The Great Big Astro Lab Manual

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Cow Canyon Saddle, Mt. Baldy, Los Angeles, CA, USA. Yvonne Ban, 24 Oct 2014.
Model: Emily Schooley

Contents

Preface

0 How to use this manual

Hello friend! Welcome to my masterwork.

0.1 Manual

General information about the setup of the course can be found in Section 2, including grade breakdown and rubrics. The prep, procedure, and script for each lab is found in Section 3.

Labs are organised by content, and the order presented here does not prescribe or suggest a schedule. The exact schedule for each semester is at the discretion of the organising instructor. I've moved the material covering the lab projects into their independent sections for organisation.

0.2 Prep and Script

I have designed it such that most of the script for each class can be essentially read off the slides. More details can be found in the accompanying script.

The pre-lab survey and lab quizzes are also included for reference.

0.3 Worksheets and Handouts

NOTE: THE WORKSHEETS IN THIS MANUAL ARE *NOT* PRINT READY!! To compile print-ready worksheets, reference Section 0.4 and use the worksheet master document `ws.tex`.

The content of the worksheets and handouts can be found in the appendices for reference.

0.4 Using `.tex` files

Each worksheet is in its independent `.tex` file so they can be compiled in the manual (this file, `main.tex`) or for printing in `ws.tex`. Therefore, to edit the content of a worksheet, use the specific `.tex` file for the worksheet.

To use `ws.tex` to compile worksheets **for printing**, simply open the `.tex` file and arrange the code blocks for each respective lab in the scheduled order. To skip labs that are not part of the schedule, just comment the code block out. This should compile a master worksheet document with all of the worksheets in order and properly paginated for printing.

Take note of labs with table worksheets: Labs 3 (Angular Size vs. Distance), 6 (Solar Power), 9 (The HR Diagram), and 10 (Distances of Stars in Space) have table worksheets. **Don't forget the table worksheet code block when formatting!** I've also tagged the code blocks in `ws.tex`.

Lastly, beware of breaking paths if you reorganise files, particularly with moving the images in the directory. I probably should have moved them all into an img directory for neatness, but I didn't, and now we all have to live with it, as is the way with history.

1 Introduction

Astronomy is the study of the heavens. As such, a fundamental limitation of the subject is that we do not, in general, conduct *experiments*, only *observations*, where we snatch jealously at the sparing scraps of information tantalisingly offered by nature. One could argue that astronomy lives at the very cutting edge of our knowledge, where the scientific exercises of hypothesis formulation and testing are most active and challenging.

Such lofty heights of intellectual endeavour are difficult to convey to the next generation of scientists; astronomy draws on physics, chemistry, mathematics, engineering, programming and computer science at an ever increasing rate, and sometimes even biology. Overwhelmingly, astronomy in the academic institution is presented either in lectures or in research projects involving data from observations. The lucky few may even get the opportunity to personally participate in a physical observation run at one of the awe-inspiring cathedrals of science that are the observatories. None of these formats apply to the Astronomy Lab.

Instead, Astronomy Lab is not so much about *experiments* but more about the *models* that we use in astronomy, which play a larger part in the formation of knowledge in astronomy as compared to other subjects. The in-class activities of the course provide an opportunity to teach students about astronomical models in a more engaged and hands-on manner than can be accomplished in a lecture. Using a variety of excellent pedagogical materials, ranging from web apps and planetarium software to experiments and physical models that the students construct themselves, the goal of the course is to use kinesthetic and self-guided exploration to let students learn and internalise the concepts and models of astronomy.

This manual was precipitated by the COVID-19 pandemic, which caused schools to transition to remote learning, sometimes being as remote as the other side of the Earth. Through adapting this course for this mode, and then adapting it back to in-person classes, we drew from the trials and experiences therewith to formalise a robust programme that will minimise the work needed to plan and oversee the conduction of the course.

2 Setup

2.1 Course setup

The Astronomy 100/1 Lab is conducted in tandem with the Astronomy 100 and(/or) 101 courses and is required to be taken simultaneously.

2.1.1 Schedule

Each semester, 6 independent sections are held on Monday, Wednesday, and Friday of every school week at 12:20-1:10pm (1220-1310) and 1:25-2:15pm (1325-1415). Generally, a lead teaching assistant (TA) and assistant TA is assigned for each section. The workload can be split up amongst the assigned TAs so that each section is covered. There may also be assistance from undergrad TAs.

2.1.2 Technical details

Every class is held in the Integrated Learning Center (ILC) room S220. The room consists of:

- 11 round tables at which students sit with power points (and table microphones)
- 3 physically secured Macbooks at each table that can be accessed with one's NetID and have Stellarium installed
- 1 central instructor's (standing) desk ("lectern") with elevated chair
- 1 lectern computer controlling lights and A/V of room
- Lights with 3(?) brightness settings
- 2 wireless microphones, one handheld, one wired clip-on
- 2 HDMI and VGA feeds each, "Lectern Laptop" and "Lectern Aux"
- Digital document projector on left side of instructor's desk, "Document Cam"
- Whiteboards that wrap around the room
- 11 eye-level screens with 2 separate feeds, "A" and "B", one located nearest each table
- 4 screens located above instructor's desk, "Stadium"

2.2 Materials

N.B.: Vis-à-vis worksheets, please reference Section 0.3.

Every student gets an individual lab worksheet for each lab. Activities that involve teamwork at each table may have a table worksheet for each table. Copies of the syllabus and Stellarium guide may also be provided in hard copy. All materials and instructor presentations are copied on the class webpage on Moodle (Moonami, or Moodle in the Cloud).

All individual student submissions, including all end-of-class quizzes, are administered on Moodle. Table teams fill out and submit table worksheets in class.

Demo materials for specific labs are listed for each lab and can be found in the class supply room.

2.3 Grade breakdown

The total Astronomy Lab grade makes up 25% of the overall Astronomy 100/1 course grade, and does not have a separate grade. The remaining 75% of the Astronomy 100/1 course grade comes from lecture assignments and exams. Within Astronomy Lab, the grade assignment is broken down as shown in Table 1.

Table 1: Breakdown of grade assignments for Astronomy 100/1 Lab

Lab	Component	%
1	Background knowledge survey	7
	Quiz	3
	Total	10
2	Quiz	10
	Total	10
3	Survey	2
	Quiz	8
	Total	10
4	Survey	2
	Quiz	8
	Total	10
5	Survey	2
	Quiz	8
	Total	10
6	Survey	2
	Quiz	8
	Total	10
7	Survey	2
	Quiz	8
	Total	10
8	Survey	2
	Quiz	8
	Total	10
Sunset photo project	Photo policy	1
	Calibration photos	2
	1st sunset photo and location	9+1
	2nd sunset photos	8+1
	Total	20+2
Extra credit project	Photos	5
	Report	5
	Total	10

2.3.1 Manual grading rubrics

Sunset(/sunrise) photo project (20+2)

1. 1st photo (10+1)
    a. Auto (3)
        i. Photo policy (1)
        ii. Calibration photos (2)
    b. Manual (7+1)
        i. Photos (7)
            1. 1st sunset photo (5)
                a. Photo exists and correct format (1)
                b. Sun location (3)
                    i. Azimuth discernible (1)
                        - -1 Sun's position along the horizon is unclear
                    ii. Altitude discernible (1)
                        - -1 Sun's position is unclear
                    iii. Altitude within 5 to -1 deg above horizon (1)
                        - -1 Sun is too far above the horizon
                        - -1 Sun is below the horizon
                c. Horizon (1)
                    i. Visible (0.5)
                        - -0.5 Horizon is not visible
                    ii. Features (0.5)
                        - -0.5 Horizon has no features
            2. Location photo (2)
                a. Location discernible (1)
                    - -1 Location unclear
                b. Location repeatable (1)
                    - -1 Location not accurately enough indicated
        ii. Early (on-time) submission (+1)
2. 2nd and 3rd photos (8+1)
    a. Auto (2)
    b. Manual (6+1)
        i. Photos (2+1)
            1. 2nd photo (2)
                a. From exact same spot (0.5)
                    - -0.5 Location changed
                b. Date is ≥ 1 week after 1st sunset (0.5)
                    - -0.5 Too close to 1st photo

c. Sun can be located (0.5)
   - -0.5 Sun cannot be located

d. Horizon visible + Sun close enough to horizon (0.5)
   - -0.5 Horizon cannot be seen or too far from sunset

2. 3rd photo (+1)
   a. Attempt (0.5)
   b. Successful (0.5)

c. Quiz (4)
   i. Short essay (1)
      1. Agrees with annotated picture (0.5)
         - Sunset locations
         - Picture scale
      2. Sensible (0.5)

d. Annotated picture (3)
   i. $\geq$ 3 Locations marked (1)
      - -0.5 Location missing
      - 2 locations missing means 0
   ii. Annotations (1)
   iii. Locations reasonable (1)
      1. Summer (winter) solstice sunset(/-rise) is East (West) of earlier sunsets(/-rises) (0.5)
         - -0.5 Summer (winter) solstice sunset(/-rise) location wrong
      2. To scale (0.5)
         - -0.5 Locations not marked to scale

3. End-of-lab quiz (2)
   a. Auto (2)

Extra credit Moon photo project (10)

1. Auto (1)
   a. Quiz question (1)

2. Manual (9)
   a. Photos (5)
      i. Uploaded pictures in readable format (1)
      ii. Zoomed-out daytime picture of Moon with horizon visible (2)
         1. Horizon can be behind something as long as they make clear what's level to camera and use that to estimate Moon's altitude

    - -2 Picture not taken in daytime
    - -1 Picture taken just after sunset

  iii. Zoomed-in picture of Moon taken with same camera at same time (1)
  iv. Stellarium screenshot makes sense and lists moon parameters (1)
    - N.B.: Auto question also asks for Moon parameters

b. Essay (4)
  i. Clear explanation of Moon's altitude relative to the calibration picture (1)
    - values don't have to be correct, but see if they compare numerically
  ii. Reasonable explanation for how they found size of Moon based on calibration photo (1)
  iii. Reasonable explanation of comparison to golf ball (1)
  iv. Attached photo of golf ball (1)

3 Labs

3.1 Lab 1: Astronomical Angles and Stellarium

3.1.1 Overview

Topics covered:

- Angular measurements
- Using Stellarium
- Azimuths and Altitudes of astronomical objects

Notes:

-

3.1.2 Materials needed

Instructors:

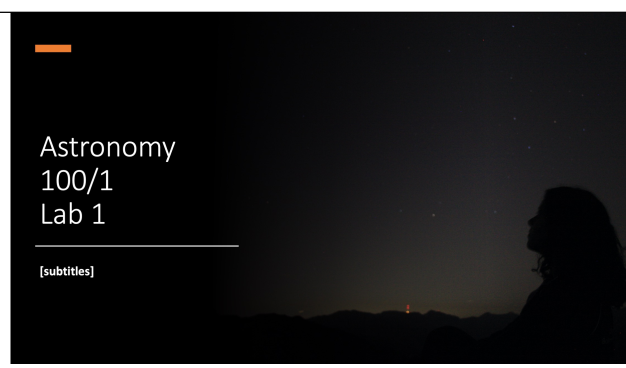
- Lab worksheets: Appendix 1.1
- Syllabus: Appendix 0.1
- Stellarium guide: Appendix 0.2

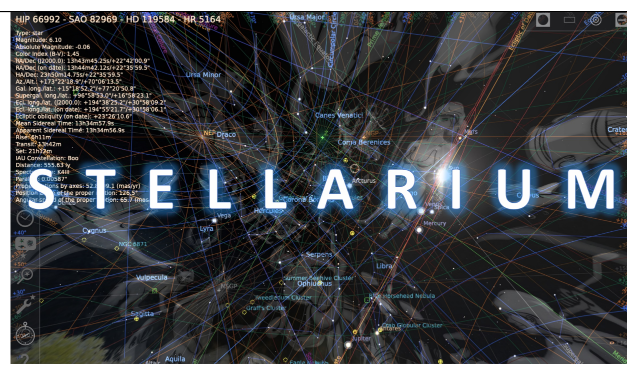
Students:

- Computer

3.1.3 Script

Before the end of class, set the Moodle Lab Quiz access password.

Pick up copies of lab worksheet, syllabus, and Stellarium guide.	

Log in to Moodle, go to the Astronomy 100/101 Lab page, and fill out the Astronomy Background Survey. (The survey is graded on participation only.)	Scheduling 6 sections per week, all recorded, same link • Mon/Wed/Fri, 12.20 and 1.25 pm • Same content Moodle: all the things • Recordings, materials, submissions 6 labs, 2 weeks each 2
Astronomy Lab grade makes up 25% of the Astronomy 100/101 total grade. **Submitting work or pictures that are not your own, or having someone else do it for you, is dishonest and will be dealt with harshly.** Lab usually improves your overall grade, if you put in the small time and effort commitment needed.	Grading 100% of lab grade makes up 25% of ASTRON 100/101 grade Not grading attendance or participation • Interacting with us live is best, recommended • Others probably have same questions 4
If you miss a lab, look out for at-home makeups or scheduled makeup labs, and try to let us know ASAP. Don't procrastinate on the project; it's not difficult, but is impossible if left to the last minute.	Stuff you need Computer • Lab 0 survey on Moodle Camera • Can be phone, just be consistent Access to sky 6
Stellarium is a planetarium software that simulates what the sky looks like at different locations and times.	

Getting started

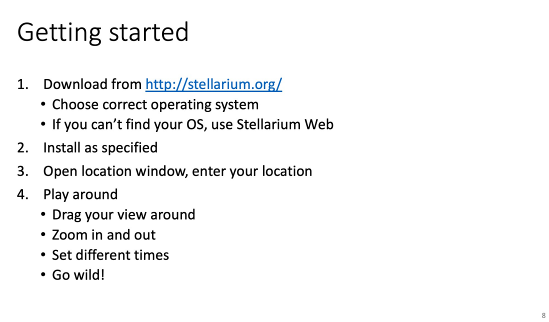
1. If you're using a lab computer, Stellarium is already installed and you can just pull it up. If you're using your own computer, download the correct installer from this website and install it. If your OS isn't available, you can use the web version.

2. Open the Location Window from the left-hand menu panel or by pressing F6. In the search bar under the top right menu, type "Amherst" and select "Amherst Center, United States".

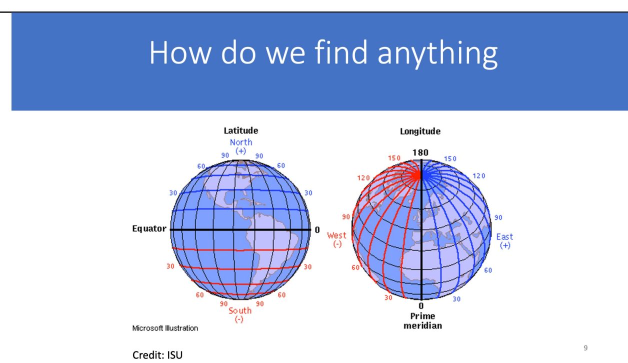
   Take note that it's "Amherst Center", not "Amherst" (that's in NY somewhere). Also, **do not type** into the "Name/City" box. That renames the location.

3. Close the window and open the Date/Time Window from the left-hand menu panel or by pressing F5. Set the time to 7:00 pm tonight to see what will be visible.

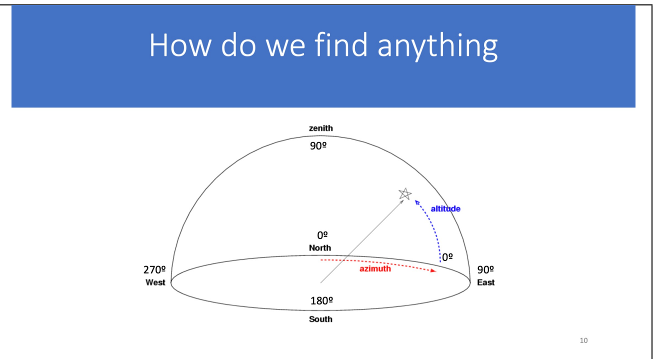
4. Practice dragging the view with the cursor to view different directions. Note that to zoom in, you scroll **up**, and to zoom out, you scroll **down**.



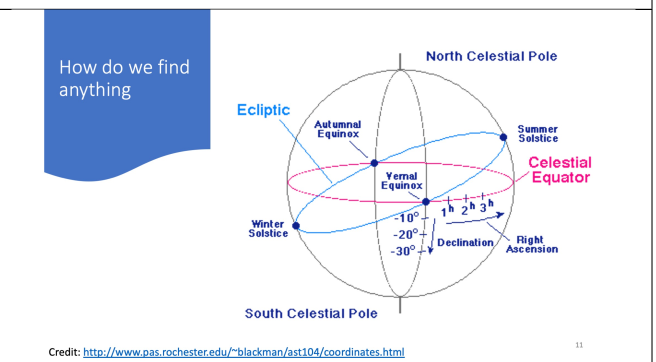
In astronomy, we use angles to measure positions and separations of objects in the sky. Your position is measured by latitude and longitude. (These are angles measured with the vertex at the centre of the Earth. Where is the angle of your position measured relative to?)



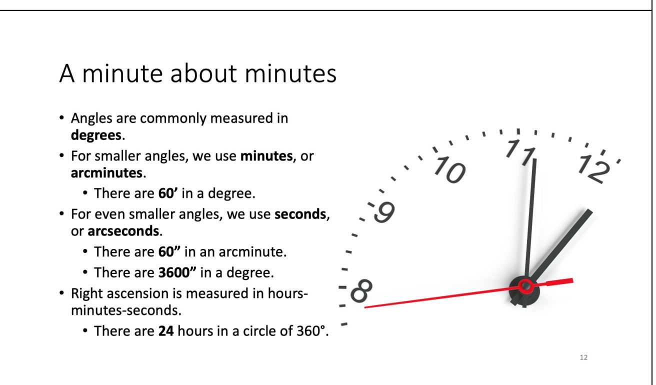
From your point of view, an object's position is given by **azimuth** and **altitude**. Similar to before, we take the vertex of the angle measurement to be your position. For altitude, the angle is measured relative to the horizon. For azimuth, the angle is measured relative to due north.



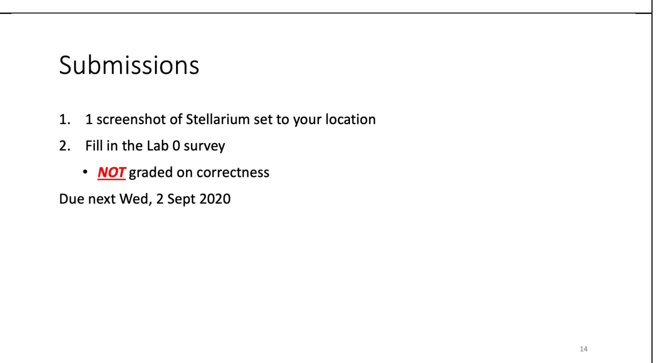
To compare astronomical positions independent of observer location, we use the celestial coordinate system. It's very similar to latitude and longitude, which correspond to declination and right ascension respectively.



Astronomers use the **sexagesimal** system for recording angles. Each degree is divided into 60 **arc minutes** ($'$), and each arc minute is divided into 60 **arc seconds** ($''$).
Right ascension also measures angle, but it is measured like how we measure time, in hours-minutes-seconds. In right ascension, there are 24 hours in a circle of 360 °.



Remember to complete the pre-lab survey.



3.1.4 Submissions

Moodle:

1. Astronomy background survey

In-class:

1. None

3.1.5 Astronomy Background Survey

This survey is given before any instruction is given, and questions 1-11 are surveyed again at the end of the course.

1. As seen from Amherst, MA, when will an upright flagpole cast no shadow because the Sun is directly above the flagpole?
   - Everyday at noon.
   - Only on the first day of summer.
   - Only on the first day of winter.
   - On both the first days of spring and fall.
   - <u>Never.</u>
2. When the Moon appears to completely cover the Sun (an eclipse), the Moon must be at which phase?
   - Full
   - <u>New</u>
   - First quarter
   - Last quarter
   - At no particular phase
3. Imagine that you are building a scale model of the Earth and the Moon. You are going to use a 12-inch basketball to represent the Earth and a 3-inch tennis ball to represent the Moon. To maintain the proper distance scale, about how far from the surface of the basketball should the tennis ball be placed?
   - 4 inches (1/3 foot)
   - 6 inches (1/2 foot)
   - 36 inches (3 feet)
   - <u>30 feet</u>
   - 300 feet
4. Imagine that the Earth's orbit were changed to be a perfect circle about the Sun so that the distance to the Sun never changed. How would this affect the seasons?
   - We would no longer experience a difference between the seasons.
   - We would still experience seasons, but the difference would be much LESS noticeable.

- We would still experience seasons, but the difference would be much MORE noticeable.
- <u>We would continue to experience seasons in the same way we do now.</u>

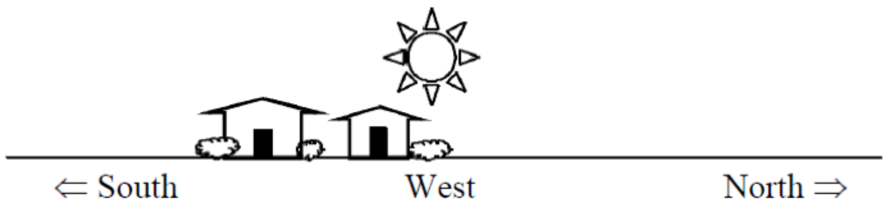


Figure 1:

5. On about September 22, the Sun sets directly to the west, as shown on the diagram below (Fig. 1). Where would the Sun appear to set two weeks later?
   - Farther south
   - In the same place
   - <u>Further north</u>
6. As viewed from our location, the stars of the Big Dipper can be connected with imaginary lines to form the shape of a pot with a curved handle. What is the closest point you would have to travel to in order to observe a substantial change in the shape formed by these stars?
   - Across the country
   - A distant star
   - Europe
   - Moon
   - Pluto
   - <u>A distant star</u>
7. With your arm held straight, your little fingernail is just wide enough to cover up the Sun. If you were on Saturn, which is 10 times farther from the Sun than the Earth is, which of the following objects could you use to just barely cover up on the Sun?
   - Your wrist
   - Your thumb
   - A pencil
   - A strand of spaghetti
   - <u>A hair</u>

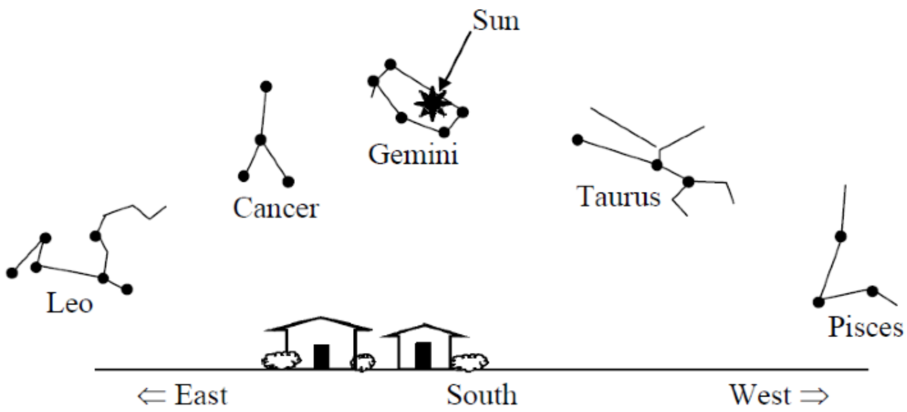


Figure 2:

8. If you could see stars during the day, this is what the sky would look like at noon on a given day (Fig. 2). The Sun is near the stars of the constellation Gemini. Near which constellation would you expect the Sun to be located at sunset?

   - Leo
   - Cancer
   - Gemini
   - Taurus
   - Pisces

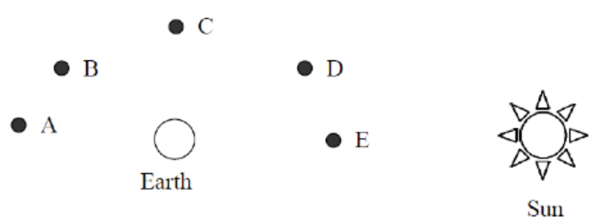


Figure 3:

Figure 4:

9. The diagram below (Fig. 3) shows the Earth and Sun as well as five different possible positions for the Moon. Which positions of the Moon would cause it to appear like the picture of the Moon below (Fig. 4) when viewed from Earth?

- A
- B
- C
- D
- E

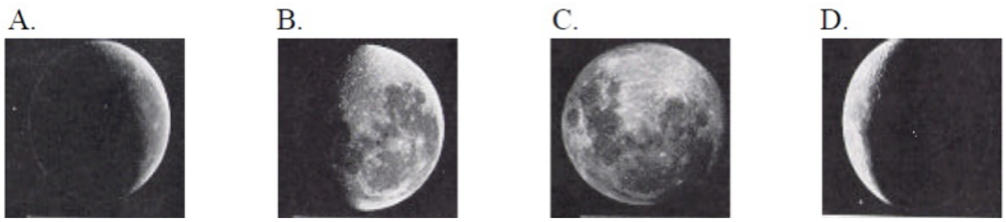


Figure 5:

10. You observe a full Moon rising in the east. How will it appear in six hours? See Fig. 5 for the options.
    - A
    - B
    - C
    - D

11. In general, how confident are you that your answers to this survey are correct?
    - Not at all confident (just guessing)
    - Not very confident
    - Not sure
    - Confident
    - Very confident

12. Which Astronomy Class are you signed up for?
    - Astronomy 100 (10936), TuTh at 10:00am
    - Astronomy 100 (10937), TuTh at 1:00pm
    - Astronomy 101 (23073), TuTh at 2:30pm

13. What time zone do you call home?
    - Eastern
    - Central
    - Mountain

- Pacific
- Other: []

14. What computer operating system do you use for homework?

    - Apple MacOS
    - Microsoft Windows
    - Apple iOS (e.g., iPad)
    - Chromebook
    - Linux
    - Other: []

15. For the purpose of the project this semester, what is the model of the phone or camera that you will be using? (Example: iPhone X, Samsung Galaxy S8, Nikon D3500 camera, etc.)

    *Note: you definitely do **not** need a state-of-the-art camera for these projects – you just need to be able to take basic photos.*

16. Over the course of these labs you will be taking pictures of sunsets (or sunrises) with your camera. To do this you will need to have access to a spot where you can view the western horizon for sunsets (eastern for sunrises). It's fine if these pictures are taken through a window.

    If you believe you need special accommodations for taking these photos or that the project will be impossible for you, please explain your circumstances below, and we will work out alternatives with you. (Otherwise, leave blank.)

3.1.6 Quiz

1. What was the approximate altitude of Jupiter at 6:00pm on January 31, 2022? *(choose closest)*

    - 11°
    - 34°
    - 67°
    - 145°
    - 260°

2. From the northern hemisphere, how do the azimuth and altitude of an object in the southeastern sky change with time?

    - Both decrease.
    - <u>Both increase.</u>
    - The azimuth decreases while the altitude increase.

- The azimuth increases while the altitude decreases.

3. From the northern hemisphere, how do the azimuth and altitude of an object in the southwestern sky change with time?
   - Both increase.
   - Both decrease.
   - The azimuth decreases while the altitude increases.
   - The azimuth increases while the altitude decreases.
4. How do you predict the Sun's azimuth and altitude change as it sets in the western sky?
   - Unlike stars, it goes straight down, so its azimuth is constant.
   - Its altitude and azimuth change much like those of any other setting star.
   - You can't measure altitudes or azimuths for the Sun.

3.2 Lab 2: Angular Sizes on the Sky (equiv. to Project pt. 1)

3.2.1 Overview

Topics covered:

- Estimating angular sizes and separations
- Determining the field of view of your camera
- Angles on the sky

Notes:

-

3.2.2 Materials needed

Instructors:

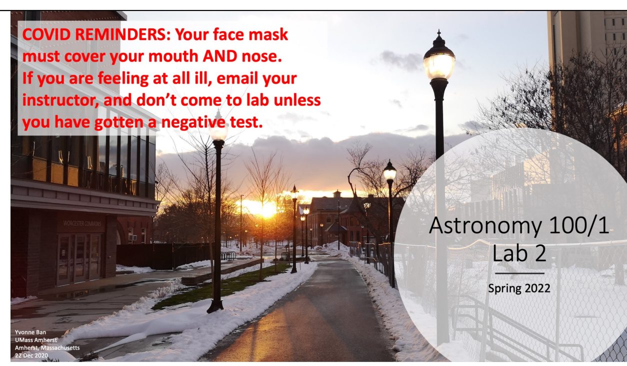
- Lab worksheets: Appendix 2.1
- Calibration grids

Students:

- Fingers and arms
- Camera

3.2.3 Script

Before the end of class, set the Moodle Lab Quiz access password.

<table>
<tr>
<td>Pick up a copy of the lab worksheet.</td>
<td>
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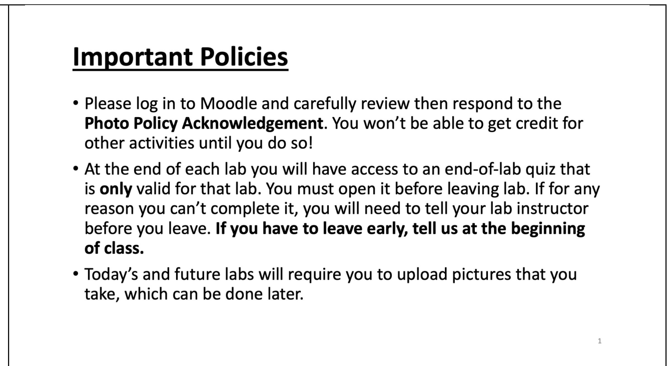
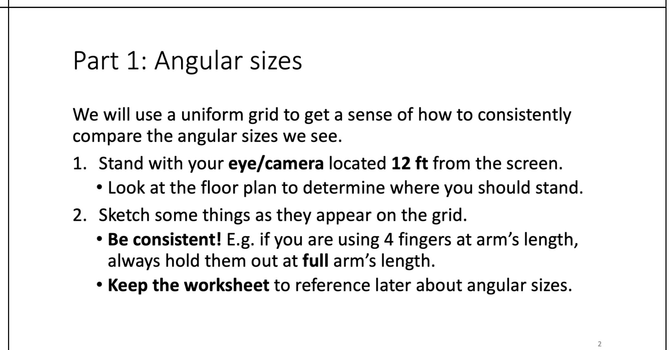
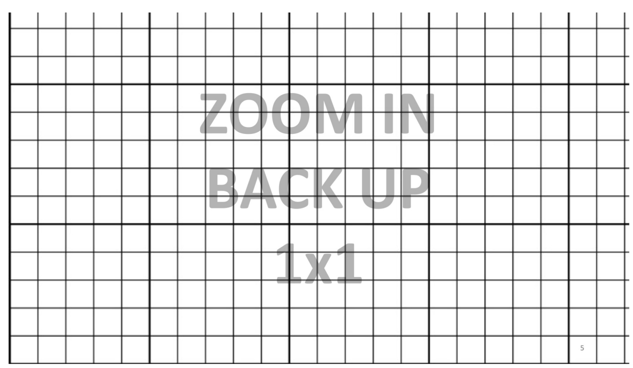
Log in to Moodle and go to the Astronomy 100/101 Lab page. Review and respond to the Photo Policy Acknowledgement. You must respond in order to receive credit for this lab and the project.



