Montana State University
Physics 312 Lab Manual

MSU Physics Department

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Introduction

Welcome to Physics 312 lab. This lab manual is meant to compliment the Physics 311 manual. Physics 312 covers different astronomical subjects than 311; the labs here will reflect the material from 312. If you have interest in basic astronomical observation or in the solar system, you should take 311 and the corresponding lab.

In the 311 lab, you have the opportunity to do nighttime observation with the department telescopes. During the course of the 312 lab, you will be doing some daytime observations including solar studies with special filters and telescopes. You will be given at least one opportunity to do night observing. Of course you cannot depend on clear weather every time lab meets, so many of the labs in the manual will be done indoors.

Although this manual was written to coincide with the 312 course as well as possible, the work you do in lab may be on a subject matter not yet covered in class, or have been covered a while back. The labs will hopefully stimulate your interest and increase your understanding of the concepts introduced in your coursework. Most of the information you need to complete the labs will be given to you. Sometimes, you may need to reference your text or the Internet. Also, you will be using computers and computer software in many labs. If you need help understanding any of the labs or concepts therein, please talk to your lab instructor about attending his or her office hour or setting up a separate time to meet.

Grading

As in the 311 lab, grading for this lab class is based on a total number of points. Once you have all of your points, you can choose to be done with lab. Feel free to complete more labs to enhance your understanding of the 312 subject areas or to participate in telescope observation. Grades are as follows:

110 points = A
100 points = B
90 points = C
80 points = D
Less than 80 points = fail lab

It will be very easy for you to get an A in this lab. Each lab is worth ten points, unless you complete the extra credit that follows some of the labs. The points given to you for the extra credit is determined by your lab instructor. If you do well on your labs for just twelve weeks, you'll have an A.

Unlike the 311 lab, there are no required labs for 312. You choose the labs you would rather complete. Each week during your lab meeting, your instructor will choose one lab to teach, usually the one corresponding to material the course instructor is currently covering. The smoothest way to get your A is to come each week to lab, and do the lab the instructor is teaching. Some of the labs in the manual will be impossible to do on your own, but many of them will be doable whenever you choose. Hopefully this will give you enough flexibility to gain exactly what you want from the laboratory work.

Telescope Operating Instructions

•The Telescopes

There are ten Schmidt-Cassegrain telescopes available for your use; four Meade 8", four Celestron 8", and two Meade 10". Each of these is mounted on a specific pier on the roof. Your lab instructor will demonstrate how to get a telescope from the store room and mount it on its pier.

A wedge is attached to the top of each pier so that the axis of the telescope mount will point to the north celestial pole. This saves a lot of time that is normally spend aligning a telescope. Simply mount the telescope on its wedge and you can begin viewing. **A telescope is an expensive instrument and should be handled with the care appropriate to such a fine instrument.**

•Magnification

The 8" telescopes have focal lengths of 2000 mm; while the 10" have a focal length of 2500 mm. Different magnifications may be obtained by using the different eyepieces available. The magnification may be found by dividing the focal length of the telescope by the focal length of the eyepiece, or ocular. For example the magnification for an 8" telescope with the 40 mm ocular is 2000/40 = 50x and with the 25 mm ocular it is 2000/25 = 80x. Therefore, objects will appear larger when you use smaller diameter oculars.

Generally it is a good idea to begin with the 40 mm ocular. The smaller magnification lets you see more of the sky, making it easier to locate objects. After you find the object, you can try larger magnifications. However, bigger is not necessarily better! Other factors also contribute to your ability to see the object. If you are looking at a planet, large magnification may produce a very good image if the seeing (atmospheric steadiness) is good, but deep sky objects may look better using a lower magnification. You should experiment with several magnifications to see which one yields the best view.

•Aiming a Telescope

The telescopes are mounted on wedges so that the two motions of the telescope are along the direction of right ascension and declination (If you don't know what these words mean, see Appendix A.). This allows you to track a star or other celestial object with one of the motions - right ascension - as the earth turns. The star can be tracked by hand or with the electric motor built into the base of the telescope.

Each axis of the telescope is provided with a clamp to hold it in a given orientation. **It is very important to release these clamps before you manually change the telescope alignment**. The right ascension clamp is the lever located on the base of the fork mount. The declination clamp is the lever at the top of the left hand fork tine.

Small adjustments of the telescope alignment can be made with the slow motion controls. These knobs work with the declination clamp tightened all the way and the right ascension clamp finger tight. The slow motion knob for right ascension is located next to the clamp at the base of the mount. The declination knob is located inside the base of the left hand fork tine. Be careful that the bar on the inside of the left fork tine is not all the way to one side or the other. If it is, use the declination slow motion control to move it to the center. This will allow you to adjust the declination in either direction.

The finder scope is located on the side of the barrel of the main telescope. This can be used to aim the telescope at the brighter objects in the sky. The eyepiece slides into the diagonal mirror and is held in place by a screw knob on the side. The diagonal mirror can be adjusted to an angle to minimize the contortion needed to look through the ocular.

The focus knob is located near the eyepiece and is parallel to the axis of the telescope . You will normally need to adjust it to obtain the clearest view of an object. When you change oculars, you will need to make significant changes in the focus.

The location and uses of the clamps, knobs, and other devices will be demonstrated by your lab instructor. You must demonstrate your knowledge of these location and uses before you use the telescope.

Night Obvserving

•Introduction

No astronomy lab is complete without an opportunity to do some telescope observing. In this class, most of the labs are such that they require you to be indoors, not out looking through an eyepiece. For this lab, however, you will have the chance to visit the roof of AJM to observe some of the fascinating sights above. Your lab instructor will set a couple of dates for everyone to come in the evening after the sun sets. If you cannot make the set dates, talk to you lab instructor. This lab, like all of the labs in this manual, is not required (you simply need to obtain 110 points in the lab class).

•Credit

Your lab instructor will set up a few telescopes on the roof of AJM. Read the ***Telescope Operating Instructions*** on page four of this manual before heading up to the roof. During the course of the observation session the instructor will show you a variety of celestial objects. In the spaces provided below, draw what you see. Make sure to mark down the type of telescope and eyepiece you made your observation with.

Telescope:

Eyepiece:

Telescope:

Eyepiece:

Telescope:

Eyepiece:

Taylor Planetarium

•Introduction

Visits to a planetarium can be very helpful in developing an understanding of the motions of the celestial objects. We are very fortunate in Bozeman to have access to the Taylor Planetarium at the Museum of the Rockies. In addition to the main attraction that is currently playing, the Museum offers a current sky program that is a live presentation of what is happening in the night sky.

Information about the planetarium shows and their times is available from the Museum or your lab instructor.

•Credit

To receive credit for attending a planetarium program, you must write a critical review of the presentation. The review must be typewritten, double spaced, and a minimum of two pages long.

Each critical review of a planetarium visit is worth 10 points. You may receive credit for a maximum of two reviews during the semester.

Luminosity

•Materials

Solar cell with leads
Voltmeter
Ammeter
1-Ohm resistor
Calculator

•Introduction

In this lab, you will make an order of magnitude estimate of the sun's luminosity. **Luminosity** is the amount of light energy a star emits each second. We will measure the luminosity in watts, one watt = 1 joule per second.

To find the luminosity, we first need to think a little about geometry. Picture a series of concentric hollow spheres with the sun at the center. The farther away the sphere is from the sun, the larger its surface area. The surface area of a sphere is $4\pi r^2$, where r is the radius. On Earth, we do not receive the total amount of light emitted from the sun every second. We receive only our surface area divided by the surface area of the sphere at 1 AU. The surface area of this sphere is $A_E = 4\pi d^2$, where the radius of the sphere reaching from the Sun to Earth is d = 1 AU = 1.5×10^{11} m. In this lab, we will be collecting sunlight on a small solar cell, and will need to account for it's surface area size in comparison with the surface area of solar irradiance at Earth's distance, A_E.

The quantity we'll actually be measuring is brightness, the amount of energy that passes each second through a square meter of A_E.

$$b_o = L_o/4\pi d^2 \qquad (1)$$

To recover L_o from our measurement, we'll multiply b_o by $4\pi d^2$. Find the numerical value for A_E, and complete the equation below.

$$L_o = \_\_\_\_\_\_\_\_\_\_\_\_\_\_ \; b_o \qquad (2)$$

The next detail we must consider is the size of our solar cell. Above, we accounted for measuring light energy in one square meter of the whole surface area A_E. In reality, we are not measuring even one square meter, unless we had a large solar cell that was 1 m by 1 m.

So we need to know how much of a square meter our solar cell is, and account for it in our luminosity calculation. For example, if our solar cell is 5 cm by 5 cm, it's total area is 0.05m x 0.05m = 0.0025 m^2. To get the brightness, watts per m^2, we need to multiply our measured value for power by 1/0.0025 = 400. If M denotes our measured value, and A is the area of our solar cell in *meters*,

$$b_o = (1/A) \times M \qquad (3)$$

The next factor to consider is the efficiency of the solar cell, how much power is put out over the power input. It is beyond the scope of this lab to measure the exact efficiency of the cell, so assume the solar cell has a 10% efficiency. To account for this, you need to multiply b_o by a factor of 10; the real power per square meter is ten times what you get as the output power.

$$b_o = 10 \times (1/A) \times M \qquad (4)$$

Okay, we now have the basic geometry of the problem down. Now, there is one more important factor to account for. If we could go into space and do this measurement, we would have all of the factors we needed. However, we are not in space, and there is a dense atmosphere between us and the pure solar light energy. There is a whole field of science that measures the amount of light we receive on the ground for various weather and atmospheric conditions. Here, if it is a sunny day, simply assume that you receive just 10% of the total amount of sunlight that is radiated upon the Earth *above* the atmosphere. So we must multiply b_o by another factor of 10,

$$b_o = 10 \times 10 \times (1/A) \times M. \qquad (5)$$

Finally you have all of the tools you need to make an order of magnitude calculation of the luminosity of the sun.

•Procedure

This experiment should be conducted outdoors on a sunny day.

1) Obtain a solar cell, two digital multimeters (each with a black and a red connection wire), and one 1 Ohm resistor from your lab instructor.

2) Hook up your solar cell according to the instructions on the next page.

3) Take your cell outside, and point it in the direction of the sun.

4) After waiting a few moments for the readings to become stable, make several measurements of the output in Amps and Volts.

5) Back inside, calculate the power ouput of your solar cell:

Power = Amps x Volts (6)
(Power = current x voltage)

6) This power of the solar cell is the M in equation (5). Plug in your value and write the answer here:

b_o = 10 x 10 x (1/A) x _______________

b_o = ________________

7) Now you're ready to find your luminosity estimate. Use equation (2) and your value of b_o above to calculate L_o

$L_o = 4\pi d^2 b_o$ = ________________

8) Compare your answer to the actual value of about 4 x 10^{26} W. What is your percentage error?

% error = (|actual-measured|/actual) x 100.

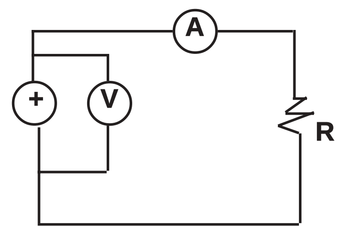
% error = ________________

9) Where do you think your error came in? How could you measure the luminosity more correctly?

For credit, turn in your calculations, measured values and answers to all questions posed.

•Directions for hooking up your solar cell

As a guide, look at the circuit diagram below. If you have trouble connecting your circuit, ask your lab instructor for assistance.



a) The symbol with the + sign refers to the solar cell. It is your power source. Attach the red lead from the solar cell to the mA (milliamp) setting on your ammeter. An **ammeter** measures current. The symbol A in the diagram above refers to the ammeter.

b) The symbol R is the 1-Ohm resistor. Attach the black (ground) ammeter connector to one end of the resistor.

c) Attach the other end of the resistor to the black lead from the solar cell.

d) V in the diagram refers to the voltmeter. A **voltmeter** measures volts. Attach the two connectors from the voltmeter, with the red connector in the millivolt setting, one to each solar cell lead.

e) Your circuit is now set up. Both meter's black connectors should be plugged into ground (COM). If you have trouble getting a reading, try checking the order of your circuit - you might be registering negative values.

f) Remember when making your measurements to convert from milliamps and millivolts back to amps and volts.

