days

Procedure

Launch the Stellarium program and set your location for right here in Conway, AR. Make sure you are located at the correct place on the map before you continue. If it is not already, make this your default location (so that the program will automatically place you at the correct location on startup).

Noon Is 12:00, Right?

Again, we all know when noon is…it's 12:00 noon. The sun is straight overhead at noon, right? Check it.

1. **Locate the sun:** For the four dates shown below, find the sun at noon exactly (12:00). Record the Az/Alt coordinates of the sun on each of these days.

A more precise definition for solar noon is the time when the sun crosses the **meridian** (the imaginary line from due N to due S can be turned on from the Viewing Options window). Toggle the meridian on.

2. **Is the sun on the meridian?** On any of the days you observed, is the sun on the meridian (az = 180° is the meridian) at noon? Is 12:00 on the clock before or after solar noon for our location?

DATE	12:00 NOON		SUN CROSSES MERIDIAN		
	AZ	ALT	TIME	AZ	ALT
09/21/16					
12/21/16					
03/21/17					
06/21/17					

3. **Find solar noon:** Advance the time until the sun crosses the meridian. For each of the four dates, record the time and the

az/alt coordinates (do not try to fill in this example table, there is simply not enough room).

4. **Is the sun directly overhead?** On any of the days you checked, does the sun ever reach an altitude of 90° (directly overhead)?

5. **Where will the sun be directly overhead?** The figure below shows the positions of the sun for an observer located at 35°N latitude (Hey! We are located at 35°N latitude!). Use this figure to help you determine at what northern latitude the sun will be directly overhead on June 21. Where will the sun be if you are in a location 10° south of this latitude?
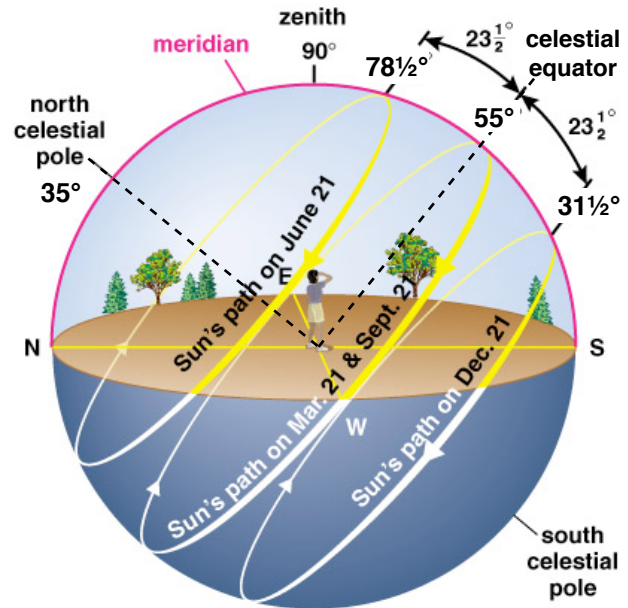
Copyright © Addison Wesley

And a Day Is a Day Is a Day…

A solar and sidereal day each measure the rotation of the earth, but in relation to different objects. The solar day looks at rotation with respect to the sun: how long does it take for the earth to complete one rotation with respect to the sun (noon to noon, as long as you are measuring noon with respect to the meridian). The sidereal day measures the same thing, but uses a distant star instead (any star will do).

6. **How long is one solar day?** For any random day you like, position the sun precisely on the meridian. Use the Date and Time Window to advance by exactly one calendar day, and notice the position of the sun. Record the day you selected, and the Az/Alt coordinates of the sun on that day, and the next.

7. **How long is one sidereal day?** For the same day as above, position a star on the meridian (if you toggle off the atmosphere, you can see the stars even if it is still daytime). Advance the time until the same star is again on the meridian (an easy way to do this is to advance one calendar day, then increase or decrease minute by minute until the star is back on the meridian).

Shown below is **Figure 0.5** (page 06) from the textbook. It has been color-inverted so that the sky appears white and the starlight appears gray or black. A long photographic exposure will show the apparent path of the stars as the earth spins. Thus, in exactly one sidereal day, a star would trail out a complete circle of 360°. By measuring the fraction of that circle exposed, and knowing the length of the exposure, you can experimentally calculate the length of the sidereal day.

8. **Measure the trails:** With a ruler and protractor, measure the angles of the three star trails labeled A, B, and C. Follow the example on the figure, labeled with a 1. Calculate the average angle of the star trails.

9. **Calculate the sidereal day in minutes**: The photographic exposure time was 287 minutes. Use this time (t) and the average angle (θ) to find the length of the sidereal day (day) in minutes:

$$\frac{\theta}{360°} = \frac{t}{day}, \text{ or}$$

$$day = (t)\left(\frac{360°}{\theta}\right)$$

10. **Convert this time to hours:** $hours = \dfrac{day(\min)}{60\left(\frac{\min}{hour}\right)}$

11. **Compare this value to a standard 24 hour solar day.** Also compare your value to the accepted value of a sidereal day (23h56m, or 23.93h). Is your value higher or lower than the accepted value?

12. **Explain the difference:** Refer to the figure below, or to Figure 0.7 (page 08) of your text, and explain in your own words why the solar and sidereal day cannot be the same length of time.
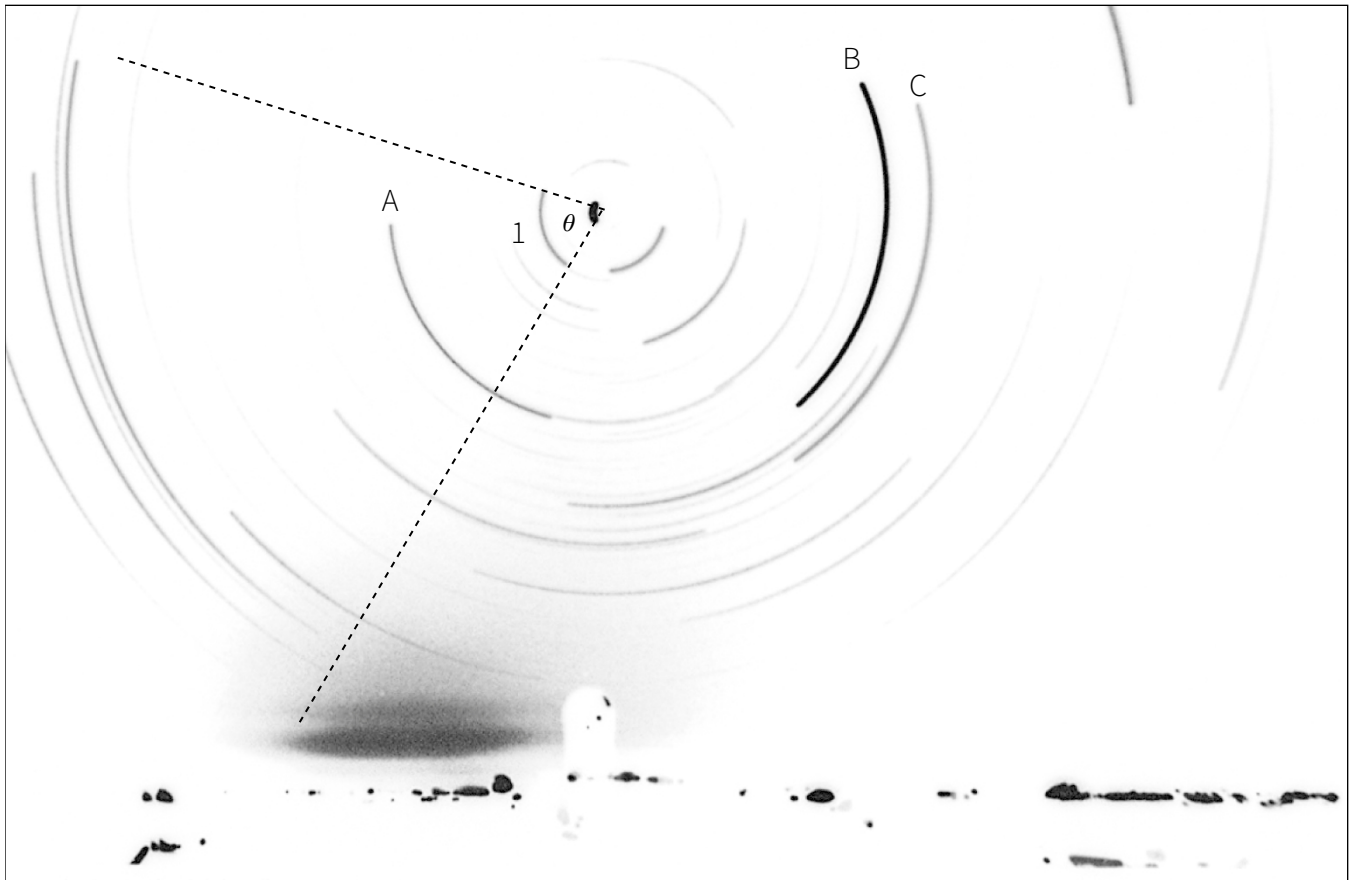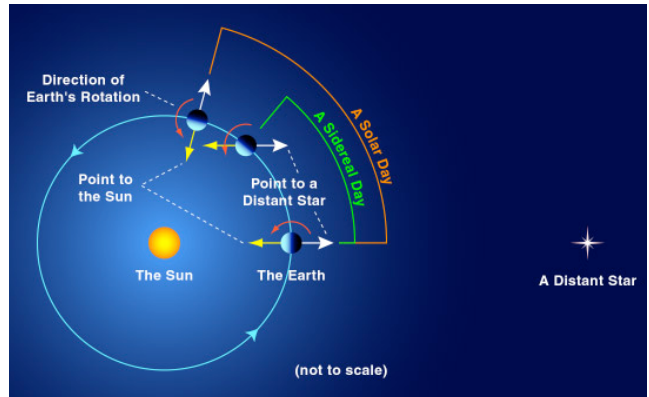
Example Calculation for Star Trail 1

Measure: $\theta = 76°$

Calculate: $day = (287\min)\left(\dfrac{360°}{76°}\right) = 1359\min$

Convert: $hours = \dfrac{1359\min}{60\frac{\min}{hr}} = 22.7hr$

Compare: $sidereal = \left(\dfrac{22.7}{24}\right)solar = 0.95solar$

Make sure that you are recording everything you do in your lab notebook. When you take your quiz in class next week, you will be allowed to use your notebook, a calculator, and clicker, but no additional resources.
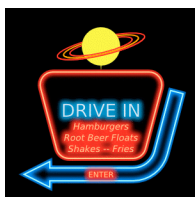
Lab 03: Spectroscopy

Introduction

Why do neon lights glow? That, and why do they glow in different colors? First the glow: a neon tube is sealed and contains atoms of gas (neon, or maybe something else–more on that in a minute). When a voltage is applied, the tube begins to glow: flip the switch, the light comes on. The gas is energized by the voltage: all the neon atoms are the same, which means that the electrons of all the atoms exist in orbits with the same energy levels. Whatever precise amount of energy it takes to move an electron from one orbit to another, it's the same for all the neon atoms. So what you are seeing as the glow is electrons jumping from one energy level to another. As they fall back down to their original orbits, they emit an exact amount of energy in the form of a photon. When the millions of atoms in the tube all do this at the same time, all those emitted photons create the glow.

Now about the color. We know that the orbits correspond to precise energy quanta. But the quantum of energy is different for electrons belonging to different types of atoms. It does not take the same amount of energy to move an electron from one orbit to another in a hydrogen atom as it does to move between orbits in a neon atom. Different energy, different color. Neon glows strongly red, but mercury glows strongly blue. So it's not always actual neon in the neon light; it may be argon (with mercury particles), helium (yellow-gold) or even CO_2 (bright white).

Objectives

- View emission–line spectra of various elements
- Identify elements based on the pattern of emission lines
- Associate wavelengths of visible light with color
- Correlate the color of emitted light to the temperature of an object

- Determine the radial velocity of an astronomical object by observing the Doppler shift in its emission spectrum lines

Experimental Equipment

- Handheld spectroscope
- Gas–filled lamps

Procedure

1. **Point** the slit of the spectroscope directly at the gas–filled lamp.

2. **View** the emission lines that appear, and record the color and wavelength for each line.

3. **Note** the color–code identification on the lamp.

4. **Identify** the gas in the lamp by comparing the observed lines to the standard spectra provided.

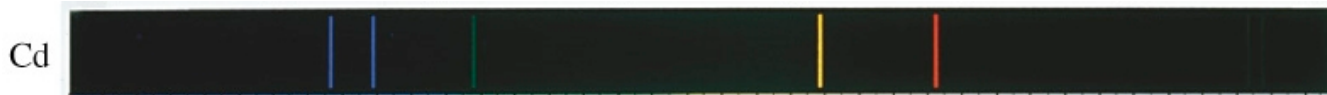5. **Repeat** for the remaining lamps.

