Foundational Labs:

Introduction to Active Learning
-Counting galaxies based on morphology and color

Observing the Night Sky
-Understanding the Celestial Sphere and using Star Wheels, Stellarium, and the Star Walk Application to find astronomical objects in the night sky (available for day labs)

Introduction to Telescopes
-Understanding lenses with the Galileo scopes and how to set up and calibrate C8s (available for day labs)

Parallax Lab
-Understanding angular size, the small angle formula, and parallax measurements to find distances to stars

Small Angle Lab
-Students will learn the small angle formula and angular size to find the distance to the Old Capital Building

Introduction to Rigel Observing
-Students will learn about filters and exposure times for observing with VAO/Gemini and will learn how to setup and submit observing files.

Image Analysis
-Students will learn how to use images to find angular size and distance to objects and how to make tri color images. Students will learn MaxIm DL for image processing.

Observational Labs:

Stellar Photometry
-Students will find magnitudes and temperatures of stars. Students will construct an HR diagram to find spectral types of stars.

(New) Stellar Photometry of a Globular Cluster
- Students will determine the main sequence turn off age of a globular cluster by doing stellar photometry and making an HR diagram. This lab is an alternative to Stellar Photometry as it teaches the same ideas, but emphasizes main sequence turn off ages as a topic.

Observing Lunar Features
-Students will identify features on the moon through observations and learn about craters

(night lab).

Impacts Lab
-Students will learn about crater physics. Parts of this lab are present in the Lunar Features, and Near-Earth Asteroids labs.

Observing Giant Planets
-Students will observe giant planets (if available that night) to identify moons and features (night lab).

Exoplanet Discovery (potential 2 part lab)
-Students will plan and submit observations of an exoplanet in order to construct a light curve and possibly determine quantities such as: the goldilocks zone, planet temperature, luminosity of host star, and size of the planet.

Near-Earth Asteroids
-Students will learn about crater impacts and calculate sizes of near Earth asteroids.

Mass of Jupiter
-Students will calculate the mass of Jupiter from images to understand Kepler's Laws and gravity.

Observing the Sun
-Students will identify features on the Sun (e.g., sunspots), track the solar cycle, and do solar observing (Day lab)

Introduction to Spectroscopy
-Students will identify spectral lines from such elements as Hydrogen, Helium, Neon, Argon, and Nitrogen. Using these spectral lines, they will also examine a Solar spectrum.

Astronomical Redshift
-Students will use spectra of quasars to calculate redshifts to the galaxies. Students make use of doppler shift and Hubble's law to calculate a new Hubble's constant and the age of the universe.

Observing Comets
-Students will learn about properties of comets, and how comets interact with the solar wind. Students will use the small angle formula to calculate the extent of the coma and tail of comets.

Main-Belt Asteroids
-Students will learn how to detect and identify asteroids as well as about how asteroids rotate.

(New) Classifying Galaxies
-Students will classify galaxies based on morphology to reconstruct the Hubble tuning fork and discuss galaxy evolution.

Eclipsing Binary Stars
-Students will observe a binary star system and construct a light curve to find luminosity, size, and potentially spectral type of the stars in the system.

Over View of Final Research Projects

Introduction to Active Learning: Instructor Manual

Equipment needed:

None

Demos from Dale:

(Potential)
The Galaxy Model 8C10.60
One Million Galaxies 8C10.80
Galaxies – 100 Mpc 8C10.50

Lab Outline

1. Mechanics of Team Learning
    a. Discuss expectations of being a team. Show videos (it's a good ice breaker)
    b. Have groups assign roles. These roles can be flexible during the semester.
2. Pre-Lab Quiz (Part 1)
    a. Review answers with students and answer questions.
3. Working together to Discover Galaxies (Part 2)
    a. Introduce Hubble Space Telescope, the images, and websites they will use.
    b. Introduce galaxies: how we classify them.
    c. Draw a diagram of Hubble optics to help them answer question 1.
        i. Ask How many stars in the image (~7-8)
    d. Students complete Part 2
        i. Have them write on the board the following answers
            1. How many Galaxies they found
                a. Talk about Order of magnitude and how it's okay to not get the right answer
            2. Most common color
            3. Percent of Spiral vs elliptical
4. Group Discussion Questions (Part 3)
    a. Students may work into part 3 before the rest of the class. However, this is a group discussion. With at least 20-30 minutes before the end of class, have everyone focus on Part 3 and guide the discussion through the questions. The lab website has some background information to help, but this should be a discussion, not answering the questions outright for the students.

Name(s): ________________________________ ________________________________

________________________________ ________________________________

Date: ____________________ Course/Section: ____________________

Grade: ____________________

Introduction to Active Learning

Learning Objectives:

Students will learn how to work within their assigned teams to complete surveys and experiments, which introduce active learning concepts that will be applied in later labs.

Checklist:

- ☐ **Complete the pre-lab quiz with your team (if required).**
- ☐ **Compile a list of resources you expect to use in the lab.**
- ☐ **Work with your team to complete the lab exercises and activities.**
- ☐ **Record your results.**
- ☐ **Share and discuss your results with the rest of the class.**
- ☐ **Determine if your team's answers are reasonable.**
- ☐ **Submit an observation request for next week (if required).**

Introduction: Mechanics of Team Learning

Record the names of each team member and which role they will take in the group.

Part 1: Trivia Quiz

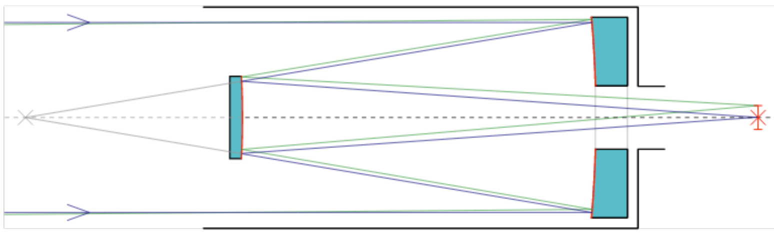
Record your team's answers, and give any reasons/facts you used to help make your guesses.

1. 1990
2. 400 nm—750 nm
3. 100 Billion Stars
4. Earth, Solar System, Milky Way, Local Group, Virgo Cluster, Laniakea Supercluster
5. 13.6 Billion years old and 4.6 billion years

Part 2: Working Together to Discover Galaxies

You will be using two websites on this page, the *Space Telescope Institute's* website and *UDF SkyWalker* to explore the Hubble Deep Field image. Answer the questions below using these two websites. You may find that some questions are easier with one image than the other.

1. How can you tell the foreground stars from the galaxies in the Hubble Ultra Deep Field (UDF)? (Note: Foreground stars are stars from the Milky Way. You cannot resolve individual stars in other galaxies with Hubble.) How many stars are in this image? 7—8 stars


HST: Cassegrain reflector.

The cross shape visible on bright objects (such as stars) in Hubble images is a form of distortion that is visible in all telescopes that use a mirror rather than a lens to focus light rays. The crosses, known as diffraction spikes, are caused by the light's path being disturbed slightly as it passes by the cross-shaped struts that support the telescope's secondary mirror. (Credit: NASA)

2. NASA claims that there are 10,000 galaxies in the UDF image. Develop a way to test this claim by making your own estimate of the number of galaxies in this image. Explain your method and use units in your answers. Show your work.

Using UDF, count the number of galaxies in one circle. Estimate how many circles make up entire image.

They should count within a number of circles to get an average, as one circle is not enough to sample entire image.

3. What is the most common color of galaxy in the image? Report your findings in percentages, justify your answer, and explain your work.

Yellow/other and Blue/White galaxies. (See Question 2 for tips)

4. If objects appear bigger if they are closer, would you agree or disagree with the observation that "nearby galaxies are evenly split between elliptical and spiral galaxies"? Justify your answer.

The "closest" galaxies are the brightest and largest in the image. Spiral galaxies slightly outnumber the ellipticals.

5. Determine the distribution of spiral vs elliptical galaxies for distant galaxies (remembering that apparent size corresponds to distance). Report your finding in percentages, justify your answer, and show your work.

See Question 2. Note: Distant galaxies. This question is slightly different than question 4.

6. In question 5, what difficulties did you have in determining the distribution?

   For distant galaxies, it is hard to determine if a galaxy is a spiral or elliptical because they all look like ellipticals. This is due to the resolving power of Hubble.

7. What correlations do you observe between the types of galaxies and the colors?

Spirals appear to be blue. Ellipticals appear, generally, to be red.

Part 3: Discussion

1. As we currently understand galaxy evolution, spiral galaxies can merger together to form elliptical galaxies, but it takes a long time to do so. What color do you expect elliptical galaxies to be? Why?

Elliptical galaxies are generally red because only old stars are still alive. More star formation has stopped in elliptical galaxies.

2. If a spiral galaxy is actively forming stars, what color do you expect it to be? Why?

Blue

3. Think about your answers in Part 2. Do your observations agree with how we understand galaxy evolution? Why or why not?

Observing the Night Sky: Instructor Manual

Equipment Needed:

Star Wheel
Ipads
Stellarium (on computers)

Demo From Dale:

Celestial Sphere 8A35.10

Lab Outline:

1. Pre-Lab Quiz
   a. Option: Don't give out answers. Instead, have a discussion at end of class where students can revise their answers.
2. Part 1: Celestial Sphere
   a. This is designed to be a class discussion. Draw it on the board.
   b. Introduce Coordinate systems, Right Ascension, Declination, Longitude, latitude, zenith, horizon, North celestial pole, celestial equator
   c. Demo from Dale
3. Students do Celestial Sphere: Local viewpoint and zooming out
   a. Discuss and have them draw on board, labeling angles
4. Explain how to use Ipads, star wheel, and stellarium
   a. In Part 2 and 3, students should use 8pm tonight.
   b. In Part 4, students should use the current time and day. (Optional for time management)
   c. Part 5: Optional for night labs
5. Night Labs: Observe on Roof and make Star Chart.
   a. TA needs green lasers but cannot let students use them.
6. Give answers to Pre-Lab Quiz.
7. Race with the Star Wheels: (optional)
   a. Discussion Post Part 1—3
   b. With the star wheel, TA choses a few objects (constellation/star/messier object) and students will determine if they are up at 8pm tonight. Make it a race with the entire class.

Name(s): ________________________________ ________________________________

________________________________ ________________________________

Date: ____________________ Course/Section: ____________________

Grade: ____________________

Observing the Night Sky

Objectives:

Students will familiarize themselves with different methods for locating objects in the night sky and use star wheels, atlases, and digital applications to locate objects and answer questions.

Checklist:

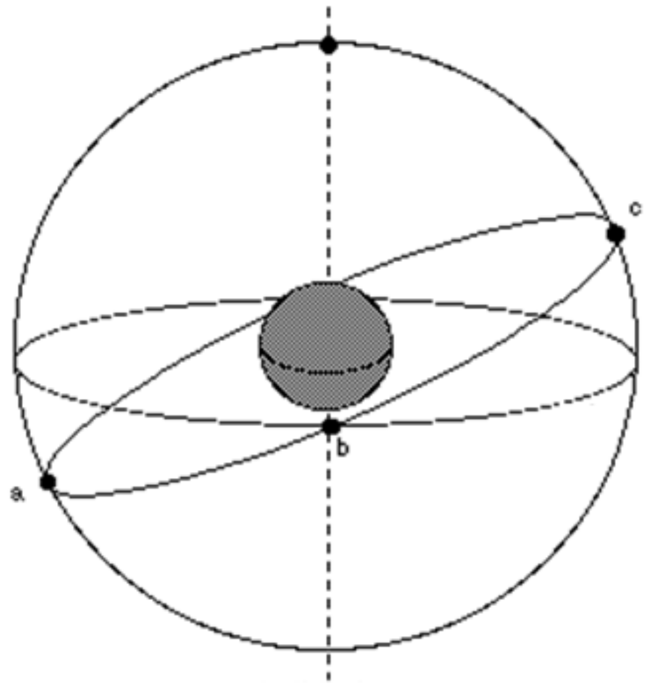
- ☐ **Complete the pre-lab quiz with your team (if required).**
- ☐ **Compile a list of resources you expect to use in the lab.**
- ☐ **Work with your team to complete the lab exercises and activities.**
- ☐ **Record your results.**
- ☐ **Share and discuss your results with the rest of the class.**
- ☐ **Determine if your team’s answers are reasonable.**
- ☐ **Submit an observation request for next week (if required).**

Pre-Lab Quiz

Pre-Lab Quiz is located on the Website.

1. *It depends.*
2. *The Earth's Equator*
3. *6h*
4. *Polaris*

Part 1: The Celestial Sphere



Label the Celestial Equator, the Earth's Equator, the North and South Celestial Pole, the Ecliptic, the position of Polaris, and the Earth's rotation axis. Mark where the summer and winter solstice and the autumnal and vernal equinox occur.

