

Astro 140 Lab Manual

Paglione, Edition 4
York College
City University of New York

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Lab 1: The Sky & Seasons

Astronomy 140

Due at the *beginning* of lecture a week from today

Name: _____

Date: _____

The planetarium is a powerful tool for visualizing the sky and the motions of celestial objects. This exercise addresses the questions:

- How do the Sun and stars move through the day and year?
- What causes the seasons?
- How do we identify important markers in the sky and on the horizon?
- What are the currently visible constellations?

The Starlab Planetarium

Although an excellent representation of the sky, as with any planetarium, the sky in the Starlab is not exactly how the real sky looks. In particular, you should consider the top of the dome as the point in the sky above your head – the **zenith** – despite the fact that you cannot sit right in the center of the Starlab. The real constellations also appear much larger than they do in the Starlab.

The Real Sky

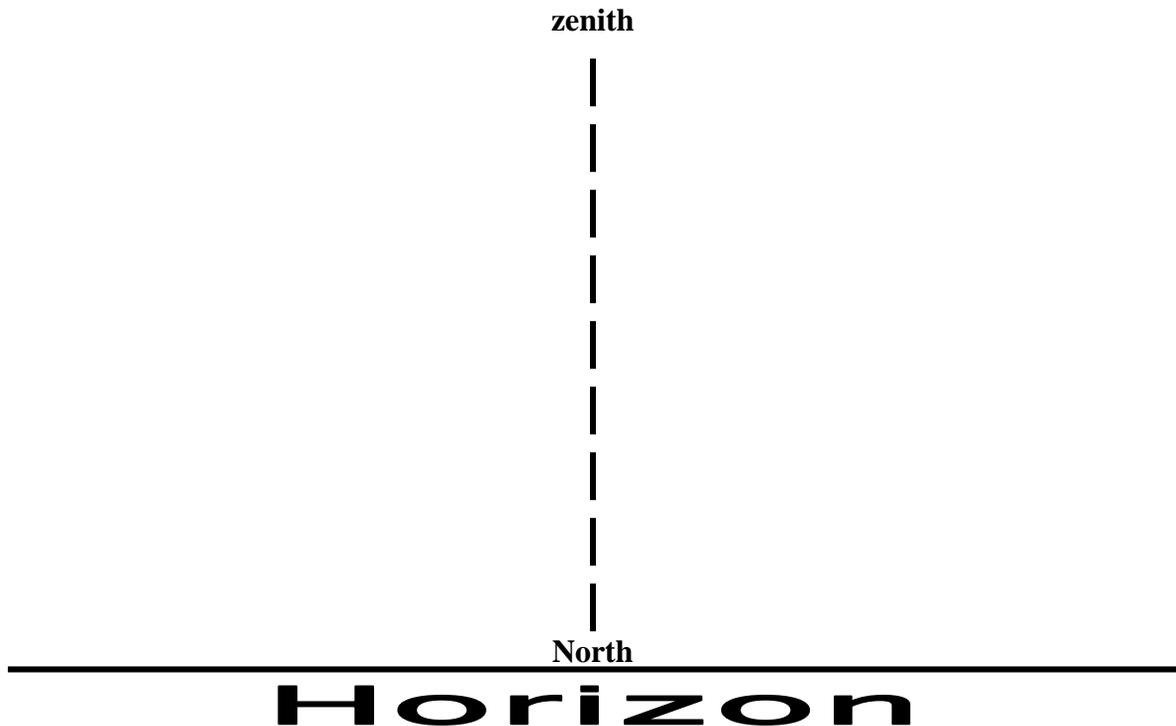
It is important to follow up this exercise with observations of the actual sky on your own. Living in a city is no excuse – the sky will be clear enough to answer all of the follow-up questions!

Exercises and Questions: Orientation

(5 points each)

Following the motion of the Sun, determine the points on the horizon for North, South, East and West. In the northern sky, find the **Big Dipper** and the “pointer stars.”

1. Sketch the Big Dipper and **Polaris** below and label the **pointer stars**.



2. Label the **East** and **West** points on the horizon in the figure above.
3. Indicate the **rotation** of the sky in the figure above using arrows near the East and West **horizons**, and near **Polaris**.
4. Is the Big Dipper currently rising or setting?

Exercises and Questions: Seasons

Identify the **zenith** and **meridian** in the Starlab. Watch a star as it rises and sets. Convince yourself that it reaches its highest point when it crosses your meridian.

5. Watch the **Spring** Sun rise. Does it rise *directly* from due East? If not, does it rise from North or South of due East?

6. Does the Sun rise straight off the horizon or at an angle? Estimate the angle.

7. Estimate the height of the Sun at **noon**. Time how long it takes to set.

8. Now estimate the height of the **Summer** Sun at noon. Is it lower or higher than in Spring? Time how long it takes to set. Is it shorter or longer than in Spring?

9. Does the Sun set directly due West in Summer? If not, does it set North or South of due West?

10. Follow the rising **Winter** Sun. Does it rise directly from the East, or North or South of East? Is the noontime Sun higher or lower than in Spring and Summer? Is the length of day in Winter longer or shorter?

11. From your observations, give *two* reasons why it is hotter in Summer than in Winter.

Lab 2: The Celestial Sphere

Astronomy 140

Due at the *beginning* of lecture a week from today

Name: _____

Date: _____

Partner(s): _____

Though no longer a valid model of the universe, the **celestial sphere** is still a powerful tool for navigation and for visualizing the motion of the heavens. This exercise addresses the questions:

- What and where are the important parts of the celestial sphere?
- How does the Sun move through the sky day and year?
- How do we determine our position on the Earth by observing the sky?

Setting up the Celestial Sphere

(20 points)

Using the toothed dial at the bottom of the sphere (the sphere lifts out of the base), **orient** the Earth so New York City lies directly beneath the vertical ring. Put the sphere in the base so the vertical ring lays in the tracks in the horizontal ring. Both New York and the label “South” on the base (the direction of the southern horizon) should face you.

Use the post-it notes to label the following on the celestial sphere:

- The North and South **celestial poles**
- Your **meridian** from New York City
- The **equator**
- Indicate the *direction* **East** with an arrow along the equator
- The **ecliptic**, the Sun’s annual path through the sky
- The position of the Sun on the summer and winter **solstices**, and the vernal (spring) and autumnal (fall) **equinoxes**

Be sure the instructor has checked over your celestial sphere before moving on to the questions. You may refer to the figures in your book.
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Exercises and Questions

(10 points each)

Remember that our view of the celestial sphere is from the *inside*, standing on the Earth, so some of this will be difficult to visualize. The Earth sits motionless at the center. The terrestrial and celestial poles are aligned with each other.

1. Imagine you are standing at the **North Pole** of the Earth. What point on the celestial sphere is directly above your head (at your **zenith**)?

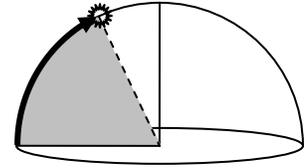
2. Orient the sphere so this zenith points straight up. Rotate the sphere to show its daily East-to-West motion. Use the small toothed dial near the North Pole to move the Sun around. The vertical ring is useful for measuring angles. As seen from the North Pole, how many degrees from the horizon is the Sun on:
 - a. June 21?
 - b. December 21?
 - c. September 21?

3. Now imagine you are observing from the **equator** (from say, Quito, Ecuador). Orient the sphere so this new zenith points straight up, and move the sphere to indicate daily motion. At what time(s) of the year (dates) is the noontime Sun directly overhead in Quito?

4. Now imagine you are observing from **New York City** (at a latitude of about 40°). Orient the sphere with NY's zenith pointing straight up. Do we ever see the noontime Sun directly overhead here? Briefly explain.

5. At what time of the year (what date) is the noontime Sun highest?

6. Of course, the Sun is lowest 6 months later. About how many degrees above the horizon is the noontime Sun then? (*Count* along the vertical ring – don't just read the values.)



7. Again, move the sphere to show its orientation for observers at the pole and the equator. Note the location of the **North Star**, Polaris, from the horizon for these observers. Roughly how many degrees (again, *count* along the vertical ring) above the horizon is Polaris for someone at the following latitudes:

a. North Pole (+90°)	
b. The Equator (0°)	
c. 60° North (+60°)	
d. 30° North (+30°)	
e. 30° South (-30°)	

8. From number 7, what is the relation between the height of Polaris and an observer's latitude?

Lab 3: Planetary Motion

Astronomy 140

Due at the *beginning* of lecture a week from today

Name: _____

Date: _____

Partner(s): _____

Visualizing the apparent motions of the planets is often very difficult. This exercise allows you to answer the questions:

- Why does retrograde motion happen?
- Where must planets be in relation to the Earth during retrograde?
- What are the special planetary alignments?
- Are all planets visible at night all the time? Why or why not?

The Shadow Orrery

Equipment:

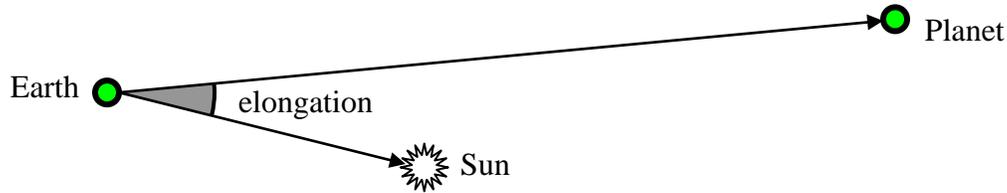
- Light source (Earth)
- Ball stands (planets)
- Paper “sky”

The light source is the **Earth**, the point of observation. You will essentially create a mini model of the solar system (an **orrery** is a mechanical one), in which the shadow represents the apparent position and brightness of a planet in the sky. A larger shadow indicates a brighter planet.

Always move planets counterclockwise (some people say anticlockwise). This direction as viewed from above is eastward – normal – motion.

Planetary Alignments

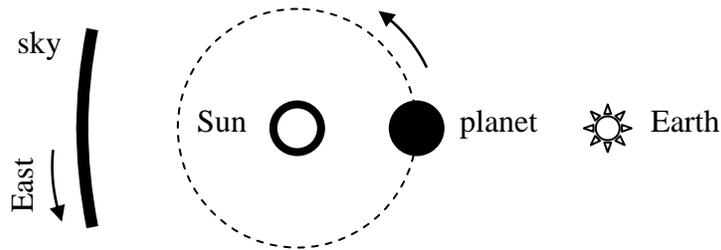
The alignments of the Earth, Sun and a planet have special names. We often measure this alignment by the **elongation**, the angle between the Sun and planet as viewed from Earth.