Data

Make a table of the lamps you have viewed, and use it to identify the vapor in each lamp. You will need more rows for more lamps, and more columns for more observed emission lines than the example table shown below.

TUBE NUMBER	EMISSION LINE WAVELENGTH (TOP) AND COLOR (BOTTOM)								VAPOR ID
EXAMPLE	460	496	609	670					lithium
	blue	blue	yellow	red					
1									
2									
ETC.									

Use the reference table shown online and the wall chart to complete your identification of the lamps.

Questions

1. **Label the lines:** The emission spectrum for cadmium (Cd) is shown below in color. Using the table that correlates the color of the emission line with wavelength and the wall chart, label each emission line with an approximate wavelength.

2. **Recognize the patterns:** On the right and in color are the emission spectra for five of the gases in the tubes you have examined. Because line strengths vary (and this is not shown on the figure), you may not have seen every line shown. Identify each of the shown spectra with the correct element.

3. **Find the temperature:** The temperature (in Kelvins) of an object can be determined by noting the wavelength of its strongest emission (brightest color):

$$T = \frac{3 x 10^6 \text{K}}{\lambda_{max}}$$

with λ_{max} measured in nm. Find the temperature of a

A)   red star: $\lambda_{max} = 650$nm.

B)   blue star: $\lambda_{max} = 425$nm.

C)   block of ice: $\lambda_{max} = 10^4$ nm.

4. Find the speed: The radial velocity of a star can be determined from the Doppler shift of the lines of its spectrum. This is given by:

$$v_r = \frac{(\lambda - \lambda_o)}{\lambda_o}\left(3 \times 10^5 \text{ }\frac{\text{km}}{\text{s}}\right)$$

650nm   500nm   400nm

ELEMENT: _____

ELEMENT: _____

ELEMENT: _____

ELEMENT: _____

ELEMENT: _____

where λ_o is the unshifted wavelength, when the velocity of an object is zero. The observed wavelength λ is the shifted wavelength of the object in motion. Find the radial velocity of

A)   a star observed to have an H-alpha line ($\lambda_o = 656.30$nm) at a wavelength $\lambda = 656.52$nm.

B)   a galaxy observed to have a calcium K-line ($\lambda_o = 393.40$nm) at a wavelength $\lambda = 445.85$nm.

5. Compare the elements: The figure on the left shows the emission spectra for helium ($_2^4\text{He}$) and uranium ($_{92}^{238}\text{U}$). A neutral helium atom has just two electrons, while a neutral uranium atom has 92. Briefly explain why the emission spectrum for uranium has so many more lines than the helium spectrum.

Make sure that you are recording everything you do in your lab notebook. When you take your quiz in class next week, you will be allowed to use your notebook, a calculator, and clicker, but no additional resources.

Lab 04: Lunar Synodic and Sidereal Months

Introduction

Everyone knows how long a month is...it's 30 days. Or is it 31? Maybe 28, or even, on occasion, 29? A calendar month can ultimately trace its origin back to the idea of marking time by the cyclic phases of the moon, but there is currently no correlation between any specific day or date and any specific lunar phase. You cannot say that the moon will always be full on January first, and you cannot say that January ends and February begins precisely at the next full moon.

As we saw previously, the length of a day depends on how you measure it. It should not surprise us, then, that the same thing is true of the moon. We have the obvious cue of the phase: one month is how long it takes for the moon to complete one cycle of phases, from full moon to full moon (or new to new, or whatever phase you choose). This is a **synodic month**. Like the measure of a sidereal day, the measurement of the **sidereal month** references the motion of the moon to a stationary star. We will use the Stellarium program to examine and compare both of these ideas.
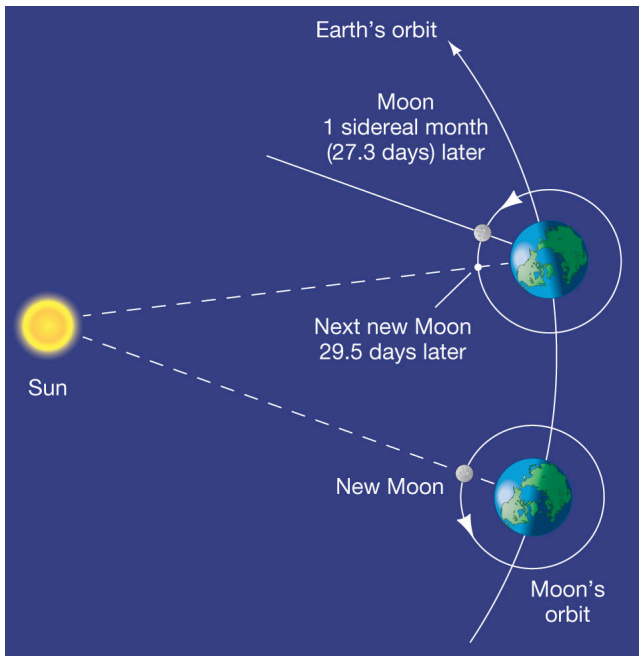
Objectives

- Distinguish between synodic and sidereal period of revolution
- Measure the synodic period of the moon
- Measure the sidereal period of the moon
- Practice locating and referencing objects using celestial coordinates

Synodic Month

1. **Open Stellarium:** Make sure your location is correctly set for Conway, AR. If Conway is not the default location, you may want to make it the default location.

2. **Find the moon:** Use the Find Object window to locate the moon, and then click Center on Selected Object (keystroke = space bar). To zoom in on the moon and see its phase, use the forward-slash keystroke (back-slash zooms you back out). Toggle off both the atmosphere and the horizon to better see the phase information.

3. **Set the date**: For today, 07/11/16 (time 17:00:00), and adjust the time (increment the minutes) until you see the moon in its first quarter phase (0.50). Exactly half of the moon should be illuminated, and the terminator should be straight (as opposed to curved). To keep this simple, adjust time by hour and minute increments. Do not attempt to fine-tune this to the level of seconds.

4. **Advance the date:** Increase by exactly one calendar month, then adjust the day forwards or backwards until you have the moon in the same phase (0.50, or 50.0%) again. Fine-tune the phase by adjusting time in hour and minute increments (again, no seconds). Record the date and time of the first quarter moon.

5. **Calculate the month**: The elapsed time from first quarter to first quarter phase is one synodic month. You may use an online unit conversion program to determine the length of time between your observations:

   http://www.onlineconversion.com/days_between_advanced.htm

   This will give you a time in **hours**. Convert this value to **days** by dividing the hours by 24.

6. **Complete the observations:** Reproduce the table below in your lab notebook (do not try to fill in this example table, there is simply not enough room), completing the observations. Determine the synodic month for each of the intervals over the course of a year:

DATE	TIME	SYNODIC MONTH (DAYS)
07/11/16		
10/08/16		
01/05/17		
04/03/17		
AVERAGE SYNODIC MONTH		

7. **Calculate the synodic month:** Average the length of a synodic month from your data. Compare this to the accepted value of 29.5 days by calculating the percent error in your value.

$$\% \ error = \left(\frac{accepted - average}{accepted} \right) \times 100$$

8. **Why is your percent error not exactly zero?** Discuss/ explain why your results do not match the known value exactly.

Sidereal Month

To measure the lunar sidereal month, we need to compare the position of the moon with the position of a fixed star. The easiest way to do this is to select a star that lies on or near the ecliptic, since the moon cannot stray far from this line. In one sidereal month, the moon will be in the same position with respect to the star. We will select an appropriate star, then adjust the date and time until the moon matches the RA coordinate of the chosen star.

1. **Increase your field of view:** Zoom out (\) for a greater field of view. It will also be helpful to toggle on the equatorial grid (keystroke = e) and the ecliptic (keystroke = comma).

2. **Set the date and time:** Go to 07/13/16 at 20:00, and center on the moon. You should notice that there is a star (Zubenelgenubi) almost exactly on the ecliptic, close to Mars and Spica.
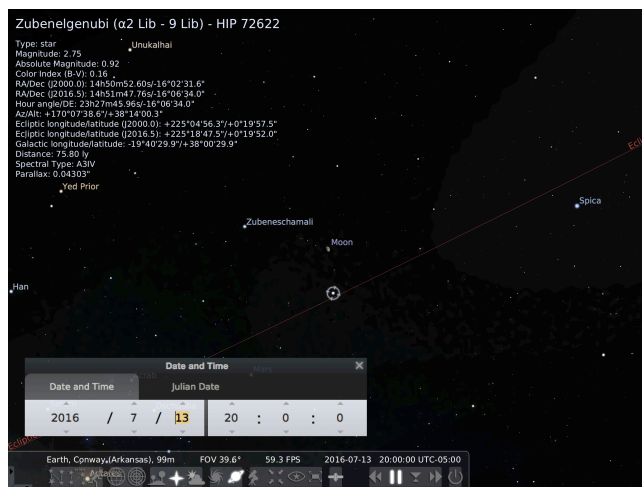
3. **Find Zubenelgenubi:** Click on the star and record its J2000 RA coordinate. Remember that the RA/DE coordinates of the stars do not change. Note that you only need the RA coordinate, however.

4. **Match the RA**: Click on the moon again, and adjust the time until its J2000 RA matches that of Zubenelgenubi. You must adjust both minutes and seconds to fine-tune the alignment. *(Note that the DE of the moon will never precisely match the DE of the star.)*

5. **Record and advance:** Note the date and time, then advance the date by exactly one calendar month. As in the previous exercise, adjust the day and then the time until the moon has precisely the same RA alignment with Zubenelgenubi. By adjusting the time down to the second, you should be able to match the RA exactly.

6. **Observe the moon phase:** Zoom in on the moon and accurately sketch or describe its phase. Note that the new moon is 0.00, and a full moon has phase 1.00. You should distinguish between a waxing and waning moon. For example, a phase = 0.50 may mean either a (waxing) first or (waning) third quarter moon.

7. **Complete the observations:** Reproduce the table below in your lab notebook (do not try to fill in this example table, there is simply not enough room), completing the observations. Determine the length of the sidereal month for each of the intervals over the course of the year:

DATE	TIME	LUNAR PHASE	SIDEREAL MONTH (DAYS)
07/13/16	20:08:59		
10/03/16			
01/20/17			
04/12/17			
AVERAGE SIDEREAL MONTH			

8. **Calculate the sidereal month:** Using the same technique as before, calculate the elapsed time between observations. This is the sidereal month. Use the online conversion tool at: **http://www.onlineconversion.com/days_between_advanced.htm** Divide the total number of hours (with decimal) by 24 to get the sidereal month in days (with decimal).

9. **Calculate the percent error**: Find the average length of the sidereal month. Compare it to the accepted value of 27.3 days by calculating the percent error in your average sidereal month:

$$\% \ error = \left(\frac{accepted - average}{accepted} \right) \times 100$$

10. **Why are the phases different?** Explain why the phase of the moon is different for each of your sidereal observations.

11. **Why are the months different?** Use a sketch to clearly show why the synodic and sidereal periods of the moon are different. You should be able to see from your sketch why the sidereal month is shorter than the synodic.

Make sure that you are recording everything you do in your lab notebook. When you take your quiz in class next week, you will be allowed to use your notebook, a calculator, and clicker, but no additional resources.
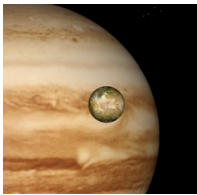
Lab 05: Determining the Mass of Jupiter

Introduction

We have already explored how Kepler was able to use the extensive observations of Tycho Brahe to plot the orbit of Mars and to demonstrate its eccentricity. Tycho, having no telescope, was unable to observe the moons of Jupiter. So, Kepler was not able to actually perform an analysis of the motion of Jupiter's largest moons, and use his own (third) empirical law to deduce Jupiter's mass. As we learned previously, Kepler's Third law states:

$$p^2 = a^3,$$

where p is the orbital period in Earth years, and a is the semi-major axis of the orbit in AU. Writing Kepler #3 this way is convenient for comparing one planet to another orbiting our sun, but it also applies to any object in orbit around any other object. A more mathematically general statement of Kepler #3 can be written by combining Newton's Second Law and Newton's Law of Gravity:

$$T^2 = \left(\frac{4\pi^2}{GM}\right)r^3$$

where T is the orbital period in seconds, r is the orbital radius in meters, G is the universal gravitational constant, and M is the mass of the body being orbited. This is a valid relationship for any object in orbit around any other body. To make this general relationship easier to apply, we will do two things:

1. replace the constants with their numeric values, and
2. perform unit conversions to express T and r in more convenient units.

