

29:50/29:51
Stars,
Galaxies and
the Universe

Lab Manual

Lab manual for the introductory astronomy course of *Stars, Galaxies and the Universe*. Topics covered in this manual include units of measurement, star charts, parallax, spectroscopy, the sun, stellar classification, and basic astronomical image analysis. Last edited August 2009 by T. Jaeger

Plus Appendices

ABOUT THIS MANUAL

This packet contains a series of lab projects intended to supplement the material covered in your introductory astronomy course. As this is a separate lab course, the subjects covered may not always directly follow material discussed in the lecture. Instead, the **projects are meant to support the concepts taught in the lecture and teach you techniques used by past (and present) astronomers to reveal the secrets of the universe around them.**

Along with instructive text, the individual lab exercises contain a series of questions designed both to guide your progress and test your understanding of the concepts discussed. Your score for the project will be determined by how well you answer these questions. **If you are confused about questions as you progress, ask your lab instructor for assistance.** Questions near the end of the project often build on earlier ones, so it is better that you ask now than to be confused later. Each project is designed to take one full lab period and (unless otherwise instructed) is to be completed and returned to your lab instructor at the end of the allotted lab time.

Projects are intended to be done with a lab partner. While discussion is encouraged, make sure that the answers to each question are your own. Do not simply copy the results from your lab partner and submit them as your own. While rarely an issue, **Plagiarism is a serious offence, punishable by a zero grade for the project (first offence) and a failing grade for any subsequent offence.** A simple rule-of-thumb to follow is to make sure you understand why you are answering a particular way and that you have answered each question using your own words.

TABLE OF CONTENTS

Scales of the Universe	5
Measuring the Sky	15
Measuring the Azimuth of Sunset Through the Semester	23
Using Star Charts	25
Spectroscopy	33
Observations of the Sun.....	41
Parallax Measurements	49
Spectral Classification of Stars	57
Image Analysis: Basic Techniques.....	67
Determining Stellar Properties Using BV Photometry	75
Tri-Color Imaging	85
Radio Astronomy of Pulsars	93
Appendix A: Guidelines for Final Lab Projects	107
Appendix B: Guidelines for Power Point Presentations	109
Appendix C: Analyzing Astronomical Images with MaxIM DL.....	111
Appendix D: Table of Constants and Equations	119
Appendix E: Hertzsprung-Russell Diagram.....	121

Name _____

Date _____

Lab Partner(s) _____

Project Score

SCALES OF THE UNIVERSE

Based on text by Dr. H. Bryce

PROJECT LEVEL: Introductory

PROJECT GOALS: Students will gain experience in using scientific notation, significant figures, choosing suitable units and the small angle formula.

1 INTRODUCTION

Many students may feel that their mathematical knowledge will be a hindrance to their progress through introductory astronomy labs. This project is designed to prepare you for the mathematical techniques that will be used this semester. It will also help you gain some insight into the size of the Earth, Sun, distances to nearby stars, distances within the Milky Way Galaxy, and distances to other galaxies. You should not be intimidated by this worksheet. Most of what follows is math you may already use in your everyday life (i.e. calculating tips at a restaurant, deciding which product at the store is a better deal), it has just been formularized and adapted to the field of Astronomy.

2 MAKING SCIENTIFIC MEASUREMENTS

An aspect of Astronomy, like in other sciences, is making measurements and performing calculations based on those measurements. Sometimes you may do these tasks simply to satisfy your personal curiosity. However, often you are asked to report your findings to a supervisor or you would like to discuss your result with peers. It is important in these situations to express numerical values in a clear manner which helps the reader understand the significance of the result. When expressing numerical results, you should consider the following questions:

What, if any, units (length, mass, time, temperature, etc.) does my value represent?

Is my result written in a format used by other scientists?

Does my result reflect the how well I can estimate a number or measure a value?

In the sections that follow, we will discuss ways to answer these questions, giving you the tools needed to share and discuss your results in the scientific community.

2.1 USING SCIENTIFIC UNITS

The metric system or the **INTERNATIONAL SYSTEM OF UNITS** (SI for short) is the form of units commonly used in all sciences to express mass (kilograms, kg), size (meters, m), and time (seconds, s). It

is a convenient choice, as it is devised around the number 10, allowing you to quickly calculate and compare numbers across a large range of magnitudes. In the United States, we often use a local system, expressing mass in pounds (lb), size in inches (in) feet (ft) yards (yd) or miles (mi), and time in seconds (s). This often gives rise to some confusion. This manual will typically adopt the SI system of units for calculations, but occasionally will use the local system to help you visualize the scale of a measurement. To convert from one system to the other, please consult the Appendix.

In many situations, you will add, subtract, multiply and divide numbers with units. When doing so, it is important to first convert similar types of measurements to one common unit system. Consider the following examples:

TABLE 1 - UNIT MATH

Same System, Same Type	$10 \text{ meters} \times 10 \text{ meters} = 100 \text{ m}^2$ or 100 <i>square meters</i>
Same System, Mixed Type	$2 \text{ kilograms} \times \frac{2 \text{ meter}}{3 \text{ seconds}} = 1.33 \frac{\text{kg} \cdot \text{m}}{\text{s}}$
Mixed System, Same Type	$10 \text{ meters} - 10 \text{ feet} = 10 \text{ m} - 10 \text{ ft} \times \frac{1 \text{ m}}{3.28 \text{ ft}} = 6.95 \text{ m}$
Mixed System and Type	$\frac{10 \text{ feet}}{1 \text{ seconds}} \times \frac{5 \text{ seconds}}{2 \text{ meters}} = \frac{10 \text{ ft}}{1 \text{ s}} \times \frac{1 \cancel{\text{m}}}{3.28 \text{ ft}} \times \frac{5 \text{ s}}{2 \cancel{\text{m}}} = \frac{25 \text{ s}}{3.28 \text{ s}} = 7.62$

2.1.1 PRACTICE WITH SCIENTIFIC UNITS

Please answer the questions below about Scientific Units.

QUESTION 1:

Simplify the following expressions. See the Appendix for conversion factors if needed.

$s \times \frac{\text{m}}{\text{s}}$	
$\frac{15 \text{ m}}{\text{kg}} \times \frac{\text{kg}}{5 \text{ s}}$	
$1 \text{ kg} - 0.5 \text{ lb}$	
$\frac{50 \text{ }^\circ\text{F}}{10 \text{ }^\circ\text{C}}$	

2.2 SCIENTIFIC NOTATION

Calculations in astronomy frequently involve very large or very small numbers. For this reason, **SCIENTIFIC NOTATION** is a convenient way of expressing these numbers and when used correctly should lead to fewer mistakes. For example, the *average* distance to the Sun (our nearest star) is 149, 597, 870, 690 meters (commonly called 1 Astronomical Unit or 1 AU). To simplify this you could say 150 thousand million meters but this can easily lead to confusion. Astronomers would rather write the following:

$$1 \text{ AU} = 149,597,870,690 \text{ m} = 1.50 \times 10^{11} \text{ m}$$

which is said out loud as *one point five zero times ten to the eleven meters*.

Scientific Notation is often called **POWERS OF TEN** due to the “x 10”, which means that the **BASE** is 10 and changing the **EXPONENT** (in this case 11) by 1 will increase or decrease your number by a factor of ten. In Scientific Notation, the exponent must always be a whole number; it can be positive or negative but never a fraction. You may find it useful to remember that the exponent is the number of places that the decimal point *moves* if you want to return to the *long* form of the value.

Also note that numbers that are between -1 and 1 will have negative exponents. For example -0.0084 will be written in Scientific Notation as -8.4×10^{-3} .

2.2.1 USING SCIENTIFIC NOTATION

Complete the exercises that follow to practice using Scientific Notation.

QUESTION 2:

Which of the following numbers (if any) are NOT valid exponents for Scientific Notation?

2	8	0.2	15	-23	-1.5	1/2
---	---	-----	----	-----	------	-----

QUESTION 3:

In the example above, 1.50 is the **COEFFICIENT**. Coefficients in Scientific Notation must be a number (regardless of sign) greater than or equal to 1, but less than 10. Which of the following numbers (if any) are NOT valid coefficients?

3.07	5.2197	-3	0.8	15.7	-1.298	-20
------	--------	----	-----	------	--------	-----

QUESTION 4:

Which of the following numbers results from multiplying 1.2×10^3 by 100 (i.e. 1×10^2)?

1.2×10^1	1.2×10^2	1.2×10^3	1.2×10^4	1.2×10^5	1.2×10^6	1.2×10^7
-------------------	-------------------	-------------------	-------------------	-------------------	-------------------	-------------------

2.3 SIGNIFICANT FIGURES

You may have noticed that in our average Earth Sun distance, we approximated 149,597,870,690 to 1.50×10^{11} by both rounding up as well as using scientific notation. This leads one to ask, “How do we choose the number of decimal places to use in the coefficient, and what does the number of decimal places indicate?” The number of decimal places chosen should reflect the number of **SIGNIFICANT FIGURES** in your calculation. Significant Figures are a handy way to represent **SCALE** and **PRECISION** of a number, i.e. how large is it in comparison to other similar measurements what is the most number of decimal places you can use before you are overstating how well you can actually measure a value.

For example, pretend you have a standard meter stick with markings for centimeters (1/100 of a meter) and millimeters (1/1000 of a meter). You are now asked to measure the length of the classroom and find a length (with the best possible precision) of 12,009 millimeters. Your lab partner now measures the

width of the classroom, but he/she uses a meter stick only marked with centimeters. The result of your lab partner's measurement is a classroom width of 610 centimeters. Let's now express both measurements in centimeters using Scientific Notation and look at the similarities and differences.

$$\text{Your Measurement: Classroom Length} = 1.2009 \times 10^4 \text{ mm} = 1.2009 \times 10^3 \text{ cm}$$

$$\text{Lab Partner's Measurement: Classroom Width} = 6.1\bar{0} \times 10^2 \text{ cm}$$

Both measurements are written in Scientific Notation, following the rules from above. However, your measurement has 5 Significant Figures, while his/her measurement only has 3 Significant Figures. The bar above the zero indicates that it should be considered significant. Typically trailing zeros are NOT considered significant unless indicated otherwise. Now pretend you repeat your lab partner's measurement of the classroom width, but use your millimeter precision ruler.

$$\text{Your Measurement: Classroom Width} = 6096 \text{ mm} = 6.096 \times 10^2 \text{ cm}$$

Because you can measure the classroom width 10 times more precise than your lab partner, your measurement has 4 Significant Figures, while his/her measurement only has 3. **Note that your measurements are identical if you round your measurement to 3 Significant Figures.**

The power of Scientific Notation and Significant Figures can be illustrated by one last example. Let's use your measurement of the classroom length and your lab partner's measurement of the width to calculate the area of the room. The area of the classroom is simply the room length times the room width.

$$\text{Area} = \text{Length} \times \text{Width}$$

$$1.2009 \times 10^3 \text{ cm} \times 6.1\bar{0} \times 10^2 \text{ cm} = (1.2009 \text{ cm} \times 6.1\bar{0} \text{ cm}) \times 10^{(3+2)} = 7.33 \times 10^5 \text{ cm}^2$$

Notice how easy it is to multiply numbers in Scientific Notation. You multiply the coefficients and add the exponents. Also note that while the length measurement has 5 Significant Figures and the width has 3, the result is written with 3 Significant Figures. Because the width measurement was done with a less-precise instrument and the length of the room is much longer than the width, the resulting area must reflect the precision of that device. **In this class, we will typically assume 3 Significant Figures for measurements and calculations (unless otherwise noted). You should therefore refrain from expressing your results in more than 3 Significant Figures.**

2.3.1 USING SIGNIFICANT FIGURES

To practice what you have just learned, answer the following questions. Some questions are tricky, so ask your instructor for assistance if you get stuck.

QUESTION 5:

What is the number of Significant Figures for the numbers given below?

1.203	
1.200	
$1.38\bar{0} \times 10^2$	

QUESTION 6:

Write the following numbers in ordinary notation.

8.008×10^2	
1.58×10^{-1}	
1.38950×10^6	

QUESTION 7:

Write the following numbers in Scientific Notation with **NO GREATER THAN 3** Significant Figures.

34.875×512.8	
0.38×10^2	
8.008×10^7	

QUESTION 8:

Complete the table below, using what you have learned about Scientific Notation and Significant Figures.

Scientific Notation	Ordinary Notation	Coefficient	Exponent	Significant Figures
1.58×10^{-1}		1.58	-1	
	124.9			4
	0.039020	3.902		
1×10^2			2	1

2.4 REPORTING UNCERTAINTY

All measurements have an associated uncertainty in their value. This is simple because we do not have the ability to create measuring devices with *infinite* precision. Consider the ruler example from the Scientific Notation section. In that example, you and your lab partner used rulers with different **RESOLUTION** (yours with millimeter markings and theirs only with centimeter markings). In some situations, you may want to do more than just use Scientific Notation and explicitly report the uncertainty of your measuring device. You would then do this in the following way:

Your Measurement: Classroom Length = 1.2009×10^3 cm +/- 1 mm

Lab Partner's Measurement: Classroom Width = 6.10×10^2 cm +/- 1 cm

Note that the (+/-) indicates to the reader that the uncertainty equally *over-estimates* and *under-estimates* the value. This method of error reporting is called **ABSOLUTE ERROR** reporting. In some instances, it is handy to instead report the **PERCENT ERROR** or **PERCENTAGE ERROR**. These cases include times where the measurement is unit-less, or you have performed multiple measurements and want to express the scatter in your values. The Percent Error and Percentage Error expressed in equation form look like the following:

$$\text{Percent Error} = \frac{\text{Uncertainty}}{\text{Value}} \times 100\% , \text{Percentage Error (or PE)} = \frac{\text{Uncertainty}}{\text{Value}}$$

2.4.1 PRACTICE REPORTING UNCERTAINTY

QUESTION 9:

Using a meter stick with no markings, you measure the width of Van Allen Hall and find a value of 20 meters. What are the Absolute and Percent Errors of your measurement? (Hint: 20 m +/- ?)

Absolute	
Percent	

3 MEASURING THE REALLY BIG (AND THE REALLY TINY)

3.1 QUICK NOTE ABOUT USING YOUR CALCULATOR

Most calculators have the ability to quickly enter numbers in Scientific Notation (instead of always entering a number, then multiplying by 10 raised to a power). However, one of the most problematic complications is that different calculators, computers, books have different ways of displaying scientific notation. Your calculator may use a button labeled **EE**, **E**, or **EXP**. Locate the appropriate button for your calculator and try entering a number such as 3.2×10^5 . For example, if your calculator uses **EXP**, you can type 3.2 <EXP> 5.

You will find this type of functionality on just about any calculator that does math (function like sin, cos, tan, log, y^x , etc...). This means that most anything you want to calculate can be done easily on a \$10 calculator. For this reason, a simple calculator might be a good investment to make (even if you already have a more powerful calculator, as some instructors may not allow you to use the more advanced calculators during exams).

3.2 USING RATIOS

Because it is difficult for most people to visualize really large or really small numbers, we often compare large quantities to a quantity that we can comfortably visualize. This is called a **RATIO**. Ratios are handy, as using them often simplifies the math and makes constants common to both numbers drop out (so we get to do less math). Most of the problems you will do in this course involve some type of ratio. To illustrate how ratios aid in understanding large scales, consider the following example.

During the peak of the 2008 Iowa City flood, approximately 40,000 cubic feet of water per second was flowing through the Coralville dam (including the emergency spillway flow). It is difficult to visualize that

amount of water. However, we can think about the amount of water contained in something familiar and use it for comparison. An Olympic sized swimming pool is typically 160 feet by 80 feet with a depth of 6 feet. This gives us a total volume of 76,000 cubic feet. Divide the volume of the flood water to that of the swimming pool. Make your calculation below.

QUESTION 10:

What is the flood water flow rate (volume per time) in terms of Olympic sized swimming pools? Express your result in Scientific Notation with 3 Significant Figures.

$\frac{40,000 \text{ ft}^3}{\text{s}} \times \frac{1 \text{ pool}}{76,000 \text{ ft}^3}$	
--	--

If you calculated your values right, you found that the water flow rate is approximately equal to 1 Olympic pool every 2 seconds, i.e. at this flow rate it would take less than 2 seconds to empty the UI Fieldhouse swimming pool.

3.3 COMMON SCALES IN ASTRONOMY

One of the biggest difficulties when first studying Astronomy is getting comfortable with different (sometimes drastically different) scales. While we may feel comfortable with scales in our day-to-day lives (like the size of a city, or the mass of a car, etc.), these references are many orders of magnitude larger than objects at the atomic level and many many orders of magnitude smaller than the distance across galaxies or the masses of stars.

Let's use what we have learned about ratios to gain a better understanding of objects you will hear about throughout the course.

Express all your answers with 3 Significant Figures.

QUESTION 11:

The wavelength of red light is approximately 665 nanometers (1 nm = 1 x 10⁻⁹ m). Given that your fingernails are roughly 1 centimeter wide, how many waves of red light does it take to span one of your fingernails?

$\frac{\text{red wavelength}}{6.65 \times 10^7 \text{ m}} \times \frac{1 \times 10^{-2} \text{ m}}{\text{fingernail}}$	
--	--

QUESTION 12:

The total mass of all the objects in the Solar System (planets, meteors, comets, etc.) **excluding the Sun** is roughly equal to 1 x 10²⁷ kg. Look up the mass of the Sun in kilograms (check the Appendix or use the web) and calculate the ratio of the solar mass to the mass of everything else.

Solar Mass	
Mass Ratio	

QUESTION 13:

Think of two object everyday object with roughly the same mass ratio that will help give you a better understanding of the value. Write your analogy below.

Analogy (Sun)	
Analogy (Rest of the Solar System)	

QUESTION 14:

Imagine you have been hired by the Department of Physics and Astronomy to build a scale model of the Solar System across Van Allen Hall. The Sun will be on the east end of the building and Neptune (30 AU) will be located on the west end, rough 100 m away. What is the ratio of the length of Van Allen Hall to the size of the Solar System? Express your result both with mixed units and as a unit-less decimal. ($1 \text{ AU} = 1.50 \times 10^{11} \text{ m}$)

Model Ratio (m/AU)	
Model Ratio (unit-less)	

QUESTION 15:

Where (how far from the east end) is the earth located in this model?

Earth Location	
----------------	--

QUESTION 16:

The Sun has a radius of 6.96×10^8 meters. How big is the sun in this model? Give an example of an object of similar size. How about the earth, with a radius of 6.37×10^6 meters?

Solar Model Size (6.96×10^8) x (unit-less Model Ratio)	
Example Solar Object	
Earth Model Size	
Example Earth Object	

QUESTION 17:

At the very edge of the Solar System is a region of icy comets (composed mostly of water, ammonia, and methane) named the **OORT CLOUD**. The Oort Cloud represents farthest distance that the Sun's gravity influences the motion of objects and is located at a distance of roughly 50,000 AU. Where (near what major city) would you place the Oort Cloud on your model?

$(50,000 \text{ AU}) \times (\text{m/AU Model Ratio})$	
Nearby City	

QUESTION 18:

In 2006, the US launched the "New Horizons" spacecraft, traveling to Pluto (39.5 AU) at speeds up to 10 miles per second (16 km/s). How long will it take "New Horizons" to reach the dwarf planet? Express your answer in years. (*Note: This is a somewhat simplified calculation, as spacecraft do not travel in a straight line, but instead "curve" towards the target*)

$39.5 \text{ AU} \times \frac{\text{s}}{16 \text{ km}}$	
---	--

QUESTION 19:

Assuming an average human lifespan of 67 years, how far will the space craft have traveled in one human lifetime?

$67 \text{ years} \times \frac{16 \text{ km}}{\text{s}}$	
--	--

QUESTION 20:

The distances to nearby stars are given in units called parsecs (pc). 1 parsec is equal to 3.09×10^{16} meters or 206,265 AU. At best speed, how many lifetimes would it take for the "New Horizons" satellite to reach the nearest stars?

Number of Lifetimes	
---------------------	--

Name _____

Date _____

Lab Partner(s) _____

Project Score

MEASURING THE SKY

Based on text by Professor S. Spangler

PROJECT LEVEL: Introductory

PROJECT GOALS: Students will learn about angular measurements, how they change with distance, and how they are used to estimate linear distances

1 INTRODUCTION

The point of this lab is to get you outside, looking at and thinking about the sky. You will also become acquainted with angular measure and the **HORIZON SYSTEM** for specifying the coordinates of an astronomical object.

THIS WEEK'S PROJECT WILL HAVE THREE PARTS.

- I. We will make a simple scientific device with which you can measure the angular distance between two astronomical objects, such as a bright star and the Moon or a planet.
- II. We will go on the roof of Van Allen Hall and become acquainted with the Horizon System for describing the positions of astronomical objects, and use instruments called **THEODOLITES**. We will measure the **AZIMUTH** and **ALTITUDE** angles of landmarks around Iowa City. We will also measure the altitude and azimuth angles of the Sun, and see how they change during the lab period.
- III. In coming weeks you will use these Theodolites to determine distances via **PARALLAX** measurement, observe the changing position of sunset, and make other basic astronomical measurements.

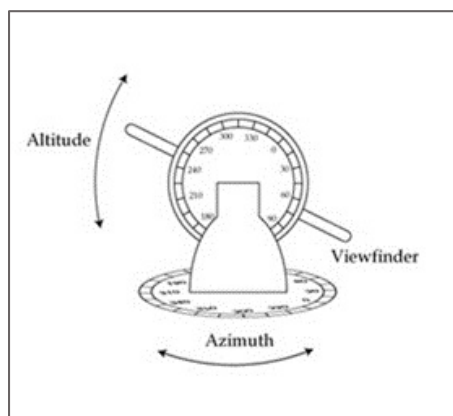


FIGURE 1 - DIAGRAM OF A BASIC THEODOLITE; A DEVICE USED TO MEASURE AZIMUTH AND ALTITUDE ANGLES

2 SIMPLE SCIENTIFIC DEVICE

2.1 BUILDING A ANGULAR MEASURING DEVICE

Ask your instructor for a length of string. While in the lab room, there is a mark on the outer wall which indicates 8 degrees. If you stand on the far side of the room (inner wall), this mark subtends 8 degrees. Hold your string at arm's length and hold your fingers at the points corresponding to the tips of the mark. Either make knots here or use a pen to mark the string at these two points. Put another knot or mark halfway between. You now have knots or pen marks at intervals of 4 degrees. Divide these to provide 2 degree intervals. Finally, copy this whole sequence over, so you have a string capable of measuring a total angle of 24 - 30 degrees. **Note the resolution and total angular span below.**

QUESTION 1:

What is the Resolution and Total Angular Span of your home-made measuring device?

Resolution	
Angular Span	

2.2 TESTING YOUR MEASURING DEVICE

Before testing your string out on the sky, let's try it out on something indoors. Go into the hallway and have your lab partner stand 50 feet away. Now, use your string device to measure the height of your lab partner in degrees.

QUESTION 2:

What is the Angular Size of your Lab Partner?

Angular Size (θ)	
---------------------------	--

Using the relationship below, now convert the angular measurement to a linear measurement. (This is a common application of angular measurements, one you will perform multiple times throughout the course.)

To convert angular size to linear size, use the following relationship:

$$d = D \times \frac{\Delta\theta}{57.30 \text{ deg}}$$

Here, **D** is the distance to your lab partner (50 feet in this case), $\Delta\theta$ is the angular size in degrees, and **d** is the linear size (or in this case, the height of your lab partner).

How well did you do? If you wanted to express this (your accuracy) as a number, what would that number be? One way would be to subtract the known value from the measured one. However, this does not take into consideration the size of the object you are measuring. For example, if you are off by a few feet

measuring the height of your lab partner, the error is much more significant than if you were measuring the height of a building.

To express this *significance*, we will use a formula called the **FRACTIONAL ERROR EQUATION**.

The Fractional Error is expressed as:

$$\text{Fractional Error} = \frac{\text{Known Value} - \text{Experimental Value}}{\text{Experimental Value}}$$

Measure your lab partner's height directly using the provided tape measure (if unknown) and calculate the Fractional Error of the linear size you measured above.

QUESTION 3:

Calculate the Fractional Error in your height measurement?

Known Height (feet)	Measured Height (feet)	Fractional Error

2.3 MEASURING LARGER OBJECTS

You are now ready to use your string measuring device to make a larger measurement. Follow your lab instructor to the West end of Van Allen Hall and use your string to measure the distance from the bottom of the First Congregation Church steeple to the top. Consider the steeple to start where the red bricks end and stop at the very top of the tower peak. Consult the image below for more information.

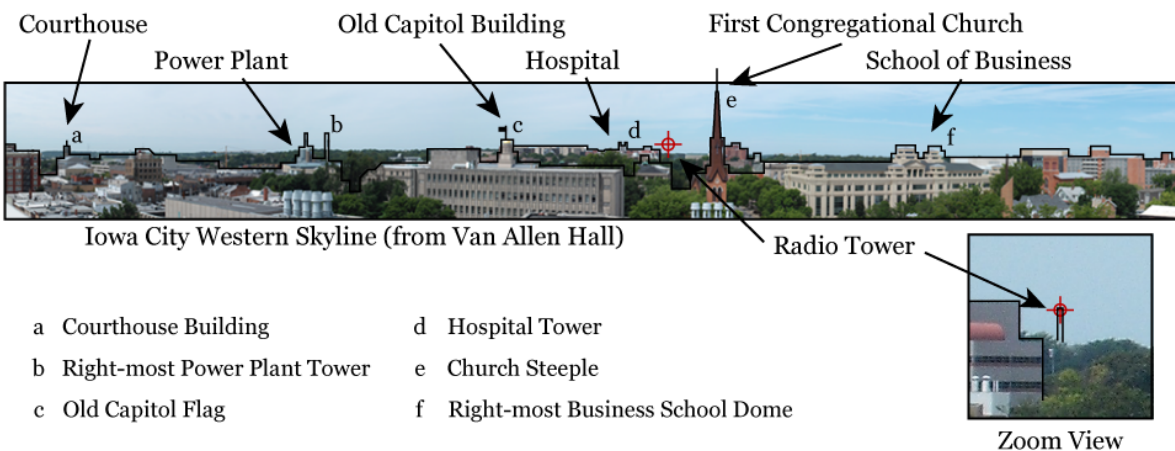


FIGURE 2 - IOWA CITY SKYLINE

QUESTION 4:

What is the Angular Distance between the bottom and top of the Church steeple? If the distance to the Church is 120 meters, how tall is the steeple?

Angular Distance (θ)	
Steeple Height (m)	

You are now done with Part 2 and can put away your string.

Later in the semester, we will use the string to measure angular distances between stars, and between stars and planets, so make sure you keep your string.

3 MEASUREMENTS WITH THE THEODOLITES

The Theodolites are mounted on the west railing of the roof of Van Allen Hall. A schematic illustration of one is shown in Figure 1.

3.1 GETTING FAMILIAR WITH THE THEODOLITES

To use the Theodolite, sight through the tube at the object you are measuring. The viewfinder tube will move in both azimuth angle (horizontal scale) and altitude angle (vertical scale). Start out by familiarizing yourself with the instrument. When pointing the tube at the horizon, due south, you should measure an azimuth angle of 180 degrees, and an altitude angle of 0 degrees. Move the sighting tube to the east. You should see the azimuth angle change to an angle less than 180 degrees. Point the sighting tube higher up in the sky. You should measure an altitude angle greater than 0 degrees. Carefully read the scales on the Theodolites. **Record the resolution of both scales in the table below. Note that this is also the UNCERTAINTY in your measurements.**

QUESTION 5:

What is the Resolution of the Theodolite?

Azimuth Resolution	
Altitude Resolution	

3.2 MEASURING THE LANDSCAPE

The teaching assistant will point out a few objects in the Iowa City western skyline. Use the Theodolite to measure the Azimuth and Altitude positions of the objects given. If you forget which object is which, please consult Figure 2 showing the Iowa City skyline.

QUESTION 6:

Measure the azimuth and altitude angle of all three objects, and record them here. Make sure to measure these values to the precision of the device.

Object	Azimuth	Altitude
Courthouse Building Flag (a)		
Power Plant Tower (b)		
Old Capitol Building Flag (c)		
Hospital Tower (d)		
Church Steeple (e)		
Business School Dome (f)		

3.3 COMPARISON TO STRING MEASURING DEVICE

Now that you are more familiar with the Theodolites, let's repeat the Church steeple measurement you made in Part 1 and compare the results. With the Theodolite, record the position of the bottom and top of the steeple. Next, use the positions to calculate the **ANGULAR DISTANCE** between the two points.

The **ANGULAR DISTANCE (θ)** is given by:

$$\Delta\theta = \sqrt{\Delta AZ^2 + \Delta AL^2}$$

Where ΔAZ is the difference between the azimuth angles of the tree and the Jefferson building, and ΔAL is the difference in the altitude angles.

QUESTION 7:

What is the Angular Distance between the top and bottom of the Church steeple, measuring now with the Theodolite? Using the Theodolite measurement as the *known* value, what is the Fractional Error in your measurements? Use the workspace provided.

Bottom	AZ		AL	
Top	AZ		AL	
Change in Angle	ΔAZ		ΔAL	

$\Delta\theta$ Theodolite	
$\Delta\theta$ String (from Question 4)	
Fractional Error	

4 CONCEPT QUESTIONS

Please answer the following questions relating to concepts from this lab. Most of the information needed can be found in the introductory material or presented throughout the lab text.

QUESTION 8:

What range of angles does Azimuth cover? What range does Altitude cover?

QUESTION 9:

In Part 2, you measured the height of your lab partner standing 50 feet away. What, if anything, would change if your partner was standing 100 feet away? How about 1,000 feet?

QUESTION 10:

Imagine you are describing the location of the sun you just measured with your Theodolite to a friend who is studying abroad in Europe. Will he/she observe the sun in the same location as you observed it in Iowa City? Can you describe a coordinate system that would be better to use in the situation?

Name of Student

MEASURING THE AZIMUTH OF SUNSET THROUGH THE SEMESTER

This part of the lab project is to be done during the next 2-3 months of the semester. During your lab section, you should go to the roof of Van Allen Hall on clear days and measure the altitude of the sun. Try and do this 4 times throughout the semester to observe how the position of the sun changes from month to month when observed at similar times. Use the table below to record your results and turn it in after the final session.

	Date	Time	Azimuth
Session 1			
Session 2			
Session 3			
Session 4			

Name _____

Date _____

Lab Partner(s) _____

Project Score

USING STAR CHARTS

Based on text by Professor S. Spangler

PROJECT LEVEL: Introductory

PROJECT GOALS: Students will learn about various types of star charts and their use. Students will also learn about the Equatorial Coordinate System.

1 INTRODUCTION

Star charts are literally maps of the sky. We use them for a number of purposes, such as telling us what time of night certain stars and constellations will be visible, plotting the positions of the Sun, Moon, and planets against the background stars, and locating non-stellar objects such as nebulae and galaxies in the sky.