- (2 points each) Draw the Sun, Earth and a planet in the following alignments:
 - Opposition:** Sun and planet on *opposite* sides of the sky (180° elongation).
 - Conjunction/Superior Conjunction:** Planet behind Sun (0° elongation).
 - Inferior Conjunction:** Sun behind planet (0° elongation).
- (1 points) Which alignment(s) happen *only* for superior planets like Jupiter?
- (1 points) Which alignment(s) happen *only* for inferior planets like Venus?
- (2 points) Can Venus have an elongation of 90° ? Can Jupiter? Explain.

Inferior Planets

Venus and Mercury move so much faster than the Earth that for this demonstration we can assume the **Earth stands still** while they orbit the Sun. Place two ball stands inside the arc of the “sky,” and place the flashlight on the edge as shown below. The innermost ball is the Sun, the other is either Venus or Mercury, and the light is the Earth.



Slowly move the planet around the Sun along a circular path. Try to move it at as constant a speed as possible. Notice the varying position and size of the shadow.

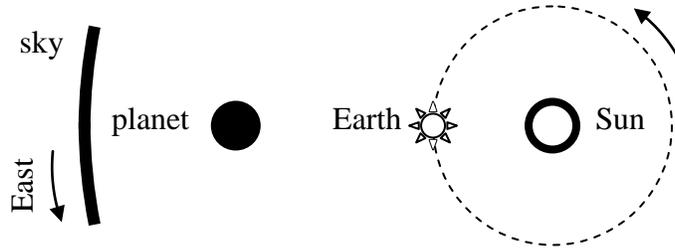
5. (5 points) Is retrograde (westward) motion noticeable? Describe where an inferior planet is with respect to the Earth and Sun when it appears to move in retrograde. What is the name of this planetary alignment?

6. (5 points) Is a planet brighter or fainter while in retrograde? Why?

7. (5 points) The side of the Earth facing the Sun is obviously in daylight. Is an inferior planet ever seen at midnight?

Superior Planets

Now orient the planet, Sun and Earth as shown:



We can now assume that Jupiter and the other superior planets practically stand still while the **Earth moves**. Slowly move the Earth (flashlight) in a circle around the Sun. Again, try to move it as consistently as possible.

8. (5 points) Do superior planets also move in retrograde? What is the name of the planetary alignment during retrograde? Is the planet near or far from the Earth during retrograde?

9. (5 points) At what time of day/night would you expect to see a superior planet high in the sky while in the middle of its retrograde loop?

10. (5 points) Does the Sun ever move in retrograde (to the West)? Why or why not?

Lab 4: Phases of Venus

Astronomy 140

Due at the *beginning* of lecture a week from today

Name: _____

Date: _____

Partner(s): _____

Galileo's remarkable discovery of the phases of Venus helped change the way we view our place in the Universe. However, visualizing the apparent phases and motions of the planets is often very difficult. This exercise helps you address the questions:

- What are the implications of Galileo's observations of the phases of Venus?
- How do the phase and apparent size of Venus vary over time?
- Why do they vary that way?

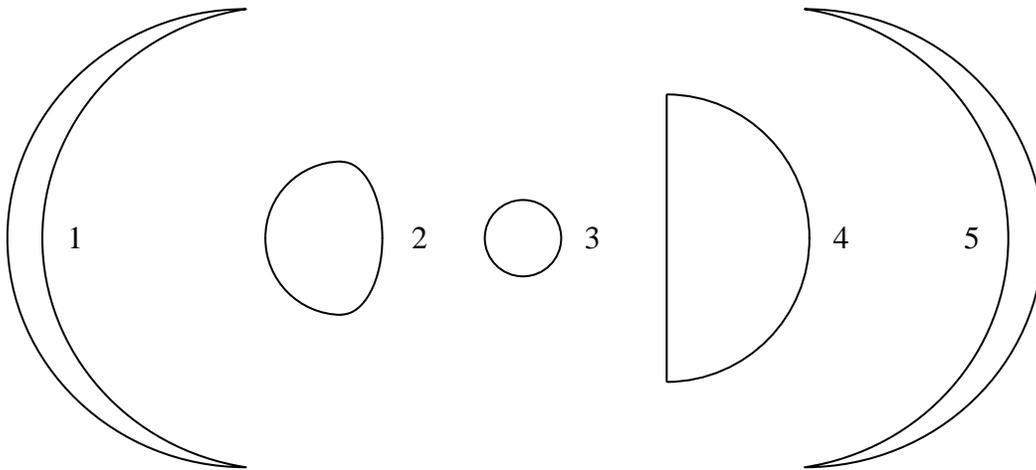
Before Galileo

The planet Venus was well known to numerous ancient cultures around the world. Its motion and dramatic changes in brightness were recorded:

- Venus is only visible near **sunrise** or **sunset**.
- Venus, like all planets, exhibits **retrograde** (westward) motion.
- Venus, like all planets, is **brightest** during retrograde.

Galileo's Observations

Through a telescope, Venus appears to vary in size and phase. The phase and size of Venus (its illuminated face) observed at various times through a telescope are indicated in the figure. Venus is brightest when it appears biggest.



Please answer on a separate sheet of paper.

On the large paper, **mark** the location of the **Sun** (flashlight) and **Earth** (your point of view). Always view Venus (the ball) from the direction of the Earth.

1. (10 points) **Draw** a line on the paper separating day and night as observed from the Earth and **label** day and night on the paper. Given that the Earth spins, or rotates, counterclockwise (to the East), **draw** a line separating morning and afternoon and **label** am and pm. **Draw** a single, large arrow to indicate the direction East.
2. (20 points) **Move** Venus (the ball) around on the paper so that, as viewed from the Earth, the shape and size of the lit part facing you matches the appearance in the figure. **Mark** the appropriate number (1–5) corresponding to Venus’ phase above on the paper at the ball’s location.
3. (10 points) Describe Venus’ motion through space.
4. (2 points) Is Venus far from or near the Earth during **retrograde** motion?
5. (5 points) What is the **phase** of Venus during retrograde motion? Why is Venus so bright at that time?
6. (10 points) Based on Venus’ position, motion and brightness *today* (provided by the instructor), plot its position on the paper and estimate its phase (label its position with a *T* for “today”).
7. (3 points) Do these observations prove anything about the *Earth’s* motion through space? Explain.

Lab 5: The Moons of Jupiter

Astronomy 140

Due at the *beginning* of lecture one week from today

Name: _____

Date: _____

Partner(s): _____

In this exercise you will work in pairs at the computer to record the motions of *two* of Jupiter's four bright moons to determine the mass of Jupiter using Kepler's third law. We will address the following questions:

- How do we “weigh” astronomical objects?
- How can we measure their orbital properties?

Contemporary Laboratory Exercises in Astronomy (CLEA)

The CLEA software you will use today is instructive, powerful and fun. We will use more CLEA programs during the semester.

Save your recordings frequently!! Very often you can lose your data if you leave CLEA or a particular CLEA window.

Kepler's Third Law

Typically seen for planets as $P^2 = a^3$, this equation is *only valid if*:

1. The semi-major axis, a , is measured in **Astronomical Units** (AUs),
2. AND the period, P , is measured in **years**,
3. AND the object is orbiting the **Sun**.

For the moons of Jupiter, we need the more general form of Kepler's third law:

$$P^2 = a^3/M, \quad \text{or} \quad M = a^3/P^2$$

where M is the **mass** of the object being orbited, in this case, **Jupiter**, measured in **solar masses**. The period and semi-major axis must still be in years and AUs.

PLEASE READ THE INSTRUCTIONS COMPLETELY!!

Getting Started:

- Go to the **Start** menu.
 - How? Run the mouse to the bottom left corner of the screen. Click the left mouse button with the cursor over the button that says “Start.”
- Go to Programs, CLEA Exercises, **Jupiter Moons**.
 - How? Keep placing the cursor over the menus that pop up and click the mouse until you get to where you want.
- Click File and “Log in...”
- Enter your name(s) and click OK (ignore the table number entry).
- Click File, “**Run...**” and OK when the date appears (we’re starting on today’s date).
- Go to File, Preferences, and click **ID Colors**. This color codes the moons so they’re easy to identify.
- You can **zoom** in to get a better view of the moons by clicking the 200X, 300X or 400X buttons. Play around with the zoom.

Taking Measurements:

- Click anywhere on the screen to get the position of the cursor.
 - We record the X value listed in **Jupiter diameters** (Jup. Diam.) which shows how far to the left or right of Jupiter the cursor is in terms of the size of the planet. E or W indicates east (left) or west (right) of Jupiter.
 - The X and Y values are the distances away from the **upper left corner** of the black part of the screen. We won’t use these values.
- Click on (or move the cursor over) a **moon** to identify it and get its position.
- You can **hold down** the mouse button while moving the cursor and it will constantly return the cursor position and highlight any moon you may touch.

Recording Measurements:

- Click “Record Measurements...”
 - The “Record/Edit Measurements” window will pop up.
- Record the **distances** *Ganymede & Europa* are from the planet in **Jupiter diameters**. Be sure to label east or west with an “e,” “E,” “w” or “W.”
 - You should **continue** to make measurements with the Record/Edit window **still open**.
 - Don’t bother with the moons Callisto and Io.
- Click **OK** when you’ve entered data for the moons if they were visible that day.
 - Sometimes a moon is not visible. It may be behind Jupiter, or it could be **cloudy**. Cloudy days will be obvious.
 - A moon may also be in front of Jupiter, but still visible. Look carefully.
 - Skip the moon if it isn’t visible.
- **Save** the data under File, Data, Save. Click OK to all the queries.
- Click **Next** to go to the next day. If the next day is cloudy, just click Next again. Take measurements as before.
- (30 points) Record data for ***at least 15 non-cloudy days***, but you can always get more later.