For the moons of Jupiter, expressing a period in days is an appropriate unit, and expressing the orbital radius as a multiple of Jupiter's diameter also makes sense. If we skip the details of putting the numbers into the equation, the final result looks like this:

$$M = \left(2.27 \times 10^{26}\right)\frac{r^3}{T^2}$$

If you measure r in units of Jupiter's diameter (JD) and T in units of days, the resulting mass of Jupiter will be in kilograms.

Objectives

- Use Kepler's Third Law to determine the mass of Jupiter
- Visualize how an apparent motion in 1-dimension actually corresponds to a 2-dimensional movement
- Become familiar with the CLEA/VIREO astronomy simulation software
- Collaborate to combine independent observations into a coherent model
- Compare the accuracy of small and large data sets

Procedure

1. **Review the manual:** Before you come to lab! The Student Lab Manual for this exercise is available online as a .pdf document. You may download it from: [**ftp:// io.cc.gettysburg.edu/pub/clea_products/manuals/Jupit_sm.pdf**]. A clickable link is provided on the course web. ***You probably don't need to print it***, but you should spend a little time getting familiar.

2. **Open the program:** We will be using the CLEA exercise **"The Revolution of the Moons of Jupiter,"** and there is a clickable shortcut on the desktop to open the exercise. Remember that you are free to use the computers in LSC 174 at any time.

3. **Know your moon:** Each student will be responsible for making observations of one of Jupiter's four major satellites. You will be assigned to observe one of the following: Io, Europa, Ganymede, or Callisto. When you have completed your set of observations, you must share your results with the class. There will be several sets of observations for each of the observed moons. We will combine the data to calculate an average value.

4. **Log in:** When you are asked to log in, use your name and the computer number on the tag on the top of the computer. This is so your data is saved in a unique location, and you can refer back to it later if necessary.

5. **Select *File → Run*:** A dialog box will open, and you should set the observation time, date, and observing interval. Set the start date for July 18: 07/18/16. You may leave the default time (0:00 UT). The default observation interval is 24 hours. This is adequate for all of the moon except Io. If you are assigned to observe Io, you must change the interval to 6 hours.

6. **Observe the motion:** Before you begin collecting data, you can take a moment to observe the motion of the satellites. From the File menu, select Preferences → Animation, and you can see the moons in motion. From the Preferences menu you may also select Top View, which will give you another perspective on the motion.

7. **Collect the data:** Turn off the Animation feature before collecting data, and make sure to return to your 07/18/16 start date.

8. **Record the position:** Place the cursor over your moon and left-click. You should see displayed the name of the moon, and its position coordinates. If you do not see the name of the moon, you have not clicked on the moon itself. Record only the x-coordinate, specified in units of JD (Jupiter diameters). You should also record the direction, E or W that is displayed.

9. **Save your data in two ways:** In the program, select Record Measurements, and enter your data for your specific moon. You must enter each observation you make. Save this data (File → Data → Save) frequently. Also record the observation date and position of the moon in a table in your lab notebook.

10. **Advance to the next observation:** Click the Next button, and continue to observe and record your particular moon until you have made 30 observations. This will be July 18 through August 17 for all moons except Io. With a 6hr observation interval, you will observe Io 4 times each day, so you will begin on July 18 at 0:00, and end on July 26 at 12:00.

11. **Advance through clouds**: If you miss an observation due to cloudy weather, you should add an extra interval at the end until you have recorded 30 actual positions for your moon. Clouds should not happen very frequently, but you can expect one or two nights to be obscured.
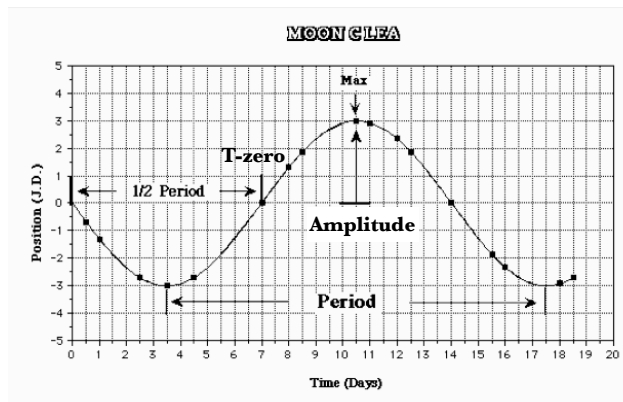
Data

Your data should consist of the table of observations for your assigned moon. You are not responsible for recording data on other moons which you have not observed.

Analysis

The program will perform the initial analysis of the data, and give a result for your moon's period T (in days) and orbital radius r (in JD).

1. **Select *File → Data → Analyze*:** Choose the moon you observed from the Select menu.

2. **Select *Plot → Plot Type → Connect Points*:** This will display a jagged, "connect-the-dots" version of your graph. When this graph of data points appears, try to find a pattern by eye, and take note of any data points that seem to be out of place.

3. **Select *Plot → Fit Sine Curve → Set Initial Parameters*:** You are being asked to provide the program with initial values to use so that it can accurately construct a smooth sine curve to fit your data. Use the graph to find values for **T-zero** and **Period**.

4. **Determine T-zero:** Click on a point at which the line connecting the data crosses from **negative to positive**. (If this happens several times, choose a point toward the left of the screen.) A date and a value very close to zero should appear in the box marked Cursor Value. Enter the **date** as your **T-zero** parameter.

5. **Calculate the Period:** Go back to the graph and find the next point at which the line passes from **negative to positive** (that is, when the moon has completed one full orbit). Subtract the earlier date from the later date and enter this as **Period** in the dialog box. If the line does not cross from negative to positive twice, use the interval between any two crossings as a good estimate of *half* the period and then double it. If it is convenient, you can count the number of days of one period directly on the screen, but you will probably have to make an estimate.

6. **Estimate the Amplitude:** Click on the highest or lowest peak of your graph and read the value in the **Cursor Position** box. The **Amplitude** is equal to the absolute value of the highest peak or the lowest valley of your graph.

7. **Click *OK*:** A blue sine curve will appear. It should be a rough fit for all your data points. If not, you need to repeat the *Set Initial Parameters* step. If only one or two points are significantly off the blue line, they may represent inaccurate measurements.

8. **Refine the curve fit:** Three scroll bars have appeared: **T-Zero**, **Period**, and **Amplitude**. Adjust each individually until your curve matches your data.

9. **Adjust the T-Zero point:** As you adjust this value, the entire curve will slide to the left or right. Try to achieve the best fit for the data points closest to the T-zero value you selected above. At this stage, pay no attention to the number labeled RMS Residual; just use your eyes. After you've adjusted the T-zero

value, you may notice that the points farther away from your T-zero point no longer fit as well.

10. **Fit the Period:** Scroll to stretch or shrink the curve and achieve a better fit. If at any time you cannot scroll far enough to get a good fit, select *Plot → Reset Scrollbars → Normal Sensitivity* to re-center the bars.

11. **Adjust the Amplitude:** Fit the points near the peaks and valleys. You may wish to return to the other scroll bars for further adjustment, but the goal at this point is a good, though not necessarily perfect, fit.

12. **Fine tune the curve fit:** Return to adjusting the T-zero scroll bar, this time observing the **RMS Residual**. The smaller the value of this number is (note that it is expressed in scientific notation), the better the fit. Continue this process with the **Period** and **Amplitude** bars. Repeat the scroll bar adjustments until all three yield the lowest RMS Residual.

13. **Record your results:** When your curve fit is sufficiently accurate, record the values for the **period** (T in days) and **amplitude** (r in JD). Post your values on the board to share with the class.

Questions

1. **Calculate the mass:** Use the equation below and your own individual data to calculate the mass of Jupiter in kilograms (kg).

$$M = \left(2.27 \times 10^{26}\right)\frac{r^3}{T^2}$$

2. **Determine your accuracy:** For your individual data, calculate the % error in your result for Jupiter's mass. The accepted value for the mass of Jupiter is **1.9x10²⁷kg**:

$$\%error = \left(\frac{M - 1.9 \times 10^{27}}{1.9 \times 10^{27}}\right) \cdot 100$$

3. **Summarize the class results:** Construct a table for the mass and % error, calculated from the class data.

MOON	AVERAGE MASS OF JUPITER (KG)	% ERROR
IO		
EUROPA		
GANYMEDE		
CALLISTO		
OVERALL AVERAGE		

4. **One or many?** Is the overall average of combining many sets of observations better than an average obtained from a single set of data? Why might this be?

5. **Bad moon?** Does the data from one moon appear less accurate than the others? Why might this be?

6. **Better data?** What could you do differently to get better data? Suggest specifically how, using this method, you might improve the accuracy of your calculated mass.

7. **Themisto?** Predict the orbital period in days of Jupiter's moon Themisto, which has an orbital radius **r = 52 JD**. Calculate using the accepted value for the mass of Jupiter, **1.9x10²⁷kg.**
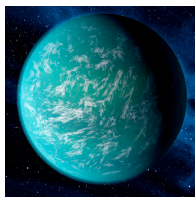
Lab 06: The Discovery of ExoPlanet 51 Pegasi b

Introduction

Since the first extra-solar planet was discovered in 1989, there have been over 1000 additional planets confirmed to be orbiting other suns. In the fall of 1995, astronomers were excited by the possibility of a planet orbiting a star in the constellation Pegasus. Why such a fuss over this particular star (called 51 Pegasi), located 50 light years from the Earth? Because it is a star almost identical to our own sun! Just slightly more massive and a bit cooler than the Sun, it seemed like a good place to look for planets—given that we know for a fact that at least one sun-like star (our own!) has an extensive planetary system, with at least one planet (our own!) capable of supporting life!

Objectives

- ◉ Identify the presence of an extra-solar planet by its effect on its parent star
- ◉ Prepare an accurately scaled graph of radial velocity data
- ◉ Perform basic curve fitting to match plotted data
- ◉ Calculate the orbital period of the exoplanet and use it to locate the planet's distance from its star
- ◉ Determine the mass of this newly discovered exoplanet

Procedure

Until very recently, the most common method of exoplanet detection involves radial velocity measurements. As we know, the light from an object moving towards us will be shifted toward shorter wavelengths (blue-shifted), and motion away results in light that is red-shifted towards longer wavelengths. This Doppler shift can be used to calculate the speed with which an object is hurtling at us through space.
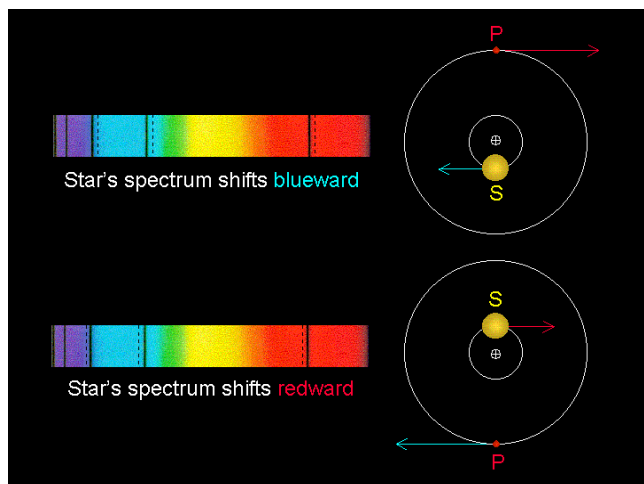
Well, how does this help us "see" a very tiny planet orbiting a very distant star? Even if the planet is too small for us to image directly, its presence can be detected by its gravitational pull on the star it orbits. Technically, the star and planet are both orbiting their common center of mass. Because the star is so much larger, the planet moves very noticeably, and the star remains virtually stationary. But it's

not quite perfectly still: the star will wobble slightly with each orbit of the planet, first one way, then the other. Since the planet's orbit is periodic (Kepler! Number! Three!), so is the wobble of the parent star. What that means is that the star's radial velocity will change slightly, increasing and decreasing with the same periodicity as the planet's orbit.

With each orbit of the planet, you can watch any particular spectral line you like (maybe the H_α?) shift slightly to the red, then to the blue. Because you know where the line ought to be (656nm), you can determine the radial velocity, and the bigger the Doppler shift, the more massive the planet is. The period of the planet in orbit can be measured by watching the pattern repeat. And once you know there's a planet out there, and what its orbit looks like, it's not that hard to calculate its mass (Newtonian Gravity and Kepler #3!).

Data & Analysis

The table below is some of the actual Marcy & Butler data collected in October of 1995 at the Lick Observatory in California.