1. What angle is the ecliptic inclined with respect to the celestial equator?

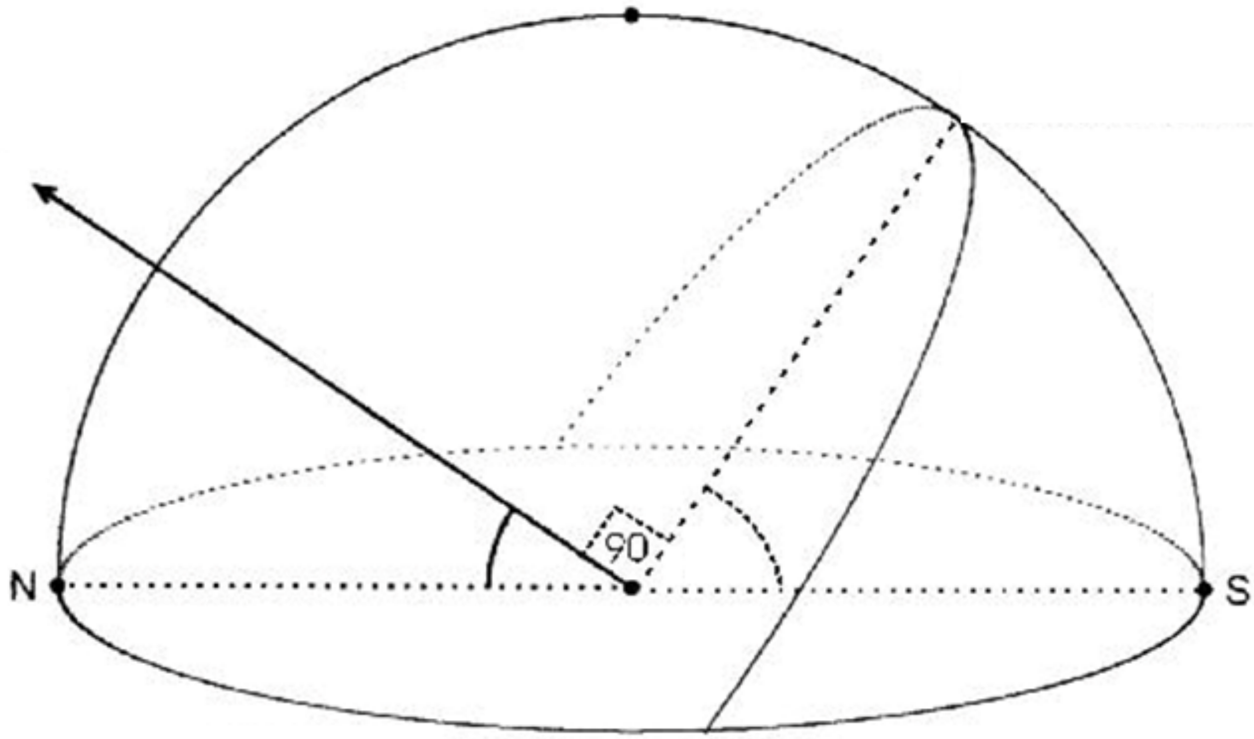
23.5 deg

2. What celestial objects lay on the ecliptic?

The Sun, and for the most part, planets (+/- a few degrees) Mercury is 7 deg off. Pluto is 17 deg off.

The Celestial Sphere: Local Viewpoint

Assume the diagram below is for Iowa City, IA, which is at a latitude of 41.6 deg.(~42deg). Identify the North Celestial Pole (NCP), Celestial Equator, Zenith, and the Horizon. Then, draw where Polaris is.



Angle Between NCP and Horizon (deg)	*41.6 deg*
Angle Between NCP and Celestial Equator (deg)	*90 deg*
Angle Between Zenith and NCP (deg)	*48.4 deg*
Angle Between Celestial Equator and Horizon (deg)	*48.4 deg*
Angle Between Zenith and Celestial Equator	*41.6 deg*

Think about the ecliptic and how it relates to the celestial equator to answer these questions.

1. For Iowa City, what is the elevation of the Sun at noon, on June 21st? Mark it on the Diagram above.

48.4 deg + 23.5 deg = 71.9 deg (Celestial Equator + Max. Ecliptic)

2. What is it at noon on the Vernal Equinox? Mark it on the Diagram above.

48.4 deg (Equinox, celestial equator and ecliptic match up)

Part 2: Using a Star Wheel

1. Dial up the 8pm on your star wheel. Find a constellation that has just risen. Find on that has just set.

Just risen – Star Wheel	
Just set – Star Wheel	

2. At 8pm tonight, where is the constellation *Ursa Major*, also called the Big Dipper? What are the names of the three brightest stars in this constellation? (You may want to use the Sky Walker app to help)

Alioth, Dubhe, Benetnash/Alkaid

3. There are three bright stars close to overhead in the early-Fall evening sky, these stars are known as the Summer Triangle. What are the names of these stars? Where are they at 8pm tonight?

Altair, Deneb, Vega

4. The constellation Orion is a favorite nighttime object for many observers.

   During which months is Orion observable in the early evening? (explain how you define *early evening*)

   Jan—Jun ~5pm

   Is Orion above the horizon right now? Check your answer with Star Walk.

5. What does it mean for a star or constellation to be circumpolar?

   a. Name 3 circumpolar constellations for Iowa City, IA.

Part 3: Using Stellarium

Use the Stellarium program to complete the following exercises.

1. What constellation is M44, the Beehive Cluster, located in?

    Cancer

    Is M44 observable tonight? If so where in the sky would it be located? If not what time of year would be best to observe it?

    Describe one interesting fact about the Beehive Cluster.

2. An object of great interest in astronomy can be located at the following coordinates:

RA = 0h 43m, Dec = 41° 16' *(Sometimes, Stellarium doesn't go right to it)*

What is this object's name and what type of object is it?

Andromeda Galaxy

Find and describe two interesting facts about this object.

Part 4: Using Star Walk (Ipads)

2. With Star Walk set to the current time, determine the information below.

What is the purpose of the red solid line in the *Star Walk* display?	*Horizon (really hard to see sometimes as it is not always red)*
Is the moon above the horizon right now?	
Which planets are above the horizon at this moment?	

3. Using the Star Walk app, fill in the information for Iowa City, IA for today.

Sunrise, sunset times	
Names of planets visible tonight (30 min after sunset to 30 min before sunrise)	
Phase of the moon and its rise and set times.	

Part 5: Using the Stars

Your instructor will initial here once you are able to identify your objects correctly in the night sky.

Finder Chart Activity (for daytime labs/inclement weather)

Find a planet that will be visible in the night sky tonight and make a *finder chart* that will enable you to locate it at the best time for viewing.

Use *Star Walk* or your team's own naked-eye observations to check the accuracy of your finding chart. If your chart does not correctly show the position of the planet, explain what went wrong:

Introduction to Telescopes: Instructor Manual

Equipment Needed:

1. Galileoscopes
    a. Three Eye pieces:
        i. Large eye piece is Modern
        ii. Small eye piece (needs small ring attachment) is Galileo
        iii. Combo of small and large eye piece (with tube attachments) is Barlow
2. C8s
    a. Tripod
    b. Wedge
    c. Telescope
    d. Screws
        i. 6 per telescope
3. Yard Stick

Demo From Dale:

None

Lab Outline:

8. Pre-Lab Quiz
    a. Discuss answers and take questions
9. Introduce C8s
    a. Key parts: Right ascension axis, declination axis, wedge, how to assemble
        i. Note: Stress dangers of wedge falling on toes
10. Introduce Galileoscopes
    a. Key parts: three eye piece configurations
    b. Objective lens
    c. How to take it apart and put it together
    d. Method for answering question 4:
        i. Students will take the lens into the hallway. One person will hold it up near the door to the stairs. Another student will try to focus the exit sign at the end of the hallway by looking through the lens and moving. The third student will measure the distance between the one holing the lens and the one looking through it. Assume S2 is infinity.
    e. Method for Q. 5 is similar in idea to Q4. They will not get accurate measurements
    f. Calculate magnification (m)
        i. Real Magnifications: Galilean 25, Modern ~ 25, Barlow ~50
11. You may have to split the class between Part 1 and Part 2 (limited C8s and TA time management)
12. Instruct students to read the lab manual on line for Part 1
13. For Part 2, each group should assemble the C8s as instructed by the TA
    a. The TA needs to draw a star on a white board and write a RA for it. Have students calibrate their telescopes to that star. Draw a second star on another blackboard and have students find the RA of that one. Once they have done so, the TA should check their answer.
    b. Disassemble the C8s for the next group.

Name(s): ______________________________ ______________________________

______________________________ ______________________________

Date: ___________________ Course/Section: ___________________

Grade: ___________________

Introduction to Telescopes

Objectives:

Students will study telescope optics and assemble a simple telescope. Students will also learn how to set up and properly align a tripod-mounted telescope for nighttime viewing.

Checklist:

- ☐ **Complete the pre-lab quiz with your team (if required).**
- ☐ **Compile a list of resources you expect to use in the lab.**
- ☐ **Work with your team to complete the lab exercises and activities.**
- ☐ **Record your results and mark which resources you used.**
- ☐ **Share and discuss your results with the rest of the class.**
- ☐ **Determine if your team's answers are reasonable.**
- ☐ **Submit an observation request for next week (if required).**

Pre-Lab Quiz

Record your group's answers to each question, along with your reasoning. These concepts will be relevant later in this lab exercise.

1. early 17th
2. Pluto
3. Above atmosphere
4. Arecibo

Part 1: The Galileoscope

1. What are some of the difference between a refracting telescope and reflecting telescopes? (Drawing a diagram may be helpful)

2. Is the Galileoscope a refracting or a reflecting telescope? What type of celestial objects would you be likely to see using the Galileoscope?

It's a refracting telescope, and you would want to use it for lunar viewing and planetary viewing. It is not good for deep sky objects like nebulae or galaxies.

3. Why does the objective lens of the Galileoscope consist of two separate lenses fused together? You may need to research this answer.

To correct for chromatic aberration.

4. Find and explain your method for determining the focal length of the objective lens.

See TA instructions above: f ~ 1.2m.

5. Describe the view using the Galilean eyepiece. How do you think this would have affected Galileo's observations?

Galilean eyepiece is small and fuzzy. It's hard to see out of.

6. Describe the view using the modern lens.

The modern lens is clear but upside down. It has a large field of view.

7. Compare the view using the Barlow lens to that when using the other two lenses. Explain the differences you find.

The Barlow is smaller field of view, high magnification, up side down

8. The telescope with the Galilean eyepiece has a magnification of 25. Based on your observations, what is the magnification of the telescope with the Modern eyepiece? What about the Barlow eyepiece?

9. Using the observed magnifications, calculate the focal length of the Galilean, Modern, and Barlow eyepieces.

Eyepiece	Focal length in m
Galilean	
Modern	
Barlow	

10. Compare your observed magnifications with the real magnifications. How accurate were you?

Part 2: Aligning an Equatorial Telescope

1. Equatorial telescopes have two axes, which one is aligned with the Earth's rotation axis.

The right ascension axis.

2. Explain the purpose of the mounting wedge for this telescope.

To calibrate the declination axis such that at 90 deg in declination corresponds to the North Celestial Pole. The mounting wedge adjusted specifically for your latitude.

3. Why is it better to choose a star near the celestial equator when aligning the right ascension axis of the telescope? (Hint: Draw a globe with lines representing right ascension and declination)

The lines of constant Right Ascension are more widely separated at the Celestial equator, which makes it easier to calibrate.

4. When you have properly set up and aligned your telescope, your instructor will give you an object on which to align your telescope. Once you have calibrated the right ascension axis of your telescope, find the right ascension of a different object provided by your instructor.

Parallax Lab Instructor Manual

Equipment Needed:

1. Compasses from Dale
2. Rulers
3. Meter Sticks

Demo From Dale: None

Lab Outline:

1. Introduction
    a. Angles – fist is 10 deg, finger is 1 arcsec
    b. Angular Size vs Linear Size
    c. Small Angle Formula
        i. Use to relate angular size, distance, and linear size
2. Part 1: Small Angle Formula
3. Part 2: Parallax
    a. What is a parsec?
        i. 3.26 ly
        ii. The distance equal to 1 arcsecond
    b. Parallax
        i. Apparent motion of a star in the sky
        ii. Example: Hold finger at arms length, covering an object. Close one eye, then close the other and open the first. The object will "move"—this is parallax
        iii. How do we take these measurements of Parallax?
            1. Two observations separated by 6 months (draw diagram)
    c. Introduce/ Derive D=1/P Equation
        i. D in pc, P in arcsecond
4. Part 3: Introduce Tropocentric Parallax
    a. Using simultaneous observations of a solar system object at 2 different points on the Earth to observe the Parallax
    b. Activity: Go onto the roof of Van Allen with compasses. You have the students stand on one side of the roof and find the angle (wrt N or another cardinal point) and a building. Then, stand on the other side and find the new angle to the same building. If you use the Old Capital (N to S side of roof) building, it's a small angle ~3 degrees. If you use the longer (E-W) side of the roof, it will probably work better.
        i. The parallax angle is half the angle they measure, and d is half the total distance between the two points of measurement. The posts on the roof are about 1.3 m a part from each other, so they should count the number of posts to find d.
        ii. Use Google maps to find the real distance to the building. They should grab a ruler and use the scale on google maps to find the distance, since mapping a path won't give you the right distance.
        iii. If you use the Old Capital, it's about 273 meters from Van Allen.
        iv. If the weather is terrible, you can probably do this from the windows in the lab room, but have them choose something very close by.
        v. Where this will go wrong is with the angle measurement. The students will not keep, for example, North facing North, so they will measure an angle change >90 degrees. You should tell them that it is within ~10 degree change or so.

Name(s): ______________________________ ______________________________

______________________________ ______________________________

Date: ___________________ Course/Section: ___________________

Grade: ___________________

Parallax

Objectives:

Students will apply the parallax concept to measure the distance of an astronomical object.

Checklist:

- ☐ **Complete the pre-lab quiz with your team (if required).**
- ☐ **Compile a list of resources you expect to use in the lab.**
- ☐ **Work with your team to complete the lab exercises and activities.**
- ☐ **Record your results and mark which resources you used.**
- ☐ **Share and discuss your results with the rest of the class.**
- ☐ **Determine if your team's answers are reasonable.**
- ☐ **Submit an observation request for next week (if required).**

Resources:

Pre-Lab Quiz

Record your group's answers to each question, along with your reasoning.

1. The apparent motion of the stars in a year
2. Stars further than 10000 parsec have “fixed” and do not have Parallax that is observable from Earth
3. D=1/P So the Further the Star, the smaller the Parallax
4. Balloon B Is closest
5. Balloon A is furthest
6. B is 2 times closer than E apparent size scales like 1/distance

Part 1: The Small Angle Formula

1. Calculate the apparent angular size of the building shown in the lab manual if it is 50 feet tall and you are 300 feet away from it. Show your work.