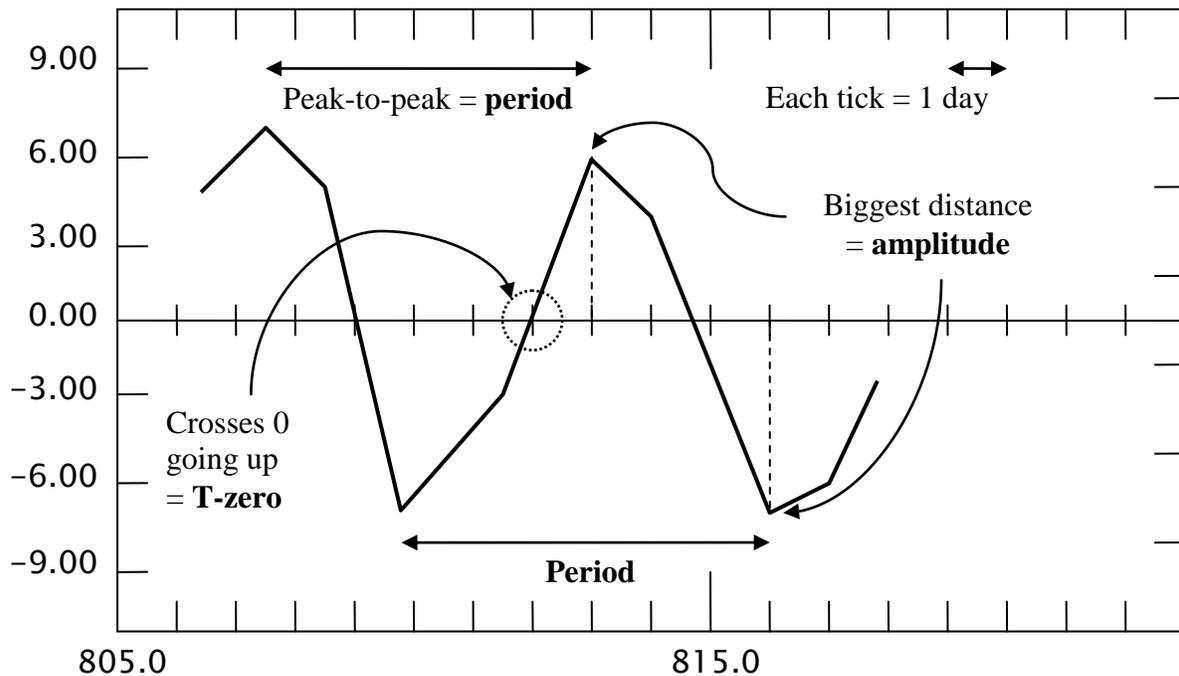
Reviewing, Deleting or Changing Measurements:

- You may **review** or **edit** the data you’ve entered so far by going to File, Data, “Review...”
 - The **Julian Date** is just the date of the measurements (the time in days), and the distances you recorded for each moon are listed in the appropriate columns.
 - If you didn’t record a particular moon one day, it is listed as an asterisk (*)
 - **Check** the data for anything suspicious.
- You can delete, alter or repeat the data for any particular day
 - Highlight the entry with the mouse and click Edit or Delete as appropriate.
 - The same “Record/Edit Measurements” window as before will appear.
 - Repeat a measurement using “Run...” and inputting the date.

Analyzing the Data:

The idea here is to fit a **sine curve** to the data to estimate the semi-major axis and period of each moon's orbit. Look at the data and guess the values that draw the curve. Then adjust those values to fit the data. You want to **minimize** the so-called "**RMS Residual**."

- Go to File, Data, "**Analyze...**"
- Choose a **moon** from the Select menu
- The data will be plotted on the screen. Again the date is given as the Modified Julian Day. Don't be intimidated by that – it's just the *day* in astro-speak.
- Go to Plot, "Plot Type," and click "Connect the dots." You will see something like:



- Go to Plot, "Fit Sine Curve," "Set Initial Parameters..." and **GUESS** the parameters:
 - **T-Zero** is the value on the center axis of the plot where you think the sine curve crosses zero on its way **up** (marked with a circle above).
 - The **period** is the peak-to-peak time (marked with arrows above).
 - The **amplitude** is the full height (or depth) of the curve, typically the maximum or minimum value of the moon's distance. Click on a very high (or very low) data point and its position will be displayed in the bottom corner of the plot screen. (Don't input a negative amplitude.)
- In the example above, T-zero \approx 812, the period \approx 6, and the amplitude is \approx 8.

- A sine curve is now plotted over the data points. Your goal is to make the curve fit the data as best as possible.
- Adjust the parameters using the **scroll bars** until the “RMS Residual” is as low as you can get it.
 - The **RMS residual** is in exponential notation:
 - 3.000E+00 means 3.0
 - 3.000E-01 means 0.3
 - 3.000E-02 means 0.03
 - Try to get a small number up front and a big negative number after the E.
 - Find the best value (minimum RMS Residual) for each parameter one at a time and keep cycling through them.
 - You can **reset** the scrollbars if you reach their limits by clicking “Reset Scrollbars” and “Normal Sensitivity.”
 - You should reach a point where clicking on any of the 3 scrollbars in any direction makes the RMS Residual bigger (in other words, you already have it as small as it gets).
- After reaching the minimum, **print** the screen from Plot, “Print Current Display.” (Not all computers may be able to print – that’s OK.)
- Do this for **both moons**. Select the new moon from the Select menu.
- **Write** down the *final* period and semi-major axis (amplitude) for each moon.

(20 points) *Final results after finding minimum RMS Residual:*

Moon	Amplitude, a, in Jupiter diameters	Period, P, in days
Ganymede		
Europa		

- Check the parameters for the moons’ orbits (Table 8.1 of your text, page 214) for comparison and/or guidance. Note that they list the moons’ semi-major axes in Jupiter radii, not diameters, so they’re twice as big as your results.

Determining the Mass of Jupiter:

(6 points) Use a calculator to complete the table below using your solutions.

Moon	a^3	P^2	a^3/P^2
Ganymede			
Europa			

Note that the value in the last column should be **nearly the same** for both moons.

To convert your final number into kilograms, you must **multiply it by 0.2318**. The result is actually a factor of 10^{27} too small, but that is included below.

- (4 points) List Jupiter's mass using the data from each moon ($M = 0.2318 \times a^3/P^2$).
 - Jupiter's mass from **Ganymede** data: _____ $\times 10^{27}$ kg.
 - Jupiter's mass from **Europa** data: _____ $\times 10^{27}$ kg.
- (2 points)

Jupiter's average mass = $(1a + 1b) \div 2 =$ _____ $\times 10^{27}$ kg.
- (2 points) Compare your result to Jupiter's actual mass (in Table 2B of the Appendix of your text, page A-4). Are you close? Are you proud? You should be! This can be easily done in real life. If you aren't close, **double check** for simple errors.
- (6 points) Use Kepler's third law to estimate the period (in days) of Jupiter's moon Callisto, which has an orbital semi-major axis of 13.15 Jupiter diameters. (Hint: use the factor in the **last column** of your table. Solve for P^2 and then P.)

Lab 6: Light & Kirchhoff's Laws

Astronomy 140

Due at the *beginning* of lecture one week from today

Name: _____

Date: _____

Partner(s): _____

The *only* way we learn *anything* about astronomical objects is by studying the **light** they emit, absorb or reflect. One of our most powerful tools is **spectroscopy**, the study of an object's spectrum. **Just by looking**, we can infer an object's temperature, what it's made of, how it's moving, and often more. Understanding how and why things emit as they do is critical.

In this exercise you will work in small groups to answer the following:

- What can we learn just by looking at something?
- How do we distinguish between light emitted by a solid object or a gas?
- How do we recognize different gases using their spectra?

Spectroscopy

Equipment:

- Spectroscopes
- Emission tubes
- Light bulb and variable power source

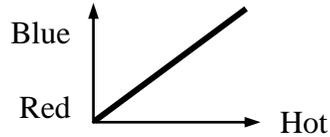
The three sections in this exercise each demonstrate a different one of Kirchhoff's laws. You may *do them in any order*, so begin anywhere.

I. Kirchhoff's First Law:

A hot opaque object emits at all frequencies – a continuous spectrum.

The continuous spectrum has a characteristic shape with a peak, and **Wien's Law** says that the **frequency** of the peak (f_{peak}) is related to the object's **temperature** (T):

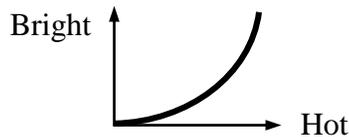
$$f_{\text{peak}} \propto T.$$



So as $T \downarrow$ then $\lambda_{\text{peak}} \uparrow$ and vice versa. A hot object's spectrum peaks at a lower wavelength (bluer) and a cooler object looks redder.

Also, a hotter object will be **brighter** following **Stefan's Law**, which says that the **energy** emitted every second from every square centimeter of an object's surface (called the **flux**) rises quickly with **temperature**:

$$\text{flux} \propto T^4.$$



So a hotter object is much, much brighter than a cooler one since the brightness changes so fast. For example, if you double the temperature of something, it emits $2^4 = 16$ times more energy every second from every part of its surface.

1. (5 points) What changes most obviously as you increase the voltage (temperature)? Is this expected? Explain.
2. (2 points) Observe the light bulb connected to the variable power supply.
 - a. When the voltage (temperature) is very low, what **color** is the bulb?
 - b. What is the bulb's **color** when the voltage is very high?
3. (10 points) Now look through the spectroscope at the bulb. You should see a rainbow. As you increase the voltage, does the peak in the spectrum seem to move? (It's hard to see the peak move. Concentrate on the violet part of the spectrum.) Does it move as you expect based on **Wien's Law**? Explain.

II. Kirchhoff's Second Law:

A hot gas emits only at specific frequencies – an emission line spectrum.

The spectrum emitted by an atom depends on its internal structure, so every atom has its own characteristic light “**fingerprint.**”

4. (15 points) Using a spectroscope, observe the emission tubes. Draw their spectra below with the colored pencils. Indicate brighter lines with **heavier coloring** or broader lines. Record the **spacing** of the lines as carefully as possible. Label the element and the overall color of the tube.

Element _____ Overall color of tube _____

Lab 7: Comparative Planetology

Astronomy 140

Due at the *beginning* of lecture a week from today

Name: _____

Date: _____

Partner(s): _____

The members of the solar system are often separated into two groups: the Earthlike **terrestrial planets** (Mercury, Venus, Earth & Mars) and the **gas giants** (Jupiter, Saturn, Uranus & Neptune), which are Jovian, or like Jupiter. Along with the major 8 planets are other bodies in the solar system that are more difficult to categorize, such as Pluto, asteroids and comets. Consider the following:

- What are the overall properties of solar system bodies and their orbits?
- Do the different classes of object share any characteristics?
- What properties distinguish terrestrial and gas planets?
- How do Pluto, comets and asteroids compare to the major planets?