In this week's activity, we will become familiar with star charts and how to use them. You will use three types of star charts. These chart types are:

- Sky and Telescope Star Wheel
- The SC1 Constellation Chart
- The Pocket Sky Atlas

Today in lab, you will use each of these charts to answer a set of astronomical questions. Later in the Semester, you may also be asked to use them in a nighttime observing exercise designed to help learn features of the sky.

Students may keep the SC1 chart for use throughout the semester. The star wheels and Pocket Sky Atlases should be returned to your teaching assistant at the end of the lab period or observing period.

1.1 A DIGRESSION ON STAR NAMES

We will be spending a lot of time this semester finding stars and using them as points of reference. It is worthwhile to learn about how they are named.

- The brightest stars have commonly used names which come from Greek (Antares), Latin (Regulus, Castor, Pollux), and most commonly Arabic (Betelgeuse, Deneb, Algol)

- Second-ranked stars (less bright) also have Arabic names (Algenib, Na'ir al Saif, etc), but they typically don't appear in scientific use.
- The most common way of naming reasonably bright stars (even the brightest ones) is by a Greek letter, followed by the name of the constellation. Examples are Alpha Lyrae (α Lyr), Delta Scorpii (δ Sco), Beta Cygni (β Cyg). The choice of Greek letter indicates the relative brightness of the star compared to other stars in the constellation. Relative brightness follows the order of the Greek alphabet ($\alpha, \beta, \gamma, \delta$, etc.).
- You may also notice that the names of the constellations have changed a little, i.e. Lyra goes to Lyrae, Scorpius to Scorpii, and Cygnus to Cygni. Those who have studied Latin will recognize the latter form is the genitive, or possessive of the first form. Don't worry about the Latin grammar; just write them down as best you can.

QUESTION 1:

Imagine there is a Constellation named in your honor. What would the name of the brightest star be? How about the 5th brightest?

Brightest Star Name	
5 th Brightest Star Name	

2 THE STAR WHEEL

The Star Wheel is an analog computer for calculating the **HORIZON SYSTEM** positions of stars, based on their celestial coordinates, the date, and the time of day. Star wheels are specific to the latitude at which observations are made. Rotate the wheel until the date of interest lines up with the time of day you want. Take notice that you can find positions for both **DAYLIGHT SAVINGS TIME** (Yellow) or **STANDARD TIME** (White). The oval region shows you the stars that are above the horizon, and also shows the different directions. This oval region is a reasonably accurate picture of the sky above the horizon. It allows a good estimate of the azimuth and altitude angles of any star at the specified date and time.

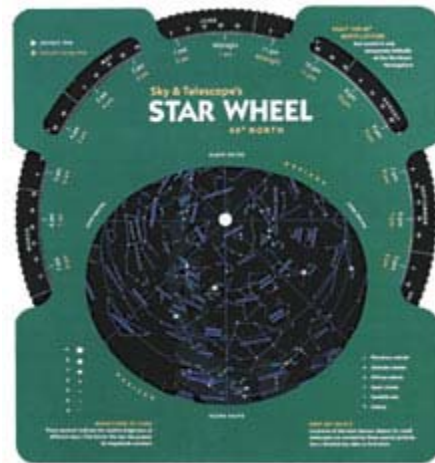


FIGURE 1 - SKY AND TELESCOPE STAR WHEEL

If you flip the star wheel over, you have an alternative (and in some ways superior) representation of the stars close to the horizon in the south and southwest.

2.1 STAR WHEEL EXERCISES

Use the star wheel provided to answer the following questions about the evening sky. Make sure to use the correct times (standard time vs. daylight-savings time) when answering the questions. Ask your lab instructor if you are unsure which time mode you are in.

QUESTION 2:

Dial up 9PM for tonight. What constellation has just risen? Which has just set?

Just Risen	
Just Set	

QUESTION 3:

In what part of the sky at 9PM would you find the constellation Ursa Major, otherwise known as **The Big Dipper**? Try to be descriptive as you can. For example, you might write something like “south south east, low in the sky”.

Location	
----------	--

QUESTION 4:

What bright star is close to the **LOCAL MERIDIAN** and about halfway up the sky from due south? The local meridian line is an imaginary arc in the sky connecting the Celestial North Pole to the South Celestial Pole, traveling through the point directly above your head.

Bright Star	
-------------	--

QUESTION 5:

The constellation Orion is a favorite nighttime object for many observers. What months is Orion visible in the early evening? For the purpose of this question, let *the early evening* be 7 PM.

Months for Orion	
------------------	--

QUESTION 6:

The brightest star in the sky is Sirius, in the constellation of Canis Major (**The Big Dog**). On approximately what date will it be rising just before 5 AM standard time?

Date Sirius rises in the AM	
-----------------------------	--

Interesting Note: This corresponded to the time of year when the Nile River flooded; the ancient Egyptians made a supernatural connection between the rising of this bright star, and the annual flood which brought life to Egyptian civilization.)

3 THE SC1 CONSTELLATION CHART

The SC1 chart is a flat, long strip of paper that resembles maps of the world. Instead of the surface of the Earth, however, the SC1 shows the surface of the celestial sphere. The two coordinates on the SC1 are the celestial coordinates of Right Ascension and Declination. The SC1 is useful for showing the coordinates and names of a large number of stars. It can be used by itself for learning the constellations, although it is not quite as convenient as the star wheel.

The SC1 shows the **MAGNITUDES** of stars by the size of the dot representing the star. The correspondence between the magnitude of a star and the size of its plotted symbol is shown in the scale on the lower right edge of the chart. Note that the brightest stars like Arcturus and Vega have magnitude 0, while the faintest ones visible to the eye have magnitudes of about 5-6. The stars in the Big Dipper are “second magnitude”, meaning magnitudes between 1 and 2.

The SC1 Chart can be used to tell which stars are up at any time of the day or night, although it is not as easy as with the star wheel. Along the bottom edge of the chart, just below the numbers corresponding to the **RIGHT ASCENSION**, are dates. A ruler placed vertically at that point shows the location of the meridian at 8PM standard time on that date. The location of the meridian at later times on that date can be found simply by moving the ruler 1 hour of Right Ascension to the left for each hour of time. Note the heavy double line running horizontally through the middle of the chart. This line represents the **CELESTIAL EQUATOR**. This is the line that defines a value of 0 degrees for the **DECLINATION**. The curved line that looks like the sine function from trigonometry represents the **ECLIPTIC**, which is an extremely important imaginary line in astronomy. This is the path along which the Sun, Moon, and planets move.

The dates along the ecliptic show you the location of the Sun on that date. From this chart, you can see that the Sun reaches its highest declination on about June 21.

3.1 SC1 CHART EXERCISES

Answer the following questions using your SC1 Chart.

QUESTION 7:

The celestial coordinates for M44 (*The Beehive Cluster*) are Right Ascension (RA) = 8h40m, Declination (Dec) = 20d. What constellation is M44 in?

Location of M44	
-----------------	--

QUESTION 8:

What bright star has the following coordinates: RA = 19h51m, Dec = +8d51m?

Bright Star	
-------------	--

QUESTION 9:

Find the location of the meridian at 8PM tonight. Is the star you found above east of the meridian, on the meridian, or to the west of the meridian?

East/West of Meridian line	
----------------------------	--

QUESTION 10:

At 9Pm tonight, where in the sky would you look to find the constellation Perseus? Try to be descriptive as you can. For example, you might write something like “due north, middle of the sky”.

Location of Perseus	
---------------------	--

QUESTION 11:

What is the RA and Dec of the sun on the following days?

March 21 st	
June 21 st	
Sept 21 st	
December 21 st	

4 “SKY AND TELESCOPE” POCKET SKY ATLAS

The Pocket Sky Atlas is a detailed map of the sky in which each page shows a region about the size of a constellation, and which plots stars as faint as 7th magnitude. This is considerably fainter than can be seen with the unaided eye, but easily visible with binoculars. The Pocket Sky Atlas is useful for finding fainter stars, locating planets and asteroids that cannot be seen with the naked eye, and observing non-stellar objects such as nebulae and galaxies. We will use the Pocket Sky Atlas for this last purpose later in the semester.

An analogy can make the function of the Pocket Sky Atlas clearer. The star wheel and SC1 Chart are similar in function to a map of the entire world. The Pocket Sky Atlas is however more like an atlas which has a map of each state on a single page, with similar detail for the rest of the world.

The legend for the atlas is given just before Map 1, and shows

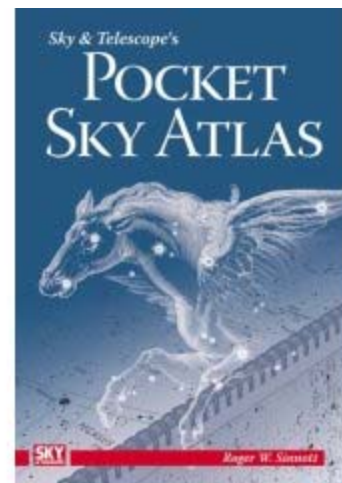


FIGURE 2 - POCKET SKY ATLAS

the scale for the magnitudes of stars, the symbols used for star clusters and galaxies, etc. The maps are organized in sets of 10, with 10 maps being used to cover 3 hours of Right Ascension. For example, maps 1 - 10 cover the Right Ascension range 0h – 3h, charts 31 - 40 cover the range 9h – 12h, etc.

Each map shows the grid of celestial coordinates, allowing measurement of a position to fraction of a degree, the outline of constellations in that part of the sky, and the locations of galaxies, nebulae, and star clusters. Note that the smaller dots represent fainter stars. The location of the ecliptic is also indicated.

The Pocket Sky Atlas is a powerful aid to the sky, but it is best used together with the Star Wheel or SC1 to get oriented.

4.1 GENERAL EXERCISES

Use any of the charts you like to answer the questions below.

QUESTION 12:

An object of great interest in astronomy, which we will discuss later in the semester, has the following coordinates: RA = 0h43m, Dec = +41d16m. What is the name of this object? What kind of astronomical object is it?

Mystery Object Name	
Object Type	

QUESTION 13:

An object of great interest in astronomy, which we will discuss later in the semester, has the following coordinates: RA = 0h43m, Dec = +41d16m. What is the name of this object? What kind of astronomical object is it?

Mystery Object Name	
Object Type	

QUESTION 14:

Give the name of a star located within a degree or two of this object which would help you find it in the night sky. Give the name of a second star.

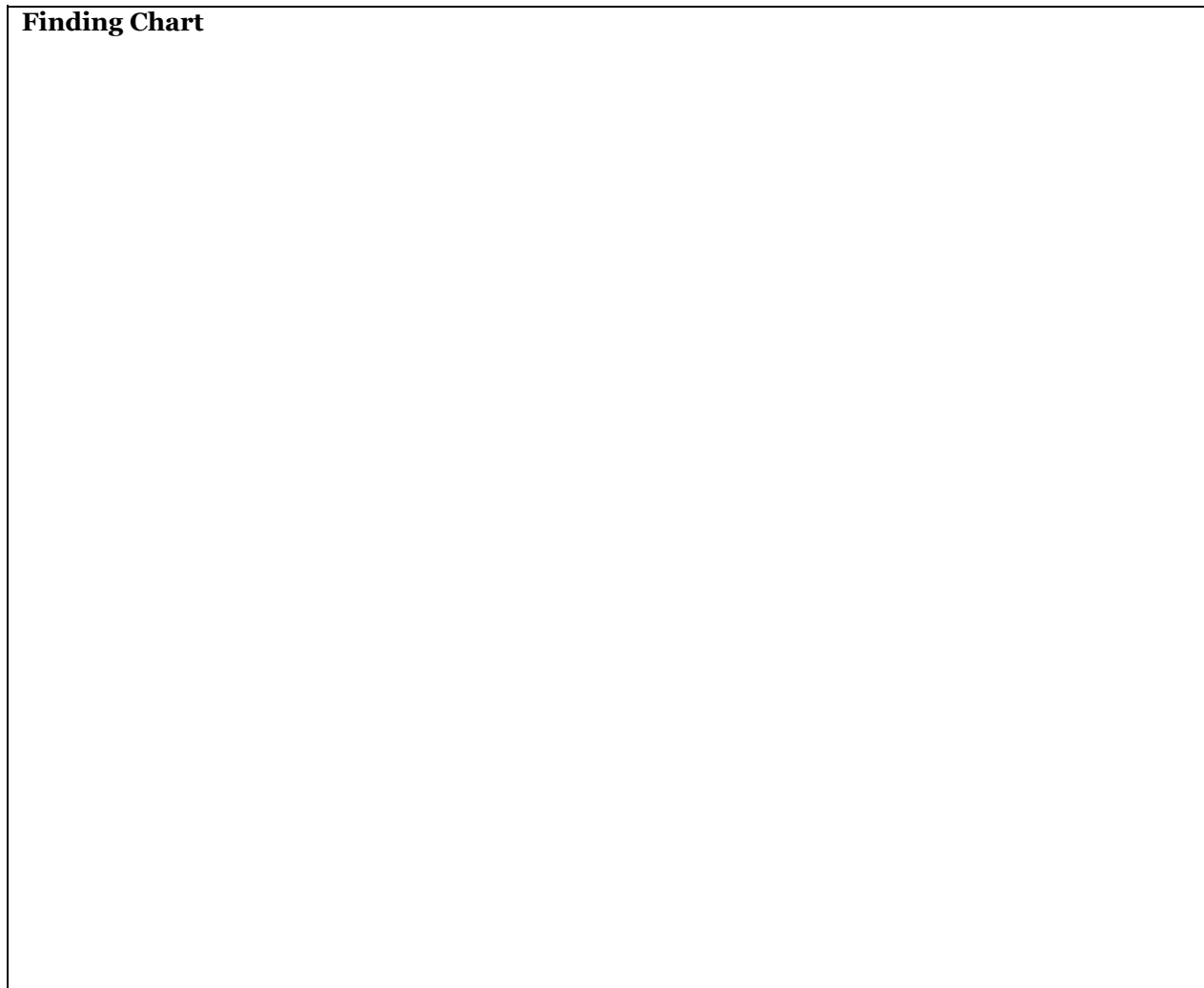
Finder Star 1	
Finder Star 2	

QUESTION 15:

In the space provided below, draw a map that would help you find this object when observing it through the eyepiece of a low magnification telescope or a pair of binoculars. This sort of map is called a **FINDING CHART**. Keep in mind that the **FIELD OF VIEW** (the region of the sky you can see) with a small telescope is ~ 3-5 degrees.

A good finding chart contains the brightest stars in the region and notes indicating where the object is situated relative to the pattern the stars make in the sky. Label the galaxy and bright stars and try to identify one geometric pattern (triangle, square) that will help you to better locate your object.

Finding Chart



Name _____

Date _____

Lab Partner(s) _____

Project Score

SPECTROSCOPY

Based on text by Professor S. Spangler

PROJECT LEVEL: Intermediate

PROJECT GOALS: Students will measure the wavelength range of the visible colors, and learn about different light emission processes.

1 INTRODUCTION

Spectroscopy is the measurement of the intensity of light at many different wavelengths, and the interpretation of those measurements using theories of physics. **Spectroscopy is absolutely crucial to astronomy.** With few exceptions, such as the study of rocks returned from the Moon or data from spacecraft on Mars, almost everything we know about the universe comes from analysis of light from astronomical objects. **It is from spectroscopy that we have learned of the temperatures, luminosities, and chemical compositions of the stars.**

Spectroscopy is also of importance in other fields of science and technology. It can be used to measure the chemical and physical state of ocean water, glucose levels in human blood, and in industrial procedures. Spectroscopy is one of the better examples of a field of physics that has significantly impacted society.

The purpose of this laboratory exercise is to illustrate some of the capabilities of spectroscopy, using a sophisticated spectroscopic instrument. You will study spectra from different types of objects in the lab and measure wavelengths of spectral lines. You will also be asked to analyze the spectral properties of two important gasses, (Hydrogen and Helium) and compare your measurements to the known values.

1.1 EXPLANATION OF EQUIPMENT

For much of twentieth century astronomy, the detector was a **PHOTOGRAPH PLATE**. Photographic plates are still used in some spectroscopic applications. Modern instruments use a CCD (charge-coupled device) in which an electronic wafer builds up an electrical charge when light shines on it. This charge is later read out and measured by a computer.

Most spectrometers are fundamentally simple in design. A thin beam or ray of light passes through, or is reflected from an object which spreads out, or disperses the light according to wavelength. An easy way of visualizing this is to think of a prism which spreads out light into all the colors of the rainbow. The dispersing element (a **PRISM** or **DIFFRACTION GRATING**) sends the violet light in one direction,

the yellow light in a slightly different direction, the red light in still a different direction, and so on. This dispersed, polychromatic light is then focused onto a surface which acts as a detector.

1.1.1 OCEAN OPTICS SPECTROMETER

The spectrometer which is used in this exercise is a **USB2000** device manufactured by **Ocean Optics Company**. It is an amazingly compact device which has one input (a fiber optics cable which shines the light into the spectrometer) and a USB port to send data to the analysis computer. Software provided with the spectrometer permits display and analysis of the spectra.

An image and diagram of the USB2000 is shown in the figure below.



FIGURE 1 - OCEAN OPTICS SPECTROMETER

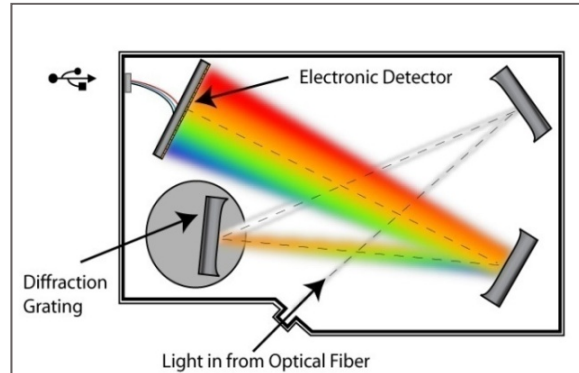


FIGURE 2 - DIAGRAM OF SPECTROMETER LIGHT PATH

When the spectrometer is connected to the computer, and the control program is running, there are a number of simple controls the user has over the display and analysis of the spectrum.

- The green vertical cursor measures the wavelength of observation and gives the intensity of light at that wavelength. It is controlled by the mouse and the wavelength-intensity values are shown in the lower left corner of the screen. If you do not see this, ask your lab instructor for help.
- Right above the spectrum are a number of data boxes that can be set by the user. The one at the far left gives the integration time (the length of time the device averages the signal before readout). The units are milliseconds. The longer the integration time, the stronger the signal is recorded. Next to it is the number of spectra that are averaged before display. A larger the number of spectra average results in a clearer and less noisy the spectrum.
- Finally, at the top of the screen will be a set of standard Windows menu bars. The one labeled "View" can be used to set the scale of the spectrum. If you bring up the dialog box, you can set the range of the **ABSCISSA** (x coordinate) and **ORDINATE** (y coordinate). This is a very useful feature for making precision measurements of spectral lines, or examining the shape of spectral lines. Each spectrometer is designed to operate in a specific range of abscissa and ordinate values. Experiment and make note of the ranges are for the spectrometer at your station.

2 MEASUREMENTS

Double click on the **OOI BASE 32** icon to start the program. Look around on the lab table and identify the USB2000 unit, the fiber optics cable connected to it, the stand for holding the fiber optics cable, and the USB cable connected to the computer. You're ready to start.

There are a number of steps or parts to this lab, intended to give you a clear idea of what the spectrometer is doing, and the information we have in the light from an object.

2.1 SPECTRA OF LIGHT SOURCES

There is a black plastic box on the lab table with several small light bulbs on the top. These bulbs are labeled and each is a different color. Some bulbs may emit light at a wavelength undetectable by the human eye. For each of the bulbs, measure the central wavelength (λ **CENTER**, wavelength at which the light bulb is brightest), and the range of wavelengths over which the light emits significant amount of light. Record your data in the table below.

QUESTION 1:

Complete the table below.

Bulb #	Color	λ Center (nm)	λ Range (nm)	Comments (if any)

2.2 SPECTRAL PROPERTIES OF HYDROGEN AND HELIUM

Kirchoff's second law of spectroscopy says that a hot, tenuous gas emits a spectrum which consists of isolated, bright emission lines. The wavelengths at which these lines occur are a unique "fingerprint" of the gas that is being excited. Each lab table will have two discharge tubes, one of hydrogen and the other of helium.

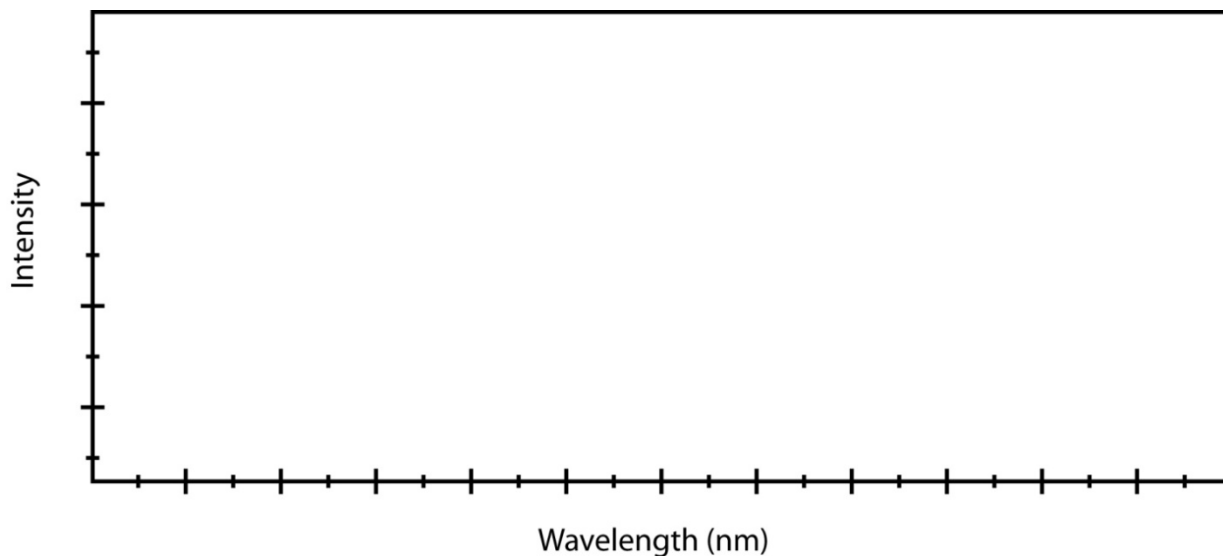
For each source, sketch the observed emission. **Be sure and put numbers on the axes and use the correct units!** Also, try and identify the 4 strongest spectral lines for each source. You may have the increase the sensitivity of the spectrometer by changing the integration time, or the number of cycles

to average. Some lines will be much more intense than the others, so you will need to record these first, then concentrate on the others. Further, when measuring the wavelength of a line, be sure the cursor is exactly in the middle of the line. Otherwise, a significant and avoidable error will result.

SAFETY NOTE: THE POWER SUPPLIES FOR THE SPECTRUM TUBES ARE HIGH VOLTAGE AND THE TUBES WILL GET VERY HOT. FOR YOUR SAFETY, DO NOT TOUCH CONTACTS ON THE POWER SUPPLIES AND ALLOW TIME FOR THE SPECTRUM TUBE TO COOL BEFORE HANDLING.

QUESTION 2:

Make an accurate sketch of the observed Hydrogen Emission Spectrum below.



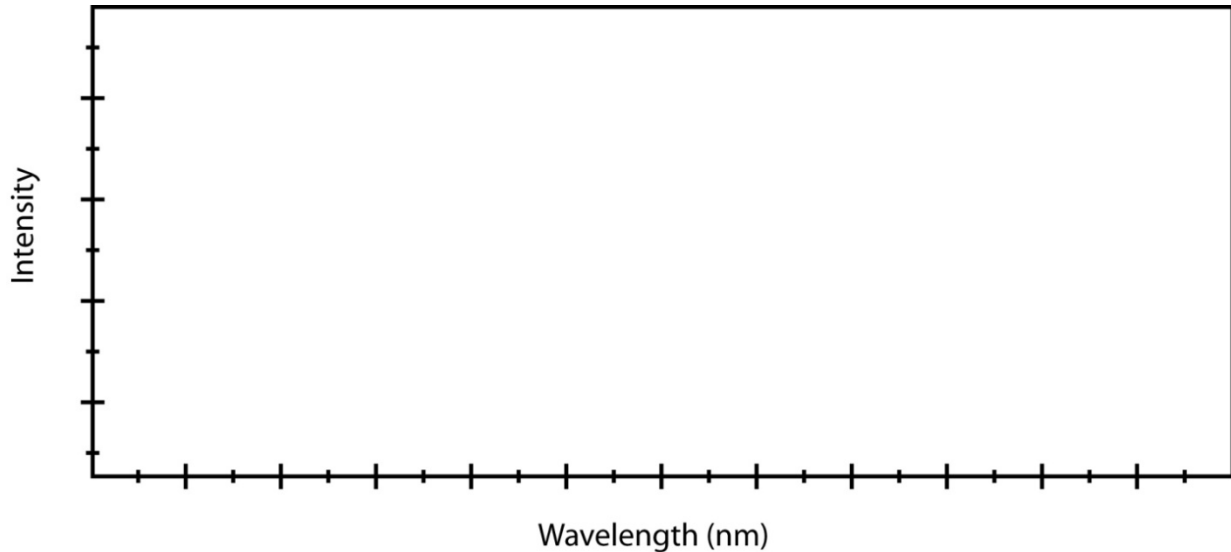
QUESTION 3:

What are the 5 most intense spectral lines in the Hydrogen spectrum?

Relative Intensity	λ Measured	Approximate Color
1 st		
2 nd		
3 rd		
4 th		
5 th		

QUESTION 4:

Make an accurate sketch of the observed Helium Emission Spectrum below.



QUESTION 5:

What are the 5 most intense spectral lines in the Helium?

Relative Intensity	λ Measured	Approximate Color
1 st		
2 nd		
3 rd		
4 th		
5 th		

2.3 SPECTRUM OF A CONTINUOUS SOURCE

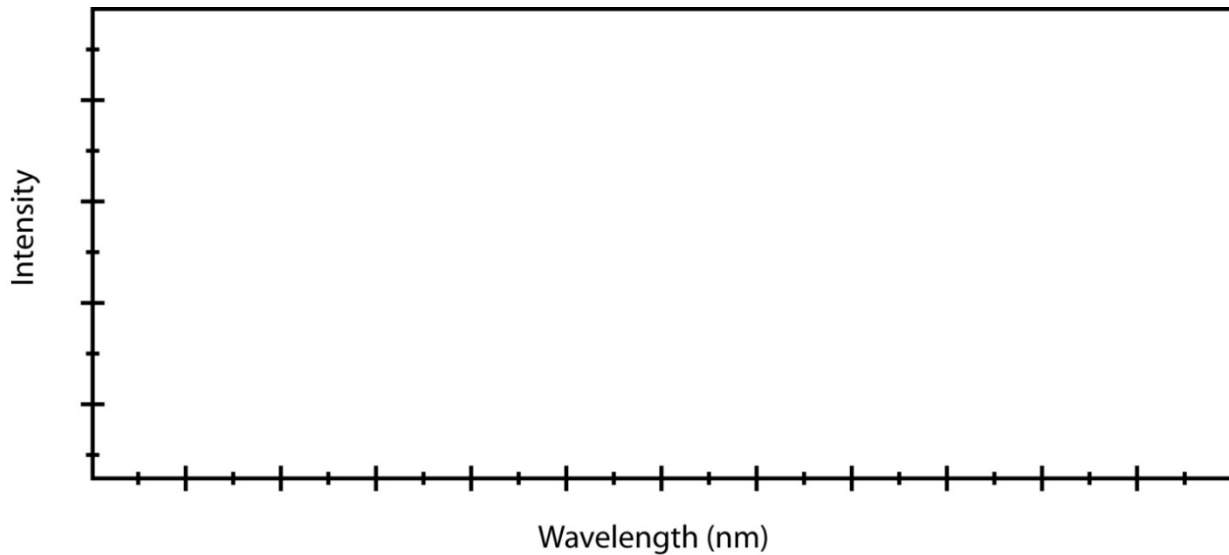
Some sources emit radiation across a continuous range of wavelengths. One example of a continuous source is an incandescent light bulb. Turn on the over-head projector near your station and point the opening of the fiber optic at the light bulb inside. The bulb will be bright, so adjust parameters such as integration time, number of cycles to average, and scale of the spectrum to give you a good display that is convenient for making measurements.

Make a reasonably accurate drawing of the spectrum you see in Figure 3.

It is important to make a fairly accurate sketch here as you will make a calculation based on your sketch later in the lab.

QUESTION 6:

Make an accurate sketch of the observed Continuous Spectrum below.

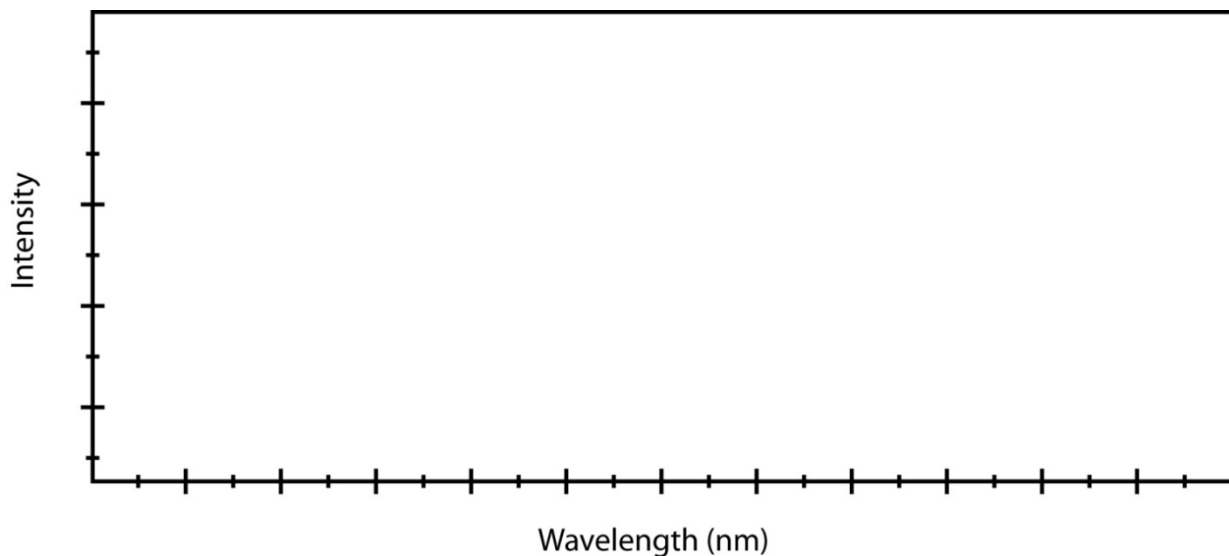


2.4 SPECTRUM OF THE SUN

Now point the entrance to the fiber optics cable at the window of the lab room. Direct sunlight is not necessary, and even on a relatively cloudy day, the light should be bright enough. The spectrum of this light will be the spectrum of sunlight. Draw an accurate sketch of the spectrum below. Again, be careful here as you will use this sketch to make a calculation later.