We will use a uniform grid to get a sense of how to consistently compare the angular sizes we see.

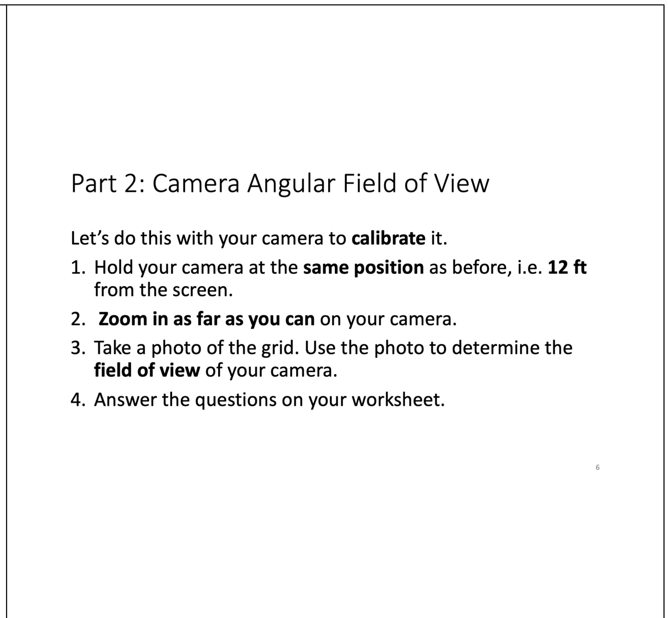
1. Stand with your eye/camera located 12 ft from the screen.
2. Look at the floor plan to determine where you should stand.
3. Sketch some things as they appear on the grid.
4. Be consistent! E.g. if you are using 4 fingers at arm's length, always hold them out at full arm's length.
5. Keep the worksheet to reference later about angular sizes.



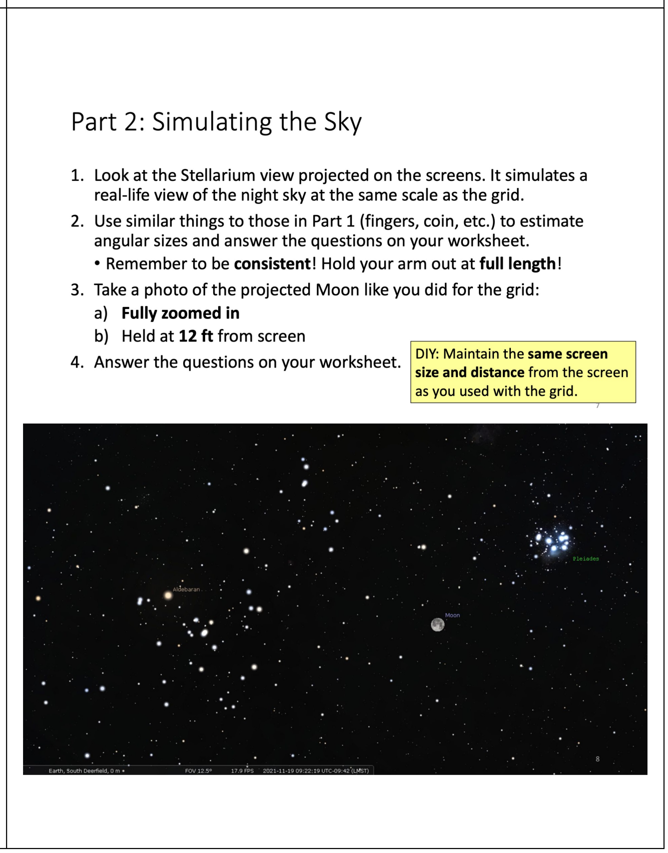


Now we'll do the same with your camera to calibrate it.

1. Hold your camera at the same position as before, i.e. 12 ft from the screen.
2. Zoom in as far as you can on your camera.
3. Take a photo of the grid. Use the photo to determine the field of view of your camera.
4. Answer the questions on your worksheet.

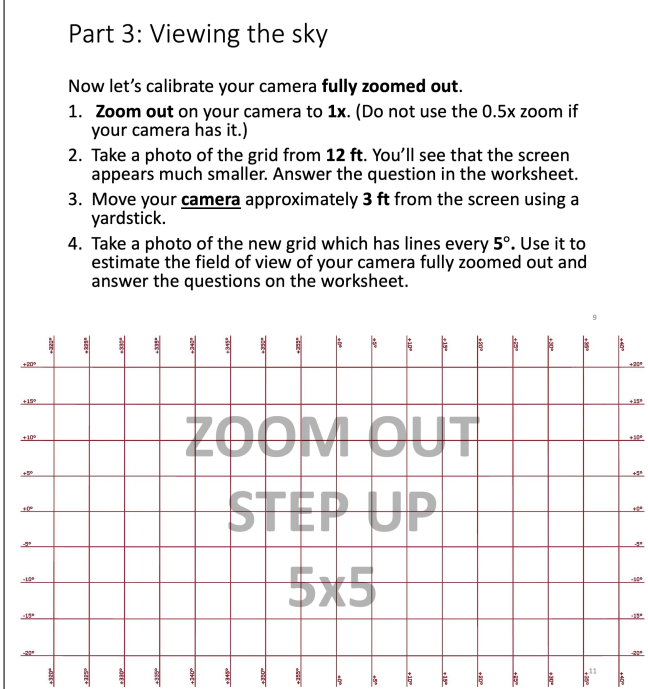


1. Look at the Stellarium view projected on the screens. It simulates a real-life view of the night sky at the same scale as the grid.
2. Use similar things to those in Part 1 (fingers, coin, etc.) to estimate angular sizes and answer the questions on your worksheet. **Remember to be consistent! Hold your arm out at full length!**
3. Take a photo of the projected Moon like you did for the grid:
   - Fully zoomed in
   - Held at 12 ft from screen
4. Answer the questions on your worksheet.



Now let's calibrate your camera fully zoomed out.

1. Zoom out on your camera to 1x. **If your camera has 0.5x zoom or similar, do not use it.**
2. Take a photo of the grid from 12 ft. You'll see that the screen appears much smaller. Answer the question in the worksheet.
3. Move your camera approximately 3 ft from the screen using a yardstick.
4. Take a photo of the new grid, which has lines every 5°. Use it to estimate the field of view of your camera fully zoomed out. Answer the questions on the worksheet.

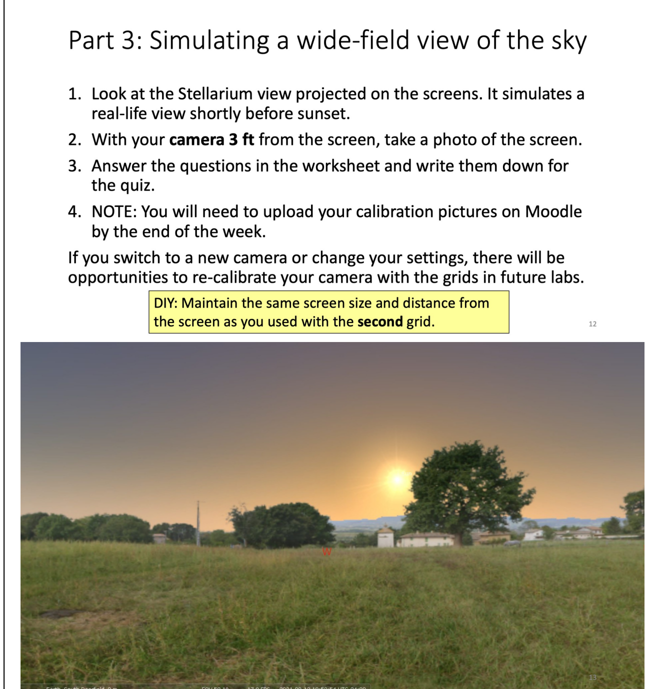


Look at the Stellarium view projected on the screens. It simulates a real-life view shortly before sunset.

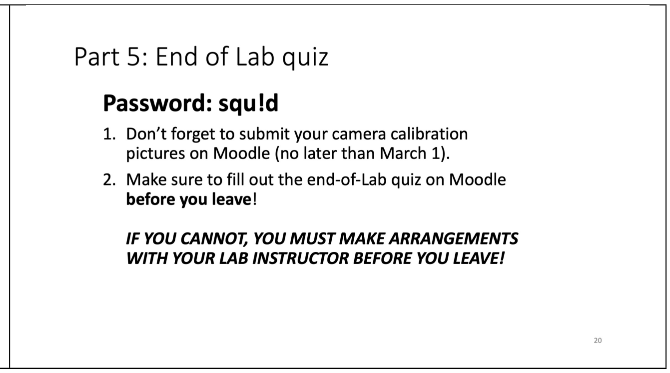
1. With your camera 3 ft from the screen, take a photo of the screen.
2. Answer the questions in the worksheet and write them down for the quiz.

Take note that you will need to upload your calibration pictures on Moodle by the end of the week.

If you switch to a new camera or change your settings, let your TAs know. There will be opportunities to re-calibrate your camera with the grids in future labs.



At ∼10 min from class end, show Moodle quiz password.
Complete the Lab quiz on Moodle.
Remember to complete the pre-lab survey.



3.2.4 Submissions

Moodle:

1. Lab quiz

In-class:

1. None

3.2.5 Quiz

1. What is the approximate angular size of the Moon?
   - 0.2°
   - 0.5°
   - 3°
   - 8°
   - 15°
2. What is the approximate angular separation between Aldebaran and the Pleiades?
   - 0.2°
   - 0.5°
   - 3°
   - 8°
   - 15°
3. Four billion years ago, the Moon was half as far away from Earth as it is now. What was the angular size of the Moon back then?
   - 2× bigger
   - 4× bigger

- 2× smaller
- 4× smaller
- the same

4. Suppose that you have an emergency and have to go home so you can't take your final sunset picture later in the semester. What should you do?
   - Try photoshopping the Sun on another picture you took
   - Ask a friend to take the picture for you
   - Use a friend's photo instead.
   - Take a photo from home.
   - Contact your lab instructor about what you might do instead.

5. From the picture in part 3 of the lab, what were your estimates of the Sun's azimuth and altitude?
   - Azimuth: [x] ° (enter a number only)
   - Altitude: [y] ° (enter a number only)

3.3 Lab 3: Angular Size vs. Distance

3.3.1 Overview

Topics covered:

- Observing angular size of an object at different distances
- Interpreting the inverse relationship
- The Sun's angular size throughout the year

Notes:

-

3.3.2 Materials needed

Instructors:

- Lab worksheets: Appendix 3.1
- Volleyball/"volleyball"
- Tripod/something to hold up volleyball e.g. lab stands $\times 3$
- Blue tape to secure

Students:

-

3.3.3 Script

Before the end of class, set the Moodle Lab Quiz access password.

Pick up a copy of the lab worksheet. Also, get a table worksheet for each table.	

In groups at each table, you will investigate how the angular diameter of a spherical body (a ball) depends on its distance from you. Discuss and agree on a plan for how to make measurements of the sphere to explore the relationship between its angular size and distance. Make sure each person makes **at least one** measurement of the ball's angular size and distance. Consider:

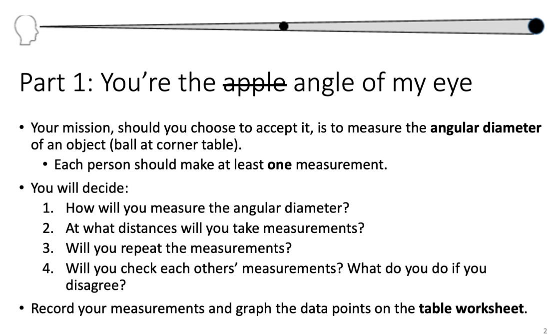
a. What distances will you make measurements from?

b. How will you measure the distances?

c. Will you repeat the measurement with different people? (This is called replication.)

d. What will you do if points disagree?

Record your measurement on both your lab and table worksheets. Then, mark and plot your points on the table worksheet.

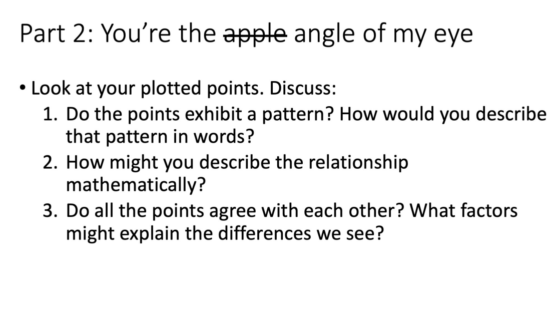


Look over the points plotted by your group and discuss the following:

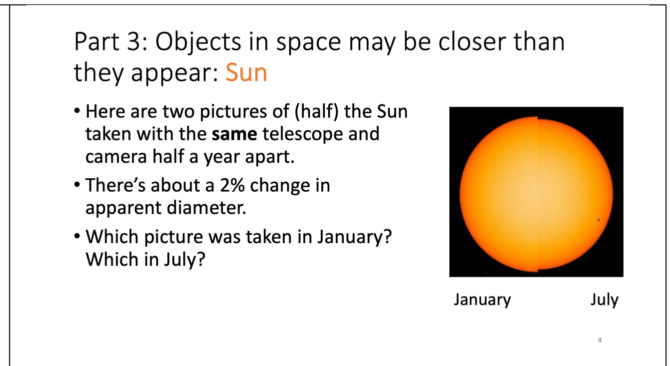
1. Do the points exhibit a pattern? How would you describe that pattern in words?

2. How might you describe the relationship mathematically?

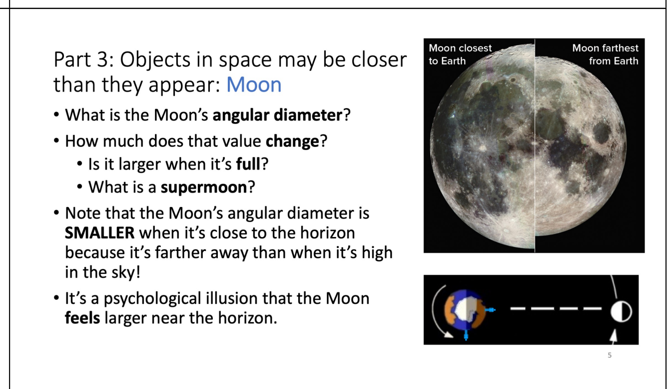
3. Do all the points agree with each other? What factors might explain the differences we see?



Here are two pictures of (half) the Sun taken with the same telescope and camera half a year apart. There's about a 2% change in apparent diameter. Which picture was taken in January? Which in July?

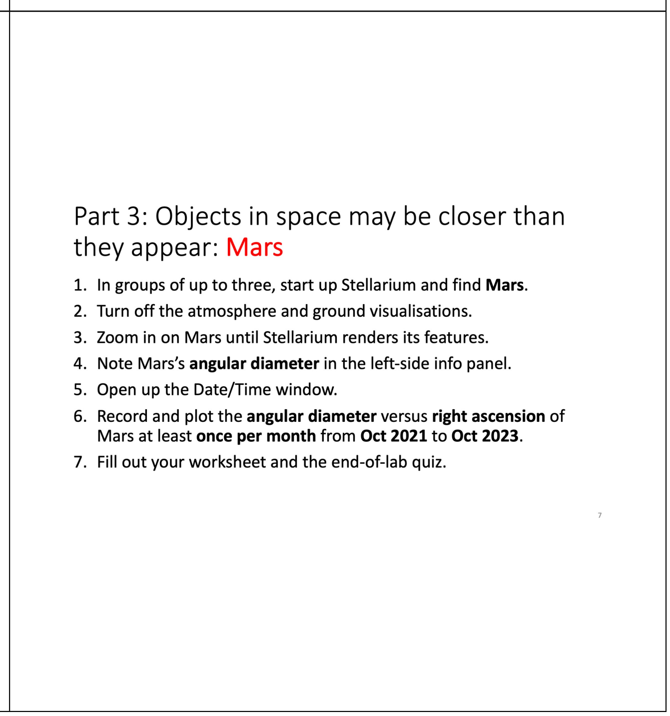


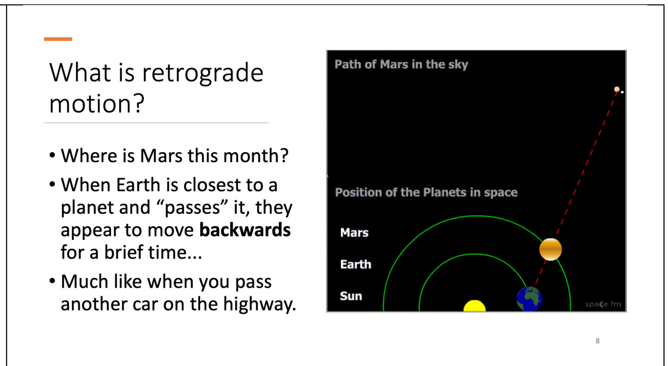
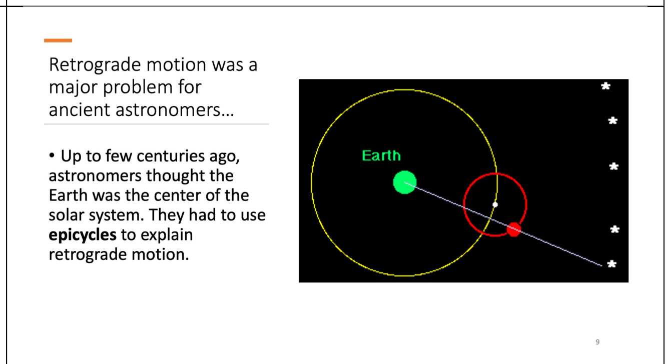
Now let's look at the Moon. What is the Moon's angular diameter? How much does that value change? Is it larger when it's full? What is a supermoon? Note that the Moon's angular diameter is actually SMALLER when it's close to the horizon because it's farther away than when it's high in the sky! It's a psychological illusion that the Moon feels larger near the horizon.



In groups of up to three,

1. Start up Stellarium and find Mars.
2. Turn off the atmosphere and ground visualisations.
3. Zoom in on Mars until Stellarium renders its features.
4. Note Mars's angular diameter in the left-side info panel.
5. Open the Date/Time window.
6. Record and plot the angular diameter versus right ascension of Mars at least once per month from Oct 2021 to Oct 2023.



Where is Mars this month? When Earth is closest to a planet and "passes" it, they appear to move backwards for a brief time, much like when you pass another car on the highway. This is called retrograde motion.	
Up to a few centuries ago, astronomers thought the Earth was the center of the solar system. They had to use epicycles to explain retrograde motion.	
Fill out your worksheet. *At ∼10 min from class end, show Moodle quiz password.* Complete the Lab quiz on Moodle. Remember to complete the pre-lab survey.	

3.3.4 Submissions

Moodle:

1. Lab quiz

In-class:

1. None

3.3.5 Quiz

1. What is your team's table number?
   - 1
   - 2

- 3
- 4
- 5
- 6
- 7
- 8
- 9
- 10
- 11

2. a. When does Mars have the largest angular size?
      - Oct 2021
      - Nov 2021
      - Dec 2021
      - Jan 2022
      - Feb 2022
      - Mar 2022
      - Apr 2022
      - May 2022
      - Jun 2022
      - Jul 2022
      - Aug 2022
      - Sep 2022
      - Oct 2022
      - Nov 2022
      - Dec 2022
      - Jan 2023
      - Feb 2023
      - Mar 2023
      - Apr 2023
      - May 2023
      - Jun 2023
      - Jul 2023
      - Aug 2023
      - Sep 2023
      - Oct 2023

   b. What was its angular size in arcseconds? [$\underline{17 \pm 4}$] $''$ (enter number only)

   c. Was it undergoing retrograde motion at this time? <u>Yes</u>

3. Even though the Sun is physically much bigger than the Moon, they both have angular diameters of about 0.5°. This is because:

    - the Sun is so much brighter that we cant look at it directly.
    - the Moon has a solid surface, but the Sun is a transparent gas.
    - the Sun is as many times farther away as it is larger.
    - our eyes cannot distinguish such small sizes, so they look the same.
    - All of the above.

4. Which of the following is a significant cause of Amhersts summers being warmer than its winters?

    - Earth is closer to the Sun in the summer than in the winter.
    - The northern hemisphere is closer to the Sun in the summer than in the winter.
    - The ground faces the Sun more directly in the summer than in the winter.
    - All of the above.

5. Suppose you see two friends across campus who you know are the same height as each other. Adam is 2° tall and Beth is 6° tall by your estimate.

    Therefore, [Adam] must be [3] times **further away** from you.

6. When does the Moon have the largest angular size?

    - When it is near the horizon.
    - When it is in the part of its orbit closest to Earth.
    - When it is full
    - When Earth is in the part of its orbit farthest from the Sun.
    - All of the above.

3.4 Lab 4: Phases of the Moon

3.4.1 Overview

Topics covered:

- Relative size of Earth and Moon
- Modelling phases
- Relationship of moon phase to position in orbit and in our sky

Notes:

-

3.4.2 Materials needed

Instructors:

- Lab worksheets: Appendix 4.1
- Golf balls (box)
- Lightbulbs on stands ($\times 11$)
- Tape measure
- Golf ball on stand

Students:

- Computer

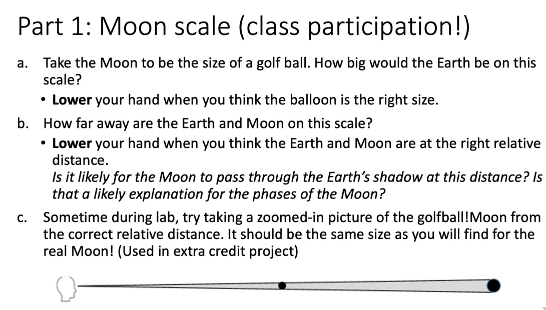
3.4.3 Script

Before the end of class, set the Moodle Lab Quiz access password.

Pick up a copy of the lab worksheet.	

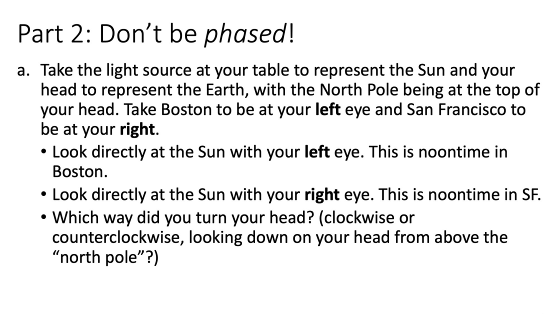
<table>
<tr>
<td>
We'll do this demonstration as a class.

1. Suppose the Moon is the size of a golf ball. On this scale, how big is the Earth? **Lower** your hand when you think the demo balloon is at the right size.
2. Now, how far away are the Earth and Moon on this scale? Lower your hand when you think the Earth and Moon are at the right relative distance.

Relative to the size of the golf ball, this distance is the same as the as the distance from the Earth to the Moon, relative to the size of the real Moon. Hence, **the angular sizes are the same.** If you take a zoomed-in picture of the golfball at this distance and compare it to your zoomed-in calibration grid, you will find the golf ball has the same angular size as the real Moon.
As part of the extra credit project, take a picture of the golf-ball Moon from the to-scale distance.
</td>
<td>


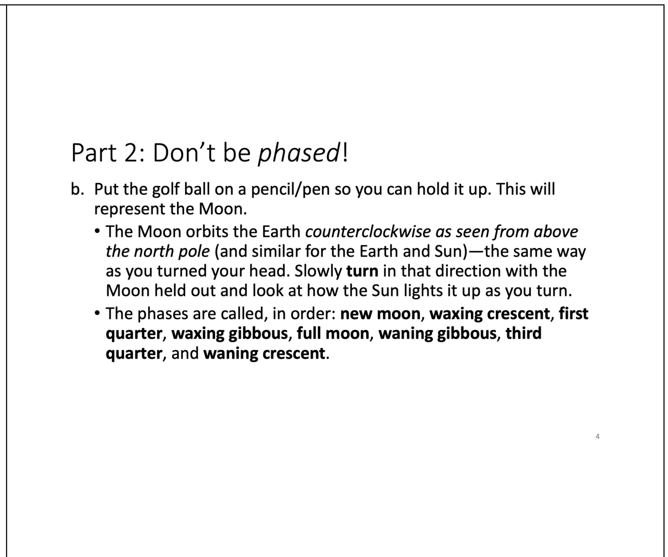
</td>
</tr>
<tr>
<td>
Take the light source at your table to represent the Sun and your head to represent the Earth, with the North Pole being at the top of your head. Take Boston to be at your left eye and San Francisco to be at your right.

1. Look directly at the Sun with your left eye. This is noontime in Boston.
2. Look directly at the Sun with your right eye. This is noontime in SF.

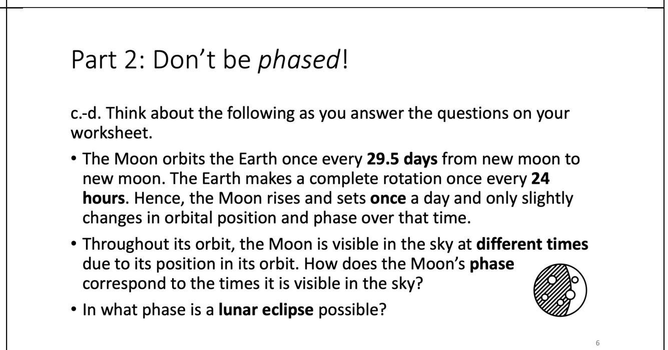
Which way did you turn your head? (Clockwise or counterclockwise, looking down on your head from above the north pole?)
</td>
<td>


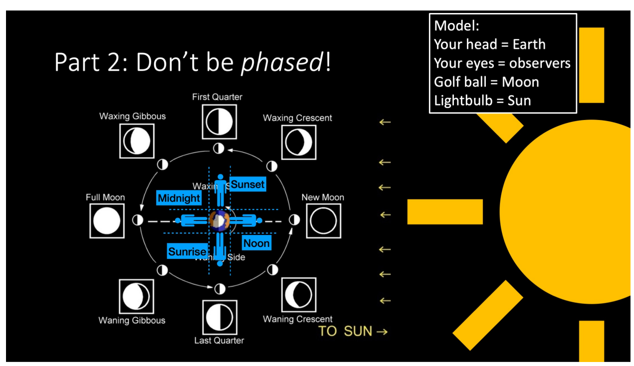
</td>
</tr>
</table>

1. Put the golf ball on a pencil/pen so you can hold it up. This will represent the Moon.
2. The Moon orbits the Earth counterclockwise as seen from above the north pole (and similar for the Earth and Sun)the same way as you turned your head. Slowly turn in that direction with the Moon held out and look at how the Sun lights it up as you turn.



The phases are called, in order: new moon, waxing crescent, first quarter, waxing gibbous, full moon, waning gibbous, third quarter, and waning crescent.
The Moon orbits the Earth once every 29.5 days from new moon to new moon. The Earth makes a complete rotation once every 24 hours. Hence, the Moon rises and sets once a day and only slightly changes in orbital position and phase over that time.
Throughout its orbit, the Moon is visible in the sky at different times due to its position in its orbit.
Accurately visualising this combination of motions is challenging!
Answer the questions on the worksheet.



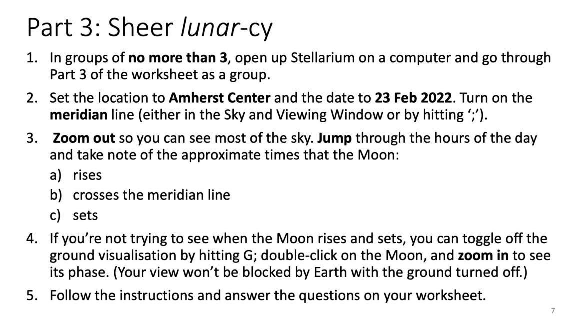


<table>
<tr>
<td>In groups of no more than 3, open up Stellarium on a computer and go through Part 3 of the worksheet as a group.

1. Set the location to Amherst Center and the date to 28 Sept 2021. Turn on the meridian line (either in the Sky and Viewing Window or by hitting ;).