Small Angle Formula. ~9.4 deg

2. Determine the angular size of an object in the lab. Explain your procedure in detail and record the measurements for the object's true size and how far away you are from it.

3. How does the angular size of the object depend on where you stand?

Part 2: Parallax with Rigel

1. Explain what kind of observations you would use to measure the parallax of Alpha Centauri.

   You would take two observations of the star separated by 6 months to have the longest (~1 AU) baseline separation

2. Using the small angle formula, calculate the distance to Alpha Centauri in AU and parsecs. Show your work.

This question and question 3 are giving the same answer, but showing how if we assume d=1AU, and put D in parsecs, then the small angle formula has a "special" relationship of D=1/P.

1.34 parsec

3. Now calculate the distance to Alpha Centauri using D=1/P instead of the Small Angle Formula. Show your work and report your answers in parsecs.

   It's helpful to derive D=1/P sometimes to help the students see that D=1/P is only good when d=1AU

4. Using the Rigel image scale, determine the resolution limit of Rigel in Pixels. Show your work.

The students will multiply 0.73 arcsex/pix * 3arcsec = 2.11 arcsec^2 /pixel instead of dividing.
3arcsec/0.73 arcsec/pixel = ~4 pixels

5. Using the Rigel image scale and the known parallax angle, determine how many pixels Alpha Centauri would shift between two images taken 6 months apart with Rigel, and compare your answer to the resolution limit of Rigel. How would this affect your calculation of the distance to Alpha Centauri? Show your work.

0.73 arcsec/pixel *0.75 arcsec =1.02 pixels. Alpha Cen would be ~ 1 pixel wide in an image. Rigel can only resolve >4 pixels, so you couldn't accurately say where Alpha Cen would be within the 4 pixel beam. For majors, have them talk about errors as in 1 pixel +/- 4 pixels.

Strictly speaking, you only actually need the centroid position so you could use Rigel.

6. Hubble Space Telescope has a resolution of 0.1 arcseconds. If you could use Hubble instead of Rigel to find the Parallax of a star, what is the distance of the farthest star you could measure? Is such a star in our Galaxy still? Show your work.

D=1/0.1 arcseconds D= 10 pc, so still within our nearby galaxy.

Part Three: Determining the Distance to a Building from Van Allen

Read the description of the activity in Part 3 on the lab manual and answer the following questions.

1. Describe your method for measuring the distance to a building from Van Allen using parallax.

2. Explain why you would not want to use the formula D=1/p to find the distance.

3. Fill out the chart below and calculate the distance to the building using the small angle formula. Show your work.

Name/Description of Building:
Angles Measured (degrees):
Parallax Angle (arcseconds):
Distance between measurements, d (meters):

4. Find the real distance to the building using Google Maps. How accurate were you?

Introduction to Rigel Observing

Equipment:

None –Stellarium and Iowa Robotic Observatory Website

Demos:

Color Filters, CCD chip

Terms: Meridian, Local Sidereal Time (LST), Field of View, Resolution, Magnitudes of stars

Lab Outline:

Part 1:

Students will learn about Rigel using the Iowa Robotic observatory website. They will learn how to use the RST tool, and use it and Stellarium to find when objects are above the horizon. The goal is to have them understand that we want to observe objects when they are transiting the meridian and to understand the purpose of filters.

Part 2:

Students will organize and plan a project. There are possible projects listed on the lab website with filter and exposure times. Students will need to think of science objectives that can be answered with the observations proposed. Students should write a lab writeup (if time), not just throw down bullet points.

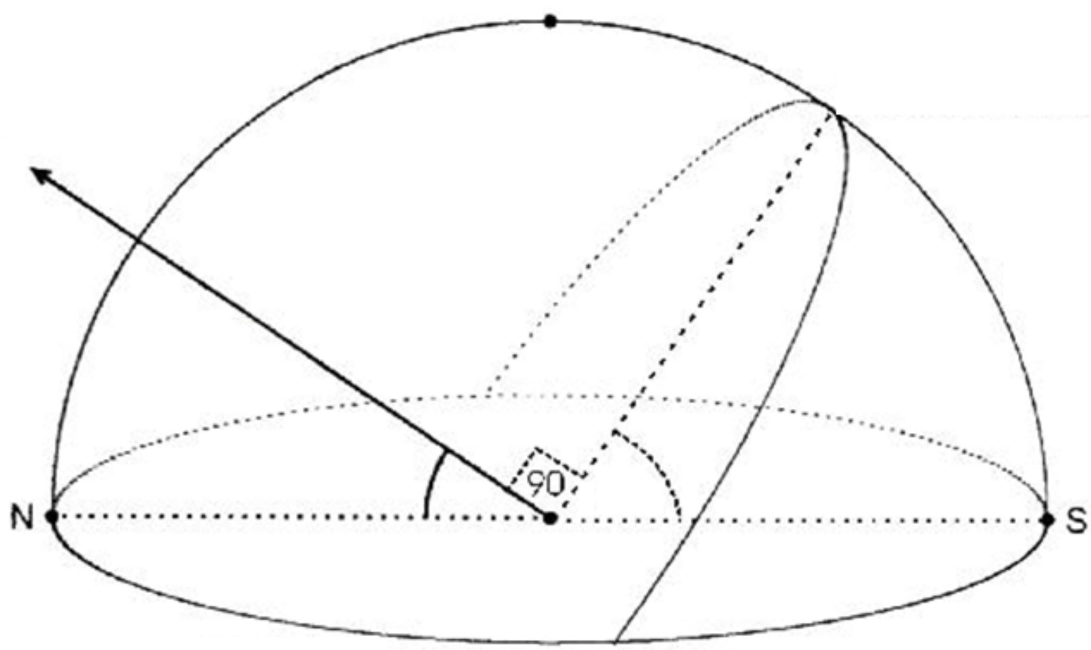
Students will try and write questions like "Can we observe this object with Rigel" or "Can we use the Hydrogen filter to observe this object?" these are not science questions but technical questions about observations.

Pre-Lab Quiz

1. straight up towards Zenith. Looking at lower elevations means looking through more atmosphere
2. When it crosses the local meridian
3. It is equal to the RA of stars that are currently crossing the local meridian
4. dimmer
5. Sun has RA of ~6 hours in June so only M57 would be up at night. Venus is never up at midnight because we always have to look towards the sun's direction to see Venus since it is in an orbit interior to ours (same with Mercury).
6. The left hand (one without the galaxy) needs more exposure

Pre-Lab Follow Up Questions

1. Assume the diagram below is for Iowa City, IA, which is at a latitude of 41.6 deg (~42deg). Identify the North Celestial Pole (NCP), Celestial Equator, Zenith, the Horizon, and the Meridian.



2. If stars with a right ascension of 6 h are currently on the meridian, what is the local sidereal time (LST)?

LST is 6 hours

Part 1: Learning about Rigel and Scheduling

Using the Rigel website, work with your team to find the following information.

1. Where is the Rigel Telescope located? (the latitude and longitude, and the city)

   Winer Observatory in Sannomiya Az, N 31 deg 39 ‘ 53.00’’ W 110deg 36’ 06.42 ‘’

   This is easily found using Stellarium and looking at the location.

2. Examine the table on the website that lists the times when Jupiter is above the horizon in March. When is Jupiter above the horizon at night? At what time(s) would it be best to observe Jupiter? Explain your reasoning.

First observable at 20:07:28 MST until 04:07:28 MST

You want to observe Jupiter when it is highest in elevation. (Preferably when crossing the meridian) So ~ 23:07:28 MST

3. Using the Rise and Set Calculator on the Rigel website (RST Calculator) and Stellarium, determine if the objects listed in the table below are observable by Rigel tonight. Fill in the chart for each object, and if it isn't above the horizon tonight, be sure to note that in the appropriate column. Then, research what type of object it is (Planet, galaxy, nebula, etc.) and/or its name.

Object Name	Times Observable	Right Ascension (RA)	Declination (Dec)	Best time to Observe	Type of Object
Pleiades					
M31					
Saturn					
M13					
M57					

4. The variable star UV And, which is in the constellation Andromeda, has a RA of 01h 26m 25.4s. Without using the rise and set calculator to look it up, what time of year would be best to observe UV And? Explain how you determined this.

UV And's RA is 01h. The Sun has a RA of ~1h in April, so you wouldn't want to observe it then. Instead, you want to observe it when the Sun has a RA of ~12 h. So, September 21 to Dec 23 are probably good viewing times.

5. What is the field of view of Rigel, and what does it mean if Rigel has a resolution of 3 arcseconds? Explain what these parameters mean and why they are important when setting up observations.

The FOV is about 25 arcmin by 25 arcmin for Rigel.

FOV of Gemini 13 arcminutes and a resolution of 0.776 arcseconds/pixel~ 1.3 arcseconds with a clear night

6. Why does the Rigel telescope have different filters? Explain specifically the purpose of the red, green, and H alpha filters.

H alpha traces ionized hydrogen, red traces hydrogen gas, and green traces OIII

Part 2: Planning and Submitting an Observation

Describe the observations your group is planning using the form below.

Object:

What kind of object are you observing? What science questions could you ask pertaining to this object, i.e., what do you want to know about it, and how can your observations answer these questions?

Filters used with exposure times for each:

Times of Observations (Day, Time of Day)

Instructor Manual: Observing the Sun

Equipment: Solar Telescopes

Demos from Dale: None

Lab Outline

1. Features on the Sun: Images in Labimage folder-> Solar
    a. Show a video of a coronal mass ejection.
    b. Why do we care?
        i. Geomagnetic storms on the Earth, the Aurora
        ii. The Carrington Event, when a CME hit the Earth in 1859. You could see the aurora in the Caribbean and it induced a current across the telegraph wires. This caused fires and disruption of the telegraph wires. If a CME hit us today, it would cause huge problems for our modern, wired, civilization.
    c. Introduce websites like SOHO and BBSO—show where the images of interest are. On BBSO, they are under DATA →Latest Images.
    d. Use MaxIM DL or just the normal mac image viewer to measure a change in pixels on the Sun.
    e. Overview of BBSO and SOHO images
        i. MDI Continuum: Michelson Doppler Imager
            1. Prominent features on sunspots in Ni I (6768 Angstrom) line
        ii. MDI Magnetogram
            1. Shows magnetic fields: black and white are opposite polarities
        iii. LASCO: Large Angle Spectrometric Coronagraph
            1. Images Solar corona, 8.4 Mkm away
            2. Large Angle, 32x (solar diameter)
        iv. EIT: Extreme Ultraviolet Imaging Telescope
        v. BBSO
            1. BBSO has a lot of images, mostly just want to look at the Halpha filter, which shows sunspots and filaments
2. Part 2: The Solar Cycle
    a. Students will not pick the same sunspot on the each image.
    b. They will also put years on the y axis and not the x axis.
3. Part 3: Solar Observing
    a. Take the students to the roof to do solar observing with the solar telescopes.
    b. Minimize the shadow of the telescope to help find the Sun

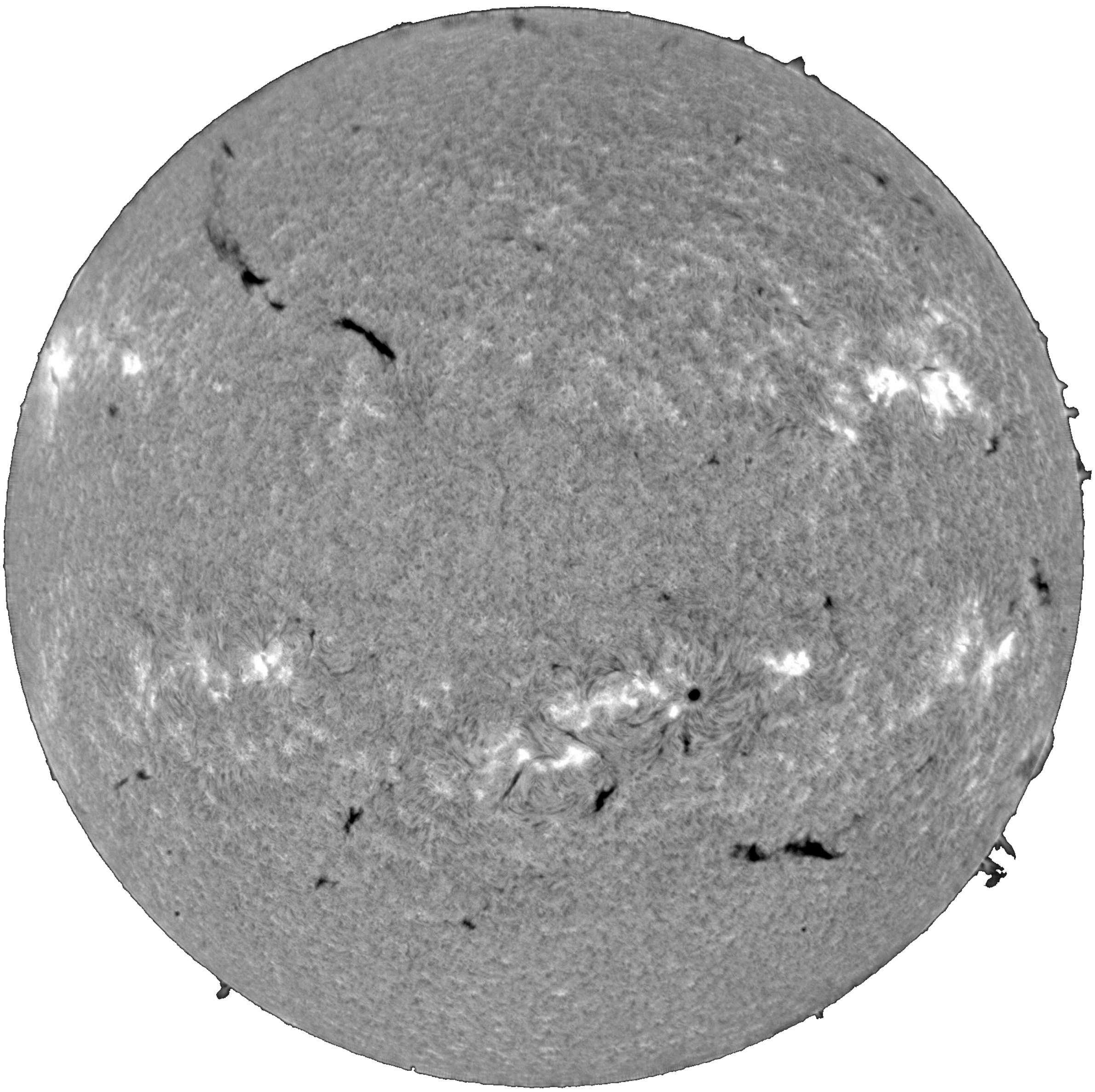
Pre-Lab Quiz

Record your group's answers to each question, along with your reasoning. These concepts will be relevant later in this lab exercise.