Day	V (m/s)	Day	V (m/s)	Day	V (m/s)	Day	V (m/s)
0.6	-20.2	4.7	-27.5	7.8	-31.7	10.7	56.9
0.7	-8.1	4.8	-22.7	8.6	-44.1	10.8	51
0.8	5.6	5.6	45.3	8.7	-37.1	11.7	-2.5
1.6	56.4	5.7	47.6	8.8	-35.3	11.8	-4.6
1.7	66.8	5.8	56.2	9.6	25.1	12.6	-38.5
3.6	-35.1	6.6	65.3	9.7	35.7	12.7	-48.7
3.7	-42.6	6.7	62.5	9.8	41.2	13.6	2.7
4.6	-33.5	7.7	-22.6	10.6	61.3	13.7	17.6

1. **Graph the data:** Plot the above data in your lab notebook. Scale the **time** in days on the **x-axis**, and the **radial velocity** on the **y-axis**. It is very important that you scale your axes accurately and consistently. On the time axis (x), run from **0 to 14 days**, and on the velocity axis (y) scale from **–70 to +70 m/s**.
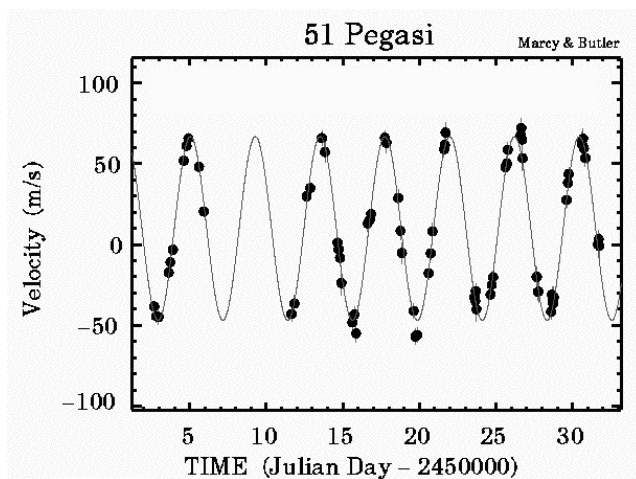
Your graph will not be identical to this one! However, it should give you an idea of what to expect as you plot your own data.

2. **Fit the curve:** Once you have the points plotted, carefully sketch a curve fit. The shape should be a sine curve, like you see on the right. Notice above that, even if there are gaps in the data, the curve is smooth and continuous.

Questions

1. **Why sine?** Why is a sine curve used to fit this data? Why not just connect the dots?

2. **Why are there gaps in this data set?** Look at the pattern, and notice two reasons for missing data. How could you compensate for this?

3. **Determine the orbital period of the planet:** There are several methods to extract this information from your graph. Use at least two different techniques to obtain at least three separate values, then calculate the average period in days.

4. **Convert the average period in days to years:**

$$P = \frac{average\ days}{365}$$

5. **Find the distance:** Use the average period P in years and Kepler #3 to calculate the average distance a (in AU) of the planet from its star:

$$\text{Kepler\# 3: } P^2 = a^3$$

$$a = \sqrt[3]{P^2} = P^{(0.67)}$$

6. **Average the amplitude:** Examine your graph again, and record the maximum (+) and (–) amplitudes of the sine curve. For example, if the maximum (+) velocity is +70, and the maximum (–) velocity is –68, then the amplitude K is:

$$K = \frac{+70\frac{m}{s} - \left(-68\frac{m}{s}\right)}{2}$$

$$K = \frac{138\frac{m}{s}}{2} = 69\frac{m}{s}$$

(Note: Your value is not going to be exactly 69m/s!)

7. **Calculate the mass:** By combining Kepler #3 with Newton's Universal Gravitation, we can calculate the mass of 51 Pegasi b. Instead of an absolute mass in kilograms, we will calculate based on comparison to Jupiter. Once we have combined Kepler and Newton, then performed the unit conversions we are left with:

$$M_{51PegB} = \left[\left(\frac{P}{12}\right)^{(1/3)}\left(\frac{K}{13}\right)\right]M_{Jupiter}$$

where P and K are your values for 51 Pegasi b. The 12 is Jupiter's orbital period in years, and the 13 is the radial velocity wobble of the sun due to Jupiter's pull. Do not substitute a number for Jupiter's mass; calculate the mass of 51 Pegasi b in terms of $M_{Jupiter}$.

8. **Why does this work?** The mass equation we used above makes several simplifying assumptions. Address each of the following assumptions, and explain why it is reasonable.

   A) **Assumption:** The mass of the planet is much, much less than the mass of the star.

   B) **Assumption:** The mass of the star 51 Pegasi is the same as the sun (hint: compare its spectral type to the sun's).

   C) **Assumption:** The planet's eccentricity is 0 (remember that e=0 is perfectly circular).

   D) **Assumption:** The planetary system is being viewed edge-on (as opposed to top-down). What would the star's spectra look like if the system was observed from above?

Make sure that you are recording everything you do in your lab notebook. When you take your quiz in class next week, you will be allowed to use your notebook, a calculator, and clicker, but no additional resources.

Labs 07 and 08: The Photoelectric Photo-metry of the Pleiades

Introduction

Professional astronomy can be surprisingly competitive. There are not many large telescopes, and telescope time is limited by daylight and cloudy conditions. When an astronomer applies for observing time, he is not guaranteed that it will be granted–there are a large number of astronomers applying for a small amount of time. And even if telescope time is awarded, that's no guarantee of observing time: weather conditions may prevent observations, and once your time is up, it's up and the next guy in line gets his turn!

Lucky for us, we can simulate the observing experience with astonishing realism. We will not be able to get observing time on a real telescope, but the VIREO (The VIRtual Education Observatory) program we will use has been designed by astrophysicists to reproduce an accurate observing experience. The Student Manual for this exercise is freely available online at:

 ftp://io.cc.gettysburg.edu/pub/clea_products/manuals/Photo_sm.pdf

The advantage of this manual is that is provides additional detail describing the program features, but you may not need to print the entire document. A clickable link is provided on the course web, and remember that you can run these programs any time the lab LSC 174 is open.

Objectives

The Pleiades are a cluster of stars that not only appear close together to us here on Earth, but are actually located close to each other in space. Our goal is to determine how far this cluster is, relative to the Earth.

You have been granted unlimited observing time on a 0.4 meter optical telescope and permission to request time on a 1.0 meter and/or 4.0 meter optical telescopes. The telescopes will be equipped with filter wheels and photoelectric photometers. Your project mission is to

- ◉ Obtain multi-color (B (for short-λ blue) and V (for visible, peak λ in the green)) photometry of a sample of 24 stars in the Pleiades star cluster
- ◉ Compare the main sequence of the cluster to a calibrated absolute magnitude main sequence
- ◉ Graphically determine the distance to this cluster

Procedures

This lab will take two sessions to complete. You should spend the first lab period using the computer to collect observational data. If you need additional time, you may use the computer lab the following day when it is not reserved for another class.

We will spend the second lab period performing the analysis of the photometric data. We will meet in the lab classroom, and you must be prepared with your complete set of observational data.

Monday: Observation and Data Collection

1. **Start *VIREO*:** Double click on the icon for the *VIREO* program found on the desktop.

2. *File → Login*: Enter your name and the number of the computer and click *OK*.

3. *File → Run Exercise → Photoelectric Photometry of the Pleiades*.

4. *Telescopes → Access 0.4 Meter*: Choose a telescope, or *Request Time→* on either the *1.0 Mete*r or *4.0 Meter*. If you are granted time on either of the larger telescopes, then you will have to access them from the menu in order to use them. (Hint: Bigger telescope means more light-gathering power means shorter exposures required!)

5. **Control the scope:** Once you have selected of one of the telescopes you will need to open the dome, and once the dome is open you will need to turn on the *Telescope Control Panel*.

6. **Tracking:** Turn on the telescope *Tracking* on from the control panel.

7. **Field of view:** Toggle from *Finder* view to *Telescope* view. This switch occasionally sticks, and you might have to toggle a second time to change to the *Telescope* view.

Sky Calibration

The sky is never perfectly dark. You will need to teach the instrument computer what the sky brightness level is for your observing session by observing blank region of sky.

8. **Clear the field of view:** Make sure there are no objects in the circular aperture of the photometer. If there are, use the *N-S-E-W* buttons to move the telescope aperture to a part of the sky free from any apparent objects.

9. **Access the *Photometer Control Panel*.**

10. **Calibrate the *B*:** Set *Filter → B*, *Reading → Sky*, *Integration Seconds → 10*, and *# of Integrations → 3*. Click *Start* to take a sky reading with the *B* filter.

11. **Calibrate the *V*:** Repeat step 10, but with the *Filter → V*.

12. **Re-calibrate:** If at any time you switch to a different telescope, you must calibrate the sky for that telescope (because it is a different size and has different light gathering power).

Targeting Stars

13. *Slew → Observation Hot List → Object View/Select from List*: Double click on the star you want to observe. Click *OK* to slew the telescope to those coordinates. Once the telescope has completed its slew, there should be a star centered in the aperture.

B and V Photometry

14. **Set exposure time:** Total exposure time is Integration Seconds multiplied by the # of Integrations. You cannot set the exposure time to any arbitrary value, but you should be able to find a combination to get you close the the exposure time you may desire.

15. **Watch your S/N:** A bigger number is better (more signal, less noise), and we want values of at least **S/N = 100**. Very bright objects will reach this level with shorter total exposure times, but dimmer objects are going to require either an increased number of Integration Seconds, or more # of Integrations.

16. *Reading → Object*: *Make absolutely certain that you do not miss this step!* If you leave your setting on *Sky*, you are not collecting data properly, and you will have to recalibrate your sky a second time.

17. **Select a filter:** Choose **B** or **V**. You will want both *B* and *V* magnitudes for each star from the *Hot List*. **You will perform an exposure for each star using each filter.**

18. **Start:** Once you have the exposure time and filter set, start the exposure (Integration) by clicking on the *Start* button.

19. **File → Data → Record/Review:** Once the exposure is complete, the sky-subtracted magnitude and S/N ratio will be displayed. Record in your note book the stellar magnitude and also save the results on the computer.

20. **Complete your data table:** Obtain a *B* magnitude and *V* magnitude for each star in the *Hot List*. Write down the values in your notebook as well as saving them on the computer.

STAR	B	V	B – V
N2230-01442	10.508	8.797	1.711
etc...			

Notice as you collect and record data that the **brighter** a star appears, the **lower** its B or V brightness number is! A dim star has a high B or V magnitude, a bright star has a low or even a negative value.

Wednesday: Data Reduction and Analysis

1. **You must have a complete data set to proceed.** Please do not skip the Week 1 data collection and then expect someone else in lab to hand over their painstakingly collected data for you to use.

2. **Compute:** Calculate the **B-V** color index for each of the stars by taking the B-magnitude and subtracting the V-magnitude from it.

3. **Graph:** Using most of a lab notebook page, create a graph like the one shown below. The larger you make your graph, the more accurate your results will be.
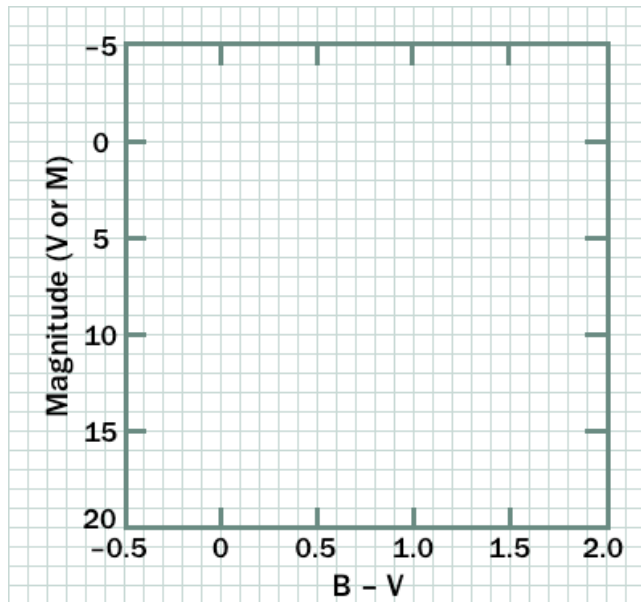

4. **Plot your data:** For each of the 24 stars, plot **B-V** on the **x-axis** and **V** on the **y-axis**. Do not label each star but use the same plot symbol (or color) for each of the Pleiades stars.

5. **Plot the reference stars:** On the same graph, plot a calibrated set of main sequence stars. From the table below, plot **B-V** as the **x-coordinate** and **M** (absolute magnitude) for

the **y-coordinate** using a different plot symbol (or color) than the one used for the Pleiades.