QUESTION 7:

Make an accurate sketch of the observed Solar Spectrum below.



The solar spectrum is a mix of the continuous spectrum you observed with the light bulb with a second spectrum called an **ABSORPTION LINE SPECTRUM**. An absorption line spectrum is similar to the emission line spectrum examined earlier except in this case, cooler clouds of gas between you and the source are now “stealing” radiation from the continuous spectrum. Absorption lines can also be used as “fingerprints” for identifying types of gasses. Choose 4 of the strongest absorption lines in your solar spectrum and try to identify the gas by using the table on display in the lab room. There are many lines listed, but if you stick the strong ones, you should be able to identify the element responsible for the

QUESTION 8:

What are the 5 most intense spectral lines in the Helium?

Relative Intensity	λ Measured	Element
1 st		
2 nd		
3 rd		
4 th		
5 th		

NOTE: Spectral Lines are sometime recorded in units of Angstroms ($\text{\AA} = 10^{-10}$ meters) instead of nanometers. To convert from Angstroms to nanometers, simple divide by 10.

3 WEIN’S LAW

Here is a chance to apply an equation you have learned about in class to a real physical situation. Recall that **WIEN’S LAW** is a relationship between the **TEMPERATURE** of an object and the wavelength at which it is brightest. The relationship is

$$T = \frac{2.9 \times 10^6}{\lambda_{MAX}}$$

Where **T** is in degrees Kelvin and λ_{MAX} is the wavelength at which the object emitting the radiation is brightest. ***This equation has been scales so that wavelength must be input in nanometers.*** This means that for any continuous source (like the sun, or the incandescent light bulb), you can calculate the temperature of source simply by measuring the wavelength that is responsible for the most emission.

Answer the following questions about Wein’s Law.

QUESTION 9:

If you were to measure wavelength in Angstroms instead of nanometers, how would you have to change the constant in Wien's Law?

QUESTION 10:

Wien's Law Calculations

T_{SUN} (K)

T_{BULB} (K)

You may be surprised to see that the temperature you calculated using Wien's Law for the incandescent bulb is so close to the temperature at the surface of the sun. This is most likely due to some confusion between the concepts of **TEMPERATURE** and **HEAT**. Heat is a measure of the total energy due to molecular motion in a substance while temperature is a measure of the average molecular motion. Heat energy depends on the speed of the particles, the number of particles (the size or mass), and the type of particles in an object while temperature only depends on the molecular speed. For example, the temperature of a small cup of water might be the same as the temperature of a large tub of water, but the tub of water has more heat because it has more water and thus more total thermal energy.

Name _____

Date _____

Lab Partner(s) _____

Project Score

OBSERVATIONS OF THE SUN

Based on text by Professor S. Spangler

PROJECT LEVEL: Introductory

PROJECT GOALS: Students will learn about features on the solar surface through direct observation. Students will also estimate the rotation period of the sun by observing the change in position of sunspots over the period of a week.

1 INTRODUCTION

The Sun is our prototype of a **MAIN SEQUENCE** star, and it is has provided us with much of what we know about stars in general. In addition, the Sun is the dominant object in the sky, and many of its characteristics are among the most interesting phenomena in astronomy. Examples are **SUNSPOTS**, **PROMINENCES** (huge arcs of material suspended above the surface of the Sun by magnetic fields) and **SOLAR FLARES**. Prominences can be seen in absorption on the disk of the Sun as long, dark lines called **FILAMENTS**.

This laboratory is well equipped for observations of the Sun, and it will provide students with a chance to make “real time” observations of the Sun in an observatory setting. The Sun is an interesting object to study in a telescope, because it changes from month to month and day to day. Sometimes it even changes from one minute to the next. Observations this year will be made at the time of **SOLAR MINIMUM**, when surface features like sunspots are rare. Try and check out the Sun again in 5 years, when it has swung around to the maximum state.

Notice!!!

A general rule is to never directly look at the Sun through a telescope. Even looking directly at the Sun with the naked eye can damage the eye. Sunlight intensified through a telescope can cause permanent damage to the eye. The telescopes used in this project are perfectly safe, due to carefully engineered filters employed to reduce solar light to safe levels. If you are interested in solar observations of your own, either use a telescope to project the Sun's image on a screen, or buy a special solar telescope. Make sure to get a good one, such as that used in this exercise.

There are two types of observation which will be made in this week's project.

- I. Observations will be made at the eyepiece of a specialized telescope for solar observations called a **PERSONALIZED SOLAR TELESCOPE** made by the Coronado Filters Company. More will be said about this telescope in Section 2. These observations will be made during the regular lab period, although students are certainly welcome and encouraged to return for subsequent observations.
- II. Additional observations will be made with solar data from research observatories available online on the internet. Real-time, or near-real-time images of the Sun are available from the **NATIONAL SOLAR OBSERVATORY** at Sunspot, New Mexico (<http://www.sunspot.noao.edu>) and the **SOHO** spacecraft approximately a million kilometers out in space in the direction of the Sun (<http://sohowww.nascom.nasa.gov>).

1.1 EQUIPMENT AND SOLAR FEATURES

Some solar telescopes show the Sun in **WHITE LIGHT**, meaning that all the light from the Sun is taken, without filtering with respect to color. The telescope used in this exercise employs a **HYDROGEN ALPHA** filter. This transmits only light in a narrow range of wavelengths around the **BALMER ALPHA** line of the hydrogen atom. This line is the bright red emission line that you see in hydrogen spectra. By applying Kirchoff's Laws, we see that the Hydrogen Alpha filter will allow us to see hydrogen gas clouds glowing against the dark background of space, or in absorption against the solar disk.

1.1.1 THE PERSONAL SOLAR TELESCOPE

The main instrument used in this exercise is the Personal Solar Telescope (PST), manufactured by Coronado Filters Company. A picture of it is shown below. With it you can see the Sun in white light, or the light of hydrogen alpha. Your teaching assistant will show you how to set up this telescope on its special tripod. In addition to manually pointing the telescope to keep up with motion of the Sun across the sky, there are two controls you will need to use.

The focus knob can be rotated clockwise or counterclockwise to sharpen the focus for your eyes. You should adjust the focus so you can see the limb of the Sun as a sharp edge. The filter tuning dial is also very important. The PST only admits a very small range of wavelengths. By rotating the filter tuning dial you can choose which set of wavelengths you are seeing. This operation is completely analogous to turning the dial on your radio to tune in wavelengths of different radio stations. In the case of the PST, tuning the filter will allow you to see different features on the surface of the Sun. Physically what is happening is that different parts of the Sun have different velocities of motion relative to us, and the **DOPPLER EFFECT** causes the different velocities to show up at different wavelengths of light.

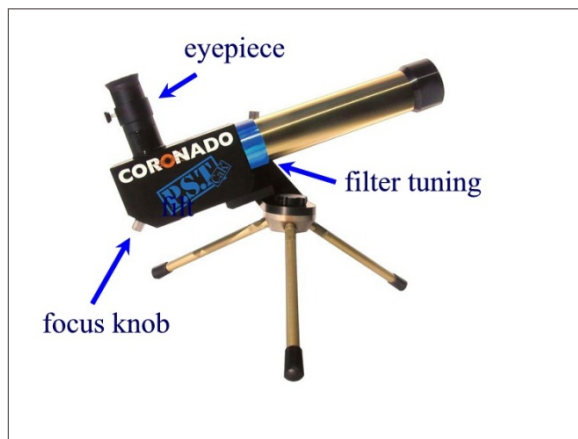


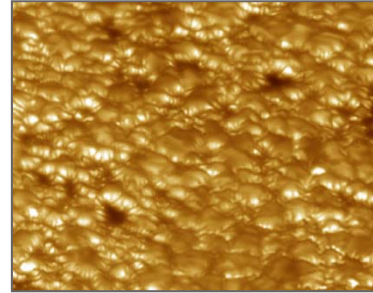
FIGURE 1 - CORONADO PERSONAL SOLAR TELESCOPE

The task for this lab period is to draw the disk of the Sun as accurately as you can (in the light of hydrogen alpha) and see how many of the above phenomena you can see. You should also note what strikes you as noteworthy or interesting. You can then compare your results with the images from the National Solar Observatory or the SOHO spacecraft over the next several days provided by the observatories.

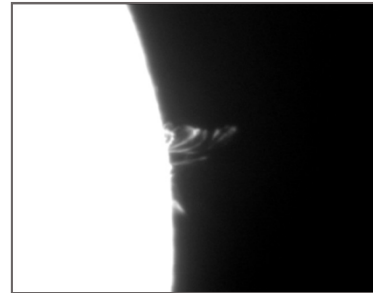
1.1.2 SOLAR FEATURES

During your observations, you should be looking for the following features/phenomena on the solar disk.

GRANULATION. Granulation is the mottled appearance of the solar disk as seen in hydrogen alpha and is always present. Granulation is an illustration of convection (the process by which heat flows from the interior to the surface) in the Sun. When you are looking at the granules, you are looking at hot blobs of matter that are rising to the surface of the Sun from the even hotter interior, cooling off, then sinking back into the interior again.



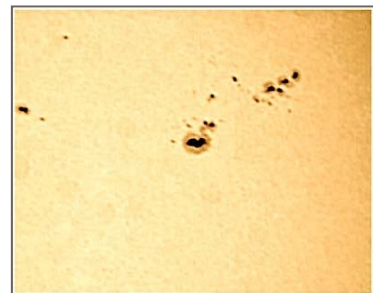
PROMINENCES. Prominences are bright clouds seen at the edge of the Sun against the black of outer space. Often, these appear as bright arches, pushing outward due to magnetic forces. They are bright because they are hot and made of hydrogen, so according to **KIRCHOFF'S SECOND LAW** (A hot gas under low pressure produces a bright spectrum) they glow in the spectral lines of hydrogen.



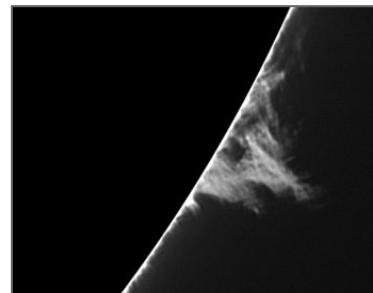
FILAMENTS. Filaments will almost certainly be seen in the observing exercise. They look like long, dark lines on the solar disk. They can only be seen with a hydrogen alpha filter. They represent prominences which are seen in absorption against the light of the Sun, rather than in emission against the dark sky at the solar limb.



SUNSPOTS. Sunspots are somewhat more obvious in white light, but if there are some on the solar disk at the time of the observations, we should see them with the PST. They probably will be surrounded by bright regions called **PLAGES**. The number of sunspots increases and decreases with solar cycle, so you may see many, or none at all depending on the year.



SOLAR FLARES. One of the most exciting phenomena to see is a solar flare. Flares are huge explosions on the surface of the Sun and their occurrence can sometimes be detected at Earth (one astronomical unit away). If you see a flare, it will appear like a flame on the solar edge, or like a bright point on the solar disk, almost always in the vicinity of a sunspot. Flares are short lived, increasing to maximum brightness and fading away in a matter of minutes.



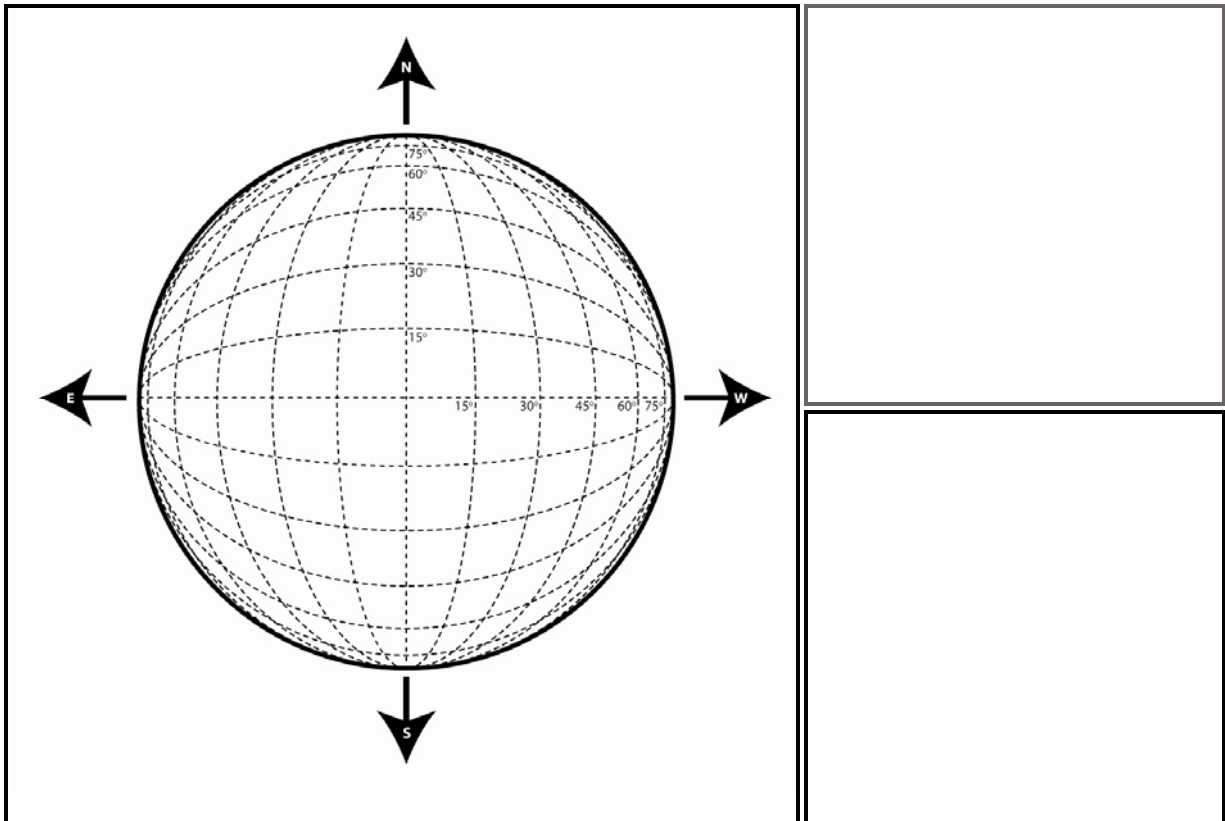
2 OBSERVATIONS

2.1 OBSERVATIONS WITH THE PERSONAL SOLAR TELESCOPE

Work in pairs with your lab partner and set up the PST. Ask your lab instructor for assistance if needed. You can find the Sun by looking for the bright dot in the viewfinder screen near the eyepiece. When you have the Sun in the viewfinder, look in the eyepiece and you will see the Sun in the light of hydrogen alpha. When looking at the Sun you should first determine the directions, and orientation of the solar disk. This may be done by simply watching the Sun drift out of the field of view. The Sun drifts westward due to the Earth's rotation, so the west limb will leave the field of view first. You can determine north and south by moving the telescope north (upwards) or south (downwards). The Sun will then move out to the south or north, respectively. Do this determination first. This will let you accurately draw the location of features you observe.

QUESTION 1:

Draw the features you see in the space provided and record their locations as accurately as possible. You can also sketch other interesting features you see off to the side, such as prominences, or filaments.



Features may be drawn in more detail on the right side of the form, or in any blank space on this document. Below, make a list of the solar features which you observed. Also specifically state what phenomena were not present at the time of your observations. **Be sure to note the time of your observations.** This information will be needed later.

QUESTION 2:

Locate a feature (preferably near the left-most limb) that you will be able to recognize when asked to make a second observation. Describe the feature below, indicating its approximate position (latitude, longitude), size, and color. Also record the time of your observation.

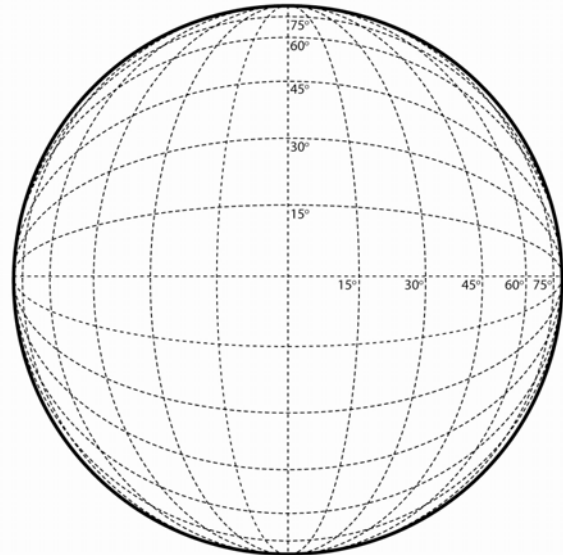
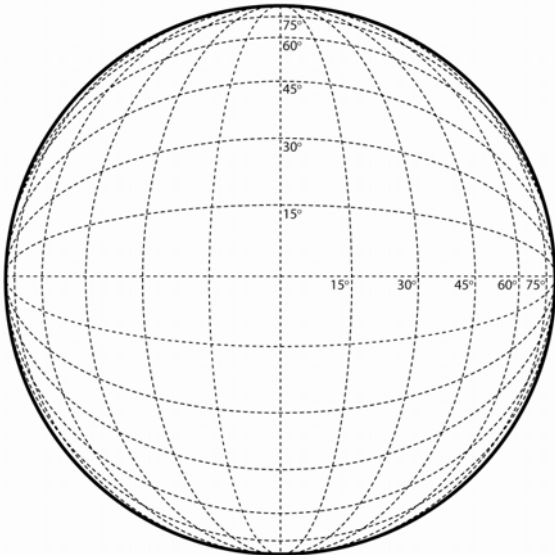
2.2 COMPARISON WITH DAILY OBSERVATORY IMAGES

During the next week, download an image of the Sun in hydrogen alpha from the National Solar Observatory or an ultraviolet image of the Sun from the SOHO spacecraft. Examine these images and compare them with those you made on the rooftop. You can also examine white light images from the NSO or Big Bear, or the SOHO spacecraft. Accurately sketch any important features and give each an appropriate label. Make sure to record the date and time of your observations, as you will need this information for the final section of this lab. ***You will be required to do this 4 times over the next week. If you use Images from different sources, make sure you have properly rotated each image so your sources match orientations***

.

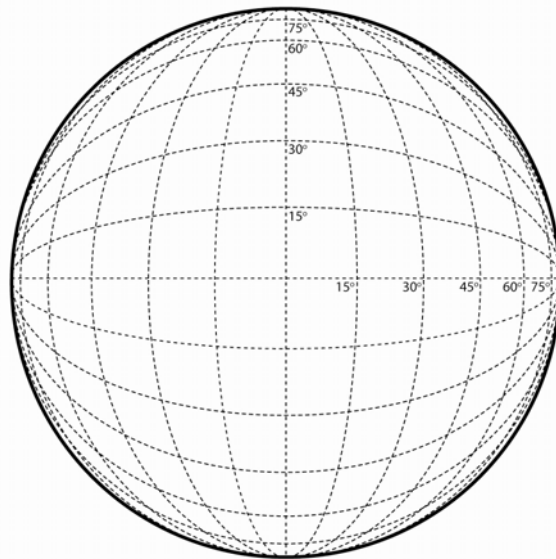
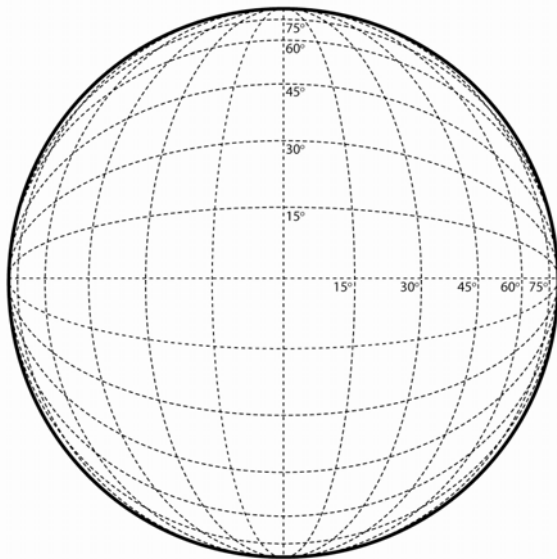
DATE, TIME AND SOURCE:

DATE, TIME AND SOURCE:



DATE, TIME AND SOURCE:

DATE, TIME AND SOURCE:



2.3 MEASURING SOLAR ROTATION

If you pick a feature on the solar surface, such as a sunspot or filament, and watch it over a period of several days, you will see it move across the solar disk from east to west. By measuring the rate of change of the feature with respect to time, you can determine the angular speed of rotation of the Sun, and thus its period. The steps involved in measuring the angular speed of the Sun are as follows.

1. For each day, note the location of a solar feature that was visible for a majority of your observations. This feature should follow a constant line of **LATITUDE** on your images.
2. Convert your date and times to **DECIMAL DATE**, i.e. the days since your first observation plus the fraction of that day the time represents. For example, if your first observation is on Tuesday at 12:30PM, your Decimal Date for that observation is 0.52 (Try this). If your second observation is on Wednesday at 4:15PM, your second decimal date is 1.59 (Try this as well. If this step is confusing, please ask your lab instructor for help).
3. Scale all of your Decimal Dates by the time of the first measurement. Do this by subtracting each date by the Decimal Date of your first observation.
4. Record **LONGITUDE** of the feature for each observation day. Use negative numbers for θ if the feature is to the left (east) of the center and positive values of θ if it is to the right (west). For many of your measurements you will need to estimate the position between grid spaces.
5. To account for the earth's motion between your observations, add the scaled date to your longitude measurements before you plot them. This corrects for the ~ 1 degree per day motion of the earth around the sun.
6. Make a graph in which you plot Longitude vs. Scaled Date for your observations. When you have plotted all of your data points, draw the line through them. The slope of this line will be the angular rotation speed of the Sun, and will have units of degrees/day. This final value for the rotational speed of the Sun can be denoted by the variable **W**, and has units of degrees/day. Do all of your calculations in the space provided.
7. Finally, the rotational period **T** of the Sun is given by $T = 360 \text{ deg}/W$

If there are several features on the surface of the Sun, see if you get the same value for W and T for features at different solar latitudes.

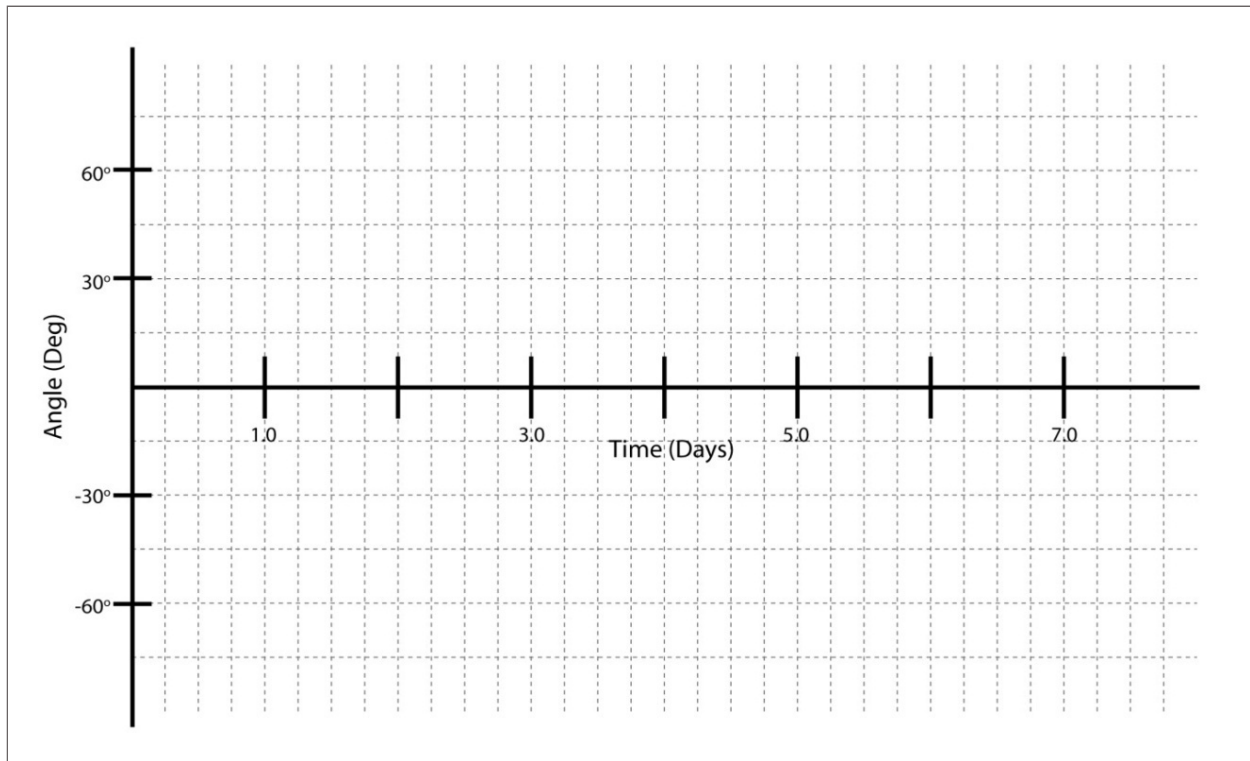
QUESTION 3:

Record your observations in the table below.

Date and Time of Observation	Decimal Date	Scaled Date	Theta(degrees)	Corrected theta

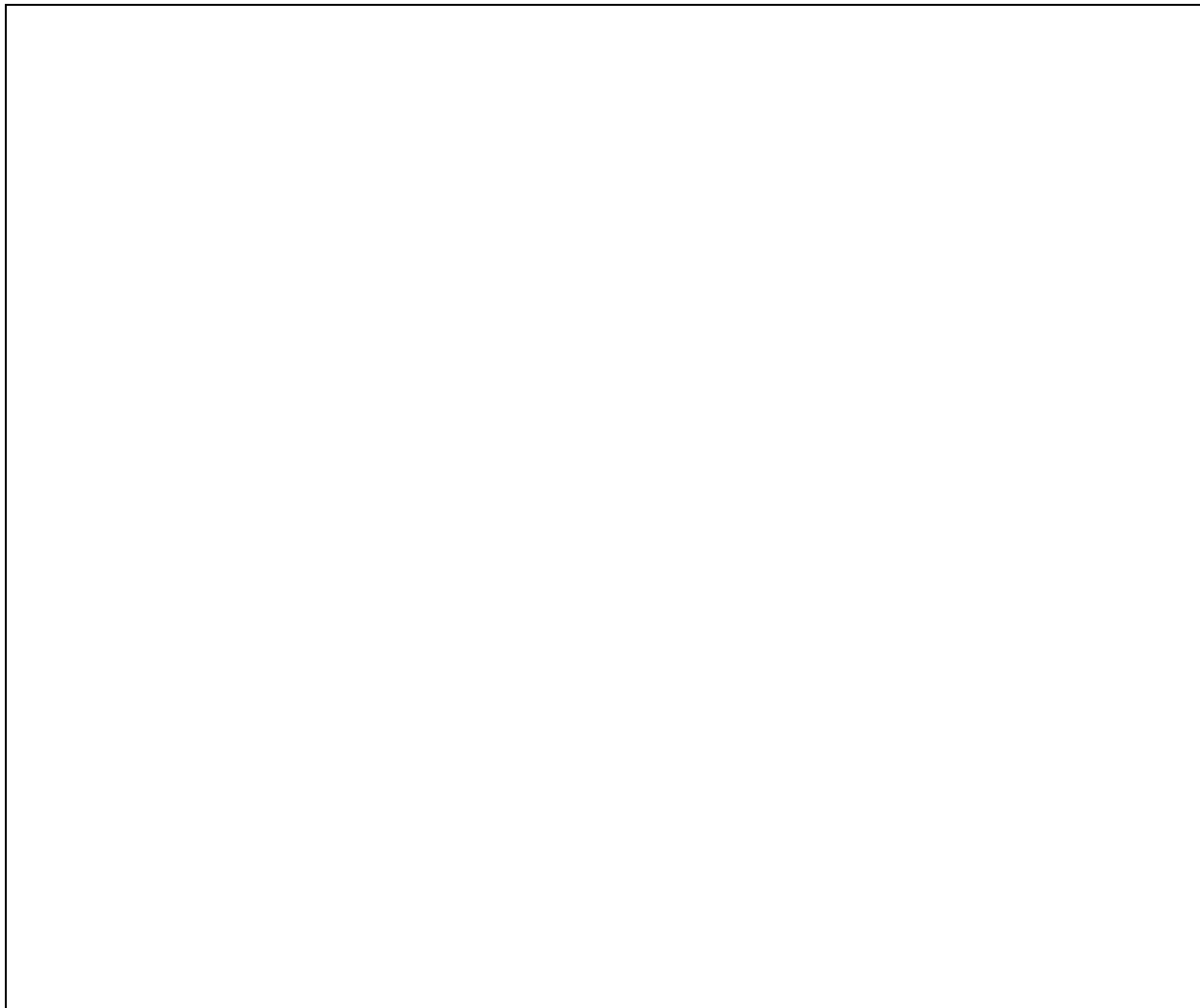
QUESTION 4:

Make a plot of Longitude Angle (deg) with respect to the Scaled Date.



QUESTION 5:

Draw a line through the points in your plot and estimate the slope of the line (change in angle divided by the change in time). Use this slope to calculate the rotational period of the sun at your feature's latitude.



Slope

Period (T)

Name _____

Date _____

Lab Partner(s) _____

Project Score

PARALLAX MEASUREMENTS

Based on text from S. Spangler and *Imaging the Universe - A Laboratory Manual for Introductory Astronomy*, Professor R. Mutel et. al.

PROJECT LEVEL: Intermediate

PROJECT GOALS: Students will use angular measurements to calculate parallax angles and determine the distance to a familiar object.

1 INTRODUCTION

PARALLAX is a term that refers to the apparent shift in location of an object against the distant background caused by a change in the observer's position. Through the use of some simple geometry (see Figure 1), you can use the apparent shift and the change in the observer's position to estimate the distance to an object.