Spectra I

•Materials

diffraction grating
helium lamp
oxygen lamp
hydrogen lamp
sodium lamp
mystery lamp

•Introduction

The figure below is an example of several spectra from each stellar **spectral class**. In each spectra, you can see not only what colors are emitted, but also dark lines, called **absorption lines**. The continuous spectrum is created by the hot glowing gas in the low-lying levels of the star's atmosphere. The absorption lines are created when this light flows outward through the upper layers of the star's atmosphere. Atoms in these upper layers absorb radiation at specific wavelengths, which depend on the specific kinds of atoms present. Scientists group stars with similar spectra into spectral classes. Above or below the diagram, label the following absorption lines:

1) Hα: red, strong in the mid spectral classes
2) He I: yellow, strong from O to K
3) Hβ: blue-green, strong from B5 to F5
4) Na I: yellow, strong in M
5) Hγ: blue, strong in B and A stars.

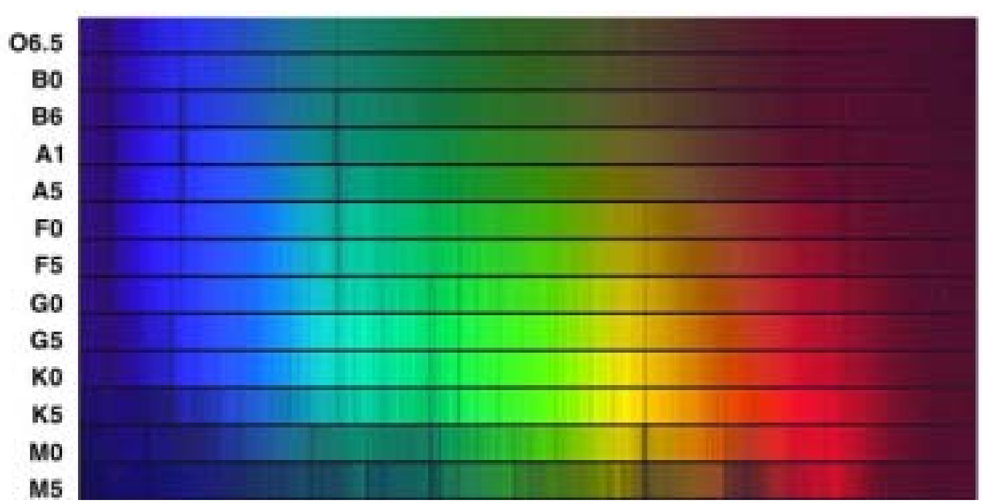
You may be wondering what the symbols α, β, and I refer to. Hα is the symbol for hydrogen alpha, the Balmer alpha electron transition for hydrogen. Similarly for Hβ, only the Balmer beta transition. Refer to your text for more information on energy level transitions. I refers to the fact that helium in this case is not ionized. He II is helium that has lost one electron, Fe IX has lost eight electrons, and so on.

A gas made of a certain element has its own characteristic absorption lines. In this lab, you will look at spectra from several gases, making detailed observations of the lines. This will prepare you for the next lab, Spectra II, where you will actually analyze the spectra of some stars and identify their chemical makeup by observing their absorption lines.

•Procedure

1) Your lab instructor has several gas lamps, one with helium gas, one with hydrogen gas, one with oxygen gas, one with sodium gas, and a mystery lamp (you have to guess what's in it). You will be given a diffraction grating, which works like a prism, spreading out the wavelengths of light. As the instructor turns on each lamp, hold the diffraction grating to your eye so you see a spread of colors. There are only two orientations for the diffraction grating, one that you will be able to see the bands and one you won't. Ask your lab instructor if you cannot make out the bands. Write or draw your observations.

2) Although each lamp cannot be on for more than about 30 seconds, your instructor will turn on each lamp several times. Draw in the absorption lines you see in the appropriate boxes on the following page.



Hydrogen

blue red

Helium

blue red

Oxygen

blue red

Sodium

blue red

Mystery

blue red

3) What is mystery lamp?

4) **Turn in your observations for credit.** Your instructor will return them to you for the Spectra II lab, where you will use them to help you identify the absorption lines of the stars you study.

Spectra II

•Materials

text book, computers

•Introduction

In this lab, you will analyze at the actual spectra of a few stars. Stellar spectra are the source of almost all information we have about stars and galaxies. See the Spectra I lab for more information.

•Procedure

1) On this and the following page are spectra from six different spectral classes of stars, O, B, A, F, G, and K. You might want to refer to the color table in the Herschel Experiment lab and the image in Spectra I to help you associate wavelengths with colors. By using the list of absorption lines below and the descriptions of the spectral classes, label the lines you see in each graph. Remember, the symbol I after an element indicates a neutral element, and II indicates that the element is singly ionized (has lost one electron). H**β** and H**γ** are the Balmer beta and gamma lines of hydrogen. Your lab instructor will go through the first one with you.

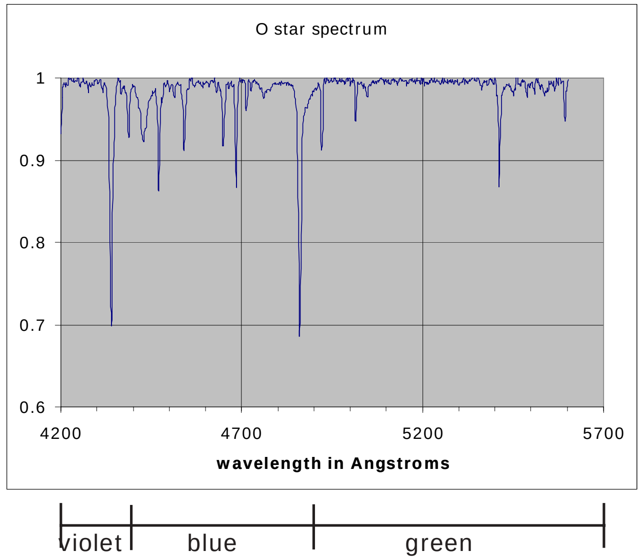
Chemical Name	Wavelength (Angstroms)
Fe I	4303
Hγ	4340
He I	4386
He I	4470
He II	4685
Hβ	4860
He I	4920

[1 Angstrom = 10^{-10} m]

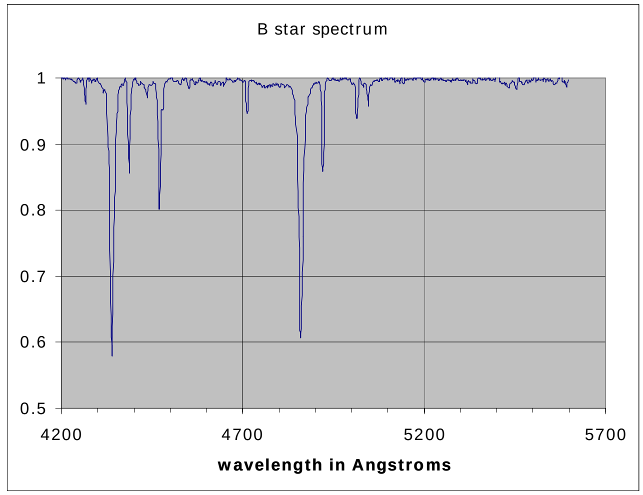
Spectral classes:

O - Ionized helium, weak hydrogen lines
B - Helium and hydrogen lines
A - Strong hydrogen lines
F - weaker hydrogen lines than A stars, Iron lines
G - neutral metals, even weaker hydrogen lines
K - neutral metals
M - molecules and metals

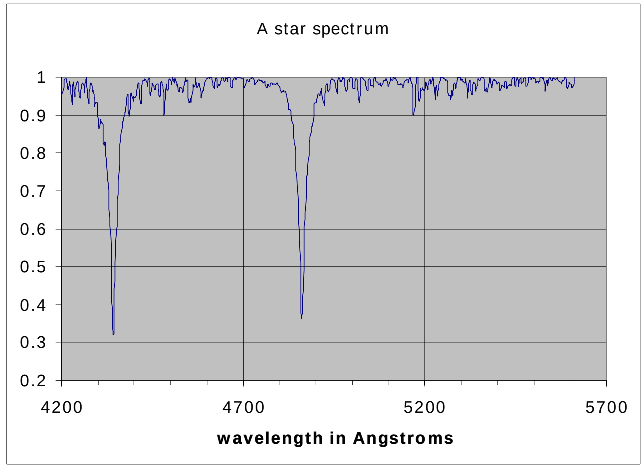
O Star



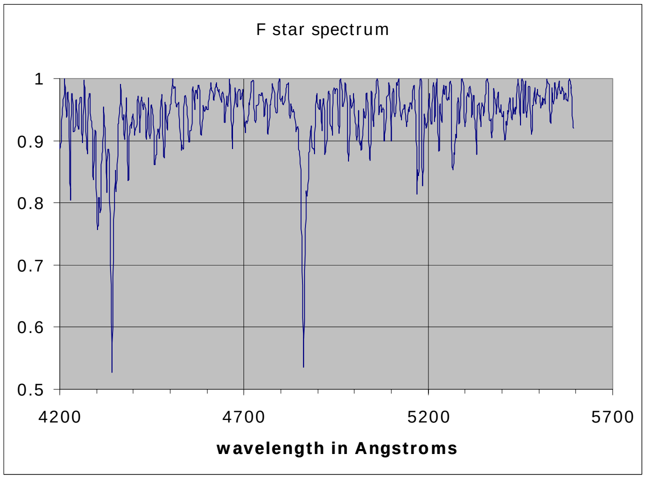
B Star



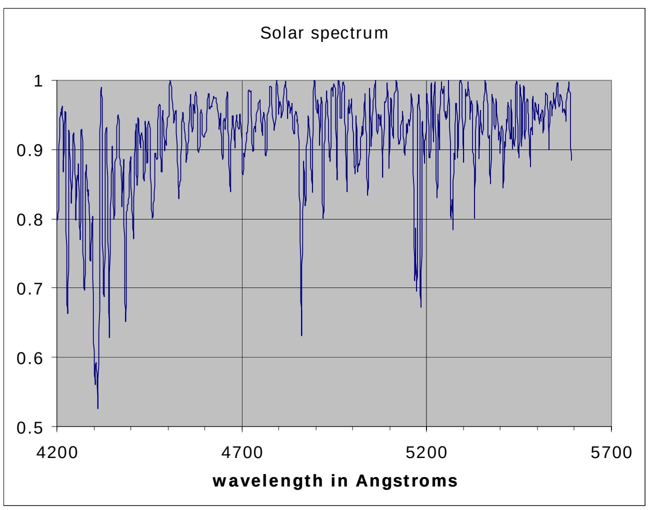
A Star



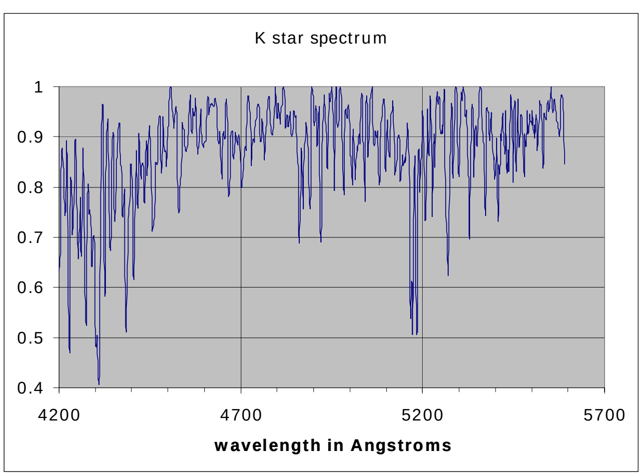
F Star



G Star



K Star



2) Turn on your computer. Open a web browser and go to the following site:
http://stellar.phys.appstate.edu
Choose any star you'd like and save the data. Open Excel, import the data, and make a plot like the ones in this lab. If you need help doing this, ask your lab instructor. What spectral lines do you observe in your plot?

