

ASTR 2040 WSU Fall 14 23209

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General Information

Class Times MWF 12:30 - 1:20 pm

Required Texts Observing the Universe by Andrew J. Norton (ISBN 0-521-60393-5)

Instructor Dr. John Armstrong

Office Hours MW 9:30 - 11:30 or By Appointment

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Phone 801.626.6215

Twitter [@jcaastro](https://twitter.com/jcaastro) (<https://twitter.com/jcaastro>) or #ASTR2040

Facebook [Weber State Astronomy](https://www.facebook.com/pages/Weber-State-Astronomy/1490135397876660) (<https://www.facebook.com/pages/Weber-State-Astronomy/1490135397876660>)

Note: Canvas email, Gmail (weber.edu), twitter, and office phone are all acceptable modes of contact. I will respond to you with 24-48 hours.

Course Overview

Course Description

Principles of Observational Astronomy is an introductory course in observational astronomy. Topics will include planetary, stellar, and galactic astronomy, with a focus on modern observational techniques, including digital imagery, spectroscopy, and observing with science-grade astronomical instrumentation. **Prerequisite:** [MATH 1060](#)

(http://catalog.weber.edu/search_advanced.php?cur_cat_oid=7&search_database=Search&search_db=Search&cpage=1&ecpage=1&ppage=1&spage=1&tpage=1&location=33&filter%5Bkeyword%5D=ASTR2040&filter%5Bexact_match%5D=1#tt9527)

(minimum grade of C).

Course Goals

Welcome to Principles of Observational Astronomy. In this class, we will deal with the cutting edge of the science of astronomy with a special emphasis on observational techniques and scientific experimentation of astronomical phenomena. We will discuss how the stars and planets move in the sky, and we will talk about constellations and how to find your way home if lost in the woods at night. But we'll also talk about exploding stars, colliding galaxies, the formation of planets, and the state of life in the universe. By the end of this class, you will, if nothing else, leave with an overwhelming sense of the size and scope of the universe.

It is my hope that you'll get some sense of the scale of the Universe, and the events that unfold within it. As such, after this course you should gain:

- An understanding of the scale of the solar system, the milky way galaxy, and the universe.
- Knowledge of the tools and techniques astronomers use to probe the nature of the universe.
- A sense of the nature of life in the Universe and its place within it.
- An ability to examine the universe from a scientific perspective.

For more information, please see the [Natural Science General Education Learning Outcomes](http://www.weber.edu/AcademicAffairs/natural_sciences.html). (http://www.weber.edu/AcademicAffairs/natural_sciences.html)

Technology Requirements:

All technology required for this course will be provided by the instructor. However, we will discuss how to acquire some of the astronomical software and equipment if you would to use it at home or after the course has ended.

Course Modules and Activities

Modules

The course is broken up into modules based on reading assignments in the text:

- [Observational and Research Skills](https://weber.instructure.com/courses/341128/modules/400492) (<https://weber.instructure.com/courses/341128/modules/400492>) - Part II of your text: we will review these briefly first but return to them in detail throughout the course
- [Coordinate Systems](https://weber.instructure.com/courses/341128/modules/400487) (<https://weber.instructure.com/courses/341128/modules/400487>) - Part I, Chapter 1: On overview of how to find things in the night sky.
- [Telescopes, Detectors, and Reducing CCD Data](https://weber.instructure.com/courses/341128/modules/400489) (<https://weber.instructure.com/courses/341128/modules/400489>) - Part I, Chapters 2, 3, 4 and 5: Various light detectors and how to analyze or "reduce" data.
- [Photometry and Spectroscopy](https://weber.instructure.com/courses/341128/modules/400490) (<https://weber.instructure.com/courses/341128/modules/400490>) - Part I, Chapters 6 and 7: Using the main astronomical techniques for exploration of astronomical phenomena.
- [Analyzing Planetary Surfaces](https://weber.instructure.com/courses/341128/modules/400491) (<https://weber.instructure.com/courses/341128/modules/400491>) - Part I, Chapter 9: A special discussion on observing planetary surfaces.

Interspersed throughout the course will be other reading assignments to help you get a better understanding of the astronomical phenomena we will be discussing.

[Course Schedule](https://weber.instructure.com/courses/341128/pages/course-schedule) (<https://weber.instructure.com/courses/341128/pages/course-schedule>)

Assignments

This is a hands-on course. We will have regular assignments that will be started in a tutorial setting in the classroom and you will complete them on your own. Due to the nature of the assignments, some will take more time than others. Keep an eye on the Canvas calendar for assignment descriptions and due dates.

Project

Since this is an observational astronomy course, you will prepare an original research project for presentation at the end of the course. You will have access to remote telescopes, large datasets, and theoretical material. As we go through the course, I'll help you narrow down your topic of interest. More details will be posted to Canvas as we go along.

Research Notebook

Throughout this class, (and it's a good idea for every research project you do!), you will be keeping a research notebook. This notebook should contain all your work for the class. Your notes from the text, questions that occur to you, things to follow up on. All your calculations, drafts of work, reminders of instructions for how to do things, notes from class, etc. There are several ways to organize this so that it works for you. For myself, I start a new page every day. At the top, I write a sentence or two about what I expect to accomplish that day. At the bottom, I summarize what I did that day, and where I left off working (so the next day, I don't have to rely on a faulty memory!) This notebook must be neat, legible and well-organized. Why? Because you might make a discovery! Or invent a new way to think about a problem! Or think of a patent-able idea! In all of these cases, you will want to be able to walk others through your thought process, and find things when you need them.

Grading

Since astronomy is an experimental and observational science, you learn the most by doing astronomy directly. The grade breakdown for the course reflects this.

Assignments	40%
Project	40%
Research Notebook	20%
Total	100%

Grading Policy

Grades will be assigned based on the following percentages:

A	= 95.0-100%	A-	= 90.0-94.9%
B+	= 87.0-89.9%	B	= 83.0-86.9%
B-	= 80.0-82.9%	C+	= 77.0-79.9%
C	= 73.0-76.9%	C-	= 70.0-72.9%
D+	= 67.0-69.9%	D	= 63.0-66.9%
D-	= 60.0-62.9%	E	< 60%

Academic Honesty/Ethical Conduct

Expectations and Responsibilities

I want to stress upfront that this is a quantitative science course. With that in mind, we will be doing some math. Some of your assignments will require you to employ some mathematical skills, which I will help you refresh/acquire in this course. I expect you to give yourself adequate time to complete the assignments and to put a good faith effort into all of your collaborative work. You should expect me to provide you with as much support as humanly possible, including technical/psychological math support and general sympathy. That said, starting the assignment on the day it is due is an excellent way to dissolve the sympathy part! If you give me enough lead time to help, I will make sure you get it. My office hours are posted, and I can be available at other times if necessary. I am here to make sure you get as much out of this course as you possibly can.

Academic Integrity

Regarding academic integrity, I will enforce policies as laid down in Section IV:D of the Student Responsibilities outlined in the Student Code. Specifically, no cheating or other forms of academic dishonesty will be tolerated. The first instance of cheating will result in a zero on that assignment. The second instance will result in failing the class. During the online sessions, you may wish to work in groups, however, so you will be required to distinguish the difference between collaboration and cheating. When in doubt, make sure to give credit where credit is due. If you are caught cheating in this course, you will be subject to academic discipline including the imposition of University sanctions. A description of cheating and possible sanctions is found in the WSU Student Code available [here](http://www.weber.edu/ppm/Policies/6-22_StudentCode.html) (http://www.weber.edu/ppm/Policies/6-22_StudentCode.html).

Accommodations for Students with Disabilities

In compliance with the American Disabilities Act (ADA), Weber State University seeks to provide equal access to its programs, services, and activities for persons with disabilities. Any student requiring accommodations or services due to a disability must contact the Services for Students with Disabilities (SSD) office. SSD can also arrange to provide course materials (including the syllabus) in alternative formats if necessary. For more information about the SSD contact them at voice: (801) 626-6413, TDD (801) 626-7283, ssd@weber.edu, (<mailto:ssd@weber.edu>) or <http://departments.weber.edu/ssd> (<http://departments.weber.edu/ssd>).

Harassment/Discrimination

Weber State University is committed to providing an environment free from harassment and other forms of discrimination based upon race, color, ethnic background, national origin, religion, creed, age, lack of American citizenship, disability, status of veteran of the Vietnam era, sexual orientation or preference or gender, including sexual/gender harassment. Such an environment is a necessary part of a healthy learning and working atmosphere because such discrimination undermines the sense of human dignity and sense of belonging of all people in the environment. Thus, students in this class should practice professional deportment, and avoid treating others in a manner that is demeaning or derisive in any respect. While diverse viewpoints and opinions are welcome in this class, in expressing them, we will practice the mutual deference so important in the world of work. Thus, while I encourage you to share your opinions, when appropriate, you will be expected to do so in a manner that is respectful towards others, even when you disagree with them. If you have questions regarding the university's policy against discrimination and harassment you may contact the university's AA/EEO office (626-6239) or visit its website: <http://www.weber.edu/aaeo> (<http://www.weber.edu/aaeo>)

Threat to Self or Others

Any disclosure by a student, orally or in writing, whether related to class assignments or not, that communicates the possibility of imminent danger to the student or others will be shared with the appropriate authorities

Participation

You are expected to attend all class sessions, arrive on time and remain until the end of class. Any exceptions should be cleared with me in advance. You are also expected to actively participate in the online discussions and in-class activities and exercises.

Class Demeanor

You are expected to conduct yourselves with a high level of professional decorum. This includes listening attentively and respectfully to the comments and contributions of others, including guest speakers and your fellow students.

Laptops and Cell Phones

You are welcome to bring your laptop computer to class in order to follow along with class postings and online resources or work on team assignments. However, laptops can become a significant distraction to learning, so please avoid doing non-class related activities during class time. Out of courtesy to other students and to avoid disruption of classroom activities, please keep electronic devices (e.g. cell phones and PDA's) silenced and put away during class. If you must take a call, please leave the room to do so.

Support Contact Information

For assistance with Canvas related technical issues, please call 801-626-6499. This phone is staffed Mon-Thurs from 8am – 5pm and Fridays from 8 – 4:30pm. A message can be left during non-business hours for a return call. Alternatively, students can send an email message to wsuonline@weber.edu (<http://ced.weber.edu/wsuonline/spring-2014-faculty-newsletter/wsuonline@weber.edu>).

For assistance with Chi Tester issues please call 801-626-6477.

If students have technical issues related to usernames/passwords, please call the Help Desk at 801-626-7777, or email csupport@weber.edu (<http://ced.weber.edu/wsuonline/spring-2014-faculty-newsletter/csupport@weber.edu>).