ABSOLUTE MAGNITUDES OF MAIN-SEQUENCE STARS

| B-V	M (ABSOLUTE MAGNITUDE)	B-V	M (ABSOLUTE MAGNITUDE)
-0.31	-4.1	0.7	5.1
-0.16	-1.1	0.89	5.9
0	0.4	1.18	7.3
0.13	2	1.45	9
0.27	2.6	1.63	11.8
0.42	3.4	1.81	16
0.58	4.4		

6. **Fit both curves**: Draw a smooth curve though the main-sequence for the Pleiades and for the calibrated stars. Your graph should look similar to the one below.
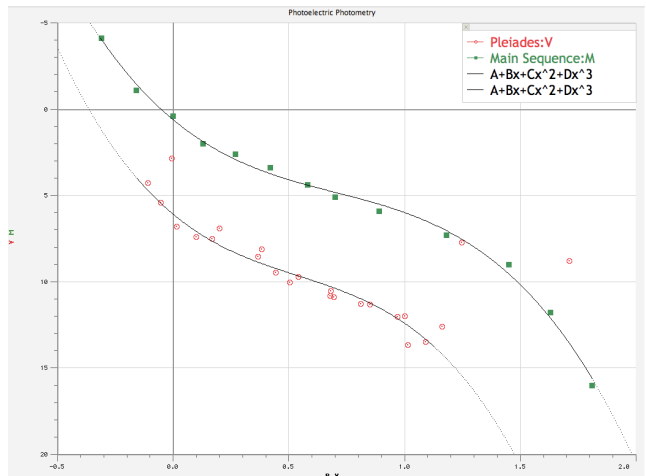
7. **Skip the outliers:** If there are any Pleiades stars that are not main-sequence stars, indicate them and do not draw your curve through them.

8. **Compare the curves:** Is your Pleiades curve brighter or dimmer than the 10 pc curve? The calibrated main-sequence represents the magnitudes that a cluster of main-sequence stars would have if they were 10 pc from the Earth. Keeping that in mind, are the Pleiades further or closer than 10 pc?

9. **Find (V–M):** To determine how many parsecs (pc) the Pleiades cluster is from us, you need to measure how many magnitudes separate the Pleiades main-sequence and the standard main-sequence (V-M). We will discuss exactly how to do this during the second lab session.

10. **Calculate:** Use the equation below to find the distance to the Pleiades in parsecs.

$$d = 10^{\left[\frac{(V-M)+5}{5}\right]} \text{pc}$$

11. **Compare:** If the accepted value for the distance to the Pleiades is 135 pc, what is your percent error?

$$\%error = \left(\frac{d - 135}{135}\right) \times 100$$

12. **Convert:** What is the distance in light years given 1 pc=3.26 ly?
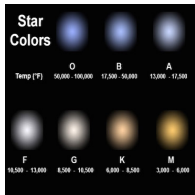
Lab 09: Stellar Spectroscopy and Classification

Introduction

Once upon a time, astronomers had to perform their observations in cold, open-air observatories, using telescopes which had to be positioned by hand. Over the past thirty years, telescopes have become increasingly automated. The observatory dome can be opened at the touch of a button. The telescope can be positioned on the desired object as quickly as the astronomer can type the coordinates into the computer. Data collection can be performed at precise and regular intervals, with the information stored on computers, either local or remote. It is now possible for an astronomer in Arkansas (or wherever) to perform observations using a telescope in Arizona (or anywhere), without ever leaving home.

What that means to us is that we can simulate the observing experience with astonishing realism. We will not be able to get observing time on a real telescope, but the VIREO (The VIRtual Education Observatory) program we will use has been designed by astrophysicists to reproduce an accurate observing experience. The Student Manual for this exercise is freely available online at:

ftp://io.cc.gettysburg.edu/pub/clea_products/manuals/Specl_sm.pdf

A clickable link is provided on the course web, and remember that you can run these programs any time the lab LSC 174 is open.

We will start by examining stellar spectra. Similar to the spectroscopy we performed in lab previously, astronomers look to stellar spectra to determine many things about a star. By determining the spectral type of a star, we can find its temperature, luminosity, and color. From these fundamental facts, many more properties of the star can be extrapolated: its mass, its distance, its life history…the list goes on and on.

Objectives

You have been granted unlimited observing time on a 0.4 meter optical telescope and permission to request time on a 1.0 meter and/or 4.0 meter optical telescopes. The telescopes will be equipped spectrographs. Your project mission is to:

- ◉ Obtain spectra of a sample of 10 stars
- ◉ Determine the spectral and luminosity types for each
- ◉ Calculate the distances of main-sequence stars

Start up Procedures

1. **Start *VIREO*:** Double click on the icon for the *VIREO* program found on the desktop.

2. ***File → Login*:** Enter your name and the number of the computer and click *OK*.

3. ***File → Run Exercise → Classification of Stellar Spectra*:** Choose the appropriate exercise.

4. ***Telescopes → Access 0.4 Meter*:** Choose a telescope, or *Request Time →* on either the *1.0 Mete*r or *4.0 Meter*. If you are granted time on either of the larger telescopes, then you will have to access them from the menu in order to use them. (Hint: Bigger telescope means more light-gathering power means shorter exposures required!)

5. **Control the scope:** Once you have selected of one of the telescopes you will need to open the dome, and once the dome is open you will need to turn on the *Telescope Control Panel*.

6. **Tracking:** Turn on the telescope *Tracking* on from the control panel.

7. **Field of view:** Toggle from *Finder* view to *Telescope* view. This switch occasionally sticks, and you might have to toggle a second time to change to the *Telescope* view.

Targeting Stars

8. ***Slew → Set Coordinates*:** Enter the coordinates for the target star. Coordinates are listed on the table below.

9. **Double check**: Once the telescope has slewed, there should be a star centered on the spectrograph aperture.

NAME	I.D.	RA (H, M, S)	DEC (°, ′, ″)
EPSILON ERIDANI	S0730-01533	03 32 55.8	-09 27 29.7
SIRIUS	S1500-02767	06 45 08.9	-16 42 58.0
TAU CETI	S1500-02288	01 44 04.1	-15 56 14.9
PHI ORIONIS	N0730-02401	05 34 49.2	09 29 22.0
MU DRACONIS	N5230-01396	17 05 19.7	54 28 13.0
MINTAKA	S0000-02445	05 32 00.4	-00 17 57.0
PROCYON	N0000-02180	07 39 18.1	05 13 29.0
ARCTURUS	N1500-01426	14 15 39.7	19 10 56.0
BETELGEUSE	N0000-01873	05 55 10.3	07 24 25.4
BARNARD'S STAR	N0000-02498	17 57 54.1	04 33 04.0

Acquiring Spectra

10. **Open the spectrometer:** Choose *Spectrometer* using the *Instrument* slider, and click *Access* to bring up the *Reticon Spectrometer Reading* control panel.

11. **Double check:** Verify that you are on the correct star by comparing the I.D. listed on the table above with the Object displayed on the Spectrometer control panel.

12. **Collect the data:** Click on *Go* to start an exposure and Stop once the Signal-to-Noise Ratio is sufficiently high (S/N should be greater than about 500 for best results). A dimmer star (greater V means dimmer star) will require a longer exposure time.

13. **Record the apparent magnitude (V) of the star.**

14. **Save the spectrum:** *File → Save Spectrum*.

15. **Target the next star:** Repeat the above steps until you have saved a spectrum for each star.

Spectral Classification

16. **Tools → Spectral Classification :** Go to the VIREO Exercise-The Classification of Stellar Spectra Window and *Tools→Spectral Classification* to bring up the *Classify Spectra* tool.

17. **File → Display → Show Difference:** This displays the comparison of the *Standard* spectra and the *Unknown* spectrum. When the spectra match, the difference will literally be zero.

18. **File → Unknown Spectra → Saved Spectra:** Choose a saved spectrum for one of the stars you observed.

19. **File → Atlas of Standard Spectra:** Select the *Main Sequence Atlas*. Now you can compare the spectrum of the target star "Unknown" to a sample of main-sequence star spectra by choosing them from the Standards list. The *Difference* will give a quantitative look at how close the Standard and the Unknown match. If you find an exact match, then you can identify the spectral and luminosity type. If you cannot find an exact match, then there are two possibilities:

     A) **The star might be a giant star.** To check, return to the *Atlas* and chose "Luminosity at _____", where _____ is the spectral type that fits the closest when comparing to main-sequence stars. You will be given a sample spectra of different luminosity classes at that spectral type. If you find an exact match, or a better match, then you can conclude it is one of these spectral and luminosity types.

     B) **The star really is a main sequence star.** If you have ruled out that the star is some sort of giant star then the star is a main-sequence star (luminosity class V) but a spectral sub-class not part of the example standards given. If that is the case, you will need to estimate the sub-type.

20. **Repeat:** Classify all of the stars for which you have collected spectral data.

21. **Organize:** Construct a table in your notebook to summarize your classification results.

STAR	SPECTRAL TYPE	NOTES
EPSILON ERIDANI		
SIRIUS		
TAU CETI		
PHI ORIONIS		
MU DRACONIS		
MINTAKA		
PROCYON		
ARCTURUS		
BETELGEUSE		
BARNARD'S STAR		

In the column labeled "Notes," you might simply cite that the overall match is very exact, or that you saw two possibilities and had to check/compare the luminosity classes, or that you have estimated a spectral sub-type. Just include a brief note for your own reference to remind you how you came to a specific conclusion.

Spectroscopic Parallax

For the stars you identified as being main-sequence stars (luminosity class V), determine their distances.

1. **Absolute Magnitude:** Use Appendix II from the Student Manual and the spectral type of each main-sequence star to determine the Absolute Visual Magnitude (M) for each. If it is more convenient, you may look these stars up using Wikipedia. The data for these particular stars is accurately reported.

2. **Calculate (V-M) for each star.** Remember that you only need to do this for the main sequence stars!

3. **Calculate the distance:** Use the equation below to calculate the distance to each star in parsecs (pc).

$$d = 10^{\left(\frac{(V-M)+5}{5}\right)}\text{pc}$$

Note that the equation reads "ten raised to the power of." *You are not multiplying ten by the value in parentheses.*

4. **Summarize:** Construct a table in your lab notebook to summarize your findings. Note that you may not fill in the values for every star you observed! *Only calculate distance for the stars you have identified as main sequence.*

STAR	ABSOLUTE MAGNITUDE (M)	APPARENT MAGNITUDE (V)	V–M	DISTANCE IN PC
EPSILON ERIDANI				
SIRIUS				
TAU CETI				
PHI ORIONIS				
MU DRACONIS				
MINTAKA				
PROCYON				
ARCTURUS				
BETELGEUSE				
BARNARD'S STAR				

Make sure that you are recording all your answers in your lab notebook. Include any sketches or additional explanations that you think may help you answer quiz questions!
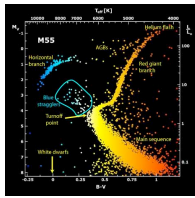
Lab 10: Determining the Ages of Star Clusters

Introduction

As we have seen, observing the individual stars in a cluster can give us information about the cluster as a whole. We will continue our examination of star clusters this, extending our observations to multiple different clusters. Because there is not sufficient time for you to observe the individual stars of each cluster, we will use some photometry that has already been provided for us. This is not an unrealistic scenario for an astronomer: because telescope time is such a precious commodity, it is common for raw data to be shared. One set of observations may provide a research group with answers to a specific question. That same data might be used again, analyzed in a different way, to provide a different group answers to an entirely different set of questions.

When we construct an H-R diagram using randomly selected stars, we expect to get a distribution of stars along the main sequence, along with scattered giants and dwarf stars. We would expect, if enough stars are observed, to see examples of almost every spectral type and luminosity class.

If we restrict our observations to related groups of stars (clusters), we expect to see something different. All of the stars in the cluster formed at the same time, but they will not all live the same length of time. Giant stars have very short lives, and can burn through their fuel in tens of millions of years. Smaller, more modest suns consume their hydrogen more slowly, and therefore live longer lives. As all stars age, they will eventually leave the main sequence, with the hottest stars disappearing first.

A cluster that has many hot, bright stars must therefore be younger than a cluster showing many cooler red stars, but few hot blue stars. Examining the distribution of the stars within the cluster can tell us the age of the cluster.

The Student Manual for this exercise is available online at:

ftp://io.cc.gettysburg.edu/pub/clea_products/manuals/HRdiag_sm.pdf

The advantage of this manual is that is provides additional detail describing the program features, but you may not need to print the entire document. A clickable link is provided on the course web, and remember that you can run these programs any time the lab LSC 174 is open.