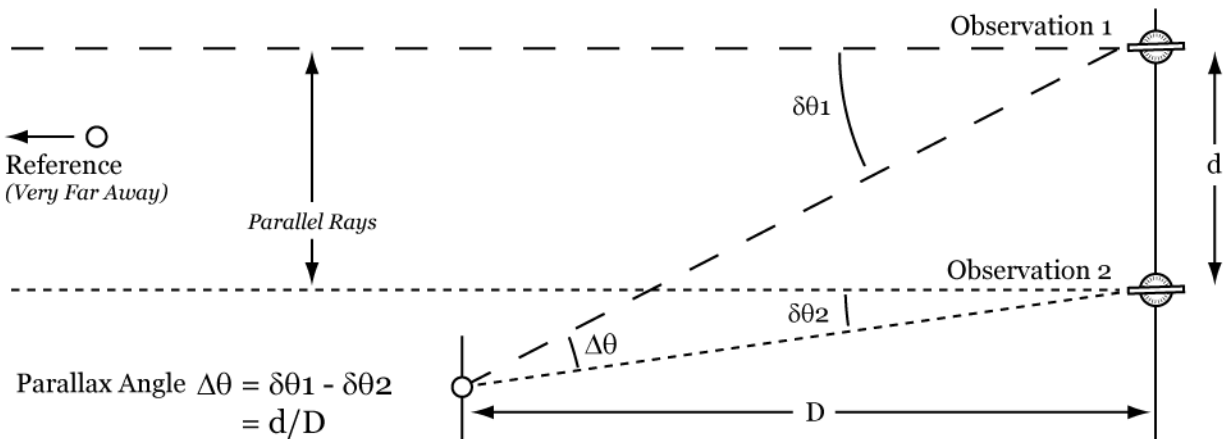


FIGURE 1 - ILLUSTRATION OF PARALLAX

This equation only works when the Reference object, in this case the radio tower, is much farther away than the object you are trying to measure. In this limit, the observations of the Reference result in parallel lines, making the angle $\Delta\theta$ equal to $\delta\theta_1 - \delta\theta_2$.

In this exercise, we will do just that and use parallax to determine the distance to a familiar object. The instruments used to measure the parallax angle will be the same **THEODOLITES** which were used in a previous exercise. It is important to note that this technique is the same as what astronomers use to determine the distances to stars (**STELLAR PARALLAX**). Although the measurements are mathematically identical, the parallaxes measured in astronomy are much smaller than those we will be dealing with today.

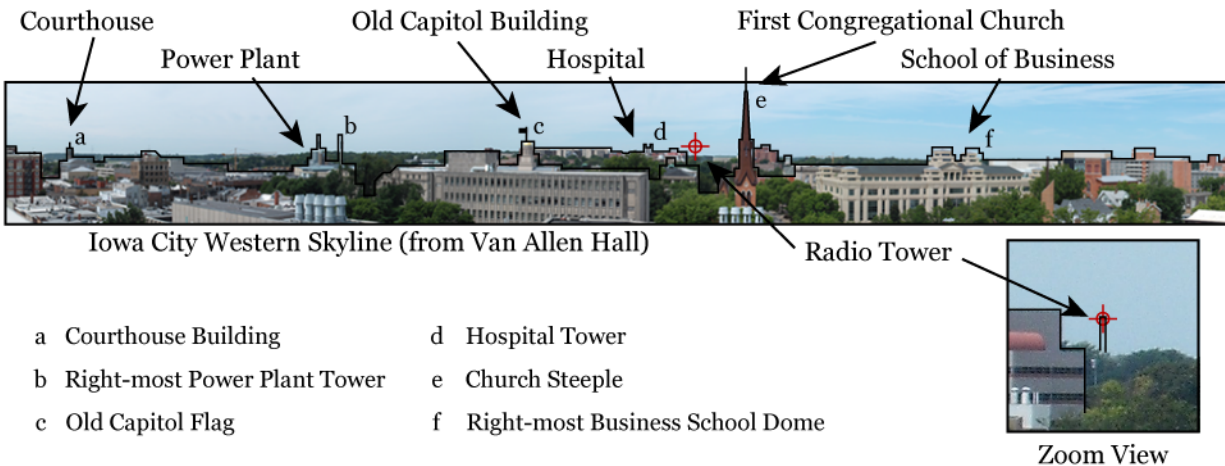


FIGURE 2 - WESTERN SKYLINE FROM VAN ALLEN HALL

The object you will be observing today is the **HOSPITAL TOWER**. After determining the distance to the Hospital Tower by parallax, we will look up the “ground truth” value from a map, and see how close our result is.

2 DISTANCE TO THE HOSPITAL TOWER VIA PARALLAX

The geometry of the situation is shown in Figure 3. Positions 1, 2, and 3, and 4 represent the locations of the four Theodolites. **For this experiment, you need to make measurements with a pair of Theodolites** i.e., you need to make measurements with 1 and 3, or 2 and 4. The analog of this in the stellar parallax case would be like pretending that the two Theodolite positions (say 1 and 3) would correspond to the location of the Earth at different times of the year.

In this experiment, the object we use as the very remote reference (like distant stars in stellar parallax measurements) is a small radio tower visible just to the right of the hospital building. Your lab instructor will point the tower out to you, but if you missed the explanation or just forget, you can consult the Zoom View in Figure 2 for assistance re-locating locating the object.

2.1 PROCEDURE

1. Choose a set of Theodolites, either 1 and 3 or 2 and 4. Go to either one of the Theodolites (pick one with the minimum mob scene) for your first set of measurements. Record your pair selection where indicated.
2. Measure the azimuth angles of the radio tower and the Hospital Tower with the Theodolite. Call these numbers θ_1 and θ_2 , respectively, and write down your measurements in the space provided.
3. Write down the difference $\delta\theta_1 = \theta_1 - \theta_2$ in next column.

4. Move to the second Theodolite in your pair. Again, measure the azimuth angles and calculate the difference. Call this difference $\delta\theta_2 = \theta_1 - \theta_2$ for the second Theodolite.

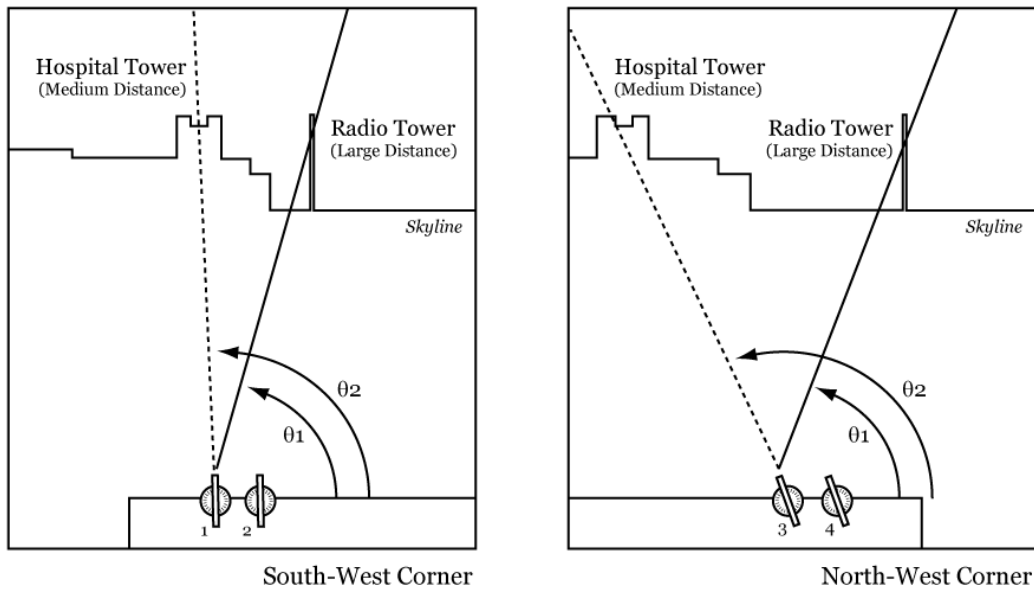


FIGURE 3 - OBSERVING SETUP

If the Hospital Tower were very far away (a distance much greater than the distance between the two Theodolites) $\delta\theta_1$ and $\delta\theta_2$ would be identical. **Since the distance to the Hospital Tower is measurable, $\delta\theta_1$ and $\delta\theta_2$ will be different.** Calculate your value as $\Delta\theta = \delta\theta_1 - \delta\theta_2$. The quantity $\Delta\theta$ is the parallax of the Hospital Tower. Record your result in the $\Delta\theta$ column of the table.

Don't forget your units!

QUESTION 1:

Record your angle measurements for a pair of Theodolites

Pair

Num	θ_1	θ_2	$\delta\theta_1$	Num	θ_1	θ_2	$\delta\theta_2$		$\Delta\theta$

2.2 ESTIMATES OF THE ERROR IN THE MEASUREMENT

A fundamental concept in measurements in the physical sciences is that of errors. **Every measurement has an associated error.** The term error does not mean that some mistake was made that makes the number complete nonsense. Rather, this term means that there is an uncertainty

associated with the measurement. Some measurements are good to 25%, others good to 1%, and sometimes there are precise measurements that are exact to within a tiny fraction of 1%.

The subject of how to estimate the errors associated with a measurement is a large subject in its own right. In this exercise, we will adopt a much simpler approach to estimating the error, but one which will give us an approximate idea of the uncertainty associated with our measurements.

Repeat the procedure described above two more times. For the first repeat, use the second set of spaced Theodolites (in other words, if you used 1 and 3 in your first set of measurements, use 2 and 4 the next time). For the third and final set of measurements, go back to the set you started with. Enter all the data in the table below.

QUESTION 2:

Record your angle measurements for the second pair of Theodolites

Pair

Num	θ_1	θ_2	$\delta\theta_1$	Num	θ_1	θ_2	$\delta\theta_2$		$\Delta\theta$

QUESTION 3:

Repeat you angle measurements for the first pair of Theodolites

Pair

Num	θ_1	θ_2	$\delta\theta_1$	Num	θ_1	θ_2	$\delta\theta_2$		$\Delta\theta$

When you are done with the three measurements, calculate the average value, called the **MEAN**. As a measure of the uncertainty, calculate the maximum difference of a measurement of $\Delta\theta$ from the mean. To put a name on this variable, we call it **M θ** . The significance of the error is that the true value for the parallax of the Hospital Tower could be anywhere between $(\Delta\theta - M\theta)$ to $(\Delta\theta + M\theta)$.

QUESTION 4:

Calculate the mean parallax angle.

$\Delta\theta$ (Trial 1)	
$\Delta\theta$ (Trial 2)	
$\Delta\theta$ (Trial 3)	
$\Delta\theta$ Mean	

QUESTION 5:

What is the maximum difference between your individual measurements and the mean value you calculated in Question 4?

$M\theta$	
-----------	--

QUESTION 6:

Your percentage error is the maximum difference divided by the mean value, **PE = $M\theta / D\theta$ (MEAN)**. Calculate your value of PE and record it below.

PE	
----	--

2.3 CALCULATION OF THE DISTANCE TO THE HOSPITAL TOWER

The relationship between the object distance **D**, the *baseline* size **d** (how much the observer moves), and the parallax is:

$$\Delta\theta = d/D$$

To use this formula, it is necessary that $\Delta\theta$ is a small angle (say less than 10 degrees), and $\Delta\theta$ must be expressed in radians. Remember that one radian is 57.3 degrees. In the exercise above, we measured the parallax in degrees, so we must divide by 57.3 to get the angle in radians. The distance to the object is then given by:

$$d = D \times \frac{\Delta\theta}{57.30 \text{ deg}}$$

To make this calculation, we need to know **d**, the distance between the Theodolites. You can calculate **d** by using the fact that the distance between the cylindrical posts on the railing is 7.5 ft. Count the number of posts between the Theodolites, and multiply by given separation.

It is recommended to express the distance in meters, which is the metric unit of length (1 meter = 3.28 feet).

QUESTION 7:

Calculate the distance between the Theodolites using the method described in the text.

d	
---	--

You now have everything you need to calculate the distance to the Hospital Tower.

QUESTION 8:

In the space provided, calculate the distance to the Hospital Tower. Give the range of acceptable distances allowed by the errors. *Show your work.*

Distance to Building

--

Error Range

--

QUESTION 9:

Get a map of downtown Iowa City from the internet or phone book (be sure to get one with a scale; travel.yahoo.com, maps.google.com are just a few of many that do), and measure the distance from the Hospital Tower to the middle of the west end of Van Allen Hall. Record your findings below.

Map Source	
Distance from Map	

QUESTION 10:

In the space below, briefly comment on the degree to which the two values are, or are not in agreement. Are they *consistent* with each other?

Name _____

Date _____

Lab Partner(s) _____

Project Score

SPECTRAL CLASSIFICATION OF STARS

Written by T. Jaeger, Spectrum Images from *The Classification of Stellar Spectra*, Project CLEA

PROJECT LEVEL: Introductory

PROJECT GOALS: The spectral classification system will be introduced. Students will use the spectrum of known spectral type stars to visually determine the spectral type of unknown stars. Lastly, students will use the Luminosity to Mass relationship for main sequence stars to construct a Hertzsprung-Russell diagram.

1 INTRODUCTION

Scientists across all fields use classification systems to help them sub-divide the vast universe of objects and phenomena into smaller groups, making them easier to study. In biology, life can be categorized by cellular properties. Animals are separated from plants, cats separated from dogs, oak trees separated from pine trees, etc. This framework allows biologists to better understand how processes are interconnected and quickly predict characteristics of newly discovered species. In Astronomy, the stellar classification system allows scientists to understand the properties of stars. Early astronomers began to realize that the extensive number of stars exhibited patterns related to the star's color and temperature. This classification was good, but had limitations (especially for studying distant stars).

By the early 1900's, a classification system based on the observed stellar spectra was developed and is still used today. A **STELLAR SPECTRUM** is a measurement of a star's brightness across of range of wavelengths (or frequencies).

It is in a sense a "fingerprint" for the star, containing features that reveal the chemical composition, age, and temperature. This measurement is made by "breaking up" the light from the star into individual wavelengths, much like how a prism or a raindrop separates the sunlight into a rainbow. Figure 1 shows a spectral measurement of the star Vega, the brightest star in the constellation Lyra. The spectrum has many interesting features that allow astronomers to determine the physical properties of the star. By **WEIN'S LAW**, the temperature can be measured by recording the wavelength where the profile is the

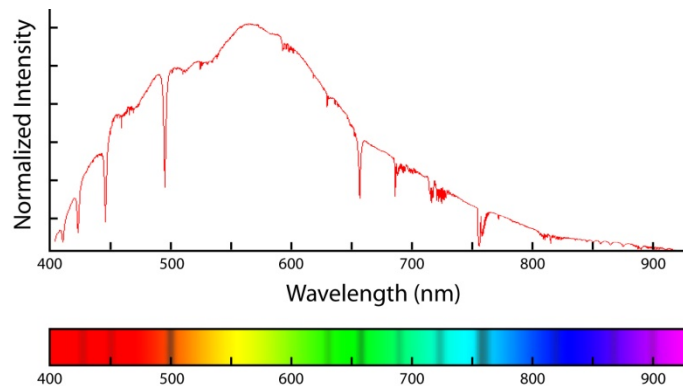


FIGURE 1 – SPECTRA OF THE SPECTRAL CLASS A0V STAR VEGA (α LYRAE) IN VISIBLE WAVELENGTHS

strongest. The chemical composition can be determined by the locations of the dips or dark patches (absorption lines) and properties such as density can be inferred by measuring the depth and width of the lines.

The main purpose of this exercise is to learn more about the stellar classification system. You will be asked to identify 14 “Unknown” stars based on their spectral properties. To do this, you will be given a list of “Reference” stars with various spectral types to be used as a basis for comparison. All the stars listed in this lab are members of a sub-classification called main sequence stars. Our sun is a member of this class. They are called main sequence because of a unique pattern they make when they are displayed on a plot of their Luminosity with respect to their spectral type. This plot is called a **HERTZSPRUNG-RUSSELL DIAGRAM** (or H-R diagram). To see this unique grouping, you will be asked to make an H-R diagram of your own using the stars (both the “Reference” and the “Unknown”) in this lab. Lastly, you will use the given stellar masses to estimate the lifespan of a star in each spectral class.

By the end of lab, you should have a good understanding of stellar types, how they are organized, and what properties each type represents.

1.1 SPECTRAL CLASSIFICATION

1.1.1 MAIN CLASSIFICATION SYSTEM

The stellar classification system groups stars into the following categories:

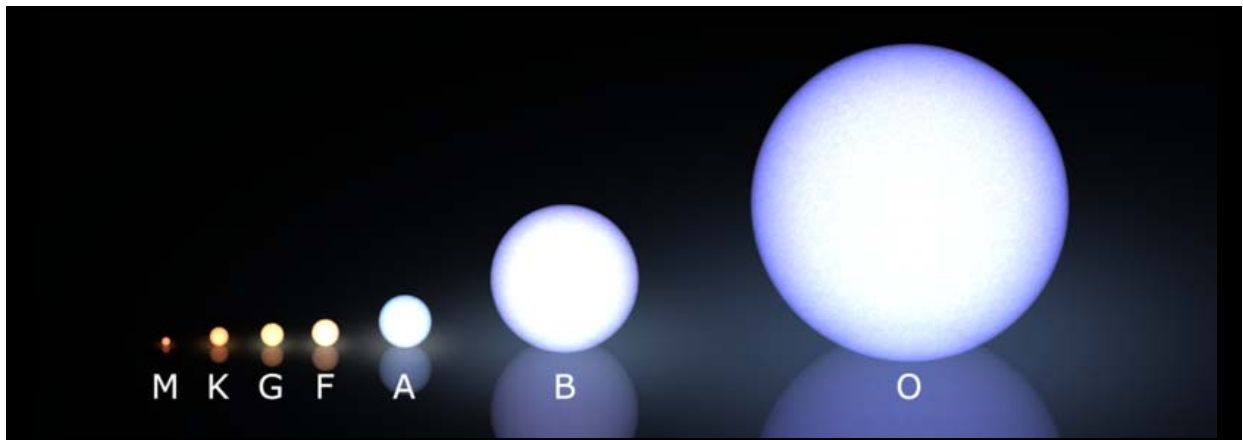


FIGURE 2 - ILLUSTRATION OF THE STELLAR CLASSIFICATION SYSTEM

TABLE 1 - STELLAR CLASSIFICATION SYSTEM

Type	Color	Temperature	Energy source
O	blue-white	35 000 Kelvin	ionized helium
B	blue-white	21 000 Kelvin	helium
A	white	10 000 Kelvin	hydrogen
F	creamy	7 000 Kelvin	ionized calcium

G	yellow	6 000 Kelvin	calcium
K	orange	4 500 Kelvin	titanium oxide
M	red	3 000 Kelvin	titanium oxide

1.1.2 SUB-CLASSIFICATIONS

Each spectral type is further sub-divided into narrower divisions to help classify the subtle differences in each type. This is done through the use of the numbers 0 - 9 and the Roman Numerals I - VII. The main star in each spectral type is represented by the number 0 and the number increases as the luminosity decreases (moves toward cooler, dimmer spectral type). The Roman Numerals indicate the stars luminosity and start with the brightest (I for **SUPERGIANTS**, II for **BRIGHT GIANTS**, III for **GIANTS** and IV for **SUBGIANTS**), and work down to fainter (V for **MAIN SEQUENCE**) and fainter (VI for **SUBDWARFS**, VII for **WHITE DWARFS**) stars.

QUESTION 1:

Figure 1 shows the spectrum of Vega. Vega has a stellar classification of A0V. What sub-class does Vega belong to?

Sub-Class	
-----------	--

QUESTION 2:

Approximately what temperature is Vega? What element(s) is/are being fused at Vega's core?

Temperature	
Material(s)	

QUESTION 3:

If Vega suddenly cooled and was measured to be 8500 Kelvin, what would new stellar classification be?

New Classification	
--------------------	--

2 DETERMINING SPECTRAL TYPE

Attached with this lab is a transparency which displays a series of stellar spectra for a wide variety of main sequence stars. Use the transparency to identify a series of "Unknown" spectral type stars by placing "Reference" spectra over the target star and moving from type to type until the spectra match. Be careful! Not all the spectra are exactly the same and you may have to guess between two types. For example, if you were between a K0 and K5 star, you could estimate a K2 or K3. Or, if between an A5 and a F0, you could choose an A7 or A8.

QUESTIONS 4,5, AND 6:

Make your estimates of the 14 “Unknown” sources and enter your results below. When you are done, move on to Part 3 for instructions how to complete the table.

Name	M/msun	Type	Luminosity	Log ₁₀ (L)
Zeta Puppis	40.0	O5	4.05x10 ⁵	5.61
Phi Orionis	18.0	B0		
Theta CrB	5.40	B6		
Alpha Gem	2.15	A1		
Beta Pictoris	2.10	A5	13.4	1.13
Gamma Virginis	1.70	F0		
Eta Arietis	1.29	F5		
Beta Comae Ber	1.10	G0	1.40	0.14
Alpha Mensae	0.93	G6		
70 Ophiuchi A	0.78	K0		
61 Cygni A	0.69	K5		
Gliese 185	0.47	M0	7.12x10 ⁻²	-1.15
EZ Aquarii A	0.21	M5		
BD63137	0.35			
Feige41	4.80			
HD6111	0.99			
HD17647	0.89			
HD23733	1.75			

HD24189	1.17			
HD27685	1.08			
SAO81292	0.18			
HD35619	20.1			
HD66171	0.90			
HD240344	19.2			
HD124320	2.50			
HZ948	1.25			
HD35215	31.0			

3 MASS, LUMINOSITY AND THE H-R DIAGRAM

3.1 THE MASS, LUMINOSITY RELATIONSHIP

At the core of these stars, matter is being converted into energy through fusion. This process is very sensitive and small changes in the stars mass can create dramatic changes in the **LUMINOSITY**. Expressed mathematically, the relationship has the following form:

$$L = M^{3.5}$$

Here, **L** is the luminosity of a main sequence star (in units of the Sun's luminosity) and **M** is the mass of a main sequence star (in units of the Sun's mass).

QUESTION 7:

What is the Luminosity of a star (in solar luminosities) that is twice the mass of the Sun?

Luminosity	
------------	--

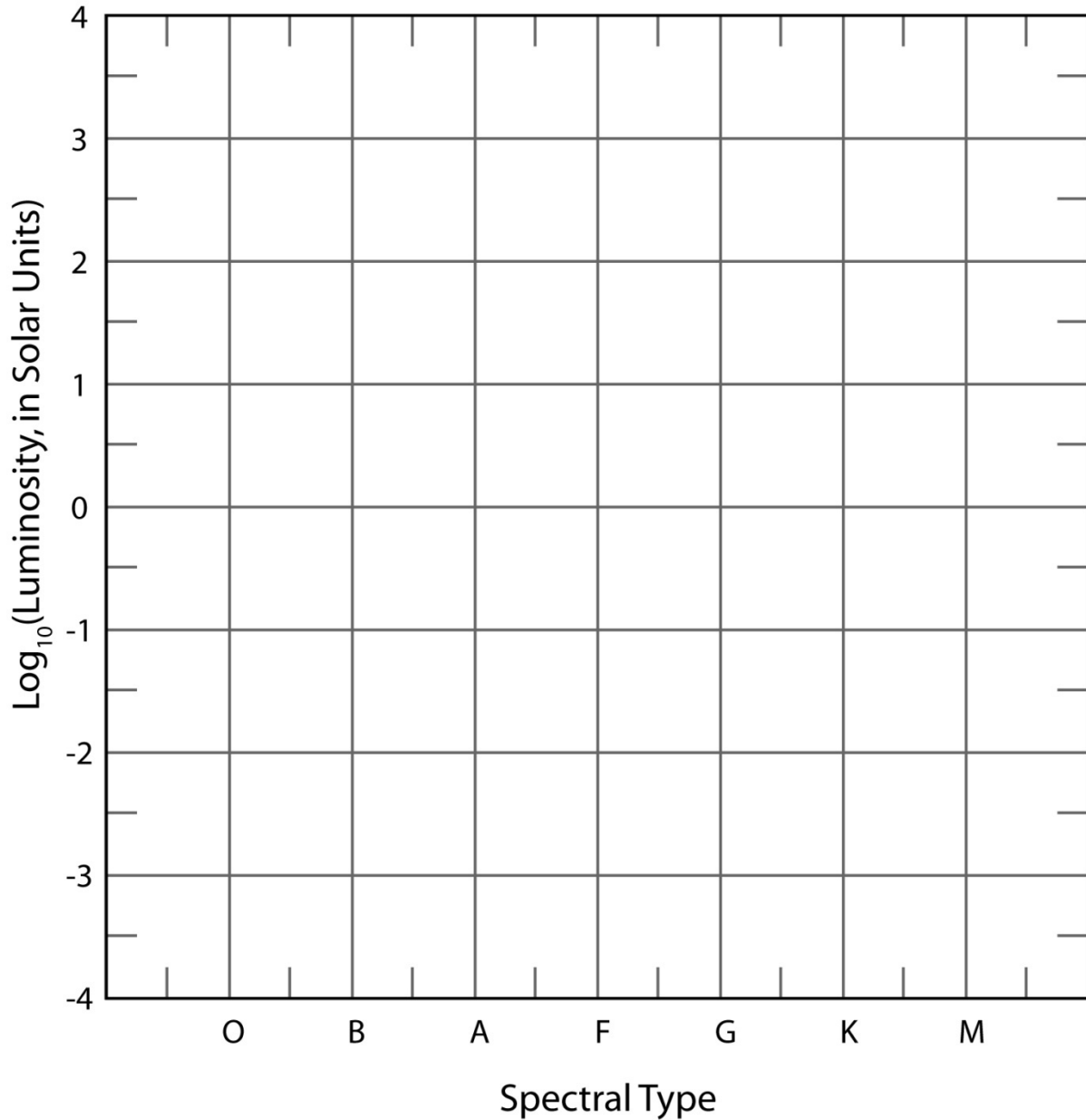
Use the Mass, Luminosity Relationship above to complete the **Luminosity** and **Log10(Luminosity)** columns in Question 4.

3.2 HERTZSPRUNG-RUSSELL DIAGRAM

The H-R diagram is a common way for astronomers to display the stellar classification system. It is simply a plot of a star's luminosity versus its spectral type (or sometimes its color/temperature vs. absolute magnitude). Similar stellar types will tend to "cluster" on the H-R Diagram. The stars used in today's lab are all main sequence (sub-type V) stars and their grouping should be evident though plotting.

QUESTION 8:

Plot the values of **Log₁₀ (Luminosity)** vs. **Spectral Type** for the listed stars and reveal the pattern. The arrangement is what is commonly called the **MAIN SEQUENCE LINE**.



4 MAIN SEQUENCE LIFESPAN

The length of time a star spends as a main sequence type depends on how long it takes to use up the hydrogen at its core. Stars with high luminosities require large amounts of energy and hence use up their hydrogen faster than stars with lower luminosities. The lifespan of a star is a measure of how much fuel it has divided by the rate at which it uses its fuel. In this case, the fuel is the mass, and the rate the star uses fuel is the star's luminosity.

Using the **MASS, LUMINOSITY RELATIONSHIP** from Section 3.1, it is straight-forward to see that the main sequence lifetime of a star is just:

$$\tau = \frac{M}{L} = \frac{M}{M^{3.5}} = M^{-2.5} * \text{age of the sun } (\sim 10 \text{ billion years})$$

QUESTION 9:

What is the Main Sequence Lifetime for a star with one-half the mass of the Sun? (After this time, the star will cool and no longer be located on the Main Sequence Line you plotted in Question 8.)

Lifetime	
----------	--

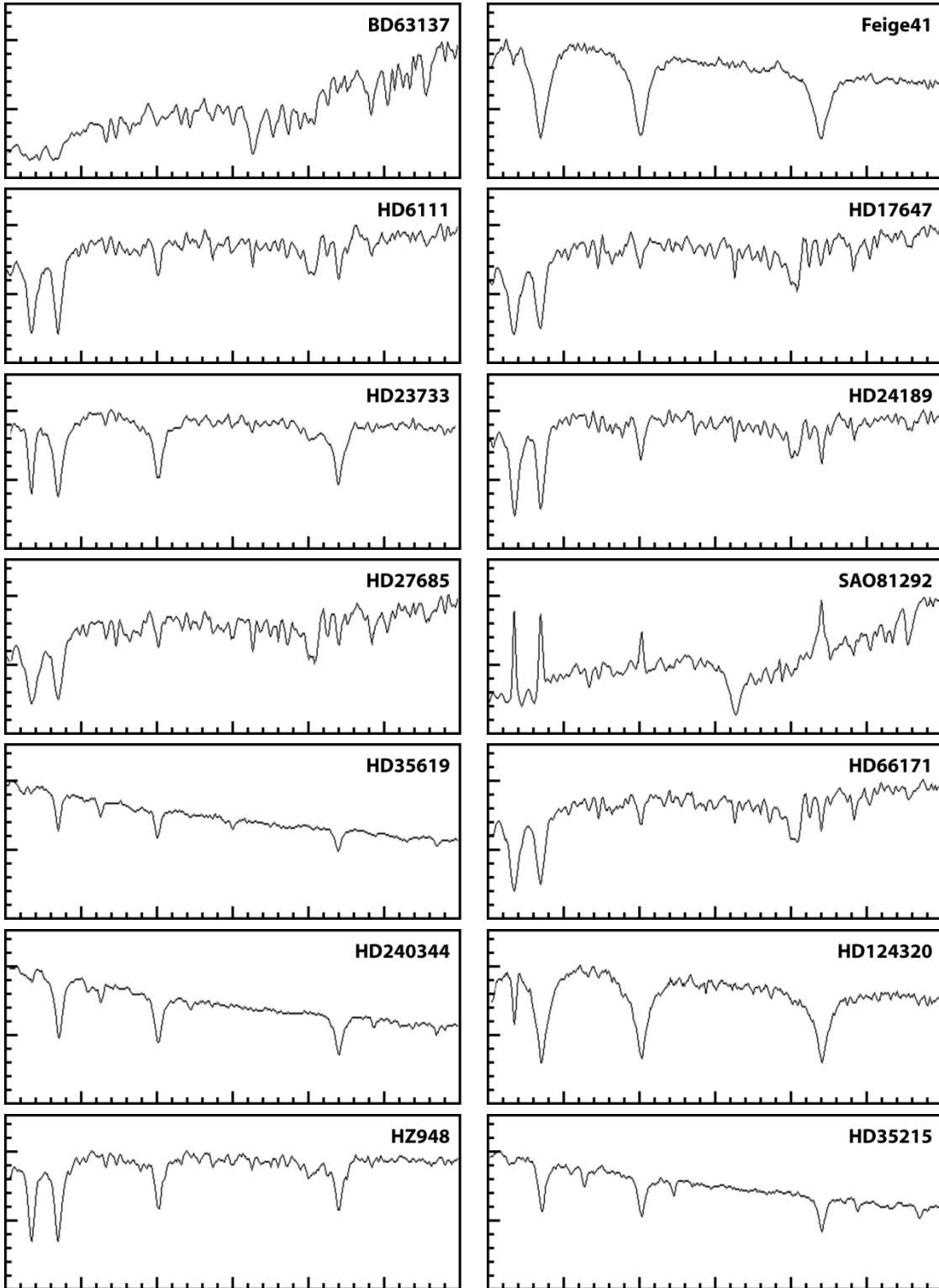
QUESTION 10:

Choose a star from each main spectral type (O,B,A, etc.) and calculate its main sequence lifespan.