You can also include support information on the home page footer of all of your Online and Web Enhanced courses. Here is an example:

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For Technical Support contact:

801-626-7777 or csupport@weber.edu (<mailto:csupport@weber.edu>) (username/password/login issues)

801-626-6499 or wsuonline@weber.edu (<mailto:wsuonline@weber.edu>) (Canvas issues)

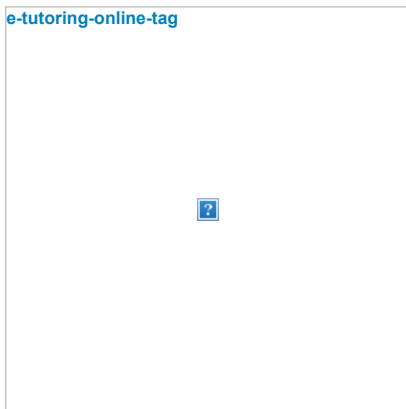
801-626-6477 or chitester@weber.edu (<mailto:chitester@weber.edu>) (Chi Tester issues)

Additional WSU Resources

- [WildCat Mail](http://mail.weber.edu) (<http://mail.weber.edu>)
- [WSU Library](http://library.weber.edu) (<http://library.weber.edu>)
- [Stewart Library EReserve](http://ereserve.weber.edu) (<http://ereserve.weber.edu>)
- [WSU Online Home](http://wsuonline.weber.edu) (<http://wsuonline.weber.edu>)

Online Tutoring

e-tutoring-online-tag



(<https://www.etutoring.org/login.cfm?institutionid=291>)

We want to remind you of a fantastic opportunity for your students because of our partnership with the Western eTutoring Consortium. Administered through Washington State University, the eTutoring consortium brings together top-notch tutors from more than 30 institutions throughout the northwest U.S. Please be sure to direct your students to login with their Wildcat ID and password at the [eTutoring site](https://cas.weber.edu/login?service=https://www.etutoring.org/login.cfm?institutionid=291) (<https://cas.weber.edu/login?service=https://www.etutoring.org/login.cfm?institutionid=291>). Assistance is available in the following subjects:

- accounting
- anatomy & physiology
- biology
- chemistry
- economics
- engineering (circuits and digital systems only)
- math (developmental through calculus)
- MS Office 2007

- physics
- spanish
- statistics
- web development (xHTML, CSS, Adobe Dreamweaver)
- writing

*See [current subject list](https://www.etutoring.org/login.cfm?institutionid=291) (<https://www.etutoring.org/login.cfm?institutionid=291>).

FOR TECHNICAL SUPPORT CONTACT: 801-626-7777 OR CSUPPORT@WEBER.EDU
 FOR WSU ONLINE SUPPORT CONTACT: 801-626-6499 OR WSUONLINE@WEBER.EDU

<https://weber.instructure.com/courses/341128/modules>

Date	Details	
Fri Aug 29, 2014	Assignment 1 - Scales of the Solar System	11:59pm
Fri Sep 5, 2014	Assignment 2 - The Celestial Sphere	11:59pm
Fri Sep 12, 2014	Assignment 3 - Angles and Parallax	11:59pm
Fri Sep 19, 2014	Assignment 4 - Basic Image Analysis	11:59pm
Fri Oct 3, 2014	Assignment 5 - How to read astronomical journals	11:59pm
Fri Oct 10, 2014	Assignment 6 - Mass of Jupiter	11:59pm
Fri Oct 17, 2014	Assignment 7a - Photometry of the Pleiades	11:59pm
Fri Oct 24, 2014	Assignment 7b - The HR Diagram	11:59pm
Fri Oct 31, 2014	Assignment 8 - Rotation Curves of Asteroids	11:59pm
Fri Nov 7, 2014	Assignment 9 - Curve Fitting	11:59pm
Fri Nov 14, 2014	Assignment 10 - Spectral Classification	11:59pm
	Work Week 1	11:59pm
Fri Nov 21, 2014	Work Week 2	11:59pm
Mon Dec 8, 2014	Final Project	11:59pm

RESULTS SHEET 3 The Celestial Sphere

NAME _____ DATE _____ SECTION _____

PART 1: COORDINATES ON THE CELESTIAL SPHERE

Zoom in and click on the following stars. Record their declination (Dec.):

Star near the north celestial pole: _____

This star's name: _____

Capella: _____

Alnilam (near the celestial equator, in Orion's belt): _____

Canopus: _____

Now record the right ascension (RA) of the following stars:

Arcturus: _____

Regulus: _____

Aldebaran: _____

Markab: _____

Vega: _____

Between which two of the above stars would the line of 0 hrs right ascension be?

PART 2: THE COORDINATES OF STARS

In the table below, enter the information for the star with a similar declination to *Mirphak* and the star with a similar right ascension to *Almaak*. Zoom in on the star to make it easier to click on it to bring up the **Data Panel**.

Star	Declination	Right Ascension
<i>Mirphak</i>		
Star with <i>Mirphak's</i> declination:		
<i>Almaak</i>		
Star with <i>Almaak's</i> right ascension:		

PART 3: GLOBAL AND LOCAL VIEWS

Describe the changes you see in the stars and the reference markers when you:

change location from east to west.

change location from north to south.

Circle the names of the reference markers that move when you change location. *Do not* circle those that remain stationary.

<i>Lines</i>	<i>Points</i>
Horizon	Zenith
Meridian	Cardinal Points
Celestial Equator	Celestial Poles

The reference markers that *do* move as you change location are part of the **EQUATORIAL | ALTAZIMUTH** (*circle one*) coordinate system. Those that *do not* move as you change location are part of the **EQUATORIAL | ALTAZIMUTH** (*circle one*) coordinate system. Therefore, equatorial coordinates are a **GLOBAL | LOCAL** (*circle one*) system and altazimuth coordinates are **GLOBAL | LOCAL** (*circle one*).

PART 4: VIEWS FROM AROUND THE WORLD

Your Latitude: _____

Predicted Altitude of Polaris: _____

Actual Altitude of Polaris: _____

Explain the reasoning behind your prediction:

Answer the following questions by changing your latitude on the **Location Panel** and observing the changes that occur on your Sky Chart.

As you move north, describe what happens to:

the north celestial pole.

the celestial equator.

Once you get to the North Pole, 90°N latitude, the north celestial pole is seen at the _____.
The celestial equator is seen at the _____.

As you move south, describe what happens to:

the north celestial pole.

the celestial equator.

Once you get to the equator, 0° latitude, the north celestial pole is seen at the _____.
The celestial equator is seen going through the _____.

In the southern hemisphere the altitude of the _____ will be equal to your southern latitude. So, as you move south, the altitude of this point **INCREASES** | **DECREASES** (*circle one*).

Once you get to the South Pole, 90°S latitude, the _____ is seen at the zenith.
The _____ is seen on the horizon.

CONCLUSION

In the space below, write a conclusion for this activity. Briefly explain what you did and what you learned from it.

CHECK YOUR UNDERSTANDING 3: THE CELESTIAL SPHERE

MULTIPLE-CHOICE QUESTIONS

1. As you change locations, which of a star's coordinates will change?
 - a. right ascension and declination
 - b. altitude and azimuth
 - c. latitude and longitude
 - d. [none of the above will change]
2. If you want to tell a friend who lives at a different latitude than you where to look for an object in the sky, you should give them the object's
 - a. right ascension and declination.
 - b. altitude and azimuth.
 - c. latitude and longitude.
 - d. [any of the above will be the same].
3. Which of the following reference markers are NOT local?
 - a. zenith
 - b. meridian
 - c. cardinal points
 - d. north celestial pole
4. Which of the following reference markers are NOT global?
 - a. horizon
 - b. celestial equator
 - c. north celestial pole
 - d. [all three ARE global]
5. Which is most similar to latitude?
 - a. right ascension
 - b. declination
 - c. altitude
 - d. azimuth
6. Which is most similar to right ascension?
 - a. latitude
 - b. longitude
 - c. altitude
 - d. declination

7. Which is NOT measured in degrees?
- right ascension
 - declination
 - altitude
 - latitude
8. The _____ of the pole star is equal to the _____ of the observer.
- latitude, altitude
 - declination, latitude
 - altitude, latitude
 - latitude, declination
9. The declination of the celestial equator is
- $+90^\circ$.
 - -90° .
 - 0° .
 - [none of the above].
10. The declination of the north celestial pole is
- $+90^\circ$.
 - -90° .
 - 0° .
 - [none of the above].

OPEN-ENDED ACTIVITY

Use the skills you learned in this activity to determine the lowest declination that is visible from your location and to find an object that is near this declination.

Angles and Parallax

Objective

The goal of this lab is to develop an understanding of astronomical parallax, through the use of both terrestrial and astronomical examples. This exercise demonstrates the geometry of parallax measurements, introduces typical astronomical size scales and develops an understanding of the small angle formula.

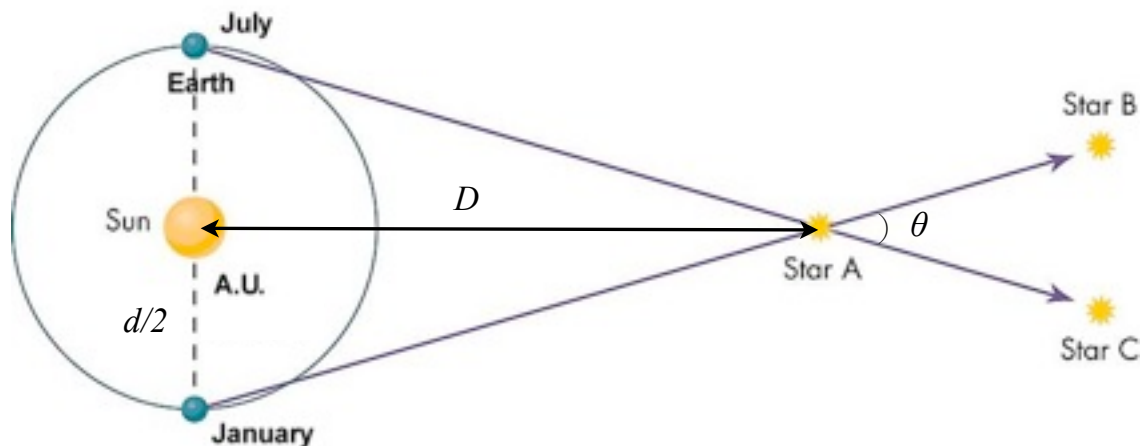
1. This activity addresses WSU Natural Sciences Gen Ed Learning Outcomes: F2, F4, P1
2. Terminology: Astronomical Unit (AU), arcseconds, declination, parsec, radian, right ascension

Background and Theory

Parallax is a geometrical measuring technique in which an angular measurement is combined with a baseline measurement to find the distance to an object. Because the angles measured decrease as the distance to the object increases, the method is only useful for finding distances to the nearest stars.

Observations of a nearby star from two different locations will show an apparent motion, relative to more distant stars. Figure 1 shows that in January, Star A is in the direction of Star B, while in July, Star A is in the direction of Star C. θ is the full angular motion of the star from January to July.

The average distance from Earth to the Sun is defined as 1 Astronomical Unit (or 1 A.U.). Therefore, the average diameter of Earth's orbit, d , is 2 A.U. If a star is observed from one



point in Earth's orbit, and then observed again six months later, it has been observed from two points that are 2 A.U. apart.

The triangle in Figure 1 can be bisected to form a right triangle with vertices Sun, Earth, Star A. The shortest side of the triangle has length $d/2$, equal to the radius of Earth's orbit, 1 AU. The distance, D , between the Sun and Star A can be found from the trigonometric relationship: $(d/2)/D = \tan(\theta/2)$.

Since, for astronomical measurements, θ is a very small angle, $\tan(\theta/2) = \theta/2$ (θ measured in radians, of course!). Typically, this angle is very small indeed, and is measured in arcseconds. Converting from arcseconds to radians introduces a factor of 206,265. Putting all of this together, we can write

$$\theta / 2 = 206,265'' \frac{d / 2}{D}$$

where d and D are measured in the same units of length.

For the case of stellar distances, the distance d is 2 A.U. It is then convenient to define the half-angle, $\theta/2$, to be the parallax angle, or **parallax, p** . Then the two factors of $1/2$ disappear. It is also convenient to define a unit of distance so that D is 1 when p is $1''$. This unit is called a parallax second, or parsec, and it is equal to 206,265 A.U. This simplifies the above equation even further to

$$p('') = \frac{1}{D(pc)}$$

where the parallax angle is measured in arcseconds, and the distance is measured in parsecs.

Procedures

I. Lunar Parallax

1. Estimate the distance from Science Lab building to the observatory. (Google maps, anyone?)
2. Find the distance to the moon in the same units as your estimate.
3. What parallax would the moon have if the measuring points were Science Lab and the observatory?
4. If you wanted to measure the parallax using your pinky finger (which spans 1° on the sky, when held at arms length), how much longer would your baseline need to be? i.e. how far from Science Lab building would you have to travel?
5. Use Google maps to find an observing site to conduct that observation. Where would you go? Why would you choose that site?