Data

The data are listed in the following **graphs** and tables. They are organized more or less into general categories of orbits, basic physical properties, rotation information and satellites. The largest **asteroid**, Ceres, and the famous **comet** Halley are also included.

Look for correlations between the different properties (for example, are the largest planets generally the most massive?).

New Terms

A few terms have not yet been covered in class:

Albedo: The reflectivity of the visible surface (1 = 100% reflective = shiny, and 0 = completely absorbing = black).

Oblateness: The difference from a spherical shape:



Obliquity: The angle between a planet's equator and the ecliptic (23.5° for Earth).

Exercises

Please answer on a separate sheet. Refer mostly to the **graphs** to answer the questions unless explicitly directed to use the tables. Each question is worth 5 points.

Orbits

1. Discuss the distinctions between the **orbital sizes** and **orbital periods** of the terrestrial and gas planets. Are the two groups distinguishable by their orbits?
2. Using the values of a and P for at least 3 planets, verify **Kepler's third law**. (Hint: the value of P^2/a^3 should be the same for all of them.)
3. To which group does **Pluto** seem to fit based on its orbit?
4. Do **comets** distinguish themselves by their orbital properties? Which properties are unusual compared to the planets?
5. Do the other **minor bodies** Ceres and Pluto also have any of these unusual orbital properties? If so, which one(s)?

Physical Data

6. Discuss the terrestrial/gas giant distinctions based on their **sizes**, **masses** and **densities**.
7. Based on these data, why do you think Jupiter has so many **moons** and Venus has none?
8. Can we conclude anything about the **composition** of the planets based on these data? Please explain.
9. Based on these data, does **Pluto** most resemble a terrestrial or gas planet?
10. Do the other **minor bodies** Ceres and comet Halley fit into either group based on these data? If so, to which do they belong? (Note that they may not belong to the same group.)
11. Refer to the **data table**. Do the planets resemble the **Sun** in any way? If so, list which properties are similar and for which planets. (Be careful about exponential notation: $3E+04$ means 3,000 or "a 3 with 4 zeroes after it.")

Rotation

12. Discuss the terrestrial/gas giant distinctions based on their **rotation speeds**, **oblateness** and **magnetic fields**.
13. Do you see any connection between **rotation** and **magnetic field** strength? If so, please explain. Be careful not to include any bodies without this information (refer to the table).
14. Give 2 reasons explaining why **Saturn** is so **oblate** or flattened (see Figure 12.1c, page 303 in your text). You will need to refer to other graphs. It may be helpful to consider why it is more oblate than Jupiter.
15. To which group, terrestrial or Jovian, do the **minor bodies** Pluto, Ceres and comet Halley seem to fit based on these data? (They may not all belong to the same group.)

Temperature

16. Discuss the terrestrial/gas giant distinctions based on their **temperatures** and **albedos**.
17. Since albedo indicates how much sunlight is absorbed by a planet, we should expect some trend between **albedo** and **temperature**. Is one apparent? If not, which property or properties seem(s) important for determining temperature? You will need to refer to other graphs.
18. Why do **Venus** and the **Earth** have steady day/night temperatures, but **Mars**, which is similar in many respects, does not? You may need to refer to the table and your book for supplemental information (Sections 7.2, 9.5 and 10.5).
19. Give 2 reasons why **Mercury** has such an enormous **day/night difference** in temperature. You will need to refer to other graphs and the table.

Pluto's status

20. Please answer the following question concisely and completely, using full sentences and proper grammar, and in *only 100–200 words*. Do you think **Pluto** should be considered a full-fledged **planet** like the Earth or Jupiter, or a **minor body** like a comet or asteroid? Your answer should not rely solely on your gut feeling or opinion! Please refer to the **data** you have been examining and cite **examples**. You may want to refer to your book for more information (Sections 13.8–13.10) but rely mostly on the data from this lab and use your own words.

Comparative Planetology Data

	Star	Terrestrial Planets					Gas Giants				Asteroid	Comet
Orbits	Sun	Mercury	Venus	Earth	Mars	Jupiter	Saturn	Uranus	Neptune	Pluto	Ceres	Halley
semi-major axis (AU)		0.39	0.72	1	1.52	5.2	9.54	19.18	30.06	39.44	2.77	17.80
period (yr)		0.24	0.62	1	1.88	11.86	29.46	84.01	164.8	248.6	4.60	76.6
eccentricity		0.206	0.007	0.017	0.093	0.048	0.056	0.047	0.009	0.249	0.079	0.967
inclination (°)		7.00	3.39	0.01	1.85	1.31	2.49	0.77	1.77	17.2	10.58	52.04

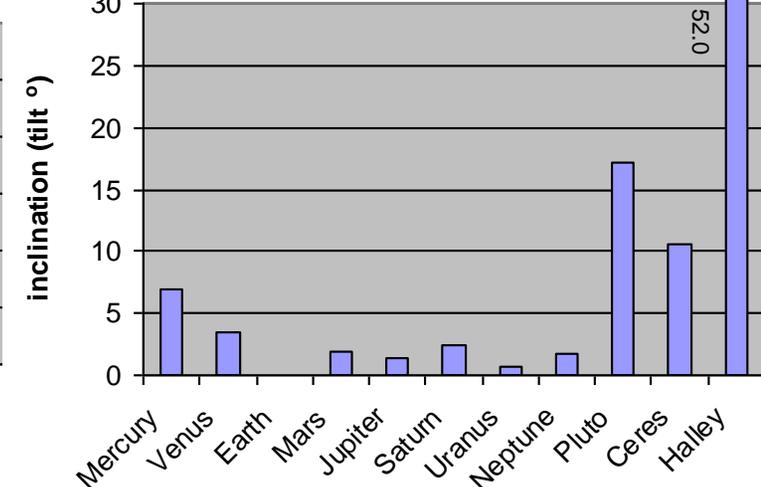
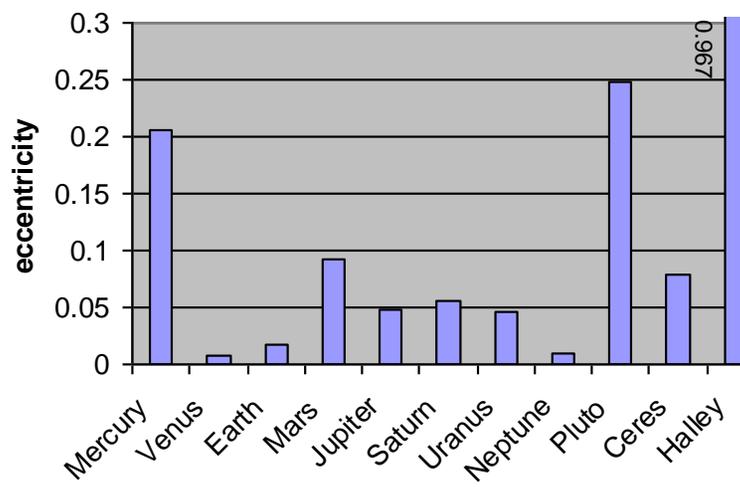
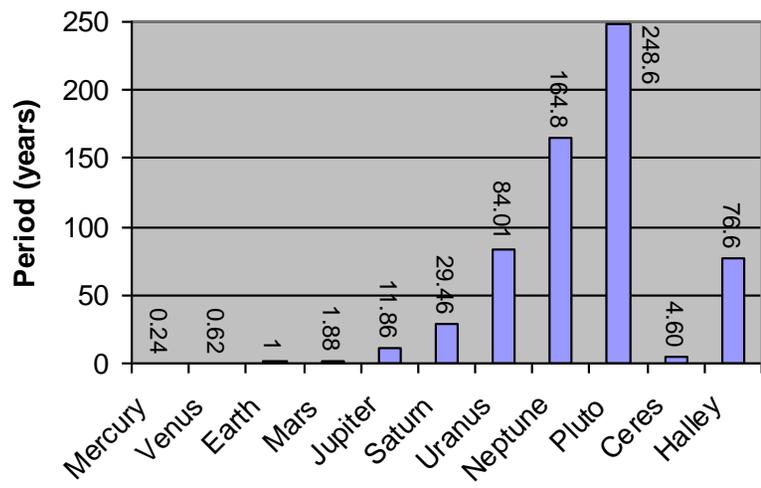
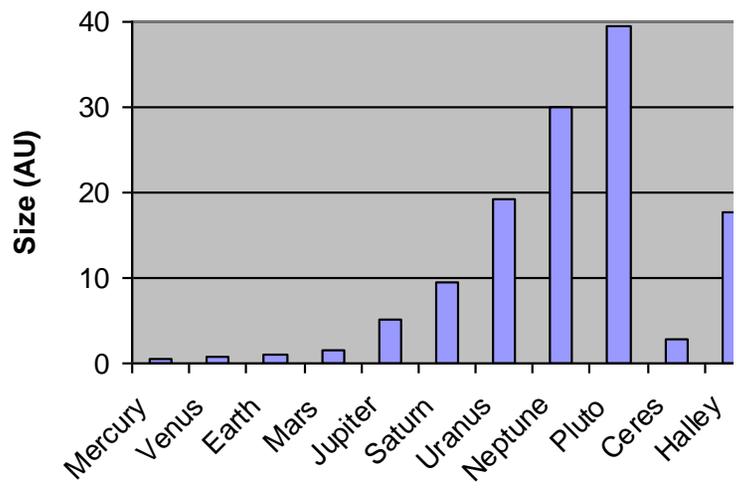
Physical Data	Sun	Mercury	Venus	Earth	Mars	Jupiter	Saturn	Uranus	Neptune	Pluto	Ceres	Halley
radius (km)	696,000	2,440	6,052	6,378	3,394	71,492	60,268	25,559	24,766	1,137	480	16
mass (kg)	2E+30	3E+23	5E+24	6E+24	6E+23	2E+27	6E+26	9E+25	1E+26	1E+22	9E+20	1E+14
mass/Earth's	333,333	0.06	0.82	1	0.11	318.26	95.14	14.54	17.09	0.002	0.0001	2E-11
density (kg/m ³)	1410	5430	5240	5520	3930	1330	690	1270	1640	2060	2700	170

Rotation	Sun	Mercury	Venus	Earth	Mars	Jupiter	Saturn	Uranus	Neptune	Pluto	Ceres	Halley
rotation rate (days)	30	58.6	243	0.9973	1.026	0.41	0.44	0.72	0.67	6.39	0.378	2.17
rotation speed (km/hr)	6,074	11	7	1,674	866	45,650	35,859	9,294	9,677	47	332	2
oblateness	0	0	0	0.0034	0.0052	0.062	0.096	0.06	0.02	0		
magnetic field (gauss)	3000	0.003	0	0.31	0.0004	4.28	0.22	0.23	0.13			
obliquity (°)	7.3	0.0	-2.6	23.5	25.2	3.1	26.7	-82.0	29.0	-58.0	10	