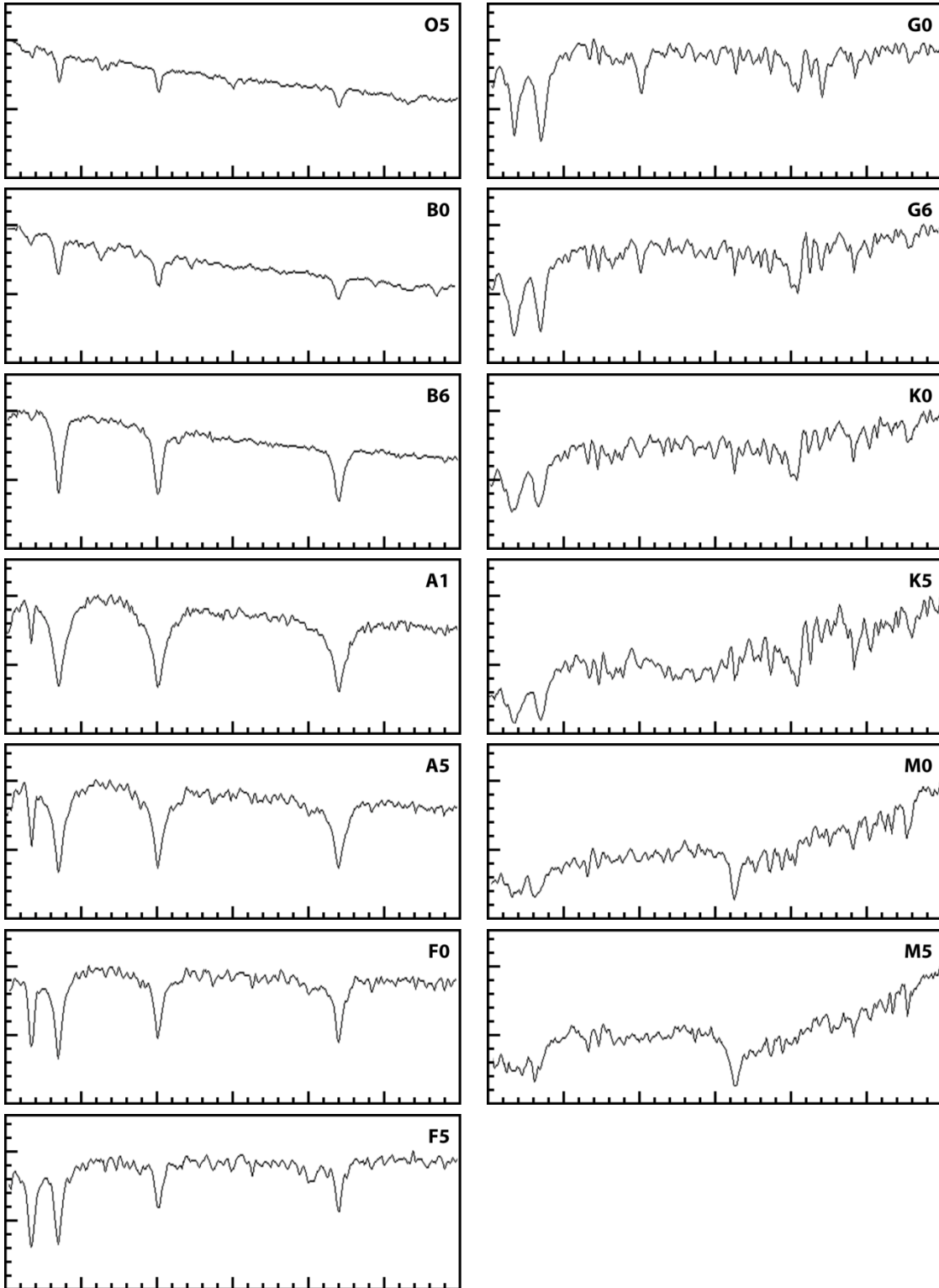
TABLE 2 - MAIN SEQUENCE LIFETIME

Type	Mass	Lifespan

LIST OF UNKNOWN SPECTRA



LIST OF REFERENCE SPECTRA



Name _____

Date _____

Lab Partner(s) _____

Project Score

IMAGE ANALYSIS: BASIC TECHNIQUES

From: Imaging the Universe - A Laboratory Manual for Introductory Astronomy, R. Mutel et. al.

PROJECT LEVEL: Introductory

PROJECT GOALS: The student will become familiar with the image analysis programs used in lab, and also will develop an understanding of the size and age of planetary nebulae. A number of basic concepts of image analysis are introduced, including ADU count, histogram adjustment, angular distance measurement, convolution, and image arithmetic.

IMAGE DIRECTORY/LIST: proj-04_Image_Analysis: chapel.fts, m42.fts, m57.fts

1 INTRODUCTION

Obtaining useful scientific results from an image often requires the application of image analysis tools. Many of the most commonly used tools are illustrated in this exercise using one terrestrial image and two astronomical images. The following is intended only as a brief summary of the basic concepts.

A CCD image consists of a rectangular array of cells called pixels, each of which is assigned a number (the **ANALOGUE TO DIGITAL UNIT** or **ADU COUNT**) which is proportional to the brightness of the image at that location. For the images in this exercise, the range of ADU values is 0 to 65536 or 216; i.e., there are 16 bits assigned to hold the value of each pixel. A single image is inherently monochromatic ('black and white') so that the display program normally converts the ADU counts to shades of gray, a so-called 'grayscale' image. Since most computer video systems can only display 8 bits of grayscale (256 shades), it is necessary to select the

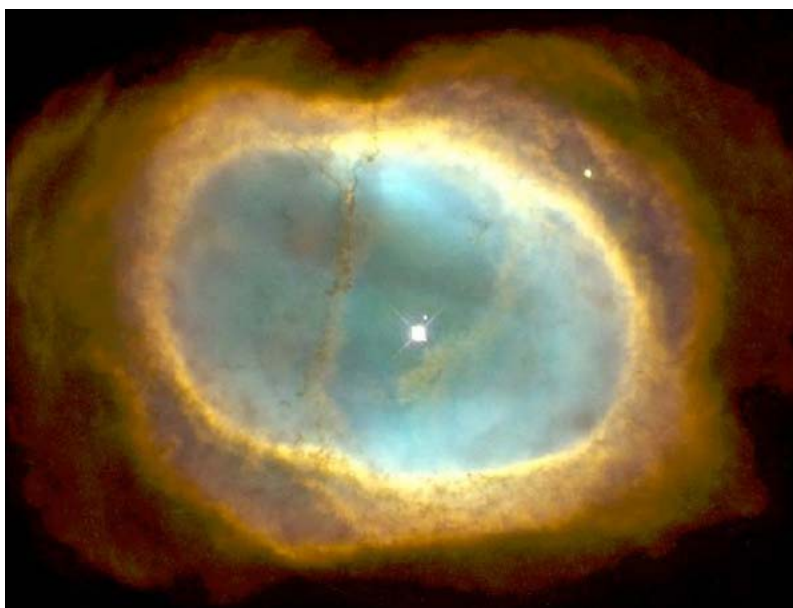


IMAGE 1 - HST IMAGE OF THE RING NEBULA (M57)

minimum and maximum ADU counts corresponding to the black and white levels, respectively. This can be done either by adjusting the contrast/brightness control or by using the **HISTOGRAM TOOL**. The

histogram is a plot of the number of pixels at each ADU level. The user adjusts the minimum and maximum level using the mouse and the arrows at the bottom of the histogram.

The x and y coordinates of individual pixels can be read directly by moving around the image with the mouse. One can display multiple images at the same time, and rotate, expand and contract selected images. Images may also be added, subtracted, multiplied, and divided by either constants or other images.

The grayscale representation of an image can be converted to a **PSEUDO-COLOR IMAGE** by changing the **COLOR PALETTE**, i.e. the mapping of ADU levels to a sequence of colors. These are not true colors in the sense that of a color photograph, but it is sometimes useful to choose a color palette to emphasize small intensity differences, particularly in extended objects such as nebulae. The lab uses three sample images to illustrate some of these image analysis tools. The images of M42 and M57 were taken with the **RIGEL TELESCOPE** in Arizona, while the Chapel image was taken with a regular digital camera.



IMAGE 2 – RED FILTERED IMAGE OF THE DANFORTH CHAPEL

CHAPEL.FTS is an image of the Danforth Chapel near the Iowa Memorial Union.

M42.FTS is an image of the well known star formation region M42 (The Great Orion Nebula) in the sword of Orion. ***It is about 400 pc distant.*** The total mass of the nebula is about 10^6 solar masses. The central part of the nebula containing the 4 Trapezium stars is overexposed and cannot be seen clearly.

M57.FTS is an image of the Ring Nebula, a famous example of a planetary nebula (the reason the name *planetary* nebula was coined is probably because these objects are similar in appearance to faint planets when viewed with modest-sized telescopes -- both look like fuzzy disks). The object consists of a central hot star and a surrounding cloud of gas. The gas is glowing because of ionization from ultraviolet radiation from the central star. The Ring Nebula, shown in Figure 1, is one of the brightest of all planetaries, but imaging it with small telescopes is difficult, since it is quite small and the central star is very faint ($V=15$). ***The distance to the Ring Nebula is about 700 pc.***

1.1 ADU COUNTS AND ADJUSTING CONTRAST/BRIGHTNESS

Run **MAXIM** by clicking the icon on the desktop or by locating the program through the Start Bar.

Load the image **CHAPEL.FTS** (located in directory misc). To do this, click on File in the menu bar at the top of the screen. Then choose Open from the pull-down menu. Choose the image drive from using the box next to the words "Look in". Ask your instructor if you can't remember which drive contains the laboratory images. Open the misc folder. Now double-click on the file name chapel.fts.

The image you are seeing is composed of individual pixels arranged in a rectangle, with dimensions 800×600 or 480000 pixels altogether. The image display program reads each ADU value and converts it into a gray level, with larger values being more nearly white and smaller values more nearly black. The position

and ADU count of the individual pixel under the cursor can be read at the bottom of the screen. The ADU count (the i ;) is given next to the set of (x,y) coordinates at the bottom right corner of the screen.

You may notice that the counts in adjacent pixels are often different from one another, even if the pixels *look* equally bright. Because of the nature of photons; the change in the number of photons has to be fairly large before a brightness change is obvious.

QUESTION 1:

Give an example of a region in “chapel.fts” with a high ADU count. How about a low ADU count?

High Count	
Low Count	

It is sometimes convenient to adjust the image display gray levels in order to enhance faint features in the image. This is known as adjusting the histogram. To do this, use the **SCREEN STRETCH WINDOW** (shown at right) which should have been displayed upon starting the program. If not, select View from the menu and Screen Stretch Window from the pull-down menu. **To adjust the display, move the green and red arrows under the main window.** The red arrow adjusts the black background and the green adjusts white levels. Moving the arrows close together produces a high contrast. The histogram is adjusted automatically as you move the arrows. Continue to adjust the histogram until you find a setting that brings out a maximum amount of detail. As you adjust the histogram, you are adjusting the 256 shades of gray scale to cover the desired range of brightness within the image. Including the entire range of brightness within the 256 gray-scale levels can sometimes make it difficult to detect fine differences. Including a small range of brightness hides a lot of information off of the edges of the scale.

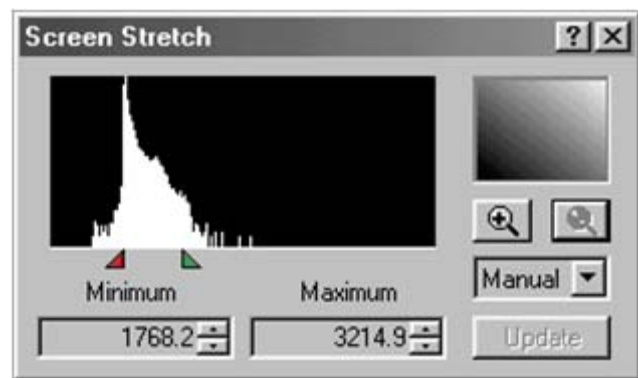


IMAGE 3 - MAXIM DL HISTOGRAM TOOL

You may also adjust the contrast and brightness of the image by clicking in the smaller window on the right side of the Screen Stretch. When you click and hold in the window, your cursor will change to a cross. Moving your cursor vertically will adjust the brightness and moving horizontally will adjust the contrast. Note that the green and red arrows will also move as you move your mouse in this small window. As before, the adjustments will occur automatically. Continue to adjust the histogram until you feel you have the most detail possible. Adjusting the histogram optimally takes a lot of practice. Don't be frustrated if you spend fifteen minutes doing what your lab instructor does with just a few clicks.

To examine the image more closely, especially the variation in pixel intensity (ADU count), select the Zoom from the program menu. You may also press the + and - buttons next to the zoom pull down. Select a reasonable zoom level for examining the image. This level will change from image to image. For the chapel image, you will need to select a zoom of at least 400%, perhaps larger.

While the original image is reasonably clear, we can highlight small scale features using a **CONVOLUTION MASK**. (The process of convolving an image involves manipulating its ADU counts according to some predetermined mathematical function. You can think of convolving an image as applying one of several special filters to it.) Click on **Filter** and choose **Unsharp Mask**. A new window will open. Don't worry about any of the options; just use the default values for now. Click OK and you should be able to see more detail in the vehicles in the background.

1.2 MEASURING POSITIONS

Along with pixel counts, MaxIM displays the (x,y) coordinate of the pixel directly beneath the mouse cursor. For most images, the pixel corresponding to the position (0,0) is in the top left corner of the image with x increasing to the right and y increasing downward. (Try this out) Hidden in every picture is the **SCALE FACTOR**. The Scale Factor of an image represents the angular size of a single pixel and is determined by the optics of the telescope (or digital camera) and the size of the CCD chip. Typically this value is given to you for Astronomical images.

Once the Scale Factor is known, you can determine linear size of the objects in the image simply by knowing the distance to each object. This relationship is called the **SMALL ANGLE FORMULA** and is expressed as:

$$d = \frac{D \times \Delta\theta''}{206,265''}$$

where **d** is the linear size, **D** is the distance to the object and **Δθ** is the observed (angular) size of the object in arcseconds (1/3600th of a degree, analogous to seconds on a clock with degrees substituted for hours).

QUESTION 2:

The Scale Factor of the Chapel image is given as 4 arcminutes (1 arcminute = 60 arcseconds) per pixel. If the photographer is standing 150 feet away, what is the resolution of a single pixel in units of feet/pixel? How about in meters/pixel?

feet/pixel	
meters/pixel	

You can now measure the height of the chapel building in pixels by putting the cursor at the bottom of the building, and marking down the coordinates (x,y) shown. Find the coordinate at the top of the building by moving the cursor to the top of the building while keeping the x coordinate constant. Calculate the building height in pixels by subtracting the y values. Calculate the actual height of the building in both feet and meters using the image scale found in Question 2.

QUESTION 3:

What is the Height of the Chapel Building?

Height (pixels)	
Height (feet)	
Height (meters)	

2 ORDER OF MAGNITUDE CALCULATION

Astronomers are often interested in the **ORDER OF MAGNITUDE OF A CALCULATION**. That is, do we expect to see millions of stars in a region, or just a few? As an example, we can estimate the number of solar-mass size stars that may be formed from the glowing gas of M42. To do this, you must first find the radius of M42. In Question 3, you found the height of the chapel building by measuring two points, careful to keep the x coordinate fixed. In general, the distance between any two points can be found by using the distance formula.

$$r = \sqrt{(x_1 - x_2)^2 + (y_1 - y_2)^2}$$

Here, **r** is the radius and the **x**'s and **y**'s are the coordinates you measured.

2.1 SIZE AND MASS OF THE ORION NEBULA (M42)

Discard the chapel image by clicking on the small **x** in the upper right corner of the image window. Now, load the image **M42.FTS** by clicking on File/Open. Click on m42.fts in the image list box, and click on Open. Adjust the histogram. Faint nebulae can often be seen better by producing a negative image. Try this by reversing the positions of the red and green arrows. That is, put the red arrow to the right of the green arrow.



IMAGE 4 - HST IMAGE OF THE ORION NEBULA (M42)

To estimate the mass of the Orion Nebula, we must first estimate its size. The nebula is irregularly shaped, so this can be a difficult task. To form an order of magnitude estimate (one we expect to be within a factor of 10 of the true size), we can *assume* the nebula is spherical. This is a convenient choice because the volume ($V = 4\pi r^3/3$) can be estimated simply by finding an average radius.

QUESTION 4:

Estimate the radius of the Orion Nebula Move the cursor over a point near the center of the nebula. Mark down the coordinates (x,y) shown. Next move the cursor to a point on the edge of the nebula and mark those coordinates down. Calculate the radius in pixels using the distance formula. **Take at least 2 more measurements of radius, choosing different locations along the nebula edge.** Use your three measurements to find the average radius of M42 in pixels.

	Center Coordinate	Edge Coordinate	Radius
Measurement 1			
Measurement 2			
Measurement 3			
		Average (pixels)	

QUESTION 5:

Convert the average radius in pixels to a linear distance given that Scale Factor of the M42 image is 3 arcseconds per pixel. You also need to know the distance to M42 which is located in the introduction. Express your answer in meters.

Distance to M42	
Linear Size	

Spectral lines indicate that the cloud is made mostly of hydrogen, and that there are roughly 10^{10} atoms per cubic meter ($n = 10^{10} \text{ m}^{-3}$). Since we know the mass of hydrogen, the mass density ρ of the nebula can be obtained by (ρ is the Greek letter rho, pronounced “row”):

$$\rho = n \cdot m_H = (10^{10} \text{ atoms}) \times (1.6 \times 10^{-27} \text{ kg/atom}) \approx 1.6 \times 10^{-17} \text{ kg/m}^3$$

QUESTION 6:

Calculate the volume of the nebula using the average radius (converted to linear size) and determine the mass by multiplying the mass density times the volume. (The answer should be a very large number of kilograms)

Volume of M42	
Mass of M42	

QUESTION 7:

How many solar mass stars can be created by the gas in M42 if it all collapses to form solar mass stars? (See Appendix for the mass of the sun.)

Number of Stars	
-----------------	--

2.2 SIZE AND AGE OF THE RING NEBULA (M57)

Discard M42.fts and load **M57.FTS**. Adjust the histogram so that the ring is not so glaringly bright – use your best judgment to determine when the ring shows the most detail. The Ring Nebula is a type of **PLANETARY NEBULA**. Planetary nebulae are formed at the end of a medium to low mass (like the Sun) star’s life when it has stopped fusing Hydrogen at its core. In order to burn heavier elements, the star must change form, and in doing so blows off its atmosphere into space. The discarded gas is stimulated by the ultraviolet radiation from the original star and glows. Notice the star at the center of the nebula. (There is another star inside the ring, offset from the center. This is a foreground star and has nothing to do with the nebula.) This is the star which is shedding its outer atmosphere to produce the nebula.

QUESTION 7:

Measure the distance from the center star to the ring’s edge at three different locations. Calculate the radius in pixels using the distance formula. **Take at least 2 more measurements of radius, choosing different locations along the nebula edge.** Use your three measurements to find the average radius of M57 in pixels.

	Center Coordinate	Edge Coordinate	Radius
Measurement 1			
Measurement 2			
Measurement 3			
		Average (pixels)	

QUESTION 8:

Convert the average radius in pixels to a linear distance given that Scale Factor of the M57 image is 0.5 arcseconds per pixel. You also need to know the distance to M57 which is located in the introduction. Express your answer in AU.

Distance to M42	
Linear Size	

QUESTION 9:

If the sun were to produce a nebula of the same size as M57, would the Earth be inside or outside of it?

Earth's Location	
------------------	--

The average expansion speed of the gas in the nebula is 20 km/s. If it is assumed that the nebula has been expanding at this speed for its entire lifetime (not a very sound assumption, but it is OK as a rough estimate), it is fairly simple to estimate the nebula's age, since $t = r/v$ where r is the distance, v is the velocity, and t is time.

QUESTION 10:

Estimate the nebula's age in seconds and convert the answer to years. For a solar type star, is the planetary nebula phase a small or large fraction of its lifetime?

Age (years)	
Large/Small Fraction?	

Name _____

Date _____

Lab Partner(s) _____

Project Score

DETERMINING STELLAR PROPERTIES USING BV PHOTOMETRY

Based on text from Imaging the Universe - A Laboratory Manual for Introductory Astronomy,
R. Mutel et. al.

PROJECT LEVEL: Intermediate to Advanced

PROJECT GOALS: The student will learn to apply BVRI photometry to an open cluster to determine some properties of the stars.

IMAGE DIRECTORY/LIST: proj-26_Photometry_BVRI:

REFERENCES: Webb Society Deep-Sky Observer's Handbook Vol. 1: Double Stars; Starlist 2000 (Dibon-Smith); Astronomical Photometry (Henden and Kaitchuck).

1 INTRODUCTION

Although stars have an enormous range of masses, sizes, temperature, and luminosities, a simple measurement of the **APPARENT MAGNITUDE** at two wavelengths is often sufficient information to determine these characteristics. To make these measurements, optical astronomers typically use **FILTERS** to capture only the light from specific wavelengths at a time. The filters we will use for this project select the **BLUE** (B), **GREEN** (V, for visual as the sun's peak wavelength is green and our eyes are most sensitive to green), **RED** (R), and **NEAR-INFRARED** (I). Other interesting filters (unused here) are **HYDROGEN-ALPHA** (H) filter which select only the strongest Hydrogen Balmer line, or the **OXYGEN III** (O) filter which selects the strongest spectral line of ionized Oxygen. In many cases, the use of filters can quickly indicate the presence (or absence) of an element and give Astronomers one more tool to study the Universe.

In this observing project, you will choose a young open cluster star system and observe several stars using visual (V) and infrared (I) colored filters. Using these measurements, it will be possible to determine the distance, temperature, luminosity, radius, and mass of each star. The V and I magnitudes for each star are obtained using differential photometry and a reference star in the same field with known magnitudes.

Magnitude System

The magnitude system is a method used by Astronomers to convert the huge range of object luminosities into a more manageable scale. This is done by comparing (using a ratio) the flux of the object (flux = luminosity / area) to a reference value and then taking the logarithm of the value. Expressed as an equation, this looks like:

$$V = -2.5 \times \log\left(\frac{F}{F_0}\right)$$

Here, **V** is the **APPARENT MAGNITUDE** in the visual filter and **F**, **F₀** are the fluxes of the object and reference (also measured in the V filter). Typically, **F₀** is chosen to be the flux of the star **VEGA** (alpha Lyra, an AOV class star). With the naked-eye, the apparent magnitudes of stars in the sky will roughly bin in the range of -1 (the brightest) to 6.5 (faintest). The **ABSOLUTE MAGNITUDE (M_v)** of an object is defined as the apparent magnitude the object would have if it were located at a distance of 10pc.

Here are a few examples:

TABLE 1 - TABLE OF APPARENT AND ABSOLUTE MAGNITUDES FOR SAMPLE OBJECTS

Source	V	M _v
Sun	-29.3	4.8
Sirius	-1.43	1.4
Vega	0	0.6
Polaris	2.0	-3.2
Crab Supernova	8.4	-3.1

2 BASIC STELLAR PROPERTIES

Stars are relatively simple entities which can be described by a few elementary laws of thermodynamics and radiation. (This ignores details of the fusion engine in the core, which are not so simple!) In particular, the observed radiation has the same characteristic intensity–wavelength dependence that all thermal emitters (e.g. stovetops, people) have, creating a simple relation between observed color and surface temperature. If the star is on the main-sequence (90% of all stars are), the luminosity can be inferred from the color. Since the total luminosity of the star is proportional to surface area and we know that (most) stars are (mostly) spherical, the radius of the star can be inferred from the luminosity. Finally, it turns out that stellar models predict a simple mathematical relationship between luminosity and mass which is verified by observations.

1.1 SURFACE TEMPERATURE

Once the apparent B and V magnitudes are found, the **COLOR INDEX (B – V)** can be calculated. For B-V in the range 0.0 to +1.5, the relationship between B-V and the surface temperature can be written as:

$$T = \frac{6901K}{(B - V) + 0.70}$$

The color index can also be used to determine the spectral type using Table 2 at the end of this section.

1.2 DISTANCE

The clusters chosen for this project are relatively young, so most cluster members are on the main sequence. Therefore, the spectral type can be used to determine the **ABSOLUTE VISUAL MAGNITUDE (M_V)** using the HR diagram in Table 3. The distance in parsec is related to the observed visual magnitude (**V**) and absolute visual magnitude by:

$$d = 10^{(V-M_V+5)/5}$$

1.3 LUMINOSITY

The luminosity of the star depends on the **ABSOLUTE BOLOMETRIC MAGNITUDE (M_{bol})** which represents the sum of the energy output at all wavelengths. This is given in Table 3 for main sequence stars as a function of spectral type. The luminosity can be determined by comparison with the sun's bolometric luminosity

$$\frac{L}{L_{sun}} = 10^{0.4 \times (M_{sun} - M_{bol})}$$

where **$M_{sun} = 4.8$** and **$L_{sun} = 3.8 \times 10^{26} \text{ W}$** .

1.4 RADIUS

The stellar radius is given by considering the formula for the Stefan-Boltzmann law for the star and for the Sun and dividing the two equations to eliminate constants. One obtains:

$$\frac{R}{R_{sun}} = \left(\frac{T}{T_{sun}} \right)^{-2} * \left(\frac{L}{L_{sun}} \right)^{-0.5}$$

where **$R_{sun} = 6.96 \times 10^5 \text{ km}$** and **$T_{sun} = 5700 \text{ K}$** are the radius and surface temperature of the sun, respectively.

1.5 MASS DETERMINATION

For stars on the main sequence, the mass-luminosity relation can be approximated by the following function:

$$\log \left(\frac{L}{L_{sun}} \right) = 4.2 \cdot \sin \left[\log \left(\frac{M}{M_{sun}} \right) - 0.281 \right] + 1.174$$

Here, the sine argument is in **RADIANS**. (NOTE: In this case M_{sun} is the mass of the Sun, **not** its absolute visual magnitude).

Solving for $\log (M/M_{sun})$, we get:

$$\log \left(\frac{M}{M_{sun}} \right) = 0.281 + \arcsin \{ 0.24 \cdot \left[\log \left(\frac{L}{L_{sun}} \right) - 1.174 \right] \}$$

2 IMAGE ANALYSIS

Before you can use your cluster images to determine properties of individual stars, you must first **CALIBRATE** your image. You may recall from previous projects that the telescope images are measurements of photons striking the CCD chip, resulting in a number of digital (ADU) counts. Calibration is the process by which you *teach* MaxIM to convert ADU counts into magnitude units.

Run MaxIm. Choose one of the open clusters from Table 2 and load both the V and B images. You may need to adjust the histogram. Recall that you do this moving the colored arrows on the Screen Stretch window. When the image is clear, and you are confident that you can see all of the stars, click on View/Information Window to open the information window, and then press the Calibrate button in order to prepare for photometry. You should see a box appear underneath the Calibrate button with several selections that we will later use to calibrate the program.

You will be doing **DIFFERENTIAL PHOTOMETRY** on this cluster of stars. Differential photometry is done by first making a circle around a star and adding up all of the ADU counts within that circle. The sky background brightness is subtracted from this total, and the resulting ADU counts are set equal to a magnitude. The magnitudes of other stars in the field are determined relative to this star by comparing ADU counts. Fortunately, programs such as *MaxIm* remove most of the tedium of photometry by doing the arithmetic for you.

In order to do photometry properly, you must set up your cursor to check the correct radius. When the information window is active, your cursor will look like a targeting crosshair surrounded by three circles in the active image window. By pressing the right mouse button, you can select the size of the centroid Aperture, Annulus, and Gap Width. The centroid is the area of interest for the cursor. You want to set the Aperture size to be just larger than the largest star you are measuring (note: not necessarily the largest star on the image itself). The Annulus is used to calculate the average background brightness of the image so its size determines how much is averaged. The Gap Width determines how far away from the annulus the background is measured. Scan the image and the finding chart at the end of this lab to determine the largest star you will be looking at. Move the cursor over that star and select an Aperture size. Adjust this until the centroid circle is just larger than that star. You do not want the circle too large, as it will then be difficult to accurately record the magnitudes of smaller stars. Consult your instructor if you are unsure if your centroid circle is too large or small. For the purposes of this lab, a Gap Width value of 3 and an Annulus value of 2 are adequate.

Now you need to calibrate *MaxIm* for photometry. In the area underneath the Calibrate button, you have three Magnitude Calibration selections, *Intensity*, *Exposure*, and *Magnitude*. All three are needed, but only one (*Magnitude*) requires information not found from the image itself. The magnitude of stars for photometry is usually found from finding charts, and here we give you the value. A list of files to be used as finding charts is also found in Table 2. They include calibrator stars to be used in the absolute magnitude calculations.

Enter the magnitude given for the reference star in the Magnitude box. Next, click the Set from FITS button next to the *Exposure* box. This sets the exposure time from the FITS header in the image. Now, click the Extract from image button next to the *Intensity* box. Use the finding chart again to locate the reference star for your cluster and click on star in your image. This extracts the intensity level from the image, and sets the star you clicked on to the magnitude you entered in. If you started with the V image, make sure that you enter the V magnitude here. You have now set your reference star. (Note: Make sure you do not adjust anything in the magnitude calibration area again, else you will have to recalibrate and re-measure every star.)

QUESTION 1:

Load the V image. Select 5 stars from the cluster, making sure the stars you select are visible in both images and are not overexposed. Sketch a simple finding chart to help you remember the selected stars.

Cluster Name	

QUESTION 2:

Calibrate the image using the steps described above and record the V magnitudes in the Data Table 1 at the end of the lab.

QUESTION 3:

Now load the B image. Select the same at least five stars from the cluster, making sure the stars you select are visible in both images and are not overexposed. Calibrate the image using the steps described above and record the B magnitudes for the same 5 you chose in Question 1.

QUESTION 4:

Using Table 3, estimate the Spectral Type, absolute magnitude, and bolometric magnitude for each of your stars. In most cases, the values you measured will not directly correspond to a value from the table. In these cases, do your best to interpolate between the given values. Record your estimates for each star in Data Table 1.

QUESTION 5:

What is the distance to each of your chosen stars? Calculate these values and record them in Data Table 2. The distance to each star should be roughly the same, as they should all be members of the same cluster. If there is a star whose distance is much different than the others, the star may be a foreground or background star, and not actually a member of the cluster.

QUESTION 6:

Using the absolute and bolometric magnitudes, calculate the Luminosity of each star. Express your answers in terms of the Solar Luminosity, i.e. calculate L/L_{sun} for each star.