2. The Distance to Algol

- The location of a star is given by two numbers, the **right ascension** and the **declination**. The right ascension is analogous to longitude on Earth (measuring East-West), while the declination is analogous to latitude (measuring North-South). Right ascension is measured in hours (h), minutes (m) and seconds (s). Declination is measured in degrees ($^{\circ}$), arcminutes ($'$), and arcseconds ($''$). The location of the star Algol at two different times of year is given as follows:

	January	July
Right Ascension	3 ^h 8 ^m 10.13702 ^s	3 ^h 8 ^m 10.14292 ^s
Declination	40° 57' 20.2424''	40° 57' 20.2584''

- Determine the change in right ascension ($\Delta R.A.$) for Algol between January and July. Then determine the change in declination ($\Delta Dec.$)
- The change in right ascension must be converted from seconds to arcseconds. Multiply by 15. (Convince yourself that since 1 hour of R.A. is 15° at the equator, one second of R.A. is 15 arcseconds at the equator...) Then we must also make a correction for the declination of Algol, by multiplying by $\cos(Dec)$. 41° is close enough for our purposes here.

$$\Delta R.A.('') = (\Delta R.A.(s)) \cdot 15 \cos(41^{\circ})$$

- Now, determine the angular motion of Algol using the Pythagorean Theorem:

$$\theta^2 = (\Delta R.A.)^2 + (\Delta Dec)^2$$

- Find the distance to Algol in parsecs.
- Evaluate this answer to try to put it in perspective. How far is Algol from the Sun compared to the size of the Solar System? (Yes, go ahead, use the Google!) How far is Algol from Earth compared to the distance to the nearest star, Proxima Centauri? How far is it compared to the distance to the nearest globular cluster? How far compared to the distance to the galactic center? Find some way to make this distance make sense to you.

Image Analysis in ds9

Objective

The goal of this lab is to begin to explore how to analyze images in ds9, an astronomical image analysis software package.

1. This activity addresses WSU Natural Sciences Gen Ed Learning Outcomes: F2, F4, P1
2. Terminology: CCD, filter, [OIII], [NII], H-alpha

Background and Theory

There are two basic types of astronomical data: images and spectra. You may note that both of these are all about photons. That's because we pretty much get light from the sky. And then we look at it. Most of the time, there is absolutely no other investigation method available to us.

All modern astronomical images are digital. Even old photographic plates have been scanned in and MADE digital, although they were not taken that way originally.

Digital images are taken with a CCD camera. This camera consists of a rectangular array of pixels. Each of these is assigned a value proportional to the brightness of the image at that point. Each single image is inherently gray-scale---it has no color. Astronomers typically take an image through a filter that allows through only blue light, and then one that allows through only red light, and then one that allows through only green light. Then they color the images in the computer, and add them together to get pretty color pictures. Sometimes, instead, these images are taken in different spectral lines (for example Hydrogen-alpha (H- α), doubly-ionized oxygen ([OIII]), or singly-ionized nitrogen ([NII])). These kinds of images allow astronomers to compare different regions with each other.

ds9 is a software package that enables astronomers to make tri-color images, measuring things on the sky, measuring brightnesses, etc. It's pretty powerful, which translates into complicated, in the usual way.

Procedures

1. **Getting some images. Do this before class!**
 1. First, you will need some images to work with!
 2. Go to http://www.mistisoftware.com/astronomy/index_fits.htm

3. Pick one of the objects, and download the red, green and blue images of the object. (On a Mac, ctrl-click on the filename, and select “Download Linked File” It will go to the Downloads folder on the dock.
4. Remove the .html extension from each filename so that ds9 can “see” it.

2. Using ds9

1. Open ds9, by going to Applications/ds9
2. First, we will make an RGB image.
3. Select Scale, from the bar in the middle of the ds9 window. Then click zscale. This will adjust the brightness levels as we read the image in.
4. Choose Frame: New Frame RGB
5. A new window opens. This is the controller window for this special frame.
6. When you have the Current radio button checked, you are working with the element image for that color only. You can be showing all 3 colors, but you will be changing the display properties of only the one that is checked as current.
7. To start building your 3-color image, **check the red as the current** image in the small RGB window.
8. Choose File: Open from the **main ds9 window** (why is it there and not in the little window... I don't know!). Pick the image/element you chose to be red.
9. Return to the little window. **Check green as the current image** in the little window. (Alt-Tab allows easy window switching in Windows).
10. Return to your main ds9 window. Choose File: Open from your **main ds9 window** and navigate to the element/image file you selected to be represented in green.
11. Your frame should now have a reddish green image on it. If you now have a red frame and a green frame - then you did not perform the steps correctly. Don't close the RGB window - just hide it from view between steps. This is a common mistake.
12. Return to your small RGB window. Check blue as the current image in the little window.
13. Choose File: Open from your **main ds9 window** and navigate to the element/image file you selected to be represented in green.
14. Ta-da! A 3 color image in one frame.
15. Select Zoom: Zoom to Fit Frame, if necessary to fit the whole image in the picture.
16. Now, play with the histograms of each piece of the image (under Scale: Scale parameters) to adjust the brightness of each color! This is the artistic part...

ASTR 2040; Reading Scientific Literature

Part I: Literature search: Introduction to the ADS

The Astrophysical Data Service is a product of the Smithsonian Astrophysical Observatory and NASA. This is the complete compendium of all astrophysics journals, journal articles, poster abstracts, etc. It's all there somewhere. Older articles are scanned in. Newer ones appear with hot links and links to computer accessible data tables. I had the good fortune to start my astronomy career in the post-ADS era. I can't even imagine what it must have been like before this, when you had to follow the trail of breadcrumbs to find out what people already know about your research topic!

(Note: you may need to do this from on-campus, because WSU has on-line subscriptions to all the journals. And you probably don't.)

- 1) Go here: http://adsabs.harvard.edu/abstract_service.html
- 2) In class, we explored the ADS somewhat. Use it to find and download an article by R. Jacob, D. Schonberner and M. Steffen about the evolution of planetary nebulae, from expansion rates and visibility times. It was published in 2013.
- 3) Before we leave the ADS, take note of a couple of other cool features on the search page. The filters section can help you weed out poster presentations from actual articles, by clicking on 'All refereed articles'. Clicking on 'current journals' is a good way to keep up, once you are in the habit of reading journals regularly. The interface keeps track of you, via your IP address, so that if you click on 'Unread Journals' it will show you only the ones you haven't looked at yet. You can change your sorting parameters. You can require only some fields. You can do all kinds of things. The ADS is extremely powerful, and it is your friend. Learn to love it.

Part II: Reading a journal article.

Everyone does this a little differently. I will tell you some hints here, that I have learned, mostly from others. Try it this way first, then modify to suit what works for you. I have found that I can actually read them on line if I do it this way. That saves me from having to carry or store them. It can easily take me more than an hour to properly read a ten-page journal article, especially when I'm new to a subject. After a while, it goes much faster, because everyone working on it is using the same methodologies, and there's not that much difference from one paper to another. But in the beginning, it's painstaking (i.e. sometimes painFUL) work.

For the purposes of this exercise, assume that you are trying to find out about the the evolution of elemental abundances in the Milky Way. A quick search has turned up this article, and you want to know if it's useful to you, even though you don't know anything about planetary nebulae specifically.

- 1) Get your notebook.

- 2) Open to the first blank page. Read the title of the article again, and copy or paraphrase it into your notebook. Also write down the date of the article, and the primary authors. I like to format this information the same way all the time. Because I am almost always working on more than one project at a time, at the top of the page, I make a notation about which project I think this article is useful for. I could do this by using separate notebooks, but I sometimes make serendipitous discoveries by noticing that something I did for project A also applies to project B. In this case, the project notation might read 'Galactic Abundances---Planetary Nebulae'.
- 3) Read the abstract. Read it again. You may need to read it a third time. (The information in an abstract is ridiculously dense.) What is the article about? Write it down.
- 4) Now skim the introduction. Flip to the summary or conclusion, and skim that too. What in this article is useful to your project? Write it down.
- 5) Jump back to the beginning of the article, and flip through it again, this time looking at the pictures, tables and graphs, and reading their captions. From looking at the data, what kinds of problems might the researchers have? Make a note in the margin of your notebook, if you can think of questions you'd want answered.
- 6) Look at the graphs, and see if you can figure out what the heck they are doing in each graph. For example, the first graph, in Figure 1, is showing two different measures of the velocity, plotted one against the other. If the two methods agree, what do you expect this plot to look like? Does it actually look like that? Look at each figure, and ask yourself similar questions.
- 7) Flip through one more time. Make a mental note for yourself of the sections of the paper. Typically, a paper like this one will have an 'Observations' section, a 'Models' section, and several analysis sections, sandwiched between the introduction and the summary.
- 8) Phew! Now you are ready to actually read the paper. Well, sort of. Typically, what I do is skim the observations section. I make a note of notations that were used in the figure captions, and what they mean. Sometimes, if I have a question about the observations, I'll make a note. Or if I'm not sure it's good methodology, or if it's a new idea to me, I'll make a note of that too. Just writing it down makes it stick in my head better.
- 9) Next, skim the models section, again making a note if anything seems either odd or clever.
- 10) Moving on to the analysis section. I read each subsection separately, and summarize each subsection in one or two sentences in my notebook. This forces me to slow down and stop skipping over things. I also, at the bottom of my notebook page, make a note of particular references that I might want to look up. I'll just write these as they are cited in the text (name year).

Afterwards, I fill this out with the full citation from the references section at the end of the article.

- 11) Then I look back over my sentences and write my own, two sentence summary.
- 12) Which I compare to their summary.
- 13) Then I decide if this paper is actually going to help me answer my own research question. Am I likely to need to reference it again? Or is it just useful background. If it seems important, I'll give it three stars at the top of the first page. If it's probably just useful background, I'll give it one. If it really didn't fit in, I won't give it any. This helps me find them later.
- 14) While I'm still thinking about it, I make a note of ideas that occurred to me for future work, or questions I have about their methodology.
- 15) Finally, I look at the list of references, to see what else I should go and read. Then I go and look those up on the ADS.

That probably seems like a lot of work. It is. But this is perhaps the most important piece of any research project. There is absolutely no point in wandering around with no understanding of what others have already done. Sometimes it makes sense to repeat their work. But more often, it makes sense to extend it. Any time you are wondering what to do for your next research project, dive into the literature, to look for ideas.

It also probably seems like you'd never finish a literature search. Every paper references other papers, right, so how would you ever come to the end? But as you delve in, you start to realize that there are 3 or 4 canonical papers, that are cited by everyone in the subfield. And then there are usually 10 or 12 other papers that are all very similar, looking at different objects, or using different instruments, or otherwise varied in the details, but doing the same overall science. AND, there is usually a Review article, sometime in the last 10 years or so, that summarizes EVERY piece of research that has come before. So once you get back to that review article, you need go no further to get a general overview. Only if you are specifically looking for a specific paper about a specific method on a specific object would you continue.

After I've read about 10 or so papers in a new sub-field, I'll sit down and read over my notes. Then I'll write a bulleted list of questions that people are trying to answer. Then I stop to think. I ask myself, 'Are there questions that should be asked that are not being asked?', 'What are they missing?', 'Is there another way to try to answer the question?', 'Can I add to this effort?' And I make some notes about what I want to try.

THEN, I start looking for objects, archives, and telescopes. Which is a job for another assignment.

Mass of Jupiter

Objective

The goal of this lab is to explore how simple measuring data, such as could be obtained in ds9, can be used to find the mass of Jupiter.