•Questions

1) Which type of star is hotter, an O star or a G star?

2) Why do stars have hydrogen and helium absorption lines?

3) Why don't the cooler stars have strong ionized lines?

4) Why don't the stars that are more hot have metal lines? (Here, "metal" refers to any element heavier than helium).

5) How could you tell, from this data, if a star was moving relative to us?

6) What lines did you expect to see in the spectra, but didn't due to the fact that the spectra stop at about 5600 Angstroms? Make a list below for each spectral type, using your observations from the *Spectra I* lab for hydrogen and helium.

O -

B -

A -

F -

G -

K -

For credit, turn in your labeled spectra and answers to the questions.

Spectra obtained from data at stellar.phys.appstate.edu

Size

•Materials

Calculator

•Introduction

Stars, except the sun, are too far away to directly measure their radius. Therefore, astronomers use an indirect technique to estimate the size of stars. In this lab, you will use this technique to explore the variation of size in different types of stars.

The **Stefan-Boltzman law** describes how much energy is emitted per second per square meter of a blackbody's surface,

$$F = \sigma T^4, \qquad (1)$$

where F is energy flux, $\sigma = 5.67 \times 10^{-8}\ Wm^{-2}K^{-4}$ is the Stefan-Boltzman constant, and T is the surface temperature of the blackbody. This equation applies very well to stars, whose spectra are quite similar to that of a perfect blackbody. A star's luminosity is the amount of energy emitted per second from its entire surface. In the case of stars, we can safely assume a spherical emission surface with area $4\pi R^2$, where R is the radius of the star. The luminosity is therefore

$$L = 4\pi R^2 \sigma T^4. \qquad (2)$$

Since we are interested in finding the size of stars, we would like an equation expressing R in terms of the other variables. A useful way of expressing the numbers in this kind of problem is to use ratios referring to the sun. For the sun,

$$L_o = 4\pi R_o^2 \sigma T_o^4, \qquad (3)$$

where $L_o = 3.8 \times 10^{26}$ W, $R_o = 6.96 \times 10^8$ m, and $T_o = 5776$ K. Dividing equation (2) by equation (3) and solving for R/R_o, we get

$$R/R_o = (T_o/T)^2 (L/L_o)^{1/2}. \qquad (4)$$

We now have the tool needed to calculate the size of stars. In order to use this equation, we need two pieces of information for each star: the surface temperature and the luminosity. The surface temperature is determined by the spectral class. See the table below for the relationship between surface temperature and spectral class. *Remember, an A1 star is hotter than an A7 star.*

Spectral Class	Temperature (K)
O	30,000 - 50,000
B	11,000 - 30,000
A	7,500 - 11,000
F	5,900 - 7,500
G	5,200 - 5,900
K	3,900 - 5,200
M	2,500 - 3,900

To find the luminosity, we can use measurements of the absolute magnitude, M. Absolute magnitude is a quantity that describes the brightness of a star (see the Luminosity lab) and determines luminosity via the formula

$$M - M_o = 2.5 \times \mathrm{Log}(L/L_o). \qquad (5)$$

M_o is the absolute magnitude of the sun, and is equal to +4.8. We want to know the luminosity given the absolute magnitude, so we'll rewrite the equation in the form

$$L/L_o = 10^{(M_o - M)/2.5}. \qquad (6)$$

Notice that there is *not* an absolute value sign around $(M_o - M)$. It is important to use the correct sign for the star's magnitude, M, as very *bright stars have negative absolute magnitudes*.

•Procedure

Use equation (6), the table, and equation (4) to find the radii in terms of the solar radius for each star in the chart on the following page. To get temperature, make an estimate given the table above. For example, G2 star: (5900 K-5200 K)/10 = 70 so G2 = 5900 K - 140 K = 5760 K. Fill in the blanks in the chart as you go. Answer the questions in the section below.

•Questions

1) Are all of the stars in the chart that are hotter than the sun bigger than the sun?

2) Are all of the stars in the chart that are more luminous than the sun bigger than the sun?

Star	Spectral Type	Temperature	M	L/L_o	R/R_o
Alpha Centauri A	G2		4.4		
Arcturus	K2		-0.3		
Betelgeuse	M2		-5.6		
Capella	G2		0.0		
Deneb	A2		-7.1		
Proxima Centauri	M5		15.4		
Sirius	A1		1.5		
Spica	B1		-2.0		
Vega	A0		0.5		
Wolf 359	M6		16.7		

3) Do all stars with the same luminosity have the same size? Give an example.

4) Do all stars with the same temperature have the same size? Give an example

5) What, if anything, strikes you about Betelgeuse? What type of star do you think it is?

6) How does size vary with temperature (i.e. to what power does size depend on temperature)? How does size vary with luminosity?

7) According to equation (2), luminosity is related to temperature. How so? Does this explain your answer to question 5)?

For credit, turn in your calculations and answers to all questions.

The H-R Diagram

•Materials

Computer Program: Microsoft Excel or equivalent

•Introduction

The purpose of this lab is to give you a hands (and computer) on experience with the Hertzprung-Russell, or H-R diagram. A simple review of its characteristics will be given. For more information, please consult your textbook. A basic knowledge of Microsoft Excel is helpful.

•Basics: the H-R diagram

The H-R diagram is a plot of the **absolute** magnitudes of stars, M, versus their spectral type. Sometimes you will see the *y axis* in units of solar luminosity, L_o. Luminosity is directly proportional to absolute magnitude, and in this lab, we will use the absolute magnitudes of stars. Remember, the more negative an absolute magnitude, the BRIGHTER the star. We will also be using the **apparent** magnitude, m, of stars. The apparent magnitude refers to how bright a star appears to us on Earth.

The *x axis*, spectral type, is a measure of a star's surface temperature. Astronomers label spectral type with integers and letters, ranging from M10 (cool, red), to O0 (hot, blue). Note that a M7 type star is cooler than a M0 star, and that the order of letters from cool to hot is: M, K, G, F, A, B, O. The Sun is a G2 star with surface temperature of about 5800 K.

•Basics: Luminosity classes

In addition to classifying stars into spectral types, we group them into luminosity classes. A star with the temperature 5800 K might be a very luminous star (one with a negative value of M), or a dim star (large, positive M). Astronomers give groups of stars with similar luminosities special names.

For example, the brightest stars are called luminous supergiants and are labeled with the luminosity class Ia. The Sun is a main sequence star, class V. See the chart below for additional information.

Luminosity Class	Star Type
Ia	luminous supergiants
Ib	less luminous supergiants
II	bright giants
III	giants
IV	subgiants
V	main sequence

•Basics: Plotting and using Excel

Here are some tips and hints for plotting your data in Excel. The intent of these hints is not to teach you how to use Excel. If you have questions, see your instructor:

1) Convert your *x axis* values to numbers. For example, set B=0, A=1, etc. Then you can use G2=3.2, or K1=4.1, and so on.

2) In Excel, punch in your numbers for your *x* and *y axis*.

3) Make a scatter plot, including axis labels.

4) To get the correct *y axis,* with negative values at the top, click on the *y axis* in the plot you've already created. Go to "Format", "Selected axis", "Scale" tab. At the bottom, click "values in reverse order."
See your lab TA if you have questions.

•Create your H-R diagrams

A) Main Sequence Stars

Plot, in Excel or another graphing program, the stars in Table A. The curve that approximately connects these points is the main sequence; most stars lie on this line. As mentioned earlier, the main sequence stars are luminosity class V stars. Make a label in your plot that indicates this fact.

B) Giant Stars

Now plot the stars in Table B on the same diagram. These are giant stars, luminosity class III.

C) The Brightest stars in the sky

In a new diagram, plot all of the stars from Table A and Table C. In Table C, the roman numerals refer to the luminosity class, as in the table above. "M" is absolute magnitude, and "m" is apparent magnitude.

D) The Nearest stars in the sky

In another new diagram, plot all of the stars in Table D.

Table A

Star	Type	M
Sun	G2	+5.0
σ Per A	B0	-3.7
γ Cet	A2	+2.0
α Hyi	F0	+2.9
Kruger 60B	M6	+13.2
Procyon A	F5	+2.7
61 Cyg A	K5	+7.5
τ Cet	G8	+5.7
α Gru	B5	+0.3
Kapteyn's Star	M0	+10.8

Table B

Star	Type	M
Arcturus	K2	-0.3
Capella	G2	+0.0
Aldebaran	K5	-0.7
Pollux	K0	+1.0

Table C

Star	Type	M	m
Sirius	A1V	1.5	-1.4
Canopus	F0Ib	-4.0	-0.7
Rigil Kentaurus	G2V	4.4	-0.3
Arcturus	K2III	-0.3	-0.1
Vega	A0V	0.5	0.0
Capella	G2III	0.0	0.1
Rigel	B8Ia	-7.1	0.1
Procyon	F5IV	2.7	0.4
Betelgeuse	M2Ia	-5.6	0.4
Achernar	B5IV	-3.0	0.5
Hadar	B1II	-3.0	0.6
Altair	A7IV	2.3	0.8
Acrux	B1IV	-3.9	0.8
Aldebaran	K5III	-0.7	0.9
Antares	M1Ib	-3.0	0.9
Spica	B1V	-2.0	0.9
Pollux	K0III	1.0	1.2
Fomalhaut	A3V	2.0	1.2
Deneb	A2Ia	-7.1	1.3
Beta Crucis	B0III	-4.6	1.3
Regulus	B7V	-0.6	1.4
Adhara	B2II	-5.1	1.5
Castor	A1V	0.9	1.6
Shaula	B1V	-3.3	1.6
Bellatrix	B2III	-2.0	1.6
Elnath	B7III	-3.2	1.7
Miaplacidus	A0III	-0.4	1.7
Alnilam	B0Ia	-6.8	1.7

Table D

Star	Type	M	m
Sun	G2	4.8	-26.8
Proxima Centauri	M5	15.4	0.1
Alpha Centauri A	G2	4.4	1.5
Alpha Centauri B	K5	5.8	11.0
Barnard's Star	M5	13.2	9.5
Wolf 359	M6	16.7	13.5
Lalande 21185	M2	10.5	7.5
Sirius A	A1	1.5	-1.4
Luyten 726-8A	M6	15.3	12.5
Luyten 726-8B	M6	15.8	13.0
Ross 154	M5	13.3	10.6
Epsilon Eridani	K2	6.1	3.7
Luyten 789-6	M6	14.6	12.2
Ross 128	M5	13.5	11.1
61 Cygni A	K5	7.5	5.2
61 Cygni B	K7	8.3	6.0
Epsilon Indi	K5	7.0	4.7
Procyon A	F5	2.7	0.3
Cincinnati 2456A	M4	11.2	8.9
Cincinnati 2456B	M4	12.0	9.7
Groombridge 34A	M1	10.4	8.1
Groombridge 34B	M6	13.3	11.0
Lacaille 9352	M2	9.6	7.4
Tau Ceti	G8	5.7	3.5
Luyten's Star	M4	11.9	9.8
Lacaille 8760	M1	8.8	6.7
Kapteyn's Star	M0	10.8	8.8
Kruger 60A	M4	11.7	9.7
Kruger 60B	M6	13.2	11.2

•Questions

Answer the following questions on a separate piece of paper. For credit, turn your answers and your plots.