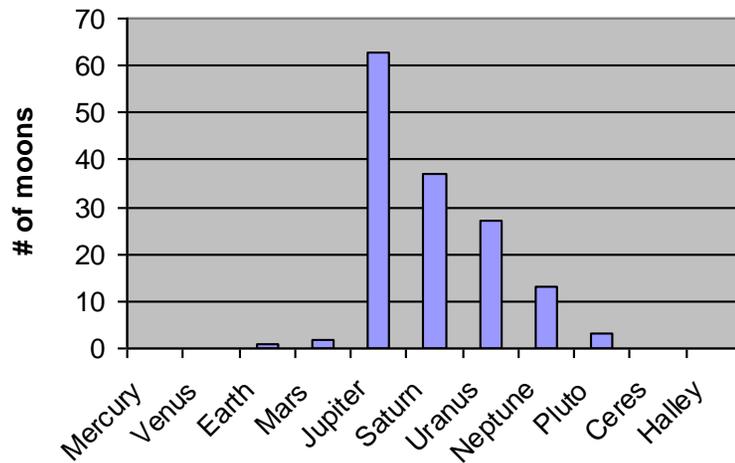
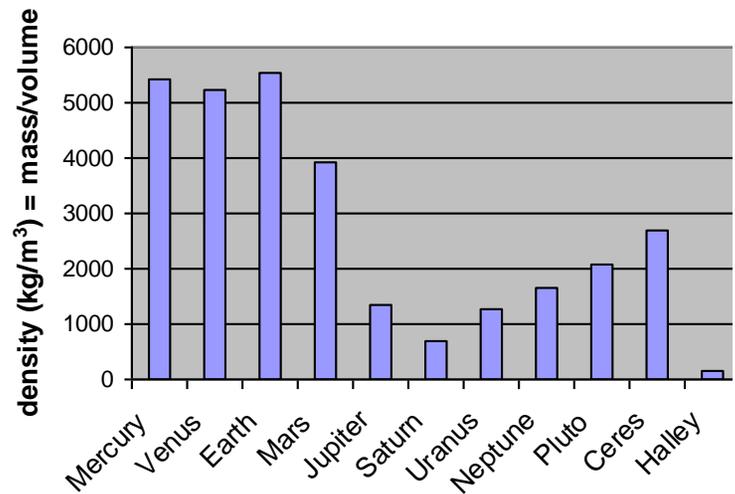
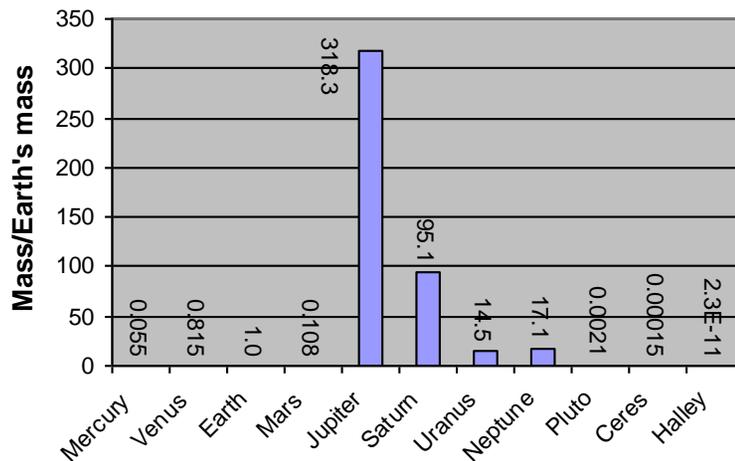
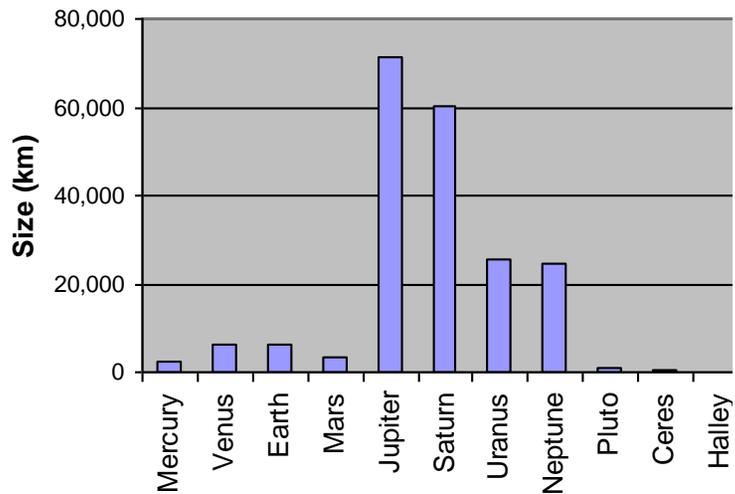
Temperature	Sun	Mercury	Venus	Earth	Mars	Jupiter	Saturn	Uranus	Neptune	Pluto	Ceres	Halley
Albedo		0.06	0.76	0.4	0.16	0.51	0.5	0.66	0.62	0.5	0.073	0.04
day surf. temp. (K)	5770	700	730	290	300	124	97	58	56	40		330
night surf. temp. (K)		100	730	290	210	124	97	58	56	40		

Extras	Sun	Mercury	Venus	Earth	Mars	Jupiter	Saturn	Uranus	Neptune	Pluto	Ceres	Halley
satellites	zillions	0	0	1	2	63	37	27	13	3	0	0
rings	yes	no	no	no	no	yes	yes	yes	yes	no	no	no
atmosphere	all gas	no	thick	thick	thin	all gas	all gas	all gas	all gas	thin?	no	rarely

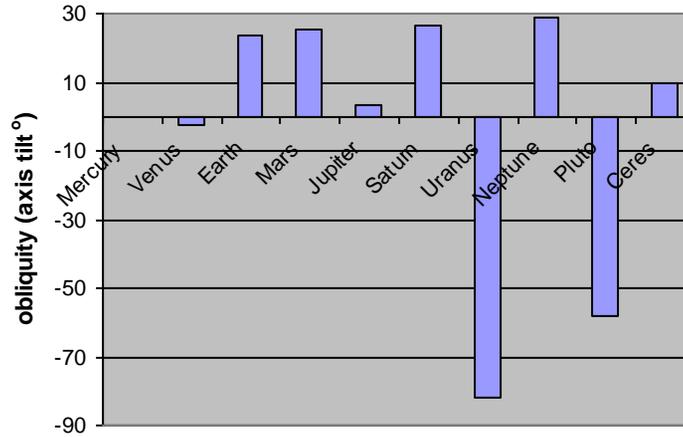
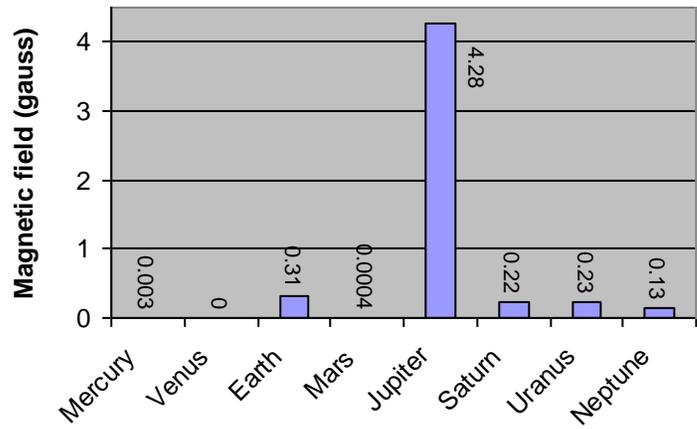
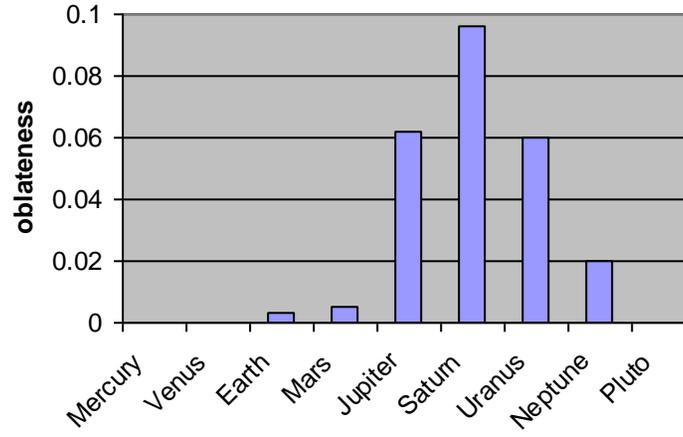
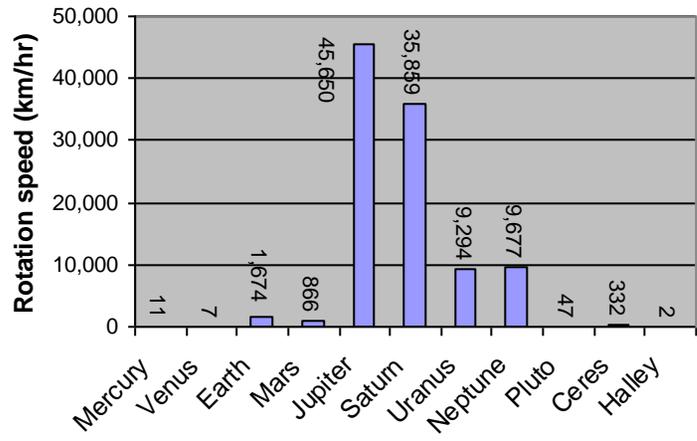
Orbits