QUESTION 7:

Now that you have the Luminosity, determine the radius of each star using the formula provided. Having this equation is quite handy. At stellar distances, the resolution of the best optical telescopes is still too coarse to measure the radius of individual stars.

Let's explore Question 7 further. Using the distances you determined in Question 5, calculate an average distance (**D_{avg}**) to your cluster (you can leave this in parsecs for now). The best optical observatories can take images with a resolution (Scale Factor) around 1 arcsecond per pixel. Using the small angle formula,

$$d = \frac{D_{\text{avg}} \times 1''}{206265''}$$

calculate the minimum size that can be accurately measured by simply counting pixels. Convert this number to km and compare it to the radii you calculated for Question 7.

QUESTION 8:

How much larger is this number than your largest star?

Average Distance	
1 pixel size (km)	
Pixel Size / Largest Star	

QUESTION 9:

What is the mass of each of your chosen stars? Use the Luminosity and Temperature values along with the equation in Section 1.5 to calculate the results. Express your answer in Solar mass units.

QUESTION 10:

Discuss what is similar and what is different about your collection of stars. Do you see any trends in your result?

DATA TABLE 1

Star	B	V	(B-V)	Type	Mv	Mbol
1						
2						
3						
4						
5						

DATA TABLE 2

Star	T (K)	d (pc)	L/Lsun	R/Rsun	M/Msun
1					
2					
3					
4					
5					

CALCULATIONS

--

TABLE 2 - FINDING CHARTS FOR OPEN CLUSTERS

Cluster ID	Finding Chart	RA	Dec
M29	M11_REF.jpg	20:23:54	+38:32:00
M36	M36_REF.jpg	05:36:06	+34:08:00
M50	M50_REF.jpg	07:03:12	-08:20:00
M52	M52_REF.jpg	23:24:12	+61:35:00
M67	M67_REF.jpg	08:50:24	+11:49:00
NGC1342	NGC1342_REF.jpg	03:31.36	+37:20:00
NGC1502	NGC1502_REF.jpg	04:07:42	+62:20:00
NGC1528	NGC1528_REF.jpg	04:15:24	+51:14:00
NGC1545	NGC1545_REF.jpg	04:20:54	+50:15

TABLE 3 - RELATIONSHIP BETWEEN B-V COLOR INDEX AND SURFACE TEMPERATURE AND ABSOLUTE MAGNITUDE OF MAIN SEQUENCE STARS

Spectral Type	B-V	Mv	Mbol
O5	-0.28	-5.8	-10.0
B0	-0.25	-4.1	-6.8
B5	-0.13	-1.1	-2.6
A0	0.00	0.7	0.1
A5	0.10	2.0	1.7
F0	0.22	2.6	2.6
F5	0.34	3.4	3.4
G0	0.47	4.4	4.3
G5	0.57	5.1	5.0
K0	0.72	5.9	5.8
K5	0.98	7.3	6.7
M0	1.17	9.0	7.8
M5	1.32	11.8	9.8

Name _____

Date _____

Lab Partner(s) _____

Project Score

TRI-COLOR IMAGING

From: Imaging the Universe - A Laboratory Manual for Introductory Astronomy, R. Mutel et. al.

PROJECT LEVEL: Introductory

PROJECT GOALS: The student will learn how to use an image processing program to combine filtered monochrome images in order to make a true-color image. Topics discussed are synchrotron radiation, chromatic filters (C,R,B,V), and spectral line emission

IMAGE DIRECTORY/LIST: proj-05_Tri_Color: chapel-[rgb].jpg, crab-[rgb].fts, m27-[rgb].fts

1 INTRODUCTION

This laboratory exercise demonstrates how color images are produced not only in astronomical imaging, but in everyday applications such as television. You will use filtered **MONOCHROME** CCD images of the **CRAB NEBULA** (M1), the **DUMBBELL NEBULA** (M27), and a building on campus to make true-color images from grey-scale filtered images.

1.1 USING FILTERS

To most people, color images are the most interesting to look at, but at the low-light levels prevalent to most visual astronomy, images seem to be grayscale because the light levels are not high enough to stimulate the cones in the human eye. The cones are responsible for color vision, while the rods are responsible for monochromatic, but are sensitive to lower light levels. Varying wavelengths of light will stimulate the cones in different combinations to produce the color vision we are used to. CCD cameras do not have the same limitations that the human eye has, however, and are able to “see” colored light at levels that a human cannot. However, the images taken, even without a **FILTER**, contain only shades of gray. How can astronomers produce such stunning astronomical images as appear in magazines and other journals? Filters exist that can be put in between the camera and the telescope that enable images to be taken that will only allow light of a certain range of colors through. These filters range from the infrared to the ultraviolet, although the visually colored filters are the most important for making color images. The filters most used for color processing are the red, blue, and visual (green) filters while the clear filter image is used for more advanced image processing. These filters are used because they correspond exactly to the cones that process color in the human eye. A fine example of combining R, G, and B filtered images to produce a true color picture of an astronomical object (the Crab supernova remnant discussed below) is shown in the figure on the next page.

This sort of processing is used by most people every day, without even knowing it. It is known as **RGB PROCESSING**. Every television set reproduces an image using signals sent with data using red (R), green

(G), and blue (B) filters, and translates it into a working image on your screen. Color cameras also process images like this, reading what color levels are present in what you are imaging and translating it onto the film or CCD. A more advanced form of processing is known as LRGB, where the L stands for luminance. This is a better processing method in that it can correct for the brightness of objects that can be lost when images are taken through the colored filters.

2 CREATING TRUE-COLOR IMAGES

2.1 THE DANFORTH CHAPEL

Run MaxIm. Open the tricolor directory and load the chapel images **CHAPEL.JPG**, **CHAPEL-R.JPG**, **CHAPEL-B.JPG**, and **CHAPEL-G.JPG**. These images were taken across Hubbard Park from the Danforth Chapel near the IMU on campus in June 2001.

Look at the unfiltered image first (chapel.jpg). This is a color image of the building. This is what you would see if you looked at the building under most conditions (with some variation due to time of day, etc.) We will try to reproduce this image using the filtered images of the building.

Move the three filtered image windows 5 so that you can see all three at once as best you can. Note how the different filters highlight different areas of each image, even though the images are not obviously different other than apparent amount of detail shown. Note the differences do you see in the images (e.g. the blue sky is quite dark in the R image).

QUESTION 1:

Describe the differences in the three filtered images. Where is the R filter image brightest? Where is the G filter brightest? Is this what you expect?

You can use these separate red, green, and blue images to make a true color image. Select one of the filtered images, and **click on Color and then Combine Color** from the menu at top. A new window will open displaying a list of 3 or 4 images, a preview box, and a ratio box. Above the image list is a selection called Conversion Type. Make sure RGB is selected from these selections. On the image list, make sure the correct images correspond to the correct colors (chapel-r to red, etc.).

Set the ratios to 1:1:1 for now, and hit the preview button. In the small window you will see a preview of the image that will be produced after combining the colors. Even though the preview does not quite look like the original (unfiltered) image, click OK. Note how the image is similar to the original, but there are some differences.

QUESTION 2:

Discard the image you just produced and repeat the above step. This time change your mixing ratios. How does this affect the resulting image?

QUESTION 3:

What mixing ratio gives you the best match to the original image? (Hint: a ratio of 1:2:3 is the same as a ratio of 2:4:6. If you are trying to change the overall brightness and contrast of the image, try using the Screen Stretch tool.) How close did you come? Note that you will not be able to reproduce the original image exactly. Describe any differences between your image and the original in the space provided.

R		G		B	

2.2 THE CRAB SUPERNOVA REMNANT

Open the images **CRAB-R.FTS**, **CRAB-G.FTS**, and **CRAB-B.FTS**. These images were taken of the “Crab” supernova remnant (Messier catalog number 1) using red, green, and blue filters. You may get a warning about “negative pixel values,” but do not worry about this, it does not affect the image.

Move the image windows so that all three images are visible at the same time. You will need to adjust the image in order to bring out the maximum amount of detail. This is known as adjusting the histogram. Using the Screen Stretch window, move the red and green arrows underneath the graph to adjust the background (or black) with the red arrow and the brightness (white) with the green. Adjust each of the three images in this fashion.

Notice that the images are obviously different from each other.

The red image shows a fair amount of filamentary structure produced by hydrogen gas glowing most intensely at 656.3 nm (the red Balmer H α line).

The more diffuse emission seen in the blue image results from electrons spiraling around magnetic field lines at very high speeds, and is called synchrotron radiation.

The green (visible) image contains both synchrotron radiation and the Balmer H β line.

QUESTION 4:

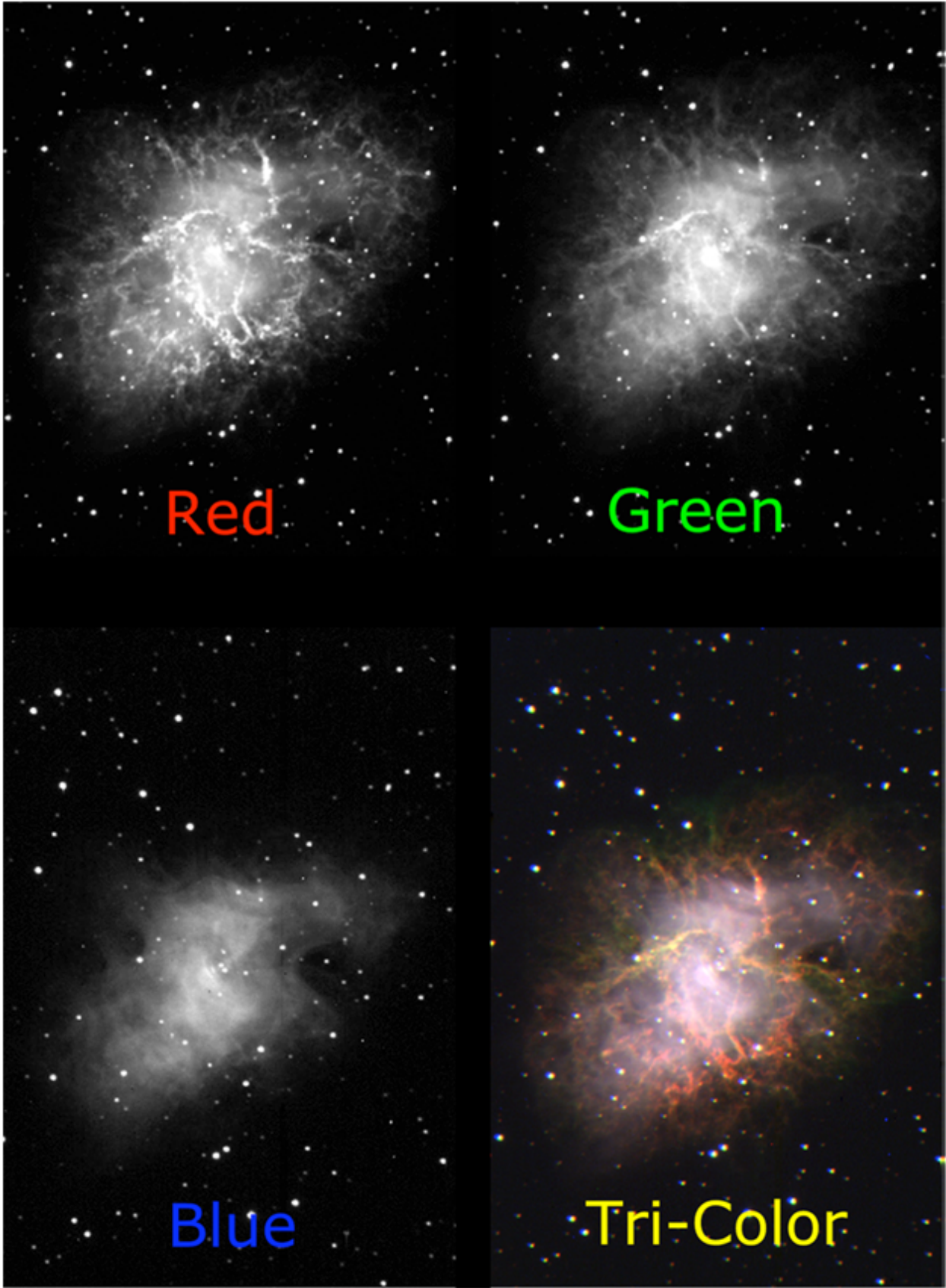
Discard the differences in the filtered images. What can you say about the nebula environment based purely on the filtered images? Are there filaments? What about hot electrons and magnetic fields?

You can use the separate red, green, and blue images to make a true color image, as we have done with the chapel images. Select Color and Combine Color again. Make sure that the image names are in the correct places in the window that opens up. Use the ratios and preview again to examine your image. You should see a beautiful image of the Crab with the red hydrogen filaments extending slightly beyond the hazy white-blue glow of the synchrotron radiation nebula. If you do not see this, adjust the ratios until you are close. Use the series of images on the next page as a reference.

QUESTION 5:

What mixing ratio gives you the best match to the original image? How close did you come? Describe any differences between your image and the original in the space provided.

R		G		B	



Since the Crab Nebula is believed to be the remnant from a supernova recorded by Chinese astronomers in 1054 A.D., we can use its present size and the present year to determine the expansion speed of the nebula. To do this, measure the average radius of the Crab Nebula in pixels. **The pixels in the image have an angular size of 1.2 arcseconds. Convert the radius to arcseconds, and then to a.u. and km using the small angle formula. The nebula is about 2000 pc away.** (You might need to consult the instructions for the Image Analysis Lab for some help with this.)

QUESTION 6:

Estimate the radius of the Crab Nebula. Calculate the radius in pixels using the distance formula. **Take at least 2 more measurements of radius, choosing different locations along the nebula edge.** Use your three measurements to find the average radius of M1 in pixels.

	Center Coordinate	Edge Coordinate	Radius
Measurement 1			
Measurement 2			
Measurement 3			
		Average (pixels)	

QUESTION 7:

Convert the average radius in pixels to a linear distance using the Scale Factor of the M1 image and the given distance. Express your answer in kilometers. Assuming that the remnant's expansion speed has been constant since the explosion (since there is no accelerating force acting on it), calculate the expansion speed of the material in km/s by dividing the radius of the nebula in km by the age in seconds.

Linear Size (pc)	
Linear Size (km)	
Age of M1 (years)	
Age of M1 (s)	
Expansion Speed (km/s)	

2.3 M27 (THE DUMBBELL NEBULA)

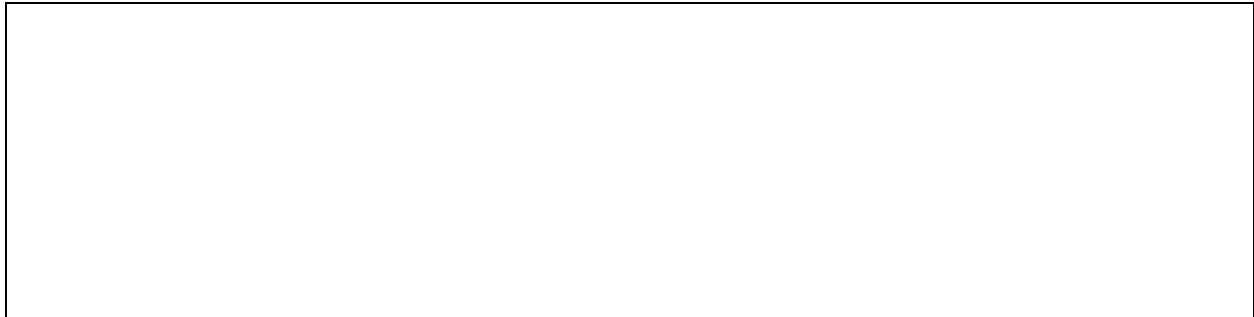
The Dumbell Nebula is a famous example of a planetary nebula. These beautiful objects result from a dying star which is expelling large amounts of gas. The nebula is caused by glowing gas surrounding a

dying star (at the center). The gas is glowing because the star is emitting intense ultraviolet radiation, exciting the atoms in the gas to glow. The greenish center of the nebula is radiation primarily from oxygen and nitrogen, while the red glow near the outer boundary is due to hydrogen (H α line).

Open the images **M27-C.FTS**, **M27-G.FTS**, **M27-B.FTS**, and **M27-R.FTS**.

QUESTION 8:

Discard the differences in the filtered images. What can you say about the nebula environment based purely on the filtered images? Are there filaments? What about hot electrons and magnetic fields?

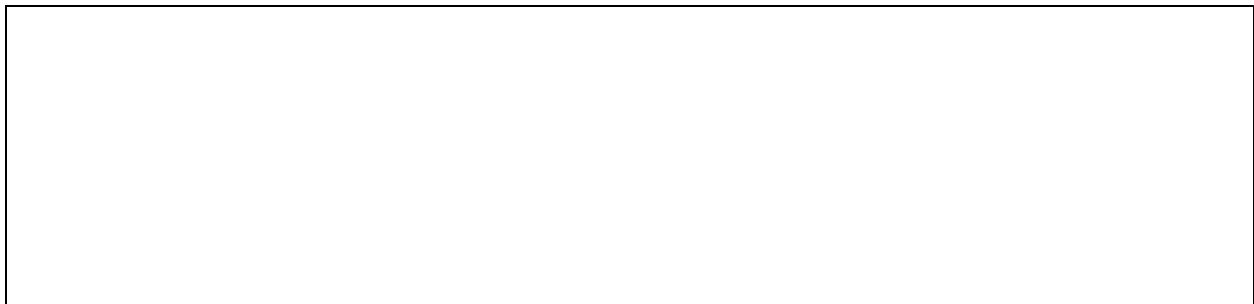


In addition to the RGB images, you now have a clear filter image of the planetary nebula. We will now be combining images in a somewhat more advanced way, using **LRGB COMBINATION**. What the clear filter image will do is add brightness which can be lost in the other images to the color image. Start the color combination in the same fashion that we have been doing so far.

Start with the standard RGB image processing that we have been doing, and form your image. Leave this image open, but move it to the side if necessary. Now, click on one of the filtered images and repeat the above step. Instead of selecting RGB in the color combine window, you now need to select LRGB from the Conversion Types. This will open up one more position in your image selection list, but this selection will be blank. Click on the arrow on the box labeled Luminance, and select the m27-c image for your luminance. There is no ratio for luminance like there is for each color, but there is a “weight,” a value representing how strongly it will affect the combined image. Try 100% at first, but vary with the weight for best results.

QUESTION 9:

What differences are visible between the RGB and LRGB images?



QUESTION 10:

What mixing ratio gives you the best match to the original image? Compare your color image of M27 with the web image at <http://antwrp.gsfc.nasa.gov/apod/ap981009.html>. Describe any differences between your image and the original in the space provided.

R		G		B	

Name _____

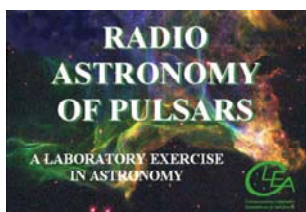
Date _____

Lab Partner(s) _____

Project Score

RADIO ASTRONOMY OF PULSARS

From: Lab Exercise Document SM 8: Version 1.1.1 lab, Department of Physics at Gettysburg College
Gettysburg, PA



PROJECT LEVEL: Introductory

PROJECT GOALS: You should be understand the fundamental operation of a radio telescope and recognize how it is similar to, and different from, an optical telescope. You should understand how astronomers, using radio telescopes, recognize the distinctive properties of pulsars. You should understand what is meant by interstellar dispersion, and how it enables us to measure the distances to pulsars.

1 BACKGROUND: NEUTRON STARS AND PULSARS

Many of the most massive stars, astronomers believe, end their lives as neutron stars. These are bizarre objects so compressed that they consist entirely of neutrons, with so little space between them that a star containing the mass of our sun occupies a sphere no larger than about 10 km. in diameter, roughly the size of Manhattan Island. Such objects, one would think, would be extremely hard, if not impossible, to detect. Their surface areas would be several billion times smaller than the sun, and they would emit so little energy (unless they were impossibly hot) that they could not be seen over interstellar distances.

Astronomers were therefore quite surprised to discover short, regular bursts of radio radiation coming from neutron stars—in fact it took them a while before they realized what it was they were seeing. The objects they discovered were called pulsars, which is short for “pulsating radio sources.”

The discovery of pulsars was made quite by accident. In 1967, Jocelyn Bell, who working for her Ph.D. under Anthony Hewish in Cambridge, England, was conducting a survey of the heavens with a new radio telescope that was designed specifically to look for rapid variations in the strengths of signals from distant objects. The signals from these objects varied rapidly in a random fashion due to random motions in the interstellar gas they pass through on their way to earth, just as stars twinkle randomly due to motions of air in the earth’s atmosphere.

Bell was surprised one evening in November, 1967 to discover a signal that varied *regularly and systematically*, not in a random fashion. It consisted of what looked like an endless series of short bursts of radio waves, evenly spaced precisely 1.33720113 seconds apart. The pulses were so regular, and so unlike natural signals, that, for a while, Bell and Hewish tried to find some artificial source of radiation—like a radar set or home appliance—that was producing the regular interference. It soon became clear that

the regular pulses moved across the sky like stars, and so they must be coming from space. The astronomers even entertained the idea that they were coming from “Little Green Men” who were signaling to the earth. But when three more pulsating sources were discovered with different periods (all around a second in length) and signal strengths in different parts of the sky, it became clear that these “pulsars” were some sort of natural phenomenon. When Bell and Hewish and their collaborators published their discovery, in February 1968, they suggested that the pulses came from a very small object—such as a neutron star—because only an object that small could vary its structure or orientation as fast as once a second.

It was only about six months after their discovery that theoreticians came up with an explanation for the strange pulses: they were indeed coming from rapidly spinning, highly magnetic, neutron stars. Tommy Gold of Cornell University was the first to set down a this idea, and, though many details have been filled in over the years, the basic idea remains unchanged.

We would expect neutron stars to be spinning rapidly since they form from normal stars, which are rotating. When a star shrinks, like a skater drawing her arms closer to her body, the star spins faster (according to a principle called conservation of angular momentum). Since neutron stars are about 100,000 times smaller than normal stars, they should

spin 100,000 times faster than a normal star. Our sun spins once every 30 days, so we would expect a neutron star to spin about once a second. A neutron star should also have a very strong magnetic field, magnified in strength by several tens of billions over that of a normal star—because the shrunken surface area of the star concentrates the field. The magnetic field, in a pulsar, is tilted at an angle to the axis of rotation of the star.

Now according to this model the rapidly spinning, highly magnetic neutron traps electrons and accelerates them to high speeds. The fast-moving electrons emit strong radio waves which are beamed out like a lighthouse in two directions, aligned with the magnetic field axis of the neutron star. As the star rotates, the beams sweep out around the sky, and every time one of the beams crosses our line of sight (basically once per rotation of the star), we see a pulse of radio waves, just like a sailor sees a pulse of light from the rotating beacon of a lighthouse.

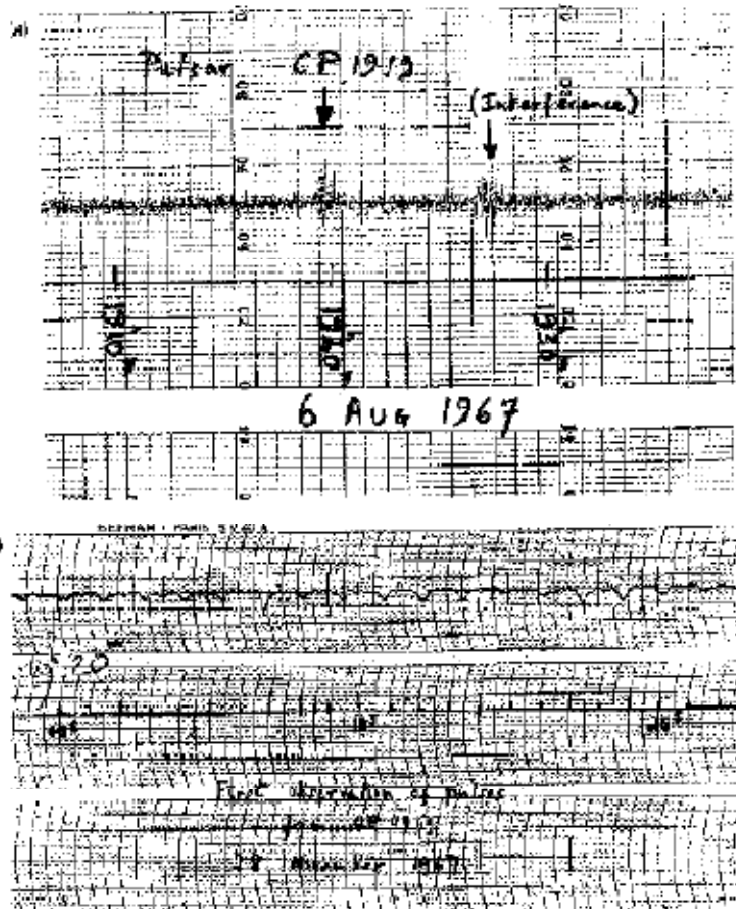


FIGURE 1 - CHART ON WHICH JOCELYN BELL DISCOVERED HER FIRST PULSAR

Today over a thousand pulsars have been discovered, and we know much more about them than we did 1967. The pulsars seem to be concentrated toward the plane of the Milky Way galaxy, and lie at distances of several thousand parsecs away from us. This is what we'd expect if they are the end products of the evolution of massive stars, since massive stars are formed preferentially in the spiral arms which lie in the plane of our galaxy. Except for a few very fast "millisecond" pulsars, the periods of pulsars range from about 1/30th of a second to several seconds. The periods of most pulsars increase by a small amount each year—a consequence of the fact that as they radiate radio waves, they lose rotational energy. Because of this, we expect that a pulsar will slow down and fade as it ages, dropping from visibility about a million years after it is formed. The faster pulsars thus are the youngest pulsars (except for the "millisecond pulsars, a separate type of pulsars, which appear to have been spun up and revitalized by interactions with nearby companion.)

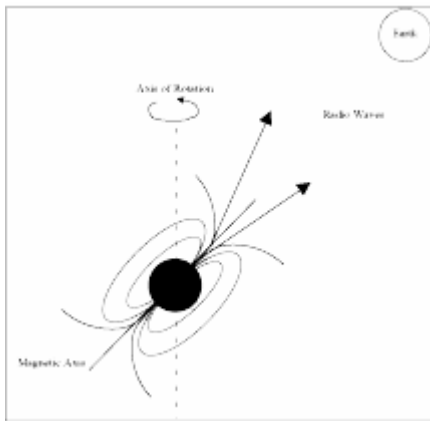


FIGURE 1 - THE PULSE IS "ON." THE EARTH RECEIVES THE RADIO WAVES

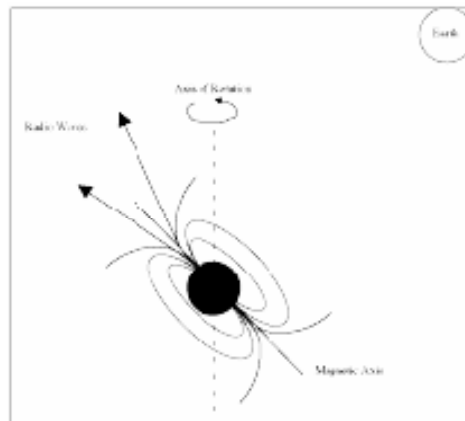


FIGURE 2 - THE PULSE IS "OFF." THE EARTH DOES NOT DETECT THE RADIO WAVES

To an observer, a pulsar appears as a signal in a radio telescope; the signal can be picked up over a broad band of frequencies on the dial (In this exercise, you can tune the receiver from 400 to 1400 MHz). The signal is characterized by short bursts of radio energy separated by regular gaps. (See FIGURE 3). Since the period of a pulsar is just the length of time it takes for the star to rotate, the period is the same no matter what frequency your radio telescope is tuned to. But, as you will see in this lab, the signal appears weaker at higher frequencies. The pulses also arrive earlier at higher frequencies, due to the fact that radio waves of higher frequency travel faster through the interstellar medium, a phenomenon called interstellar dispersion. Astronomers exploit the phenomenon of dispersion, as described later in the text of this exercise, to determine the distance to pulsars. In this lab, we will learn how to operate a simple radio telescope, and we'll use it to investigate the periods, signal strengths, and distances of several representative pulsars.

2 PROCEDURE

The lab consists of the following parts:

- I. Familiarization with the radio telescope.
- II. Observation of a pulsar with a single-channel radio receiver to learn about the operation of the receiver and the appearance of the radio signals from a pulsar at various receiver settings.
- III. Determination of the pulse periods of several pulsars.

- IV. Measurement of the distance of pulsars using the delay in arrival times of pulses at different frequencies due to interstellar dispersion.
- V. Determine the distance of a pulsar using the techniques you have just learned.

2.1 STARTING THE PROGRAM

Your computer should be turned on and running Windows. Your instructor will tell you how to find the icon or menu bar for starting the Radio Astronomy of Pulsars exercise.

- I. Position the mouse over the program's icon or menu bar and click to start the program. When the program starts, the CLEA logo should appear in a window on your screen.
- II. Go to "File" on the menu bar at the top of that window, click on it, and select Login. Fill in the form that appears with your name (and your partner's name, if applicable). Do not use punctuation marks. Press tab after entering each name, or click in each student block to enter the next name. Enter the Laboratory table number or letter if it is not already filled in for you. You can change and edit your entries by clicking in the appropriate field and making your changes.
- III. When all the information has been entered to your satisfaction, click OK to continue, and click yes when asked if you are finished logging in. The opening screen of the Radio Astronomy of Pulsars lab will then appear.

2.2 THE RADIO TELESCOPE

- I. Click File on the menu bar, select Run and then the Radio Telescope option. The window should now show you the control panel for the CLEA radio telescope. A "view screen" at the center shows the telescope itself, a large steerable dish, which acts as the antenna to collect radio waves and send them to your receiver. The Universal Time (UT) and the local sidereal time for your location are shown in the large digital displays on the left. The coordinates at which the telescope is pointed, Right Ascension (RA) and Declination (Dec), are shown in the large displays at the bottom.