1. This activity addresses WSU Natural Sciences Gen Ed Learning Outcomes: F1, F2, F3, F4, P1, P2, P4
2. Terminology: Amplitude, Phase, angular frequency, sinusoidal, eccentricity, Kepler's third law, period

Background and Theory

In 1609, Galileo Galilei began using a telescope for astronomical observations. One of his most important discoveries was that there were four moons revolving about Jupiter, with **periods** ranging from about 2 to about 17 days. (Many more moons of Jupiter have since been discovered). This discovery showed that bodies could orbit other moving bodies. This was at odds with the prevailing geocentric view that all celestial bodies revolved about the Sun, which then revolved about Earth.

By carefully measuring the distance from Jupiter to these moons over the course of a few weeks, Galileo found the moons' orbital periods and average orbital radii. However, there was never any clear relation between the two parameters until Johannes Kepler published his third law in 1619. Kepler's third law states that the square of the period of an orbiting object is proportional to the cube of the radius of the orbit ($P^2=Kd^3$). The constant, K , depends on the mass of the central object. Though Kepler didn't know that K depends on mass, he was still able to show that P^2/d^3 is the same for the orbit of Mars as it is for the orbit of Earth. The mass of Jupiter can be found using a revised version of Kepler's third law, along with observations of Jupiter's moon Europa.

Of the four Galilean moons, Europa is the second closest to Jupiter. It has an icy crust, with a salt water ocean beneath, and a rocky core. Three characteristics of Europa's orbit make it desirable for use in this exercise. First, its orbital eccentricity is low. Second, the orbital plane is nearly in the plane of the ecliptic, so that we observe the orbit nearly edge-on from Earth. By assuming that the orbit is a perfect circle viewed edge-on, the variation of radial distance with time can be modeled as a simple sinusoidal function. Finally, the period is quite short, so it is easily measured.

Procedures

1. Begin the Windows Emulator.

2. Begin the CLEA Exercise: “Revolution of Jupiter Moons”
 - a. At the left edge of the Windows Desktop is a quick link to the CLEA exercise: “Revolution of Jupiter Moons”. Start this exercise by double-clicking.
 - b. Go to “File/Login”, and Log in to the program (just put your name...)
 - c. Go to “File/Run”.
 - d. Select a time to begin your observation.
 - e. Go to “File/Timing”, and check to make sure your data interval is set to 5 hours (so that you observe Jupiter a couple of times per day).
3. Get ready to take data.
 - a. You will need a place to log your data. On the Mac desktop, open a Numbers spreadsheet with three columns. Label these columns “Hour” and “R position (Europa)”.
 - b. Fill in the first column, beginning with 0, and incrementing each row by five, to keep track of the hours. (You can make this faster if you fill in the first 3 or 4 cells, then select them with the mouse, and then drag the corner of the selection box downward.)
4. Take data
 - a. Return to the Windows Emulator, where your experiment is running. Click on the moons until you find Europa. Record its distance from the center of Jupiter, in Jupiter diameters, in your data table. If Europa is to the left of Jupiter, record a negative number. If it is to the right, record a positive number.
 - b. Click “Next”, to proceed to the next observation. (Note that the Julian date counter changes...) Take your data.
 - c. Continue taking data for 45 data points.
5. Analyze the data
 - a. First, make a quick plot of the data.
 - i. Highlight both columns.
 - ii. Click on “Charts”, and choose the fifth one down in the left column, that looks like two irregular lines. Make the chart bigger, so you can actually see it...
 - iii. You should see lots of dots, with no apparent pattern.
 - iv. Imagine a sine curve passing smoothly through these data. (Why do we think it should be a sinusoidal function?)
 - v. Estimate the amplitude of the sine function from your graph sketch.
 - vi. Estimate the period of the orbit from your graph sketch.
6. Model the data
 - a. The next thing to do is to try to fit a sin curve to these data. Recall that the form of a sin function is: $y(t)=A\sin(\omega t+\phi)$ A is the amplitude, ω is the angular frequency (or $2\pi/T$), and ϕ is the phase, which controls where the sin “begins”.
 - b. Somewhere on your spreadsheet, create a small box to keep track of your parameter settings. It should look about like this:

Amplitude	2.9	R_{Jup}
Period	48	hours
Phase	-1.670796327	hours

- c. Now make a new column so to hold the values of the sine function at each of the times of your observations. In the first cell, type in: “ $=\$H\$4*\text{SIN}((2*\text{PI}()/\$H\$5)*\$A2+\$H\$6)$ ”, where $\$H\4 is the location of the cell that holds the Amplitude. $\$H\5 is the location of the cell that holds the period, and $\$H\6 is the location of the cell that holds the phase. $\text{PI}()$ is a function that returns the value of pi. $\$A2$ is the cell that holds the first time value (the left-most column). Drag to fill the column with these values.
 - d. Make a new graph, with both Europa’s data and the sinusoidal values. (Command-click will select add a column selection to those already selected.)
 - e. Now, “fiddle” with your parameters until you can match the sine curve to your data. Make a note of your final parameters.
7. Find the Mass of Jupiter
- a. Use Kepler’s Third Law: $M = \frac{4\pi^2 d^3}{GP^2}$ to solve for the mass of Jupiter, in kg. (d is the average orbital radius in meters, and P is the period of the orbit in seconds.)
 - b. Compare this mass to the accepted mass of Jupiter. How far off were you?
 - c. How might this measurement of the Mass of Jupiter be improved?
8. Write up your results in the following way: Pretend that you have just measured the mass of Jupiter for the first time, and now you must report those results. You should have at least one sentence in each of the following sections: Abstract, Introduction, Observations, Analysis, Conclusion, Future Work. Include a printout of your data and your best-fit sinusoidal graph.

Photometry in the Pleiades

Objective

The goal of this lab is to introduce the fundamentals of stellar photometry. Students will measure the magnitudes of stars in the Pleiades.

1. This activity addresses WSU Natural Sciences Gen Ed Learning Outcomes: F1, F4, P1, P2, P3
2. Terminology: photometry, magnitude, apparent magnitude, absolute magnitude, calibration, sky brightness, open cluster, globular cluster



Background and Theory

The Pleiades is located west of Orion in the night sky. This grouping of stars is relatively easy to identify because it looks faintly fuzzy even to the naked eye.

The Pleiades is a **cluster** of stars, which means that all the stars formed at the same time out of the same cloud of dust and gas, and are still gravitationally bound together. This is an **open cluster**, as opposed to a **globular cluster**, because the stars are fairly spread out, and there is a small number of them, compared to a globular cluster. Stars in a cluster can be considered to be all the same age, and all the same distance away, within reasonable error bars.

You will use a realistic simulation of a UVB photometer (this is like a small camera that looks at one star at a time) attached to a moderate-sized research telescope to measure the apparent magnitudes of 24 stars in the Pleiades through two filters.

The aperture of the instrument is much larger than most of the stars under study. Since the sky is not perfectly dark, the sky within the aperture contributes a certain number of photons.

These unwanted photons are counted by finding the **sky brightness** in an empty piece of sky.

The star to be measured is then centered in the aperture, and a second observation is taken.

The photon count for the star is the difference in counts between the stellar observation and the observation of the sky brightness.

You will make a graph of the apparent magnitude of each star as a function of the color index (B-V). This is a version of the H-R Diagram, which is critical to understanding the evolution of stars.

Procedures

1. Starting the Windows Emulator

1. Use the spotlight (magnifying glass in upper right of desktop) to search for 'Windows'.
2. Double-click on the folder labeled "Windows Box".
3. Ctrl-click on Windows Box.vbox, select **OPEN WITH/OTHER**. Change the box at the bottom to "All Applications", then choose "Virtual Box"
4. Select "Windows" in the left panel, and press the big green arrow.
5. Wait for windows to boot.

2. Opening the CLEA Exercise "Photometry of the Pleiades"

1. Open the "VIREO" program on the bottom-left of the windows desktop. This is an observatory simulation program shockingly like remote operations of an actual telescope.
2. Login under **FILE/LOGIN**.
3. Go to **FILE/RUN EXERCISE** to run the exercise "Photoelectric Photometry of the Pleiades".
4. Go to **TELESCOPE/OPTICAL** to **ACCESS** the 0.4 m telescope.
5. Once you have been given control of the telescope, **OPEN** the dome.
6. Turn the telescope control panel **ON**.
7. Turn on **TRACKING** (what does this do?)
8. **SLEW** via **SET COORDINATES** to the Pleiades (any star on your target list will do...).

3. Find the Sky Brightness:

1. Change the **VIEW** from the Finder to the Telescope.
2. Place the circle over a blank area of sky with no stars in it. The circle represents the field of view of your photometer.
3. **ACCESS** the photometer.
4. Set the Filter to "B".
5. Set the integration time (seconds) to 10 seconds, and the number of integrations to 5.
6. **START** taking data.
7. When the measurement is completed, the mean sky count will appear in the box labeled "Mean Sky Count/Sec". Record that value here: Sky Count (B) = _____
8. Repeat the measurement using the "V" filter. Sky Count (V)= _____

4. Photometry of the Stars:

1. Close the instrument window.
2. **SHIFT** from Telescope to Finder.
3. Center one of your target stars in the red box.
4. **SHIFT** back to Telescope from Finder.
5. Center the star in the red circle.
6. **ACCESS** the Photometer.
7. **SELECT** an appropriate integration time. Use short integration times for bright stars to save time, and use long integration times for faint stars to increase the signal to noise ratio.
8. Choose a number of integrations.
9. Change the Reading to be an “Object” reading instead of a “Sky” reading.
10. **START** taking data on the star in both B and V filters. Check to make sure you have a signal to noise ratio that is adequate. The integration time should be adjusted upward if the SNR is below 100. For some dim stars, a SNR of 70 is acceptable. The instrument automatically subtracts off the sky brightness, and reports an apparent magnitude in the magnitude box. Record the B and V magnitudes in a spreadsheet (SAVE OFTEN!).
11. Repeat the previous ten steps for each target star.
12. In your spreadsheet, calculate the color index (B-V) for each star. This is a proxy for temperature, because the hotter a star is, the bluer it is (and thus the smaller, or more negative, the color index.)

5. Making Meaning from the Data:

1. Using the spreadsheet program, graph your data, with the V magnitude on the y-axis, and the color index on the x-axis. Plot your y-axis so that brightness increases upward, and your color index so that bluer stars are on the left.
2. Study your data. Is there a correlation? Are there outliers? We will have a class discussion about this, and see if we can make meaning out of what you have observed.
3. Properly shut down the telescope, close the dome, and leave things nice for the next observer, by picking up all your candy wrappers and night lunch crumbs...

Star	RA (h m s)	Dec (deg m s)	Star	RA (h m s)	Dec (deg m s)
1	3 41 05	24 05 11	13	3 44 27	23 57 57
2	3 42 15	24 19 57	14	3 44 39	23 27 17
3	3 42 33	24 18 55	15	3 44 39	24 34 47
4	3 42 41	24 28 22	16	3 44 45	23 24 52
5	3 43 08	24 42 47	17	3 45 09	24 50 59
6	3 43 08	25 00 46	18	3 45 27	23 17 57
7	3 43 39	23 28 58	19	3 45 28	23 53 41
8	3 43 42	23 20 34	20	3 45 33	24 12 59
9	3 43 56	23 25 46	21	3 46 26	23 41 11
10	3 44 03	24 25 54	22	3 46 26	23 49 58
11	3 44 11	24 07 23	23	3 46 57	24 04 51
12	3 44 19	24 14 16	24	3 47 29	24 20 34

Stellar Properties and the Hipparcos Data Set

For this assignment, you will use data obtained by the *Hipparcos Space Astrometry Mission*, which pinpointed the positions of more than one hundred thousand stars with high precision, and more than one million stars with lesser precision.