1. Sunspots are slightly cooler spots on the sun with strong magnetic fields
2. all of the above
3. is wrapped and twisted by the Sun’s atmosphere
4. By looking at its image project on a screen

Part 1: Features of the Sun

Study the hydrogen-alpha image of the Sun below and identify and label one or more examples each of filaments, solar prominences, sunspots, and granulation.



7. On the SOHO website, what does EIT stand for and what temperatures do the different filters image?

Extreme ultraviolet Imaging telescope.

304 A: T ~60,000~80,000 K

171 A: 10^6 K

195 A: 1.5 Mega K

284 A: 2 Mega K

The different wavelengths probe different layers of the Sun

8. If you wanted to look at sunspots, which images would you look at on the SOHO and BBSO websites?

9. What features of the sun are best imaged with LASCO images on SOHO? Why is the occulter disk important for these observations?

10. Describe the feature you are tracking by drawing a diagram of the Sun. Measure how far the features moves between the two images in pixels and determine the diameter of the Sun in pixels.

    ~39 pixels per day and the sun is ~ 436 pixels wide

Distance Traveled by Feature (pixels):	Diameter of the Sun (pixels):

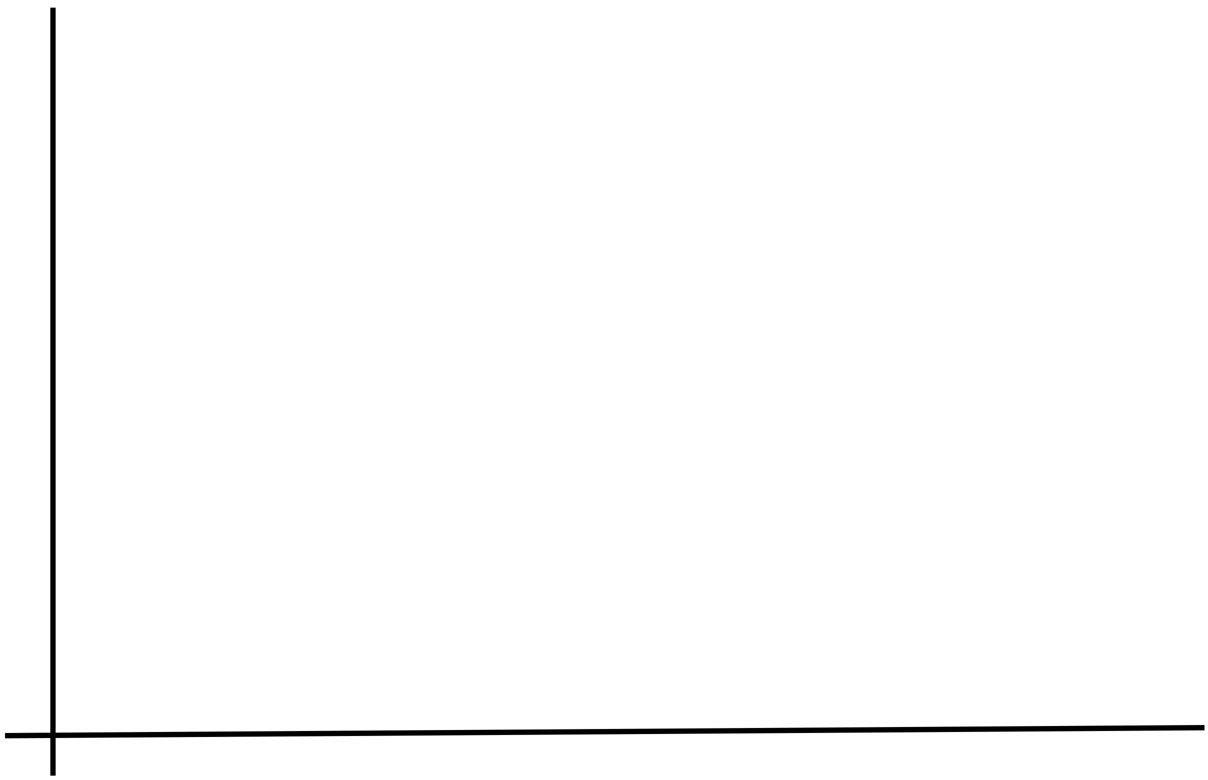
11. If the images were taken a day apart, determine how long it would take for the feature to travel all the way around the Sun. Explain your reasoning and show your work. Report your answer in days.

~25 days

Part 2: Solar Cycle

1. Write down your method for determining what constitutes a sunspot in the images.

2. Fill in the chart below (label axes), and plot the number of sunspots for each year.



3. What trend do you observe? What year had the most sunspots and what year had the least number of sunspots?

2001 is max, 2006 is min.

4. How long did it take to go from a solar minimum to a solar maximum? How long is the Solar Cycle?

About 5.5 years to go from min to max. 11 year cycle

5. From your observations, what is the Sun's activity level this year? Where in the Solar cycle is the Sun this year?

Part 3: Viewing the Sun

1. Sketch the view through the Personal Solar Telescope in the box below.

2. Which type of image from the SOHO and/or BBSO websites does the view through the telescope most resemble?

Image Analysis: Instructor Manual

Equipment Needed: None

Demos: Filters from Dominic

Lab Outline:

1. Pre-Lab Quiz
    a. Discuss Answers and take questions
2. Discuss Angular Size
    a. Small Angle Formula
    b. What is angular resolution
3. Introduce how to use MaxIm DL
    a. Loading an image
    b. FITS header window
    c. How to zoom in
    d. Aperture tool
    e. Where to find pixel values
    f. Combing Color Images
    g. Stacking Images (also on Lab website)
4. Part 1. Need image of Chapel (Shared drives)
    a. They will mess up with the pixel to arcmin conversion
5. Part 2. Image on Shared Drives or download
    a. They need to stack these images, if they do not it is wrong, even though they will get close to the right answer.
    b. Old old Rigel image scale is 1’’/pixel
    c. Hint for 4: Velocity is a vector
        i. Discuss with Class
6. Part 3 Give them images of M57 or Dumbbell Nebula from Labimage folder -> Nebula.
    a. Make tri-color image
    b. Locate Hydrogen (red filter)
    c. Find size of nebula
        i. Ring: 2300 ly away
        ii. Dumbbell: 1360 ly away

Name(s): _______________________________ _______________________________

_______________________________ _______________________________

Date: ___________________ Course/Section: ___________________

Grade: ___________________

Introduction to Active Learning

Learning Objectives:

Students will learn how to work within their assigned teams to complete surveys and experiments which introduce active learning concepts that will be applied in later labs.

Checklist:

- ☐ **Complete the pre-lab quiz with your team (if required).**
- ☐ **Compile a list of resources you expect to use in the lab.**
- ☐ **Work with your team to complete the lab exercises and activities.**
- ☐ **Record your results.**
- ☐ **Share and discuss your results with the rest of the class.**
- ☐ **Determine if your team's answers are reasonable.**
- ☐ **Submit an observation request for next week (if required).**

Pre-Lab Quiz

1. The image on the right has fewer arcsec/pixel
2. 12/0.5cm/pixel=24 pixel
3. more cm/pixel
4. higher contrast

Part 1: Measuring the Height of the Danforth Chapel

12. Determine the mixing ratio of your red, green, and blue filter images that produces the most realistic color image. Explain how you judged whether the colors were "realistic".

Red:	.288	Green:	.42	Blue:	1

13. How many pixels tall is the Danforth Chapel in your image?

179 pixels

14. What is the angular size of the chapel from top to bottom? Explain how you determined this.

179 pixels x 4 arcminutes/pixel= 716 arcmin =42960 arcsec

15. Determine the height of the Danforth chapel in meters and in feet. Show your work.

42960 arcsec= 206265* d/46 m

Height (meters):	9.6	Height (feet):	31

Part 2: Determine the Motion of Comet Garradd

1. Explain why it is important to align the two images.

2. How far did Comet Garradd travel in pixels from one image to the next?

ΔX (pixels):	47	ΔY (pixels):	4

If they don't align the images, the ΔY ~ 10 pixels

Total:	47.2 pixels

3. How far did Garradd travel in kilometers between the two images? Show your work.

47.2 pixels *1 arcsec/pixel=47.2 arcseconds

47.2=206265*d/(2.7*10^11)

d=6.2 *10^7 m

d=6.2*10^4 km

4. Using the FITS header, determine on what date were the images taken, and how much time passed between images.

   10-11-11 2:53:15.703

   10-11-11 4:01:52.717

   t~ 1.14 hours

5. How fast was Garradd travelling when the pictures were taken? Explain how you found this.

   V=d/t

V=(6.2*110^4km)/(1.15hrs)

V=945.2 km/min

V=16 km/s

6. Consider the motion of the comet in the image. What assumption was made in questions 2 and 4 to determine how fast it is moving?

You are measuring a change in position in the plan of the sky. You assume the comet is at the same distance from Earth in each image and not moving any closer or further away.

Part 3: Team Image Analysis

Using the techniques you've learned in MaxIm so far, analyze a data set and answer the questions provided by the TA.

Object:

Topical Questions: How large is the nebula in AU and Ly?

Research your object and write a brief summary of its formation.

Where is the hydrogen (red filter) and ionized hydrogen (Halpha filter) located in these images? Compare and contrast the [Ring] nebula and [Dumbbell] nebula with the Crab Nebula.

Stellar Photometry: Instructor Manual

Lab Equipment: None

Demos: None

Lab Outline:

1) Pre Lab Topics:
    a) Introduce classifications by temperature and luminosity classes
    b) Magnitude system and Color Index
2) Pre Lab Quiz
3) Part 1:
    a) Measuring Brightness on stars.
4) Part 2: Measuring Stellar Magnitudes
5) Part 3: Calculating and determining temperature and spectral class of stars and making an HR diagram

Name(s): ______________________________ ______________________________

______________________________ ______________________________

Date: __________________ Course/Section: __________________

Grade: __________________

Stellar Photometry

Objectives:

Students will learn how astronomers accurately measure the brightness of stars, as well as how the flux of a star through different colored filters can reveal its temperature.

Checklist:

- ☐ **Complete the pre-lab quiz with your team (if required).**
- ☐ **Compile a list of resources you expect to use in the lab.**
- ☐ **Work with your team to complete the lab exercises and activities.**
- ☐ **Record your results and mark which resources you used.**
- ☐ **Share and discuss your results with the rest of the class.**
- ☐ **Determine if your team's answers are reasonable.**
- ☐ **Submit an observation request for next week (if required).**

Resources:

Pre-Lab Quiz

1. F2 main sequence --- O B A F G K M, K2 luminosity classes don't matter
2. 3 times further away--- inverse square law
3. The star is more blue than red, so it is hotter. (Magnitude system is backwards, so high V value is bluer)
4. Increases in luminosity, decreases in temperature -- Basic HR diagram
5. A star 900 pc away with apparent magnitude of 3 M=m-5*log (d/10) a) m=10 b) M=-6.7 c)M= -6.4 d) m=8

Part 1: Imaging and Brightness

16. In the image of M27, identify three stars in each group by how bright they appear to you. Record the pixel location and the intensity using the aperture tool in MaximDL.

Group 1 Intensity of Brightest Stars	Group 2 Intensity of stars Half as bright as 1	Group 3 Intensity of stars Half as bright as 2

17. Compare the relationship between the maximum intensities for each group and the relative brightness as it appears to your eyes. Roughly by what factor does each group change?

18. Do your observations agree with the hypothesis that each group is half as bright as the previous one? What does this tell you about how the human eye measures brightness?

19. Using the line tool in MaximDL, measure and explain your method for determining the intensity of the Dumbbell Nebula (M27). If you make a measurement in a dark patch of the image, what do you measure and how does this affect your measurement of the nebula?

Part 2: Measuring Magnitude in Images

Now you will measure the Apparent magnitude (m) of the stars in Part 1.

R.A. and Dec:	Pixel:

Magnitude:

1. Now find three stars and record the apparent magnitude of the star. You will make better measurements by setting the aperture size for each star.

2. For one of your stars that is not the reference star, record the R.A. and Dec and find the accepted values of the apparent magnitude in **Stellarium**.

R.A. and Dec:

Measured magnitude in MaximDL:	Accepted value of magnitude in Stellarium:

How accurate was your measurement? If it wasn't accurate, how could you improve your procedure?

Part 3: Color and Temperature

Measure the magnitudes of 3 stars in your B and V filter images of an open cluster and determine their temperatures from the color index using the Equation on the lab website. You may want scratch paper in order to show all your work. Then, determine the spectral type of the star by using the HR diagram on the lab website.

Finder Chart ID	B Magnitude	V Magnitude	Color Index	Temperature	Spectral Type

Draw the HR Diagram and plot each star assuming that the stars all fall on the Main Sequence. Be sure to label the axes as well as where the Main Sequence, Giants, Super Giants, and White Dwarfs stars are. Assuming that these stars are all main sequence stars, what absolute magnitudes do you measure for them?