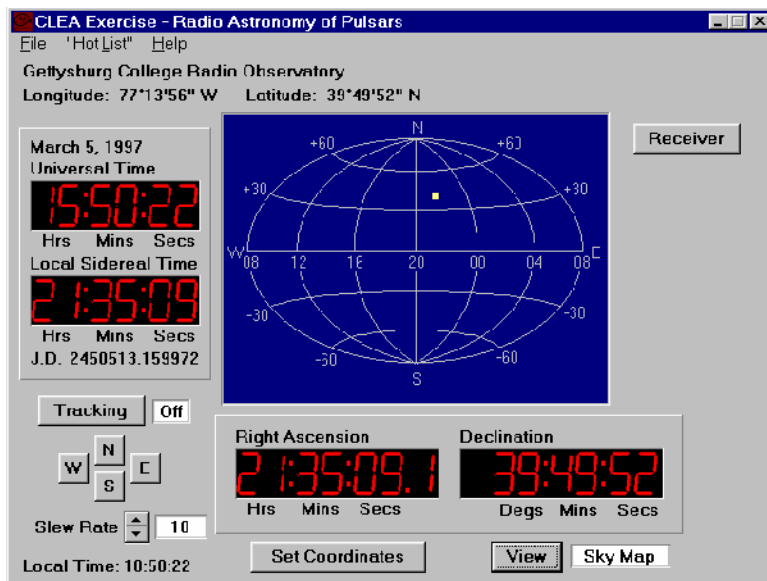


FIGURE 3 – SKY VIEW

- II. Just below and to the right of these coordinate displays is a button labeled View. Click on the View button, and screen in the center will show you a map of the sky, with the coordinate lines labeled. A yellow square shows you where the telescope is pointed.
- III. You can steer the telescope around the sky by clicking and holding down the N-E-S-W buttons at the left side of the window. Try it, and watch the square move, showing that the telescope is moving around the sky. The coordinate readouts will also move. You can change the pointing speed of the telescope by resetting the slew rate button at the lower left. Try setting it to 100, and see how much faster you can move the telescope around the sky.

- IV. You can move the telescope in two other ways:
 - a. by clicking on the set coordinates button at the bottom of the screen
 - b. by selecting objects from the Hot-List pull-down menu on the menu bar at the top of the window. We will use the Hot-List in this exercise, because it is so convenient.
- V. The telescope has a tracking motor designed to keep it pointed at the same spot in the heavens as the earth turns. Right now the motor is off, and, even if you are not moving the telescope with the N-E-S-W buttons, you will see the Right Ascension display changing, because the rotating earth is causing the telescope to sweep the heavens. You should turn on the tracking motor to remedy this. Just below the time displays on the left hand side of the screen is a button labeled Tracking. If you click on it, you will see the word on appear next to the button, and you will notice that the Right Ascension display stops changing. The telescope will now track any object it is pointed at.
- VI. You are now ready to receive signals from your first pulsar.

2.3 OBSERVATION OF A PULSAR WITH A SINGLE-CHANNEL RADIO RECEIVER

Let's begin by familiarizing yourself with the receiver and general properties of pulsars. In this part of the exercise you will point the telescope at a moderately strong pulsar and, using a radio receiver with a graphic display, look at the pulsing radio signal to get some idea of its overall characteristics. The radio waves we receive from pulsars are characterized by sharp pulses of short duration, very steady in their period of repetition, with periods of as short as a few hundredths of a second up to several seconds. The strength of individual pulses varies a bit, in a random fashion, as we shall see, but the overall strength of the signals depends most strongly on the frequency at which you observe them. Our radio receiver can be tuned to any frequency between 400 and 1400 MegaHertz (MHz), and we will use this feature to see, qualitatively, how a pulsar's signal strength changes with frequency.

- I. We want to point our radio telescope to pulsar 0628-28. To move the telescope to the proper coordinates, we will use the Hot List. The Hot List is located on the menu bar. Click and pull down the Hot List menu and choose View/Select from List. Click on the pulsar desired, 0628-08 (the name is in the leftmost column), and click on the OK button at the bottom. After asking you for verification, the telescope will begin to move. You'll see the square on the sky map move, and the coordinate displays change, until the telescope is pointing at the object.

QUESTION 1:

Write down, in the space provided, the Right Ascension and Declination you are pointing to.

RA		DEC	
----	--	-----	--

- II. Now that the big dish antenna is pointed in the right direction, you want to turn on your radio receiver. Click on the Receiver button in the upper right of the telescope control window. A rectangular window will open which has the controls for your receiver on the right, and a graphic display of the signal strength versus time on the left. The frequency the receiver is set to is displayed in the window near the upper right. It is currently set to 600 MHz, and you should leave it there. Later, when you want to change frequency, there are buttons next to it to tune the receiver to different frequencies. Fine tuning can be accomplished by changing the Freq. Incr. (frequency increment), button to its right in conjunction with the main tuning button. There are also buttons to control the horizontal and vertical scale of the graphic display.

III. Let's look at what the pulsar signal looks like. Click on the Mode button to start the receiver. You'll see a graphical trace begin at the left of the screen, tracing out the signal strength versus time on

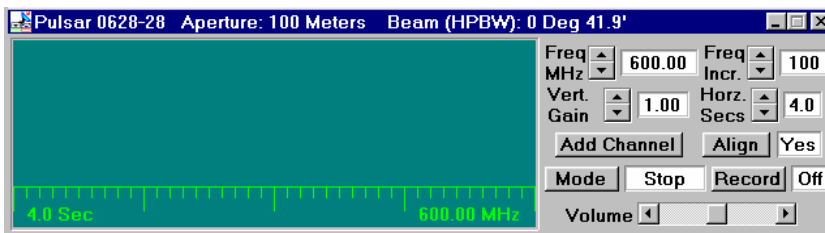


FIGURE 4 - MAIN RECEIVER WINDOW

the graph. It looks like a random jiggle, which is the background static, with an occasional brief rise in signal strength, which is the pulsar signal. (If your computer is equipped with sound, you can also hear what the signal would sound like if you converted the signal to sound, like you do when listening to a radio station). Note how regularly the signal repeats.

- IV. Click on the Mode switch again to turn off the receiver. Note that it completes one scan of the screen before it stops.
- V. Let's see what the other controls do. Start the receiver again. Now watch the trace as you change the Vertical Gain control by clicking on the up and down buttons. This is like the volume control on a radio, except it only controls the graphic display. When the gain is high (you can turn it up to 8), the graphic trace is bigger, both the background and the pulsar signal are magnified. When the gain is low (you can turn it down to 0.25) you can barely see the pulsar. You'll find that the best setting is one where the pulses are high, but don't rise above the top of the display.

QUESTION 2:

Write down the gain setting you think is best. The setting will vary from pulsar to pulsar, and also is dependent on how you have set the Horz Sec control. (It should be set at 4, right now).

- VI. Let's try changing the horizontal scale (Horz Secs). You can only set this control when the receiver is off. Click the Mode switch off, and when the trace stops, reset Horz Sec to 2. This will make the graphic trace take 2 seconds to sweep across the screen. Start the receiver again. You will see the trace race across the screen faster. You may also note that the signal seems weaker, because your receiver is spending less time collecting radio waves before it displays them on the screen. (Astronomers would say the "integration time" is shorter.)
- VII. Try resetting the Horz Sec to 0.5 sec. The pulses seem so wide you may have trouble distinguishing them, and you may have to raise the vertical gain to make them out at all.
- VIII. Change the Horz Sec to 16. The trace pokes across the screen, and because the receiver is collecting more signal at a slower pace, the signals seem stronger. You will have to turn down the gain to avoid having your pulse peaks out of range of the screen.
- IX. Now let's measure the period of the pulsar. Set the vertical gain to 4 and the horizontal seconds to 4, and make sure the frequency of the receiver is 600 MHz. Start the receiver. Let it run for a few seconds to see the pulses, then turn it off again. When the trace stops moving, you can measure the time between pulses on the screen. The computer has measuring cursors to aid you in doing this. Holding down the left mouse button produces a vertical blue line on the screen which you can move as you hold down the button. Center it in the middle of one of the pulses near the left side of the screen. Note the blue numbers on the screen that tell you the time in seconds at which the pulse arrived. You want to measure the time of arrival of the next pulse (time increases to the

right)—so you can get another line, a white one, to appear by holding down the right mouse button. Position it over the next pulse. You can read this time from numbers on the screen, too. Now record the time of arrival of both pulses on the table below. The difference between these is the period of the pulsar!

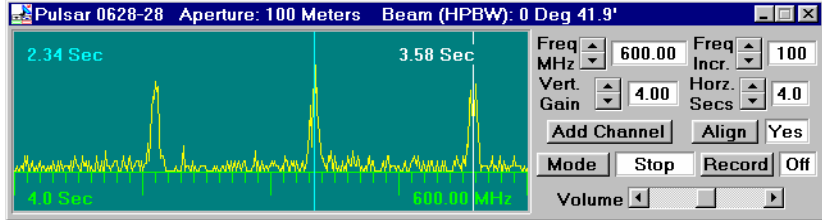


FIGURE 5 - MAIN RECEIVER WINDOW WITH PULSES

QUESTION 3:

Record the following:

Time of First Pulse (T1)	
Time of Next Pulse (T2)	
Period (T2-T1)	

- X. A more precise way of measuring the period is to measure the time elapsed between several pulses and then divide by the number of periods that have elapsed. Set the horizontal seconds control to 16, turn down the gain a notch or two, and turn on the receiver again so that you can see many pulses on one scan.

QUESTION 4:

Measure the time it takes for 10 periods, and use this to calculate the period of the pulsar. See if this gives you the same value. Record your measurements below.

Time of First Pulse (T1)	
Time 10 Periods Later (T10)	
Period (T10-T1)/10	

- XI. Now let's look at the relationship between the pulsar period and the frequency. You can tune the receiver to different frequencies and, using whichever one of these methods is most convenient, measure the period at different frequencies. Since the signal strength changes with frequency, you may have to adjust the vertical gain or the horizontal seconds controls to see the pulses clearly at each frequency.

QUESTION 5:

Fill in the following table.

Frequency	Time of First Pulse	Time of Last Pulse	Number of Pulses	Period of Pulse
400MHz				
600MHz				
800MHz				
1000MHz				
1200MHz				
1400MHz				

QUESTION 6:

From what you have measured, state briefly how the period of the pulsar depends on the frequency.

How does the pulsar signal strength depend on frequency? Clearly it does, since you have to reset the vertical gain and horizontal time controls at different frequencies. But to see how it changes in a more systematic fashion, let's keep those controls set—for example, 4 for the vertical gain and 4 for the horizontal seconds. Then look at the signal at various frequencies from 1400 MHz back down to 400 MHz. Answer the following questions.

QUESTION 7:

Is the pulsar signal stronger at lower or higher frequencies?

lower	higher
-------	--------

QUESTION 8:

If I am hunting for pulsars in the sky, or want to measure the period of a pulsar I've never investigated before, what is best frequency to tune my receiver? Why?

2.4 THE PERIODS OF DIFFERENT PULSARS

Now we will look at the periods of different pulsars. The short periods of the pulsar we have just measured is remarkable, especially when you consider that the period is the length of time it takes for the star to rotate once. Imagine an object as massive as our sun rotating once a second! The pulses of each pulsar are distinctive, both in period and in strength.

QUESTION 9:

Knowing how to steer the instrument and use the receiver, measure the periods of the following pulsars that are listed in the hot list. Also keep an eye on the signal strength. Try to rank the pulsars in order of signal strength, with the strongest pulsar labeled 1, the next strongest, 2, etc. Record your data in the table.

Pulsar	Frequency	Time of First Pulse	Time of Last Pulse	Number of Pulses	Period of Pulse	Relative Strength
2154+40						
0740-28						
0531+21						

QUESTION 10:

Generally speaking, the rotation of a pulsar slows down as it ages. Based on your measurements, rank the four pulsars you have measured, 0628-28, 2154+40, 0740-28, and 0531+21, in order of age, from the youngest to the oldest.

1 st (Youngest)	
2 nd	
3 rd	
4 th (Oldest)	

2.5 MEASURING THE DISTANCE TO PULSARS USING DISPERSION

Most pulsars can't be seen with optical telescopes, so we can't use their absolute magnitudes to determine distance. How can we determine their distance then? One powerful method is to use the phenomenon of **DISPERSION**. All forms of electromagnetic radiation, including radio waves, travel at the same speed in a vacuum. This speed is $c = 3 \times 10^8$ meters/sec. However, interstellar space is not quite a vacuum. On the average the interstellar medium consists of a few atoms and a few free electrons in each cubic centimeter. It isn't much, but it's enough to slow down electromagnetic waves slightly. The lower the frequency, the slower the radiation travels. This means that, though the effect is small, pulses from a pulsar arrive a

fraction of a second earlier at higher frequencies than at lower frequencies, because the higher frequency pulses travel faster through the interstellar medium. You'll be able to see this easily using our radio telescope, since you can receive signals at up to three wavelengths simultaneously, and can compare the arrival times on the three graphic displays.

By measuring the times of arrival of pulses from the same pulsar at different frequencies you can determine the distance to the pulsar, as long as you know the speed of radio waves through the interstellar medium at different frequencies. We do in fact know how frequency affects the speed of electromagnetic radiation from the theory of electromagnetism developed over 100 years ago.

2.5.1 DISPERSION FORMULA FOR THE INTERSTELLAR MEDIUM

In a simplified case unrelated to electromagnetism, we can look at how arrival time helps determine distance traveled by two athletes running a race. Suppose we have two runners (A and B) who are racing each other. Runner A runs a steady 5 kilometers an hour; and Runner B runs a steady 10 kilometers an hour. We do not know ahead of time HOW FAR AWAY (**L**) the start line is, but since we know their speeds and when they each finish the race, we can calculate the distance by a simple relationship. The time it takes each runner to cross the finish line is just:

$$T_A = L/v_A \text{ and } T_B = L/v_B$$

If we take the difference in each runner's finish time and solve for the race distance, we find that:

$$L = (T_B - T_A) / (1/v_B - 1/v_A)$$

The laws of physics enable us to calculate the speed of electromagnetic radiation in the interstellar medium and to derive a formula similar to the one above for the distance traveled in terms of the delay in arrival between radio pulses received at different frequencies. Lower frequencies travel slower, arriving later. In addition, the number of charged particles—the electron density— of the interstellar medium affects the delay, increasing it if the density is higher. In general, the velocity of electromagnetic radiation is proportional to the square of the frequency divided by the electron density, and theory yields the equation:

$$v = \frac{f^2}{4150 \times n_e} = \frac{f^2}{124.5} \text{ for the ISM}$$

Using this velocity in the race distance example above, we find that by observing pulses at different frequencies, the distance to a pulsar is given as:

$$D = (T_2 - T_1) / \left(124.5 \times (1/f_2^2 - 1/f_1^2) \right)$$

So in order to determine the distance of a pulsar, we simply need to measure the time of arrival of a pulse from a pulsar at two different frequencies. We'll do that in the next part for two of the pulsars we've already looked at.

2.5.2 OBSERVING PULSE DISPERSION

- I. Using the control panel of your radio telescope, go to pulsar 0628-28. Open the radio receiver window, set the vertical gain for 4 and the horizontal seconds for 4, and tune the receiver to 400 MHz. Then turn on the receiver just to make sure you are getting strong pulses.
- II. Stop the receiver now. Let's add a second receiver. Click on the add channel button and a second receiver display should appear below the first, aligned with it. Set the vertical, horizontal and frequency controls to the same values as the first receiver, a frequency of 400 MHz, 4 for the vertical gain and 4 for the horizontal secs.
- III. Set the Freq Incr. button on the lower receiver to 10 MHz, (making it possible to tune the second receiver 10 MHz at time).
- IV. Turn on the receivers by clicking the mode button located on the top receiver. Both receivers will start recording. Because they are both receiving the same signal at the same frequency, the two traces should be exactly the same (except, perhaps for a slight random noise in each separate receiver). How do the arrival times of pulses depend on frequency? Let's find out.
- V. Turn on the channels by clicking the mode button in the first channel. While the receivers are running, tune the second receiver to 410 MHz. Do you notice a difference in the arrival times of the higher frequency pulse? Watch for a few seconds.
- VI. Tune the receiver up to 420 MHz, then 430 MHz. Is the behavior becoming clearer? Tune the second receiver slowly in 10 MHz increments up to 600 MHz, pausing now and then to watch the scans.

QUESTION 11:

What can you say about the arrival times of pulses at higher frequencies? Do they arrive earlier or later than the pulses at lower frequencies? Write your conclusion as a brief statement below.

- VII. Turn off the receivers with the mode button. Now open up a third receiver using the add channel button and tune it to 800 MHz, and set both the vertical gain and horizontal gain to 4.
- VIII. Turn on the mode button in the first receiver and watch the traces on the three receivers.

QUESTION 12:

Is the behavior you see in accord with what you now understand about the arrival times of the pulses at different wavelengths? Explain.

2.5.3 MEASURING THE ARRIVAL TIMES OF PULSES

We're now ready to measure the times of arrival for the pulsar pulses. First, we record the data from several screen scans, save it in a file, and finally analyze the file in a separate graphic analysis window.

- I. Turn off the receivers with the mode switch and verify that the three receivers are set to get data at 400, 600, and 800 MHz simultaneously with the horizontal seconds set at 4 and the vertical gain at 4 in each receiver.

- II. Click on the record button to enable the data recorder, and then turn the receivers on with the mode switch.
- III. Let the receiver scan for five or six screens worth of data (only the first 4 will be saved). Then switch off the receivers. The computer will tell you that 1600 data points have been saved. It will then show you the name of the object for verification. Click OK. A pop up a screen will appear showing you information about the object you just recorded, including the time when the recording began (in Julian days—a running date), the frequencies, and the time between each sample of the signal. You cannot edit this data. This screen is for information only.
- IV. Click on OK. The computer will then ask you if you want to save the data or analyze it immediately. Click on yes, and the computer prompts us for a file name. It will make one up using the name you logged in with. If you want to change this name, you can do so.
- V. Close the receivers by clicking on the x in the upper right corner of the main receiver window. Under the File menu on the main control screen, choose Run...Data Analysis. If you have not turned off the program, a window should appear showing you the general information on the data file you just created (otherwise, it will ask you to use the Files...Load menu to choose from a menu of data files by name.)
- VI. Click on the file containing the data you want to analyze. You will see a measuring window with the three traces labeled. This is similar your three receivers, but it displays the stored data you just received. You can set down measuring lines, and scroll back and forth in the display at your leisure. Experiment with using the horizontal pan buttons, which move the traces right and left. Experiment with the zoom in and zoom out buttons, which magnify the scale of the traces.
- VII. Now let's measure the times of arrival of a pulse at the three different frequencies you recorded. Zoom in until you can see about two pulses across the screen. This high magnification will let you measure the pulse arrival times more readily. Pan the screen so that there is a pulse at 400 MHz in the right half of the top screen. You should see the same pulse arriving earlier (to the left, at an earlier time) at the 600 MHz frequency, and still earlier (even further to the left) at the 800 MHz frequency. Holding down the left hand mouse button while you're moving the mouse in a measuring window will move a vertical line back and forth across the screen. Set one line in the middle of the 400 MHz pulse. You can read the time of arrival in the blue window to the right of the measuring window. Set measuring lines similarly in the 600 MHz and 800 MHz windows.

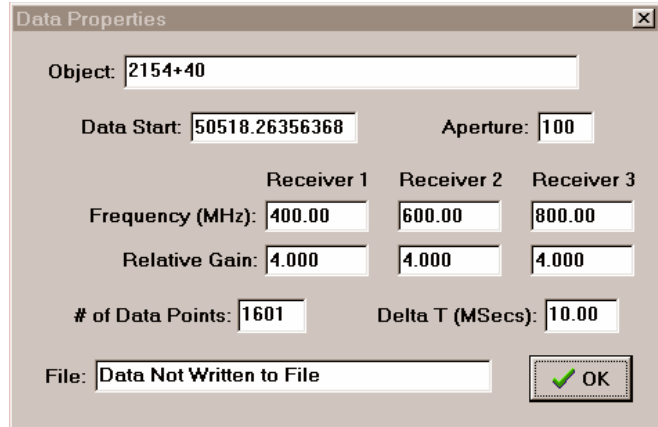


FIGURE 6 - DATA PROPERTIES PUP-UP SCREEN

QUESTION 13:

Record the times of arrival for pulses from pulsar 0628-28.

400MHz (T400)	
600MHz (T600)	
800MHz (T800)	

QUESTION 14:

Now, using the dispersion formula for radio waves described above, use the difference in arrival times at two different frequencies to calculate the distance to the pulsar.

Frequencies (MHz)				
f ₁	f ₂	T ₂ -T ₁	$\frac{1}{f_2^2} - \frac{1}{f_1^2}$	D (pc)
600	400			
800	400			
800	600			

If you've not made any numeric mistakes, your three distances should agree to at least two significant figures, and should be of the order of 1000 parsecs or so. Check over your work and your measurements if there's some disagreement.

QUESTION 15:

Now determine the distance of Pulsar 2154+40 applying the techniques you have just learned. Using the radio telescope, locate the pulsar. Record the data at three frequencies of your own choice and save it. Analyze the data to determine the distance of the pulsar. The following tables will help you organize and analyze your data.

Frequency	Arrival Time

Frequencies (MHz)				
f ₁	f ₂	T ₂ -T ₁	$\frac{1}{f_2^2} - \frac{1}{f_1^2}$	D (pc)

APPENDIX A: GUIDELINES FOR FINAL LAB PROJECTS

1 INTRODUCTION

Over the duration of this lab course, you have observed (either directly or indirectly) various features of the surrounding universe. You have also been taught methods to better investigate these features and determine their properties; properties like size, mass, age, temperature and chemical composition. By using the concepts you learned in both lecture and in lab, you now have the ability to view and analyze the cosmic world around you in a scientific manner and answer basic questions about objects of interest.

Let's summarize briefly the tools and concepts you have learned so far in lab...

In **USING STAR CHARTS**, you learned about the Right Ascension and Declination system and how to locate objects in the sky no matter what time of year.

In **PARALLAX**, you discovered that the distance to an object can be determined by measuring how much it appears to shift relative to background objects.

In **SPECTROSCOPY**, you calculated the temperatures of continuous sources using Wein's Law and "finger-printed" elements using their emission (and sometimes absorption) spectrum.

In **BASIC IMAGE ANALYSIS**, you learned about CCD cameras and how to convert observed sizes into linear distances using the Small Angle Formula.

In **DETERMINING STELLAR PROPERTIES**, you used BV Photometry to make estimates of a stars Temperature, Distance, Luminosity, Radius and Mass.

Lastly, in **TRI COLOR IMAGING**, you experimented with filters and color ratios/exposure times to make color images of celestial objects. You also learned that different filters can reveal different features, such as a red filter centered on the Hydrogen Alpha line highlights the hydrogen gas in a source, or a blue filter exposes synchrotron radiation from clouds of hot, energetic electrons.

2 PROJECT DESCRIPTION

Using the concepts refreshed above (along with others not mentioned) you will be asked to scientifically analyze a celestial object of your choosing. This can be any object discussed in lecture/lab that you want to learn more about or an object you are curious about that was never mentioned. There is a vast variety of sources to choose from, including star clusters, galaxies, planetary nebula, white dwarfs, binary stars or supernova remnants. The important thing is that it is an object that has sparked your interest.

You (and a partner if you like) will be responsible for choosing an object to observe and must follow the three guidelines listed below:

1. The object must be observable using Rigel, the remote operated telescope maintained by the Department of Physics and Astronomy here at the university. The link for the online observing site is below.

(Iowa Robotic Telescope Facility, University of Iowa)
<http://phobos.physics.uiowa.edu>

Note that the location of the telescope limits your choice to objects visible at night and in the northern hemisphere. To use Rigel, you will need an observing code. One will be assigned to you by your lab instructor and he/she will instruct you on the proper use of the telescope scheduling system.

2. You will be asked to make a color image of your object using the skills you gained during the Tri Color Imaging lab. This will require you to know the apparent magnitude of your object and calculate the correct exposure times needed for the three (possibly four) filters. Remember that filtered images highlight different features of your celestial object and color images are a great way to show off your project and get the attention of your peers.
3. From your image(s), you will be required to make some type of scientific measurement similar to the ones performed during the semester. This should be something more than a simple length measurement. An example might be using a red filtered image of a nebula to estimate the amount of hydrogen it contains. You may find that many of the interesting objects in the sky have been analyzed in great detail and the result of your measurement is already known. Do your calculation anyway and compare your result to the known value.

You will present your results to your classmates during the final week of lab. Presentations should be 10-15 min in length and include a short section explaining your motivation to choose this topic and a short description of the importance of your object. PowerPoint is the preferred method to present your work, though you may use other forms. Remember to include your color image and a description of your calculations.

If you include any comparison to known values, or use other images, **be sure to credit the source!** Plagiarism is a serious offence. The university policy on plagiarism is as follows:

All forms of plagiarism and any other activities that result in a student presenting work that is not really his or her own are considered academic fraud. Academic fraud includes these and other misrepresentations:

- *Presentation of ideas from any sources you do not credit;*
- *Use of direct quotations without quotation marks and/or without credit to the source;*
- *Paraphrasing information and ideas from sources without credit to the source;*
- *Failure to provide adequate citations for material obtained through electronic research*
- *Downloading and submitting work from electronic databases without citation;*
- *Participation in a group project which presents plagiarized materials;*
- *Taking credit as part of a group without participating as required in the work of the group;*
- *Submitting material created/written by someone else as one's own, including purchased term/research papers.*

You will be asked to hand in a printed copy of your presentation along with page showing your calculations. Note that this project is worth 2-3 times a regular lab project (depending on your Course and Lab Instructors) so take your time and do a good job.

APPENDIX B: GUIDELINES FOR POWER POINT PRESENTATIONS

Here are a few guidelines you should follow when preparing your final presentation.

1 PRESENTATION FOCUS

Your presentation should be viewed as an informal discussion with the class about what you've been doing this semester for your final project.

You should NOT read off of note cards, but instead DO present your material in a conversational way what you observed, etc. Take your time and don't panic. You will NOT be deducted points if you stutter, or fumble for words. This is not a grade on how good a public speaker you are.

2 PRESENTATION LENGTH

Your presentation should be about 8 minutes. Minimum is 5, maximum is 11. This corresponds to about 6-10 slides, depending on how fast you talk.

3 PRESENTATION CONTENT

A. BACKGROUND

In addition to telling us what you did and how you did it, your presentation should answer 3 very important questions:

1. What is your topic?
2. How did this subject tickle your interest?
3. Why is it important to astronomy?
4. What are your goals in observing your object?

B. IMAGE

One of the requirements for this project was to make a color (LRGB) image. Show off your image. Remember that images are a great way to hold the attention of your audience and get them excited about your topic. You may include other images you find on the web, but don't overdo it, and make sure you credit your source(s).

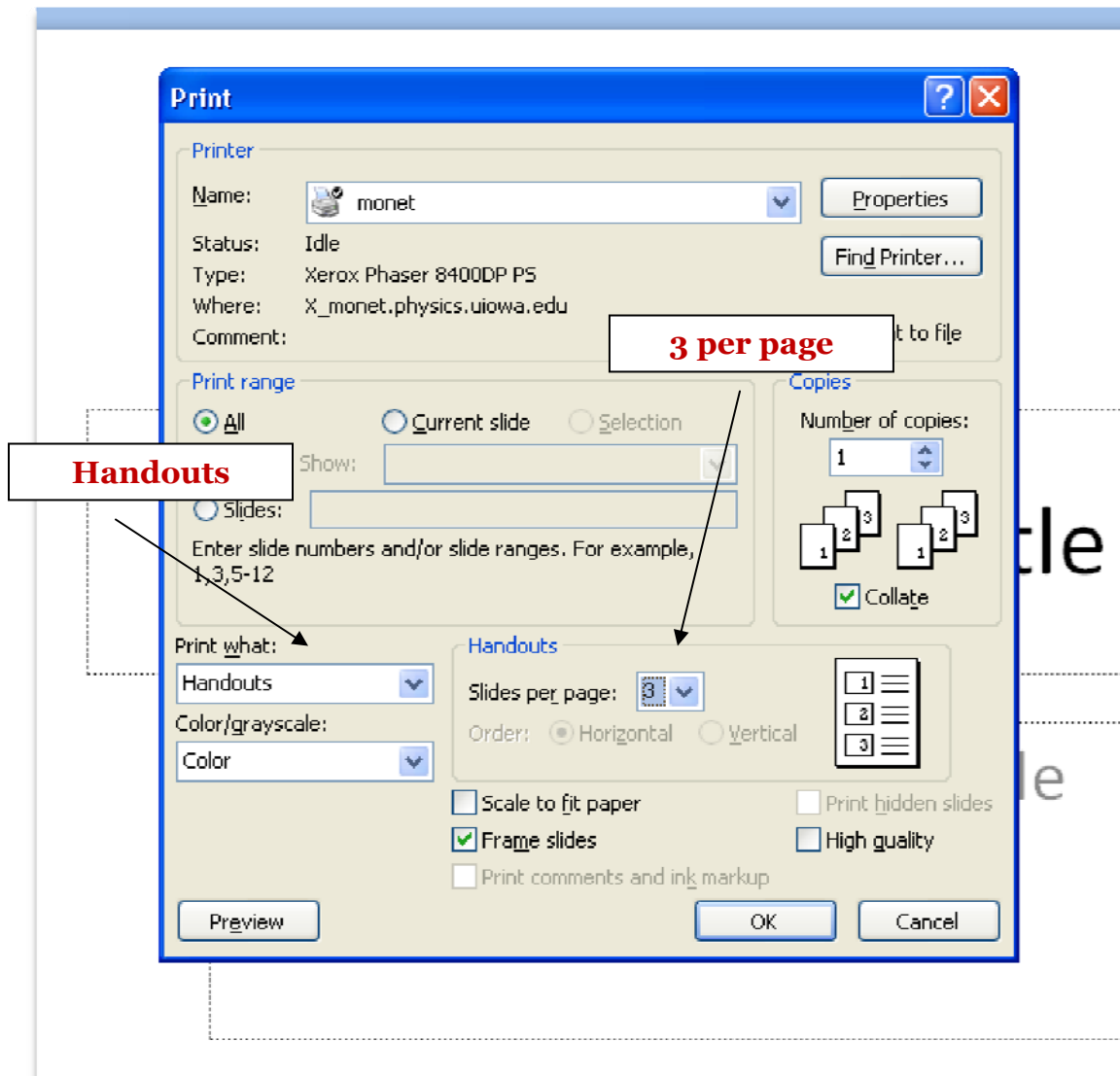
C. IMAGE ANALYSIS

Another requirement was to use the skills you have gained this semester to determine a physical property of your object. Present the results of your image analysis. Each of your classmates should know the important equations, so you only need to present formulas that are new to the class. Also, instead of explaining the details of each equation, simply tell us in words what you accomplished. The only numbers you should have should be your results. For example, what were the heights of the lunar craters? What was the concentration of Oxygen in the Orion Nebula?

4 WHAT TO HAND IN

To receive your grade, you (with your partner) will be asked to hand in two things.

- A. A printout of your PowerPoint slideshow. This should be done using the “Handout” option in the print dialog and should contain 3 slides per page.



- B. One page detailing your calculations. This can be done by hand, but PLEASE try and be neat.