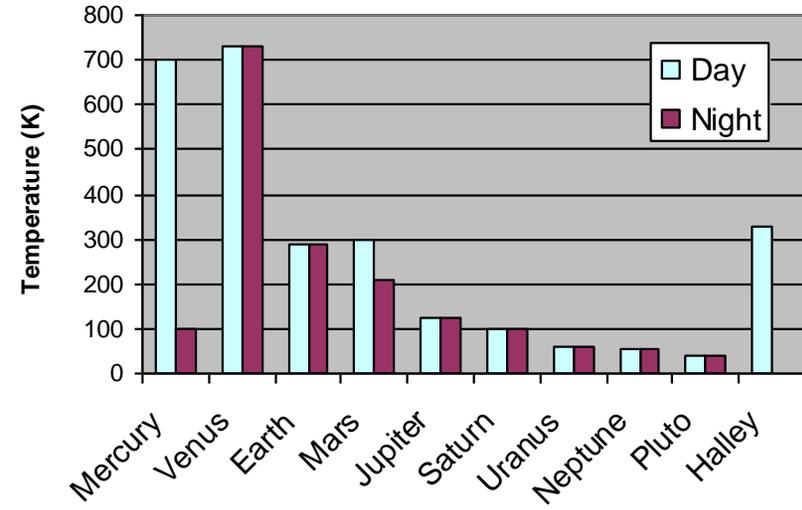
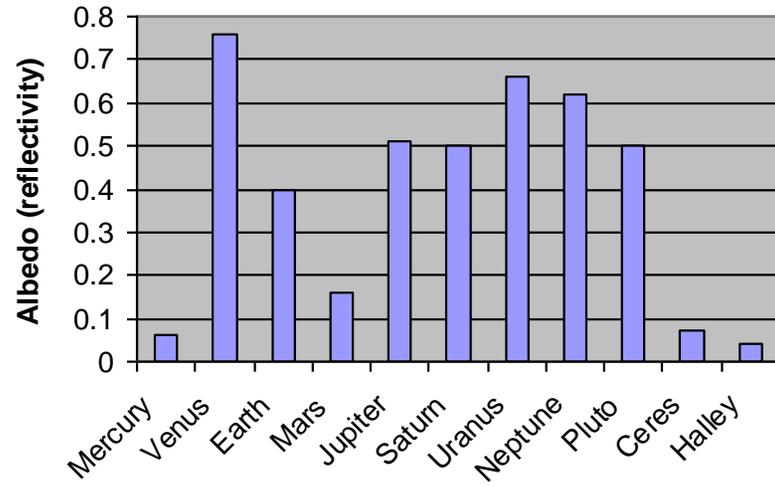
Physical Data



Rotation



Temperature



Lab 8: Martian Craters

Astronomy 140

Due at the *beginning* of lecture a week from today

Name: _____

Date: _____

Partner(s): _____

In this exercise you will work in pairs to address the following:

- Which are the major Martian surface features?
- How do we estimate their ages?
- How can we understand some of their history and nature?

Maps of Mars

We will use 3 maps of Mars centered around the Equator and the North and South Poles. The maps are color coded for **elevation**: blue means *low*, red and white mean *high*. Be very careful not to mark them in any way.

Exercise

1. (10 points) Find the approximate Martian central **latitude** and **longitude** of the following surface features and count the number of craters there:

Surface Feature	Central Latitude	Central Longitude	No. of craters
The tall volcanoes in the Tharsis region			
The huge, deep Hellas impact basin in the south			
The gigantic Valles Marineris canyon			
The icy North polar cap			

2. (10 points) Pick at least 6 delineated portions of the map to **identify** and **count** craters. Enter the **number of craters** you counted in the table for the latitude **range** of your measured boxes. Don't repeat other groups' data whenever possible. We will record the longitude ranges only in class to ensure we don't repeat measurements.
3. (5 points) Enter the crater counts of **all groups** into your table.
4. (5 points) Estimate the **average** number of craters at each latitude and calculate the **relative crater density** by multiplying your crater count by the given factor. You may choose to ignore certain **unusual regions** in a particular latitude range.

For the following questions, note that these same maps are in your book on page 173 and also at http://ltpwww.gsfc.nasa.gov/tharsis/Mars_topography_from_MOLA.

Please answer all questions on a separate sheet.

5. (5 points) Is there a noticeable difference in the crater density from North to South on Mars? Please describe.
6. (5 points) Describe a **rough** area. Does it have few or many craters? Is it at high (red/white) or low (blue) elevations? Is it in the southern or northern hemisphere?
7. (5 points) Describe a **smooth** region in the same way.
8. (5 points) Do the regions you identified in the table in #1 have many or few craters? Please explain why or why not keeping in mind the **natures** of these features.
9. (5 points) Based on *your data*, do you think the meteorite that created the **Hellas** impact basin hit early or late in Mars' bombardment period? Please explain.
10. (5 points) Many astronomers think Mars may have had an **ocean** in its past. Where do you think that ocean would have been and why? Explain your answer based on **crater density**, surface roughness and the thickness/height of the crust (continents are where the crust is thick and high, oceans are where the crust is thin and low).

Latitude range	All crater counts	Average*	× factor	Crater density
85/90			0.127	
80/85			0.128	
75/80			0.130	
70/75			0.134	
60/70			0.633	
50/60			0.700	
40/50			0.811	
30/40			1.000	
20/30			1.357	
10/20			2.217	
0/10			6.582	
0/-10			6.582	
-10/-20			2.217	
-20/-30			1.357	
-30/-40			1.000	
-40/-50			0.811	
-50/-60			0.700	
-60/-70			0.633	
-70/-75			0.134	
-75/-80			0.130	
-80/-85			0.128	
-85/-90			0.127	

* You may choose to omit certain unusual counts (like those over volcanoes etc.).

Lab 9: Stellar Classification

Astronomy 140
Due *with* Lab 10.

Name: _____

Date: _____

Partner(s): _____

In this exercise you will work in pairs to address the following questions:

- How do we classify the different types of stars?
- What are the important features in stellar spectra?
- What data are used to classify stars?
- Is there a wide variety of stars in a stellar cluster?
- What properties vary the most?

Contemporary Laboratory Exercises in Astronomy (CLEA)

The CLEA VIREO software you will use today is fun, powerful and instructive. We will work with these labs for the rest of the semester.

Getting Started:

- Click the **VIREO** icon on the desktop or from the Start menu.
- Click File and “Log in...”
- Enter your name and click OK (ignore the table number entry)
- Click File, Run Exercise..., “**Classification of Stellar Spectra**”
- Click **Telescopes**, Optical, Access 4.0 Meter (*not* 0.4 Meter)
- Open the dome by clicking the Dome **Open** switch. At this point you may want to turn the volume down – the dome’s very noisy! Then click the **Telescope Control Panel** button, which currently reads “Off.”
- You’ll see that the stars are shifting to the west as the Earth rotates. You must turn on the tracking system by clicking the **Tracking** button to track the sky before taking any data.
- Now we need to point at our target, the **Pleiades** star cluster. We will work with this star cluster again next time. Click Slew, Set Coordinates..., and enter for **Right Ascension**: 3 Hours, 47 Mins, 24 Secs; and for **Declination**: 24 Degs, 7’, 0”. The bright Pleiades cluster should be in view (verify the coordinates at the bottom).
- Use N, S, E and W to move the spectrometer aperture (the little red box) to stars in the field.
 - The **Slew Rate** controls how fast you can move the telescope (slew) in those directions.

Taking Measurements:

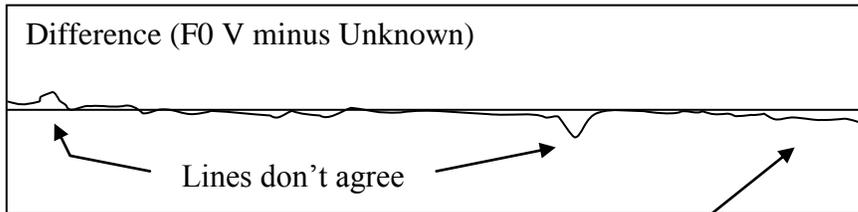
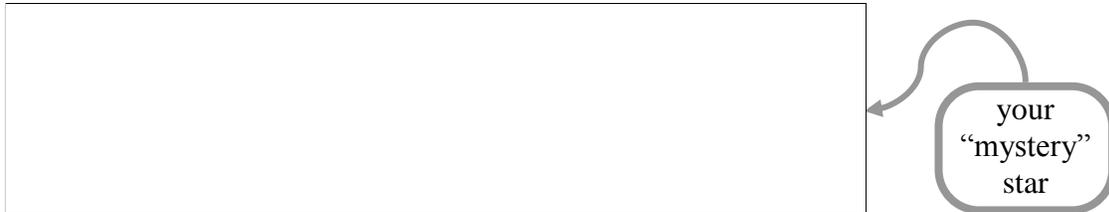
- Slew to a star you wish to study. Switch the **View** from Finder to Telescope to zoom in on a particular region to get a close-up view. Slew again until the spectrometer slit (the two small parallel lines) is centered over the star you want.
- Click the Instrument (Spectrometer) **Access** button and the Go button to obtain your spectrum.
 - Staring at a star is an *integration* in astro-speak. Fainter stars require a longer integration to achieve the same sensitivity, or **Signal to Noise Ratio**, as bright stars.
 - Sometimes for a bright star, the system will stop quickly since an enormous signal-to-noise is reached right away.
 - Integrate until you exceed a signal-to-noise of at least **50**. Click **Stop** to stop integrating once above 50 or so.
- Now save your spectrum by going to File, Data, **Save Spectrum...** Note that the file name is automatically given the object name, and this will make it easy to pull up later when you classify the star.
- **Record** in the table the **Object** name and **Apparent Magnitude (V)**, from the VIREO Reticon Spectrometer Reading window, as well as the coordinates (**Right Ascension** and **Declination**) from the VIREO Optical Telescope Control Panel window.
- You may now go back to the Telescope Control Panel and observe a new star. If you like, you may classify stars as you go, following the instructions on the next page.
- Obtain the spectra of *at least 20* stars.
 - Get a smattering of bright *and* faint stars of various spectral types.
 - Note carefully the object name to avoid repeating any stars and wasting a lot of time.
 - You do not need to exit the Spectrometer window or Classification window to observe a new star from the Control Panel.