1. Why don't the stars in Table B lie on the curve you created in part A) ?

2. How many magnitudes is Capella brighter than the Sun?

3. How many times brighter is Capella than the Sun?

4. Is Capella larger or smaller than the Sun?

5. What is the most common kind of **bright** (M) star (hot, cool, or spectral type)?

6. Estimate the average **apparent** magnitude, m, of the brightest stars (Table C).

7. When you look at a bright star in the sky, your probably looking at what speectral type of star?

8. What is the most common kind of star near the Sun?

9. Estimate the average **apparent** magnitude of the close stars (Table D).

10. We believe the stars near the sun are ordinary, common stars. Why don't we see mostly common stars?

11. What would our night sky look like if all the stars in the galaxy had the same **absolute** magnitude as the Sun?

12. Write a short summary of what you learned in the lab.

The Herschel Experiment

•Materials

One glass prism
3 alcohol thermometers with blackened bulbs
scissors
cardboard box
blank piece of white paper

•Introduction

Herschel discovered the existence of infrared light by passing sunlight through a glass prism in an experiment similar to the one you'll do here. As sunlight passed through the prism, it was dispersed into a rainbow of colors, a spectrum. Herschel was interested in measuring the amount of heat in each color and used thermometers with blackened bulbs to measure the various color temperatures. He noticed that the temperature increased from the blue to the red part of the visible spectrum. He then placed a thermometer just beyond the red part of the spectrum in a region where there was no visible light and found that the temperature was even higher. Herschel realized that there must be another type of light beyond the red, which we cannot see. This type of light became known as *infrared*. *Infra* is derived from the Latin work for "below". In this lab, you will complete an experiment very similar to Herschel's original one.

•Predictions

Before starting the experiment, make some predictions about what will happen. Write answers to the following questions on a piece of paper that you will hand in with your lab. It's okay if you don't know the answer right now, but put down your ideas anyway. In what region will you observe the highest temperature? Why? What color is the sun? Why to we see in "visible"? What kind of light is more energetic, red light or blue?

•Procedure

This experiment should be conducted outdoors on a sunny day.

1) Place the piece of white paper on the bottom of the cardboard box.

2) Carefully attach the glass prism near the top, sun-facing edge of the box. Do this by cutting out an area from the top edge of the box that the prism will fit snugly into.

3) Place the prism in the slot you created and rotate it so it creates the widest possible spectrum on the **shaded portion** of the white sheet of paper at the bottom of the box. You can elevate the sun facing side of the box to create a wider spectrum.

4) Now, place the three thermometers in the shade and record the temperature each reads.

5) Next, place the thermometers in the spectrum such that one of the bulbs is in the green region, another in the orange region, and the third just beyond the red region. If you can't get this to work out perfectly, that's okay, just make sure to record what region each of your bulbs was in during the time you took your measurements.

6) It will take 3 minutes or so for the thermometers to record the final values. Do not move the thermometers from the spectrum or block the spectrum while reading the temperatures.

7) Record all of your measurements on a piece of paper that you will turn in with the rest of your lab. You should record the temperature of each thermometer after each of the three minutes.

8) Repeat steps 4-7 two more times.

9) Calculate an average final temperature for each region and record. Compare your averages with the other lab teams.

•Questions

Answer the following questions on a separate piece of paper. **For credit, turn your answers, your predictions, and your recorded data.**

1) What color/region did you find to have the highest temperature? Did you measure infrared light? Did you record different values during different runs?

2) Does it make sense to you what region had the peak temperature? In what color do you think the sun emits the most energy?

3) Look at the following diagrams and corresponding discussions, then re-analyze your answer to question 2.

4) Answer all questions posed in the discussion.

List of visible wavelength ranges, for reference.

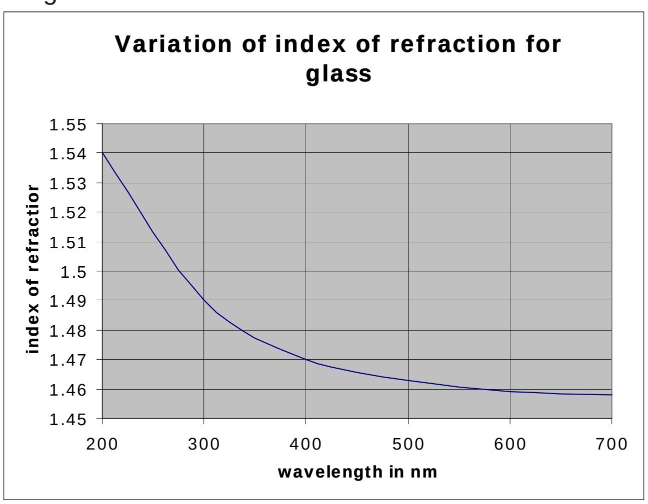
Red	620-700nm
Orange	590-620
Yellow	570-590
Green	490-570
Blue	440-490
Violet	390-440

There are 10^9 nanometers (nm) in a meter.

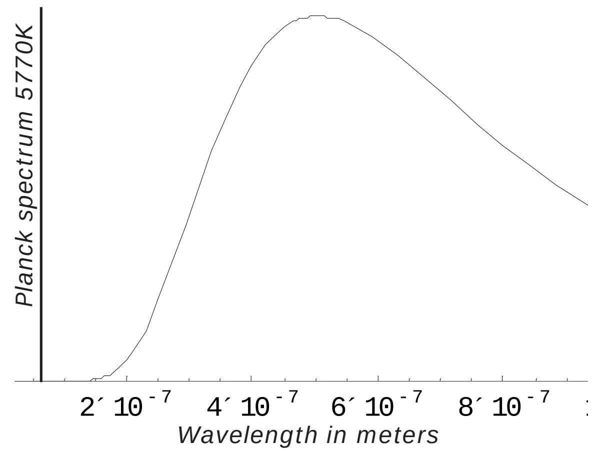
To change a wavelength into a frequency, use the formula

$$l n = 3*10^8 \text{ m/s}$$

where n is frequency in Hz and l is wavelength in meters.



The graph above is plot of how the index of refraction varies with wavelength in glass. There are actually many types of glass, and each has a somewhat different index of refraction. This one is for silica. If the plot were a straight line, “linear”, we would have equal spacing of wavelengths when light is refracted through a prism. However, the plot is not a line, but a curve which flattens out toward the red end of the spectrum. Due to the fact that the index of refraction changes very little at the red end of the plot, the wavelengths there will be bunched up, more concentrated.



You should recognize this plot as a Planck or blackbody spectrum. The radiated light from the sun can be approximated by a blackbody at 5770K. Use Wien’s Law to find the peak wavelength of the Sun’s emission.

Wien’s Law:

$$l_{max} = 2.9*10^6/T$$

Where l_{max} is the peak wavelength of the Planck spectrum in nanometers and T is temperature in Kelvin.

Is this the wavelength you expected? To obtain an energy from the Planck spectrum, integrate over a wavelength range. If you are unfamiliar with the concept of integration, you can think of it here as the area under the curve from one spot on the x axis to another. For example, you can see by simply looking at the plot that the area under the curve between 200 and 300 nm is less than the area between 500 and 600 nm. Using this type of estimation, in which color does the sun emit the most energy? The difference between energy emitted from the sun in green and red is not great, but in a well done, *corrected* experiment, is measurable.

You might now be asking yourself a logical question. If the sun emits the most in green, why does it appear yellow? In fact, it is an *appearance*. The sun is actually white, but against the blue sky, it looks yellow. **Caution: never look directly at the sun** - it can burn your eyes in a matter of only a fraction of a second. Astronauts in space observe the sun as white, due to the black rather than blue background they see it against. To prove this to yourself, try the following experiment on your own time.

Experiment:
Gather two pieces of blue paper and a small square of white paper. Attach the white square to the middle of one of the sheets of blue paper. Stare at the empty blue page for about 30 seconds, then place the other on top. What color do you observe the white paper to be? Most see the white chunk as yellowish!

It is a common misconception that the sun is yellow. In fact, most astronomy text books simply classify the Sun as a G2 "yellow" star and don't explain the difference between the spectral classification and the true "color" of the Sun or other stars. Of course, we could spend quite a bit of time discussing what exactly *color* is, and how our eyes see color, but that is left to you. The following website is helpful if you're interested:

http://casa/colorado.edu/~ajsh/colour/Tspectrum.html

5) Summarize what your Herschel experiment results were, why you got those results, and state what you should have observed if you corrected for the non-linear nature of the index of refraction of glass.

•Further investigaion (for extra credit)

The formula for Planck function is

$$B_l(T) = (2hc^2/l^5)(\exp(hc/klT)-1)^{-1}$$

Where
- h = Planck's constant = $6.626*10^{-34}$ J*s
- c = speed of light = $3*10^{-8}$ m/s
- k = Boltzman's constant = $1.38*10^{-23}$ J/K

Use T = 5770K for the temperature of the Sun.

Using Mathematica or some other math tool, plot the function. Then numerically integrate over a few wavelength ranges to obtain the energy emitted in that range. What percent of visible light energy is green? Red?

Solar Observation

•Materials

Telescope operating instructions
Sun chart
Telescope
Filters

•Introduction

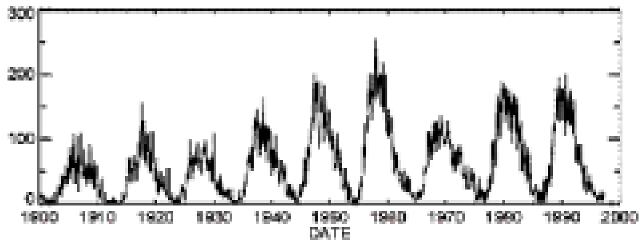
In this lab, you will use the department's 8 inch telescopes and two types of solar filters. ***NEVER LOOK DIRECTLY AT THE SUN!*** The sun can burn your eyes in a very short period of time, resulting in permanent damage. Astronomers use special filters to filter out the powerful radiation of the sun so we can safely observe it. The filters are placed on the telescopes before pointing them at the sun, because the sun can also damage the optics inside the telescope. Your lab instructor will set up the telescopes for you, so you don't need to worry about placing the filters correctly. You should, however, know the difference between the filters and how to operate the telescope while you're observing. Refer to the telescope operating instructions at the front of this manual for information on the latter.

The first of two types of solar filters you'll be using in this lab is a neutral density or white light filter. A white light filter blocks out all types of light equally. Usually, they are made of mylar. When you look at the sun through this type of filter, you will see the surface of the sun. The surface is the layer where the visible light, produced in the center of the star, is released. It is no mistake that we see in "visible"; this is the range of light that is emitted more than any other from the sun. Solar physicsits call the surface layer the **photosphere**. Often, the photosphere has large dark patches, **sunspots**, that rotate with the sun. Sunspots are regions of concentrated magnetic field. They appear dark because they are about 1500 K cooler than the surrounding "quiet" photosphere, at 5800 K. Cooler temeratures in sunspots are a result of the strong magnetic field suppressing the convection that continually brings up hotter material from under the surface. In the quiet photosphere, the convection results in granulation cells. You won't be able to observe the granulation cells with the telescopes we have, but take a look at the following web site to see some amazing images of granulation and sunspots.

http://www.solarview.com/eng/sunspot.htm

You will be able to see sunspots well. That is, if there are any to be seen! The sun has an eleven year activity cycle, and sun spot number is a good indicator of activity. At solar maximum, there will likely be as many as 100 sunspots visible from Earth. During minimum, chances are there will be only a couple or even none. The last solar max was around 2000-2002. Solar minimum is expected to last from about 2004-2009. People have been charting sunspots for hundreds of years, since Galilleo. Look at the diagram below and make a guess yourself as to when the next solar max will take place.

Monthly Average Sunspot Number



The second type of filter you will observe with is an Ha (said "H alpha") filter. Ha refers to the Balmer alpha transition for the Hydrogen atom. (See the section of your textbook on spectral lines for more information.) The wavelength of Ha is 656 nanometers, corresponding to a red color. Through a telescope with an Ha filter on it, you will see the area of the sun's atmosphere that emits in Ha, the **chromosphere**. The chromosphere lies just above the photosphere, and is about 10,000 K. You will still see sunspots, but you should also be able to see **prominences**. A prominence is a region of dense, relatively cool plasma suspended in the hot **corona** (the outermost part of the solar atmosphere) . These mysterious phenomena are at chromospheric temperatures even though they reside in the million degree corona. Again, for more information, see your text. Look for prominences just off the limb (edge) of the sun. They will appear as reddish blurs against the dark background.