2. Zoom out so you can see most of the sky. Jump through the hours of the day and take note of the approximate times that the Moon:

a. rises
b. crosses the meridian line
c. sets

If you’re not trying to see when the Moon rises and sets, you can toggle off the ground visualisation by hitting G; double-click on the Moon, and zoom in to see its phase. (Your view won’t be blocked by Earth with the ground turned off.)
Follow the instructions and answer the questions on your worksheet.</td>
<td>
</td>
</tr>
<tr>
<td>At ∼10 min from class end, show Moodle quiz password.
Complete the Lab quiz on Moodle.</td>
<td>
</td>
</tr>
</table>

3.4.4 Submissions

Moodle:

1. Lab quiz

In-class:

1. None

3.4.5 Quiz

1. The Moon's shape appears to change over the course of each month because:
   - dark and bright spots come into view as the Moon rotates.
   - parts of it become hidden as it passes into the Earth's shadow.
   - <u>the part of its sunlit side facing us depends on its orbital position.</u>
   - the Moon's light is generated by internal volcanic processes.
2. If we see the Moon is a crescent this evening from Amherst, what phase will it be when observed from Australia?
   - <u>It will also be seen in the evening as a crescent.</u>
   - It will appear to be nearly full.
   - It will be seen as a crescent in the morning sky.
   - The Moon can't be seen from Australia.
3. If you see the Moon rising at about 9pm tonight, what time should you expect to see it rising a week from now?
   - 9pm
   - <u>3am</u>
   - 9am
   - 3pm
   - None of these is correct-the Moon always rises at sunset.
4. When can a lunar eclipse occur?
   - <u>Only when the Moon is full.</u>
   - Only when the Moon is new.
   - When the Moon is at one of the quarter phases.
   - At any phase but only at midnight.
5. In the image below (Fig. 6), showing the Moon just above the eastern horizon, what is the phase of the Moon?
   - new
   - first quarter
   - full

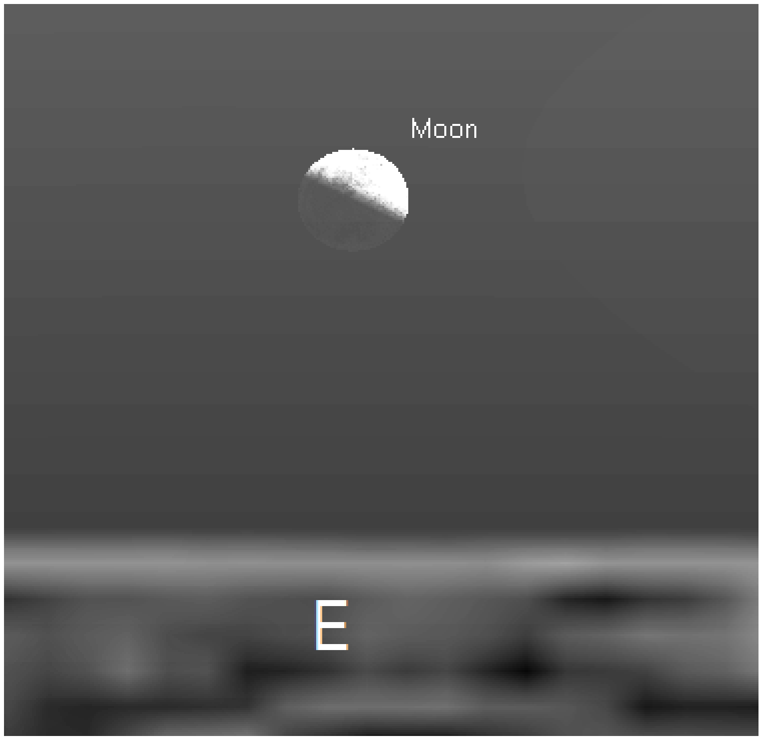


Figure 6:

- third (last) quarter

6. In the same image as the previous question, about what time is it?
    - midnight
    - sunrise
    - noon
    - sunset
7. If it is a third quarter moon tonight, about how long will it be before the Moon is full?
    - A few days
    - About a week
    - About two weeks
    - <u>About 3 weeks</u>
    - About a month
8. When the Moon is gibbous, what phase would the Earth be in as seen from the Moon?
    - new

- crescent
- quarter
- gibbous
- full

3.5 Lab 5: Motions of the Sun

3.5.1 Overview

Topics covered:

- The Sun's altitude at noon throughout the year
- The Sun's path through the sky on different dates
- The Sun's path through the sky at different latitudes

Notes:

-

3.5.2 Materials needed

Instructors:

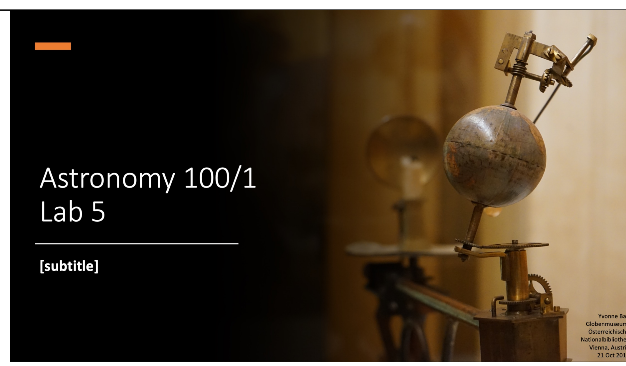
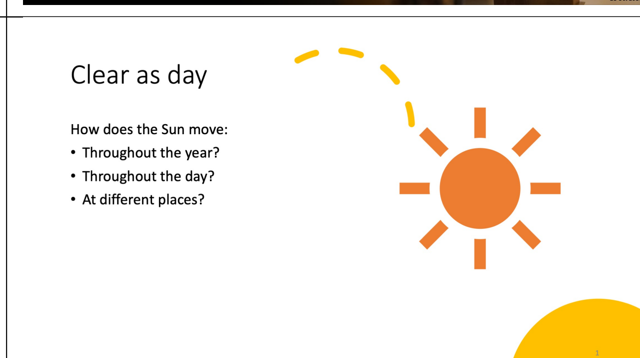
- Lab worksheets: Appendix 5.1

Students:

-

3.5.3 Script

Before the end of class, set the Moodle Lab Quiz access password.

Pick up a copy of the lab worksheet.	
Today we'll be looking at how the Sun moves across the sky throughout the day, throughout the year, and throughout the world.	

Set up Stellarium

i. Open the Location window and set the location to Amherst Center.

ii. Open the Sky and Viewing Options window.

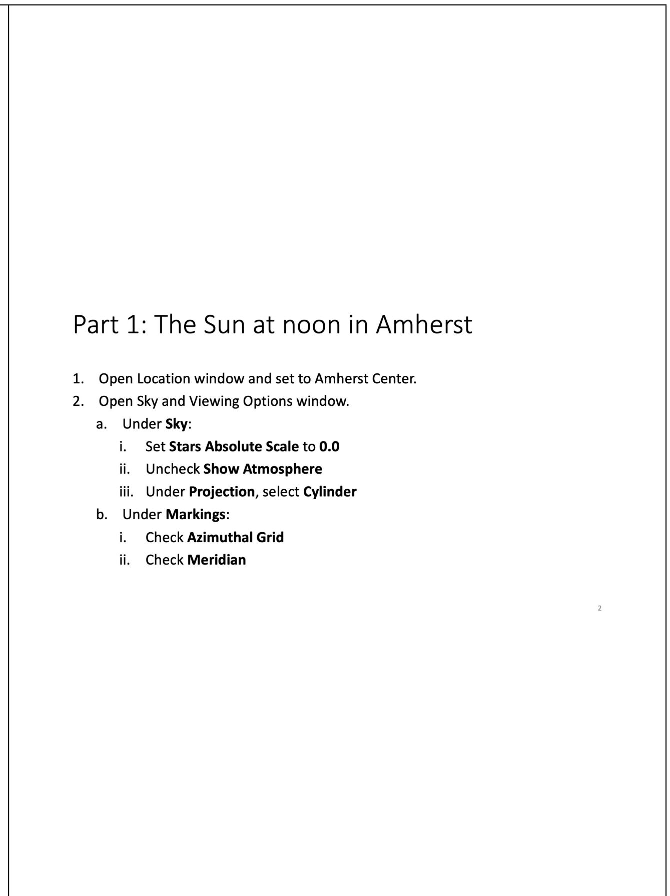
a) Under the “Sky” tab,

1) Set “Stars Absolute Scale” to 0.0 (or the lowest it will go)
2) Uncheck “Show Atmosphere”
3) Under “Projection”, select “Cylinder”

b) Under the “Markings” tab,

1) Check “Azimuthal Grid”
2) Check “Meridian”

For the web version: Turn on meridian line under View Settings and set location by clicking the lower-left grey box.)

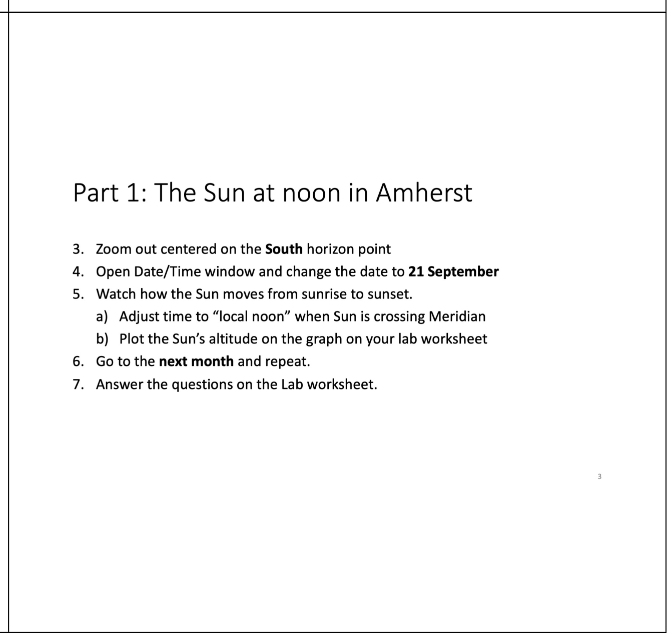


Sun max altitude over the year

1. Zoom all the way out while staying centered on the South horizon point.

2. Open Date/Time window and change the date to 21 September.

3. Find the time (to within a few minutes) when the Sun is crossing the meridian (azimuth 0°00′ or 180°00′, running from due north to due south). What time is it? What might cause it to **not** be 12:00 noon?



<table>
<tr>
<td>
Sunset position over the year

1. Watch how the Sun moves across the sky on:
  i. 21 June (summer solstice)
  ii. 21 Dec (winter solstice)
2. Look at:
  i. where in azimuth the Sun sets on each day
  ii. the angle at which the Sun approaches the horizon at sunset

Answer the questions on the Lab worksheet.
</td>
<td>
Part 2: The Sun’s path across the sky

1. Watch how the Sun moves across the sky on
  a) 21 June (summer solstice)
  b) 21 Dec (winter solstice)
2. Look at
  a) where in **azimuth** the Sun sets on each day.
  b) the **angle** at which the Sun approaches the horizon at sunset.
3. Answer the questions on the Lab worksheet.

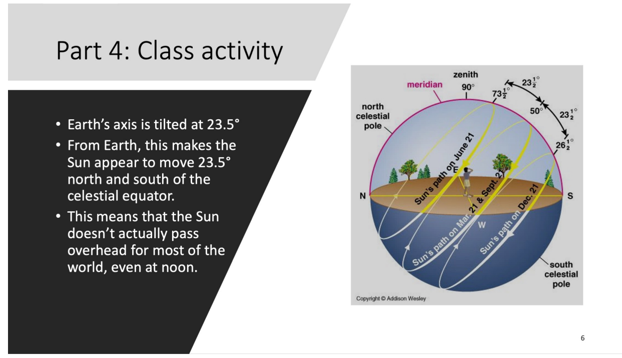
4
</td>
</tr>
<tr>
<td>
Sun max altitude over months from around the world
Work in pairs and have one person do each part.

1. Open Location window and set it to:
  i. a city in the tropics at a latitude between N 23° to S 23°
  ii. a city in the Southern Hemisphere at a latitude between S 24° to 66°
2. Find the maximum altitude the Sun reaches at each location throughout the year, and the month this occurs.

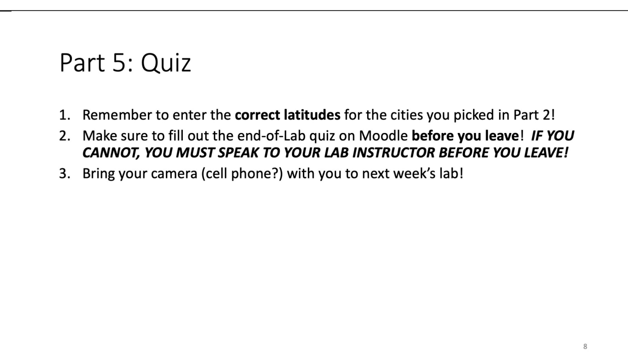
Answer the questions on the Lab worksheet.
</td>
<td>
Part : The Sun at noon at ???

1. Open Location window and set to
  a) a city in the **Southern Hemisphere** at a latitude between **S 24° to 66°**
  b) a city in the **tropics** at a latitude between **N 23° to S 23°**
2. Find the **maximum altitude** the Sun reaches at each location throughout the year, and the **month** this occurs.
3. Answer the questions on the Lab worksheet.

5
</td>
</tr>
</table>

<table>
<tr>
<td>Plot the Sun's noontime altitude throughout the year for both parts in the grid. Make sure to record the values for the quiz.
Remember that Earth's axis is tilted by 23.5°. From Earth, this makes the Sun appear to move 23.5° north and south of the celestial equator.
This means that the Sun doesn't actually pass overhead for most of the world, whether at noon or any other time!</td>
<td>
</td>
</tr>
<tr>
<td>You can explore for yourself how this affects the climate at different locations.

1. Open the Location window and type into the "Latitude" entry "N 66d 30m" (note where the spaces are). You should see the red arrow on the map jump to a location north of Amherst Center. (Leave the longitude unchanged from Amherst Center (W 72°) so the time zone stays the same.)
2. Look at how the Sun moves across the sky throughout the day and throughout the year.
3. Repeat for a position on the equator.

Answer the questions on the Lab worksheet.</td>
<td>
</td>
</tr>
<tr>
<td>At ~10 min from class end, show Moodle quiz password.
Complete the Lab quiz on Moodle.</td>
<td>
</td>
</tr>
</table>

3.5.4 Submissions

Moodle:

1. Lab quiz

In-class:

1. None

3.5.5 Quiz

1. What is your table number?
   - 1
   - 2
   - 3
   - 4
   - 5
   - 6
   - 7
   - 8
   - 9
   - 10
   - 11
2. a. What is the latitude of your city in Section 2.b) of the worksheet? [x] ° South (enter number only)

   b. At this location, what is the maximum altitude the Sun reaches during the year? [y] ° (enter number only)

   c. At this location, what month does the Sun reach its maximum altitude at noon?
      - January
      - February
      - March
      - April
      - May
      - June
      - July
      - August
      - September
      - October

  - November
  - <u>December</u>

3. Where can you see the Sun pass straight overhead at noon? (see screen for options)
   - Everywhere on Earth.
   - Everywhere between the arctic circles sometime during the year.
   - <u>Everywhere within the topic latitudes sometime during the year.</u>
   - Only on the equator.
   - Nowhere on Earth.

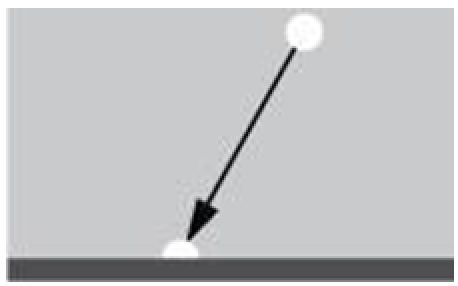


Figure 7:

4. If you were marooned on an island, and you saw a sunset angle as pictured below (Fig. 7), what latitude would you likely be at?
   - N 60
   - N 30
   - 0
   - S 30
   - S 60

5. On what day does the Sun appear highest in the sky at noon in Amherst?
   - Vernal Equinox
   - <u>Summer Solstice</u>
   - Autumnal Equinox
   - Winter Solstice

6. What month does the Sun appear highest in the sky at noon in Sydney, Australia (S 34°)? (see screen for options)
   - March
   - June
   - September
   - <u>December</u>

3.6 Lab 6: Solar Power

3.6.1 Overview

Topics covered:

- Experiments using flashlights to model the effect of distance on brightness of sunlight
- The effect of angle
- Solar heating and seasons

Notes:

-

3.6.2 Materials needed

Instructors:

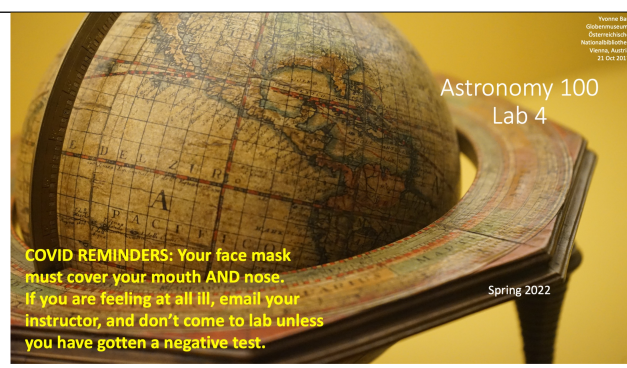
- Lab worksheets: Appendix 6.1
- Table worksheets ($\times 11$): Appendix 6.2
- Metre rules ($\times 11$)
- Protractors ($\times 11$)
- Flashlights ($\times 11$)

Students:

-

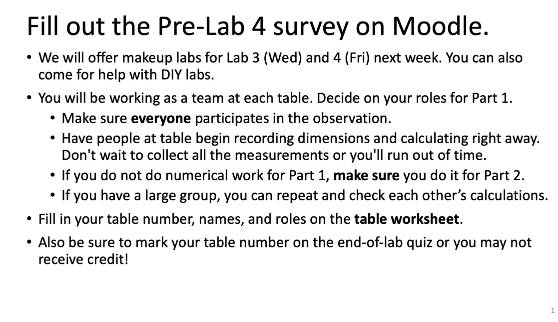
3.6.3 Script

Before the end of class, set the Moodle Lab Quiz access password.

<table>
<tr>
<td>Put a flashlight, yardstick, protractor, and table worksheet at each table.
Pick up copies of lab worksheet and make sure your table has a table worksheet.</td>
<td>
</td>
</tr>
</table>

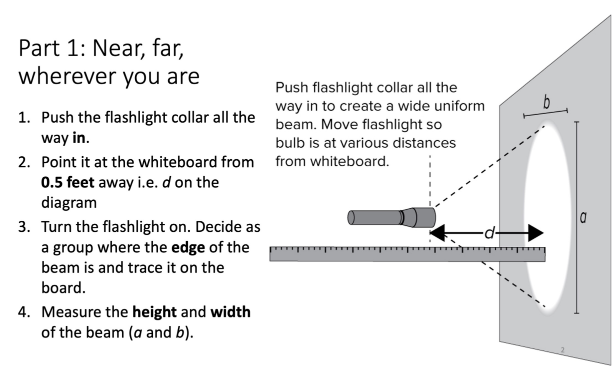
You will be working as a team at each table. Make sure to fill your table number on the table worksheet and on the lab quiz later. Your table number is the number on the whiteboard behind your table.
Decide on your roles for Part 1 and write your names and roles down on the worksheet as well.

- Make sure everyone participates in observation **and** does calculation at some point in experiment 1 or 2. If you have a large group, you can repeat and check each others calculations.
- Have people at the table begin recording dimensions and doing calculations right away. Don't wait to collect all the measurements or you'll run out of time.



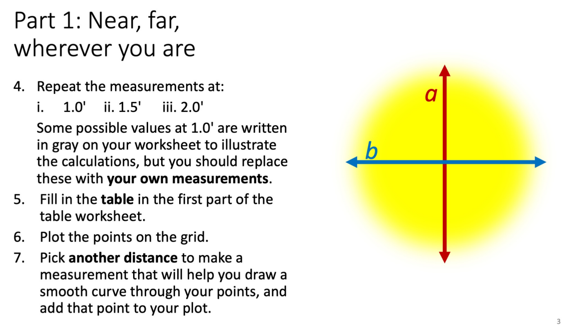
Experiment 1: Light at distance

1. Push the sleeve on the front part of the flashlight all the way **in**.
2. Shine it at the whiteboard straight on from 0.5 ft away.
3. Decide as a group where the edge of the beam is and trace it on the whiteboard.
4. Measure the height a and width b of the beam.



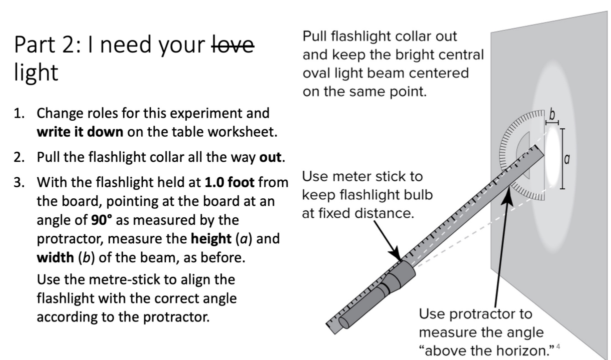
Experiment 1: Light at distance (cont.)

1. Repeat the measurements at 1 ft, 1.5 ft, and 2.0 ft. Make sure to make your **own** measurements for the suggested values on the worksheet.
2. Fill in the table on the first part of the table worksheet with your measurements and calculations.
3. Plot the points on the grid.
4. Pick one more distance value at which to make measurements to improve your plot.



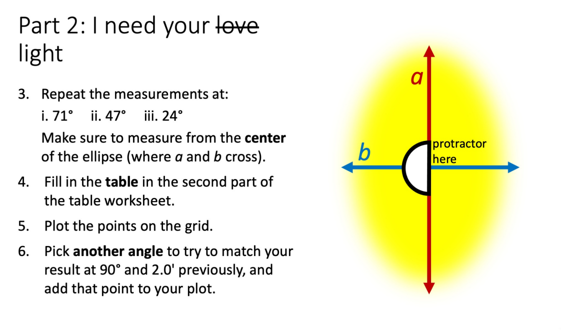
Experiment 2: Light at angle

1. Change roles for this experiment and write down your new roles on the table worksheet.
2. Pull the sleeve on the front part of the flashlight all the way **out**.
3. Shine it at the whiteboard at an angle of 90° (straight on) from 1.0 ft away. Use the yardstick to align the flashlight at the correct angle according to the protractor.
4. Measure the height a and width b of the beam, as before.



Experiment 2: Light at angle (cont.)

1. Repeat the measurements at 71°, 47°, and 24°. Make sure to measure from the **center** of the ellipse.
2. Fill in the table on the second part of the table worksheet with your measurements and calculations.
3. Plot the points on the grid.
4. Pick one more angle where the light intensity would match the value you obtained in Experiment 1 at 2.0 ft, and add your measurements to your plot.



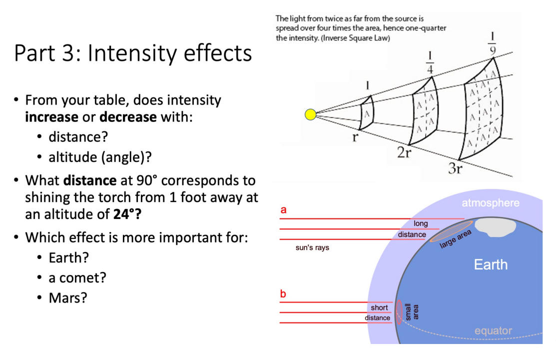
Find a good plot to project for discussion.
From your table, does intensity increase or decrease with:

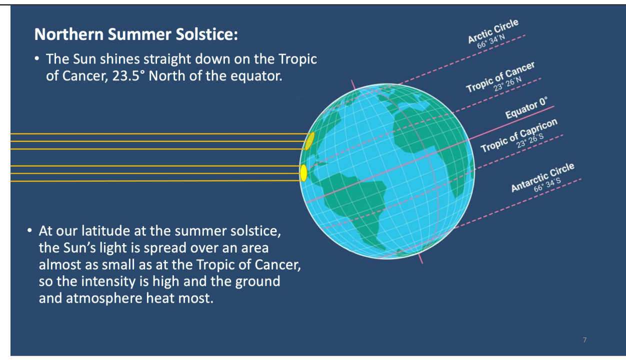
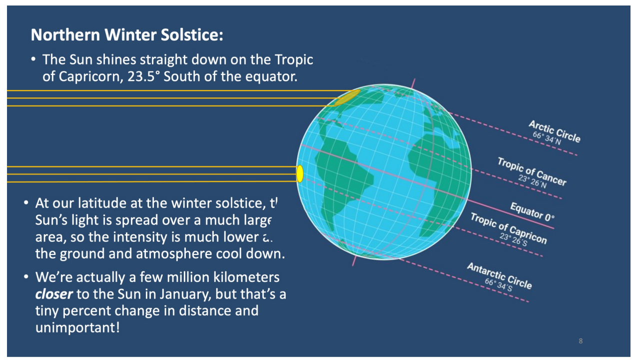
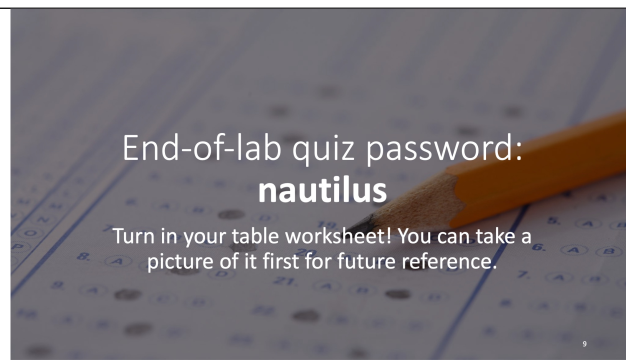
1. distance?
2. altitude (angle)?

What distance, at 90°, corresponds to shining the flashlight from 1 ft away at an altitude of 24°?
Which effect is more important for:

1. Earth?
2. a comet?
3. Mars?

Compare the shapes of their orbits and their axial tilts.



<table>
<tr>
<td>Solstices: Summer
The Sun shines straight down on the Tropic of Cancer, 23.5° North of the equator.
At our latitude at the summer solstice, the Suns light is spread over an area almost as small as at the Tropic of Cancer, so the intensity is high and the ground and atmosphere heat most.</td>
<td>
</td>
</tr>
<tr>
<td>Solstices: Winter
The Sun shines straight down on the Tropic of Capricorn, 23.5° South of the equator.
At our latitude at the winter solstice, the Suns light is spread over a much larger area, so the intensity is much lower and the ground and atmosphere cool down.
We're actually a few million kilometres closer to the Sun in January, but thats a proportionately tiny change in distance and not as important!</td>
<td>
</td>
</tr>
<tr>
<td>At ∼10 min from class end, show Moodle quiz password.
Complete the Lab quiz on Moodle.
Make sure your names are on your table worksheet and hand it in.</td>
<td>
</td>
</tr>
</table>

3.6.4 Submissions

Moodle:

1. Lab quiz

In-class:

1. Table worksheets

3.6.5 Quiz

1. What is your team's table number?

- 1
- 2
- 3
- 4
- 5
- 6
- 7
- 8
- 9
- 10
- 11

2. In what month is Earth closest to the Sun?

    - <u>Jan</u>
    - Feb
    - Mar
    - Apr
    - May
    - Jun
    - Jul
    - Aug
    - Sep
    - Oct
    - Nov
    - Dec

3. When you double the distance from a light source, the intensity of the light:

    - <u>gets 4 times smaller</u>
    - gets 2 times smaller
    - stays the same
    - gets 2 times bigger
    - gets 4 times bigger

4. Rate each of the following for its importance in explaining why we have cold temperatures in winter here in Amherst. There are three choices for each: important, unimportant/minor and has almost no effect, or works counter to the resulting temperature differences.

a. Earth's Northern Hemisphere is farther from the Sun than the Southern Hemisphere. unimportant

b. Earth's orbit is elliptical and we get further away from the Sun in part of our orbit. counter

c. The angle of Earth's axis results in the Sun having a low altitude and its light spread out. important

5. In part 3, what distance did your group estimate had the same intensity as light shining from an angle of 24? [1.5] ft (enter number only)

6. List the values (last column in tables) your group measured at:

- 2.0 ft and 90°: [x] (enter number only)
- 1.0 ft and 47°: [y] (enter number only)

3.7 Lab 7: Calendars, Horoscopes, and Precession

3.7.1 Overview

Topics covered:

- Movement of the Sun and Moon through the zodiac
- What's your sign?
- Precession and the pole star
- The motion of Mars
- How retrograde motion varies among the planets

Notes:

-

3.7.2 Materials needed

Instructors:

- Lab worksheets: Appendix 7.1

Students:

-

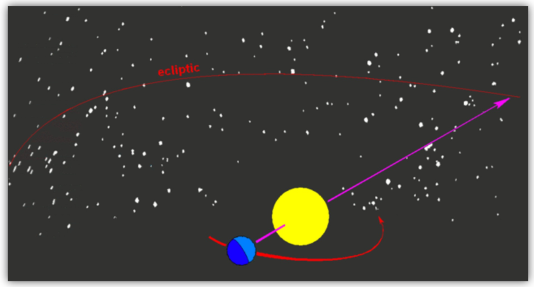
3.7.3 Script

Before the end of class, set the Moodle Lab Quiz access password.

Pick up a copy of the lab worksheet.	

As the Earth orbits the Sun, the background stars change throughout the year. The Sun traces a path in our sky called the ecliptic, and the constellations on the ecliptic make up the zodiac.

What is the Zodiac?



As the Earth orbits the Sun, the background stars change throughout the year.

Setup

1. Open Stellarium and set it to your home location. You can also stop time (the pause button in the bottom panel) and set the time to noon.
2. Make the constellations visible.
   (a) Turn off the Atmosphere visualisation.
   (b) Open the Sky and Viewing options window.
   (c) Go to the Starlore tab.
   (d) Under Options, check Show labels and Show boundaries.

The Sun, the Moon, & the Zodiac

1. Open Stellarium and set it to your **home location**.
   a. You can also **stop time** (the pause button in the bottom panel) and set the time to **noon**.
2. Make the **constellations** visible.
   a. Turn **off** the **Atmosphere visualisation**.
   b. Open the **Sky and Viewing options** window.
   c. Go to the **Starlore** tab.
   d. Under **Options**, check **Show labels** and **Show boundaries**.

Epic ecliptic

1. Find out what constellation the Sun and Moon are in today.
2. Click on the Sun and press space.
3. Move forward in time by day.
4. Find out the constellations that the Sun moves through over a year.

The Sun, the Moon, & the Zodiac

3. Find out what constellation the
   a) Sun
   b) Moon
   are in **today**.
4. Click on the **Sun** and hit the **spacebar**. This will centre and lock on the Sun.
5. Move forward in time by jumping by **day**.
6. Find out the **constellations** that the Sun moves through over a **year**.