Classifying stars:

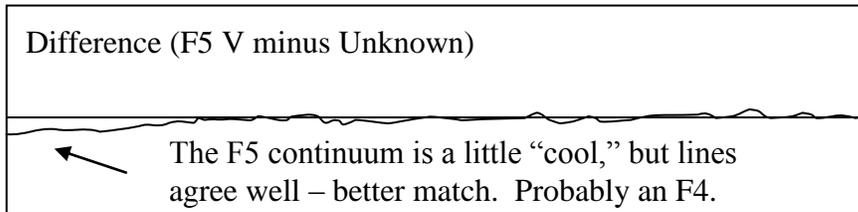
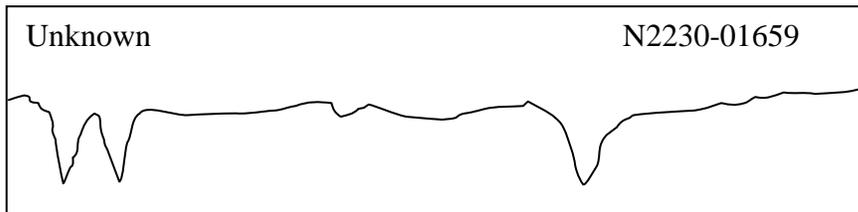
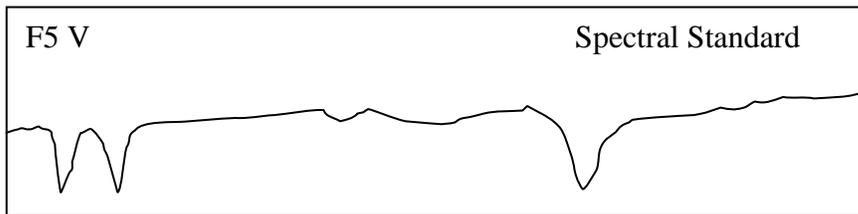
We will use these data again next time, so it is important that you've **recorded** the coordinates (positions) and brightnesses (V magnitude) of the stars you observe today.

- Go back to the main VIREO Exercise window to Tools, **Spectral Classification**.
- Load your data by going to File, Unknown Spectra, and Saved Spectra (*.SSP)... and choose a star you observed.
 - The star's spectrum will appear in the center panel along with its name.
- Go to File, Atlas of Standard Spectra, **Main Sequence**
 - Click in the Standards panel to compare the spectra; the arrow keys work in here too. There are two parts to a spectrum:
 - Continuum (recall Wien's law)
 - Absorption lines (recall Kirchhoff's third law)
 - It's more important to match the *spectral lines* than the continuum. See the sample sketches provided.
 - Estimate spectral types in between what's available if the match isn't perfect.
 - You may adjust the way spectra are displayed in File, Display. Play around. Choosing **Show Difference** is very useful – and strongly suggested – for comparing the sample spectra to the observed one.
- It's possible that no main sequence spectrum matches well (especially for a bright star of type G to M with very narrow lines). In that case you may want to try the giant star spectra around the luminosity of the best matching main sequence star.
 - Go to File, Atlas of Standard Spectra, and choose a star type (Luminosity).
 - Be sure to go back to the main sequence atlas for the next star.
- **Record** the star's information in the table under **Assigned Classification**.
- If you want to take more data, just go back to the Telescope Control Panel and pick another star. You don't have to close any open windows.

Example for determining spectral type:



and an F0's continuum is a little "hot"
– poor match.



Lab 10: The Hertzsprung-Russell Diagram

Astronomy 140

Due at the *beginning* of lecture one week from today

Name: _____

Date: _____

Partner(s): _____

The Hertzsprung-Russell (H-R) Diagram is one of the most powerful tools in all of astronomy. In this exercise you will work in pairs at the computer to create an H-R Diagram of the Pleiades cluster and answer the following:

- How do we identify the important stellar families?
- How are the stars in a cluster physically related?
- What other information does the H-R diagram give us?

Contemporary Laboratory Exercises in Astronomy (CLEA)

The CLEA VIREO software you will use again today is fun, powerful and instructive.

Getting Started:

- Click the **VIREO** icon on the desktop or from the Start menu.
- Click File and “Log in...”
- Enter your name and click OK (ignore the table number entry)
- Click File, Run Exercise..., “**Photoelectric Photometry of the Pleiades**”
- Click **Telescopes**, Optical, Access 4.0 Meter (*not* 0.4 Meter)
- Open the dome by clicking the Dome **Open** switch. At this point you may want to turn the volume down – the dome’s very noisy! Then click the **Telescope Control Panel** button, which currently reads “Off.”
- You’ll see that the stars are shifting to the west as the Earth rotates. You must turn on the tracking system by clicking the **Tracking** button to track the sky before taking any data.
- *Unlike last time*, we will point toward stars by inputting their **coordinates** from your table from last time.
 - Click Slew, Set Coordinates..., and enter the **Right Ascension** and **Declination** of a star from your table from Lab 9. The bright Pleiades cluster should once again be in view (verify the coordinates at the bottom).
- Switch the **View** from Finder to Telescope to zoom in and get a close-up view.
- If needed, use N, S, E, & W to center the aperture (the little red circle) over your star.
 - The **Slew Rate** controls how fast you can move the telescope (slew) in those directions.

Taking Measurements:

- Combine your star list with that of your partner (you should be working with someone new to extend your lists).
- *Before* you can measure the brightnesses of the stars, you must first measure the brightness of the **sky**.
 - Slew (using the N, S, E and W buttons) so the photometer aperture (the small red circle) covers no star, only **blank sky**.
 - Without measuring the sky, when you measure a star, the Magnitude window will tell you, “ERROR!” Also the “Mean Sky” window will indicate “No Sky!”
- Click the Instrument (Photometer) **Access** button to open the Photometer Control window.
 - **VERY IMPORTANT!!!** We want the **B filter** for our measurements. We already have the V (visual, yellow-green) magnitudes of these stars from last time.
 - Set the **Filter** slider to B (for blue).
 - The **Object** should be Sky.
 - One integration of 10 seconds is appropriate. Adjust those sliders.
- Click **Start**. When it finishes, you’ve successfully calibrated your photometer to give you magnitudes rather than incomprehensible counts values. You only have to do this once, and you should not to record the sky measurement in your table.
- Now that you’ve calibrated your photometer, go back to the telescope control window, slew to your star, and then click **Access**. Flip the **Reading** setting from Sky to **Object**.

(30 points)

- Obtain the B magnitudes of **at least 30** stars.
 - Check the Object name to verify you’re observing the intended star.
 - **Record** the data in the **table** under the column for B Magnitude (you don’t need to record the data in VIREO, but there’s no harm in doing so).
- A very bright star may overload the detector and it will tell you to lower the integration time. When you finish with this star, be sure the next star is read with a 10 second integration time again.
- Return to the telescope window and Slew to the coordinates of the next star. You may need to flip the Reading switch to reset the Object.

Creating the H-R Diagram

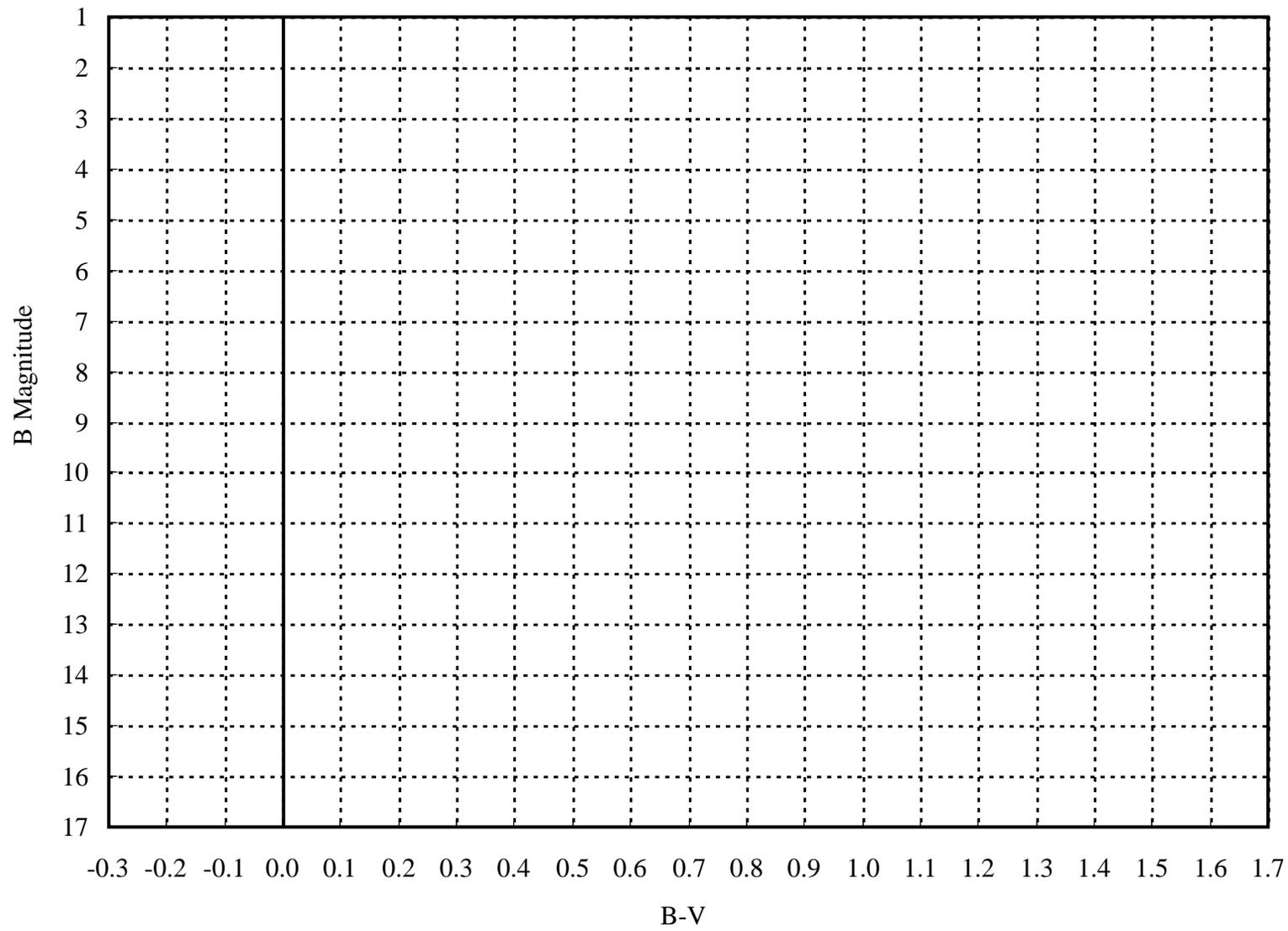
- (5 points) Calculate the difference B-V. Write it in the table.
 - This value indicates the **color** of the star. Recall that Wien's law says you know the temperature of a star from its color.
 - A high B-V means the B magnitude is bigger, in other words, the star is *fainter* in the blue. So a star with a large B-V is *red* or *cool*.
 - In contrast, a star with a low B-V is *blue*, or *hot*.
- (20 points) Plot the B magnitude versus B-V on the graph provided.
 - Recall that a small magnitude means that the star is bright, so the y-axis is upside-down, that is, with small magnitudes near the top.
 - Be very careful with your decimals!!* Values like 0.01 and 0.1 are different!
- (10 points) Label each star with its spectral type on the graph.