•Procedure

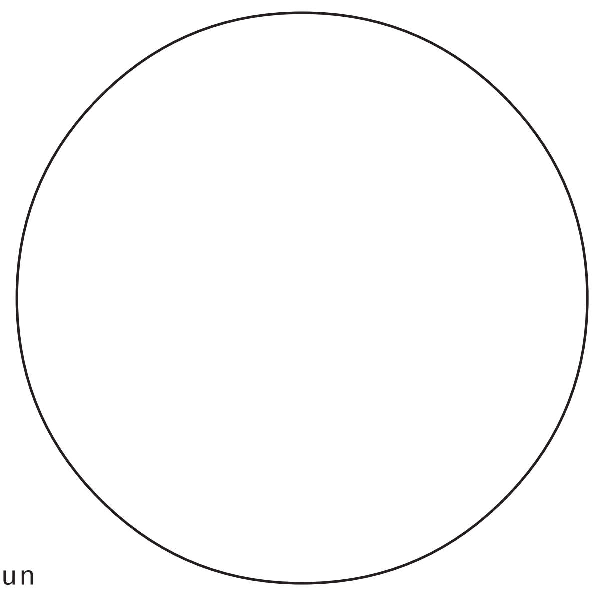
1) Read telescope operating instructions located in the front of the manual.

2) Look at the following two websites for information on what the sun currently looks like. Make some notes about how many sunspots are on the solar disk and where they're located. Do you see any prominences in the Big Bear Solar Observatory's Ha image? If so, where are they in respect to the sunspots?

http://www.spaceweather.com
http://www.bbso.njit.edu/cgi-bin/LatestImages

3) After your lab instructor has set up a filtered telescope for you, position the telescope so it is pointing at the sun. ***Important note***: make sure the viewfinder scope is covered. The easiest way to position the scope the correctly is to minimize the shadow cast by the scope. Then look through the main eyepiece. If the sun is not visible, try again. It is best to start with a wide angle eyepiece (40 mm). Once you have the sun in your field of view, you can zoom in by replacing the 40 mm eyepiece with a 20 or 25 mm one.

4) Make drawings of sunspots and prominences on the solar chart. Label the date, time, type of telescope, filter, and eyepiece type. Note that the telescope flips the image upside down and backwards. Which way is solar north? Think about this carefully!



Sun
Chart

Trace the chart onto a piece of paper or get a copy of the chart from your lab instructor.

For credit, turn in your notes from surfing the solar websites and your solar observations.

•Further investigaion (for extra credit)

The rotation of the sun is easily observed by plotting sunspot location over a series of days. Your lab instructor can set up a time for you to do a quick solar observation several days in a row. Carefully draw what you see each day. What do you guess the rotation period of the sun to be?

Stellar Structure

•Materials

Computer program: Microsoft Excel or Equivalent

•Introduction

When you think of a star, what properties do you associate with it? It's a hot ball of gas, right? What about that hot ball of gas makes it a star? A good answer to this question is that a star is stable. Our Sun, for example, is not exploding or contracting. Scientists refer to the stability of stars by saying that they are in **hydrostatic** and **thermal equilibrium**. Hydrostatic equilibrium is a balance between the forces that act on the star. The forces include downward pressure of the gas layers into the center, upward pressure of the hot gasses, and the downward pull of gravity due to the weight of the gas itself. The upward gas pressure must compensate for both gravity and the pressure of the outer layers. Thermal equilibrium means that even though the temperature in stellar interiors varies with depth, the temperature at each depth remains constant in time.

Another important property of a star is how energy is transported from its center to the surface. The energy source for stars is the nuclear reactions that take place in the core. The energy is transported to the surface by conduction, convection, and/or radiative diffusion. In the sun, energy is transported by radiative diffusion from the core to about 0.7 solar radii. From that depth out, energy is transported by convection. Some stars have very large radiative zones and little or no convective zones, while others have very deep convective zones.

Scientists use equilibrium concepts, along with energy transport mechanisms, to construct models for stellar structure. The models determine the size, temperature, and mass of the star. Some stars are very large and luminous, but cool. Others are small but very hot. The sun is a main sequence, or hydrogen burning, star. In this lab, you will study the relationship between luminosity and three factors: temperature, mass, and radius of main sequence stars.

•Procedure

In this lab, you will take a close look at how three aspects of stellar structure (temperature, mass, and size) effect luminosity. Scientists often use luminosity to learn about stellar structure because it is easily measured, and many other informative quantities can be deduced from it. You will look specifically at main sequence stars, which generally obey the following equations:

1) $L/L_o = (T/T_o)^6$

2) $L/L_o = (M/M_o)^4$

3) $R/R_o = (M/M_o)^{0.7}$

where L = luminosity, T = temperature, M = mass, R = radius, and the subscript $_o$ refers to the solar value for that variable.

*How is luminosity related to radius?

4) L/L_o = ___________

Use equations 1, 2 and 4 to fill out an Excel table. *If you are unfamiliar with doing math in Excel, see the instructions on the next page.* You will **use logarithmic x and y values** to make a plot of the three luminosity relationships in Excel. **The x axis will always have the same values, referring to T/T_o for the first relationship, M/M_o for the second, and R/R_o for the last.** Calculate the *y* axis values using the appropriate equation: $(T/T_o)^6$ for the first, etc., then take the logarithm of these values. Once you've made all of your calculations, create a plot in Excel. Excel hint: when plotting this type of data, use the scatter plot that creates a line through the data points. Ask your lab instructor if you have questions on how to create the plot. For credit, turn in your (x,y) values, plot and answers to the questions below.

•Questions

1) What aspect of solar structure increases the luminosity the most as it increases? The least?

2) Why is it better to plot the logarithm of the values you calculated rather that the actual values?

3) The plot of L/L_o vs. T/T_o is the usual way you will see a Hertzprung-Russell diagram displayed. Why is it a straight line instead of a curve? Hint: look at the procedure you followed in the H-R diagram lab compared to this lab.

Using Excel to do math

1) In Excel, create a column title for each of the columns in the chart below. In column A, enter the x axis values (0.1, 0.25, etc.).

2) Click on the box in column B that has the x value 0.1. Go to Insert -> Function -> Math and Trig -> select LOG10. Click "okay". When the box comes up asking for a number, click on the box in column A with the value 0.1. Click "okay".

3) Now select the box just created in column B (value=-1, log base 10 of 0.1) and Edit -> Copy. Next, highlight the rest of column B and Edit -> Paste. You now have the logarithmic numbers corresponding to the values in column A.

4) Now, we need to find luminosity for the temperature ratio, which goes to the 6^{th} power. When the first empty box in column C is highlighted, go to Insert -> Function -> Math and Trig -> Power. Click "okay". In the box that comes up, put 6 as the power, click the box with the value 0.1 in column A, and click "okay". Copy and paste for the rest of column C as before. Create logarithmic values of column C in column D as you did for the x values.

5) Repeat step 4) for the other luminosity relationships. **Once done, either copy the values from Excel into your notebook, or print off a copy of the Excel workbook to attach with your lab.**

6) Now, plot the three log/log luminosity relationships on the same chart. Highlight columns B, D, F, and H by using ctrl + click to select multiple columns. Go to Insert -> Chart -> XY scatter and choose the chart with the dots and the line through them. Each relationship will be a different color. Name the "series" in the first box that comes up when inserting the chart.

A	B	C	D	E	F	G	H
X Axis values		L/L. = (T/T.)^6		L/L. = (M/M.)^4		L/L. = (R/R.)^(4/0.7)	
X/X.	Log(X/X.)	L/L.	Log(L/L.)	L/L.	Log(L/L.)	L/L.	Log(L/L.)
0.1							
0.25							
0.5							
0.75							
1							
1.5							
2							
2.5							
3							
3.5							
4							
4.5							
5							
10							

For reference:

L_o = 3.86 x 10^{26} W, T_o = 5776 K, M_o = 2 x 10^{30} kg, R_o = 7 x 10^{8} m

Stellar Evolution

This is a good lab to do on your own if you have missed a lab class.

Your parents hear on TV that one day, the Sun will grow into a huge, red ball of gas extending all the way to Earth. They know you're in an astronomy class and call you up to ask if this is true. Write a phone conversation you would have with them, explaining in laymen's terms the birth and death of stars similar to the sun.

For extra credit, explain how larger and smaller stars' evolution varies from the evolution of stars the size of the sun.

Alternative:
If you like to draw, create an image for each step of the stellar evolution progress. Include a short statement of explanation with each drawing. A picture is worth a thousand words! The same extra credit applies, only with drawings and a short statement rather than in writing.

Neutron Stars

•Materials

Iron filing demonstration

•Introduction

In this lab, you will explore the properties of several types of neutron stars. First, your lab instructor will introduce the concept of **magnetic field** using a bar magnet and iron filings. Study the chart below for an understanding of magnetic field strengths.

Magnetic Field magnitude (Gauss)	Object
0.6	Earth's field
100	common hand held magnets
4000	strong sunspots
4.5×10^5	strongest sustained magnets*
1×10^8	strongest non-neutron star fields
10^{12} - 10^{13}	radio pulsars
10^{14} - 10^{15}	magnetars

*If made any stronger, the magnet would exceed the tensile strength of the material, and it will blow apart!

Gamma-ray bursts (GRBs) were first detected in the late 1960s by U.S. satellites designed to look for space-based nuclear weapons testing. GRBs are characterized by a short burst of gamma rays (from milliseconds in duration to a few minutes), and rarely have an easily detectable glow more than a few minutes after the event. GRBs are flashes-in-the-pan: they explode once, never to return.

GRBs were a big mystery to astronomers when they were first seen (and in fact, they still are). The situation became worse when, on March 5th, 1979, intense flashes of gamma rays were detected coming from the direction of the Large Magellanic Cloud, a companion galaxy to the Milky Way. Then, over the next few months, more flashes of gamma rays were detected coming from the same region of the sky. For a while, the idea that GRBs only flashed once was in doubt, but then it was realized that the repeating sources were a totally different class of object. Dubbed **Soft Gamma Ray Repeaters** (SGRs), because they peak at a slightly lower (also called “softer”) energy of gamma ray than GRBs, these were found to be neutron stars - incredibly dense remnants of supernova explosions - which have extremely strong magnetic fields, far stronger than typical neutron stars. For reasons still unknown, the super-magnetic field can cause the crust of the neutron star to slip, much like an earthquake. The intense gravity of the neutron star makes such a slip a dramatic event indeed; the energies can be enough to generate huge bursts of gamma rays which typically last for less than a second. Over time, the pressure builds up again, and another flash is seen. This is how gamma rays are seen from the same object more than once.

Also in the mid-1970s, different kinds of high-energy events were starting to be identified. The so-called **X-Ray Bursters** (XRBs) were discovered. Like SGRs, they were neutron stars with repeating bursts, but their magnetic fields, while strong, were not at the level of the SGRs’ strength. And unlike SGRs, which are isolated, individual neutrons stars, XRBs are caused by neutron stars in binary systems. The neutron star in such a system can accrete, or draw in, matter from a normal companion star. The matter builds up on the surface of the neutron star, and then suddenly explodes in a thermonuclear blast. It is this explosion which creates the burst of X-rays, which lasts for roughly 20 to 100 seconds. After the matter burns up in the blast, the accretion starts again and the pattern repeats. This causes repeated XRBs from the same object.

During the 1970s through the 1990s, much confusion arose because it was not clear at first that there were actually three different types of physical mechanisms that were producing the bursts of energy. Placing something in its correct category is half the battle in understanding it. It took 30 years for astronomers to sort out these different types of phenomena, and in fact they are still working on classifying and understanding them. You will do the same, but in just 45 minutes or so!

•Procedure

1) You will use the data given in the table on the following page to make deductions about any trends in the objects and determine how many categories (based on common properties) there are from those trends. You need to decide which objects belong to which categories.

Data types:

Object name. The name of the object is based on its coordinates on the sky. The sky is mapped by astronomers using a coordinate system similar to longitude and latitude, but the axes are called Right Ascension (or RA) and declination. RA is measured in the direction of East-West on the sky, and goes from 0 to 24 hours (each further divided into 60 minutes). Declination is measured in North-South on the sky, and goes from -90 to 90 degrees. An object's name on the card is its RA (a four digit number where the first two digits are the hours, and the second two are the minutes) and its declination in degrees, including the plus or minus sign. An object at an RA of 5 hours 30 minutes and a declination of -20 degrees would this have the name 0530-20.