Horoscope more like huh-roscope

1. Shift Stellarium to your birth date. What constellation was the Sun in? Save a screenshot of the Sun's location.
2. What is your sign based on the table shown?
3. Based on Stellarium, when is the Sun actually in your horoscope sign?
4. Set Stellarium to a date in the middle of your horoscope sign.
5. Jump back in time in 500-year blocks until the Sun is actually in the middle of your horoscope sign. How far did you have to go?

What's your sign? (a.k.a. the only astrology we're doing in this class)

1. Shift Stellarium to **your birth date**.
   a) What **constellation** was the Sun in?
   b) Save a **screenshot** of the Sun's **location**.
2. Look at the table. What is your sign?

Aries	Mar 21 – Apr 19	Libra	Sep 23 – Oct 22
Taurus	Apr 20 – May 20	Scorpio	Oct 23 – Nov 21
Gemini	May 21 – Jun 20	Sagittarius	Nov 22 – Dec 21
Cancer	Jun 21 – Jul 22	Capricorn	Dec 22 – Jan 19
Leo	Jul 23 – Aug 22	Aquarius	Jan 20 – Feb 18
Virgo	Aug 23 – Sep 22	Pisces	Feb 19 – Mar 20

3. From Stellarium, **when** is the Sun **actually** in your horoscope sign?

What's your sign? (a.k.a. the only astrology we're doing in this class)

4. How far has the zodiac drifted?
   a. Set Stellarium to a date in the **middle** of your horoscope sign.
   b. Jump back in time in **500-year** blocks until the Sun is **actually** in the **middle** of your horoscope sign. How far did you have to go?

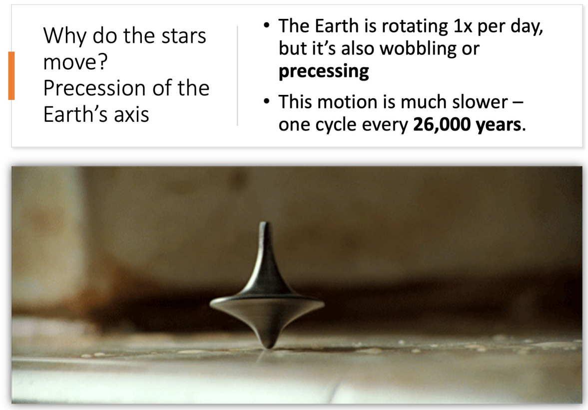
You're (not) my North Star

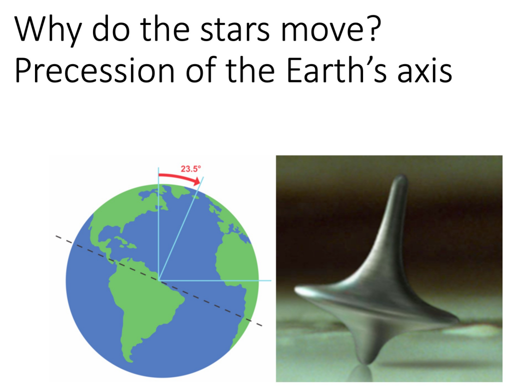
1. Jump back to today and turn on the equatorial (NOT azimuthal!) grid.
2. Look at the North celestial pole. Which star is nearest to it? Which star was nearest to it when horoscopes were aligned with the zodiacal constellations?
3. Find the star Vega. Jump back in time in 1000-year blocks. When was Vega the North star?
4. Jump forward in time in 1000-year blocks. When will Vega be the North star again?

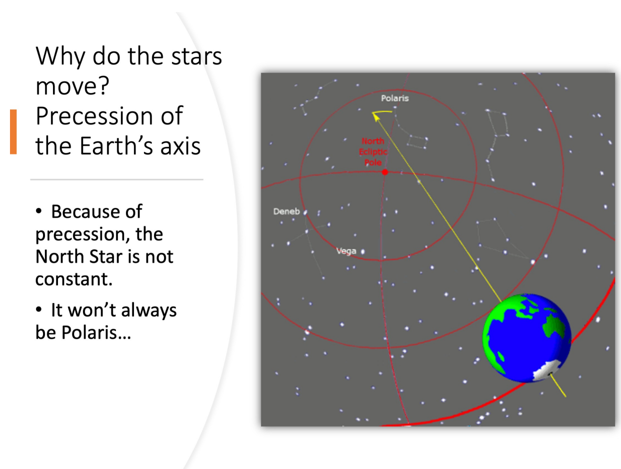
What's your sign? (a.k.a. the only astrology we're doing in this class)

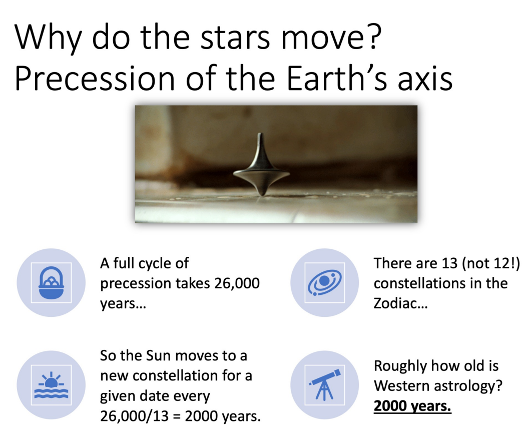
5. The stars *do* move!
   a. Jump back to **today** and turn on the **equatorial** (NOT azimuthal!) grid.
   b. Look at the **North celestial pole**.
      i. Which star is **nearest** to it?
      ii. Which star was nearest to it when horoscopes were **aligned** with the zodiacal constellations?
   c. Find **Vega** in the sky.
      i. Jump **back** in time in **1000-year** blocks. When was Vega the North star?
      ii. Jump **forward** in time in **1000-year** blocks. When will Vega be the North star?

Astrology is so last millennium
The Earth rotates 1× per day, but it's also wobbling, or precessing. This motion is much slower: one cycle every 26,000 years. Because of precession, the North Star is not constant; it won't always be Polaris.
A full cycle of precession takes 26,000 years, and there are 13 (not 12!) constellations in the Zodiac. So, the Sun moves to a new constellation for a given date every 26,000/13 = 2000 years. Roughly how old is Western astrology? 2000 years!





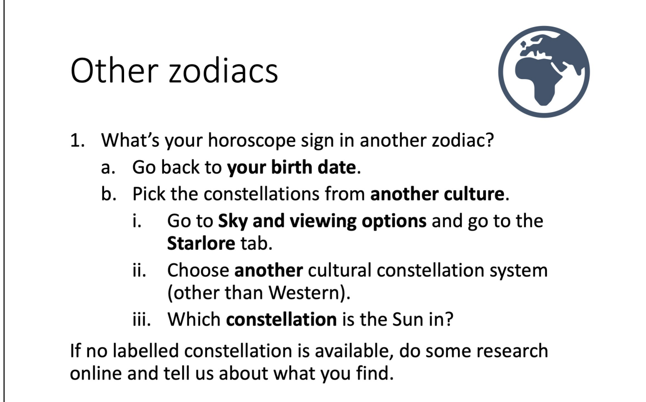




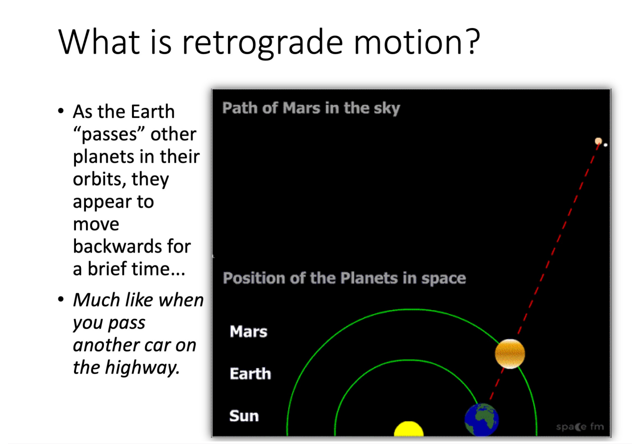
A zoo of zodiacs

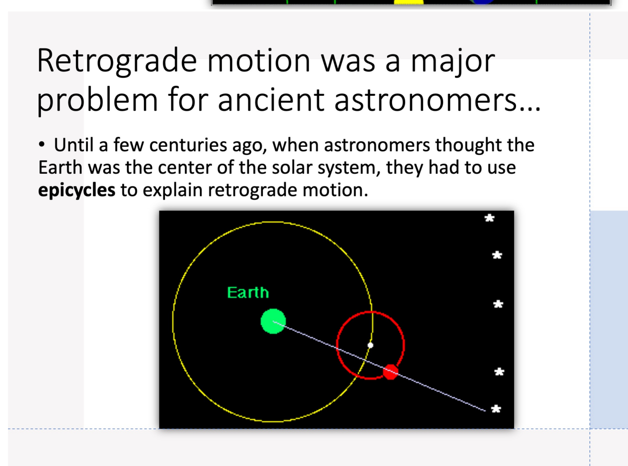
1. Go back to your birth date.
2. Pick constellations from another culture.
   (a) Go to Sky and viewing options and go to the Starlore tab.
   (b) Choose another cultural constellation system (other than Western). Which constellation is the Sun in?

If no labelled constellation is available, do some research online and tell us about what you find.



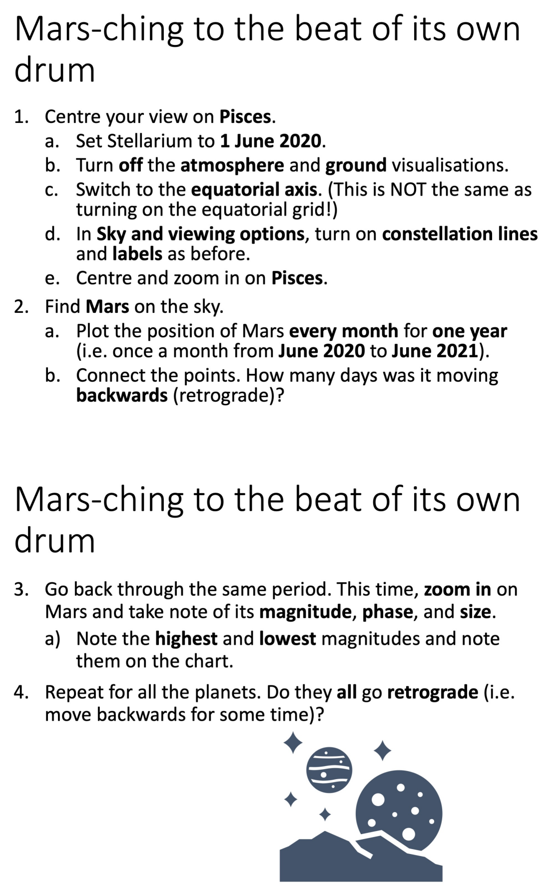
Retrograde is all backwards
As the Earth "passes" other planets in their orbits, they appear to move backwards for a brief time, much like when you pass another car on the highway.
Until a few centuries ago, when astronomers thought the Earth was the center of the solar system, they had to use epicycles to explain retrograde motion.



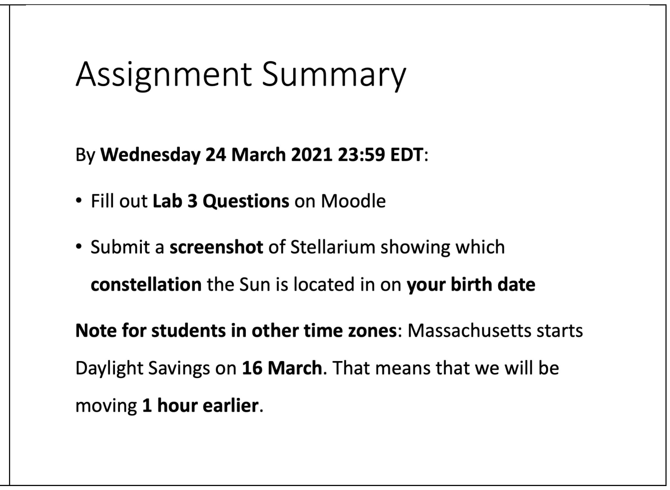


Mars-ching to the beat of its own drum

1. Centre your view on Pisces.
   (a) Set Stellarium to 1 June 2020.
   (b) Turn off the atmosphere and ground visualisations.
   (c) Switch to the equatorial axis. (This is NOT the same as turning on the equatorial grid!)
   (d) In Sky and viewing options, turn on constellation lines and labels as before.
   (e) Centre and zoom in on Pisces.
2. Find Mars on the sky.
3. Plot the position of Mars every month for one year (i.e. once a month from June 2020 to June 2021).
4. Connect the points. How many days was it moving backwards (retrograde)?
5. Go back through the same period. This time, zoom in on Mars and take note of its magnitude, phase, and size.
6. Note the highest and lowest magnitudes and note them on the chart.
7. Repeat for all the planets. Do they all go retrograde (i.e. move backwards for some time)?



At ~10 min from class end, show Moodle quiz password.
Complete the Lab quiz on Moodle.



3.7.4 Submissions

Moodle:

1. Lab quiz

In-class:

1. None

3.7.5 Quiz

1. What determines that your horoscope sign is, for example, Taurus?

   a. Characteristics that are common among people born on those dates (like being bullish).
   b. The constellation (Taurus) the Moon is in on your birthday.
   c. The constellation (Taurus) the Sun is in on your birthday.
   d. None of the above.

2. If you could see stars during the day, this is what the sky would look like at noon on a given day (Fig. 8). The Sun is near the stars of the constellation Gemini. Near which constellation would you expect the Sun to be located at sunset?

   a. Leo
   b. Cancer
   c. Gemini
   d. Taurus
   e. Pisces

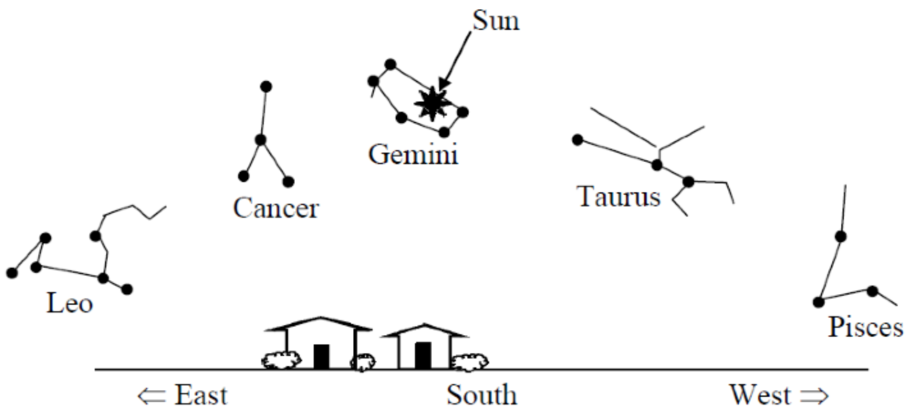


Figure 8:

3. For most people living today who, according to popular horoscopes, believe they are "a Gemini", the Sun was in the constellation [] on the day they were born.

   a. Leo
   b. <u>Cancer</u>
   c. Gemini
   d. Taurus
   e. Pisces

4. Suppose it is just after sunset, and you see the constellation Gemini just above the horizon where the Sun set. If you were looking just after sunset a month later, what constellation would be in that position?

   a. Leo
   b. Cancer
   c. Gemini
   d. <u>Taurus</u>
   e. Pisces

5. How many lunar months are there between Chinese New Years?

   a. 12
   b. 13
   c. 14
   d. <u>12 or 13</u>
   e. 13 or 14

3.8 Lab 8: Motions of the Planets in the Sky

3.8.1 Overview

Topics covered:

- Solar power at distance and altitude

Notes:

-

3.8.2 Materials needed

Instructors:

- Lab worksheets: Appendix 8.1

Students:

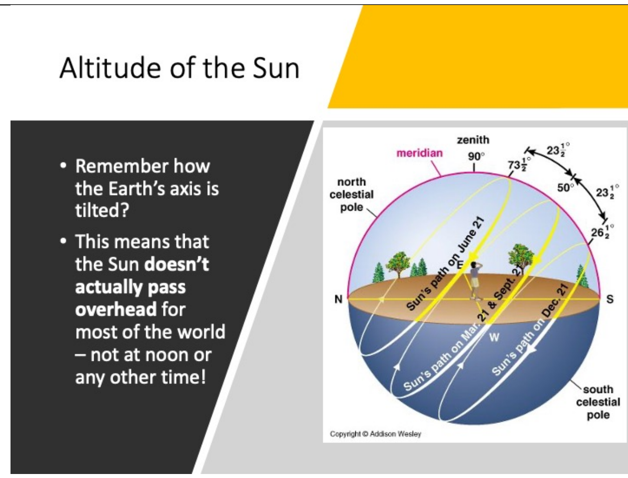
-

3.8.3 Script

Before the end of class, set the Moodle Lab Quiz access password.

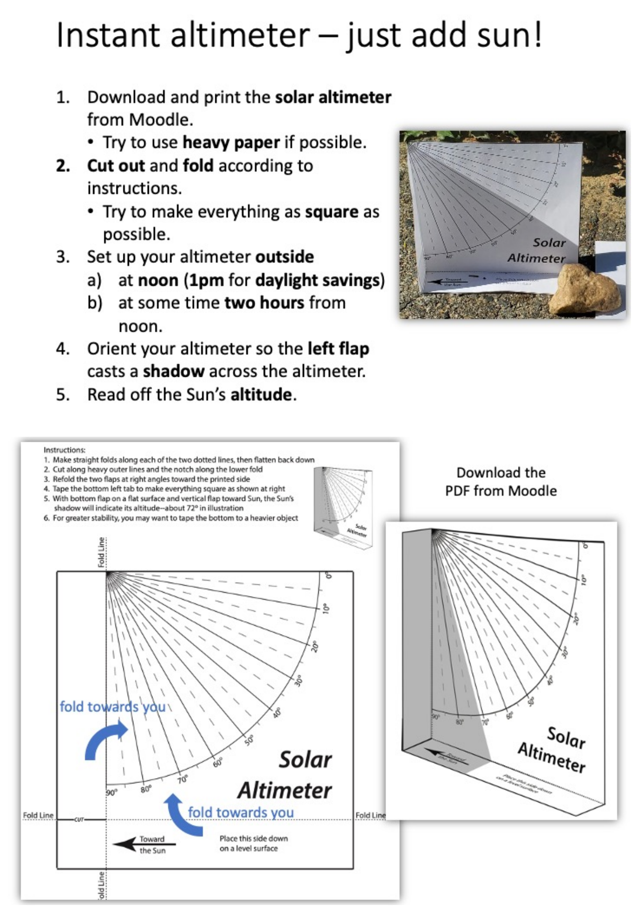
Pick up copies of the lab worksheet.	

Remember how the Earth's axis is tilted? This means that the Sun doesn't actually pass overhead for most of the world - not at noon or any other time!



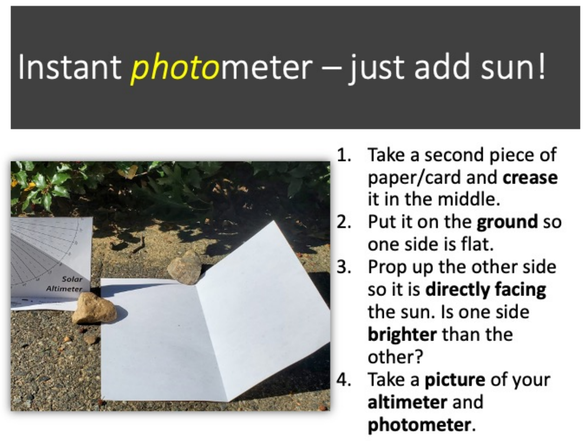
Instant altimeter - just add sun

1. Download and print the solar altimeter from Moodle. Try to use heavy paper if possible.
2. Cut out and fold according to instructions. Try to make everything as square as possible.
3. Set up your altimeter outside at:
   (a) noon (1pm for daylight savings)
   (b) some time two hours from noon.
4. Orient your altimeter so the left flap casts a shadow across the altimeter.



Instant photometer - just add sun

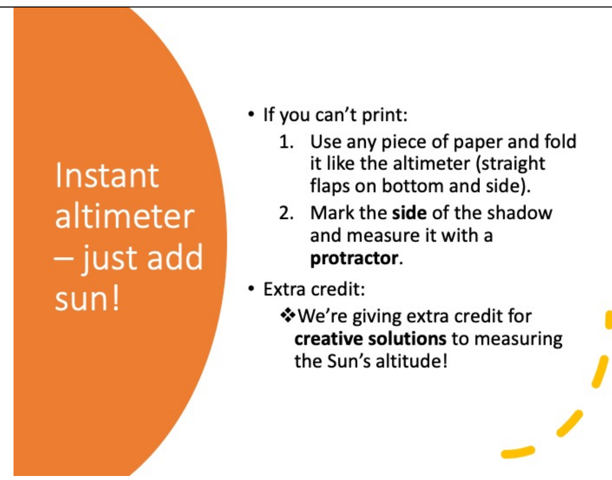
1. Read off the Sun's altitude.
2. Take a second piece of paper/card and crease it in the middle.
3. Put it on the ground so one side is flat.
4. Prop up the other side so it is directly facing the sun. Is one side brighter than the other?
5. Take a picture of your altimeter and photometer.



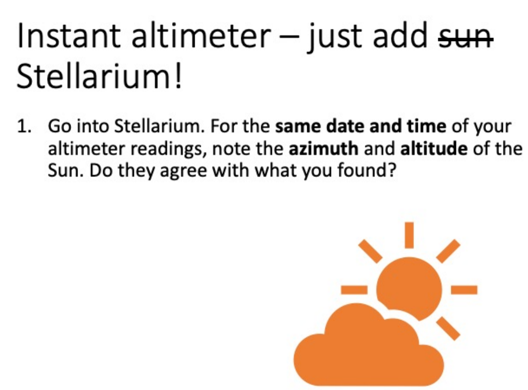
If you can't print:

1. Use any piece of paper and fold it like the altimeter (straight flaps on bottom and side).
2. Mark the side of the shadow and measure it with a protractor.

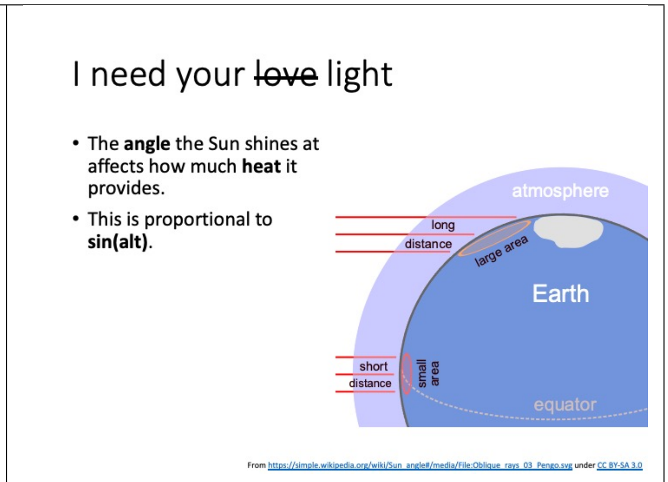
We'll give extra credit for creative solutions to measuring the Sun's altitude!



Find the azimuth and altitude of the Sun as given on Stellarium for the same location, date, and time as your altimeter readings. Do they agree with your measurements?

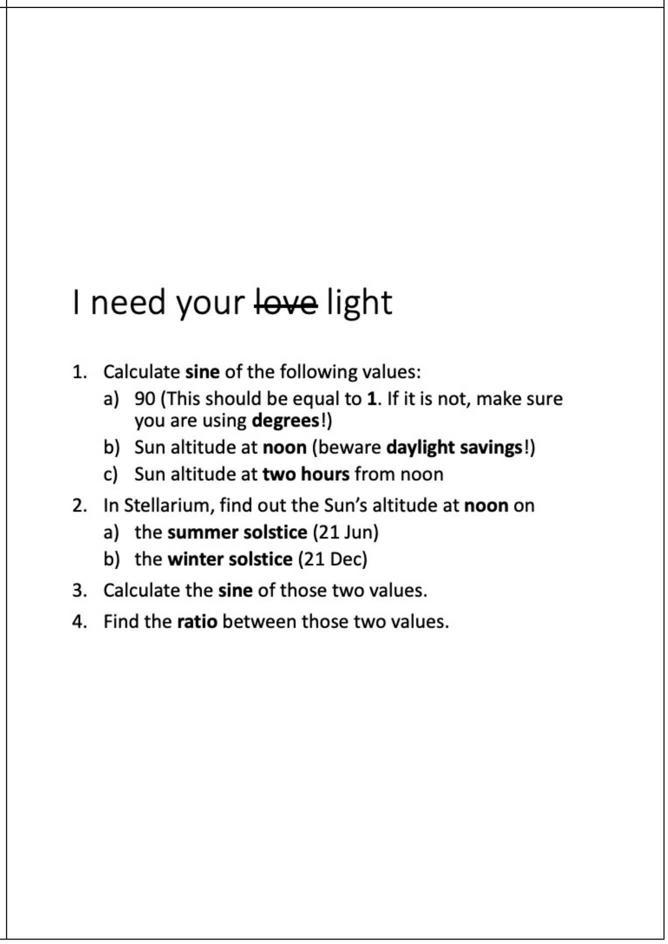


I need your light
The angle the Sun shines at affects how much heat it provides. This is proportional to sin(alt).



I need your light

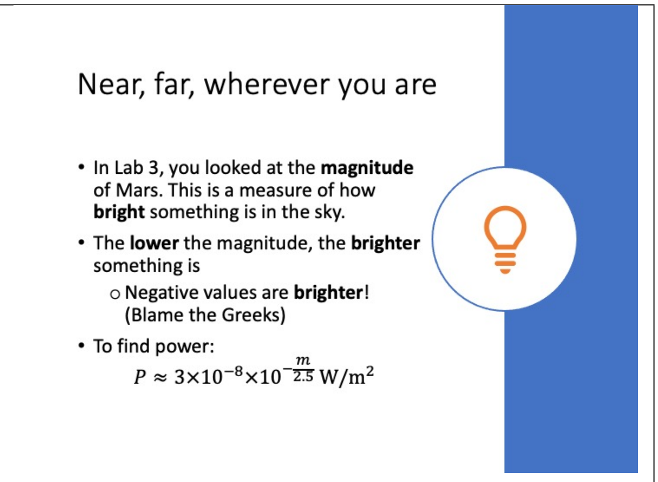
1. Calculate sine of the following values:
   (a) 90 (This should be 1. If it is not, make sure you are using degrees!)
   (b) Sun altitude at noon (beware daylight savings!)
   (c) Sun altitude at two hours from noon
2. In Stellarium, find out the Sun's altitude at noon on:
   (a) the summer solstice (21 Jun)
   (b) the winter solstice (21 Dec)
3. Calculate the sine of those two values.
4. Find the ratio between those two values.



Near, far, wherever you are
Magnitude is a measure of how bright something is. The brighter it is, the LOWER the magnitude.
Power is related to magnitude per the formula:

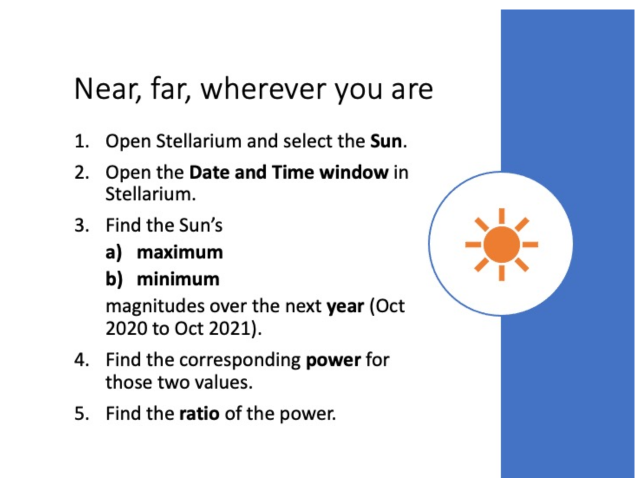
$$P \approx 3 \times 10^{-8} \times 10^{-\frac{m}{2.5}}\ \mathrm{W/m^2}$$

We'll talk about it in more detail in Lab 3.9.



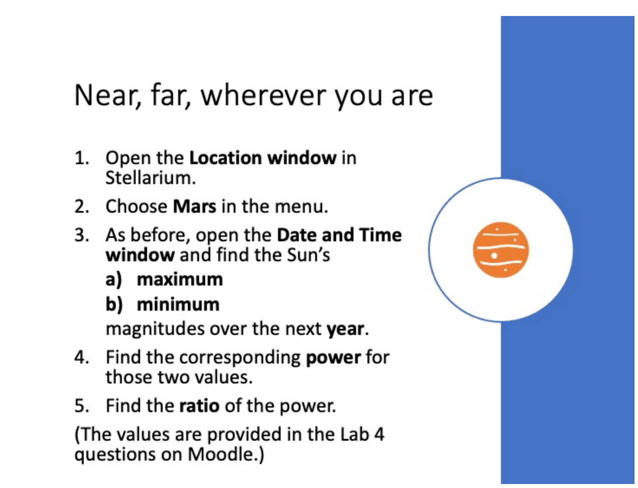
I'm dreaming of a bright Christmas

1. Open Stellarium and select the Sun.
2. Open the Date and Time window in Stellarium.
3. Find the Sun's maximum and minimum magnitudes over the next year (Oct 2020 to Oct 2021).
4. Find the corresponding power for those two values.
5. Find the ratio of the power.



Near, far, wherever you are (cont.)

1. Open the Location window in Stellarium.
2. Choose Mars in the menu.
3. As before, open the Date and Time window and find the Sun's maximum and minimum magnitudes over the next year.
4. Find the corresponding power for those two values.
5. Find the ratio of the power.



Going the distance

1. Repeat the same steps from another planet: Jupiter, Saturn, Uranus, Neptune, Ceres, Pluto, Eris, Haumea, or Makemake. N.B.: Eris, Haumea, and Makemake are listed with a numerical prefix starting with 136.