Photometry of a Globular Cluster: Instructor Manual

Lab Equipment: None

Demos: None

Lab Outline:

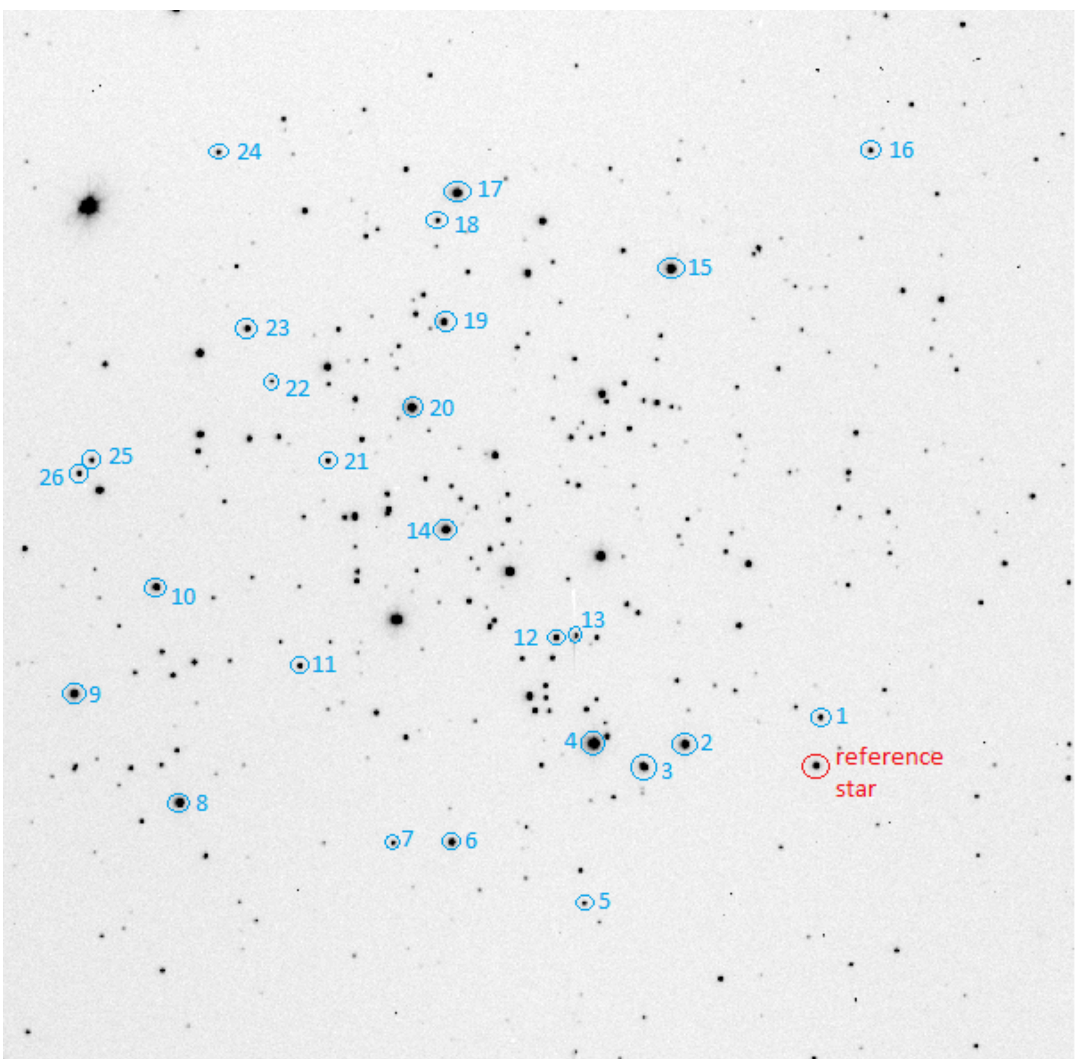
6) Pre Lab Topics:
   a) Introduce classifications by temperature and luminosity classes
   b) Magnitude system and Color Index
   c) What is a globular Cluster?
7) Pre Lab Quiz
8) Part 1: Calibrating the image for Photometry
   a) There are 27 stars in the Finder chart for M67, counting the reference star. There are two apparent magnitudes that need to be found for each star, which involve calibrating the images multiple times. To prevent confusion in calibration and to streamline the process for a two hour lab, divide the class in half. Three groups will find apparent magnitudes for the B filter, and three groups will find apparent magnitudes in V. Typically, there are 6 groups per lab, so each group will be responsible for 9 stars. If you are missing a group, the TA could easily provide the rest of the required numbers or reduce the selection. Stars with ID >20 can easily be eliminated from the list without damage to the HR Diagram.
9) Part 2: Finding the Temperature
   a) Students can either use the equation to find the temperature, or the graph. The equation is better, but the graph is close enough for non majors.
   b) Use the HR diagram to translate a temperature into a spectral class
10) Part 3: Determining the Age
   a) Make the HR Diagram (on last page) and answer the questions. Since each group only looked at 9 stars, you should have your students come together and share answers to make the complete HR Diagram. This can be done by having them write Temp and Spectral Class vs magnitude (in V) on the board as they complete part 2, or any other method that suits the TA.
   b) In questions 4 and 5, they can calculate these values using the appropriate equations or the excellent programs linked on the lab website from UNL Astronomy group. Make sure they are using the hottest stars, even if they weren't originally responsible for them.
11) Part 4: Comparing Ages of Globular Clusters (it is sometimes useful to do this part First as an introduction)
   a) There are various links to globular clusters with HR Diagrams. The goal is to not find absolute ages, but relative ages between these clusters. This part may be skipped is time is low.

Pre-Lab Quiz

1. F2 main sequence --- O B A F G K M, K2 luminosity classes don't matter
2. 3 times further away--- inverse square law
3. The star is more blue than red, so it is hotter. (Magnitude system is backwards, so high V value is bluer)
4. Increases in luminosity, decreases in temperature -- Basic HR diagram
5. A star 900 pc away with apparent magnitude of 3 M=m-5*log (d/10) a) m=10 b) M=-6.7 c)M= -6.4 d) m=8

Part 1: Calibrating an Image for Photometry

20. Follow the instructions on the lab website on Part 1 to calibrate the image of M67.
    - Load the image into MaxIm DL and open the Information Window (crtl+i)
    - Identify the Reference star using the finder chart and set the correct aperture size
    - Click the Calibrate button in the Information Window
    - Enter in the correct magnitude (B for blue filter image, V for V filter) into the Magnitude box
    - Click "Set from FITS" next to the Exposure box
    - Click "Extract from Image" next to the Intensity box
    - **Double click on the reference star (click on star AFTER intensity is set)**
    - Hit Apply
    - Check that the magnitude in the upper portion of the Information window reads the right magnitude (Double check that it is calibrated correctly. If all else fails, manually enter in intensity to calibration box)
    - Click to calibrate button to collapse the calibration window
21. Then, find the magnitudes of the stars and record them in the chart at the end of the packet.
22. Calculate the color index, which is B-V, and record it in the chart.



Part 2: Finding the Temperature and Spectral Type

1. Using the B-V values, find the temperature of each star either using the equation on the lab website, or the plot that relates color index to temperature on the lab website.
2. Using the HR Diagram on the lab website, record the spectral class of each star in the chart at the end of the packet.

Part 3: Determining the Age of M67

Make an HR Diagram for M67 using the temperatures and apparent magnitudes you recorded in Parts 1 and 2 and the results from other students.

- Label the axes (apparent magnitude, luminosity, temperature, and spectral class)
- Draw and label the main sequence and the giant branch.
- Plot the stars from your analysis and indicate the main sequence turn off point

Discussion

1. What is the Main Sequence turn off age of M67? Explain how you found this.

   True age is 3.2--5 Gyr

2. What assumptions did you make to determine the age of M67?

   All stars were at the same distance from Earth and they were formed roughly at the same time.

3. If the reference star has an absolute magnitude of M_v=1.6, find the distance to the cluster in parsecs.

Distance to M67 (parcsecs)	828.3 pc

4. Using the distance you found in Q. 3, find the absolute magnitudes of the three hottest stars in M67.

Star ID #	Spectral Class	Apparent Magnitude (V)	Absolute Magnitude
2	B8V	10.038	0.3
6	A2V	11.219	1.7
19	A2V	11.076	1.7

5. Use the HR Diagram Explorer to determine the luminosities and radii of the three hottest stars in solar units. You will need the absolute magnitudes from Q. 4 to find the luminosities. How much larger are these stars than the Sun?

Star ID #	Spectral Class	Temperature (K)	Luminosity (L_{sun})	Radius (R_{sun})
2	B8 V	11000	130	2.1
6	A2V	9500	13	1.7
19	A2V	9500	13	1.7

6. What are the luminosity classes of the three hottest stars in question 5?

Part 4: Comparing Ages of Globular Clusters

1. Follow the links provided on the lab website. Rank the clusters by age from oldest to youngest. Include your results for M67.

Pleiades, M67, M71, M2

Table 1: Properties of Stars in M67

Following the instructions on the lab manual, determine the apparent magnitudes of the stars in M67. Your group will be responsible for 9 stars in either the B or V magnitude. Once you have found the apparent magnitude in B or V, collaborate with the group that did the opposite magnitude for your stars. Then, determine the rest of the properties for all 9 stars.

Star ID #	B	V	B-V	T	Spectral Class

Star ID #	mb	mv	Color Index, I	T (K) calc	Spectral Type	L/Lsun	RA	Dec
1	13.16	12.67	0.49	6053	G0 IV	16	08 51 03.3	11 45 49.9
2	9.983	10.038	-0.055	11386	B8 V	110	08 51 11.85	11 45 23.1
3	11.36	10.92	0.44	6291	F8 V	1.4	08 51 14.5	11 45 01.4
4	11.078	9.75	1.328	3890	K4 III	45	08 51 17.51	11 45 22.6
5	13.898	13.263	0.635	5474	F9V	1.3	08 51 18.16	11 42 53.7
6	11.42	11.219	0.201	7865	A2V	17	08 51 26.5	11 43 50.7
7	13.73	13.248	0.482	6090	F9V	1.3	08 51 30.18	11 43 50.2
8	11.831	10.729	1.102	4271	K0III	96	08 51 43..57	11 44 26.2
9	11.641	10.71	0.931	4629	G4V	0.8	08 51 50.22	11 43 06.6
10	12.511	11.473	1.038	4396	K0IV	16	08 51 48.65	11 49 15.4
11	13.4296	12.702	0.7276	5170	G1 V	1.1	08 51 36.03	11 46 33.4
12	12.929	12.197	0.732	5157	F1V	12	08 51 19.9	11 47 00
13	13.578	12.857	0.721	5190	G8 III	113	08 51 18.7	11 47 02.5
14	11.062	10.515	0.547	5808	G2V	1	08 51 26.9	11 48 40.3
15	11.5	10.498	1.002	4471	G4 III	130	08 51 12.7	11 52 42.3
16	13.497	12.683	0.814	4922	G5 IV	16	08 51 00.18	11 54 32.3
17	11.569	11.117	0.452	6232	G4V	0.8	08 51 20.8	11 53 26.0
18	13.357	12.767	0.59	5639	G4V	0.8	08 51 27.743	11 53 26.3
19	11.076	10.937	0.139	8457	A2V	17	08 51 27.02	11 51 52.3
20	11.698	10.556	1.142	4196	K0III	96	08 51 29.0	11 50 32.9
21	13.469	12.853	0.616	5542	F8IV	16	08 51 34.29	11 49 44.2
22	14.313	13.711	0.602	5594	F7V	1.5	08 51 37.86	11 50 56.8
23	13.105	12.148	0.957	4570	K0III	96	08 51 39.39	11 51 45.3
24	13.358	12.799	0.559	5760	G2V	1	08 51 41.4	11 54 28.4
25	13.414	12.933	0.481	6095	G0V	1.2	08 51 49.44	11 49 43.3
26	13.29	12.65	0.64	5456	G4V	0.8	08 51 49.96	11 49 31.3
ref	11.5	11.295	0.205	7830	A7V	8.8	08 51 03.55	11 45 02.9

Introduction to Spectroscopy: Instructor Manual

Equipment needed: Spectral Carousals with tubes of H, He, Ne, Ar, N, and Air, Ocean Optic spectra graphs, fiber optics cord, usb cord, Light box with LED, fluorescent, and candescent bulbs, small box light box with colored lights, polarizing glasses

Software: Spectra Suite

Demos: Online demos

For Majors Class: Optional Part 4 (Optics Lab) and Part 6, identifying spectra of stars
Note: The Major's have slight different questions in Part 3. See Lab website.
For Non Majors Class: Do Parts 1-3, Part 5

Important: The tubes in the carousals are expensive, so to conserve them, it is best to turn them off when not using them. Also, you can pause the spectrum in the software to freeze the output. Instruct your students to then turn off the carousals in between measurements.

Tips for Spectra Suite:
Clicking on the graph will give a green marker line. This allows you to find peaks in wavelength.
Most of the time, you do not want to over saturate the lines. However, you need to do so for H to see the really weak lines.

In part 2, question 2, you could have them use the polarizing glasses to describe the bulbs.

Pre-Lab Quiz

Record your group's answers to each question, along with your reasoning. These concepts will be relevant later in this lab exercise.

1. Only a small portion of the wavelengths are visable
2. continuous, emission line, absorption
3. blue star is hottest, red is coolest. White is green star (middle of visible band)
4. All of the above

Part 1: Visible Light

1. Fill in the table below that summarizes the colors of the lights in the black box. The table should include the bulb, the range in wavelength (λ), and the peak wavelength, λ_{peak} .