Location. Latitude (b) and longitude (l) in Galactic coordinates of each burst.

Energy Peak. The energy where the burst has the maximum number of photons.

Optical Counterpart. What is seen in visible light at the position of the burst.

Distance. The distance from the Earth to the burst in light years.

Burst Repetition. How often the bursts are seen to recur, if they do recur. "None" means that no repetition has been detected, and "N/A" means no information is available.

Spin or Orbital Period. Either the spin period of the burster, or its binary orbital period if it is in a binary system.

2) Using the location data (galactic coordinates), plot the distribution of the mystery objects in the sky. Make a copy or trace the projection map at the end of the lab, then plot each of the objects on that separate page. Use a different symbol for each group from part 1.

•Questions

1) How many groups do you think there are? What properties do you think are the most useful for separating the groups?

2) What can you say about the distribution of each group on the map? Are the bursts in each group randomly located, or do they fall into a pattern on the sky?

3) What is the average peak energy of the bursts in each group?

4) What is the average distance from the Earth of the bursts in each group? Is there a lot of variation in the distances of the objects in each group, or are they all about the same distance?

5) What other properties do the members of each group have in common?

For credit, turn in your map and answers to the questions above and below.

•Further investigation (required)

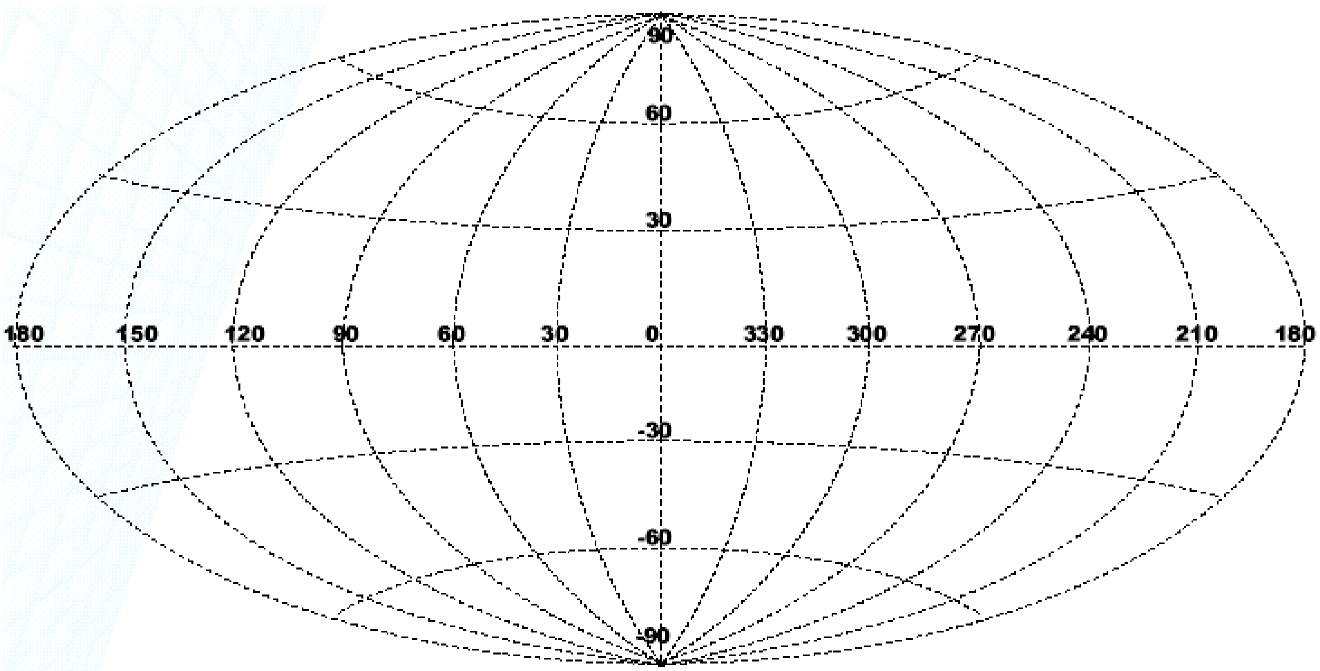
www.nasa.gov/vision/universe/watchtheskies/swift_nsu_0205.html

Explore the December 27, 2004 event on the website above and answer these questions:

1) According to your work in part 1 of the lab, what type of burst was this? What caused the burst? How far away was it? What special name is given to this type of neutron star?

2) How much more powerful was it than previous record holders? How long would it take the sun to produce this much energy?

Name	Location (l,b)	Energy Peak (keV)	Optical Counterpart	Distance (light years)	Burst Repetition	Spin or Orbital Period
0501+11	189, -18	175	Mag 25 host galaxy	5.7 billion	none	none
0526-66	276, -33	30	Super nova remnant	180,000	<1/month	8 sec
0656+79	135, 27	370	Mag 25 host galaxy	6.4 billion	none	none
2232-73	315, -40	175	Mag 23 host galaxy	4.2 billion	none	none
2359+08	101, -52	175	Mag 23 host galaxy	6.9 billion	none	none
1627-41	337, 0	20	Super nova remnant	36,000	every 1.7 hrs	N/A
1636-53	333, -5	2.3	Mag 17 star	21,000	every 7.7 hrs	3.8 hrs
1659-29	354, 7	2.5	Mag 18 star	48,000	every 9 hrs	3.4 days
0748-67	280, -20	2.2	Mag 17 star	33,000	every 10 hrs	3.8 hrs
1156+65	132, 51	370	Mag 26 host galaxy	10.5 billion	none	none
1338-80	305, -18	370	Mag 26 host galaxy	8.6 billion	none	none
1525+44	73, 55	1500	Mag 24 host galaxy	9.5 billion	none	none
1728-34	354, 0	2.8	N/A	33,000	every 7.1 hrs	N/A
1735-44	346, -7	2.3	Mag 17 star	37,000	every 5 hrs	4.65 hrs
1820-30	3, -8	2.2	Mag 19 star	21,000	every 3.3 hrs	11.4 min
1900+14	43, 1	30	Super nova remnant	23,000	every 0.14 hr	5.16 sec
1935-52	345, -28	175	Mag 24 host galaxy	.11 billion	none	none
1806-20	10, 0	25	Super nova remnant	47,000	every 1.1 hrs	7.5 sec
1837+05	36. 5	2.4	Mag 18 star	23,000	every 0.3 hr	N/A
1850-08	25, -4	2.7	Mag 20 star	22,000	N/A	N/A



View where the galaxy is centered at 0,0. Use the data from "location" to plot.

Cosmology: The Expansion of the Universe

•Materials

one balloon per person
string
rulers

•Introduction

In this exercise, you will use a two-dimensional model to explore the expansion of the universe.

Before 1917, many scientists thought the universe always existed. But Einstein's revolutionary theory of gravity changed all the rules. It opened up the mind-boggling possibility that space itself - the permanence of which had never been questioned - might actually be expanding. If space is expanding, the universe we inhabit today could once have been infinitely smaller.

In 1929, astronomer Edwin Hubble made the amazing discovery that distant galaxies are speeding away from us. This means that the galaxies we see today were once much closer together - originating from a tiny region of space.

The origin of the universe remains one of the greatest questions in science. Current scientific evidence supports the Big Bang model, which states that about 13.7 billion years ago, the entire universe began expanding from a very hot, dense state. This sudden expansion is know as the Big Bang.

What does it mean to say that the universe is expanding? The Big Bang was an expansion of space itself. Every part of space participated in it. Space is not simply emptiness; it's a real, stretchable, flexible thing. Galaxies are moving away from us because space is expanding. Galaxies are moving *with* space, not *through* space. (There is also a local motion through space as galaxies interact with their neighbors, but on larger scales, the expansion of space dominates.) The model in this activity demonstrates how the motions of the galaxies reveal the continuing expansion of the universe.

In the 1920s, Edwin Hubble measured the motion of the galaxies. By measuring a galaxy's distance from us and how fast that galaxy is receding (its recession velocity), he found a simple relationship: double the distance, double the velocity; triple the distance, triple the velocity. This is Hubble's Law. In equation form, it is written:

$$v = H \times d$$

Recession velocity = Hubble's constant x distance from us

The slope of the graph of distance vs. velocity represents the Hubble Constant for the universe.

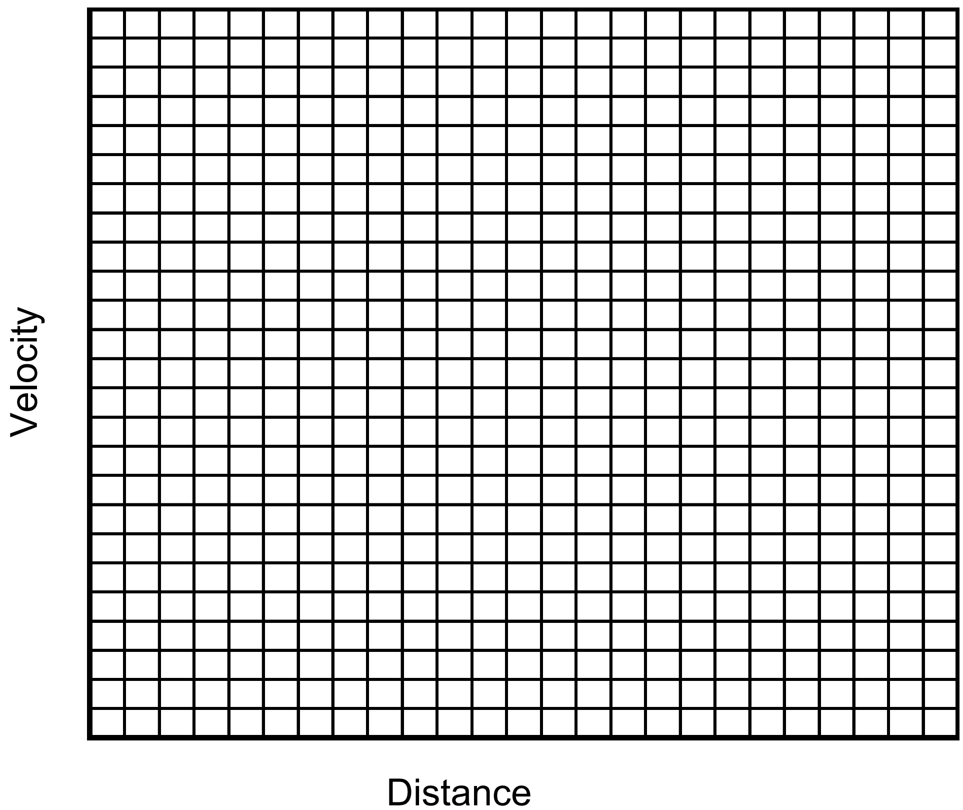
The **Hubble Constant** describes how fast the universe is expanding. By measuring the rate of expansion, the size and age of the universe can be calculated. Interpreting recent observational results from space-borne and ground-based telescopes, scientists have determined different values of Hubble's constant. Determining the precise value of the Hubble constant is key to understanding the origin of the universe, and there are several factors that affect this determination. For example, the universe may not have been expanding at the same rate throughout time; that is, the expansion itself may be accelerating. Questions like these make the age of the universe a hot topic - one of the most controversial in the study of cosmology. The age of the universe is currently estimated to be about 13.7 billion years, and the Hubble constant is estimated to be about 70 km/s/Mpc.

The age of the universe can be calculated from the Hubble constant; it is its reciprocal. However, this assumes that the universe expands at a constant rate, and that may not be accurate.

•Procedure

1) Blow up the balloon a little bit. DO NOT TIE IT SHUT!
2) Draw and number ten galaxies on the balloon. Mark one of these galaxies as the reference galaxy.
3) Measure the distance between the reference galaxy and each of the numbered galaxies. The easiest way to do this is to use a piece of string. Stretch it between the two points on the balloon, then measure the string. Record these data in the table. Be sure to indicate the units you are using.
4) Now blow up the balloon. You can tie it shut this time if you like.
5) Measure the distance between the reference galaxy and each of the numbered galaxies. Record these data in the table.