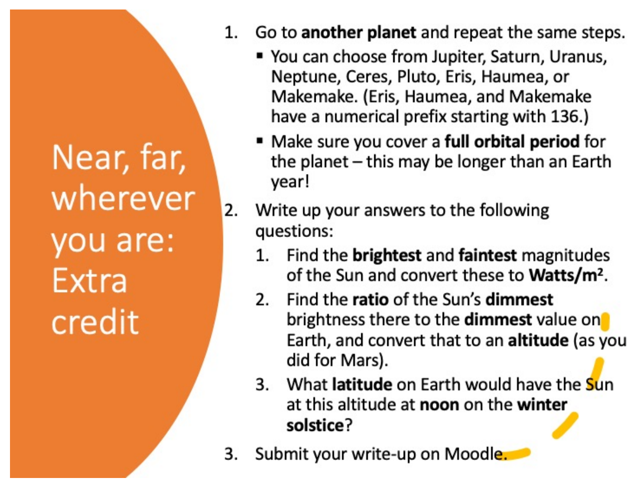
   Make sure you cover a full orbital period for the planet - this may be longer than an Earth year.

2. In your write-up on Moodle, answer the following questions:

   (a) Find the brightest and faintest magnitudes of the Sun and convert these to Watts/m^2.

   (b) Find the ratio of the Sun's dimmest brightness there to the dimmest value on Earth, and convert that to an altitude (as you did for Mars).

   (c) What latitude on Earth would have the Sun at this altitude at noon on the winter solstice?



3.8.4 Submissions

Moodle:

1. Lab quiz
2. Photos of measurement
   - At noon
   - 2h from noon
3. Extra credit writeup

In-class:

1. None

3.8.5 Quiz

1. When is Mars brightest?

   a. Just at the beginning or end of retrograde motion, when Mars appears stationary.

   b. In July, when Earth is farthest from the Sun.

   c. When it is on the far side of the Sun, so we see its fully-lit face.

   d. <u>In the middle of going through retrograde motion.</u>

2. Which planets undergo retrograde (backward) motion on the sky?

   a. Mars only.

   b. Just Mars, Jupiter, Saturn, Uranus, and Neptune.

   c. Venus only.

   d. Just Venus and Mercury.

   e. <u>All of the planets.</u>

3.9 Lab 9: The HR Diagram

3.9.1 Overview

Topics covered:

- Stellar temperatures and luminosities from colour and magnitude
- Finding stellar radii
- Bright stars vs. nearby stars

Notes:

-

3.9.2 Materials needed

Instructors:

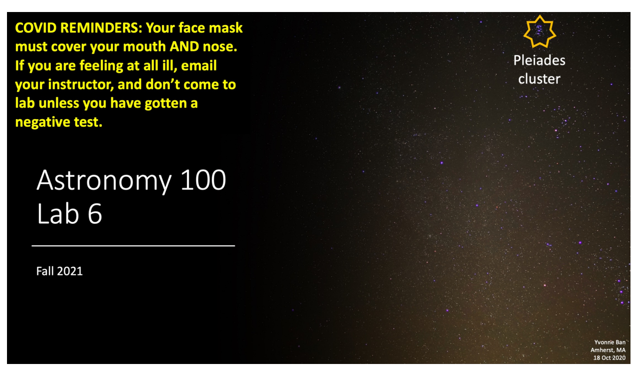
- Lab worksheets: Appendix 9.1
- Table worksheets (×11): Appendix 9.1

Students:

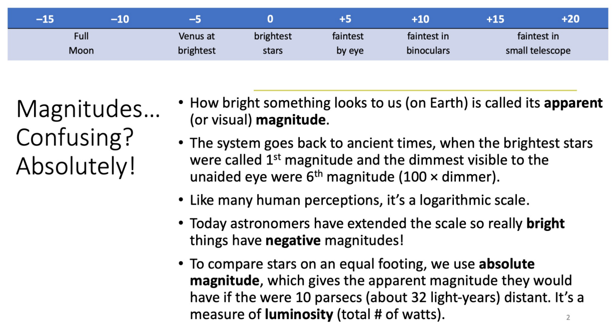
-

3.9.3 Script

Before the end of class, set the Moodle Lab Quiz access password.

1. *Write <50, 50-200, 200-1000, 1000-5000, >5000 light-years at the top of 5 neighbouring whiteboards.* 2. *Put 2 meter sticks at each of these whiteboards.* 3. *Put out the colourful markers at the whiteboards, and draw 1 cm diameter green Sun on first board.* 4. *Put a table worksheet at each table.* Pick up copies of lab worksheet and make sure your table has a table worksheet. Take note of your table today as we will ask you to return to the same table and use the same star for the next lab.	

How bright something looks to us on Earth is called its apparent, or visual, magnitude. This system goes back to ancient times, when the brightest stars were called 1st magnitude and the dimmest visible to the unaided eye were 6th magnitude, and 100× dimmer. Like many human perceptions, it's a logarithmic scale. Today, astronomers have extended the scale so REALLY bright things have negative magnitudes!
To compare stars on an equal footing, we use absolute magnitude, which gives the apparent magnitude they would have if they were 10 parsecs (about 32 light-years) distant. It's a measure of luminosity (total number of watts).

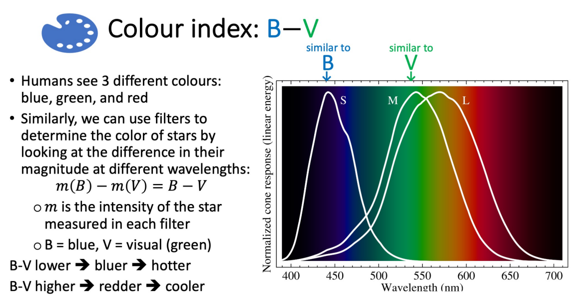


We humans see 3 different colours: blue, green, and red. Similarly, we can use filters to determine the colour of stars by looking at the difference in their magnitude at different wavelengths using the equation:

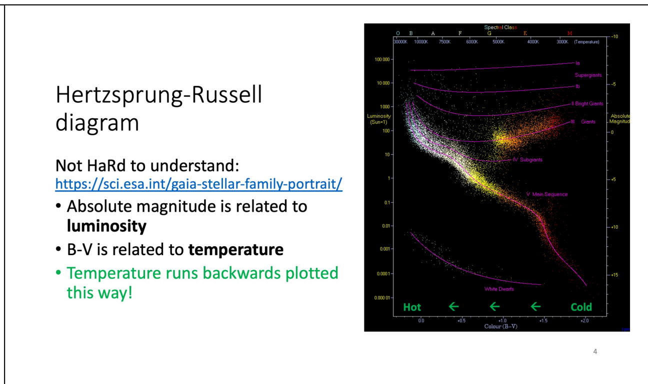
$$m(B) - m(V) = B - V$$

- m is the intensity of the star measured in each filter
- B = blue, V = visual (green)

When B-V is lower, it means the object is bluer and therefore hotter. When B-V is higher, the object is redder and therefore cooler.



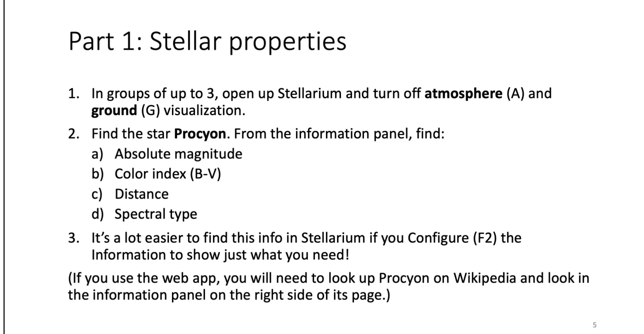
We can organise stars using their absolute magnitude and B-V value on a Hertzprung-Russell diagram, which we can see at this link. As absolute magnitude is related to luminosity, which we can relate to star size, and B-V is related to temperature, this also allows us to understand more about stars.
Note that temperature runs backwards (from right to left) plotted this way!



Procyon (Stellarium)

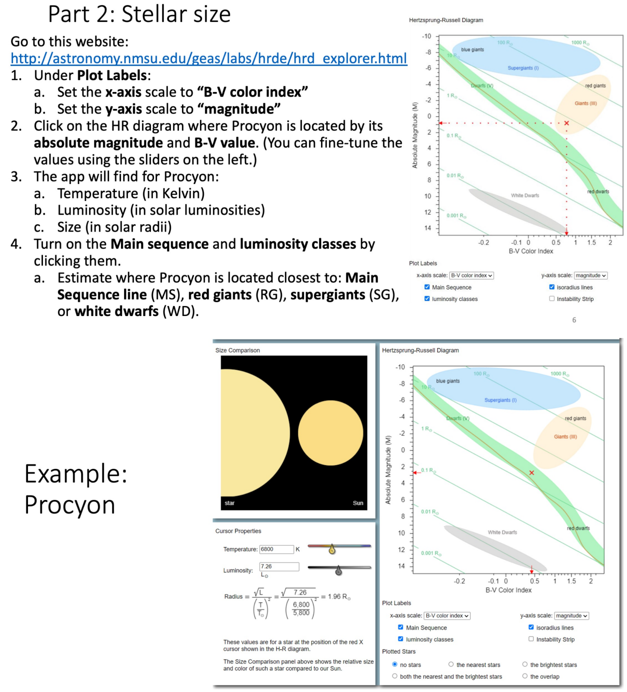
1. In groups of up to 3, open up Stellarium and turn off atmosphere (A) and ground (G) visualization.
2. Find the star Procyon. From the information panel, find:
   (a) Absolute magnitude
   (b) Color index (B-V)
   (c) Distance
   (d) Spectral type

It's a lot easier to find this info in Stellarium if you Configure (F2) the Information to show just what you need. If you use the web app, you will need to look up Procyon on Wikipedia and look in the information panel on the right side of its page.



Procyon (HRD mode)

1. Go to this website: `http://astronomy.nmsu.edu/geas/labs/hrde/hrd_explorer.html`
2. Under Plot Labels:
   (a) Set the x-axis scale to "B-V color index"
   (b) Set the y-axis scale to "magnitude"
3. Click on the HR diagram where Procyon is located by its absolute magnitude and B-V value. (You can fine-tune the values using the sliders on the left.)
4. The app will find for Procyon:
   (a) Temperature (in Kelvin)
   (b) Luminosity (in solar luminosities)
   (c) Size (in solar radii)
5. Turn on the Main sequence and luminosity classes by clicking them.
6. Estimate where Procyon is located closest to: Main Sequence line (MS), red giants (RG), supergiants (SG), or white dwarfs (WD).



Assign constellation for each table.

1. Return to Stellarium and turn on constellation labels and boundaries.

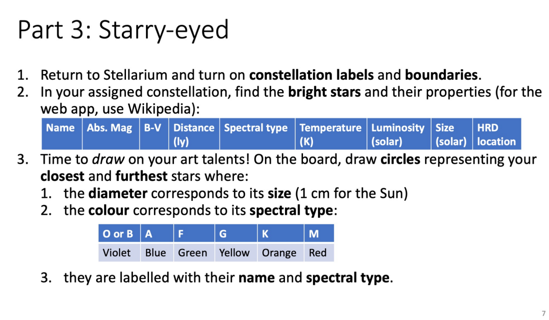
2. In your assigned constellation, find the bright stars and pick one each. Then, find their properties as shown on your worksheet. If you are using the web app, use Wikipedia.

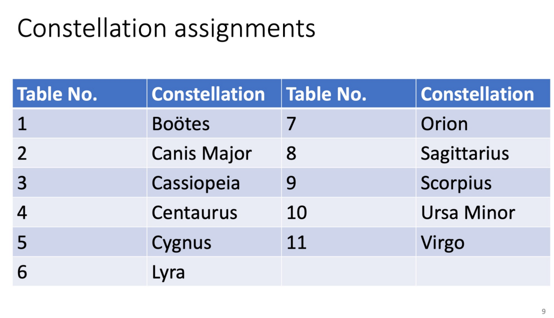
3. Time to draw on your art talents! On a blank piece of paper, draw circles representing your stars where:

   (a) the diameter corresponds to its size (1 cm for the Sun)

   (b) the colour corresponds to its spectral type according to the table

   (c) they are labelled with their name and spectral type.

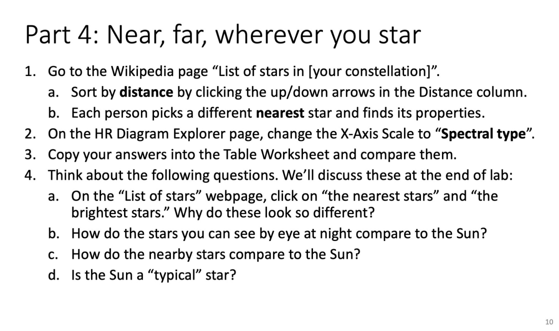


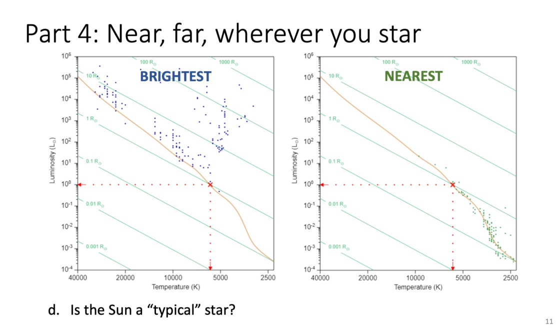


1. Go to the Wikipedia page "List of stars in [your constellation]".
2. Sort by distance by clicking the up/down arrows in the Distance column.
3. Pick a different nearest star each and find its properties.
4. On the HR Diagram Explorer page, change the X-Axis Scale to "Spectral type".
5. Copy your answers into the Table Worksheet and compare them.

Think about the following questions. We'll discuss these at the end of lab.

1. On the "List of stars" webpage, click on "the nearest stars" and "the brightest stars." Why do these look so different?
2. How do the stars you can see by eye at night compare to the Sun?
3. How do the nearby stars compare to the Sun?
4. Is the Sun a "typical" star?





At ∼10 min from class end, show Moodle quiz password.
Complete the Lab quiz on Moodle.
Make sure your names are on your table worksheet and hand it in.

3.9.4 Submissions

Moodle:

1. Lab quiz

In-class:

1. Table worksheets

3.9.5 Quiz

1. What is your team's table number?
   - 1
   - 2
   - 3
   - 4
   - 5
   - 6
   - 7
   - 8
   - 9
   - 10
   - 11
2. Enter the data you found for your bright star. (enter number only)
   Distance: [d] ly (light-years)
   Temperature: [T] K (Kelvin)
   Size: [D] $\times$ diameter of Sun
3. Which of the following is true about the Sun? (select all that apply)
   - The Sun is a star.
   - The Sun is bigger than most stars.
   - The Sun is more luminous than most stars.
   - The Sun is less luminous than most of the brightest stars we see at night.
4. Which of the following is true about the brightest stars you can see by eye at night? (select one)
   - Most are giant stars, much more luminous than the Sun.
   - Most are very nearby, making them look so bright.

- Most are small, red stars, which are the most common.
- Most are young, so they have a lot of fuel to burn.

5. What does absolute magnitude measure?

    - A star's distance in parsecs.
    - How bright a star appears to be.
    - The brightness of a star if observed from above Earth's atmosphere.
    - The power output from a star in starlight.

6. Which of the following would you need to know to find a star's surface temperature? (select all that apply)

    - Distance to star
    - Radius of star
    - Absolute magnitude of star
    - B-V color of star

3.10 Lab 10: Distances of Stars in Space

3.10.1 Overview

Topics covered:

- Building a 3D constellation
- Understanding spectral type and luminosity class
- Understanding parallax

Notes:

- Warn students to keep strings as taut as possible without pulling the tape off the whiteboard.
- A common mistake is to measure the distance from the whiteboard instead of from the "Sun" (the knot where the strings come together). Check a distant and nearby star to make sure what they've done makes sense.
- Look for common mistakes, e.g., all the stars are the largest size balls, or the colours don't make sense (sometimes they choose balls for looks rather than accuracy).

3.10.2 Materials needed

Instructors:

- Lab worksheets: Appendix 10.1
- Table worksheets ($\times$11): Appendix 10.2
- Tribbles (in box)
- Clips (in box)
- Metal poles with sightlines ($\times$11)

Students:

-

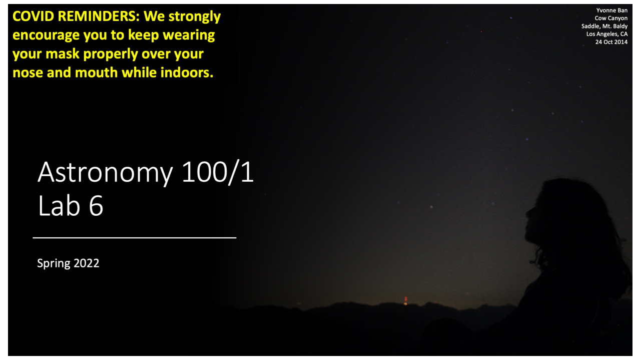
3.10.3 Script

Before the end of class, set the Moodle Lab Quiz access password.

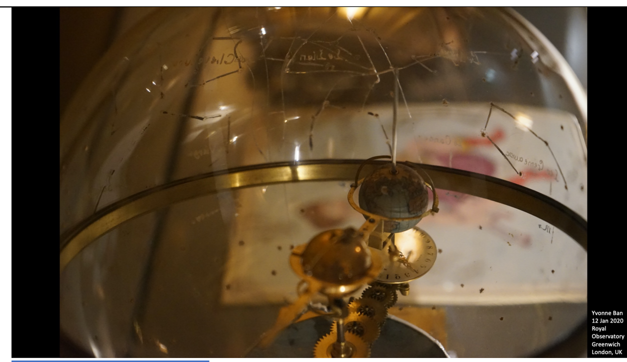
---

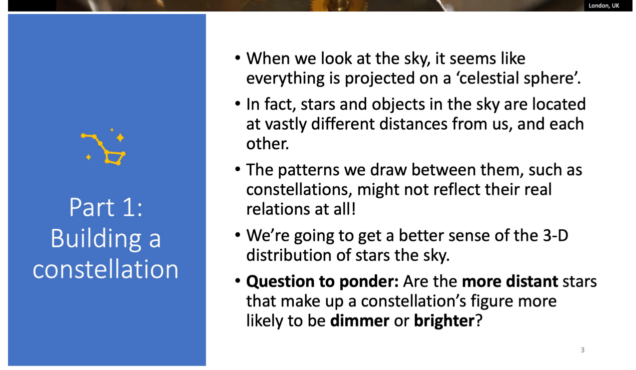
1. *Put tribbles and clips at centre/instructor's table.*
2. *Set up sightlines for each table by using chairs to prop up metal poles 5 ft from whiteboard.*
3. *Put a table worksheet at each table.*

Pick up copies of lab worksheet and make sure your table has a table worksheet.
Return to the same table and use the same star as you did for last lab.



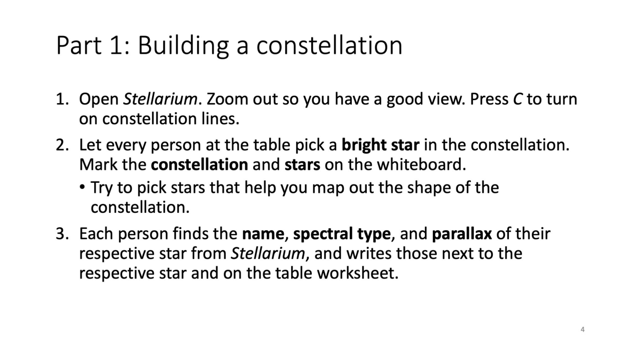
When we look at the sky, it seems like everything is projected on a 'celestial sphere'. In actual fact, stars and objects in the sky are located at vastly different distances from us, and each other. Thus, the patterns we draw between them, such as constellations, might not reflect their real spatial relations at all!
We're going to get a better sense of the 3D distribution of stars the sky.
Question to ponder: Are the more distant stars that make up a constellation's figure more likely to be dimmer or brighter?

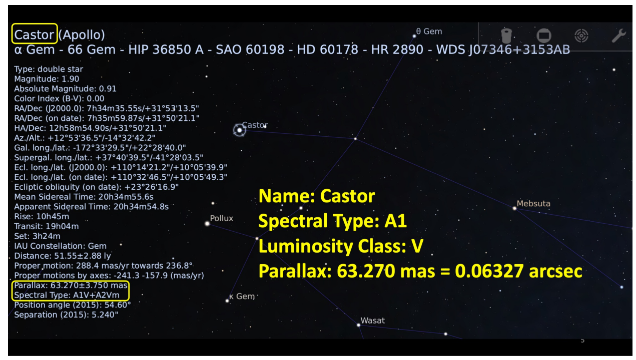




Find star info

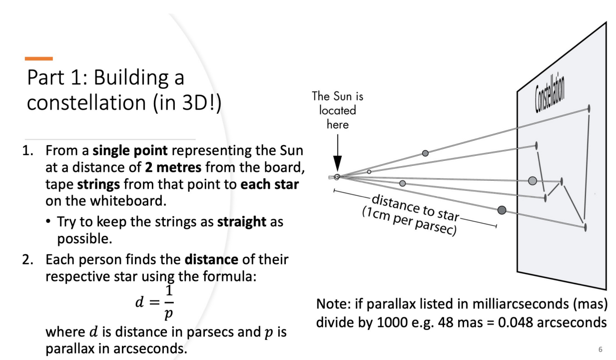
1. Open Stellarium. Zoom out so you have a good view. Press C to turn on constellation lines.
2. Pick a bright star in the constellation each. Mark the constellation and stars on the whiteboard. Try to pick stars that help you map out the shape of the constellation.
3. Find the name, spectral type, and parallax of your respective star from Stellarium, and write these on the board next to the star. Also, write it down on the table worksheet.

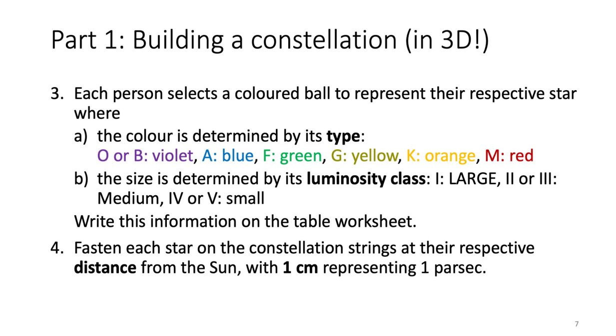




Build constellation

1. Take the tip of the metal pole and strings to be the Sun. Stretch the strings taut from that point to each star on the whiteboard, and tape them down.
2. Find the distance of your star using the formula $d = 1/p$, where d is distance in parsecs and p is parallax in arcseconds.
3. Using colour to represent type and size for luminosity class, pick a ball to represent your star.
4. Write this information down on the table worksheet.
5. Taking 1 cm = 1 parsec, clip your star on the constellation strings at the right distance from the Sun.





A change of scene 1. Move 10-20 parsecs (10-20 cm) to either side of the Sun and sketch the pattern of stars from the new position. Which star appears to move the most? Why? Neptune is 4.475 billion km / 2.793 billion miles / 0.00014502 parsecs from the Sun. Would the constellations look very different there? 2. Copy one of your pair of sketches to the table worksheet. 3. Go around the room and look at other tables' constellations. 4. Call over an instructor to inspect your work when you're done.	Part 2: A change of scene 1. Move **10-20 parsecs** (10-20 cm) to either side of the Sun and sketch the pattern of stars from the new position. a. Discuss at your table: Which star appears to move the most? Why? b. Copy one of your pair of sketches to the table worksheet. 2. Go around the room and look at other tables' constellations. 3. Neptune is 4.475 billion km / 2.793 billion miles / 0.00014502 parsecs from the Sun. Would the constellations look very different from there? 8
At ∼10 min from class end, show Moodle quiz password. Complete the Lab quiz on Moodle. Make sure your names are on your table worksheet and hand it in.	It's all about perspective Complete the end-of-lab 6 quiz before leaving, and make sure you put your name on your table worksheet before it is turned in. 9

3.10.4 Submissions

Moodle:

1. Lab quiz

In-class:

1. Table worksheets

3.10.5 Quiz

1. What is your team's table number?

- 1
- 2
- 3
- 4
- 5
- 6
- 7
- 8
- 9
- 10
- 11

2. What constellation did your table work on?

3. Light from the Sun takes about 8.5 minutes to reach Earth. About how long does light take to reach us from most of the brighter stars we see at night?

   - Several hours
   - Several months
   - 3-10 years
   - 100-1000 years
   - Millions of years

4. Most constellations are collections of stars that:

   - are not physically associated with each other.
   - are members of a group of stars gravitationally attracted together.
   - were born together out of a cloud of gas, now drifting apart.
   - were born out of the same interstellar cloud as the Sun.

5. Suppose star A has a parallax shift 10 times larger than star B. Which of the following is true?

   - Star A is 10 times closer than star B.
   - Star A is 10 times farther than star B.
   - Star A is 100 times closer than star B.
   - Star A is 100 times farther than star B.

6. If you spot a bright reddish colored star in a constellation tonight, it is most probably:

- a distant red giant star.
- a nearby low-mass main-sequence star.
- either A or B with about equal probability.

7. As viewed from Massachusetts, the stars of the Big Dipper can be connected with imaginary lines to form the shape of a bowl with a curved handle. What is the closest point you would have to travel to in order to observe a substantial change in the shape formed by these stars?

   - Across the country
   - Another continent
   - The Moon
   - Pluto
   - A distant star

8. If you lived on Mars, how would the parallax of stars differ from its value seen from Earth?

   - It would be bigger.
   - It would be smaller.
   - It would be the same.

3.11 Lab 11: Structure of the Local Group

3.11.1 Overview

Topics covered:

- Using angular sizes to estimate nearby galaxy sizes
- Building a scale model of the Local Group of galaxies

Notes:

- Make sure to demonstrate the procedure

3.11.2 Materials needed

Instructors:

- Lab worksheets: Appendix 11.1
- Metre rules (many)
- Colour paper (green, yellow, blue)
- Scissors (multiple)
- Galaxy info strips
- Milky Way scale paper disc
- Tripod/chair/something to put the Milky Way on e.g. lab stand

Students:

-

3.11.3 Script

Before the end of class, set the Moodle Lab Quiz access password.

Pick up a copy of lab worksheet.	

Galaxy types

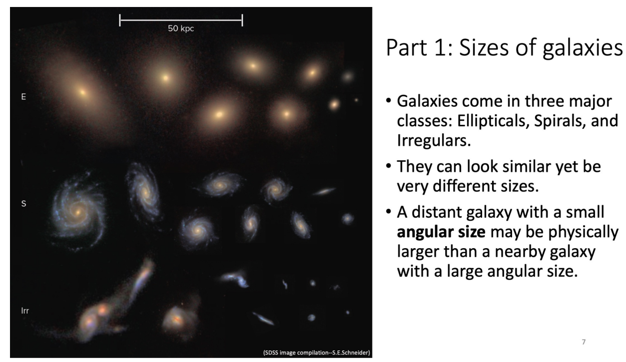
Galaxies come in three major classes: Ellipticals, Spirals, and Irregulars. They can look similar, but be very different sizes.

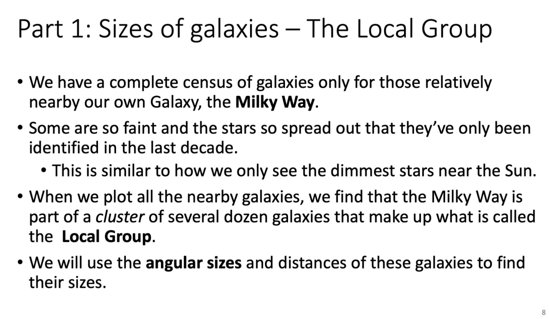
A distant galaxy with a small angular size may be physically larger than a nearby galaxy with a large angular size.

We have a complete census of galaxies only for those relatively nearby our own Galaxy, the Milky way. Some are so faint and the stars so spread out that they've only been identified in the last decade. This is similar to how we only see the dimmest stars near the Sun.

When we plot all the nearby galaxies, we find that the Milky Way is part of a cluster of several dozen galaxies that make up what is called the Local Group.

We will use the angular sizes and distances of these galaxies to find their sizes.





Galaxy sizes

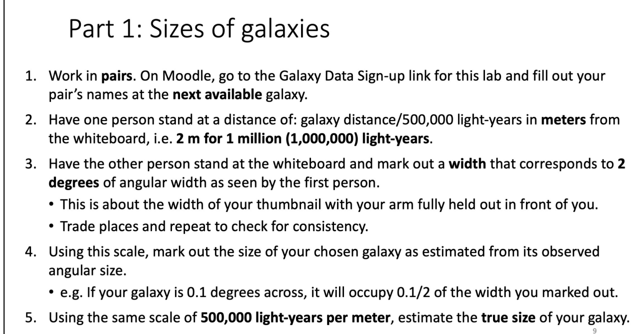
1. Work in pairs. On Moodle, go to the Galaxy Data Sign-up link for this lab and fill out your names at the next available galaxy.

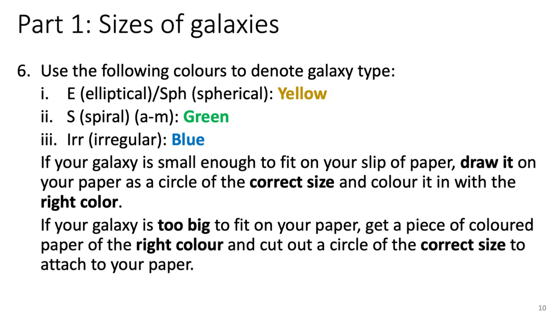
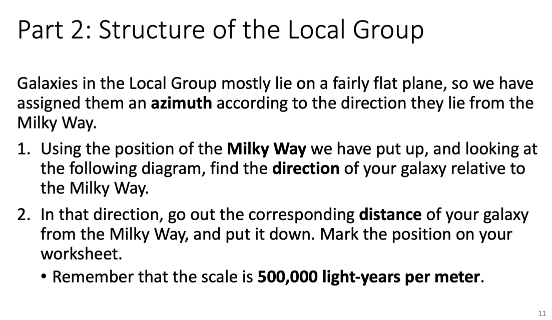
2. Using a scale of 1 m for 500,000 light-years (2 m for 1 million (1,000,000) ly), have one person stand at a distance from the whiteboard corresponding to the galaxy distance.