Objectives

Since we have already taken great pains to understand how a pair of simple measurements can be translated into an H-R diagram for a star cluster, we do not need to repeat the process. This week, we will let the computer generate the H-R plot, and we will analyze the results to determine the distance and age of several different star clusters.

Your project mission is to

- Examine and analyze photometric data for multiple star clusters.
- Compare the main sequence of the cluster to a calibrated absolute magnitude main sequence, and calculate the distance to the cluster.
- Computer-model various isochrones to fit the cluster data, and determine the age of the cluster.

Procedures

To recognize how old a cluster is, we need to compare its H-R diagram to a hypothetical curve called an **isochrone**. An isochrone is constructed by starting with a **zero-age main sequence**, where you assume that all of the stars n the main sequence were born at the same time. Now advance the time, and each of the stars ages by that same amount. Re-plot the H-R curve. Some stars remain on the main sequence, but some have left it. Advance the time again, and keep doing this. As time increases, the number of stars leaving the main sequence and joining the giant branch increases as well. The farther down the main sequence that the stars have "turned off," the older the cluster:

HR Diagrams for Various Open Clusters
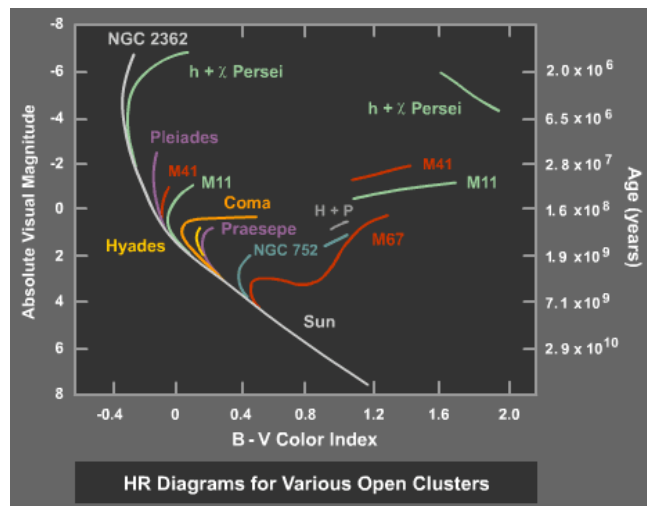
Start Up

1. **Start *VIREO*:** Double click on the icon for the *VIREO* program found on the desktop.

2. ***File → Login*:** Enter your name and the number of the computer and click *OK*.

3. ***File → Run Exercise → H-R Diagrams of Star Clusters*:** Choose the appropriate exercise.

4. ***Tools → H-R Diagram Analysis*:** When the *Color-Magnitude Diagram* window opens, you will need to load the data.

5. ***File → Load/Plot → Select Cluster Data*:** Choose a cluster from the list on the data table shown below. Make sure to record your data in your lab notebook in a neat table.

Zero–Age Main Sequence

6. ***Tools → Zero-Age Main Sequence*:** The first step is to fit a main sequence curve to the cluster data. You will see a green curve appear, and this must be adjusted to match the data.

7. **Adjust the *V–M_V* Slider:** on the right until the green curve fits the data. The *E (B–V)* slider at the bottom has been disabled, so do not worry about this.

8. **Match the middle:** You will not be able to get a perfect fit; the age of the cluster will affect how many stars are on the main sequence and how many have already left it. Fit the data as best possible. You will get the most accurate fit by matching the middle of the main sequence as closely as possible.

9. **Record the *V–M*:** This is labeled *V–M_V* on the slider.

Fitting an Isochrone

10. ***Tools → Isochrones:*** This will place a second curve on you H-R diagram, in addition to the main sequence. This isochrone must now be adjusted to determine the age of the cluster.

11. **Adjust (*B–V*):** When the *Isochrone Parameters* window opens, you will be able to adjust the *Age* slider and the *Adjust (B–V)* slider.

12. **Match the blue (leftmost) end:** Since these large blue stars will leave the main sequence first as the cluster ages, the "turnoff" point on the main-sequence is a critical function of the age of the cluster. You may not see many stars on the giant branch, since giant branch stars have relatively short life spans (about 10% of their main-sequence life span), and may have disappeared already, becoming white dwarfs, neutron stars, or black holes.

13. **Match the dimmer (bottom) side:** The stars in the main sequence of your diagram will be more scattered than the sharp isochrone line. Some of this is intrinsic to the cluster— binary stars, for instance, are brighter than corresponding single stars, and thus make the main sequence thicker. So does the fact that not all stars in the cluster are at exactly the same distance from us. There may even be a few stars included in the list that are not actually members of the cluster. Adjust your isochrone so that it runs through the points along the bottom edge of the main-sequence to avoid some of these problematic points.

14. **Adjust the Metallicity:** This refers to the abundance of elements heavier than hydrogen. Younger clusters will have greater abundances of heavier elements than older clusters.

15. **Record the age:** When you have a satisfactory curve fit, record the age of the cluster in Gyr (G = giga = 10^9 = billion).

16. **Repeat:** Continue to fit and adjust the isochrones for the clusters on your list until you have determined the age of each.

Data

1. **Organize:** If you have not yet, construct a neat table in your lab notebook and record your observations.

Cluster	V–M	Distance (pc)	Age (×10⁹ yrs)	Notes
NGC 752				
M 45				
M 41				
M 44				
IC 2391				
M 67				
M 7				
M 39				

2. **Annotate:** In the Notes column, you should record secondary age values. For example, if you find that one combination of Age/Metallicity gives you a good fit, but a second, different combination gives you about as good a result, you should make a note of both potential ages.

Analysis

3. **Calculate:** Use the computer-generated V – M value to calculate the distance to each cluster in parsecs (pc).

$$d = 10^{\left(\frac{(V-M)+5}{5}\right)}\text{pc}$$

Note that the equation reads "ten raised to the power of." You are not multiplying ten by the value in parentheses.

4. **Compare:** The accepted distance to M41 is 710 pc. Calculate the percent error in your value:

$$\%error = \left(\frac{d-710}{710}\right) \times 100$$

5. **Compare again:** If the accepted age of M44 (Praesepe, or the Beehive cluster) is 600 million years (0.600×10⁹ yrs), does your value come close? Is your value high or low? Was there much uncertainty in your isochrone fitting (meaning uncertainty in your cluster age estimate)?

6. **Compare again, again:** Examine the oldest and the youngest cluster that you have identified. Make a note of the significant differences in the appearance of the H-R diagram for each.

Make sure that you are recording all your answers in your lab notebook. Include any sketches or additional explanations that you think may help you answer quiz questions!

Make Up Lab: The Orbit of Mars

Introduction

Back in 1609, Johannes Kepler did not have a computerized planetarium that he could use to visualize the solar system at whatever instant he chose. What he did have was an enormous quantity of data inherited from Tycho Brahe, an observational astronomer so careful and meticulous that his data can still be used today to locate astronomical objects. Tycho had hoped that Kepler would be able to use his data to prove mathematically the correctness of his own geocentric cosmology (a complicated variation of Ptolemy's model). What happened instead was that Kepler went where the data took him, and it wasn't in Tycho's direction.

Kepler's First Law states that planets orbit the sun, and the orbits are ellipses. We are going to take a very small portion of data similar to what was available to Kepler, and determine the orbit of Mars using the method that he used.

Kepler was able to determine the orbital period of Mars (with respect to the stars). He determined that Mars orbited the Sun once every approximately 687 days. This is important since this tells us that Mars will be at the same location in its orbit every 687 days. Why is this important? Tycho's accurate data for Mars in the sky provided its direction but not its distance. But one can triangulate the distance by observing Mars in the same position 687 days apart.

Objectives

- ◉ Apply geometric methods of triangulation
- ◉ Use observational data to construct the orbit of the planet Mars
- ◉ Demonstrate Kepler's First Law of Planetary Motion
- ◉ Label and define the properties of an ellipse
- ◉ Apply the properties of ellipses to the orbit to determine the eccentricity e of Mars' orbit
- ◉ Calculate the percent error in your value of e

Constructing an Orbit

Earth on 11/22/41

Earth on 10/10/43

After 687 days, Mars is in the same place on its orbit, but Earth is not.
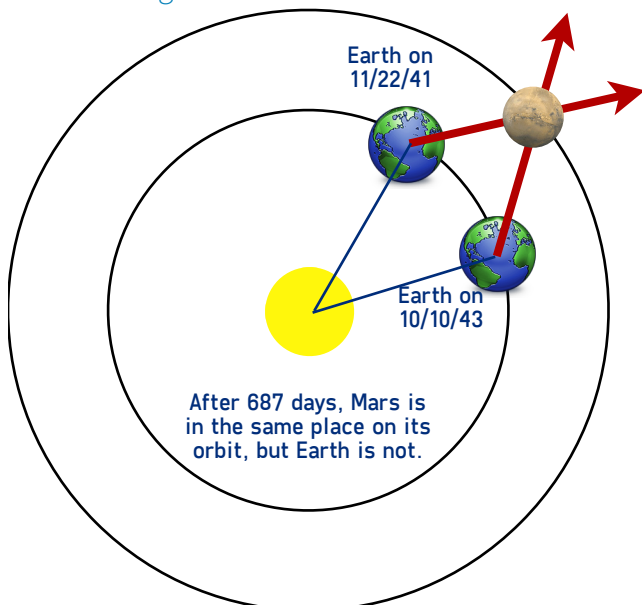
To find where Mars is with respect to the sun, we need to know both where the **Earth is with respect to the sun**, and then where **Mars is with respect to the Earth**. The figure above illustrates this.

Each data pair on the table below represents a pair of observations of Mars, taken from here on Earth. In each case, **the observations are separated in time by exactly 687 days, or the length of one Martian year**. Thus, each pair of observations puts Mars in the same place on its orbit relative to the sun. However, that does not put it in the same place relative to the Earth. This is because the Earth is also moving with respect to the sun, and after 687 days, the Earth is definitely not back in the same place it started.

The **heliocentric longitude** of Earth is the position of the Earth relative to the sun, and the **geocentric longitude** of Mars is the position of Mars relative to the Earth. Use the following table of observations to construct the orbit of the planet Mars:

	DATE	HELIOCENTRIC LONGITUDE OF EARTH	GEOCENTRIC LONGITUDE OF MARS
1	March 21, 1931	180°	118°
	February 5, 1933	136°	168°
2	April 20, 1933	210°	151°
	March 8, 1935	167°	204°
3	May 26, 1935	245°	187°
	April 12, 1937	202°	246°
4	September 26, 1939	3°	301°
	August 13, 1941	320°	20°
5	November 22, 1941	60°	12°
	October 10, 1943	17°	80°
6	January 21, 1944	121°	66°
	December 8, 1945	76°	123°
7	March 19, 1946	178°	108°
	February 4, 1948	135°	153°
8	April 4, 1948	195°	138°
	February 20, 1950	152°	191°
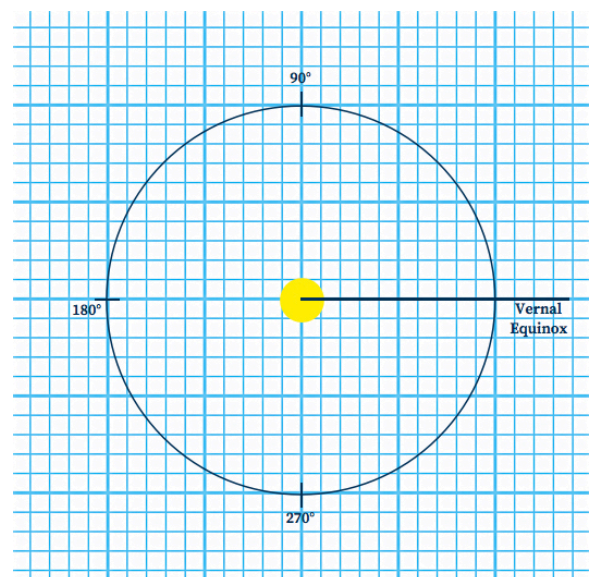
7. **Construct the orbit of the Earth:** Start by assuming that the Earth's orbit is circular. Use a compass to draw a circle with a radius of 10 squares of your grid paper. This sets the scale of your orbit to **1 square = 0.10 AU**.

8. **Draw a reference line:** As shown above, draw a horizontal line from the sun and label it "Vernal Equinox." This represents 0°, and we will measure all angles with respect to this guideline.