Step 1: Download data and import into Excel

1. Go to <http://vizier.u-strasbg.fr/viz-bin/VizieR>
2. Search for “Hipparcos” in the Catalog search
3. Click on the “I/239/hip_main” catalog
4. Generate two data sets:
 - a. One with the parallax greater than 100 mas (close stars)
 - b. One with the V mag less than 4 (bright stars)

For each dataset, set B-V to greater than -10. This ensures the objects was observed in both filters.
5. On the results page, set “Max Entries” to “unlimited” and select “;-seprated values” for output, and hit “Submit”
6. Save your data file
7. Import data into Excel:
 - a. Use the “File -> Open” command to select the file
 - b. In the Import Wizard, select “Delimited” and click “Next”
 - c. On the next screen, select “Semicolon”, then click “Finished”
 - d. Check the import and save your files
 - e. When you are finished, you should have two Excel files, one called “CloseStars.xls” and one called “BrightStars.xls”

Step 2: Calculate physical parameters from the data

1. For each of your datasets, compute the following:
 - a. The distance, in parsecs, $d = 1/p$
 - b. The absolute V magnitude, $M_V = V - 5 \log(d) + 5$
2. Save your Excel files

Step 3: Analysis of the data and your derived results

Here is where the fun begins! You now have data from two completely different stellar populations: stars closer than 10 pc, and stars brighter than 4th magnitude. You can see all of the bright stars with the naked eye, while most of the close stars you can't see without the aid of a powerful modern telescope.

Your task now is to answer the following question: What are the main differences between these two stellar populations? Some ideas on how to proceed:

1. Start graphing stuff. Look for correlations and relationships in the data. Are there any parameters that should be correlated based on your knowledge of physics? Are there any parameters that should not be correlated?
2. Look at averages. What is the average color of each data set? Average apparent magnitude? Average absolute magnitude? Average distance?
3. Probe your knowledge of physics to predict what differences might exist and then go looking for them.

What to Hand In:

For both data sets, hand in:

1. A plot of M_V vs. $B-V$
2. A plot of one other correlated property of your choice

Make sure each of your plots has a title and the axes are labeled, including units

Answer the following questions:

1. What are the main differences between these two datasets?
2. What conclusions can you draw about stars as blackbody radiators?
3. What conclusions can you draw about stellar radius as a function of luminosity? Is it constant? Does it change? Does it change in different ways for each data set?

Asteroid Rotation

Objective

The goal of this lab is to develop an understanding of light curves, using asteroid rotation as an example. This exercise explores the two contributions to an asteroid light curve, and students will find the albedo, temperature, and rotation of the asteroid.

1. This activity addresses WSU Natural Sciences Gen Ed Learning Outcomes: F2, F4, P1, P3
2. Terminology: light curve, albedo

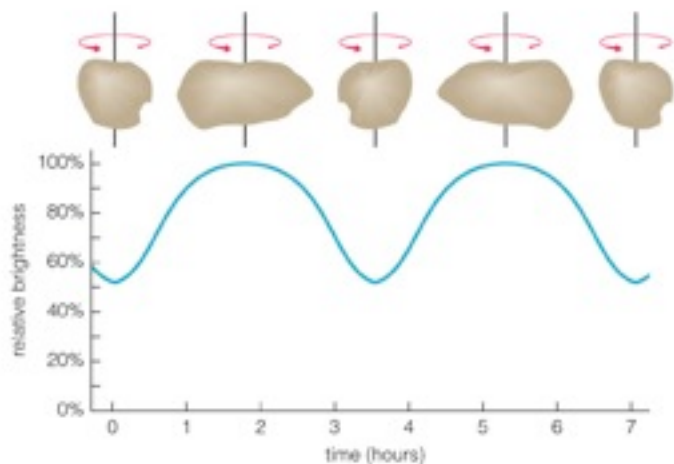
Background and Theory

Asteroids are basically potato-shaped rubble piles. Most of them orbit the Sun, between the orbits of Mars and Jupiter. As they do so, they tumble through the sky. This rotation can be observed from Earth by looking at the asteroid over time, and seeing how the reflected light from the Sun changes. A time series of brightness observations is called a **light curve**.

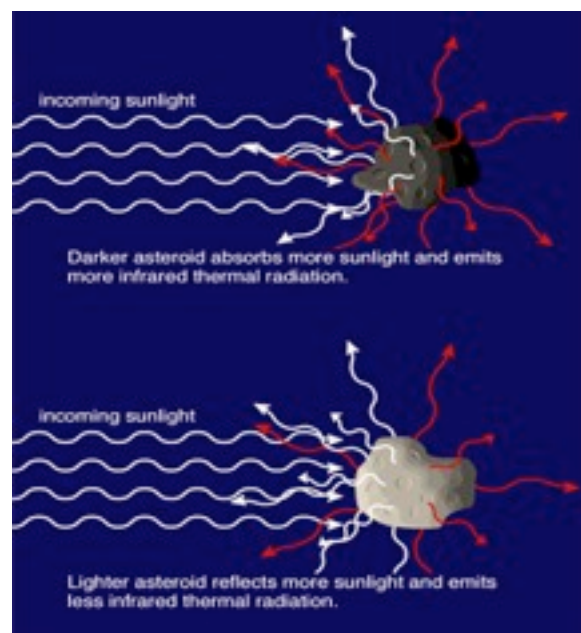
Some asteroids vary in brightness across the surface, due to changes in composition, which makes (usually small) modifications to the light curve.

Composition also affects the way in which asteroids are observed. In general, darker asteroids are more easily observed in the infrared than in the visible. The “darkness” of an asteroid is a quantity known as the **albedo**, A , the fraction of sunlight reflected. Typical values are in the range of 0.1, but a perfect reflector has an albedo of 1, and a perfect absorber has an albedo of zero.

Many asteroids spin with short rotation periods (less than eight hours), so they can be easily observed moving through one full rotation over just one night’s data. Some, however, have



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longer periods, and must be observed for multiple nights to obtain a complete light curve.

Procedures

1. Light Curve of 22 Kalliope

1. The table at right contains light curve photometry for 22 Kalliope collected from derived published literature. These observations were made on February 8, 2007. The absolute magnitude of the asteroid is 6.45, and the changes in brightness are shown as changes in this average magnitude.
2. Use Excel (or Numbers) to plot these data.
3. Measure the rotation period of the asteroid. (Hint: we did almost this same analysis for the Mass of Jupiter lab.)
4. The accepted value for the rotation period of 22 Kalliope is 4.148 h. What is the percentage error of your estimate from this value?

Elapsed Time (h)	Change in Magnitude
0.040	0.23
0.150	0.25
0.301	0.23
0.440	0.18
0.590	0.14
0.790	0.03
1.050	-0.06
1.280	-0.14
1.325	-0.12
1.550	0.00
1.645	0.03
1.710	0.06
1.855	0.10
2.190	0.21
2.380	0.22
2.700	0.14
3.000	0.03
3.325	-0.13
3.550	-0.23
3.620	-0.25
3.780	-0.17
3.950	-0.06
4.030	-0.02
4.100	0.03
4.160	0.06
4.530	0.20
4.855	0.25

2. The Temperature of 22 Kalliope

1. Open the JPL Small-Body Database browser: <http://ssd.jpl.nasa.gov/sbdb.cgi> and enter "22 Kalliope" in **SEARCH**.
2. Scroll down to the **PHYSICAL PARAMETER** table and find the **Diameter**. Convert to radius in meters.
3. Find the geometric albedo, **A**. The albedo is the ratio of the reflected light to the incoming light.
4. Use the orbit diagram (link at top of page) to find the distance from the Sun to 22 Kalliope on February 8, 2007 (the date of the observation).
5. The temperature of an object is determined from an energy balance between energy received and energy emitted. In order to figure this out for our asteroid, we need to know how much sunlight it receives (which depends on the solar luminosity, L_s and the distance between the sun and the asteroid r_{sa}), what fraction is reflected, and what fraction is emitted. We can put all these things together in the Stefan-Boltzmann equation to derive the following:

$$T_A^4 = L_S (1 - A) / (16\pi \epsilon \sigma_{SB} r_{SA}^2)$$

(ϵ is the emissivity. For rocks, that's about 0.9. σ_{SB} is the Stefan-Boltzmann constant ($5.6704 \times 10^{-8} \text{ W/m}^2\text{K}^4$))

6. Find the temperature of 22 Kalliope. (hint: did you check that all your units were in SI?)
7. It is common to report that the average surface temperature of an asteroid is -100°C . How does your computed value compare to this average value?

3. Making a home on 22 Kalliope?

1. One idea for future space stations is that they create an artificial gravity by rotating. This produces a centripetal force toward the axis of rotation. Hollowing out an asteroid might be one way to accomplish this.
2. If we hollowed out 22 Kalliope, so that it was essentially a cylinder with the diameter of the asteroid, what would the period have to be to produce a "normal" weight for a person standing on the inside of the cylinder?
3. How does this period compare to the actual period of 22 Kalliope?
4. Work the problem the other way... If 22 Kalliope was hollowed out (and the asteroid shell had the same period as currently) what would be the acceleration for a person standing on the inside of the shell?

Curve Fitting

Objective

Students will be able to:

- Explain how the range, uncertainty and number of data points affect correlation coefficient and Chi squared.
 - Describe how correlation coefficient and chi squared can be used to indicate how well a curve describes the data relationship.
 - Apply understanding of *Curve Fitting* to designing experiments
1. This activity addresses WSU Natural Sciences Gen Ed Learning Outcomes: F1, F2, F3, F4, P1, P2, P4
 2. Terminology: Amplitude, Phase, angular frequency, sinusoidal, eccentricity, Kepler's third law, period

Background and Theory

So far, we have estimated uncertainties using the standard deviation. This measures the scatter in a collection of data points, and gives a fairly good estimate of the random uncertainties in a particular measurement.

Derived quantities are found by fitting a model (typically expressed as a function) to the data, and then finding, for example, the period or the slope of the function. Estimating the uncertainty in these derived quantities requires a more detailed analysis. A full treatment of all the ways to calculate uncertainties is above the level of this course, but two common measures are fairly intuitive and straightforward to calculate.

The correlation coefficient, R^2 , gives some information about the goodness of fit of a model. It is a statistical measure of how well the regression line approximates the real data points. An R^2 of 1 means the line perfectly fits the data. It is common to approach a curve-fitting problem by maximizing R^2 . Excel can do this all by itself for linear models. The most general way to calculate R^2 is to first calculate the total sum of the squares:

$$SS_{tot} = \sum_i (y_i - \bar{y})^2$$

which is proportional to the standard deviation. Then you calculate the sum of the residuals (how far the line is from the data at each point).

$$SS_{res} = \sum_i (y_i - f_i)^2$$

Then the correlation coefficient is given by:

$$R^2 \equiv 1 - \frac{SS_{res}}{SS_{tot}}$$

Variations of this calculation method exist.