Blub	Color	λ_{range}	λ_{peak}	Sketch of spectrum
1	White	426 nm –650 nm	458 nm	
2	Purple	419 nm – 481 nm	452 nm	
3	Green	481 nm – 550nm	519 nm	
4	Orange	570 nm – 625 nm	594nm	
5	Red	604 nm—649 nm	628 nm	
6	Infrared	893 nm—978nm	932 nm	

2. Draw and label the Electromagnetic spectrum from 100 nm~1000nm. Indicate the location of each bulb on it. What type of bulb is bulb #6, and why does it not appear to light up?

Infrared bulb—our eyes don't see infrared

3. Why is the range of wavelength ($\Delta\lambda$) for white light so large?

White light is all light

Part 2: Color and Temperature

1. Draw the spectrum of each bulb. How do the spectra differ between these types of bulbs?

Incandescent bulb is continuous spectrum

Fluorescent bulb (curly one) is emission line spectrum

2. Turn on each bulb and describe the resulting light in terms of color, intensity, and anything else you notice that appears unusual.

LED	
Fluorescent	
Incandescent	

3. Record the peak wavelength of the incandescent bulb and calculate the temperature of the bulb using Wien's Law. Show you work.

4. Compare your answer in Question 3 to the temperature of the Sun.

Part 3: Analyzing Emission Spectra

1. Observe the spectrum of the hydrogen and helium samples in the spectrum tube carousel. Record the wavelength and rank them based on how strong they are.

	λ_{peak}	Relative Strength Compared to Strongest Line
Hydrogen	656 nm	Strongest, H alpha line
	486 nm	2nd Strongest, H beta
	434 nm	3rd Strongest, H gamma
Helium	588 nm	Strongest
	706 nm	2nd
	668 nm	3rd
	389 nm	4th
	502 nm	weakest

2. Draw the entire spectrum for neon and argon, then label the strongest lines for each.

Ne peaks in visible at 586 nm, Argon peaks at 751 nm but has emission in blue

3. Why is neon orange and argon purple?

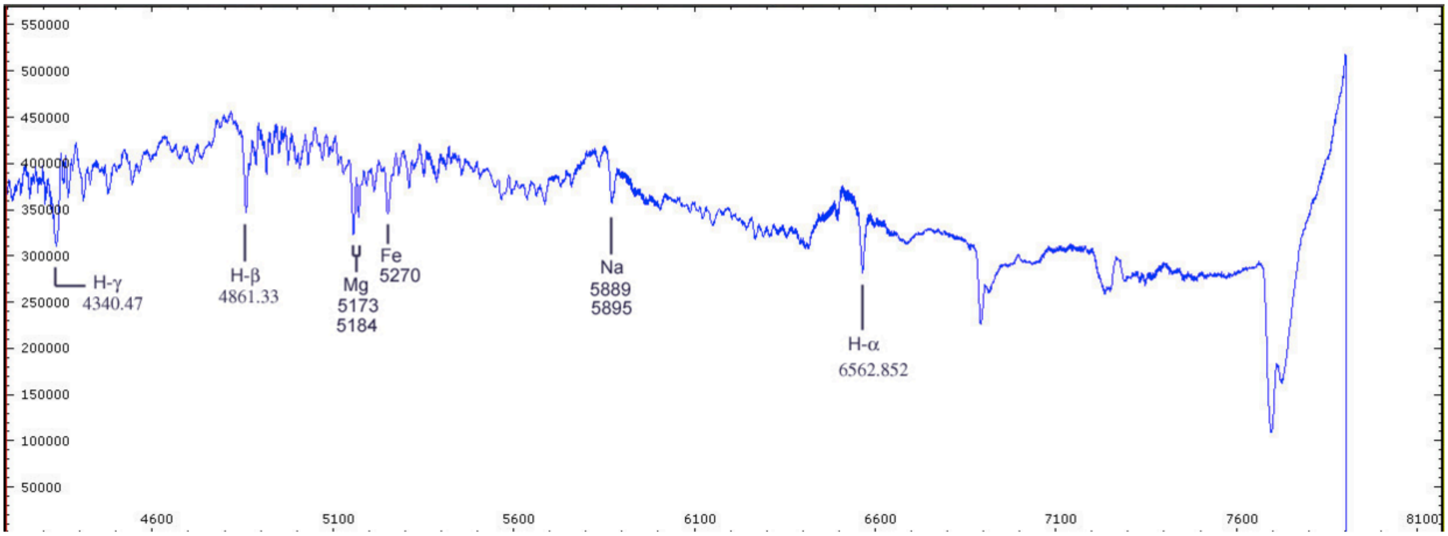
See above answer

4. Sketch the spectra of nitrogen, carbon dioxide, and air and label the strongest lines. There are more lines than you need to write down, but it will be useful later if you have some quantitative data.

Nitrogen
Carbon Dioxide
Air

5. Describe how you can determine if there is carbon dioxide and nitrogen in the sample of air. From your spectra, is there carbon dioxide and nitrogen in air?

Part 5: The Solar Spectrum



1. The spectrum above is a spectrum from the Sun's photosphere. Use your results from Part 3 of the lab to identify the six absorption lines that are marked on the graph. There are three lines for Mg 5173Å, Na 5889Å, and Fe 5270Å. The remaining lines are from Part 3 Question 1. (10 Å=1 nm)

2. What elements are present in the photosphere of the Sun based on the solar spectrum?

3. Use Wien's Law to determine the peak wavelengths of the photosphere and the chromosphere.

4. If you measured the peak wavelength of a photon from the Sun at 1.8 Å, what temperature is this photon? What part of the Sun did this photon originate in?

5. Draw the electromagnetic spectrum. Mark on it the peak wavelengths for the chromosphere, the photosphere, and the core of the Sun. What part of the electromagnetic spectrum do they correspond with?

Astronomical Redshift: Instructor Manual

Demo: None

Equipment: Spectral carousals with tubes of H, Ocean Optic Spectro graphs, fiber optics cord, usb cord

Data: Quasars in Labimage, Quasars/Galaxy

Software: Spectra Suite and Logger Pro

Topics:

Doppler Shift

RedShift (cosmological z vs Doppler redshift)

Hubble's Law, Hubble Constant, Hubble Time

Rest Wavelength

Quasar

Lab Overview:

- Part 1
  - Identifying rest wavelength of Balmer series
- Part 2
  - Goal: Find velocity, redshift, and distance to a quasar.
  - Each group of students is assigned a quasar spectrum, located in the labimage folder on the desktop. Students should identify the hydrogen lines and the doublet OIII line.
  - Students can write their velocities on the board to use for later questions.
  - They can then calculate a redshift and a velocity. Then, using hubble's law, find the distance using 72 km/s/Mpc as the Hubble constant.
  - Next, the TA will give the students the real distances to the quasars such that they will use Excel or Logger Pro to plot up v vs D. They can then do a linear regression fit (the R= button in Logger Pro) to fit a line to the data. The slope of this line is the Hubble Constant.
  - Using their new Hubble Constant, students will calculate the Hubble Age.

Pre-Lab Quiz

Record your group's answers to each question, along with your reasoning. These concepts will be relevant later in this lab exercise.

1. All of the above
2. Blueshifted: wavelength decreases, frequency increases
3. Doppler
4. Expanding at increasing Rate
5. 13.8 Gyr

Part 1: Measuring Rest Wavelengths

1. With the Hydrogen tube in the carousal, record the wavelengths of the emission lines and identify which Balmer line they are.

Relative Strength of Line	Peak Wavelength λ_{rest}	Balmer Line Name
Strongest	656 nm	Hα
2nd	486 nm	Hβ
3rd	434 nm	Hγ
4th	410 nm	Hδ
5th	390 nm	Hε

2. Sketch the spectra of Hydrogen and label the axes and the peak lines by both their wavelength and Balmer name.

Part 2: Measuring Redshifted Wavelengths

1. Sketch the spectrum of the quasar and identify the emission lines. Your spectrum may have OIII in it as well as Hydrogen lines.

2. Identify five emission lines in the spectrum of a quasar and record their measured wavelengths in the table below. Use the graph in Part 2 of the lab website to help identify the lines. Then, compute the change in wavelength ($\Delta\lambda$) using λ_{rest} from your table in Part 1. If you identified the two OIII lines, the λ_{rest} are 500.7 nm and 495.5 nm. Then, compute the average Z.

Object Name:				
Emission Line name	Rest Wavelength $\boldsymbol{\lambda}_{\mathbf{rest}}$	Peak Wavelength $\boldsymbol{\lambda}_{\mathbf{peak}}$	$\Delta\lambda = \boldsymbol{\lambda}_{\mathbf{peak}} - \boldsymbol{\lambda}_{\mathbf{rest}}$	$Z=\Delta\lambda/\lambda_{rest}$

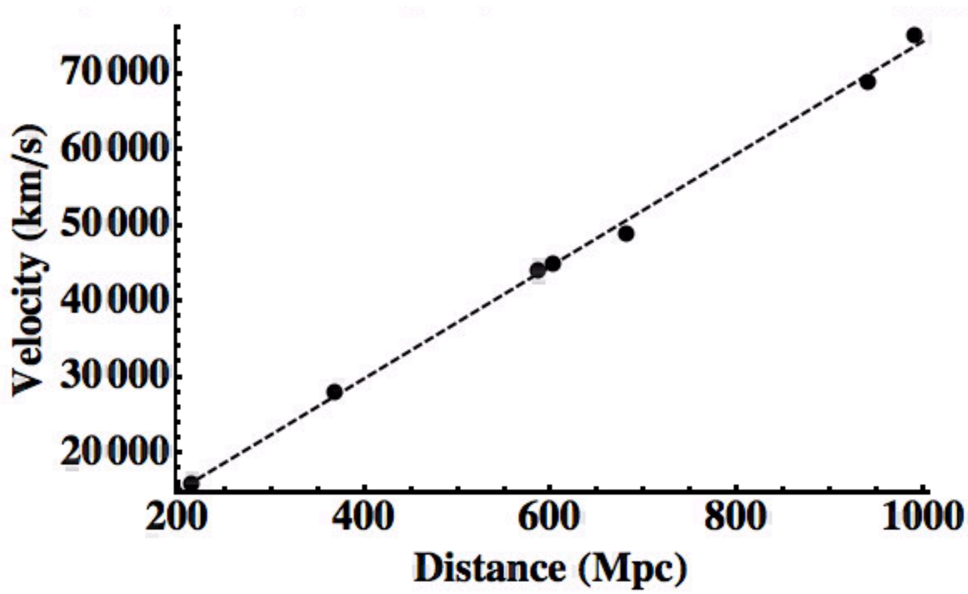
3. Find an average redshift and use it to compute the velocity in km/s of the quasar. Show your work.

Average Z=

4. Using Hubble's Law, find the distance of the quasar from Earth, given the assumed value for the Hubble constant. Show your work.

5. What is the real distance to your galaxy, and how does that compare to the calculated distance you found in question 3?

6. Make a plot of velocity in km/s vs distance in Mpc. Using the velocity computed for each galaxy and the real distance, plot each galaxy. You can make this plot in Logger Pro or Excel. Fit a line to your data to find the slope of the line. The slope of this line is the Hubble constant. Compare your value of the Hubble constant to the known one.



Hubble constant= 74 km/s/Mpc for this graph

7. With your value of the Hubble constant, calculate the age of the universe and compare it to the accepted age.

Galaxy	J0927	J1236	J1400	J1452	J1458	J1509	J2105
Hα (nm)	760.5	775.5	720.1	763.1	832.9	846.4	692.1
Hβ (nm)	563	573.8	532.4	565.1	616.9	623.4	512.9
Hγ (nm)	503	512.6	475.4	504.6	549.0	559.4	493.4
Hδ (nm)	475	483.7	449.0	476.9	519.3	527.9	459.1
Hε (nm)	459.5	467.9	434.5	460.4			
OIII (nm)	579.9	590.8	548.5	582.1	632.4	643.8	528.3
OIII (nm)	573.9	595.5	543.6	575.8	628.9	636.9	522.5
Average z	0.159	0.18	0.098	0.163	0.268	0.289	0.055
V (10^4 km/s)	4.4	4.9	2.8	4.5	6.9	7.5	1.6
Calculated D (Mpc)	608	681	389	625	958	1042	222
Known D (Mpc)	586	681	367	602	940	990	213

Known H0= 72 km/s/Mpc;

Calculated = 74 km/s/Mpc

Using 1km/s =1 pc/Myr,

72 (pc/Myr)/(Mpc)->

72/(10^6 Myr)->13.889 Gyr

Classifying Galaxies: Instructor Manual

Demos: None

Equipment: None

Terminology: Spirals, Barred Spirals, Ellipticals, Peculiar galaxies, Anemic Galaxies, Irregular Galaxies, Lenticular Galaxies, Hubble Tuning Fork, de Vaucouleur galaxy classification system.

Outline

1. Part 1:
   a. Students will learn about Hubble's Tuning Fork and how spiral and elliptical galaxies are classified on it.
   b. Goal: Recreate Hubble's Tuning Fork with supplied images of galaxies.
   c. Encourage a discussion amongst the entire class when disagreements arise over how to classify the galaxies.
2. Part 2:
   a. Goal: Learn de Vaucouleur's system and classify clusters of galaxies. Compare with Hubble's Tuning Fork.
   b. Students will now use de Vaucouleur's system to classify galaxies, which is infinitely more complex and difficult than Hubble's Tuning Fork.
   c. Part of this lab is knowing that galaxy classification is subjective and difficult to try and package all the important characteristics of a galaxy into a simple label.
   d. Each group can select a galaxy cluster to classify and recreate Hubble's Tuning Fork.
   e. When each group has their Hubble Tuning Fork, share with the class and encourage discussion over how the galaxies are classified. You may have them draw it on the board, or cast their screens to the front of the room.

Trivia Quiz

Record your team's answers, and give any reasons/facts you used to help make your guesses.