APPENDIX C: ANALYZING ASTRONOMICAL IMAGES WITH MAXIM DL

1 INTRODUCTION

Early astronomers relied on handmade sketches to record their observations (see Galileo's sketches of Jupiter's moons). In recent history, optical telescopes focused light onto photographic plates or film in order to capture and store observations. Today, images are typically captured by **CCD** (Charge-Coupled Devices) and stored electronically as **FITS** images (stands for 'Flexible Image Transport System'). The computer is a cornerstone of this modern process with a vast variety of software packages available to help view and analyze your observations. One such program is called **MaxIM DL** and is installed on every lab workstation. MaxIM DL is your main tool to extract the information from images needed to complete most of your lab projects and it is worth some time to discuss a few of its features.

For some students, these concepts may be familiar to you, as you may have already used MaxIM DL to analyze images. For others, this may be your first exposure to these concepts. The purpose of this exercise is to show some, and remind others of the basic features in MaxIM DL as to better aid your learning during lab. This Appendix will cover 3 basic concepts; **BASICS OF IMAGING**, **CALCULATING SIZES**, and **TRI-COLOR IMAGING**.

Take your time as you go through each section and ask your Lab Instructor questions that you may have along the way.

2 BASICS OF IMAGING

A modern optical telescope consists of two basic parts. The first you are probably familiar with and are the optics. Optics refers to the combination of lenses and/or mirror that collect and focus the light emitted by an object. This part is basically unchanged since the invention of telescopes in the 1600's. The second part however you are possibly less familiar. This part is the CCD device that records the focused light. The particulars of how this is done will be explained in just a bit. Together, the Optics and CCD work together to capture and store information about the target source so that it can be analyzed in greater detail at some later time. Properties of the individual parts and how they are combined defines some basic parameters about the observation, such as the **SENSITIVITY**, **RESOLUTION** and **FIELD OF VIEW**.

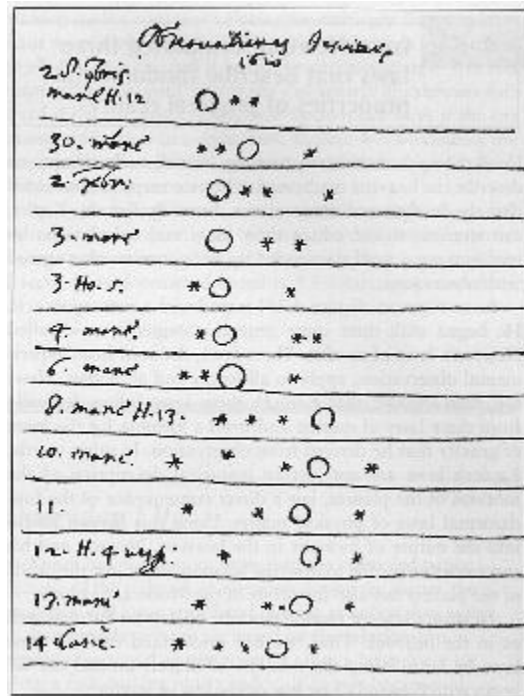


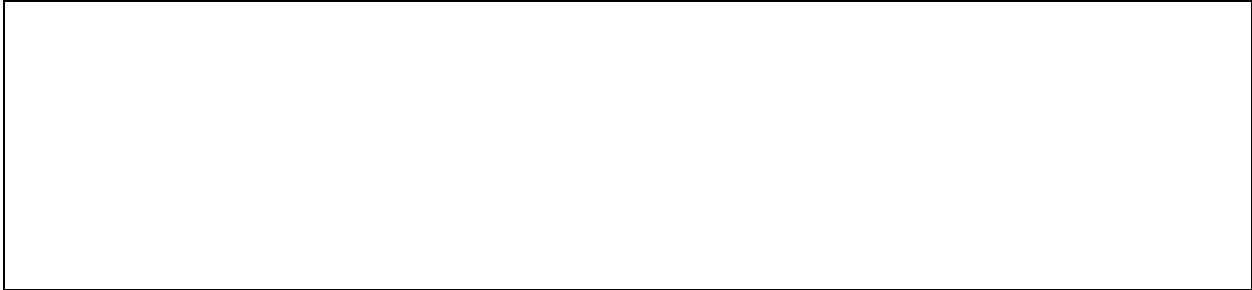
IMAGE 1 - GALILEO SKETCHING THE MOTION JUPITER'S LARGEST MOONS (IO, EUROPA, GANYMEDE AND CALLISTO)

1.1 SENSITIVITY

The sensitivity of the telescope is set by two factors; the properties of the **OPTICS** and the time spent collecting light. Greater sensitivity means greater ability to see faint objects. In many cases, the Optics of the telescope are fixed and you have no ability to change them. This leaves the **EXPOSURE TIME** as the only free parameter. Exposure time works as you would guess. Longer exposure times yield higher sensitivity to fainter objects. However, there is a caveat. Exposure times that are too long can result in brighter objects being **OVER-EXPOSED**. To see this, do the following exercise.

Start MaxIM DL and open the 4 images of **ALCYONE** (the brightest star in the Pleiades star cluster). These four images are taken with different exposure times to illustrate the effects of over-exposure. The exposure times are indicated in the filename; otherwise you can search the image header (basic information about the image saved along with the data) by navigating to **View -> FITS Header Window** or pressing **Ctrl+F**.

ROUGHLY EXPLAIN THE DIFFERENCES YOU SEE IN EACH IMAGE.



In the simplest terms, CCD chips are grids of photon “buckets” that return the number of photons in each bin when asked. The number of photons in each bucket is called the **ADU** (analog-to-digital units) count.

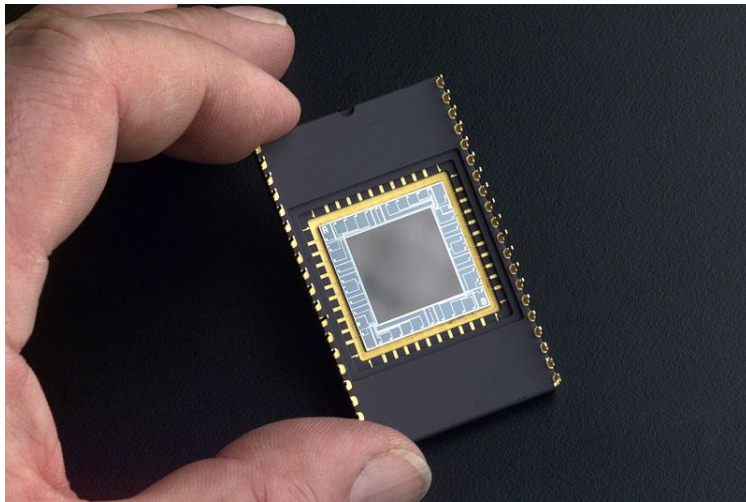


IMAGE 2 – CLOSEUP OF A CCD CHIP

In principle, the CCD does not count photons, but instead counts the number of electrons generated (digital) when a photon (analog) strikes the chip. The image you see in MaxIM DL is a map of ADU counts versus their location on the chip. At anytime, you can see the total ADU count at the location of your mouse by looking on the bottom of the program window (Image 3, appears as **i:####**, also shown is the **(x,y)** coordinate of the cursor). The total number of ADU counts any given bucket can hold is fixed. Over-exposing an image is then the same as over-filling the buckets and once full, information about additional photons

are lost. You may have noticed that overexposed images begin to develop long streaks, with the length of the streak somewhat related to how badly the image is overexposed. Sticking with the bucket analogy, when a pixel on the CCD chip **SATURATES**, it sometimes spills electrons onto adjacent bins. These bins can in turn fill and spill onto their neighbors... and on and on.

The amount of ADU counts any bin can handle depends on the chip. To get a feel for what that level is for your image, list the approximate ADU count of the dimmest star in your image for each exposure time. An easy way to do this is by using the **LINE PROFILE TOOL**. This tool allows you to draw a line across you target and plot the ADU count versus bin location. To activate this tool, navigate to **View -> Line Profile Window** or press **Ctrl+L**.

ADU COUNTS OF THE FAINTEST STAR

	0.1 sec	1 sec	5 sec	60 sec
ADU counts				

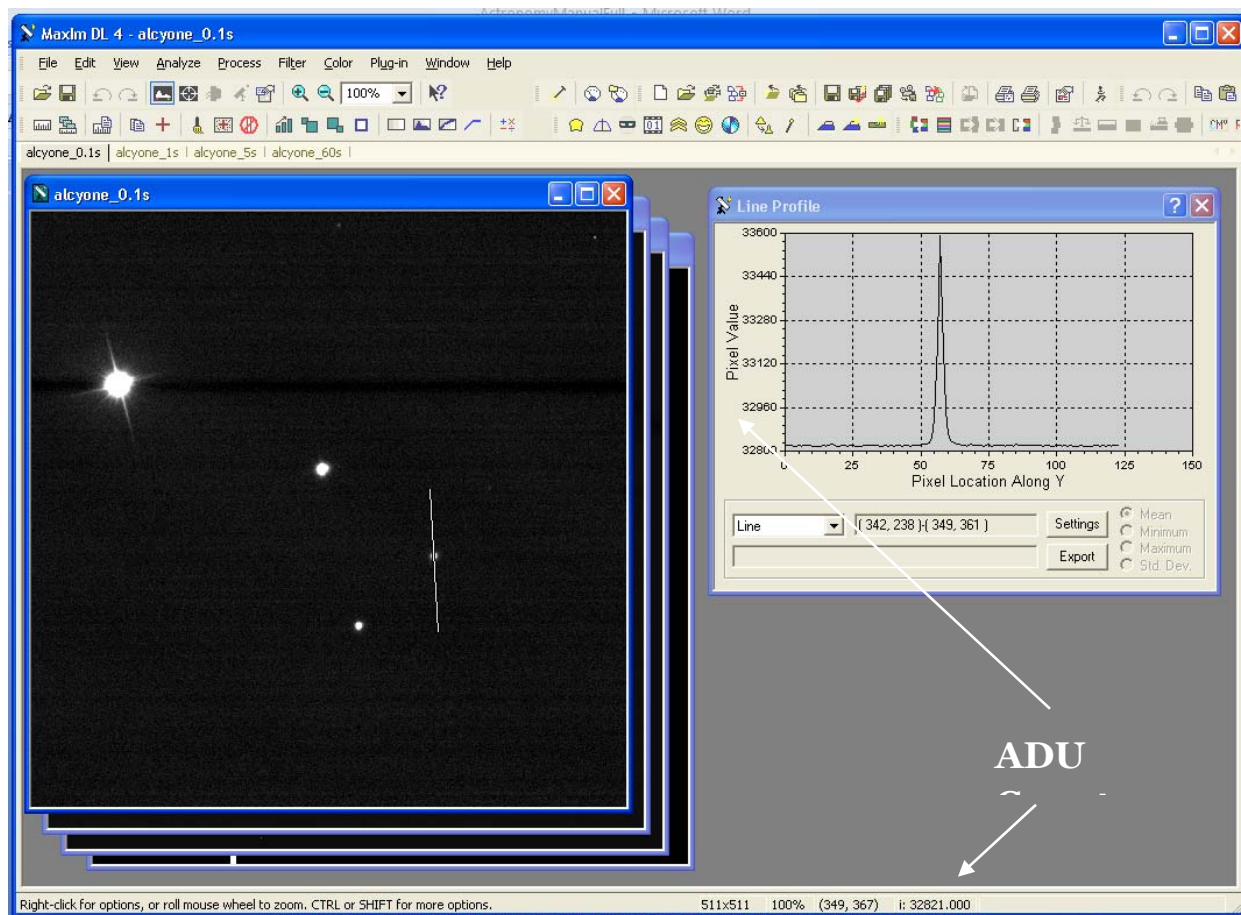


IMAGE 3 - THE LINE PROFILE TOOL IN MAXIM DL

1.2 RESOLUTION AND FIELD OF VIEW

Two other important concepts needed to analyze your images are **RESOLUTION** and **FIELD OF VIEW**. Resolution refers to how much of the sky is represented by one pixel in your image, where the Field of View refers to the total amount of sky observable. These values are both fixed by the properties of the optics and CCD chip. The resolution is equal to the ratio of the physical pixel size to the focal length

(the length over which light rays are focused) of the optics. It is handy to express this value in arcseconds. Then,

$$R = 206,265'' \times \frac{\text{pixel size}}{\text{focal length}}$$

where **R** is the resolution in arcseconds (") per pixel and **206,265** is the number of arcseconds in one radian. CCD chips typically have hundreds of pixels. The Field of View of the telescope is simply the product of the resolution times the number of pixels across the chip (for a rectangular chip, the Field of View is then different for each axis). Due to the large number of pixels, it is more convenient to express the field of view in arcminutes (1 arcminute = 60 arcseconds).

$$FOV = 3,438' \times \frac{\text{CCD size}}{\text{focal length}}$$

$$\text{CCD Size} = \text{number of pixels} \times \text{pixel size}$$

To further explore these concepts, consider the following questions.

THE RIGEL TELESCOPE AT THE UNIVERSITY OF IOWA CONSISTS OF OPTICS WITH FOCAL LENGTH = 5.18 M AND A SQUARE, 9 MEGAPIXEL (9 MILLION PIXELS) CCD CHIP THAT HAS A PHYSICAL SIZE OF 3.75 CM X 3.75 CM.

What is the Physical Size of each Pixel?

--

What is the Resolution of the Telescope?

--

What is the FOV?

--

YOU ARE ASKED TO DESIGN A TELESCOPE AND YOU HAVE THE FOLLOWING PARTS TO CHOOSE FROM:

OPTICS A: FOCAL LENGTH = 5M

OPTICS B: FOCAL LENGTH = 10M

CAMERA C: SQUARE, 3 MEGAPIXEL, PHYSICAL SIZE OF 1 CM X 1 CM

CAMERA D: SQUARE, 5 MEGAPIXEL, PHYSICAL SIZE OF 2 CM X 2 CM

Which combination has the best resolution?

--

Which combination has the best FOV?

--

2 CALCULATING SIZES

Now that you have a handle on the concepts of Resolution and Field of View, let's discuss what you can do with them. Consider the following image of the Orion Nebula (M42). **This image is 1024 x 1024 pixels with a resolution of 1.25"/pixel.** If you were to estimate the size of the center region, you could do the following:

1. The nebula is an irregular shape, but it's roughly (very roughly) spherical, so if you take a few measurements from the center to one of the edges you could estimate an average radius of the nebula. Each radius would then equal the distance in pixels between the center position (x_c, y_c) and the position of the nebula's edge (x_1, y_1), (x_2, y_2), etc. To calculate the distance, use the distance formula.

$$r_n = \sqrt{(x_c - x_n)^2 + (y_c - y_m)^2}$$

2. You measure each radius in pixels and find values of 200 pixels, 215 pixels, and 175 pixels for an average radius of 196.7 pixels.
3. Using the resolution of the image (1.25"/pixel), you convert the average radius in pixels to an average radius in arcseconds = 245.8".

This value represents the **ANGULAR SIZE** of the nebula, but does not tell you anything about how large the nebula actually is (the **LINEAR SIZE**). With a measurement of the nebula's linear size, you could measure the volume of the gas in the nebula, or measure its mass making some assumptions of the type and density of the gas. You need some method to convert angular size to linear size.

Consider the following situation. Place a piece of notebook paper a few inches away from your face. The paper appears to consume a large amount of your view (i.e. it has a large angular size). Now, move the paper an arm's length away. The page is the same physical size, but now takes up a much smaller amount of your view (it has a smaller angular size). It is clear here that angular size is **INVERSELY PROPORTIONAL** to the distance an object is away. This relationship can be expressed in a form helpful for analyzing images.

$$d = \frac{D \cdot \theta''}{206265''}$$

This formula (called the **SMALL ANGLE FORMULA**) relates the linear size **d** to the angular size **θ** (in arcseconds) and the distance to the object **D**.

CONTINUING THE EXAMPLE FROM ABOVE, ANSWER THE FOLLOWING QUESTIONS:

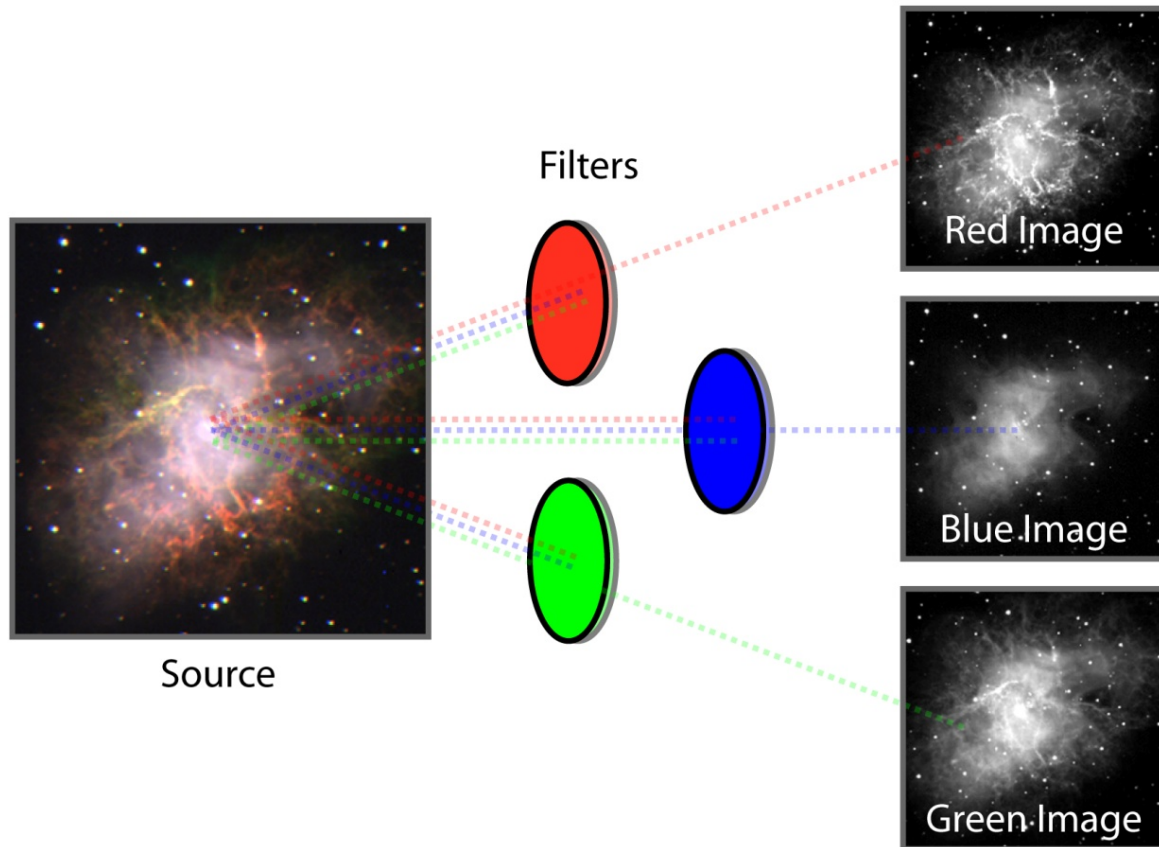
What is the Linear Size (d) of the nebula if it is approximately 400 pc away?

Assume a spherical nebula, what is the volume of the gas in cubic meters? ($V = 4/3 \pi r^3$)

If the gas has an average density of 1×10^{-17} kg/m³, what is the Mass of the Nebula?

3 TRI-COLOR IMAGING

The images so far have all been without color. This is for an important reason. On a CCD chip, color comes at the expense of resolution. On a television set, or on your computer monitor, color is produced by controlling individual clusters of colored pixels (usually a triplet of red, blue and green), so that together they appear to represent all colors of the rainbow. To capture color on a CCD chip, this would mean assigning 1/3rd of the pixels to be sensitive to red, 1/3rd to blue and the final 1/3rd to green, making the effective resolution 3 times larger. How then do you make a color image with a non-color camera?



The answer is to use filters.

Filters allow colored objects to be observed by a non-color camera. For example, by inserting a red filter, the CCD image is now no longer a record of the intensity of all light, but just red wavelengths of light. Software like MaxIM DL allows you to combine filtered images to produce a color image. Such an image is called a Tri-Color image because it is not a true representation of the original source (with a continuous range of colors), but one made of only the three **PRIMARY COLORS** red, blue and green.

Filters can also be used to highlight chemical properties. Notice that the filtered images in the example above are obviously different from each other. The red image shows a fair amount of filamentary structure produced by hydrogen gas glowing most intensely at 656.3 nm (the red **BALMER H α** line). The more diffuse emission seen in the blue image results from electrons spiraling around magnetic field lines at very high speeds, and is called **SYNCHROTRON RADIATION**. The green (visible) image contains both synchrotron radiation and the **BALMER H β** line.

The best Tri-Color images result from the following steps:

3.1 IMAGE ALIGNMENT

Since each filtered image was captured separately, the images first need to be aligned to correct for any positional changes between exposures. Without this step, the colors from each image will be slightly offset from each other and will not properly combine. First make a Tri-Color image without aligning the fields.

TRI-COLOR WITHOUT ALIGNMENT

- a. Your target is NGC2359 (Thor's Hammer). Open the files named **NGC2359_R1**, **NGC2359_G1**, and **NGC2359_B1**. These three images represent Red, Green, and Blue filtered images taken of NGC2359 with the Rigel Telescope.
- b. To make a color image, Navigate to **Color -> Combine Color**. This will open the Combine Color Tool from which you can do many different things. Most likely MaxIM DL has read the FITS header of each image and inserted them correctly into the Red, Green and Blue pull-down menus. Make sure the **Conversion Type** is set to RGB and the color **Input/Output** values are set to 1:1:1. This instructs MaxIM to use equal parts red, green, and blue (you can change this later if you like). Press **OK** and view the resulting image.
- c. Upon inspection you can see that the stars are slightly misaligned, with the "red" stars placed below the "green" stars. Here it is only a small effect, but in other images, the stars might miss each other completely.

TRI-COLOR WITH ALIGNMENT

- a. Now, navigate to Combine Color again, but this time before you press OK, press the **Align** button in the upper right corner. This will allow you to align the images before you combine their colors.
- b. Change **Align Mode** to **Auto Star Matching** and press **OK**.
- c. You will now be returned to the Combine Color window where you can again press **OK**.
- d. Take notice of the difference.

3.2 SCREEN STRETCH

Your images after combining colors may sometimes be too dark, giving the illusion that you have chosen the wrong color ratios. Instead, MaxIM may have just scaled the brightness of your image incorrectly. This can be adjusted using the **SCREEN STRECH TOOL**. The screen stretch is a plot showing the number of pixels that have a certain ADU count. From here, you can change the minimum and maximum ADU counts displayed on the screen, allowing you to adjust the brightness of your image.

Open the Histogram Tool by navigating to **View -> Screen Stretch Window** or by pressing **Ctrl+H**. Use this tool to adjust the contrast for your color image and note the results.

3.3 REMOVING BAD PIXELS

CCD chips often return a few bad ADU counts. This is an annoyance when making a color image because it creates bright colored pixels at various locations. Bad pixels are a random event. Knowing this, you can remove the false counts if you plan your observation wisely. Since ADU readout errors are random, the probability of them being in the same pixel location in many different images is small. Comparing multiple images allows you to figure out which pixels have incorrect values and filter them out.

- a. Close all of your images and now re-open only the Blue images (indicated by B1, B2, and B3).
- b. Navigate to **Process** -> **Combine**.
- c. The new window is identical to the Align window you saw before. Here is the tricky part. Change the **Output** pull-down menu to **Median**. This will tell MaxIM not only to align your images, but take the middle value for each pixel, effectively throwing away bad pixel values.
- d. Press **OK** and note the difference. It may be hard to see at first, but do this a few times and you will begin to see the effect.
- e. Save your new, corrected image to the desktop and repeat these steps for the Red and Green image sets.

Your new Red, Green, and Blue images can be used to create a Tri-Color image free of annoying bad pixels.

APPENDIX D: TABLE OF CONSTANTS AND EQUATIONS

HELPFUL EQUATIONS AND PARAMETERS

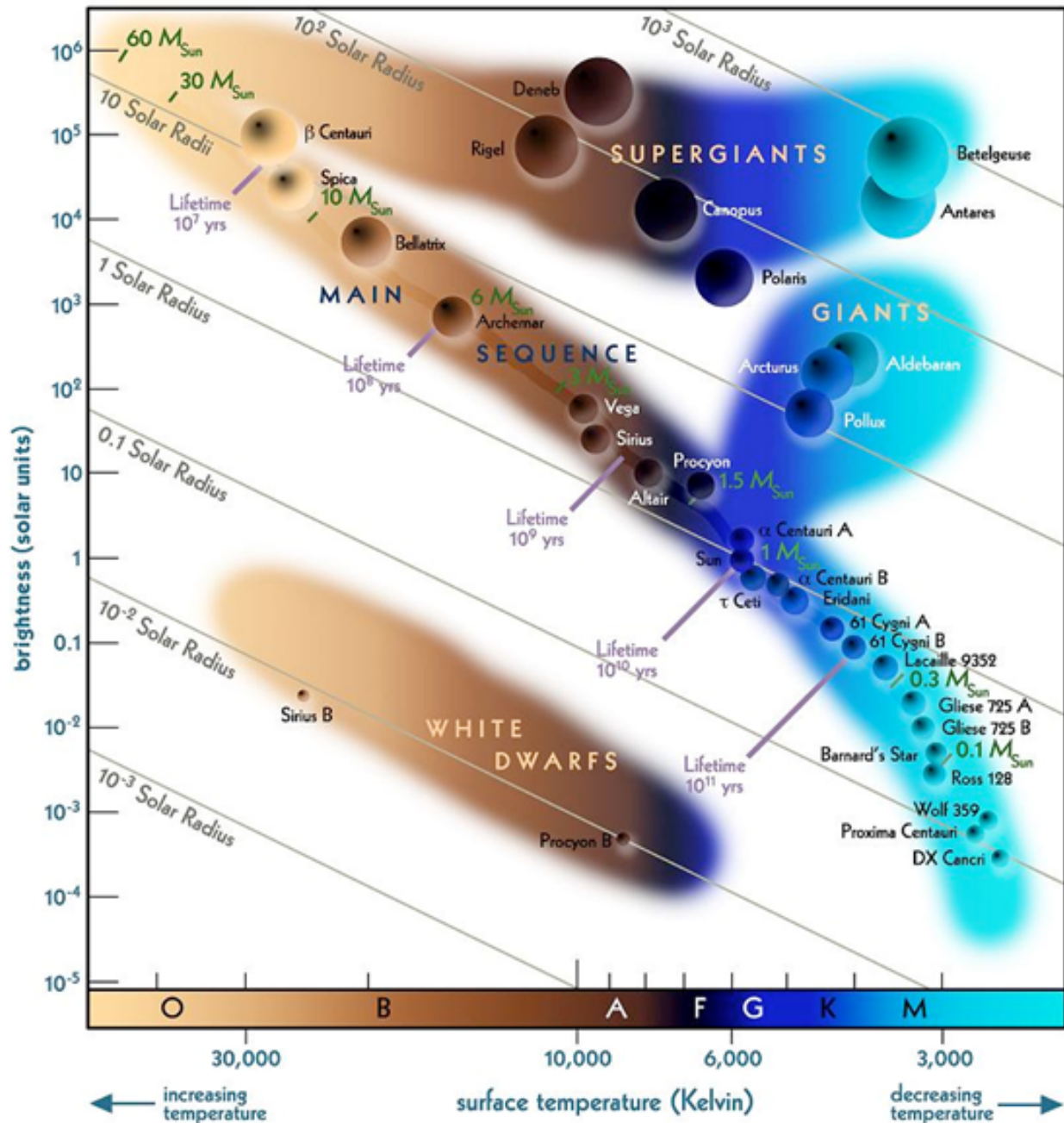
Volume of a Sphere	$V = \frac{4}{3}\pi r^3$	Best used on irregularly shaped objects when the radius represents an “average radius” calculated from many measurements
Volume of a Cylinder	$V = \pi r^2 l$	Where r is the radius and l is the length. Can be used to estimate the volume of structures that are more “tubular” than “spherical”
Small Angle Formula	$d = \frac{D \times \theta''}{206,265''}$	Relates observed size in arcsec to the linear size in units of D
Distance Formula	$r_n = \sqrt{(x_c - x_n)^2 + (y_c - y_m)^2}$	
Wein’s Law	$T = \frac{2.9 \times 10^6}{\lambda_{MAX}}$	Gives the Temperature of a continuous source by measuring the peak wavelength of the emission
Parallax	$D \text{ (pc)} = \frac{1}{p \text{ (arcsec)}}$	Finds the distance to an object in parsecs (1 pc = 3.09 x 10 ¹³ km) by measuring the shift in position relative to background stars in arcseconds (1/3600 degrees)
Typical Hydrogen Mass Densities	Diffuse Gas ~ 10 ⁻²⁰ kg/m ³ Planetary Nebula ~ 10⁻¹⁷ kg/m³ Star Formation Regions ~ 10⁻¹⁴ kg/m³	
Typical Expansion Speeds	Planetary Nebula ~ 20 km/s Solar Wind ~ 400 km/s Supernove ~ 3000 km/s	
Distance to the Edge of the Solar System	D ~ 50,000 AU	Location of the Oort Cloud

Diameter of the Milky Way Galaxy	$D \sim 100,000 \text{ ly}$ (30 kiloparsecs, kpc)
Distance to the Nearest Stars	$D \sim 2.7 \times 10^5 \text{ AU}$ (4.3 light years, 1.32 pc)
.. to the Nearest Galaxies	$D \sim 2 \times 10^6 \text{ light years}$ (0.6 Megaparsecs, Mpc)

OTHER USEFUL CONVERSIONS

1 inch	= 2.54 cm	pico (p)	= 10^{-12}
1 foot	= 30.48 cm	nano (n)	= 10^{-9}
1 mile	= 1.61 km	micro (μ)	= 10^{-6}
1 AU	= $1.50 \times 10^{11} \text{ m}$	mili (m)	= 10^{-3}
1 pc	= 206265 AU	centi (c)	= 10^{-2}
1 pc	= 3.26 ly	deci (d)	= 10^{-1}
1 pc	= $3.09 \times 10^{16} \text{ m}$	(base)	= 1
1 pound	= 0.454 kg	deca (da)	= 10^1
Electron Mass	= $9.11 \times 10^{-31} \text{ kg}$	hecto (h)	= 10^2
Proton Mass	= $1.67 \times 10^{-27} \text{ kg}$	kilo (k)	= 10^3
Earth Mass	= $5.98 \times 10^{24} \text{ kg}$	mega (M)	= 10^6
Solar Mass	= $1.99 \times 10^{30} \text{ kg}$	giga (G)	= 10^9
Mean Earth Radius	= $6.37 \times 10^6 \text{ m}$	tera (T)	= 10^{12}
Mean Solar Radius	= $6.96 \times 10^8 \text{ m}$		
Solar Luminosity	= $3.84 \times 10^{26} \text{ W}$		

APPENDIX E: HERTZSPRUNG-RUSSELL DIAGRAM



(Image from: <http://www.slackerastronomy.org>)