More commonly, in astronomy, we calculate the χ^2 (pronounced chi-squared) “goodness of fit” parameter. In an experiment, you often measure a series of paired (x,y) quantities, with each measurement denoted by (x_i, y_i) . The uncertainties in the x-values are usually negligibly small. The uncertainty in y_i is given by σ_i . The best-fit curve to the data is given by a function: $y=y(x)$, so the quantity $y(x_i)$ is the value of y predicted by the best-fit curve corresponding to the value x_i . The difference $[y(x_i)-y_i]$ is the deviation between the measured point and the predicted value. For one point, the deviation is roughly equal to the uncertainty σ_i , so the ratio $[y(x_i)-y_i]/\sigma_i$ is roughly equal to one. If all N points were like this, and you added up the ratios, and divided by N, you would get:

$$\frac{1}{N} \sum_i \left(\frac{y(x_i) - y_i}{\sigma_i} \right)^2 \approx 1$$

This situation is complicated by the fact that the function $y=y(x)$ is not the true curve, but instead is the best-fit curve to the data. If there is very little data, the best fit curve will always fit the data well, regardless of the errors in the data. Because of this, the ratios $[y(x_i)-y_i]/\sigma_i$ are generally smaller than they would be if $y(x)$ were the “true” curve. For example, if there are only 3 data points ($N=3$), and we perform a 3-parameter (quadratic) polynomial fit ($f=3$), then the fit will always pass through the three points exactly, all the deviations will be zero and the summation above will be zero. To compensate for the fact that $y=y(x)$ is not the true curve, we must divide by $(N-f)$ instead of N. The resulting quantity

$$\chi^2 = \frac{1}{N-f} \sum_i \left(\frac{y(x_i) - y_i}{\sigma_i} \right)^2$$

is called the reduced chi-square. Because we divide by $(N-f)$ instead of N, the reduced chi-square is undefined unless $N>f$. For the case $N>f$, the reduced chi-square approaches one for a good fit. In general, “curve fitting” means minimizing the χ^2 ---finding the fit parameters that make it as small as possible.

Deciding about the significance of a particular value of χ^2 requires knowing more about the type of experiment---in particular the number of degrees of freedom and the “sample distribution” from which you are drawing your data, (All of these statistical tests postulate a hypothetical distribution of potential observations, of which your particular observation is only one.) To understand what the χ^2 is telling us, we often consider the p-value. This is the probability of

observing a test statistic at least as extreme as the one observed. A p-value of 0.05 or less is usually regarded as statistically significant---that is, the curve doesn't fit very well, and the deviation of the data from the curve is significant. The following table shows how the p-value depends on the χ^2 for varying degrees of freedom.

Degrees of freedom (df)	χ^2 value [16]											
	1	0	0	0.1	0.2	0.5	1.07	1.64	2.71	3.84	6.64	10.8
2	0.10	0.2	0.5	0.7	1.4	2.41	3.22	4.60	5.99	9.21	13.8	
3	0.35	0.6	1	1.4	2.4	3.66	4.64	6.25	7.82	11.3	16.3	
4	0.71	1.1	1.7	2.2	3.4	4.88	5.99	7.78	9.49	13.3	18.5	
5	1.14	1.6	2.3	3	4.4	6.06	7.29	9.24	11.1	15.1	20.5	
6	1.63	2.2	3.1	3.8	5.4	7.23	8.56	10.6	12.6	16.8	22.5	
7	2.17	2.8	3.8	4.7	6.4	8.38	9.80	12	14.1	18.5	24.3	
8	2.73	3.5	4.6	5.5	7.3	9.52	11	13.4	15.5	20.1	26.1	
9	3.32	4.2	5.4	6.4	8.3	10.7	12.2	14.7	16.9	21.7	27.9	
10	3.94	4.9	6.2	7.3	9.3	11.8	13.4	16	18.3	23.2	29.6	
P value (Probability)	0.95	0.9	0.8	0.7	0.5	0.30	0.20	0.10	0.05	0.01	0	
	Non-significant								Significant			

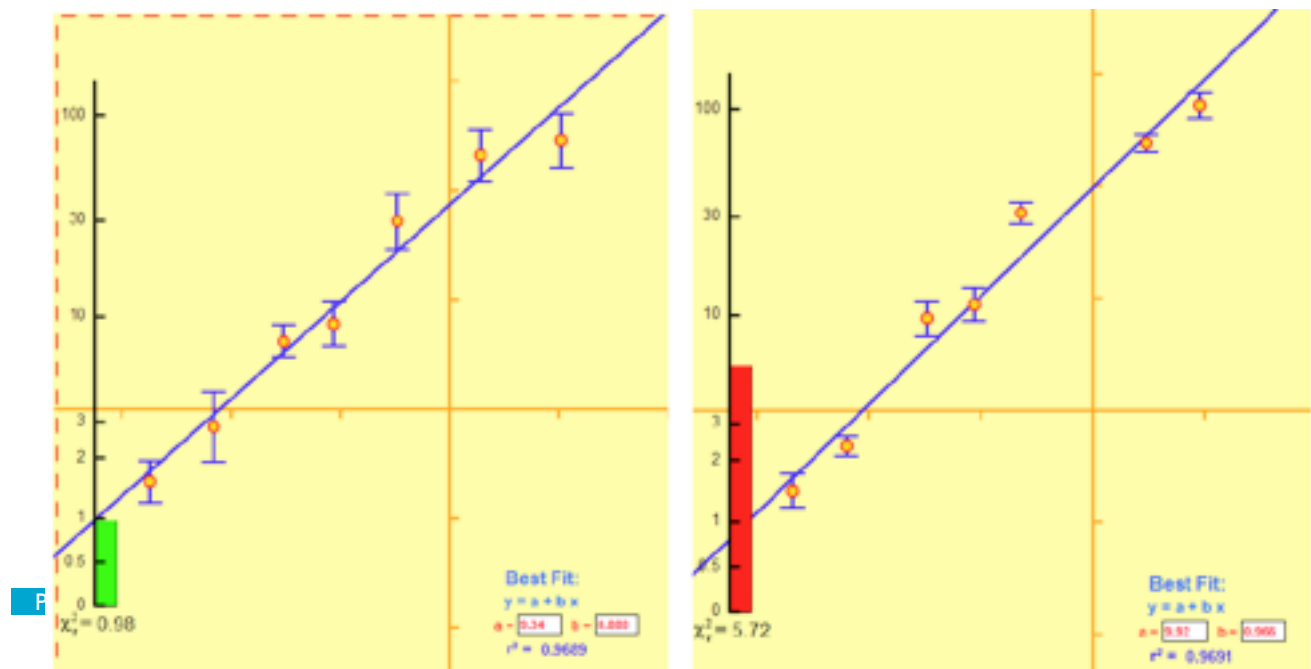
For example, suppose that a random sample of 100 people has been drawn from a population. The theoretical curve (often called the null hypothesis) indicates that men and women occur with equal frequency, so there “should be” 50 men and 50 women. If there are 44 men in the sample and 56 women, then

$$\chi^2 = \frac{(44 - 50)^2}{50} + \frac{(56 - 50)^2}{50} = 1.44$$

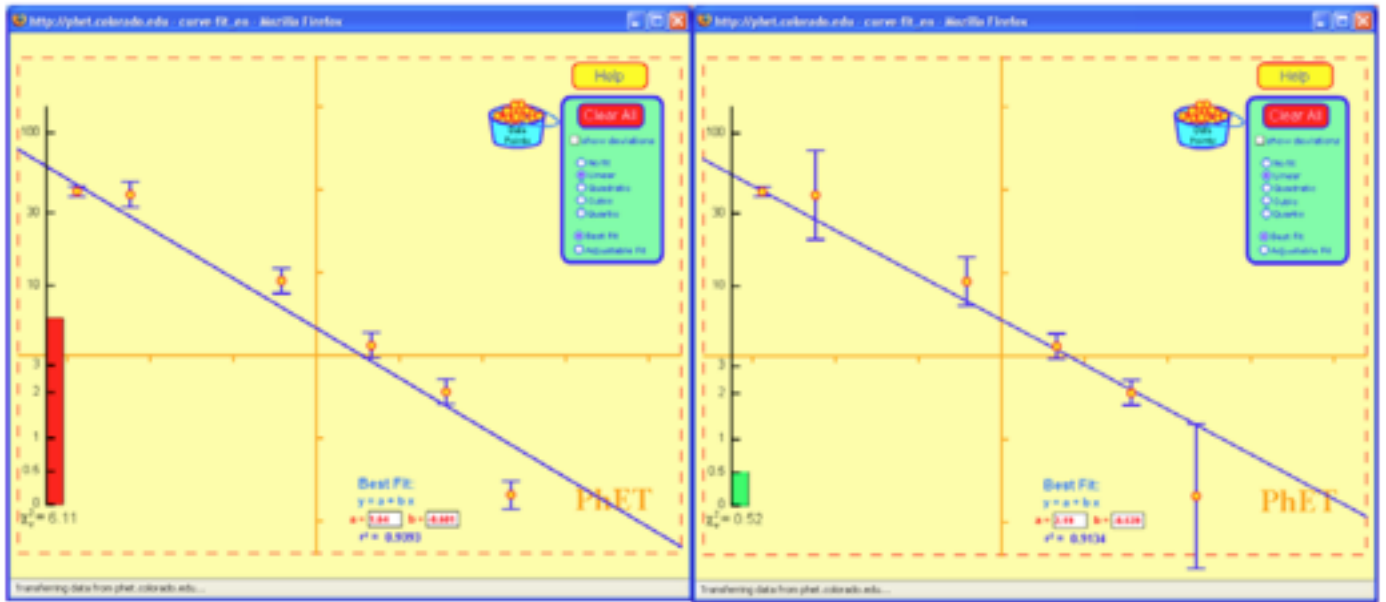
If the null hypothesis is true, this statistic is drawn from a distribution with one degree of freedom (if the number of males is known, then so is the number of females). The above table shows that the probability of observing this difference (or a more extreme one) is 0.23. This is higher than the criteria for statistical significance, so we would NOT reject the null hypothesis that the number of men is the same as the number of women.

Procedures

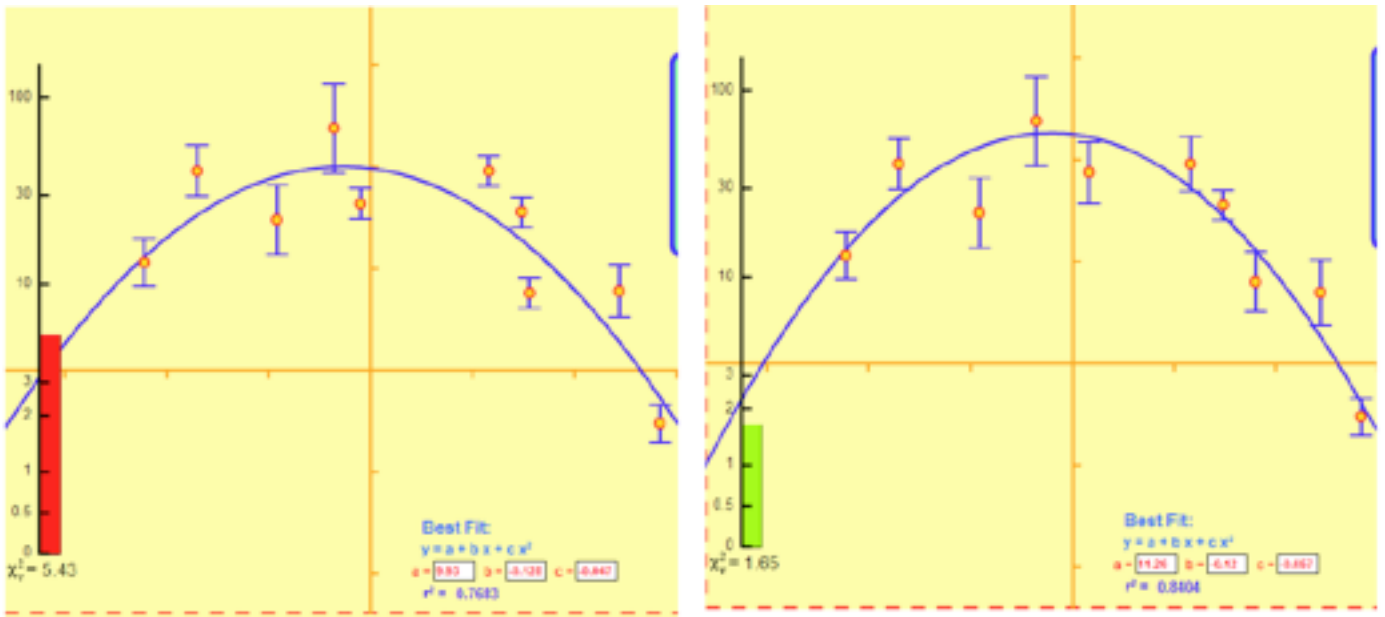
- Using any browser, download and run the Curve Fitting Simulation from: <http://phet.colorado.edu/en/simulation/curve-fitting>
- This simulation allows you to quickly and intuitively change “data” to explore how the χ^2 “goodness of fit” parameter depends on the quality and quantity of the data. At the bottom of the vertical axis, the value of χ^2 is shown, with a green bar when it is in an acceptable range. The bar is red when the χ^2 is too large. Options for the type of function to fit to the data are given in the green box on the right. Data points are in the bucket, and can be dragged and dropped onto the graph.
- Without changing any of the uncertainty bars, explore *Curve Fitting* to answer 1-4:
 - For each of the four types of curve fit (green box), what is the minimum number of points to get a good correlation **and** a curve that demonstrates the known shape for the curve?
 - For each of the four types of curve fit, what is the minimum number of points to get in the green zone for χ^2 **and** a good correlation?
 - How can you desensitize the coefficient to variation in data? (In other words, if you collect data that would not fit on the line, under what conditions would r^2 stay nearly the same?) Is χ^2 desensitized the same way?
 - Summarize the relationship between the χ^2 red zone and the correlation coefficient. Include illustrations or screen captures to support your reasoning.
 - Explore how varying the uncertainty bars affects χ^2 and r^2 and then answer these questions.
 - Two experiments were run and these graphs show the results. Which experiment has a curve fit that describes the relationship the best? What is your reasoning? Describe what is different about the data that made the quality of the fit change.



b. Which is best and why?



c. Which is best and why?