9. **Locate the position of the Earth:** Use the protractor to measure the angle of the **heliocentric longitude** of the Earth with respect to the **Vernal Equinox**. Place a dot at the location, then use this as your reference to locate the position of Mars.
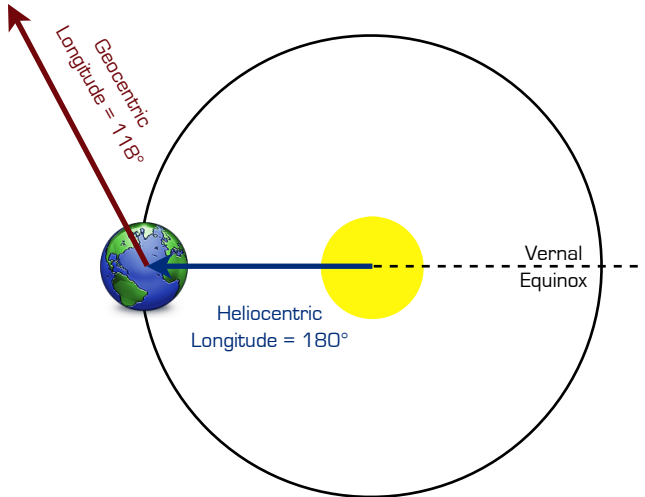

10. **Measure the geocentric longitude of Mars:** From the dot of the Earth, use the protractor to measure this angle with respect to a horizontal reference parallel to the Vernal Equinox. Using a ruler, draw the line of sight as shown above.

11. **Repeat for the second observation of the data pair:** The intersection of the two geocentric longitude lines of sight locates the planet Mars for that pair of observations. Do this for each pair of observations, until you have plotted all eight locations of Mars.
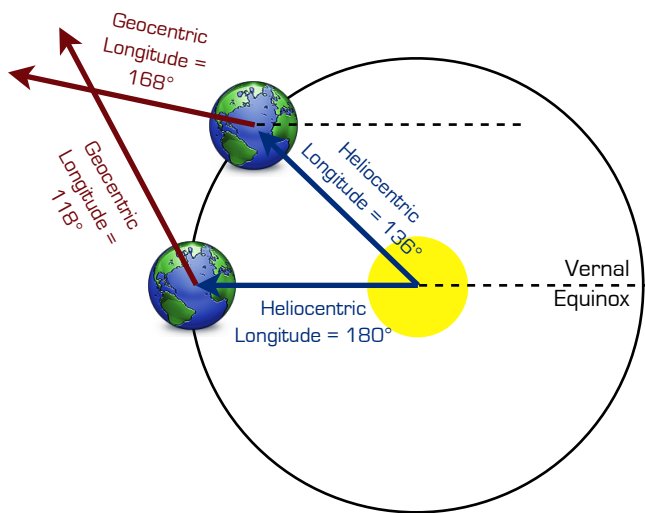
12. **Construct the orbit:** Draw a smooth curve through the eight points of the orbit of Mars (do not connect the dots).

Analyzing the Orbit

1. **Is it a perfect circle?** Apply the definitions and properties of an ellipse to your orbit using the example shown below.

**The Orbit of Mars**
(Not drawn to scale!)
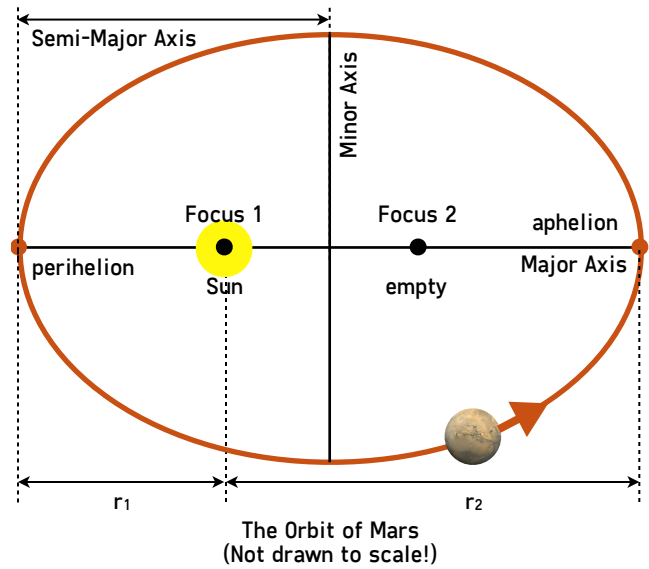
2. **Locate perihelion:** Find the data point closest to the origin (Sun) and label it **"Near Perihelion."** Because you have only eight points on the orbit, you cannot be certain that the point you plotted is the actual point of perihelion, so label it as "near."

3. **Locate aphelion:** Find the data point furthest from the origin (Sun) and label it **"Near Aphelion."**

4. **Draw the major axis:** Draw a single line that passes through the Sun with ends on the Martian orbit and close to the near perihelion and near aphelion points. This line does not have to pass through any specific data point. Label the line the **Major Axis**.

5. **Calculate the distance:** Measure the length of the Major Axis. Divide this value by two; this is the length of the **Semi-Major Axis**. What is the length of the Semi-Major Axis in AUs? What, then, is the average distance from the Sun to the planet Mars?

6. **Find the center:** Now you should be able to locate and label the center of the Martian orbit. Where is the Sun relative to the center of the orbit?

7. **Calculate the eccentricity:** For the ellipse you have just drawn, label the distance from the sun to perihelion r_1. Measure this distance. Label and measure the distance from the sun to aphelion, and call it r_2. Use these values to calculate the eccentricity:

$$e = \frac{r_2 - r_1}{r_1 + r_2}$$

8. **Determine the accuracy:** The known eccentricity of Mars' orbit is $e = 0.09$. How close is your value? Calculate the percent error in your result:

$$\%error = \left(\frac{known\ e - your\ e}{known\ e} \right) \times 100$$

Make sure that you are recording all your answers in your lab notebook. Include any sketches or additional explanations that you think may help you answer quiz questions!
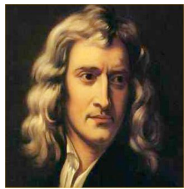
Make Up Lab: Newtonian Gravity

Introduction

It's a common anecdote, the one about Newton figuring out gravity when he saw an apple fall from a tree. The apple may or may not have hit him on the head, but it is true that Newton was able to figure out why the apple fell, as well as why the planets stay in their orbits. The idea of an action-at-a-distance force (as opposed to a contact force) was a significant scientific advancement.

In most situations Newton's Law of Gravitation (action at a distance) is sufficient. Only in cases of very large gravitational fields or when extremely high precision is needed does Newtonian gravity start to give incorrect results. In this lab you will be applying Newton's Law of Gravitation:

$$F = G\frac{m_1 m_2}{r^2}$$
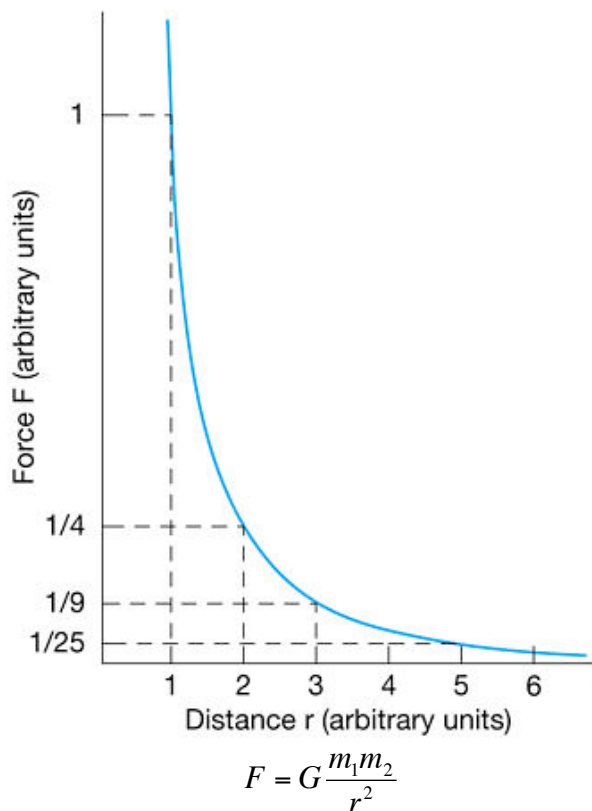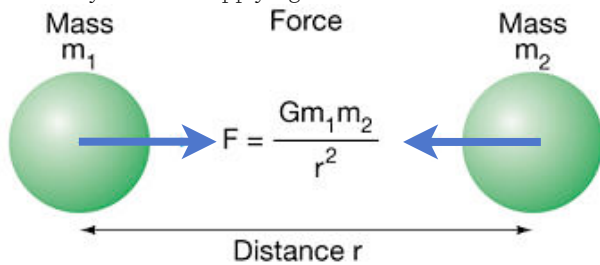
where
F = gravitational force between objects 1 and 2,
G = universal gravitational constant:

$$G = 6.67 \times 10^{-11} \tfrac{\text{N·m}^2}{\text{kg}^2}$$

m_1, m_2 = masses of objects 1 and 2, and
r = separation of masses, measured center to center.

Objectives

- ◉ Examine inverse-square behavior
- ◉ Practice using Newton's Law of Gravitation to solve quantitative problems
- ◉ Describe the force behavior qualitatively
- ◉ Use Newtonian gravity to determine the mass of the earth

The Inverse–Square Force Behavior

The gravitation equation can be rewritten in a simpler form, provided we are very careful to use the proper set of units:

$$F = \frac{100}{d^2}$$

where F = gravitational force (in units of Newtons (N)) between a 10kg mass and Earth, and
d = separation of masses, measured in units of Earth radii (R_e = 1 Earth radius).

Note carefully that this equation refers specifically and only to the force on a 10kg mass due to the Earth. It is not valid for any other size mass or any other planet!

Using this relationship, the gravitational force on the 10kg mass at 1 R_e (on the surface of the Earth) would be:

$$F = \frac{100}{(1)^2} = 100\text{N}$$

Questions

1. **Construct a table:** Use the table shown below as an example to make a similar table in your lab notebook to examine what happens to the force as we change the distance between the 10kg mass and the Earth.

d (R_e)	F (N)	d (R_e)	F (N)
1		20	
2		30	
4		40	
10		50	

2. **Calculate and compare:** Compare the size of the force when $d = 1$ to the force when $d = 2$. Calculate the ratio F_1/F_2. Now compare the force at $d = 4$ to $d = 2$, and calculate the ratio F_2/F_4.

3. **Think about ratios:** While the force values are calculated specifically for that 10kg mass, do the ratios you calculated depend on the mass being 10kg? Comment on this!

4. **Zero force?** At the distances you calculated, did this 10 kg mass ever have exactly zero gravitational force acting on it due to the Earth?

5. **Zero where?** What distance from the Earth to the mass would be required for the mass to have exactly zero gravitational force on it due to the Earth?

6. **Weightlessness?** What condition(s) is necessary for the mass to be weightless, even if there is a gravitational force pulling on it?

7. **Shrink the Earth:** Now imagine the Earth crushed down to the size of a marble, with no change in its mass. What would the gravitational force on the 10 kg mass be if it was located at a distance $d = 10^{-2}Re$?

The following questions are mental puzzles about gravitation. To solve them you will need to apply the concepts of Newtonian gravity. You can always choose to support your arguments mathematically, but you should use words/pictures to make sure you grasp the concepts.

8. **Suppose** the radius of the Sun suddenly shrank to a tenth of its present size, with no change in mass. What would happen to the force on the Earth due to the Sun?

9. **Imagine** changing the Earth from a solid sphere to a spherical shell having the same radius and mass. How would this change the weight of a mass
    A) on the surface of the Earth?
    B) 10 Earth-radii ($d = 10$) away?
    C) inside the Earth?

10. **Imagine** a hole in the smooth airless Earth bored from one side, passing straight through the center of the Earth, and coming out the opposite side. Drop a baseball down this hole, releasing it from one meter above the surface. What would be the velocity and acceleration of the ball
    A) at the start,
    B) at the center,
    C) when it comes out the other side. Will the resulting motion be periodic?