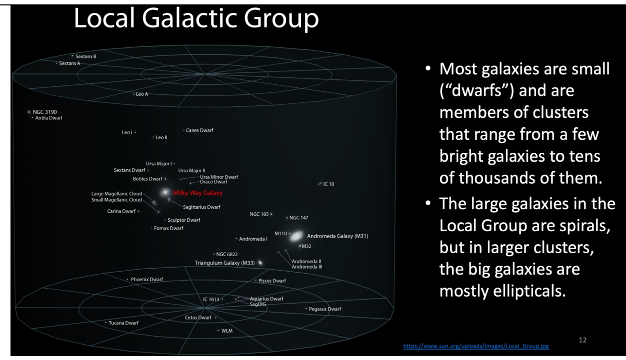
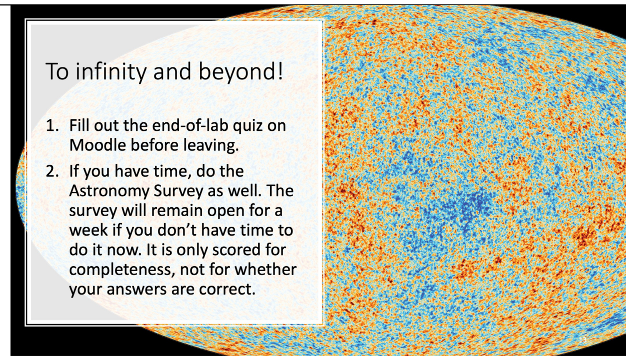
3. Have the other person stand at the whiteboard and mark out a width that corresponds to 2° of angular width, as seen by the first person. (This is about the width of your thumbnail with your arm fully extended in front of you.) Then, trade places and repeat, to check for consistency.

4. Using this scale, mark out the size of your galaxy as estimated from its observed angular size, e.g. if your galaxy is 0.1° across, it extends 0.1/2 of the width you have marked out.

5. Using the same scale of 500,000 light-years per 1 m, estimate the true size of your galaxy.



Use the following colours to denote galaxy type: 1. E (elliptical)/Sph (spherical): Yellow 2. S (spiral) (a-m): Green 3. Irr (irregular): Blue If your galaxy is small enough to fit on a small piece of paper, draw it as a circle of the correct size and colour it in with the right colour. If not, get a piece of paper of the right colour and cut out a circle of the correct size to attach to your paper.	
Local Group structure Galaxies in the Local Group mostly lie on a fairly flat plane, so we have assigned them an azimuth according to the direction they lie from the Milky Way. 1. Find the direction of your galaxy relative to the Milky Way. Use the position of the Milky Way we have put up and azimuth values we have marked. 2. In that direction, go out the corresponding distance of your galaxy from the Milky Way, and put it down. Remember that the scale is 500,000 light-years per metre. 3. Mark the position on your worksheet.	

<table>
<tr>
<td>The Local Group
Most galaxies are small (“dwarfs”) and are members of clusters that range from a few bright galaxies to tens of thousands of them.
The large galaxies in the Local Group are spirals, but in larger clusters, the big galaxies are mostly ellipticals.</td>
<td>
</td>
</tr>
<tr>
<td>At ∼10 min from class end, show Moodle quiz password.
Complete the Lab quiz on Moodle.
Remember to complete the post-lab survey.</td>
<td>
</td>
</tr>
</table>

3.11.4 Submissions

Moodle:

1. Lab quiz
2. Astronomy post-instruction survey

In-class:

1. None

3.11.5 Quiz

1. What is the number of the galaxy you worked on?
2. What was the distance of your galaxy (in light years)? [d] ly (enter number only)
3. What diameter did you estimate for your galaxy (in light years)? [D] ly (enter number only)
4. Approximately how far away is the nearest galaxy that is the size of the Milky Way or larger?
   - About 25,000 light years
   - About 2,500,000 light years
   - About 250,000,000 light years

- About 2,500,000,000 light years

5. What is the most common type of galaxy in the Local Group of galaxies?

- Spiral
- Elliptical
- Irregular
- Dwarf

6. What information is needed to find the physical diameter of a galaxy? (select only those items that are necessary)

- Angular diameter
- Distance
- Classification
- Magnitude
- Color

7. Which of the following best describes the Milky Way galaxy as compared to the other galaxies in the Local Group?

- One of the largest galaxies in the Local Group.
- One of the smaller galaxies in the Local Group.
- The only spiral galaxy in the Local Group.
- The only large galaxy in the Local Group.
- One of the only dwarf galaxies in the Local Group.

3.12 Project: Movement of the Sunset

3.12.1 Overview

Topics covered:

- Observing astronomical motion in real life

Notes:

- Students need to have filled out Photo Policy Acknowledgement
- Students need to have calibrated their cameras in Lab 2 (Section 3.2). They can recalibrate them using the calibration grids.

3.12.2 Materials needed

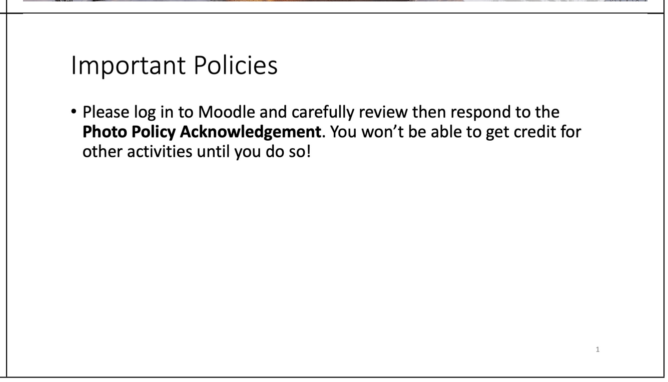
Instructors:

- Calibration grids

Students:

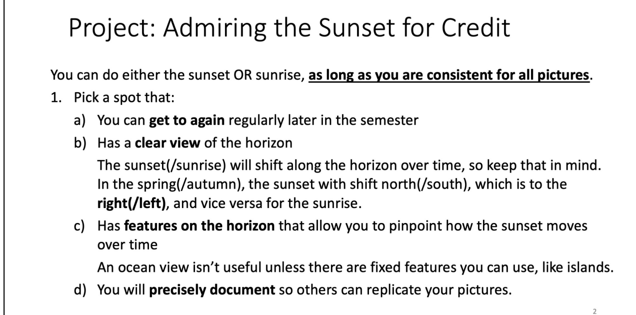
- Camera

3.12.3 Script

Pick up copies of the project worksheet.	
Make sure to read and respond to the Photo Policy Acknowledgement on Moodle. Note that you won't be able to get any credit for the rest of the project otherwise.	

Admiring the sunset for credit

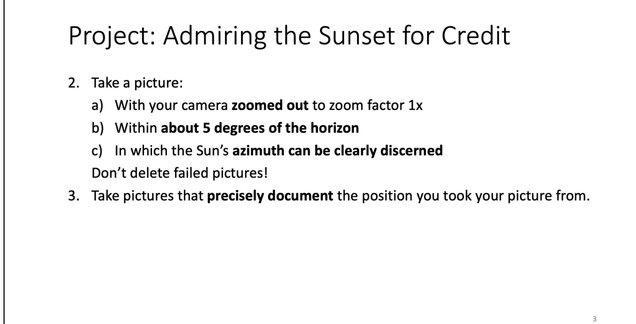
1. You can take pictures of the sunset OR sunrise, but they must be consistent for all your pictures.
2. Pick a spot that:
   (a) You can get to again regularly later in the semester
   (b) Has a clear view of horizon
   (c) The sunset(/sunrise) will shift along the horizon over time, so keep that in mind. In the spring, the sunset shifts north, which is to the right, and vice versa for the sunrise.
   (d) Has features on the horizon that allow you to pinpoint how the sunset moves over time.
   (e) You will precisely document so others can replicate your pictures.



Admiring the sunset for credit (cont.)

1. Take a picture:
   (a) With your camera zoomed out to zoom factor 1
   (b) Within about 5 degrees of the horizon
   (c) In which the Sun's azimuth can be clearly discerned

   Don't delete failed pictures!
2. Take pictures that precisely document the position you took your picture from. Someone else should be able to return to the exact same spot to take a follow-up picture.

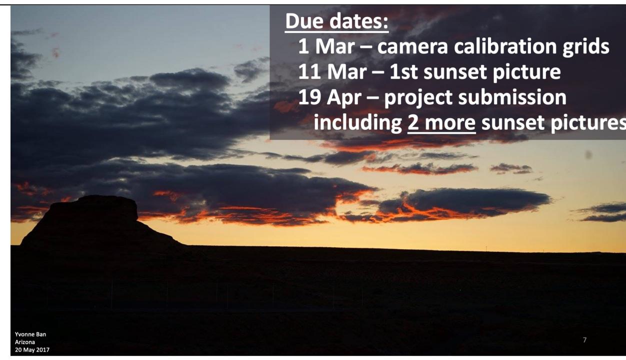


<table>
<tr>
<td>Here are examples of acceptable pictures.
The Sun doesn't need to be directly visible as long as some way to pinpoint its location (both altitude and azimuth) is clearly visible.</td>
<td>
</td>
</tr>
<tr>
<td>These pictures are not acceptable for the project.

Make sure there's some way to locate the Sun.
This means there must be features visible on the horizon to compare its position to. An ocean view isn't useful unless there are fixed features you can use, like islands.
Make sure you have some space along the horizon that will accommodate the sunset as it moves over time.
Photos from too long before or after sunset are not accepted.
</td>
<td>
</td>
</tr>
<tr>
<td>Here are examples of ways to document your location so that someone else can use it to return to the exact same spot to take a follow-up picture.

You will probably need to include a map along with photos that show clearly where you are standing when you take your pictures.
Again, make sure features around your location are visible.
</td>
<td>
</td>
</tr>
</table>

Take note of these deadlines. Don't wait to get your photos! They must be spaced a certain apart from your later photos.



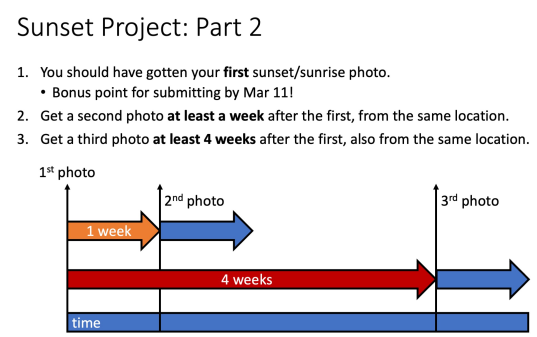
Part 2

You should have taken your first sunset/sunrise photo. You will take another 2 follow-up sunset pictures after your first one.

1. Take your 2nd photo at least 1 week after your first.

2. Take your 3rd photo at least 4 weeks after your first AND at least 1 week after your second.

If you are unable to get good sunset pictures, make sure to upload your attempts. We can give you partial credit.

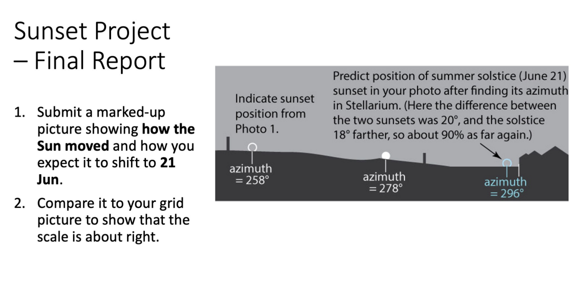


Annotated photo

1. Take one of your photos and mark on it the positions of the sunsets from your other photos.

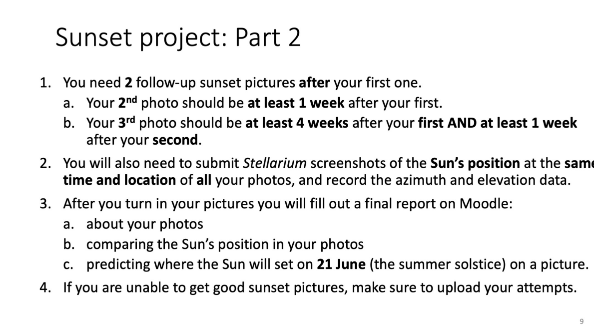
2. Based on the angular scale of your camera (from calibrating it in Lab 2), predict where the sunset will shift to on 21 Jun/Dec.

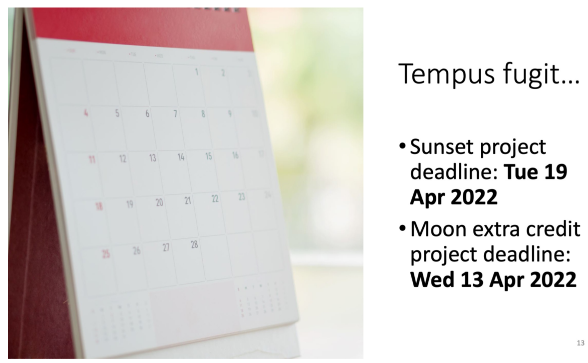
   You can make use of your calibration grid pictures.



Submissions

1. Sunset photos 1-3
2. Annotated photo (separate file) with predicted sunset position
3. Stellarium screenshots of Sun's position at same time and location of photos
4. Azimuth and elevation data
5. Final report on Moodle
   (a) Information about photos
   (b) Compare Sun's position in photos
   (c) Predict position of sunset on 21 Jun/Dec (summer/winter solstice)





3.12.4 Submissions

Moodle:

1. Photo policy acknowledgement
2. 1st sunset(/sunrise) photo
3. 2nd sunset(/sunrise) photo
4. 3rd sunset(/sunrise) photo
5. Annotated photo
6. Project quiz + essay

3.12.5 Photo Policy Acknowledgement

You will need to take several photos of the setting Sun over the course of the semester following specific directions. Taking these photos is not difficult, but it does require some advance planning. Picture requirements will be described in lab and on Moodle, but a cell phone camera is fine.

You will need to upload your own original pictures taken this semester into Moodle over the course of the semester. Submitting pictures you didn't take yourself this semester, or helping someone else to submit pictures that are not their own, is considered plagiarism and/or academic dishonesty and will be handled in accordance with the UMass Academic Honesty Policy, and may result in penalties up to a zero for the entire project.

You are responsible for saving backups of your pictures immediately, so a lost or broken phone/camera/computer is not an excuse for failing to submit your pictures on time. You can upload your pictures into Moodle as you take them and save backups of your pictures using UMass OneDrive, for example.

If you have any special circumstances that will not allow you to take sunset photos for your project. You must contact your lab instructor right away to explain the circumstances and come to alternative arrangements with them.

Please indicate that you understand these policies by typing "Y" or "yes":

3.12.6 Quiz

1. Specifics of photos
   a. First photo:
      Date: [dd/mm] and time: [hh:mm:ss]
      Azimuth of sunset/sunrise: [x] $^\circ$ (enter number only)
   b. Second photo:
      Date: [dd/mm] and time: [hh:mm:ss]
      Azimuth of sunset/sunrise: [x] $^\circ$ (enter number only)
   c. Third photo:
      Date: [dd/mm] and time: [hh:mm:ss]
      Azimuth of sunset/sunrise: [x] $^\circ$ (enter number only)
   d. Comparisons
      i. Days between 1st and 2nd picture: [x] days (enter number only)
         Sunset/sunrise shift in degrees per day: [v] $^\circ$/day (enter number only)
      ii. Days between 2nd and 3rd picture: [x] days (enter number only)
         Sunset/sunrise shift in degrees per day: [v] $^\circ$/day (enter number only)
   e. Dimensions of zoomed-in calibration photo (in degrees): Width: [w] $^\circ$ $\times$ Height: [h] $^\circ$ (enter number only)
   f. Use Stellarium to find the answer. What is the predicted azimuth for the sunset/sunrise on 21 June(/December)? [z] $^\circ$ (enter number only)

2. In the essay box below, explain the procedure you used for predicting the position of the setting(/rising) Sun on 21 June(/December) in your photo, and attach an annotated photo showing the entire horizon covering all of your sunset(/sunrise) pictures and your predicted sunset(/sunrise) position for 21 June(/December).

   The picture can be one of your sunset(/sunrise) pictures or a new picture, and it should be taken with the same zoomed-out settings as your original calibration grid photo. On the photo, mark the position of your two best measurements of the setting(/rising) Sun's position, which you will use to predict the sunset(/sunrise) position on 21 June(/December). Write the azimuth of the Sun on the picture at all three positions (two observed sunset(/sunrise) positions and predicted sunset(/sunrise) position). Also, mark on the photo the total width of your photo in degrees, based on your calibration photo.

3.13 Extra Credit Project: Photo of the Moon in the Daytime a.k.a. The Curious Incident of the Moon in the Day-time

3.13.1 Overview

Topics covered:

- Angular scale
- Observing the lunar cycle in real life

Notes:

- Students need to have a photo of the golf ball model Moon from Lab 4 (Section 3.4). They can retake the photo.

3.13.2 Materials needed

Instructors:

- Moon model golf ball
- Mount for golf ball
- Measuring tape

Students:

- Camera

3.13.3 Script

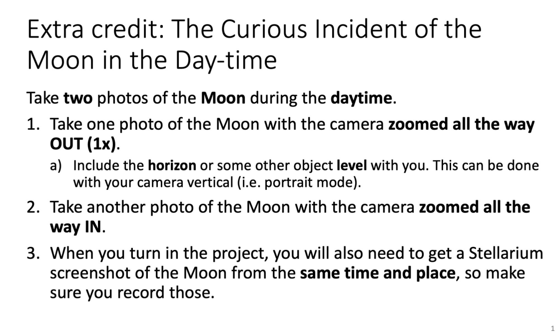
Pick up copies of the project worksheet. Take a fully zoomed-in picture of the golf ball "Moon" from the correct relative distance. It should be the same size as you will find for the real Moon!	

Take 2 photos of the Moon during the daytime.

1. With horizon: Take a picture of the Moon with the camera zoomed all the way OUT. Include the horizon or some other object level with you. This can be done with your camera vertical (i.e. portrait mode).

2. Zoomed in: Take a second picture of the Moon with the camera zoomed all the way IN.

Also, get a Stellarium screenshot of the Moon from the same time and place.



Here's an example.
Submissions:

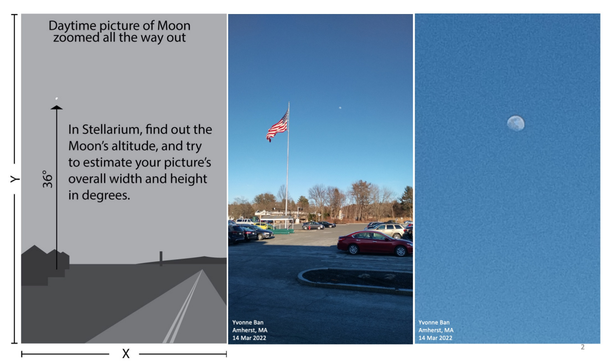
1. Photo of Moon in daytime: zoomed-out with horizon

2. Photo of Moon in daytime: zoomed-in on Moon

3. Photo of golf ball model Moon: zoomed-in from scale distance

4. Project quiz

5. Project report



3.13.4 Submissions

Moodle:

1. Photos of Moon in daytime
   - Zoomed-out with horizon
   - Zoomed-in on Moon
2. Zoomed-in photo of golf ball at to-scale distance
3. Project quiz
4. Project report

3.13.5 Quiz

1. Specifics of photos
   a. Date: [dd/mm] and time: [hh:mm:ss]
   b. Dimensions of zoomed-out calibration photo (in degrees): Width: [w] $^\circ$ $\times$ Height: [h] $^\circ$ (enter number only)
   c. Dimensions of zoomed-in calibration photo (in degrees): Width: [w] $^\circ$ $\times$ Height: [h] $^\circ$ (enter number only)
   d. Obtain the answers for this and the following sections using Stellarium. In your photos, what was the:
      - Azimuth of Moon: [x] $^\circ$ (enter number only)
      - Altitude of Moon: [y] $^\circ$ (enter number only)
   e. What time did the sun rise on this date? [hh:mm:ss]
      What time did the sun set on this date? [hh:mm:ss]
2. In the essay box below:

   (1) Compare the altitude of the Moon to the height (in degrees) of your zoomed-out calibration picture. Do these values make sense? Explain how they make sense or what might explain any discrepancy.

   (2) For the zoomed-in picture, how big is the Moon compared to the width (in degrees) found in your zoomed-in calibration photo? Do you get approximately 0.5° for the width of the Moon? Explain how you are making your estimate and/or any problems you had in making the measurement.

   (3) Remember that picture we asked you to take of the golf ball in Lab 3?* Place it alongside your zoomed-in photo of the Moon in a document and upload it here. Comment in the essay box how similar or different are the sizes in the two photos and discuss any difficulties.

   *If you need to redo your photo of the golf ball, you can repeat it by taking a photo of a golf ball from 15 ft 5 in away. Remember that you must use exactly the same settings in your camera as for the zoomed-in photo you took of the Moon.

4 Past schedules and notes

4.1 Fall 2020

First fully remote semester. Adapted labs to be 2 weeks each with lecture in first week, remote and recorded. Lab 2: Angular Sizes on the Sky (3.2) and camera calibration for project were skipped due to remote learning. Extra-credit project (3.13) was used for credit.

Table 15: Fall 2020 schedule

Week	Lab
1	Lab 1: Astronomical Angles and Stellarium (3.1)
3	Lab 5: Motions of the Sun (3.5) and Project (3.12)
5	Lab 4: Phases of the Moon (3.4) and Extra-credit project (3.13)
7	Lab 7: Calendars, Horoscopes, and Precession (3.7)
9	Lab 8: Motions of the Planets in the Sky (3.8)
11	Lab 9: The HR Diagram (3.9)
13	Turn in Project

4.2 Spring 2021

Fully remote semester. Same format as 4.1.

Table 16: Spring 2021 schedule

Week	Lab
1	Lab 1: Astronomical Angles and Stellarium (3.1)
3	Lab 5: Motions of the Sun (3.5) and Project (3.12)
5	Lab 4: Phases of the Moon (3.4) and Extra-credit project (3.13)
7	Lab 7: Calendars, Horoscopes, and Precession (3.7)
9	Lab 8: Motions of the Planets in the Sky (3.8)
11	Lab 9: The HR Diagram (3.9)
13	Turn in Project

4.3 Fall 2021

Return to in-person classes.

Table 17: Fall 2021 schedule

Week	Lab
1	Lab 1: Astronomical Angles and Stellarium (3.1)
2	Lab 1: Astronomical Angles and Stellarium (3.1)
3	Lab 5: Motions of the Sun (3.5)
4	Lab 2: Angular Sizes on the Sky (3.2) and Project (3.12)
5	Lab 4: Phases of the Moon (3.4) and Extra-credit project (3.13)
6	Lab 6: Solar Power (3.6)
7	Makeups
8	Lab 3: Angular Size vs. Distance (3.3)
9	Lab 9: The HR Diagram (3.9)
10	Lab 10: Distances of Stars in Space (3.10)
11	Lab 11: Structure of the Local Group (3.11)
12	Turn in Project/makeups

Table 18: Spring 2022 schedule

Week	Lab
1	Lab 1: Astronomical Angles and Stellarium (3.1)
2	Lab 1: Astronomical Angles and Stellarium (3.1)
3	Lab 5: Motions of the Sun (3.5)
4	Lab 2: Angular Sizes on the Sky (3.2) and Project (3.12)
5	Lab 4: Phases of the Moon (3.4) and Extra-credit project (3.13)
6	Lab 6: Solar Power (3.6)
7	Makeups
8	Lab 3: Angular Size vs. Distance (3.3)
9	Lab 9: The HR Diagram (3.9)
10	Lab 10: Distances of Stars in Space (3.10)
11	Lab 11: Structure of the Local Group (3.11)
12	Turn in Project/makeups

4.4 Spring 2022

5 Acknowledgements

First, foremost, and most fundamental, our deepest and highest thanks go to Prof. Stephen Schneider, a veritable fount of both knowledge and wisdom throughout his leadership of the course and and his guidance of us, without whom this course could not possibly accomplish even the most basic understanding and organisation, much less the transformative learning and enlightenment that it does. Needless to say, without such unfailingly steadfast and tireless efforts, this manual, which only aims to faithfully capture the amazing work already put into composing and refining this unique course, could never even observe the electromagnetic radiation of solar daytime. In particular, with the onset of the COVID-19 pandemic and accompanying worldwide quarantine measures, Prof. Schneider pulled from unfathomable reserves of persistence, foresight, and knowledge to adapt the course on-the-fly for the abrupt and drastic challenges that befell us, a feat that is both impressive and inspirational. I am enormously grateful for everything he has taught me about teaching, life, the universe, and everything, and I know his students are similarly grateful for his utmost dedication to their learning.

In a close second place, I must thank (the now Dr.!) Patrick Kamieneski, for his many years leading the on-the-ground running of the course. I was able to draw extensively on his example and his knowledge to make this manual the most complete and comprehensive it could be, and indeed his efforts were essential, both in the continued smooth running of the course through times both thick and thin, and in updating and adapting the course for each semester. I am especially grateful to him both for his memory and for letting me tap out of leading lab sections without complaint. I wish him the best and look forward to his continued achievement in his upcoming career.

I must of course extend my deepest gratitude to my other fellow T.A.s in the trenches, those of us who shared in the noble work of education together. I do wish to single out Sumner Gubisch for generously helping me with the tedious busywork of this document, and, along with all our other undergrad T.A.s, sparing his time and energy to help with making our classes run as smoothly as possible. The maturity and leadership that they consistently demonstrate gives me great assurance for their future endeavours, and it was a pleasure working with each and every one of them. I'd also like to thank Sarah Linehan for her contributions to this manual, and apologise to Sarah Bodansky for spilling my entire bottle of hot tea over both our computers in the middle of class. To my other fellow T.A.s, my words fail me and my gratitude must be encapsulated in a humble: thank you.

Last but, of course, not least, my thanks to my students, especially those who gave me feedback about the course. After all, they are who I made this for.

Appendix: Worksheets

N.B.: The worksheets here are for reference only and are **not** print-ready. To get print-ready worksheets, reference Section 0.4, and use the worksheet master document `ws.tex`.

0 General

0.1 Syllabus

0.1.1 Class information

Astronomy 100/1 Lab is conducted in tandem with Astronomy 100 and(/or) 101 courses and is required to be taken simultaneously.

The goal of Astronomy 100/1 Lab is to introduce some basic aspects of observational astronomy, and help relate that knowledge to the broader science of astronomy, which the lecture portion of the course focuses on. We will explore many aspects of the day and night sky to learn how objects move over the course of the day, month, and year, and how the patterns of what we see in the sky change from different parts of the Earth. We will also carry out several activities to help explain important ideas in astronomy.

Each semester, 6 independent sections are held on Monday, Wednesday, and Friday of every school week at 12:20-1:10pm (1220-1310) and 1:25-2:15pm (1325-1415). Every section is held in the Integrated Learning Center (ILC) room S220.

To reduce paper wastage, much of the course information is posted on Moodle. Check there regularly for announcements and any schedule changes as well.

0.1.2 Instructors

Course coordinator:	Prof.	@astro.umass.edu
Mon 12:20pm lead TA:		@astro.umass.edu
Mon 1:25pm lead TA:		@astro.umass.edu
Wed 12:20pm lead TA:		@astro.umass.edu
Wed 1:25pm lead TA:		@astro.umass.edu
Fri 12:20pm lead TA:		@astro.umass.edu
Fri 1:25pm lead TA:		@astro.umass.edu

When contacting your section TA or the course coordinator, please remember to put "Astro Lab" in the subject of your email. Most questions can be answered by your section TA. However, also note that Astronomy 100/1 Lab is **distinct** from Astronomy 100/1 lecture, so **the lab TAs cannot help you with questions about the lecture class**.

0.1.3 Grading

The Astronomy Lab total grade makes up 25% of the overall Astronomy 100/1 course grade, and does not have a separate grade. The remaining 75% of the Astronomy 100/1 course grade comes from lecture assignments and exams.

There are 8 labs that together contribute 80% of your overall lab score, and the remaining 20% is from the lab Sunset Project. There are also opportunities for extra credit.

Most of the lab work is done during section, so attendance and participation is critical to your grade. Your lab grade will usually raise your overall course grade **if** you attend lab every week and take all the required photos correctly. However, failure to attend will certainly lower your overall grade.

Grading of each lab is based primarily on participation, which is recorded using Moodle. Hence, please bring a smartphone, tablet, or notebook computer to lab. If you don't have one available, you can log in on one of the computers in class.

Submitting a photo that someone else took is plagiarism under the UMass Academic Honesty Policy, and it will be dealt with accordingly. If you have questions about what is or isn't allowed, please ask your lab instructor.

0.1.4 Attendance and schedule

Table 19: Lab schedule

Week	Month	M	W	F	Lab
1					1
2					1
3					2
4					3
5					4
6					Makeup
7					5
8					6
9					7
10					8
11					9
12					Makeup
13					Break
14					
15					Reading
16					Exams

For the project, you will need access to a digital camera (a cell phone camera is fine). You will take your own original pictures and upload them to Moodle over the course of the semester. Taking the photos is not difficult, but does require some advance planning. We will cover this in detail in Lab 3.

We also advise you to keep your lab worksheets from each week, since we will sometimes refer to them in later labs.

If you must miss a lab at your regularly scheduled time, e.g. if you are ill or have a University-sponsored event:

First, try to make up the lab at one of the other sessions the same week. Look at the lab schedule in Table 19 for a section with the same Lab number, and make sure to email the course coordinator with your proposed switch and reason.

If you can't make it, there will be make-up lab sessions for each lab later in the semester, during make-up weeks, also listed in the schedule. A specific schedule will be released closer to the date. Note that make-up sessions have to accommodate the team-based nature of the labs, so individual make-ups are not possible.

0.2 Stellarium Guide

0.2.1 Installation

You can download Stellarium for your own computer (Mac, Windows, Linux) at `http://www.stellarium.org`. The software is free, and there are links to extensive documentation on the website.

0.2.2 Quick Usage Guide

After installing it, use the following walk-through to familiarise yourself with the basics of how the program works.

N.B.: If pressing the function keys (F1 – F12) isn't working, press down the Fn key (keyboard lower left corner) and press the function key.