Galaxy Number	First Measurement	Second Measurement	Difference	Velocity



6) Subtract the first measurement from the second measurement, record the difference in the data table.

7) Estimate the amount of time it took you to blow up the balloon (in seconds). Divide the distance traveled (the difference) by this time to get a velocity.

8) Plot velocity versus the second measurement to get the "Hubble Law for Balloons". Don't forget to label the units on your axes.

9) Fit a line to your data.

10) Find the slope. Slope is the change in *y* over the change in *x*. This is exactly the way that we find the value of Hubble's Constant from Hubble's Law.

11) Find the age of your balloon universe from this slope. Remember that the age is one over the Hubble Constant.

•Questions

1) How does the age of the balloon found from the Hubble law compare to the time it took you to blow up the balloon the second time?

2) What assumptions do you make about your balloon universe when you find it's age by this method? Are these sensible assumptions?

3) How would your results change if you used a different reference "galaxy" on the balloon? If you are not sure, try it!

Planets Outside Our Solar System: Is there life on other worlds?

The Drake Equation

•Materials

calculator

•Introduction

Are we alone? For the first time in history, astronomers have discovered planets orbiting stars beyond our own Sun. In fact, planetary systems seem to be widespread in the universe. Is there life, intelligent or otherwise, in any of these alien solar systems? No one yet knows. But ours may be the first generation to detect a sign of life beyond Earth. What will it mean if we find out that we are not alone?

At first, "Is there life on other worlds?" seems a simple question to answer. However, it quickly becomes a complex web of issues. What is life, anyway? How does it begin and evolve? What conditions can life tolerate? What makes a planet habitable? How do we look for and identify extraterrestrial life? To attempt to resolve these kinds of questions, astrobiologists draw on many branches of science and employ many research strategies, such as fieldwork, laboratory research, telescopic observation, and exploration with spacecraft.

Though we have not found any examples of extraterrestrial life, comparisons with certain kinds of life on Earth suggest that potential habitats for extraterrestrial life, and maybe life itself, do indeed exist. However, contrary to popular notions, if extraterrestrial life is found in our solar system, it will most likely be bacteria-like.

In 1961, the astronomer Dr. Frank Drake suggested an organized framework for thinking about life in the galaxy. Known as the Drake Equation, it provides a way to estimate the number of worlds within our Milky Way galaxy that have intelligent life and whose radio transmission should be detectable. Drake identified a sequence of eight terms to help people think about what must occur before a world can be inhabited by a civilization with radio technology. This activity uses Dr. Drake's framework to have you consider the implications of each term and make your own estimates of life in the Milky Way galaxy.

Because we are unsure whether there is life out there, let alone intelligent life with which we can communicate, there is no correct solution to the equation - the value of each factor is open to interpretation.

•Procedure

To find out your estimate of the number of worlds in the Milky Way galaxy that have intelligent life that we can detect using radio technology, fill out the chart on the following page. Multiply the eight terms. Don't forget to convert percentages to numbers.

•Questions

1) What is your final answer?

2) Based on your estimates, how good are our chances of hearing from intelligent extraterrestrials?

3) How does your answer to 2) compare with what you thought before you began the activity?

4) What if you answer to 1) were less than one? What would that mean in terms of our existence here on Earth?

5) When making estimates, in which terms did you have the most confidence? The least? Why?

6) Are you more optimistic or more conservative when it comes to thinking about extraterrestrial life with radio technology in the Milky Way galaxy? Why?

7) How could you adjust the estimates in the equation to have it come out so that Earth is the only planet in the Milky Way galaxy with radio technology?

8) What would your reaction be if we discovered microbes on another planet? Plants? Insects? Mammals? Intelligent life?

9) If microbial life were discovered on another planet, what implications might the discovery have?

Term		Background	Conservative Estimate	Optimistic Estimate	Your Estimate
1.	The total number of stars in the Milky Way Galaxy	These numbers are based on observations of the stars in our galaxy and of other galaxies we believe to be like our own. Most scientists believe the number of stars to be 400 billion.	100 billion	600 billion	
2.	The percentage of stars that are appropriate	Many scientists believe that a star has to be like our Sun. Only about 5% of the stars in our galaxy are sun-like stars, though about 10% are closely related, either slightly warmer or slightly cooler. About 50% of stars exist in binary or multiple systems, which many scientists feel make them inappropriate.	0.05%	45%	
3.	The average number of planets around each appropriate star	Appropriate stars may not have planets circling them. We have only just begun detecting extra-solar planets, so we don't really know how common they are.	1	10	
4.	The percentage of planets within a solar system that are habitable	Our only example of this term is our own solar system. Could Earth be the only habitable place in our solar system? Is our system typical? Remember that if one system has no habitable planets and another has four, the average would be two per system.	10% On average, there is one habitable planet in every system	50% Half the planets in are habitable	
5.	The percentage of habitable planets that develop life	Having a planet that is appropriate for life doesn't necessarily mean that life will arise. No real data are available to help us estimate this term. Earth is the only planet on which we know there is life. However, bacterial life existed on Earth shortly (geologically speaking) after its formation, possibly indicating that the development of life is easy. Many scientists believe that whether or not life arises depends on many factors.	0.000001% Life is a rare accident that is unlikely to happen elsewhere	100% Life will arise if conditions are approprite	
6.	The percentage of planets with life that develop intelligent life	On Earth, humans developed intelligence, aparently as an evolutionary advantage. However, this term depends on how you define intelligence. Are dolphins, gorillas, octopus, and ants intelligent? Furthermore, single-celled life existed on Earth very early, and multicellular life took 2.5 billion years to form (a very long time, geologically speaking). Maybe the development of complex life, let alone intelligent life, is unusual.	0.0001% or less Only one in a million planets with life will devolop intelligent life	100% Any planet with life will develop intelligent life	
7.	The percentage of intelligent life that develops radio technology	Communication with intelligent extraterrestrials requires that we hear from them. Given the vast distances of space, they would probably send signals that travel at the speed of light, such as radio waves. On Earth, humans have only just developed radio technology, so possibly this term should have a low value. But, we did eventually develop radio technology, so maybe this is true of all intelligent beings.	0.0001% or less Only one in 1,000,000 planets with intelligent civilizations will develop radio technology	100% All intelligent life will develop radio technology	
8.	The percentage of "current" civilizations having radio technologies	Will an extraterrestrial's signals overlap with the lifespan of the receiving civilization? Extraterrestrials that sent signals a hundred thousand years ago from a world a hundred thousand light years away would still overlap with us, even if they died out long ago. So, how long do civilizations with radio technology last? A high level of technological development could bring with it conditions that ultimately threaten the species. Or maybe, once a society has radio technology, it may survive for a long time. Finally, radio signals may give way to more advanced, less noisy technologies such as lasers. No one would hear us then!	0.0001% or less Only in a million civilizations with radio technology will develop it in time to detect signals from another civilization	10% One in ten civilizations with radio technology will develop it in time to detect signals from another civilization	
	TOTAL	Planets in our galaxy to listen for			

10) What do you think is the most abundant life form on Earth?

11) If life exists elsewhere, what do you think it will look like?

12) Can you think of any other terms that might affect your estimation of life in the universe?

•Further Investigation (Optional)

Several space telescopes have recently (2005) made some direct images of extra-solar planets. Discuss these findings and the current status of extra-solar planet detection.

[2-5 points]

What is the Universe Made of?

•Materials

Magnetic Car and track set up with two weights and several thin boards

•Introduction

Protons, Neutrons and Electrons: The Stuff of Life

You, this computer, the air we breathe, and the distant **stars** are all made up of protons, neutrons and electrons. Protons and neutrons are bound together into nuclei and atoms are nuclei surrounded by a full complement of electrons. Hydrogen is composed of one proton and one electron. Helium is composed of two protons, two neutrons and two electrons. Carbon is composed of six protons, six neutrons and six electrons. Heavier elements, such as iron, lead and uranium, contain even larger numbers of protons, neutrons and electrons. Astronomers like to call all material made up of protons, neutrons and electrons "**baryonic matter**".

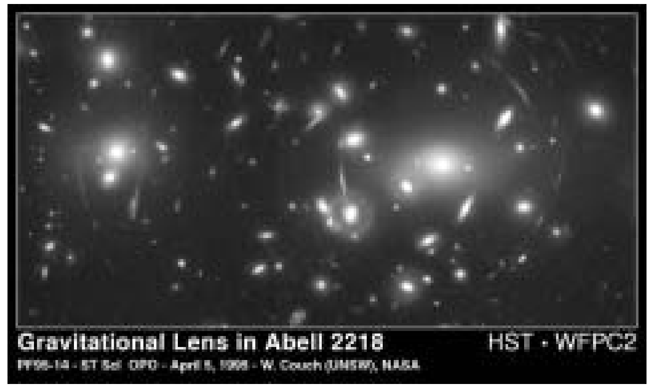
Until about twenty years ago, astronomers thought that the universe was composed almost entirely of this "baryonic matter", ordinary stuff. However, in the past decade, there has been ever more evidence accumulating that suggests there is something in the universe that we can not see, perhaps some new form of matter.

The Dark Matter Mystery

By measuring the motions of stars and gas, astronomers can "weigh" galaxies. In our own solar system, we can use the velocity of the Earth around the Sun to measure the Sun's mass. The Earth moves around the Sun at 30 kilometers per second (roughly sixty thousand miles per hour). If the Sun were four times more massive, then the Earth would need to move around the Sun at 60 kilometers per second in order for it to stay on its orbit. The Sun moves around the **Milky Way** at 225 kilometers per second. We can use this velocity (and the velocity of other stars) to measure the mass of our Galaxy. Similarly, radio and optical observations of gas and stars in distant galaxies enable astronomers to determine the distribution of mass in these systems.

The mass that astronomers infer for galaxies including our own is roughly ten times larger than the mass that can be associated with stars, gas and dust in a Galaxy. This mass discrepancy has been confirmed by observations of gravitational lensing, the bending of light predicted by Einstein's theory of general relativity.

HST Image of a gravitational lens



By measuring how the background galaxies are distorted by the foreground cluster, astronomers can measure the mass in the cluster. The mass in the cluster is more than five times larger than the inferred mass in visible stars, gas and dust.

Candidates for the Dark Matter

What is the nature of the "dark matter", this mysterious material that exerts a gravitational pull, but does not emit nor absorb light? Astronomers do not know.

There are a number of plausible speculations on the nature of the dark matter:
• Brown Dwarfs: if a **star's** mass is less than one twentieth of our Sun, its core is not hot enough to burn either hydrogen or deuterium, so it shines only by virtue of its gravitational contraction. These dim objects, intermediate between stars and planets, are not luminous enough to be directly detectable by our telescopes. Brown Dwarfs and similar objects have been nicknamed MACHOs (MAssive Compact Halo Objects) by astronomers. These MACHOs are potentially detectable by gravitational lensing experiments. If the dark matter is made mostly of MACHOs, then it is likely that baryonic matter does make up most of the mass of the universe.
• Supermassive Black Holes: these are thought to power distant **quasars**. Some astronomers speculate that there may be copious numbers of black holes comprising the dark matter. These

black holes are also potentially detectable through their lensing effects.

• New forms of matter: particle physicists, scientists who work to understand the fundamental forces of nature and the composition of matter, have speculated that there are new forces and new types of particles. One of the primary motivations for building "supercolliders" is to try to produce this matter in the laboratory. Since the universe was very dense and hot in the early moments following the **Big Bang**, the universe itself was a wonderful particle accelerator. Cosmologists speculate that the dark matter may be made of particles produced shortly after the Big Bang. These particles would be very different from ordinary ?baryonic matter?. Cosmologists call these hypothetical particles WIMPs (for Weakly Interacting Massive Particles) or "non-baryonic matter".

WMAP and Dark Matter

By making accurate measurements of the **cosmic microwave background fluctuations**, WMAP is able to measure the basic parameters of the Big Bang model including the density and composition of the universe. WMAP measures the density of baryonic and non-baryonic matter to an accuracy of better than 5%. It is also able to determine some of the properties of the non-baryonic matter: the interactions of the non-baryonic matter with itself, its mass and its interactions with ordinary matter all affect the details of the cosmic microwave background fluctuation spectrum.