1. 1 billion years
2. Horizon and Flatness Problem
3. Rotation curves of galaxies
4. False. Spirals merge to form Ellipticals or irregulars
5. Earth, Solar System, MW, Local Group, Virgo Cluster, Laniakea Super Cluster

Part 1: Hubble's Tuning Fork

1. Describe the differences between the fives types of galaxies in Hubble's Tuning Fork.

2. Using the images provided on the lab manual, classify each galaxy using Hubble's Tuning Fork.

Part 2: Classifying Galaxies with de Vaucouleur

1. Chose a galaxy cluster from the list provided on the lab website. Using the images provided, classify the galaxies using the de Vaucouleur system as well as Hubble's Tuning Fork from Part 1.

See Table on Last page for "official" classifications in de Vaucouleur/Hubble system.

Format slightly different on Lab Manual.

2. Draw Hubble's Tuning Fork and identify a representative from your galaxy cluster for each of the classifications used by Hubble. You may have some classifications that overlap or you may be missing a morphological type.

3. Based on the types of morphologies of galaxies within each cluster, make some conjectures about the age or interaction history of your group knowing what you know about how galaxies evolve.

4. Describe the differences between the de Vaucouleur system and the simple Hubble Tuning Fork.

The de Vaucouleur system expands the Irregulars from Hubble's Tuning Fork into more subclasses of spirals and irregulars.

Galaxy	Type	Distance	Name/Notes	Galaxy	Type	Distance	Name/Notes
NGC 5128	S0	14 Mly	Centaurus A Group	UGC2773	Irr	10 Mly	Maffei Group
NGC5253	Sd		RA=13h40m	UGCA86	Sm		RA=3h30m
ESO 97-13	Sb		Dec=-40 deg	UGCA92	Irr		Dec=+60deg
ESO 274-01	Scd		7 large galaxies	IC342	Sc		IC342
NGC5 5068	SBc			NGC1560	Scd		5 large galaxies
NGC 5102	S0			NGC1569	Irr		
ESO 270-17	SBm			UGCA 105	Sm		
NGC 4945	SBc			Maffei I	E		
M83	SBc			Maffei II	SBbc		
				Dwingeloo I	SBcd		
NGC4535		52Mly	Virgo I cluster				
M91	SBb		RA=12h30m	NGC 4096	SBc	30Mly	Canes II
M89	E		Dec=+12deg	NGC4144	SBc		RA=12h30m
M90	Sbab		160 large galaxies	NGC4242	SBm		Dec=+43deg
M58	SBb			NGC4288	SBc		9 large galaxies
M59	E			NGC4460	S0		
M60	E			NGC4490	SBc		
NGC4654	SBc			M106	SBb		
NGC4762	S0			NGC4618	SBd		
NGC4429	S0			NGC4625	SBm		
NGC4438	Sa			NGC7699	SBc		
NGC4450	Sab						
NGC4459	S0			NGC5248	SBbc	65~85 Mly	Virgo III
M49	E			NGC5363	S0		RA=13h30m~15h20m
NGC4473	E			NGC5364	Sbc		Dec=-5 to +10 deg
M87	E			NGC5566	Sbab		75 large galaxies
M88	Sb			NGC5577	Sbc		
NGC4526	S0			NGC5638	E		
M98	SBb			NGC5740	SBb		
NGC4216	SBb			NGC5746	SBb		
M99	Sc			NGC5846	E		
NGC4293	Sa						
M100	SBbc			NGC4845	Sab	55~80 Mly	Virgo II Cloud
NGC4365	E			NGC4753	S0		RA=12h0m~13h30m
M84	E			NGC4731	SBc		Dec=+5~-25 deg
M85	S0			NGC5084	S0		100 large galaxies
M86	E			NGC4536	SBbc		
				NGC4697	E		
				NGC4699	SBbc		
				M104	Sab		
				NGC4030	Sbc		
				NGC4123	SBc		
				M61	SBbc		

NGC 4535: SBc

Name(s): ______________________________ ______________________________

______________________________ ______________________________

Date: __________________ Course/Section: __________________

Grade: __________________

Comet ISON

Objectives:

Students will animate images of the comet ISON and calculate the size of the comet, tail, and its velocity.

Checklist:

- ☐ **Complete the pre-lab quiz with your team (if required).**
- ☐ **Compile a list of resources you expect to use in the lab.**
- ☐ **Work with your team to complete the lab exercises and activities.**
- ☐ **Record your results and mark which resources you used.**
- ☐ **Share and discuss your results with the rest of the class.**
- ☐ **Determine if your team's answers are reasonable.**
- ☐ **Submit an observation request for next week (if required).**

Resources:

Pre-Lab Quiz

Record your group's answers to each question, along with your reasoning. These concepts will be relevant later in this lab exercise.

1.
2.
3.
4.
5.

Part 1: All About Comets

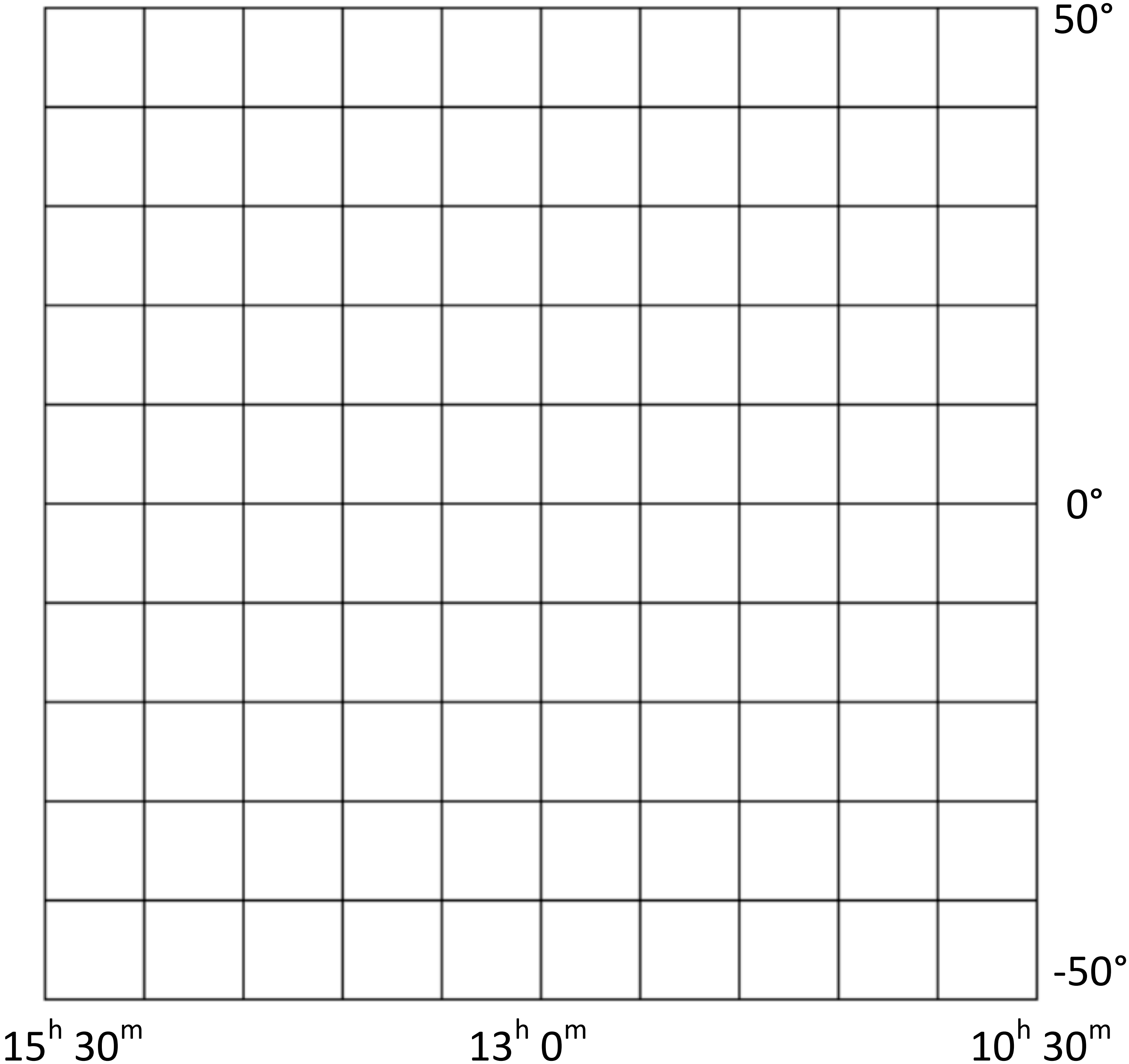
Study the animated GIFs of the comets on the lab website to answer the questions below.

1. Describe the orientation of the comet's tails with respect to the comet's motion.

2. Do you observe something strange in these GIFs? What is it? Suggest a hypothesis to explain what you observe.

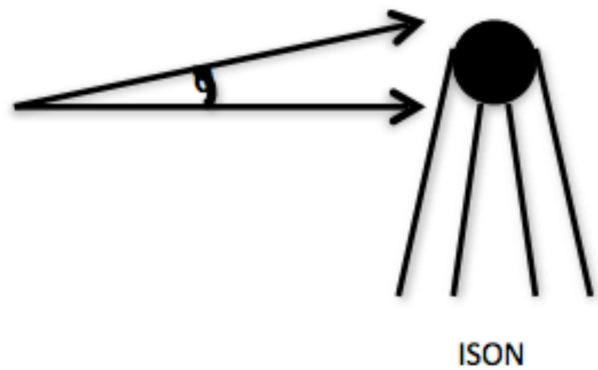
3. Using Maxim, animate the three images of Comet ISON from the website.
    a. Using the coordinate grid on the next page, plot the position of the comet and its tail orientation. (Hint: In the FITS header (crt+f), you can find the coordinates)

    b. Using your hypothesis from question 2, plot another relevant celestial object on the coordinate grid at the date of observation. What is the orientation of the comet's motion and tail direction with respect to this object?


50°
0°
-50°
15h 30m
13h 0m
10h 30m

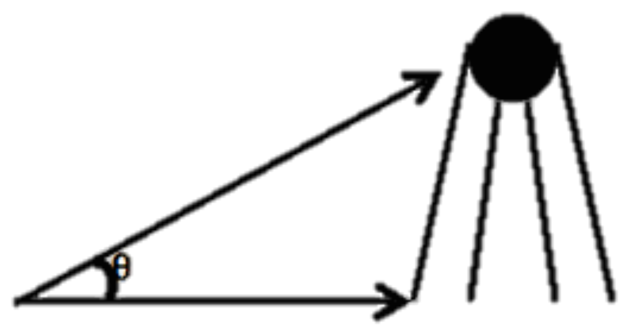
Part 2: Measuring the Size and Velocity of Comet ISON

1. Measure the diameter of the coma of the comet. Do not include the tail. Make this measurement in units of pixels



and show your work. (Hint: The graph tool in Maxim will be handy for this measurement)

2. The previous measurement is the angular size of ISON's coma. Now, convert this angular size into a linear size using the Small Angle Formula and a pixel scale of 0.725 arcsec per pixel. Show your work and give your answer in km.



3. Now, find both the angular size and linear size of ISON's tail in km. Show your work.

4. Measure the distance traveled between two images of ISON in pixels. Then, find what this is in angular distance using the image pixel scale from question 2. Show your work.

5. Using the Small Angle Formula and the distance to ISON, determine how far the comet traveled in km. Show your work.

6. Using the FITS header, determine how much time passed between your two measurements.

7. Now, calculate the speed of the comet in km/s. Show your work.

8. Is this the true velocity of the comet? Explain and be sure to include any assumptions you made in this calculation.

Name(s): ______________________________ ______________________________

______________________________ ______________________________

Date: ___________________ Course/Section: ___________________

Grade: ___________________

Exoplanet Discovery

Objectives:

Using the transit model, the images of the star, and the relations for exoplanet properties, determine the radius, orbital period, and distance from the parent star of an exoplanet.

Checklist:

- ☐ **Complete the pre-lab quiz with your team (if required).**
- ☐ **Compile a list of resources you expect to use in the lab.**
- ☐ **Work with your team to complete the lab exercises and activities.**
- ☐ **Record your results and mark which resources you used.**
- ☐ **Share and discuss your results with the rest of the class.**
- ☐ **Determine if your team's answers are reasonable.**
- ☐ **Submit an observation request for next week (if required).**

Resources:

Pre-Lab Quiz

Record your group's answers to each question, along with your reasoning. These concepts will be relevant later in this lab exercise.

1.
2.
3.
4.

Part 1: Sizes of Exoplanets

1. Explain your group's method for determining the size and position of Jupiter in the classroom scale model. Record the size of the Sun object and your estimates for the scale size and position of the Jupiter object, as well as any calculations you used to reach this conclusion.

Part 2: Transit Simulation

1. Sketch a graph of the output from the photometer used in the transit demonstration. Label the plot to show where the planet is not in front of the star, traveling over the limb of the star, and completely infront of the star.

2. Make a prediction as to the result of passing a sphere that is half the diameter of the first sphere in front of the light source. How will this affect the light curve? What property of the exoplanet might be most important in determining the change?

3. Does the demonstration verify your reasoning? Record the any values from the simulation your group thinks are important.

4. Could the photometer measure the decrease in light from a ball the scale size of Jupiter? How about a Neptune- or Earth-sized ball? What does this mean for the kind of exoplanets that are likely to be discovered?

Part 3: Detecting Alien Worlds

1. Create a light curve for your exoplanet detection using MaximDL. Record the following information:

Maximum Brightness (relative to star)	
Minimum Brightness (relative to star)	
Date/Time of Eclipse Center	
Spectral Type of Parent Star	
Mass of Parent Star (assuming main sequence)	
Radius of Parent Star (assuming main sequence)	

2. Determine the radius of the exoplanet compared to its star. How can you determine the true radius of the exoplanet? Explain your procedure.