1. Open Stellarium.
2. The default location is Paris (seen in the lower left corner). For observations made from Amherst, we need to change the location.
   i. Move the cursor to the lower-left side of the window and click on "Location Window", or press F6.
   ii. In the "Location" window, in the entry field next to the magnifying glass (for searching), type "Amherst". Then, click on "Amherst Center, United States". (**DO NOT** type "Amherst" into Name/City. It will just rename Paris to Amherst, but won't change the location. Also **DO NOT** select "Amherst, United States".)
   iii. Close the window by clicking on the cross (×) in the upper right corner.
3. Change the Date/Time to a value, e.g. 2015/09/01, 14:00:00.
   i. Move the cursor to the lower-left side of the window and click on "Date/Time Window", or press F5.
   ii. Change the date and time either by entering the values directly or using the arrow keys to increase or decrease the values.
   iii. Close the window by clicking on the cross (×) in the upper right corner.
4. Click and hold the cursor on a spot in the window, and drag it around to look in various directions.

5. Zoom in by scrolling **UP** and zoom out by scrolling **DOWN** (on touchpad, mousepad, mouse, etc.)

6. Zoom out till you see the full sky in your screen. You should see only the Sun.

   i. To turn the atmosphere visualisation on or off, move the cursor to the bottom of the window on the left side and click on the cloud icon, or press A.
   ii. To turn the ground visualisation on or off, move the cursor to the bottom of the window on the left side and click on the trees icon, or press G.
   iii. To turn the constellation lines on or off, move the cursor to the bottom of the window on the left side and click on the "N"-shaped icon, or press C.
   iv. To turn the constellation names on or off, move the cursor to the bottom of the window on the left side and click on the mirrored "N"-shaped icon, or press V.
   v. To turn the constellation art on or off, move the cursor to the bottom of the window on the left side and click on the person-shaped icon, or press R.
   vi. To turn the stars on or off, press S.

7. Click on Saturn. Notice that some information about Saturn pops up at upper left corner of the window.

   i. Press the space bar to center the view on the selected object, Saturn.
   ii. Zoom in until the field of view (FOV at the bottom of screen) is 0.1°. What objects other than Saturn can you see?
   iii. To start and stop the progression of time, move the cursor to the bottom of the window on the left side, move to the right end of the toolbar, and click on the "play" icon, or press K.
   iv. To increase the progression of time, move the cursor to the bottom of the window on the left side, move to the right end of the toolbar, and click on the "fast forward" icon, or press L.
   v. To decrease the progression of time, move the cursor to the bottom of the window on the left side, move to the right end of the toolbar, and click on the "rewind" icon, or press J.
   vi. To return to the present time, move the cursor to the bottom of the window on the left side, move to the right end of the toolbar, and click on the "hourglass" (2 triangles vertically stacked, points facing each other) icon, or press 8.

8. Search for an object, e.g. the Sun.

   i. Move the cursor to the lower-left side of the window and click on "Search Window", or press F3.
   ii. Enter the name of the object you are searching for.
   iii. Close the window by clicking on the cross (×) in the upper right corner.

9. Play around and familiarise yourself with the software. For help, press F1.

1 Lab 1: Astronomical Angles and Stellarium

1.1 Worksheet

1.1.1 Background Survey on Moodle

Log in to Moodle (on smartphone, laptop, or one of the computers at the table). Go to the section for Astronomy Lab 1 and complete the Astronomy Background Survey. Don't worry if you don't know the answers, just answer every question as best you can and you will receive full credit.

1.1.2 Stellarium

Stellarium is a planetarium software that helps us visualise the sky over time. We'll use it to begin our exploration of astronomy.

1. Go to `http://stellarium.org/` and download and install the correct version for your operating system. If you can't find it, use Stellarium Web.
2. Open the Location Window from the left-hand menu panel or by pressing F6. In the search bar under the top right, menu type "Amherst" and select "Amherst Center, United States".
   - Make sure it's "Amherst Center", not "Amherst" (that's in NY somewhere).
   - **Do not type** into the "Name/City" box. That renames the location.
3. Close the Location Window and open the Date/Time Window from the left-hand menu panel or by pressing F5. Set the time to 7:00pm tonight. Close the window.
4. Look at what the sky will look like tonight. Drag the view and scroll up or down to zoom in or out respectively.

1.1.3 Positions of Astronomical Objects

In astronomy, we use angles to measure positions and separations of objects in the sky. From your point of view, an object's position is given by **azimuth** and **altitude**. Answer the following questions.

1. How many degrees are in a circle?
2. How many degrees are in a right angle?
3. What are longitude and latitude?
4. What is the azimuth/altitude system?

Astronomers use the **sexagesimal** system for recording angles. Each degree is divided into 60 **arc minutes** ($'$), and each arc minute is divided into 60 **arc seconds** ($''$). An azimuth of $240°38'12''$ is read as 240 degrees, 38 arc minutes, and 12 arc seconds.

Set the time to 2022/1/31 at 6:00pm. Locate the object and click on it, then answer the following. At this time, what is the azimuth and altitude of:

Object	Azimuth	Altitude
Betelguese		
Jupiter		
Sirius		

Now advance the time by a few minutes. Do the azimuths and altitudes increase or decrease?

1.1.4 Moodle Lab Quiz

Go to the section for this lab on the Moodle page and complete the End-of-Lab Quiz.

If you logged into your Moodle account from a classroom computer, be sure to log back out!

2 Lab 2: Angular Sizes on the Sky

2.1 Worksheet

2.1.1 Photo Policy Acknowledgement on Moodle

On Moodle, under the section for this lab, carefully review and respond to the Photo Policy Acknowledgement. **You will not be able to get credit for the other activities OR the lab project until you do!**

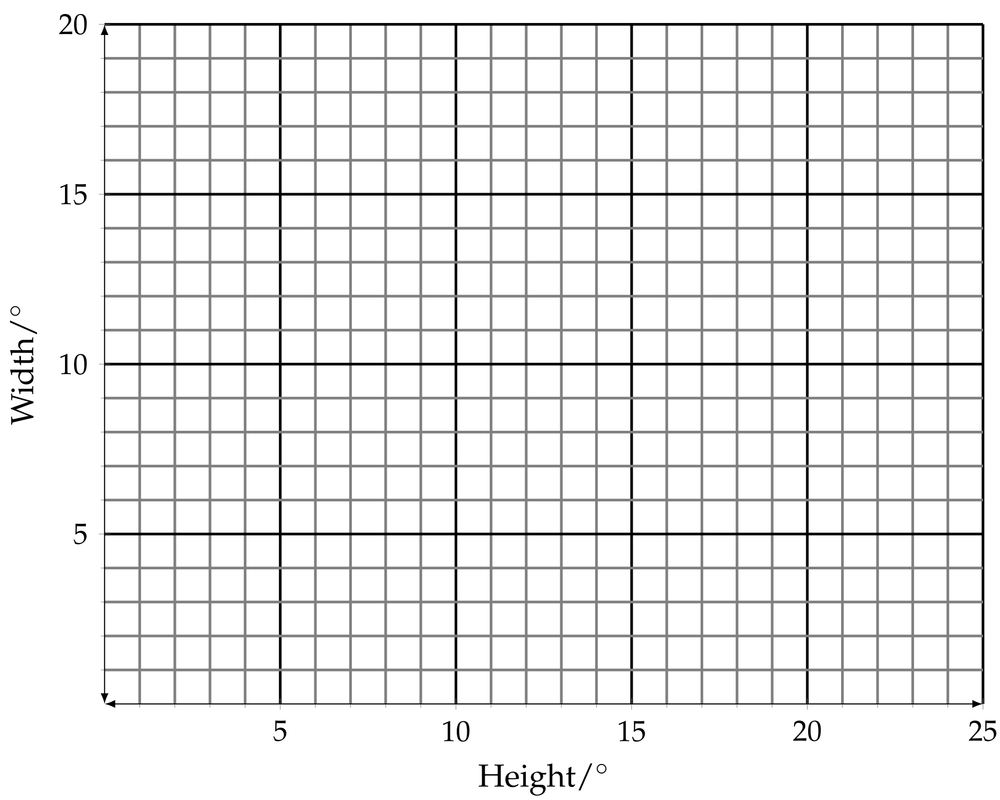
2.1.2 Angular sizes

We will use a uniform grid to get a sense of how to consistently compare the angular sizes we see.

1. Stand with your eye/camera located 12 ft from the screen. Look at the floor plan to determine where you should stand. At this distance, the squares on the grid are 1° wide on each side.

2. Try out things you can use to estimate different angles, e.g., your outstretched hand, your thumb, a credit card, a coin, a key, or even a cell phone that you always have with you. Write down what you use and sketch how they appear on the grid.

   Be consistent! E.g., if you are using 4 fingers at arm's length, always hold them out at full arm's length.



Size	1°	5°	10°	20°
Object				

2.1.3 Calibrating your camera (angular field of view)

At a set zoom level (as well as picture size i.e. height/width ratio), your camera will always cover the same angular dimensions. This is also often known as a **field of view**. Let's find out what they are by calibrating your camera.

1. Hold your camera at the same position as before, i.e. 12 ft from the screen. Make sure your **camera** is located at the 12 ft mark.
2. Zoom in as far as you can on your camera.
3. Take a photo of the grid. Try to align it with the screen.
4. Count the number of squares on each side of your picture. This will give you the angular size of each side.
5. Record all your findings and settings below.

Zoom level	Other settings	Angular size: Height	Angular size: Width

Now let's use what we've learnt to do some astronomy! First, we'll use the visual estimates from the second section.

1. Look at the Stellarium view projected on the screens. It simulates a real-life view of the night sky at the same scale as the grid before.
2. Use similar things to those in Part 1 (fingers, coin, etc.) to estimate angular sizes and answer the questions below. **Remember to be consistent! Hold your arm out at full length!**
   (a) How many degrees is Aldebaran from the Pleiades cluster of stars?

   ____

   (b) Which of your angular measures (such as hand, thumb, pencil) is most similar in angular width as the Pleiades?

   ____

   (c) How many times wider is your outstretched finger than the Moon?

   ____

3. Take a photo of the projected Moon like you did for the grid:
   - Fully zoomed in
   - Held at 12 ft from screen
4. Compare it with your calibration picture and calibrated values. How big is the Moon?

___

2.1.4 Taking a zoom back

Now let's calibrate your camera fully zoomed out.

1. Zoom out on your camera to 1x. **If your camera has 0.5x zoom or similar, do not use it.**
2. Take a photo of the grid from 12 ft. You'll see that the screen appears much smaller. Compared to before, when your camera was zoomed in, approximately how many times wider and taller is your camera field of view now? How does this compare to your previously recorded zoom level?

   ___

3. Move your camera approximately 3 ft from the screen using a yardstick.
4. Take a photo of the new grid, which has lines every 5°.
5. Count the number of squares on each side of your picture **and multiply that number by 5**. This will give you the angular size of each side.
6. Record all your findings and settings below.

Zoom level	Other settings	Angular size: Height	Angular size: Width

As you end up standing 4× closer to the screen, the projected grid has cover an area that is 4× taller AND 4× wider in order to be consistent. In general, when you get x times closer to an object, its angular size will get x times bigger.

Now, we'll look at a simulation of a sunset view, similar to the pictures you'll be asked to take for the sunset project.

1. Look at the Stellarium view projected on the screens. It simulates a real-life view shortly before sunset.
2. With your camera 3 ft from the screen, take a photo of the screen.

3. Compare it with your calibration picture and calibrated values to find the following, keeping in mind that the azimuth of due west is 270°.

Azimuth of Sun	
Altitude of Sun	

2.1.5 Moodle Lab Quiz

Go to the section for this lab on the Moodle page and complete the End-of-Lab Quiz and upload your calibration pictures on Moodle by the end of the week. Also, remember to fill out the Photo Policy Acknowledgement.

If you switch to a new camera or change your settings, let your TAs know. There will be opportunities to re-calibrate your camera with the grids in future labs.

3 Lab 3: Angular Size vs. Distance

3.1 Worksheet

In groups at each table, you will investigate how the angular diameter of a spherical body (a ball) depends on its distance from you.

3.1.1 Data and Graph

1. At your table, discuss and agree on a plan for how to make measurements of the sphere to explore the relationship between its angular size and distance. Consider:

   a. What distances will you make measurements from?

   b. How will you measure the distances?

   c. Will you repeat the measurement with different people? (This is called replication.)

   d. What will you do if points disagree?

2. Make sure each person makes **at least one** measurement of the ball's angular size and distance. Record your measurement below.

   (a) Angular diameter of ball (to nearest half-degree): ________

   (b) Distance from ball: ________

   Record all your measurements on the table worksheet. Mark the the position of your measurements at your table to **graph all the points in the table worksheet.**

3. Select someone at your table to **graph all the points in the table worksheet.**

3.1.2 Interpreting the Graph

Look over the points plotted by your group and discuss the following:

1. Do the points exhibit a pattern? How would you describe that pattern in words?

2. How might you describe the relationship mathematically?

3. Do all the points agree with each other? What factors might explain the differences we see?

3.1.3 Angular Size of Astronomical Objects

1. Let's consider the Sun.

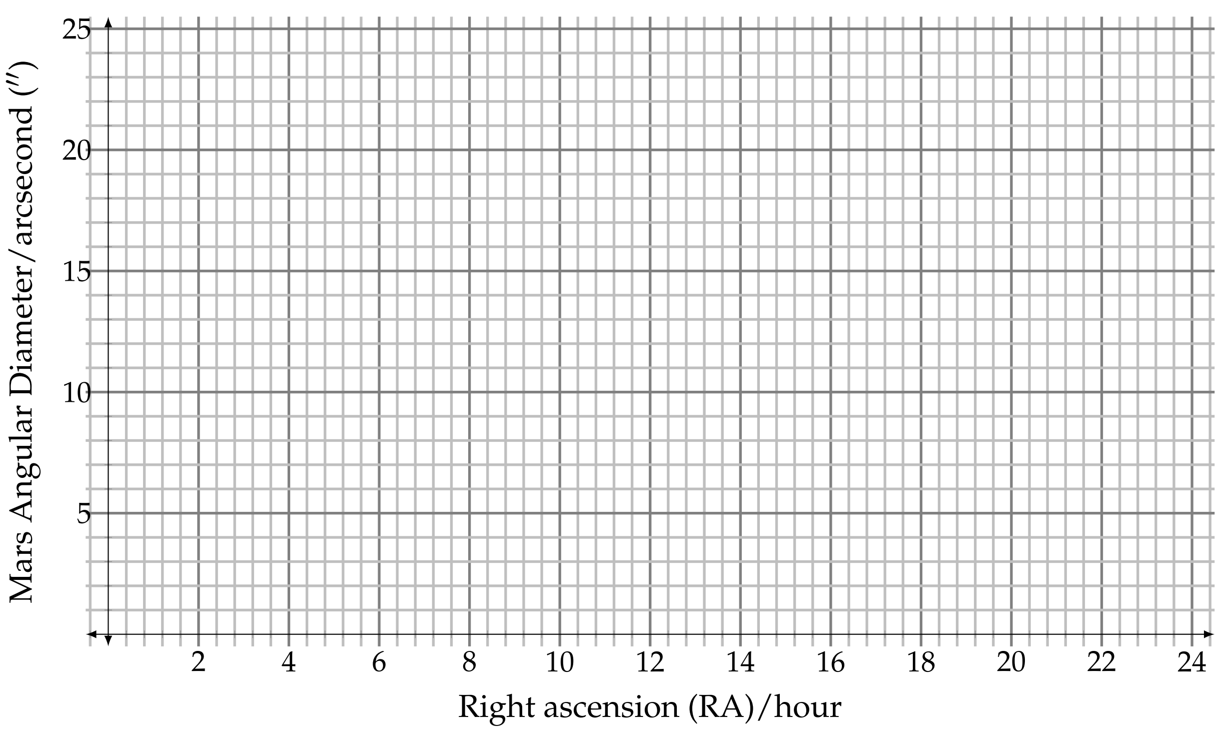
   a. Does the Sun's angular size changes during the year?

   b. What month is it the smallest? ________

2. Now let's look at the Moon.
   a. Is the Moon larger when it's full?
   b. What is a supermoon?
   c. Is the Moon larger when it's near the horizon?

The planet Mars shows the greatest variation in size of all the planets, which we will explore here.

1. In groups of 2-3, start up Stellarium. Find where Mars is today. You can turn off the atmosphere (hit A) and ground (hit G) to help.
2. Once you have found Mars, you can click on it and center the view (by pressing the space key). Take note of Mars's angular diameter (given as "Apparent diameter" in the left-hand side info panel.
3. Zoom in until Stellarium renders some surface features.
4. You are going to look at how Mars's **angular diameter** and **right ascension ("RA")** values each change over time. To do this, open the Date/Time window and vary the date from October 2021 to October 2023, one month at a time. At each date, take note of Mars's **angular diameter** and **right ascension ("RA")**. These are the values you will plot (**NOT** the date!).
5. Plot Mars's angular diameter vs. right ascension in the grid below and answer the following questions.



a. How big is Mars in October 2021? __________ arcseconds
b. Where is it in its orbit in October 2021?
c. In what month is Mars largest? __________
d. How big is it that month? __________ arcseconds
e. What explains the pattern of sizes you find in your graph?

3.1.4 Moodle Lab Quiz

Go to the section for this lab on the Moodle page and complete the End-of-Lab Quiz. Write your name on the Table Worksheet and hand it in.

3.2 Table worksheet

3.2.1 Table no.

Fill in your section and table number below.

- Section: ________
- Table no.: ________

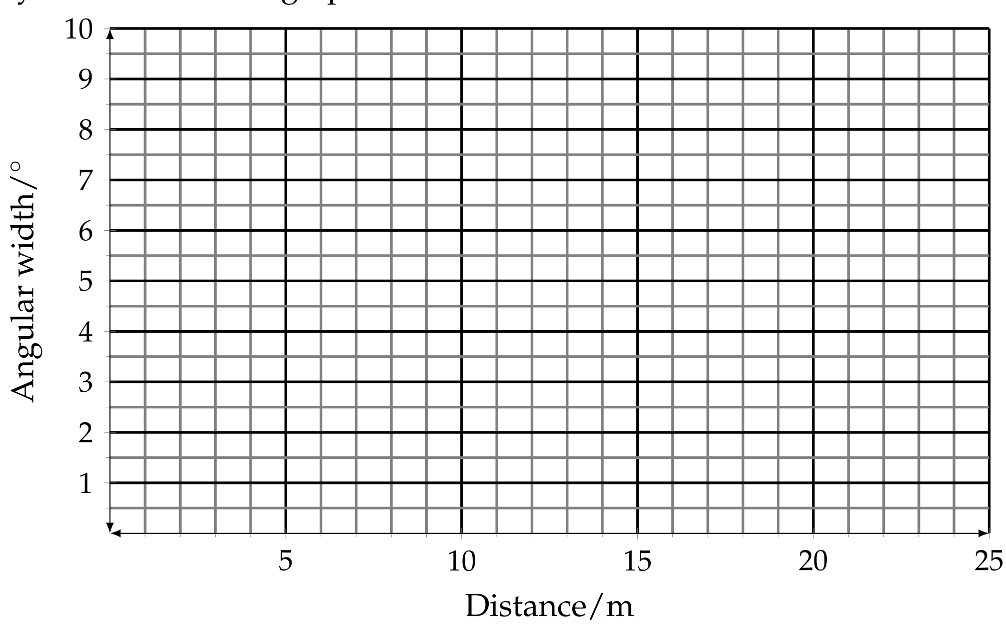
3.2.2 Measurements

Write your name, distance from object, and angular width measurement below.

Name	Distance (m)	Angular width (°)

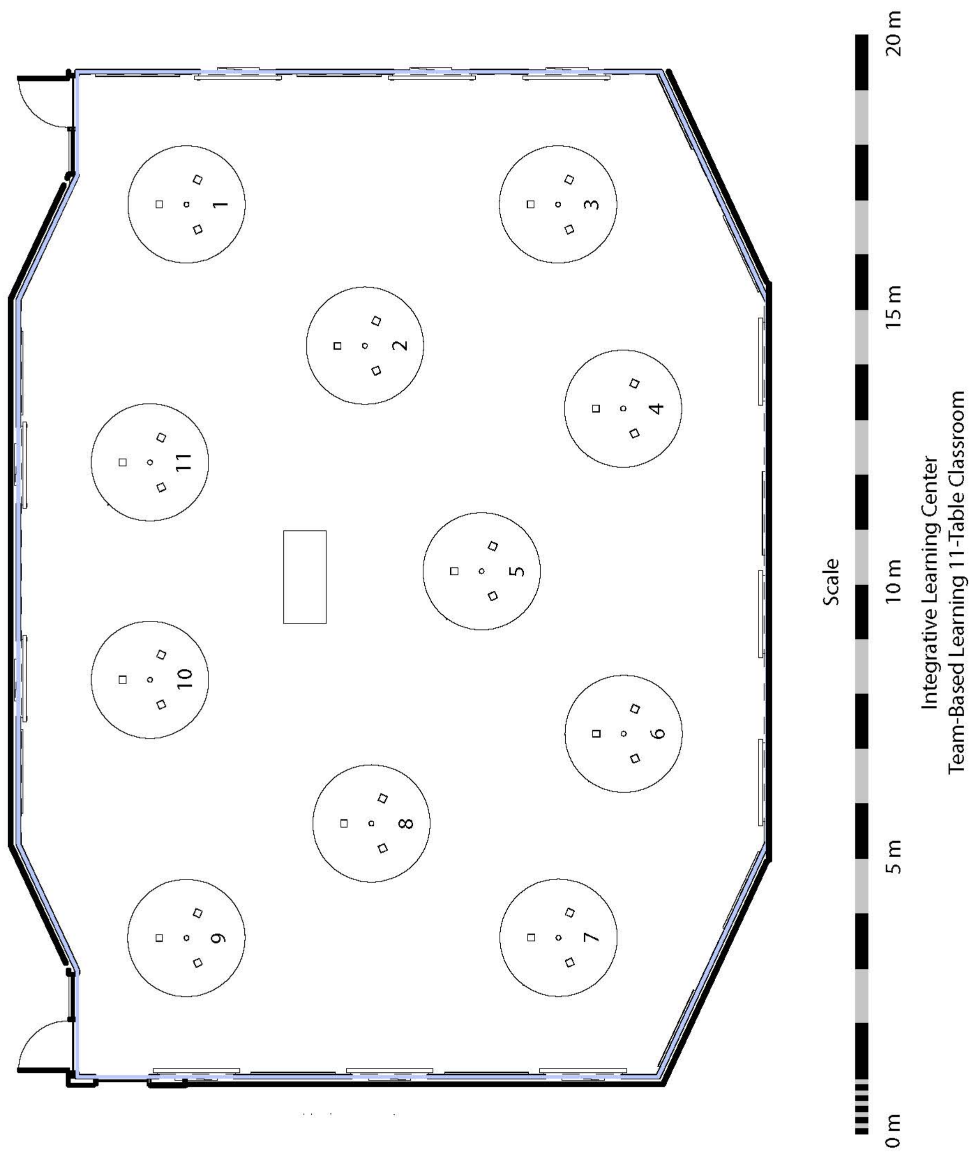
3.2.3 Plot

Plot your results in the graph.



3.2.4 Location diagram

Mark the locations where you took your measurements in the diagram.



4 Lab 4: Phases of the Moon

4.1 Worksheet

4.1.1 Actual Scale of the Earth and the Moon (Class demo)

1. Suppose the Moon is the size of a golf ball. On this scale, how big is the Earth? **Lower** your hand when you think the demo balloon is at the right size.

2. On this scale, how far would the golf ball Moon be from Earth? **Lower** your hand when you think the demo balloon is at the right distance.

   Relative to the size of the golf ball, this distance is the same as the as the distance from the Earth to the Moon, relative to the size of the real Moon. Hence, **the angular sizes are the same.** If you take a zoomed-in picture of the golf-ball at this distance and compare it to your zoomed-in calibration grid, you will find the golf ball has the same angular size as the real Moon.

3. As part of the extra credit project, take a picture of the golf-ball Moon from the to-scale distance.

4.1.2 Modelling the Moon's Phases

You will each get a golf ball with a hole in it so you can put it on a pen or pencil and hold it up. Each table will have a light source that will represent the Sun.

1. To first understand Earth's rotation in relation to the Sun, begin by picturing your head as the Earth. Imagine the top of your head is the North Pole, with Boston at your left eye, and San Francisco your right eye. Take the light bulb on the table to be the Sun.

   a. Which way does your head face when it is noon in Boston?
   b. Which way does your head face when it is noon in San Francisco?
   c. Which way does your head turn to go from noontime in Boston to noontime in San Francisco?

2. Let's examine the Moon's phases as it orbits the Earth. Make sure that you can see the portion of the Moon lit by the "Sun" in your table.

   a. Look for the **crescent** phase, and estimate the angle between the Sun and the Moon (with the Earth at the vertex) when the Moon is a crescent.
   b. Can you ever see a crescent Moon at midnight?
   c. Where is the Moon when it is **new**?
   d. Where is the Moon when it is **full**?
   e. Where is the Moon when it is **gibbous**?

3. Suppose the Moon is at **first quarter**.

a. When should it cross your **meridian**?

b. When does it rise, and when does it set?

4.1.3 Observing the Moon's Phases

1. In groups of 2-3, start up Stellarium.

2. Set up Stellarium for Amherst Center (F6) on 23 February 2022 (F5). Look toward the **east** and adjust the time until you see the Moon rising.

   a. What time does the Moon rise?

   b. Press the semicolon ";" key to turn on the meridian line. What time does the Moon cross the meridian?

   c. What time does it set?

3. If you were taking a picture of the Moon in the daytime, what is the range of times you could take a picture on 23 February 2022?

4. Zoom in on the Moon and look at its shape.

   a. What is its phase on 23 February 2022?

   b. Turn off the ground and center the view on the Moon. Advance the day by opening the Date/Time window, and then clicking the up-arrow (↑) above the day's date, until the Moon is next at first quarter. What is the date?

   c. How can you tell whether a "half-lit" Moon is in the first or third quarter?

5. On this new date,

   a. What time does the Moon rise?

   b. What time does the Moon cross the meridian?

   c. What time does it set?

6. Advance the date by 1 day. What time does the Moon rise? Cross the meridian? Set on this date?

   a. What is the Moon's phase?

   b. What time does the Moon rise?

   c. What time does the Moon cross the meridian?

   d. What time does it set?

   e. What are the differences from Part (6)?

7. Keeping the same time, change your location to Australia (hit **F6** and click on Australia in the location window). What phase is the Moon in?

8. Now, change your location to the Moon and look back at the Earth (search for and select "Moon" in the Location window). What phase is the Earth in?

4.1.4 Moodle Lab Quiz

Go to the section for this lab on the Moodle page and complete the End-of-Lab Quiz.

5 Lab 5: Motions of the Sun

5.1 Worksheet

1. The Sun's Position at Noon

In groups of 2-3, follow along the steps demonstrated by the instructor.

a. Set up Stellarium
   i. Open the Location window and set the location to Amherst Center.
   ii. Open the Sky and Viewing Options window.
      a) Under the "Sky" tab,
         1) Set "Stars Absolute Scale" to 0.0 (or the lowest it will go)
         2) Uncheck "Show Atmosphere"
         3) Under "Projection", select "Cylinder"
      b) Under the "Markings" tab,
         1) Check "Azimuthal Grid"
         2) Check "Meridian"
   iii. Zoom all the way out while staying centered on the South horizon point.
   iv. Open Date/Time window and change the date to 21 September.
   v. Find the time (to within a few minutes) when the Sun is crossing the meridian (azimuth $0°00'$ or $180°00'$, running from due north to due south). What time is it? What might cause it to **not** be 12:00 noon?

b. Plot the **altitude** of the Sun as it **crosses the meridian** on the 21st of each month throughout the year.

5.1.1 The Sun's Path during the Day

Watch the Sun's path across the sky on 21 June and 21 December (the summer and winter solstices) over the whole day. On these dates, the Sun reaches its extreme north and south positions respectively. You can advance time faster or slower (or reverse it) using the and buttons in the bottom menu bar, or by **pressing the L and J keys**. Discuss what you see in your groups and answer the following questions:

a. The Sun does not always set due west! What azimuth range do you see it setting over?

____

b. The Sun doesn't approach the horizon going straight down! Sketch what you see in Stellarium. Is the angle the same at both solstices?

____

c. What is the Sun's azimuth at sunset on the equinoxes (22 September and 20 March)? (If there is "landscape" in the way, look for when the Sun's altitude is near zero.)

____

d. Suppose there are mountains rising to an altitude of 10° to the west. How would that affect the azimuth of sunset (when the Sun passes behind the landscape, including mountains) on the equinox?

____

5.1.2 The Sun's Position at Different Latitudes

Work in pairs and have one person do each part. Then, plot the Sun's noontime altitude throughout the year for both parts in the grid. (Make sure to record the values for the quiz.)

Note: when seen from the southern hemisphere, the Sun crosses the meridian in the **northern** sky!