Gravity and Astrology

Let's go on record here: **Astrology is not science.** (And astrology is not astronomy, either. But you knew that.) However, there are still people who will refer to themselves as astrologers, and who will attempt to justify their predictions as scientific by referring to the forces exerted by the planets on a person at the moment of their birth.
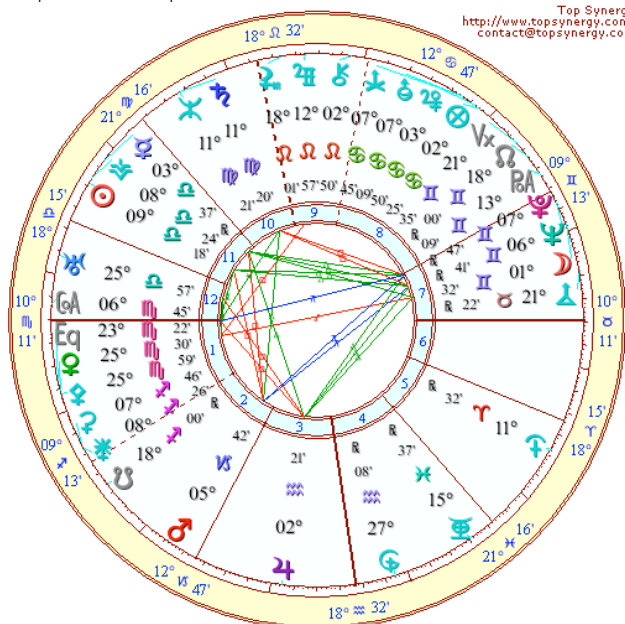
Groucho Marx
NATAL CHART

October 2, 1890   Standard time
8:35   Time Zone: 5 hours West
New York, NY   Tropical Placidus
40 N 42   74 W 00

IT LOOKS ALL TECHNICAL AND OFFICIAL, BUT IT'S NOT SCIENCE. NOT EVEN A LITTLE BIT.

Just for fun, let's do a little calculation. Let's say a baby is born when Mars is at opposition. Let's go ahead and calculate the gravitational force on that baby, then let's

compare it to the gravitational force exerted on the child by the doctor performing the delivery, and see which one would have the greater influence. Use:

$$F = G\frac{mM}{r^2}$$

where G = universal gravitational constant:

$$G = 6.67 \times 10^{-11} \; \tfrac{\text{N·m}^2}{\text{kg}^2}$$

m = 3 kg = the mass of the baby,
M = either the mass of Mars or the obstetrician, and
r = the separation between the baby and either Mars or the doctor at the instant of birth.

Questions

11. **Force due to Mars:** Calculate F_1, the force on the baby due to Mars. Mars has a mass $M_1 = 6.23\text{x}10^{23}\text{kg}$, and when it is at opposition, it is at $r_1 = 3.78\text{x}10^{11}\text{m}$ distance.

12. **Force due to doctor:** Calculate F_2, the force on the baby due to the doctor. A reasonable mass would be $M_2 = 65$ kg, and the distance would be small, $r_2 = 1\text{m}$.

13. **Which is greater?** What has a greater gravitational influence on the infant, the presence of Mars or the presence of the doctor?

Calculating the Mass of the Earth

The weight of an object is literally the measurement of the gravitational force exerted on it by the Earth. If you know how much an object weighs, you know the force on it. Newton's Third Law of Motion tells us that we also know exactly how much force is being exerted on the Earth by the object as well!

Rearrange Newton's Law of Gravity, solving the equation for the Mass of the Earth:

$$M_e = \frac{FR_e^2}{GM}$$

where M_e = mass of the Earth,
F = gravitational force between the object and Earth,
R_e = separation of masses = radius of the Earth:

$$R_e = 6.38 \times 10^6 \text{m}$$

G = universal gravitational constant:

$$G = 6.67 \times 10^{-11} \; \tfrac{\text{N·m}^2}{\text{kg}^2}$$

M = mass of the object attracted to the Earth.

Procedure and Questions

14. **Weigh:** Using a scale that measures force in Newtons (N), weigh an object with a known mass.

15. **Record:** both the mass (M) and the weight (F) of the object.

16. **Calculate:** the mass of the Earth (M_e) using the above equation.

17. **How accurate is your result?** The accepted value for the mass of the Earth is $M_e = 5.98\times10^{24}\text{kg}$. Calculate the percent error in your value.

$$\% \; error = \left(\frac{accepted \; M_e - your \; M_e}{accepted \; M_e} \right) \times 100$$

Make Up Lab: Phases of Venus

Introduction

Galileo is justifiably famous for many discoveries in both physics and astronomy. While he was fascinated by gravity and kinematics, his most valuable discovery is arguably the phases of Venus. By carefully observing and recording the progression of Venus through phases similar to our own moon, he was able to demonstrate the impossibility of the Ptolemy's increasingly complicated geocentric model.
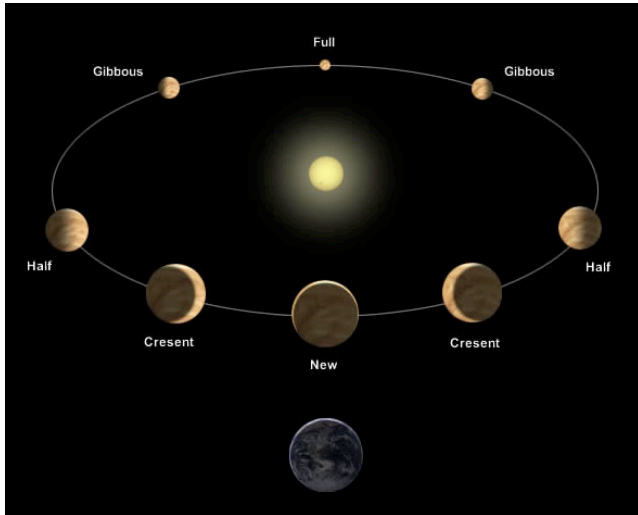
Using the Stellarium program, we can replicate his observations by placing ourselves in the same time and place as Galileo himself.

Objectives

- ◉ Distinguish the difference between sidereal and synodic measurements
- ◉ Use Stellarium to view the sky as it appeared centuries ago
- ◉ Observe and interpret the changing appearance of Venus over the course of months
- ◉ Determine the synodic and sidereal orbital periods for the planet Venus
- ◉ Discuss the reasons why Galileo did not determine the rotation rate of Venus

Procedure

18. **Launch the Stellarium program:** Your default location should be Conway, and the default time should be right now. Because the program uses the computer's clock, your time will always be local to Conway–don't be surprised when you change locations and the sun rises and sets at very odd times!

19. **Set your location:** In the search box of the location window, type in "**Pisa**," and select Pisa, Italy as your location. However, do not set this as your default location, since you can return to it quickly.

20. **Set your date and time:** Go back in time to **January 01, 1610**, and your time to **00:00:00**. You are now where and when Galileo was observing. Again, the actual hours on the clock still reference our Central Time zone, so be aware that it may be light when you expect it to be dark, and vice versa.

21. **Orient yourself:** Toggle on the constellation outlines and labels. Locate one or two constellations whose shapes you know. Are the constellations of 1610 recognizable to you? Face north and locate Polaris. Comment on the location of Polaris compared to its position today.

Synodic Period of Venus

The **synodic period** of an object is a measure of its motion with respect to Earth. We are most familiar with this idea as applied to the moon: to measure its synodic period, we count the time between successive full moons (or new moons, or whichever phase you like). As Galileo discovered, we can do precisely the same thing for Venus.

22. **Change the date and locate Venus:** Advance your date to **May 01, 1610**. Keep the time set to **00:00:00**. Locate Venus, and zoom in to notice its phase. Advance your day until Venus is fully illuminated (100.0%) and record the date. Use the table below as a model for recording your data.

23. **Watch the phase change:** Hit the spacebar once to keep Venus centered in your field of view, then zoom in until the phase is apparent. You should be zoomed in to a FOV of about 0.02°. Advance the time to **June 01, 1610**, and continue to advance by **two-month increments**, until Venus is at its least illuminated. Note that this will not be precisely 0.00%. Once you get close, you should advance time by days, not months. Record the date of Venus at its least, or new phase.

Date	Phase	Phase Sketch	Apparent Diameter	Distance
05/01/1610				
	100.0%			
06/01/1610				
08/01/1610				
10/01/1610				
12/01/1610				
02/01/1611				
	0.01%			
	100.0%			

24. **Advance rapidly back to full phase:** Once you have found "new" Venus, advance the time quickly until Venus is again full. Record the observation date on your data table.

25. **Calculate the synodic period:** The elapsed time from full phase to full is the synodic period. You may use an online unit conversion program to determine the length of time between your observations:

    http://www.onlineconversion.com/days_between_advanced.htm

    This will give you a time in days.

26. **Find your percent error:** The accepted value for Venus' synodic period is **583.9 days**. How close did you get? Calculate your percent error using:

$$\% \ error = \left(\frac{accepted - observation}{accepted} \right) \times 100$$

27. **What did you (and Galileo) actually measure?** Is the synodic period a "day" on Venus? A "year"? Use the phase diagram on the previous page and the figure below to think about this, and describe in your own words what you have actually determined. You should probably also look up "inferior conjunction."
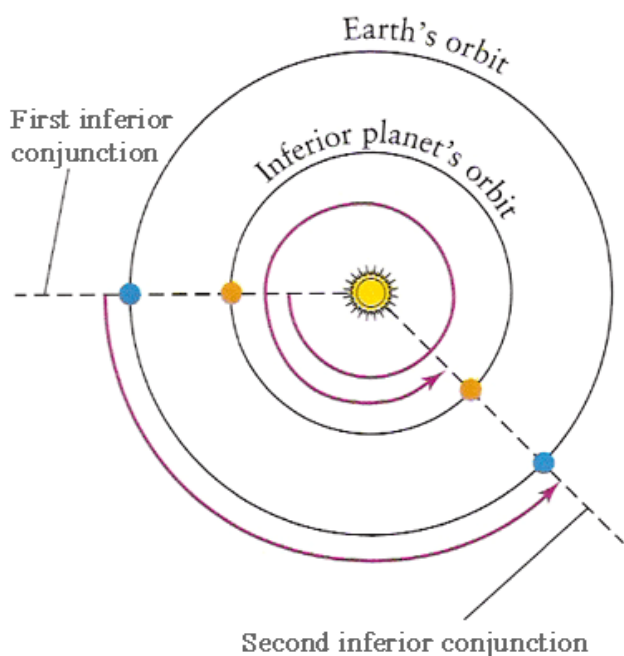
28. **Why does the size change?** Examine the data for the **Apparent Diameter** and explain why the size of Venus appears to change over the course of your observations.

Sidereal Period of Venus

When we measured the Earth's sidereal rotation, we used a distant star for reference, noting the precise elapsed time between its appearance in the same location in the sky. To measure the sidereal orbit of Venus, we will use a reference star, but we have to approach the measurement a bit differently. Let's go to the sun!

1. **Set your location:** In the search box of the location window, start typing "**Pontianak**". Select the location that pops up in Indonesia. We don't really want to be in Indonesia, but we do want to be on the Earth's equator. From the *Planet* pull-down menu, select *Sun*. You should be on the surface of the sun, at the solar equator!

2. **Set your date and find Venus:** Go to **July 11, 2016** at **00:00:00**. We do not need to be in the 17th century anymore. Locate Venus.

3. **Adjust time and align Venus:** Advance the time until Venus has a **J2000 RA = 9h00m00s**. *Adjust your time precisely*, advancing hours, minutes, and seconds of time until the J2000 RA is exact. Record your observation.

4. **Readjust and realign:** Advance the time in **one month increments** until Venus approaches the same RA = 9h00m00s again. Remember that since Venus is closer to the sun than the Earth, it won't take a full 12 months for Venus to complete its orbit. Again, fine-tune your time in hours, minutes and seconds until the J2000 RA = 9h00m00s and record the data.

DATE (MM/DD/YY)	TIME (H:M:S)

5. **Calculate the sidereal period:** The elapsed time between your observations is the sidereal period. Use the online unit conversion program to determine the length of time between your observations:

    http://www.onlineconversion.com/days_between_advanced.htm

    This time, because you have adjusted the time down to the second, record the period in hours, which will be a decimal value. Convert to days by diving by 24.

6. **Find your percent error:** The accepted value for Venus' sidereal period is **224.7 days**. How close did you get? Calculate your percent error using:

$$\% \ error = \left(\frac{accepted - observation}{accepted} \right) \times 100$$

7. **Is this what Galileo did?** Clearly not; he obviously was not simulating observations from the solar equator! You can use some basic kinematics to predict the sidereal period of a planet. Starting with the idea of relative velocity and skipping several steps of algebra:

$$\frac{1}{P_V} = \frac{1}{P_E} + \frac{1}{S_V}$$

    where P_V is the sidereal period of Venus, P_E the sidereal period of the Earth (365.25 days), and S_V the synodic period of Venus (583.9 days). Carefully calculate Venus' sidereal period using relationship. Is this method more accurate than your observations?

The Rotational Period of Venus

Galileo was able to show, using sunspots, that the sun was rotating on its axis. But he was completely unable to measure anything about the rotation of Venus. In fact, it wasn't until the mid 20th century that its period was determined.

8. **Why wasn't Galileo able to measure Venus rotation rate?** Look up how and when Venus' rotation was finally measured, and briefly describe the method. Comment on why Galileo didn't think to do it that way.