3. Look up the orbital period for your exoplanet. Determine its distance from its star using Kepler's Third Law.

Name(s): _______________________________ _______________________________

_______________________________ _______________________________

Date: ___________________ Course/Section: ___________________

Grade: ___________________

Observing Lunar Features (With Impacts)

Objectives:

The goal of this lab is for students to observe basic features on the Moon, develop a basic understanding of the causes of some features, and learn how to measure the impact crater height on the Moon using basic geometry.

Checklist:

- ☐ **Complete the pre-lab quiz with your team (if required).**
- ☐ **Compile a list of resources you expect to use in the lab.**
- ☐ **Work with your team to complete the lab exercises and activities.**
- ☐ **Record your results and mark which resources you used.**
- ☐ **Share and discuss your results with the rest of the class.**
- ☐ **Determine if your team's answers are reasonable.**
- ☐ **Submit an observation request for next week (if required).**

Note: See lab website for alternative lab without impacts.

Pre-Lab Quiz

Record your group's answers to each question, along with your reasoning. These concepts will be relevant later in this lab exercise.

1.
2.
3.
4.
5.

Part 1: Impact Physics

23. Classify the different types of impact features that can be simulated with the impact crater demonstration, and how they are produced.

24. What were the dimensions of the crater your team produced that came closest to the dimensions of Barringer Crater?

Diameter:	Depth:

25. What were the parameters of the impact event used to create this crater? Explain your team's reasoning behind any assumptions you made.

Impactor Diameter:	Impactor Density:	Impact Angle:	Impact Velocity

Part 2: Observing Lunar Features

1. Locate the Moon in the night sky. What is the current phase of the Moon? In what direction (N, S, E, W, etc.) and at what elevation (Horizon, Zenith, About half way up, etc.) is the Moon located?

2. Knowing the phase, approximately what time does the Moon rise? What time does it set? Explain your group's reasoning in determining this

3. Observe the Moon through a telescope or using the image on the lab website. What types of features do you see? Describe the types of features you see in detail.

4. How does the Moon's surface differ from Earth's? How are they the same?

5. Sketch the lunar surface. Identify 5 features and the lunar landing site on your map. Also, make sure you mark where the terminator is located. After sketching your map, use the lunar map provided to label the cardinal directions on your Moon map, as well as the names of any features you included in your map.

6. How does the impact crater demonstration compare to actual impact features on Earth or the Moon?

Part 3: Measure the Height of Lunar Craters

1. Using the method described on the lab page, calculate an estimate for the height of any two lunar craters in the images provided. Show your work.

2. How does the size of lunar craters compare to craters on Earth like the Barringer Crater? How do you explain this?

3. During what phases would the moon have to be in to determine the height of craters using this method? Explain your reasoning.

Name(s): ______________________________ ______________________________

______________________________ ______________________________

Date: __________________ Course/Section: __________________

Grade: __________________

Observing the Giant Planets

Objectives:

The goal of this lab is for students to gain a better physical understanding for the properties of the giant planets and the physical sizes of planetary features and identification of some of the largest satellites of these giant planets.

Checklist:

- ☐ **Complete the pre-lab quiz with your team (if required).**
- ☐ **Compile a list of resources you expect to use in the lab.**
- ☐ **Work with your team to complete the lab exercises and activities.**
- ☐ **Record your results and mark which resources you used.**
- ☐ **Share and discuss your results with the rest of the class.**
- ☐ **Determine if your team's answers are reasonable.**
- ☐ **Submit an observation request for next week (if required).**

Resources:

Pre-Lab Quiz

Record your group's answers to each question, along with your reasoning. These concepts will be relevant later in this lab exercise.

1.
2.
3.
4.

<u>Part 1: Identifying Moons</u>

1. Draw a diagram showing the configuration of the moons of Jupiter and Saturn during your observation, as viewed from above. Indicate the direction to Earth.

Jupiter and Moons:
Saturn and Moons:

Part 2: Measuring the Scale of Planetary Features

Jupiter's Red Spot:

1. Measure the angular size of Jupiter's Red Spot in your image and determine its size.

Average Diameter (pixels):	Average Diameter (arcseconds):
Distance to Jupiter (km):	Area of Red Spot (km^2):

2. Is the spot larger or smaller than Earth? The largest cyclonic storms on Earth cover an area roughly the size of the Gulf of Mexico. How many times larger than this is the Great Red Spot?

Cloud Bands on Jupiter:

3. How many cloud bands are you able to distinguish on Jupiter? Determine their widths in kilometers.

Saturn's Rings:

4. Determine the extent and width of Saturn's rings in your images.

Width (km):	Width (Saturn radii):
Outer Diameter (km):	Outer Diameter (Saturn radii):

5. Which rings of Saturn are visible in your image?

Name(s): ______________________________ ______________________________

______________________________ ______________________________

Date: __________________ Course/Section: __________________

Grade: __________________

Eclipsing Binary Stars

Objectives:

Students will learn how the changing light from an eclipsing binary star system can reveal information about the individual stars and their orbits.

Checklist:

- ☐ **Complete the pre-lab quiz with your team (if required).**
- ☐ **Compile a list of resources you expect to use in the lab.**
- ☐ **Work with your team to complete the lab exercises and activities.**
- ☐ **Record your results and mark which resources you used.**
- ☐ **Share and discuss your results with the rest of the class.**
- ☐ **Determine if your team's answers are reasonable.**
- ☐ **Submit an observation request for next week (if required).**

Resources:

Pre-Lab Quiz

Record your group's answers to each question, along with your reasoning. These concepts will be relevant later in this lab exercise.

1.
2.
3.
4.

Part 1: Occulting Stars

Experiment with the eclipsing binary star simulator and use it to answer the questions below.

1. How would you determine the relative temperatures of the stars in an eclipsing binary from only its lightcurve?

2. Using only the lightcurve, how would you determine the relative sizes (radii) of the stars in an eclipsing binary?

Part 2: Lightcurve Calculations

Use the provided lightcurve to determine the following characteristics of the components of the binary system.

1. What are the relative sizes of the two stars? Justify your answer.

2. Calculate the mass of the companion star. Show your work.

3. Is the companion star hotter or cooler than the Sun? Provide justification for your answer.

Part 3: Period of an Eclipsing Binary

Give your result for the time of minimum for the binary star you studied, along with an estimate of your uncertainty. Do some research to find a value for the period of this eclipsing binary. When would you next observe if you wanted to catch the next minimum?

Binary Star Name:	
Time/Date of Minimum:	
Uncertainty:	
Period (days):	
Time/Date of next Observable Minimum:	

Name(s): ______________________________ ______________________________

______________________________ ______________________________

Date: __________________ Course/Section: __________________

Grade: __________________

Properties of Asteroids

Objectives:

The goal of this lab is for students to find and identify asteroids using observations of the ecliptic and learn about some of the properties of asteroids.

Checklist:

- ☐ **Complete the pre-lab quiz with your team (if required).**
- ☐ **Compile a list of resources you expect to use in the lab.**
- ☐ **Work with your team to complete the lab exercises and activities.**
- ☐ **Record your results and mark which resources you used.**
- ☐ **Share and discuss your results with the rest of the class.**
- ☐ **Determine if your team's answers are reasonable.**
- ☐ **Submit an observation request for next week (if required).**

Resources:

Pre-Lab Quiz

Record your group's answers to each question, along with your reasoning. These concepts will be relevant later in this lab exercise.

1.
2.
3.
4.

Part 1: Detecting Asteroids

1. What is the optimal arrangement of Earth, Sun and asteroid that gives the maximum likelihood of detecting an asteroid from Earth? Explain in terms of your experiment with the flashlight and aluminum foil.

2. Determine the R.A. and Dec. coordinates with the highest chance of finding an asteroid, assuming you were to observe using the Rigel telescope at midnight tonight. Explain your reasoning.

Part 2: Identifying Asteroids

1. Record which asteroids you were able find in your images in the table below. Include the distance if available.

Catalog Name	Apparent Magnitude (V)	Distance

2. Record the data for any asteroids you found in your images *after* identifying them using the Minor Planet Checker. Compare these with the ones your team found using only the images. Why were these more difficult to find?

Catalog Name	Apparent Magnitude (V)	Distance

Part 3: Measuring Asteroid Rotation

1. Estimate the asteroid's rotation period from the lightcurve. Estimate the uncertainty in your measurement.

2. Do some research and find the currently accepted value for the asteroid's rotation period. Does it agree with your estimate, within your uncertainty?

3. Determine the period of the asteroid by performing a curve fit to the data using Logger Pro. Does the period found in this way agree better with the accepted value? Why or why not?

Name(s): ______________________________ ______________________________

______________________________ ______________________________

Date: ____________________ Course/Section: ____________________

Grade: ____________________

Impact Craters

Objectives:

The goal of this lab is for students to learn how impact craters are formed, develop a basic understanding of the magnitude of the forces involved, and learn how to measure the impact crater height using basic geometry.

Checklist:

- ☐ **Complete the pre-lab quiz with your team (if required).**
- ☐ **Compile a list of resources you expect to use in the lab.**
- ☐ **Work with your team to complete the lab exercises and activities.**
- ☐ **Record your results and mark which resources you used.**
- ☐ **Share and discuss your results with the rest of the class.**
- ☐ **Determine if your team's answers are reasonable.**
- ☐ **Submit an observation request for next week (if required).**

Resources:

Pre-Lab Quiz

Record your group's answers to each question, along with your reasoning. These concepts will be relevant later in this lab exercise.

1.
2.
3.
4.

Part 1: Impact Physics

1. Classify the different types of impact features that can be simulated with the impact crater demonstration, and how they are produced.

2. How does the impact crater demonstration compare to actual impact features on Earth or the Moon?

Part 2: Recreate the Barringer Crater

1. What were the dimensions of the crater your team produced that came closest to the dimensions of Barringer Crater?

Diameter:	Depth:

2. What were the parameters of the impact event used to create this crater? Explain your team's reasoning behind any assumptions you made.

Impactor Diameter:	Impactor Density:	Impact Angle:	Impact Velocity

3. Simulate the hypothetical Ames, IA impact event described in the lab and find the diameter of the impact crater.

Crater Diameter:

4. What kind of damage would be felt from this event in Iowa City?

Part 3: Estimating the Diameter of a NEO

Use provided images (or your own if you are lucky enough to catch a close encounter with a NEO) to estimate the diameter of the asteroid. Explain how you made your measurements and show your calculations.

Name(s): ______________________________ ______________________________

______________________________ ______________________________

Date: ___________________ Course/Section: ___________________

Grade: ___________________

Research Project Proposal

Objectives:

The group will devise a research project to conduct using images from the Rigel telescope. Group members will construct a plan for observing the object, science questions to answer, and outline methods for obtaining those answers.

Project Title:
Brief one- or two-sentence summary of project:
Object(s) that will be observed (name/type of object):

Important Notes to keep in mind:

Rigel has a maximum field of view (i.e., the largest space Rigel can see) or 25 arcminutes by 25 arcminutes. It has a minimum angular resolution of 3 arcsecs, i.e., the smallest object is can distinguish. It has a maximum exposure time of 120 seconds for one image.

Remember to use the Rigel Rise and Set time calculator and the Exposure calculator on the Rigel website.

Proposal: Science Questions

What are your science questions? Think about why you picked your topic and why it interests you.

Think about how you are going to answer these questions. Write down any equations you will need, resources (e.g., specific software), or any other helpful information to guide your research (e.g., known distance to object)

Observing Plan

1. Do you need multiple nights of observation for your project? If so, how often will you observe your targets?

2. Time when observing target(s) rise/set and transit. If your object transits during the day, record the LST time.

3. What is the angular size of your object and how does that compare to Rigel's Field of View and minimum angular resolution?

4. Does your project need multiple filters? If so, what filters do you need and why?

5. For each filter, determine the exposure time. If your object is very faint, like a galaxy, you many need more than 60 seconds per filter.

Final Project Ideas:

- Determining the Mass of Jupiter
- http://astro.physics.uiowa.edu/ITU/labs/observational-labs/the-mass-of-jupiter---part/

- Determining the MS cut off of a globular cluster
- http://astro.physics.uiowa.edu/ITU/labs/observational-labs/stellar-photometry/
- http://www.cyanogen.com/help/maximdl/Photometry.htm

- Eclipsing Binary Stars
- http://astro.physics.uiowa.edu/ITU/labs/observational-labs/eclipsing-binary-stars/
- http://www.as.up.krakow.pl/ephem/
- http://gtn.sonoma.edu/members/photometry_exercise.php
- http://www.cyanogen.com/help/maximdl/Photometry.htm

- Observing a Comet and determining its speed, directional of the tail
- http://minorplanetcenter.net/
- http://astro.physics.uiowa.edu/ITU/labs/observational-labs/observing-comets/

- Comparing supernova remnants to planetary nebula
- http://astro.physics.uiowa.edu/ITU/labs/foundational-labs/introduction-to-observing/submitting-an-observation.html
- http://astro.physics.uiowa.edu/ITU/labs/foundational-labs/introduction-to-observing/fall-observation-projects.html

- Observing Galaxies and determining size, mass, and redshift
- http://skyserver.sdss.org/dr12/en/tools/explore/summary.aspx

- Examining a light curve of a Supernova.
- http://gtn.sonoma.edu/members/photometry_exercise.php
- http://www.cyanogen.com/help/maximdl/Photometry.htm

http://astronomy.swin.edu.au/cosmos/T/Type+Ia+supernova+light+curves
http://astronomy.swin.edu.au/cosmos/L/Luminosity-Decline+Rate+Relation

- Exoplanets
- See Exoplanet Step by Step
- http://astro.physics.uiowa.edu/ITU/labs/observational-labs/exoplanet-discovery/
- http://gtn.sonoma.edu/members/photometry_exercise.php

- http://www.cyanogen.com/help/maximdl/Photometry.htm