WMAP determined that the **universe is flat**, meaning it is neither open nor closed, but right between. A closed, or elliptical, universe experiences a continuous cycle of a Big Bang, expanding a finite amount, and falling back on itself. On the other hand, an open, or hyperbolic, universe will expand to infinity quickly. It takes a flat universe, as ours is, an infinite amount of time to extend to infinity. A universe will be elliptical, flat, or hyperbolic based upon its energy density. Remember, matter is energy: $E=mc^2$. Of the total energy density of the Universe, we now know the breakdown to be:

* 4% Atoms, 23% Cold Dark Matter, 73% Dark Energy. Thus 96% of the energy density in the universe is in a form that has never been directly detected in the laboratory. The actual density of atoms is equivalent to roughly 1 proton per 4 cubic meters.

* Fast moving neutrinos do not play any major role in the evolution of structure in the universe. They would have prevented the early clumping of gas in the universe, delaying the emergence of the first stars, in conflict with the new WMAP data.

* The data places new constraints on the Dark Energy. It seems more like a "cosmological constant" than a negative-pressure energy field called "quintessence". But quintessence is not ruled out.

For more information about dark matter and dark energy, see the WMAP website:
http://map.gsfc.nasa.gov/

•Procedure

In this lab, you will explore a model for the Universe where you can change the mass and "dark energy" of the system. The mass in the model corresponds to the mass of the Universe, both baryonic and non-baryonic. The incline of the track corresponds to the dark energy. Dark energy is the energy that is pushing the universe outward. As stated above, dark energy acts like negative pressure, like the air in the balloon in the *Expansion of the Universe* lab. Due to conservation of energy, we know that all of the Universes' energy (atoms, cold dark matter, and dark energy) was present at the Big Bang. We refer to the energy which is expanding the Universe as "dark" because we have no idea what it is!

It is useful to think about dark energy in terms of anti-gravity. If there is a **great abundance** of dark energy in a universe, then the universe will be **open** - it will expand to infinity in less than an infinite amount of time. This is due to the great amount of energy pushing the matter outward. In a **closed** universe, the amount of dark energy is **small** enough that gravity will eventually take over, pulling the matter back together and creating another Big Bang. The situation directly in-between, a flat universe, has just the perfect amount of dark energy that the universe takes an infinite amount of time to expand to infinity. In our model, if the track the car runs on is at such an incline that the car **runs right past** a marked point, then the car/track universe is **open**. If the track has a greater incline and the car **stops before** the marked point, the universe is **closed** and will fall back on itself. If the car stops right at the mark, then the model universe is flat. You will also be able to change the mass of the car to see the effect of mass on the model universe.

1) Designate someone on your team for each of the following jobs:

a. The car launcher. You will obtain more consistent results by having the same person launch the car each time.

b. The stopper. This person makes sure the car doesn't run off the end of the track.

c. The observer. The observer will call out the farthest reached position of the front of the car using the ruler on the track.

d. The recorder. This person will record each of the measurements in the chart below.

2) Start with the front of the car at a good number, like 200 cm. Record this value. Do this with no incline on the track and no weight in the car. Have the car launcher do a few practice launches so the technique is consistent. Make sure the car doesn't crash off the end of the track!

3) Once you have an idea of how far the car goes with no incline and no weight (this will be the farthest the car goes), decide on a reference mark somewhere between the starting value and the value of the farthest travel distance. The model car/track universe that has the exact amount of mass and incline to be "flat" will stop here. *Note: it will be tough to get the experiment exactly flat; you'll just get as close as you can. This is true of the actual Universe as well. As far as we can tell (5% accuracy), the Universe is flat. However, it is basically impossible for the Universe to be EXACTLY flat*.

4) Repeat each of the cases in the chart below five times and record the average in the chart. You will need to decide how much incline you need to try based upon your selected mark.

•Questions

1) True or False: In this model universe, a larger incline corresponds to more dark energy. Explain.

2) How much more dark energy is in *our* Universe as compared to energy from matter?

3) What does your answer to 2) say about the accuracy of the model?

4) What seemed to have a greater effect in the model, incline or mass?

5) What other aspects of the model are inaccurate?

6) Summarize what the model helped you learn about the composition of the Universe.

For credit, each member of the team needs to turn in a copy of the filled-in chart and answers to the questions.

mark = _____ cm	No incline	Incline 1, = _____ cm	Incline 2, = _____ cm	Incline 3, = _____ cm	Incline 4, = _____ cm	Incline 5, = _____ cm
no added mass blocks						
one added mass block						
two added mass blocks						

Star Chart Lab

•Materials

Star Atlas Deluxe Edition

•Procedure

In this lab, you will explore the star charts of our night sky. You might want to skim the introduction at the front of the charts before you begin. In the front or back of the book you'll find a transparency which lays over the charts, giving you more detailed measurements. Star charts use a special type of coordinates, called the Equatorial system. If you are not familiar with this system, e.g. Right Ascension (RA) and Declination (Dec.), then take a minute to read Appendix A of this manual. Otherwise, answer the questions below.

•Questions

1)
a. What constellation is the star Alberio in?
b. What magnitude star is it?
c. What is its RA and Dec.?
d. How far is it (RA, Dec.) from Vega?

2)
a. How many stars in our night sky (seen in the Northern Hemisphere) have magnitude 0.0 or brighter?
b. What other name does Vega have, based on the naming scheme developed by Johann Bayer? The symbol α refers to the brightest star in a constellation, β the second brightest, and so on.

3)
a. What is special about the star Betelgeuse?
b. What constellation is it in?
c. What famous nebula is also in this constellation?

4)
a. What constellation is the Andromeda galaxy in?
b. How many arc minutes wide is it?

5) Name two named stars in the constellation Cassiopeia.

6)
a. About how many stars are in the Pleiades cluster?
b. Why do you think its nick name is “The Seven Sisters”?
c. Which constellation is the Pleiades cluster in?

7)
a. Which named star is ten arc minutes from the brightest star in the constellation Gemini?
b. Is the brightest “star” in Gemini actually just one star?
c. What type of object lies 38 arc minutes less in RA, 0.6^o in Dec. south from the star Pollux?
d. What type of object lies about 20 arc minuets less in RA, 1.5^o in Dec. north of Pollux?

8) When looking in the night sky from campus, you certainly see fewer stars than are on these maps. Many constellations are actually easier to find in conditions such as on campus.
a. Which stars do you think you can see in the constellation Lyra from campus?
b. What planetary nebula is in Lyra?
c. Describe how you would find the nebula in b. when looking at the night sky through a telescope.

9)
a. What do you notice in chart #13 that is interesting? Hint: look in the constellation Virgo.
b. What do you think is going on here? See chart B for the answer.
c. How many Messier objects are in this cluster?

10)
a. Name all of the main stars in the constellation Ursa Major.
b. With binoculars, you can see that the end star in the handle is a multiple star. How many arc minutes apart are the two brightests' centers?

11) Name four contellations closest to the north star.

12)
a. What magnitude is the star Kochab?
b. Is it the brightest star in its constellation? If not, which star is? How do you know?

13)
a. How many stars with magnitude four or brighter are visible within 30 arc minutes (RA), 10^o (Dec.) south of the star Mirphak?

b. Of these, which is brightest?
c. What special characteristic does the star in b. have?
d. Which constellation are all of these stars in?

14)
a. What imaginary line runs near the star Capella?
b. What does he blue on these charts represent?
c. Capella is the brightest star in which constellation?
d. Which star is the second brightest?

15)
a. Name two of the brightest stars see only from the southern hemisphere.
b. Why can't we see them from Montana?
c. Do you think people in Argentina can see the star Deneb?
d. What about the star Sirius?
e. Which constellation is the closest star, besides our sun, in? If you don't know the name of this star, ask your lab instructor or look it up online.

Appendix A:
The Equatorial System

•Introduction

Most of us have had the experience of trying to locate a small, obscure town on a road map. The straight forward method is to systematically search the whole state for the name of the town. Sometimes one is lucky, but at other times the process is slow. Fortunately there is a better way. Most maps have a list of towns with each one accompanied by a pair of symbols; usually a letter and a number. These are used to greatly reduce the amount of area that we must search by indicating the approximate location on the map. Such pairs of symbols are known as coordinates and allow one to specify the position of towns. In astronomy we are interested in specifying the positions of objects in the sky as viewed by an observer on the earth. For the moment we will not worry about the distance to the object, but concern ourselves only with the direction to the object. We can express the direction to an object in the sky by giving the values of two angular coordinates.

It helps to picture the night sky as an immense glass sphere with the earth (and the observer) at its center and the stars affixed to the sphere. This sphere is known as the **celestial sphere**. There are numerous ways to specify the two angles necessary to give the direction to a celestial object. Astronomers use the **Equatorial System.**

•The Equatorial System

You are undoubtedly aware of the rising and setting of the stars. However, you may not be aware that the stars appear to be rotating about a fixed point in the sky directly above the north point of the horizon. The fixed point in the northern sky about which this apparent stellar motion takes place serves as a convenient reference point in the sky. This point is the **north celestial pole (NCP)**, and its position in the sky is marked approximately by the bright star Polaris, also known as the North Star. If one were located in the southern hemisphere, a similar effect would be observed. The corresponding point in the sky south of the earth's equator is the **south celestial pole (SCP)**. The only difference is that the stars appear to rotate counter-clockwise about the north celestial pole but clockwise about the south celestial pole.

Although we will not prove it here, it is an interesting fact that the altitude of the NCP equals the latitude of the observer's location. This is a useful principle in navigation.

In summary, the NCP is a point on the celestial sphere which lies on the observer's celestial meridian at an altitude equal to the observer's latitude. The NCP is below the horizon of observers south of the equator, just as the SCP is below the horizon of observers north of the equator.

The circle on the celestial sphere which is 90 degrees from both the NCP and the SCP is the **celestial equator**.

In order to set up a system of coordinates on the celestial sphere, it is necessary to specify both a reference point and a reference circle. For the equatorial system, the celestial equator serves as the reference circle. The celestial equator lies on the celestial sphere and in the same plane as the equator on the earth's surface. The **vernal equinox** is selected as the reference point. This is the point on the celestial equator where the sun is located on the first day of spring. To a terrestrial observer, the sun's apparent path through the sky (called the **ecliptic path**) crosses the celestial equator from the south to north on this date. The point of crossing is the vernal equinox.

The circles on the celestial sphere which pass through both celestial poles and cross the celestial equator at right angles are called **hour circles**. The hour circle which passes through the vernal equinox is labelled O^h. Every successive 15 degree interval measured along the celestial equator constitutes 1^h.

The **right ascension (RA)** of a star is the angular distance measured in hours, minutes, and seconds from the hour circle of the vernal equinox eastward along the celestial equator to the point of intersection of the star's hour circle with the equator. Example: Since an hour equals 60 minutes, an object with RA = 15^h10^m would be $1/6^{th}$ of the way from the 15^h hour circle to the 16^h hour circle.

The **declination (Dec)** of a star is its angular distance from the celestial equator measured along its hour circle. The declination is positive for an object north of the celestial equator and negative for an object south of the celestial equator. Note that the declination is 0^0 everywhere along the celestial equator.

The main advantage of the equatorial system is that it is independent of the observer's location, since it is not dependent on the locally defined horizon circle but rather on the universally defined celestial equator. If one expresses the position of an object in the sky in terms of RA and Dec, this suffices to locate the object for another observer anywhere else on earth.

Most astronomical telescopes have equatorial mountings. Once the telescope's polar axis has been properly oriented, one can point the telescope to any object in the sky, provided its RA and Dec are known, by setting these coordinates into the telescope's RA and Dec circles.

•More help

If you're still not sure what's going on with this coordinate system, ask your lab instructor to give you a copy of the "Road Maps in the Sky" lab from the 311 lab manual. You can also use the celestial globes located in the lab room to practice with.

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