6. How does your of understanding χ^2 and R^2 help you with experimental design?

Spectral Classification of Stars in the Pleiades

Objective

The goal of this lab is to introduce the fundamentals of spectral classification of stars. Students will obtain and classify spectra of the stars in the Pleiades. In a future lab, these data will be combined with photometric data to determine the age and distance of the Pleiades.

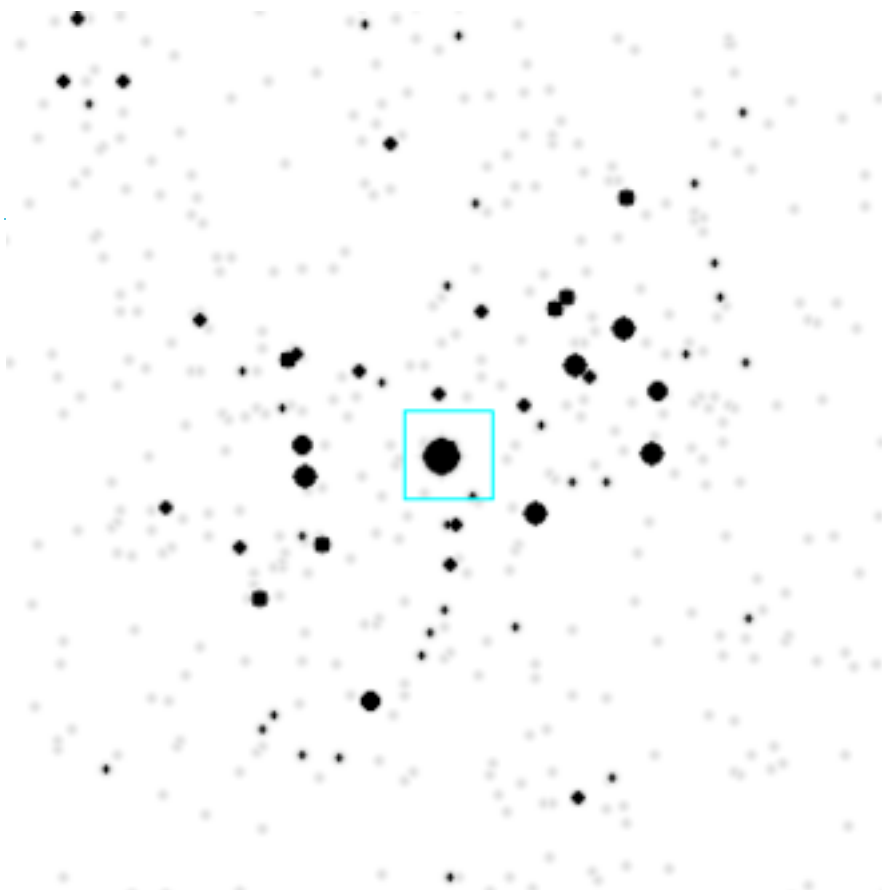
1. This activity addresses WSU Natural Sciences Gen Ed Learning Outcomes: F1, F4, P1, P2, P3
2. Terminology: Spectra, emission lines, absorption lines, continuum emission, Wien's Law,

Background and Theory

Classification lies at the foundation of nearly every science. Biologists classify plants and animals into subgroups called genus and species. Geologists classify rocks and minerals.

Scientists develop classification systems based on perceived patterns in and relationships among natural objects. Astronomers are no exception. They classify planets as terrestrial or Jovian, galaxies as spiral, elliptical or irregular, and stars according to the appearance of their spectra.

A spectrum of a star is composed of its continuum emission, as well as a number of "lines" which can be either emission or absorption lines. The continuum emission is a product of the



blackbody radiation of the star. It varies smoothly with wavelength, and has a peak at a wavelength determined by the temperature of the star. Emission lines are excesses of radiation at particular frequencies caused by electrons in atoms dropping down to lower energy levels. They can also be caused by molecular transitions to lower levels. This sort of line appears bright compared to the region around it. Absorption lines cause holes in the continuum emission where light has been removed when atoms or molecules make a transition to a higher energy state. This causes the lines to look darker than the region around them.

Stars come in a wider range of sizes and temperatures. The hottest stars in the sky have temperatures in excess of 40,000 K, whereas the coolest stars we can detect optically have temperatures of about 3,000 K. The appearance of a star's spectrum is strongly dependent on its temperature. For example, the very hottest stars show absorption lines due to ionized helium (He II) and doubly and even triply ionized carbon, oxygen and silicon. On the other hand, the coolest stars show lines produced by molecules. The spectral classification sequence is in order of decreasing temperature with the following letters: OBAFGKM. Each class is subdivided into ten classes, with a number. So a star might be an O4, or a cooler one is O8.

A sequence of standard stars makes it possible for all astronomers around the world to classify the same stars in the same way. Vega, for example, is the standard for A0, and the Sun is the standard for G2. To classify the spectrum of a star, an astronomer must first obtain spectra of all the standards with her telescope. The unknown spectrum can then be classified by the simple process of comparing it with the standard spectra. Interpolation is sometimes necessary.

The full classification of a star also includes a luminosity class, denoted by a Roman numeral, which indicates the size of the star. The Sun is a G2 V star. You will learn more about luminosity classes in a future exercise. In this exercise, you are simply classifying in the temperature dimension.

Procedures

1. Select Targets:

1. Above is a finding chart for the Pleiades, an open cluster in the constellation Taurus. At what times of year is this open cluster observable from Ogden? (Don't know the RA and Dec of the Pleiades? Wikipedia can help you...) Is this a good target for today's observations?
2. Select your target list by marking 20 of the stars on the finding chart. (You will need to be able to identify these stars in a future lab, so make sure you mark them well on your finding chart, and can find them again later!)

2. Enter the Observatory:

1. Open the windows emulator. (Refer to instructions in Mass of Jupiter lab, if necessary.)
2. Open the "VIREO" program on the left of the windows desktop. This is an observatory simulation program, that is shockingly like remote operations of an actual telescope.
3. Login under File/Login.

4. Run the Exercise: Classification of Stellar Spectra.
5. Access the 0.4 m telescope.
6. Once you have been given control of the telescope, open the dome.
7. Turn the telescope control panel On.
8. Turn on Tracking. What does this do?
9. Slew to the Pleiades.
10. Compare the view in your field to star chart to find your target stars.

3. Take Spectra:

1. Center Star A in the red box (this is the size of the field you will see through the 'scope).
2. Shift from the Finder to the Telescope.
3. Now center Star A in the vertical red lines (these represent the "slit" of your spectrometer).
4. Access the spectrometer. Press Go to begin taking data. Press Stop when you are happy with the Signal to Noise Ratio. (SNR's of about five are considered "marginal". SNR's of greater than five are considered "good data". For such a bright star, you will reach five almost instantly...)
5. Save the spectrum, with a name you will remember later.
6. Take spectra similarly for the other stars on your target list. You will probably have to shift back and forth between the finder scope and the telescope view in order to find them all.

4. Classify Stars:

1. Now it is time to classify these spectra. In the main window, click on Tools/ Spectral Classification.
2. In the classification window, load: Atlas of Standard Spectra/Main Sequence.
3. Load one of your stellar spectra, by going to File/Unknown Spectra/Saved Spectra, and choosing it from the list. In the Classify Spectra window, there are three frames. Your unknown spectrum is in the middle frame. You can scroll through the spectral types using the green box on the right. In order to find the spectral type, you must match both the underlying continuum AND the spectral absorption lines as closely as possible. If a spectrum is between two shown types, interpolate to give it a number between those numbers. For example, if it is between B5 and A1, it may be a B8 star.
4. At the same time, find the peak wavelength of the spectrum. That is, find the wavelength at which the continuum emission peaks.
5. In Excel or Numbers, make a table of the classification and peak wavelength of all of your target stars. (Be sure to keep this information. You'll use it again!)
6. Use Wien's Law to find the temperature of your target stars from the peak wavelength.

OF COURSE, YOU SHOULD PROPERLY SHUT DOWN THE TELESCOPE, CLOSE THE DOME, AND LEAVE THINGS NICE FOR THE NEXT OBSERVER. (And pick up all your candy wrappers, and night lunch crumbs!) WHAT'S WRONG WITH YOU?

Age and Distance of a Stellar Cluster

Objective

The student will learn how to make a color-magnitude diagram using differential photometry. By identifying the main sequence, the distance to the cluster can be found. Also, the relationship between the main-sequence turn-off and the age of the cluster is explored.

1. This activity addresses WSU Natural Sciences Gen Ed Learning Outcomes: F2, F4, P1
2. Terminology: Astronomical Unit (AU), arcseconds, declination, parsec, radian, right ascension
3. Software: MaxIm; Images: m67-i.fits, m67-v.fits

Background and Theory

Open star clusters are groups of several hundred stars held together by gravity. All of the stars in a cluster were born at the same time from the same parent cloud of dust and gas. Many clusters are relatively young (less than 10^8 years, young for stars!). A plot of apparent magnitude versus surface temperature (or equivalent measure) reveals a characteristic, nearly diagonal line called the main sequence. Stars on the main sequence (like the Sun) are still fusing hydrogen into helium in their cores.

However, several clusters are much older, with a large number of stars that have evolved off of the main sequence to the giant and supergiant phase. By constructing a color-magnitude diagram of such clusters, we can look for the **turn-off point**---the point at which all stars above that on the main sequence have evolved to move off of the main sequence. Evolutionary models predict the turn-off point as a function of cluster age, and so the age can be determined by measuring the turn-off point on a color-magnitude diagram.

The distance to the cluster can also be measured since the main sequence relation is between absolute magnitude and color index. By comparing an observed color-magnitude plot with a universal H-R diagram, the distance modulus can be found. The distance in parsecs can then be found from this distance modulus.