Congratulations, you have just made an H-R diagram. Technically, astronomers call this a color-magnitude diagram, since that's what is plotted.

Questions

(Answer on a separate sheet as necessary.)

- (5 points) Identify the main sequence and any other interesting features in your H-R diagram. Label/identify/draw them completely and clearly on your H-R diagram.
- (10 points) Are blue stars (small B-V) generally brighter or fainter? Is this expected? Why or why not? (Recall that brightness is related to luminosity.)
- (5 points) Are there any red giants in the Pleiades cluster? How would you find them?
- (5 points) Do you think all the stars you observed are really in the cluster? That is, could any of them be just foreground or background stars? How could you tell?
- (10 points) Do the spectral types match the colors and positions on the H-R diagram as expected? Explain. (Discuss any stars that don't seem to fit. Do you trust your classifications? Are any classes very narrow or broad in B-V?)



Exercise: The H-R Diagram

Astronomy 140

In-class exercise not to be turned in.

Name: _____

Date: _____

Partner(s): _____

The H-R diagram is one of the most important tools in astronomy. In this exercise you will work in small groups to answer the following:

- How are different stellar types identifiable from their position on the HRD?
- What are the temperatures of most stars?
- What are the luminosities of most stars?
- What are the sizes of most stars?
- What are the masses of most stars?

The H-R Diagram

As discussed in class and shown in Chapters 16, 18 & 19, the H-R diagram plots a star's **luminosity** (L) against its **temperature** (color or **spectral type** – O B A F G K M). Today you will plot these values for the nearest and brightest stars in our sky, which are listed in the attached tables. Note that a few of the brightest stars are also among the closest.

- Use the grid provided to plot the data. Use an “x” (×) to label the stars from the table of **brightest stars** and use a dot (•) for the stars on the **nearest stars** table.

Brightest Stars (×)		
Star	Spectral Type	Luminosity (Sun = 1)
Sirius	A1	23.5
Canopus	F0	1,510
α Centauri	G2	1.56
Arcturus	K2	115
Vega	A0	55
Capella	G8	166
Rigel	B8	46,000
Procyon	F5	7.65
Betelgeuse	M2	14,000
Achernar	B5	219
Hadar	B1	3,800
Altair	A7	11.5
Acrux	B1	3,470
Aldebaran	K5	105
Spica	B1	2,400
Antares	M1	5,500
Pollux	K0	41.7
Fomalhaut	A3	13.8
Deneb	A2	50,000
Mimosa	B1	6,030

Nearest Stars (●)		
Star	Spectral Type	Luminosity (Sun = 1)
Sun	G2	1
Proxima Centauri	M5	0.00006
α Centauri	G2	1.56
Barnard's Star	M5	0.0005
Wolf 359	M8	0.00002
Lalande 21185	M2	0.006
UV Ceti	M6	0.00006
Sirius	A1	23.5
Ross 154	M5	0.0005
Ross 248	M6	0.0001
ε Eridani	K2	0.3
Ross 128	M5	0.0004
61 Cygni	K5	0.08
ε Indi	K5	0.14
Grm 34	M1	0.006
Luyten 789-6	M6	0.0001
Procyon	F5	7.65
Σ 2398	M4	0.003
Lacaille 9352	M2	0.01
τ Ceti	G8	0.46

Exercises & Questions

2. Indicate/label the main sequence and the giant stars on the H-R diagram.
3. Is the Sun a main sequence or giant star?
4. Where on the H-R diagram are most of the stars from the *bright stars* list?
5. From their position on the H-R diagram, describe the typical bright star (general luminosity, size, temperature, etc.).
6. Where on the H-R diagram are most of the stars from the *nearby stars* list?
7. Describe the typical nearby star.
8. What fraction of *all* the stars is on the main sequence? (Count them.)
9. What fraction of the *bright* stars is on the main sequence? (Count them.)
10. Can we see many distant, red, *main sequence* stars? Why or why not?

Night Lab: The Sky & Constellations

Astronomy 140

Due at the *beginning* of lecture a week from today

Name: _____

Date: _____

Partner(s): _____

No amount of in-class work can replace direct observations of the night sky. In this exercise you will work in small groups to:

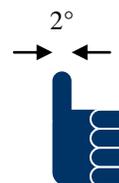
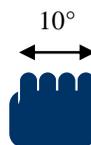
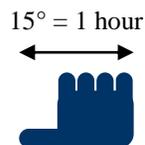
- Orient yourself to the night sky
- Demonstrate the practical use of the celestial sphere
- Identify the various constellations and other celestial bodies visible now

Introduction

The ancients believed the stars to be fixed upon a great crystalline sphere surrounding the Earth. Though we no longer share this view, the **celestial sphere** concept is still valuable in **navigation**, and it can be a practical model of one's universe. After all, everyone knows that in about 24 hours, the stars, Sun and Moon all rise in the east and set in the west. In this lab, you will locate constellations and estimate your location on the Earth from them as well.

Angular Distances and Time

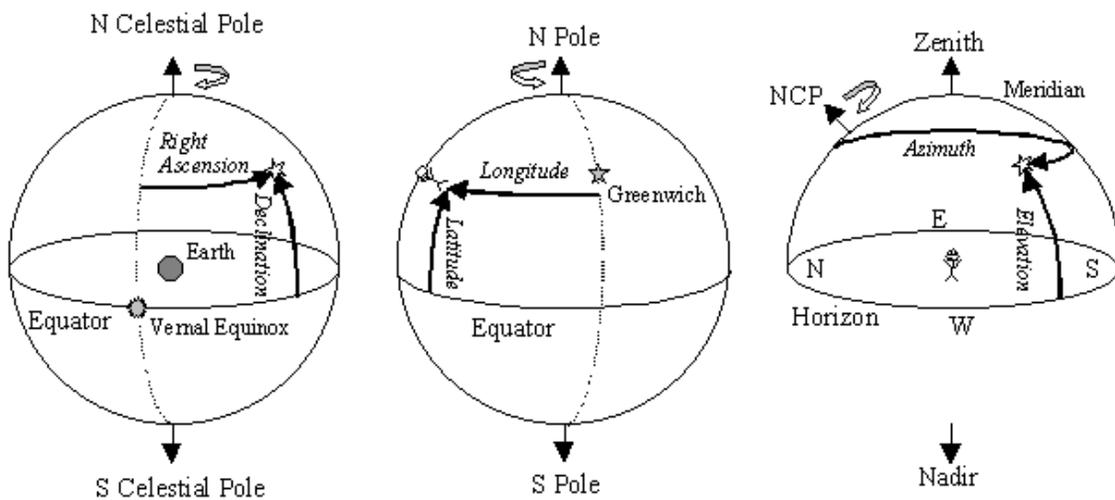
Since the sky appears spherical, astronomers measure distances in the sky as **angles**. For example, from east to west is 180 degrees and from the horizon to zenith is 90 degrees. Notice that the sky rotates a full 360° in 24 hours, or **15 degrees/hour**. With your arm extended, the apparent length of your fist with thumb raised is roughly 15 degrees, or an hour. Your fist alone (across the knuckles) is about 10 degrees. The width of your thumb held at arm's length is 1 to 2 degrees.



Celestial, Terrestrial and Local Coordinate Systems

Three coordinate systems must be defined to predict the height of a star above the horizon: the **celestial**, based on stellar positions; the **terrestrial**, using Earth-based positions; and the **local** system, centered on you, the observer. The three systems are summarized below.

- Celestial
- **Right Ascension** is measured east of the vernal equinox in hours, minutes, and seconds of time (0 to 24 hr).
 - **Declination** is measured north or south (+/–) of the celestial equator in degrees, minutes and seconds of arc (-90° to $+90^\circ$).
- Terrestrial
- **Longitude** is measured east or west of Greenwich, England in degrees, minutes and seconds of arc (180° W to 180° E).
 - **Latitude** is measured north or south (+/–) of the Earth's equator in degrees, minutes and seconds of arc (-90° to $+90^\circ$).
- Local
- **Azimuth** is measured from due north – your meridian – towards due east, along the horizon in degrees, minutes and seconds of arc (0° to 360°).
 - **Elevation** is measured up from the horizon in degrees, minutes and seconds of arc (0° to 90°).



Exercises

1. (5 points) Find a bright celestial object near transit (and away from the Pole) and estimate its **elevation and azimuth**. Record the values here, and refer to them at the end of the lab. Be sure to also include the time of the measurement.

Elevation of _____ = _____ degrees at _____ o'clock

Azimuth (circle one): E---ESE---SE---SSE---S---SSW---SW---WSW---W

2. (10 points) Find the **North Celestial Pole**, which is very near Polaris, the North Star. Polaris is a faint blue star at the end of the Little Dipper's handle. It lies due north, roughly 45 degrees above the horizon. Using the protractor device provided, measure the elevation of Polaris. Make a few observations and have your partner(s) do some also. Average the values to get a final answer.

Average elevation of Polaris = _____ degrees.

What is your latitude? _____ degrees.

Identifying Constellations

3. (10 points) Looking north, sketch the orientation of the **Big Dipper** and/or **Cassiopeia** with respect to the horizon and Polaris.



West

North

East

Horizon

4. (8 points) Following your instructor, identify at least 6 other constellations. List them here. Put a check mark in front of those belonging to the **Zodiac**.

1	5
2	6
3	7
4	8

5. (2 points) If any **planets** or the **Moon** were visible, list them and in which constellations they were found. Are these constellations on the Zodiac?
6. (10 points) Pick one constellation and **sketch** it in some detail on the next page. Use larger dots for brighter stars. *Do not refer to a book.*
7. (15 points) Research an interesting object in this constellation (mythology, star, nebula, galaxy, etc.). On a *separate page*, describe it in roughly **100 words**. Include your reference source(s).
8. (5 points) Measure again the elevation and azimuth of the object you observed previously.

(5 points) Did it move? In what **direction**? What is the difference in the values? What is the difference in the **times** of your observations? Compare this with how far the object moved. Is it close to the expected rate of 15 degrees/hour?

Elevation of _____ = _____ degrees at _____ o'clock

Azimuth (circle one): E----ESE---SE---SSE---S---SSW---SW---WSW---W

Sketch your constellation below.