Procedures

I. Data Collection and Plotting

1. Start the Windows Emulator.
2. Run Maxim-DL (upper left on the desktop).
3. Within the windows emulator, use a browser to download the images “m67-i.fits” and “m67-v.fits” from the website <http://deimos.physics.uiowa.edu/labimage> (navigate to archive/proj-12_Age_Distance_Cluster) onto your windows desktop.
4. Open the V filter image of M67 (named m67-v.fits) in Maxim-DL. You may need to adjust the histogram so that you can see all of the stars. You do this by moving the colored arrows on the Screen Stretch window.
5. 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 **Calibrate** 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 aperture photometry on this cluster of stars. Aperture photometry is done by making a circle around an object and adding up all of the counts within that circle. The sky background brightness is found from an annulus (donut) around the object. The sky background is subtracted from the total, and the resulting counts are equated to a magnitude. The magnitudes of other stars in the field are determined relative to this star by comparing counts. Fortunately, Maxim removes most of the tedium of photometry by doing the arithmetic for you.
6. 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 looks 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 your cursor. You want to set the aperture size to be just larger than image of the brightest (largest on the image) star you are measuring. 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 the lab to find the largest star you will be measuring. 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, however, as it will then be difficult to accurately record the magnitudes of smaller stars. For the purposes of this lab, a gap width of 3 and an annulus of 2 are adequate.
7. 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 requires information not supplied by the image itself. The magnitude of stars for photometry is usually found from finding charts, and here we give you the value. Enter the magnitude given for star 37 in the magnitude box. Next, click the “Set from FITS” button next to the Exposure box. This sets the exposure time by querying the FITS header of

the image. Now, click the “Extract from image” button next to the Intensity box. Use the finding chart again to locate star number 37 in the image and click on star 37 in your image. This extracts the intensity level from the image, and sets the star you clicked on to the magnitude you entered in. 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!) To check that you calibrated correctly, measure stars 9 and 13 to make sure the value agrees with the given value within a reasonable error.

8. Starting with star number 1, find each star, measure its magnitude, and record the magnitude in a table.
9. Repeat these steps for the I filter image. DONT FORGET TO RECALIBRATE FOR THE REFERENCE STAR USING THE I MAGNITUDE!
10. Fill in the third column of the table.
11. Graph the V magnitude versus the V-I color index.
12. We will do the rest as a group in class.

II. Finding the Distance

1. To your graph, add a second data set, by plotting the data from Table 2. These are the absolute magnitudes of main sequence stars. These are main sequence stars for which absolute visual magnitudes have been determined (adapted from Allen, [Astrophysical Quantities](#)).
2. Now, you need to figure out the offset between the two main sequences. By aligning the main sequences, a relationship is established between the apparent and absolute magnitude scales. In a separate cell, insert a constant that you will then add (or subtract) from all the values of V_{abs} in Table 2 (this will shift this “calibration” main sequence up or down). Adjust this constant until the two main sequences lie on top of one another. Seek a best fit for the central portion of the combined patterns. The cool red stars in the lower right of your paper graph are quite scattered and may not fit very well.
3. Consider what you are doing: You have graphs of two groups of main sequence stars. One is in terms of visual apparent magnitude (m) and the other one in visual absolute magnitude (M). Your constant offset is the distance modulus: $m - M$.
4. The absolute magnitude, apparent magnitude and the distance (in parsecs) are all related by the following equation:
$$m - M = 5 \log_{10}(d/10)$$
5. Find the distance to M67 in parsecs.
6. Convert this distance to light years.
7. Look up the accepted distance to M67 on the internet. As a percentage, how does your calculated value compare?

III. Finding the Age of M67

1. Find the main sequence turnoff apparent magnitude for M67, from visual inspection of your H-R diagram. Convert this to an absolute magnitude using the offset from Part II.
2. The luminosity of a star can be found from its absolute magnitude:

$$L = 10^{-0.4(M_* - M_\odot)} L_\odot$$

where the absolute magnitude of the Sun is 4.83. Find the luminosity corresponding to the stars at the main sequence turnoff.

3. The time on the main sequence depends on the luminosity because the luminosity depends on the mass, which determines the amount of fuel available. The relationship is slightly different depending on whether the star is more or less luminous than the Sun. The relationship between the main sequence lifetime and the luminosity is given by:

$$\tau_{MS} = 10^{10} \left(\frac{M_\odot}{M} \right)^2 \approx 10^{10} \left(\frac{L_\odot}{L} \right)^{2/3} \quad (L < L_\odot)$$

$$\tau_{MS} = 10^{10} \left(\frac{M_\odot}{M} \right)^3 \approx 10^{10} \left(\frac{L_\odot}{L} \right)^{3/4} \quad (L < L_\odot).$$

Find the age of M67 by finding the main sequence lifetime of the next star to leave the main sequence.

4. Compare your result with the accepted age range of 3.2-5 billion years.

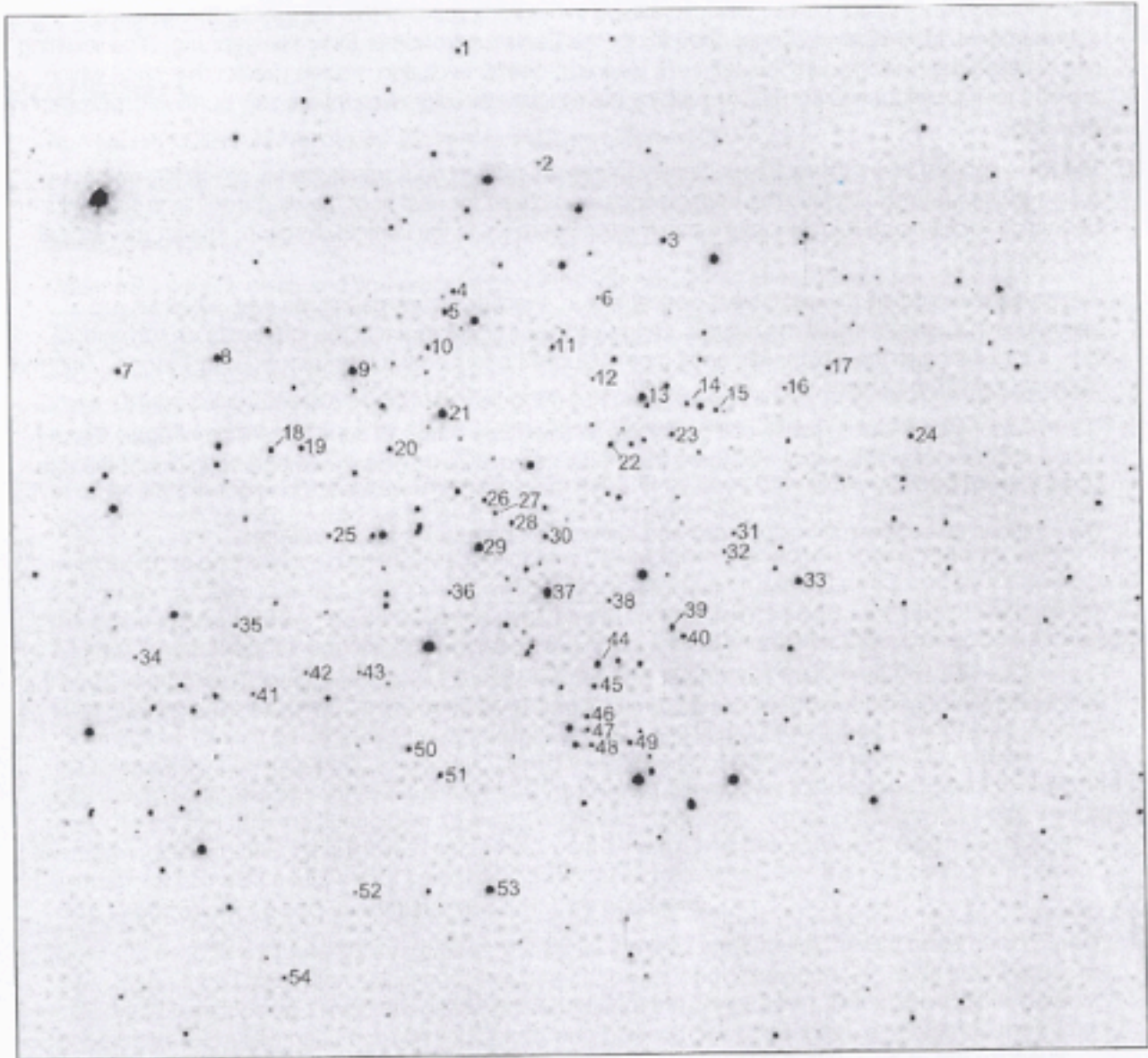
Table 1: Stellar Magnitudes of Stars in M67

Star	V	I	V-I	Star	V	I	V-I
1				28			
2				29			
3				30			
4				31			
5				32			
6				33			
7				34			
8				35			
9	10.968	10.650	0.318	36			
10				37	10.479	9.409	1.070
11				38			
12				39			
13				40			
14				41			
15				42			
16				43			
17				44	12.147	11.582	0.565
18				45			
19				46			
20				47			
21				48			
22				49			
23				50			
24				51			
25				52			
26				53			
27				54			

Table 2: Absolute magnitude and B-I index for Main Sequence Stars

V_abs	B-I	Spectral Type	V_abs	B-I	Spectral Type
-5.8	-0.83	O5	4.4	1.37	G0
-4.1	-0.73	B0	5.1	1.65	G5
-1.1	-0.38	B5	5.9	2.10	K0
0.7	0.0	A0	7.3	2.78	K5
2.0	0.31	A5	9.0	3.42	M0
2.6	0.64	F0	11.8	3.85	M5
3.4	0.99	F5	16.0	4.25	M8

Open Cluster M67 Finding Chart



Astronomy Observing and Data Analysis Project

1 Developing a Research Topic

A major component of astrophysics is observation and data analysis. For your final project, you will do one of the following:

1. Gather data using the remote robotic 0.61-meter telescope at Sierra Stars Observatory in Nevada (www.sierrastars.com).
2. Perform a data-mining “observation” of one of many online astronomical databases.

The goal today is to develop ideas for a project, and then determine the best way to gather your data. Some projects are well suited to a sophisticated telescope like Sierra Stars. Still others need to rely on the vast amounts of astronomical data from surveys posted online.

Here are the steps to develop and present a completed project:

1. Decide what you are interested in. You can start out general (“I like planets”) and make it more specific as you go.
2. Narrow your topic to a research question. You will need to present your results during a relatively short (15 minute) class presentation, so the more you can focus your question, the better.
3. Gather relevant information on your topic. This is known as background research or a “literature search”.
4. Gather data to answer your question.
5. Perform the analysis.
6. Present your results.

Some tools to help you:

- **What do other people know about this research?** The first resource is our library (you need more detail than Google can provide) but the best resource is the Astrophysics Data System:

<http://adsabs.harvard.edu/>

- **Where is (are) your object(s)?** To find RA and Dec, as well as references about your objects (on everything but planets) use the SIMBAD database:

<http://simbad.harvard.edu/>.

For planets and other bright objects, check out AstroTools. Link to it from

<http://weber.edu/planetarium>).

In particular, check out the Sky View Cafe

<http://www.skyviewcafe.com/skyview.php>.

Be sure to pay special attention to the *epoch* your coordinates are in (2000 or 1950, for example).

2 What to Turn In

For your project grade, you will turn in the following:

1. A detailed report describing your research question, your observing plan, and your results. I'll be providing you with a template for this that matches accepted standards in astrophysical research.
2. A 15 minute presentation (10 minutes + 5 minutes for questions).

3 Topic Suggestions

You are not limited to these suggestions below, but they give you an idea of the scope of research question you can address in this project:

- Lunar/Planetary topography - measurement craters/mountains/dunes on another planet.
- Determining the age and distance to an open cluster.
- Measuring the mass of Jupiter using observations of its moons.
- Properties of asteroids or comets.
- Study of binary star orbits.
- Determine the period of eclipsing binaries.
- Determine the areal density and average distance between the stars.
- Properties of planetary nebulae.
- Exploration of star forming regions.
- Comparison of galaxy colors and types.
- Search for water or water ice on Mars.
- etc...