City	Latitude	Sun max. altitude	Month
Pick a city between S 24°–60°:			
Pick a city in the tropics (between N 23° and S 23°):			

5.1.3 The Sun's Path at Different Latitudes

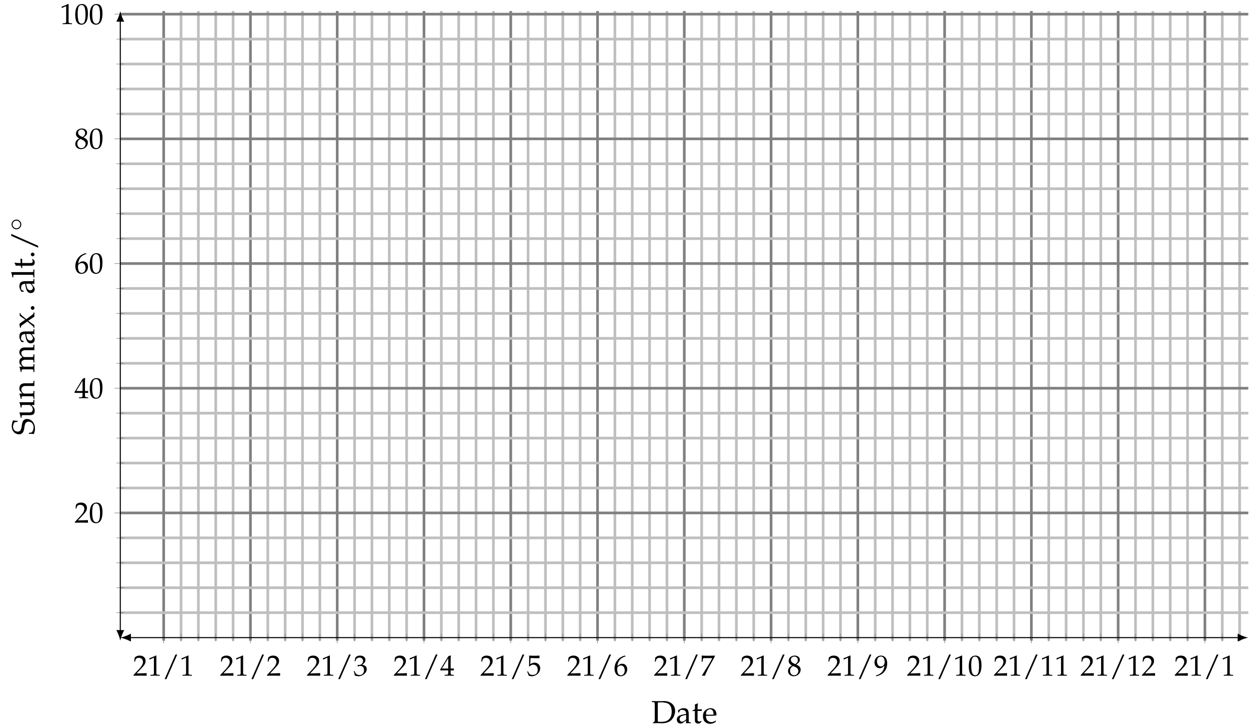
Now, let's look at how the Sun moves across the sky from different locations on Earth. Follow along with your instructor as below:

Open the Location window and type into the "Latitude" entry "N 66d 30m" (note where the spaces are). You should see the red arrow on the map jump to a location north of Amherst Center. (Leave the longitude unchanged from Amherst Center (W 72°) so the time zone stays the same.)

a. At the Arctic Circle (N 66° 30′) and northward, you can sometimes get 24 hours of daylight, and vice versa. Note how the Sun's path becomes more horizontal closer to the North Pole.

b. At the Equator (N 0°), notice how the Sun moves straight up and down as it approaches the horizon. Why would this make twilight shorter in the tropics?

____



c. From locations at mid latitudes in the Southern Hemisphere, the Sun approaches the horizon at an opposite angle from what we see, and the Sun spends most of the day in the **northern** sky. Note: Does this mean that the Sun is travelling in the opposite **direction** (east or west)?

____

5.1.4 Moodle Lab Quiz

Go to the section for this lab on the Moodle page and complete the End-of-Lab Quiz. Note that some of the questions will depend on what city your team picked for part (3), so be sure to enter the correct latitude of that city.

6 Lab 6: Solar Power

6.1 Worksheet

As a team at your table, you will carry out 2 experiments. For these experiments you have:

1. A flashlight
2. A metre stick
3. A protractor

First, decide on your roles in the experiments, e.g., experimentalist, note taker, calculations, number checker, graphing, etc. Once you've decided as a team, write down your members and roles on the Lab 6 Table Worksheet. Make sure everyone participates in observation at some point in experiment 1 or 2.

N.B.: Be sure to mark your table number on the end-of-lab quiz or you may not receive credit!

6.1.1 Power vs. Distance

In this experiment, you will measure how distance and angle affect the intensity of sunlight, and corresponding energy, that falls on the ground.

1. For this experiment, push the sleeve on the front part of the flashlight all the way **in**, i.e., make the total length of the flashlight as **short** as possible.

2. Shine it at the whiteboard straight on from 0.5 ft away. As a group, find and agree on the position of the edge of the beam.

   You can use markers to outline the dimensions a and b of the flashlight beam. They should be about the same, i.e., the beam should be circular.

3. Next, shine the flashlight at the whiteboard and measure the height a and width b of the beam from several different distances. Make measurements with the light bulb at 0.5, 1, 1.5, and 2 ft.

4. Fill in a and b in the table. Then, carry out the calculations to find the area the light is spread over, i.e., calculate the number of watts per square centimetre at each distance.

   To simplify the calculations, assume that the flashlight produces 10,000 watts (W) of light output. Measure a and b in centimetres, and then use area $= 0.79\ ab$. Next, calculate 10,000 watts/area to find the intensity in watts per square centimetre.

5. Plot your results of intensity versus distance between the board and the flashlight's light bulb. Pick one other distance to fill in any gap in your graph, or to check one of the first measurements if it seems inconsistent with the others.

6.1.2 Power vs. Angle

For this experiment, we will measure the effect of changing the angle while keeping the flashlight bulb at a constant distance of 1 ft from the whiteboard.

1. Change your role in this experiment, and write down your new role on the table worksheet.

2. For this experiment, pull the sleeve on the front part of the flashlight all the way **out**, i.e., make the total length of the flashlight as **long** as possible.

3. Use the yardstick to keep the flashlight's light bulb at a fixed distance of 1 ft from the board, and use a protractor to measure the angle.

   As before, you can use markers to outline the dimensions a and b of the flashlight beam. It will elongate into an ellipse at smaller angles. Try to keep the ellipse of the beam centered on the base of the yardstick, so the width b stays about the same.

4. Make measurements at 90°, 71°, 47°, and 24°. Assume that these smaller angles correspond to the altitude of the Sun in Amherst at noon on the summer solstice, the equinoxes, and the winter solstice respectively.

   As before, use area $= 0.79\ ab$ to find the area of the flashlight beam.

5. As before, divide 10,000 watts by the area you measured at each angle. Determine your y-axis scale based on the range of values you obtain, and fill in the table with your measurements and calculations. Then, plot the data.

6. From your plot, at what angle does the intensity of light match the intensity at 1.5 ft (50% farther away than 1 ft)? Try to estimate what that angle would be, then carry out one last measurement at that angle and fill it out in your table.

6.1.3 Distance vs. Angle

The angle you measure relative to the whiteboard is like the "altitude" of the Sun. So when the flashlight is shining straight at the board, it is like having the Sun at the zenith, 90° from the horizon.

At noon on the winter solstice in Amherst, the Sun has an altitude of about 24°. By comparing your graphs, estimate the distance where the light intensity (in watts per square centimetre), shining at 90°, is the same as the light intensity (in watts per square centimetre) at a distance of 1 ft and an angle of 24°.

What is your estimate? ______________________ (Record this for the next section.)

6.1.4 Moodle Lab Quiz

Go to the section for this lab on the Moodle page and complete the End-of-Lab Quiz. Write your name on the Table Worksheet, take a picture of it, and hand it in.

6.2 Table worksheet

6.2.1 Table no.

Fill out your section and table number below.

- Section: ________
- Table no.: ________

6.2.2 Experiment roles

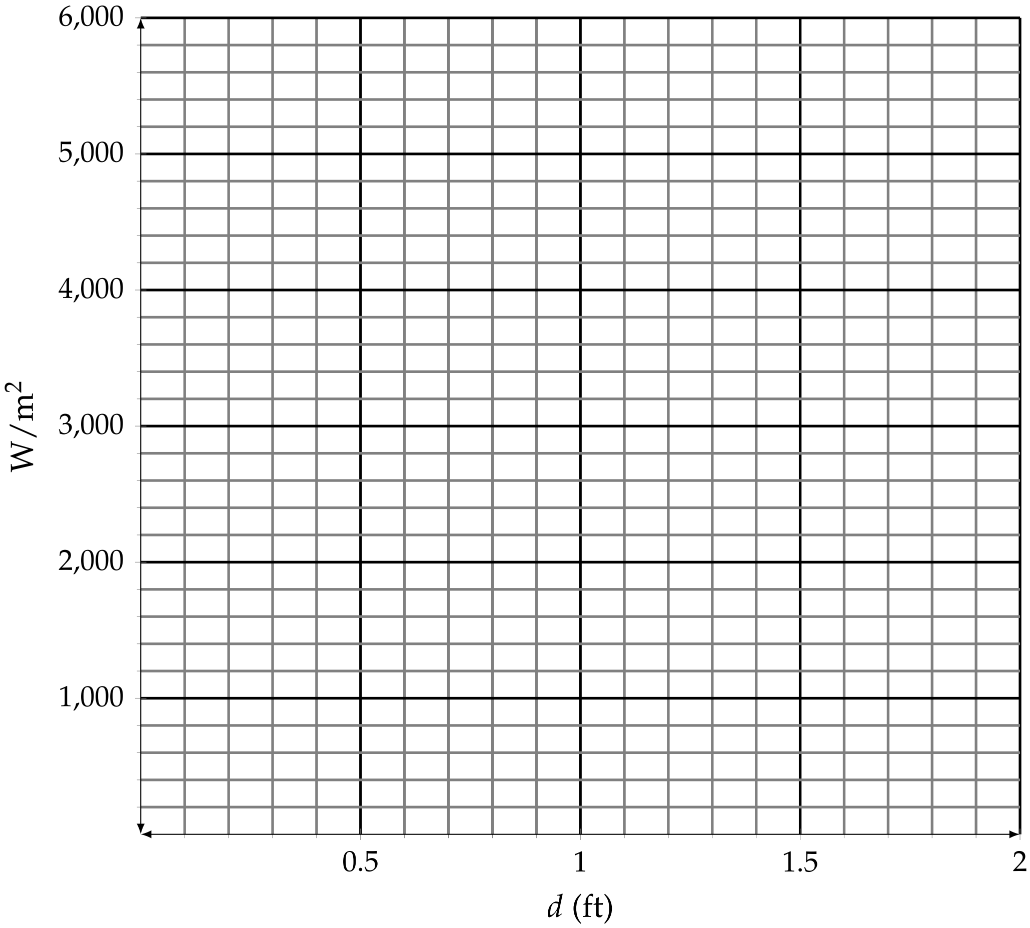
Enter your name and roles for each experiment.

Name	Experiment 1 role	Experiment 2 role

6.2.3 Experiment 1: Intensity vs. Distance

Fill out the table, then plot your data points in the graph. Then, pick another point from which to take another measurement to improve your plot.

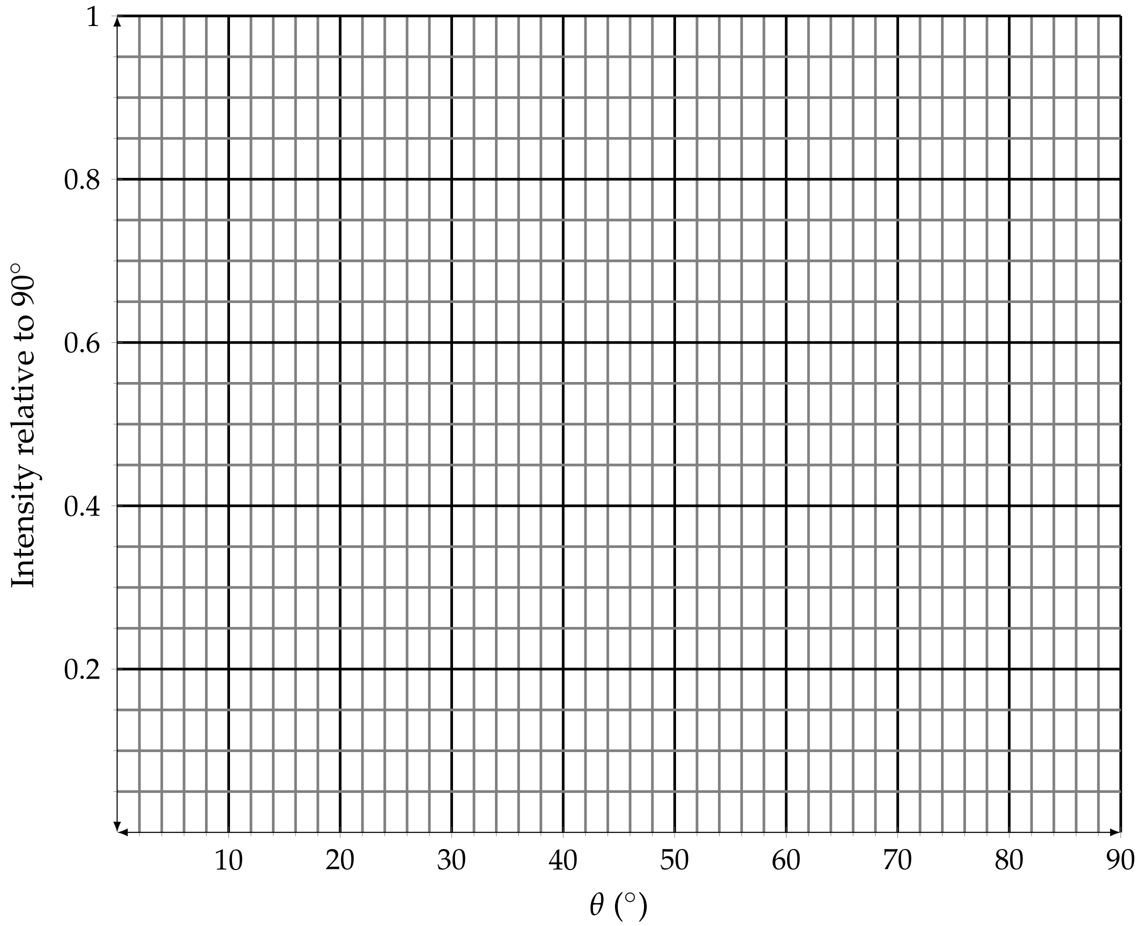
d (ft)	θ (°)	a (m)	b (m)	area (m^2)	400W/area (W/m^2)	area at 1ft/area at d
0.5	90					
1.0	90					1.00
1.5	90					
2.0	90					
	90					



6.2.4 Experiment 2: Intensity vs. Angle

Fill out the table, then plot your data points in the graph. Then, pick another point from which to take another measurement to improve your plot.

d (ft)	θ (°)	a (m)	b (m)	area (m^2)	400W/area (W/m^2)	area at 90°/area at θ
1.0	90					1.00
1.0	71					
1.0	47					
1.0	24					
1.0						



7 Lab 7: Calendars, Horoscopes, and Precession

7.1 Worksheet

7.1.1 Exploring the ecliptic

1. Open Stellarium and set it to your home location. You can also stop time (the pause button in the bottom panel) and set the time to noon.
2. Make the constellations visible.
   (a) Turn off the Atmosphere visualisation.
   (b) Open the Sky and Viewing options window.
   (c) Go to the Starlore tab.
   (d) Under Options, check Show labels and Show boundaries.

1. Find out what constellation the
   (a) Sun
   (b) Moon

   are in today.
2. Click on the Sun and hit the spacebar. This will centre and lock on the Sun.
3. Move forward in time by jumping by day, by holding down the = key.
4. Find out the constellations that the Sun moves through over a year.

What constellations does the Sun move through? What is causing the Sun to move through the stars? What other things change position among the stars as time passes?

7.1.2 What's your sign?

Table 20: Horoscope signs and dates

Sign	Aries	Taurus	Gemini	Cancer	Leo	Virgo	Libra	Scorpio	Sagittarius	Capricorn	Aquarius	Pisces
Start	21 Mar	20 Apr	21 May	21 Jun	23 Jul	23 Aug	23 Sep	23 Oct	22 Nov	22 Dec	20 Jan	19 Feb
End	19 Apr	20 May	20 Jun	22 Jul	22 Aug	22 Sep	22 Oct	21 Nov	21 Dec	19 Jan	18 Feb	20 Mar

1. Shift Stellarium to your birth date. What constellation was the Sun in? Save a screenshot of the Sun's location.

   According to the ancient idea of astrology, this is known as your sun sign or horoscope sign, which somehow determines your characteristics.

2. The dates for each horoscope sign according to modern astrologers is given in the table. What is your sign based on the table?

3. Based on Stellarium, over what range of dates is the Sun actually in the constellation corresponding to your horoscope sign?

4. Set Stellarium to a date in the middle of your horoscope sign. Jump back in time in 500-year blocks until the Sun is actually in the middle of your horoscope sign. How far did you have to go?

   N.B.: To enter a B.C. date, you may need to enter the number first, then put "-" in front.

7.1.3 Precession of Earth's Axis

In fact, the position of the Sun on a particular date shifts steadily through the sky because of the precession of the Earth's axis. Let's visualise this in Stellarium.

1. Jump back to today and turn on the equatorial (NOT azimuthal!) grid.

2. Look at the North celestial pole. Which star is nearest to it? Which star was nearest to it when horoscopes were aligned with the zodiacal constellations?

3. Find the star Vega. Jump back in time in 1000-year blocks. When was Vega the North star?

4. Jump forward in time in 1000-year blocks. When will Vega be the North star again?

7.1.4 Constellations in Other Cultures

Different cultures have come up with different groupings of stars and different stories associated with them. Let's explore them!

1. Go back to your birth date.

2. Pick constellations from another culture.

   (a) Go to Sky and viewing options and go to the Starlore tab.

   (b) Choose another cultural constellation system (other than Western). Which constellation is the Sun in?

If no labelled constellation is available, do some research online and tell us about what you find.

On Moodle, write about the culture you chose and what you've learnt about the constellation.

7.1.5 The Motion of Mars

The planets move through the stars of the zodiac and show some surprising motions, like Mars.

1. Centre your view on Pisces.
   (a) Set Stellarium to 1 June 2020.
   (b) Turn off the atmosphere and ground visualisations.
   (c) Switch to the equatorial axis. (This is NOT the same as turning on the equatorial grid!)
   (d) In Sky and viewing options, turn on constellation lines and labels as before.
   (e) Centre and zoom in on Pisces.
2. Find Mars on the sky.
3. Plot the position of Mars every month for one year (i.e. once a month from June 2020 to June 2021).
4. Connect the points. How many days was it moving backwards (retrograde)?
5. Go back through the same period. This time, zoom in on Mars and take note of its magnitude, phase, and size.
6. Note the highest and lowest magnitudes and note them on the chart.

   Note that the lower or more negative the magnitude, the brighter an object is. The magnitude scale is logarithmic: 5 magnitudes lower is $100\times$ brighter.
7. Repeat for all the planets. Do they all go retrograde (i.e. move backwards for some time)?

7.1.6 Moodle Lab Quiz

Go to the section for this lab on the Moodle page and complete the End-of-Lab Quiz.

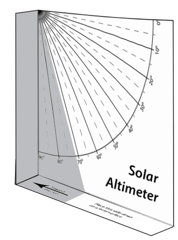
8 Lab 8: Motions of the Planets in the Sky

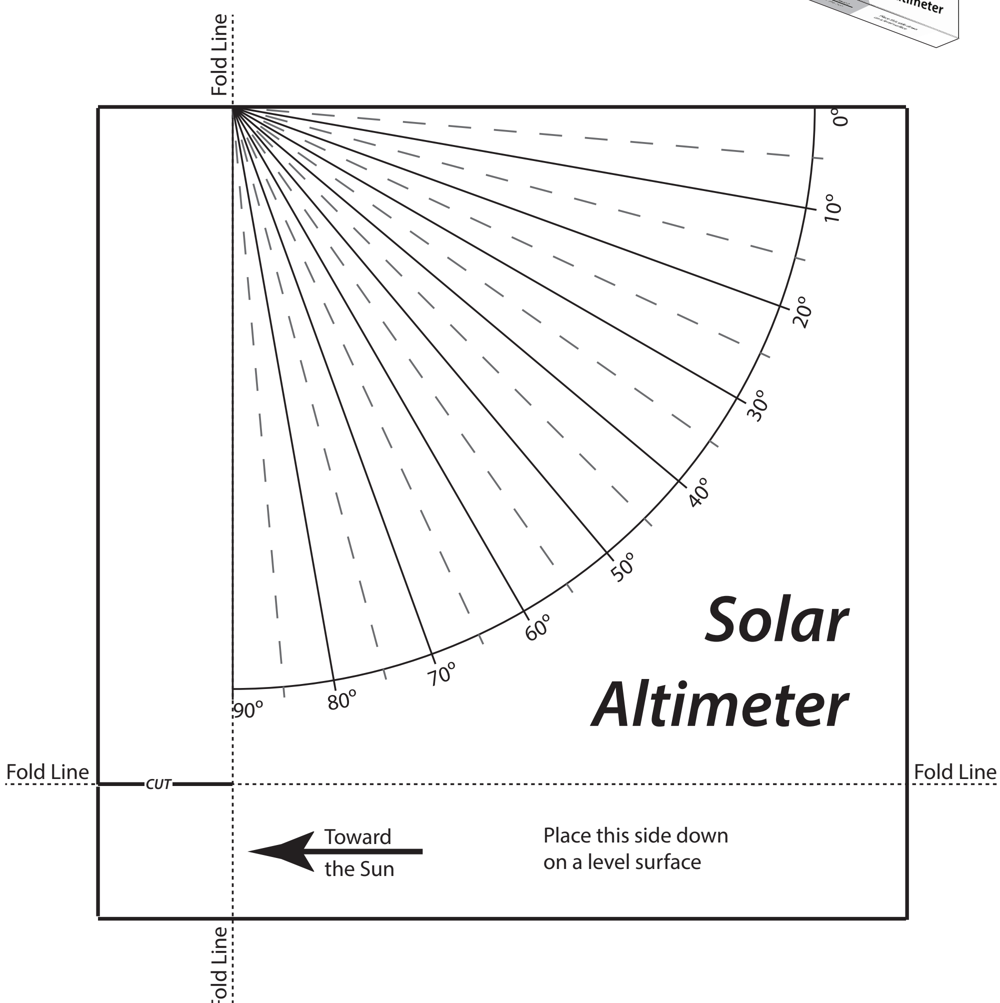
8.1 Worksheet

8.1.1 Solar altimeter

Instructions:

1. Make straight folds along each of the two dotted lines, then flatten back down
2. Cut along heavy outer lines and the notch along the lower fold
3. Refold the two flaps at right angles toward the printed side
4. Tape the bottom left tab to make everything square as shown at right
5. With bottom flap on a flat surface and vertical flap toward Sun, the Sun’s shadow will indicate its altitude--about 72º in illustration
6. For greater stability, you may want to tape the bottom to a heavier object





9 Lab 9: The HR Diagram

9.1 Worksheet

9.1.1 Stellar Properties

1. In groups of up to 3, open up Stellarium and turn off atmosphere (A) and ground (G) visualization.
2. Find the star Procyon. From the information panel, find:
   (a) Absolute magnitude
   (b) Color index (B-V)
   (c) Distance
   (d) Spectral type

N.B.: It's a lot easier to find this info in Stellarium if you Configure (F2) the Information to show just what you need. Open up the configuration window (F2), then click the information tab and click "None" at the top. Select the following to display: Name, Catalog number, Visual magnitude, Absolute magnitude, Distance, and Additional information. (If you use the web app, you will need to look up Procyon on Wikipedia and look in the information panel on the right side of its page.)

a. What is the star's magnitude? What is its absolute magnitude? Why do these differ?

____

b. Fill in the first 5 columns in the table using the information in Stellarium.

Name	Absolute Magnitude	B-V	Distance (light-years)	Spectral Type	Temperature (K)	Luminosity (× solar)	Size (× solar)	Location in HRD
Procyon								
(bright)								
(close)								

9.1.2 Stellar Sizes

We'll explore stellar properties using an interactive Hertzsprung-Russell (HR) diagram.

1. Start up a web browser, and go to this website (or click on the link in Moodle): `http://astronomy.nmsu.edu/geas/labs/hrde/hrd_explorer.html`
2. Under Plot Labels:

(a) Set the x-axis scale to "B-V color index"

(b) Set the y-axis scale to "magnitude"

3. Click on the HR diagram where Procyon is located by its absolute magnitude and B-V value.

4. Adjust the **Temperature** slider so that the red arrow on the bottom axis of the graph matches the star's B-V color value. Enter the star's **temperature** in the table.

5. Adjust the **Luminosity** slider so the red arrow on the left axis of the graph matches the star's absolute magnitude. The program calculates the star's luminosity in solar luminosities (L). Enter the star's **luminosity** value in the table.

6. With the Temperature and Luminosity sliders set to the values you just found, the program calculates the star's radius in solar radii (R), in other words, how many times bigger the star's diameter is than the Sun's diameter. Enter the star's **size** value in the table.

7. Turn on the Main sequence and luminosity classes by clicking them.

8. Which region is Procyon located closest to: Main Sequence line (MS), red giants (RG), supergiants (SG), or white dwarfs (WD)?

9.1.3 The Stars We See

Let's examine a sample of bright stars.

O/B	A	F	G	K	M
Violet	Blue	Green	Yellow	Orange	Red

1. Return to Stellarium and turn on constellation labels (V) and boundaries (B).

2. In your assigned constellation, find the bright stars and pick one each. Then, find their properties and fill them in the table as before. (If you are using the web app, use Wikipedia.)

3. Fill in the properties of your star on your table worksheet too.

4. Time to *draw* on your art talents! On a blank piece of paper, draw circles representing your stars where:

   (a) the diameter corresponds to its size (1 cm for the Sun)

   (b) the colour corresponds to its spectral type according to Table 9.1.3

   (c) they are labelled with their name and spectral type.

5. On the whiteboard corresponding to the distance of your star, draw a circle to represent your star similar as above. Write the spectral type of your star next to it.

9.1.4 Nearby Stars

Now we'll look at closest stars instead of brightest stars.

1. Go to the Wikipedia page "List of stars in [your constellation]".
2. Sort by distance by clicking the up/down arrows in the Distance column.
3. Pick a different nearest star each and find its properties.
4. On the HR Diagram Explorer page, change the X-Axis Scale to "Spectral type".
5. As before, adjust the Temperature slider so that the red arrow on the bottom axis of the graph matches the star's B-V color value. The red arrow should now also point to your star's spectral type (O,B,A,F,G,K,M). The arabic numeral (0-9) following that letter indicates where in the range the star lies, with 0 towards the left (hotter) edge and 9 towards the right (cooler) edge.

   The Sun is a G2 star. Where on the diagram would it be located?
6. Copy your answers into your table and the table worksheet. Compare your answers.

Answer the following questions.

1. In the H-R Diagram Explorer web app, and click on "the nearest stars" and "the brightest stars." Why do these look so different?

   ____

2. How do the stars you can see by eye at night compare to the Sun?

   ____

3. How do the nearby stars compare to the Sun?

   ____

4. Is the Sun a "typical" star?

   ____

9.1.5 Moodle Lab Quiz

Go to the section for this lab on the Moodle page and complete the End-of-Lab Quiz. Write your name on the Table Worksheet and hand it in.

To learn more about the H-R diagram, visit `https://sci.esa.int/gaia-stellar-family-portrait/`

9.2 Table worksheet

9.2.1 Table no.

Fill in your section and table number below.

- Section: ___________
- Table no.: ___________

9.2.2 Constellation assignment

Your table's assigned constellation is: ____________________________

Fill in your names below.

9.2.3 Bright stars data

Name	Absolute Magnitude	B-V	Distance (light-years)	Spectral Type	Temperature (K)	Luminosity (× solar)	Size (× solar)	Location in HRD

9.2.4 Nearest stars data

Name	Absolute Magnitude	B-V	Distance (light-years)	Spectral Type	Temperature (K)	Luminosity (× solar)	Size (× solar)	Location in HRD

10 Lab 10: Distances of Stars in Space

10.1 Worksheet

10.1.1 Building a Constellation

Working in teams at your table, your mission is to construct a 3-D model of your assigned constellation.

1. Using Stellarium as reference, sketch your constellation on the white board, marking out the bright stars and constellation lines (lines connecting them like a stick figure). Try to make it fill up as much of the whiteboard as possible. (To show constellation lines in Stellarium, press C.)

2. In Stellarium, click on your assigned stars. Write the Name, Spectral Type, and Parallax of the star next to it on the whiteboard, and also on the table worksheet.

3. Keep the tip of the metal pole (with attached strings) about 6 ft/2 metres from the whiteboard, and at a height of about eye level or centred to your whiteboard sketch. Gently stretch a string to each assigned star and tape the end to the board, making sure that the strings are straight and untangled.

4. Calculate the distance of your assigned star in parsecs using the following distance formula:

   $$\text{distance (in parsecs)} = 1/\text{parallax (in arc seconds)} = \underline{\hspace{3cm}}$$

   Copy this onto the table worksheet.

5. Pick a coloured ball that represents your assigned star according to the following:

Type:	O/B	A	F	G	K	M
Colour:	Violet	Blue	Green	Yellow	Orange	Red

Luminosity class:	I	II/III	IV/V
Size:	Large	Medium	Small

   Write down the colour and size of the ball you picked on the table worksheet.

   If your star has an unusual classification, try looking it up on Wikipedia for more information, and choose the closest representation you can for it.

6. Take the tip of the metal pole (where all the strings are tied together) to represent the position of the Sun. Taking 1 centimetre to represent 1 parsec, measure out distance of your assigned star from the "Sun" and clip in place your "star". If the calculated distance is larger than the length of the string, clip your "star" right at the board and write its distance beside it.

7. **When everything is in place, call over an instructor to check your work.**

10.1.2 Changing Perspective

1. Examine the stars in your constellation from the position of the "Sun". Their pattern should look very similar to the constellation you see in the sky.

   You can also go around the room to look at the other constellations.

2. On the scale of the model (1 cm = 1 parsec), how far apart are your eyes?

   ____

   Move 10 or 20 "parsecs" to either side of the "Sun" and sketch the pattern of stars from the new position. How does it compare to the original pattern?

Original	_____ pc away

   Pick an example in your group to copy onto the table worksheet.

3. Discuss and answer on the table worksheet: Which star appears to change position most relative to its original position as you move to the side?

4. Discuss: On the scale of your model, how far away from the Sun is Neptune? Should the constellations change when viewed from Neptune?

10.1.3 Moodle Lab Quiz

Go to the section for this lab on the Moodle page and complete the End-of-Lab Quiz. Write your name on the Table Worksheet and hand it in.

10.2 Table worksheet

10.2.1 Table no.

Fill in your section and table number below.

- Section: ______
- Table no.: ______

10.2.2 Constellation assignment

Your table's assigned constellation is: ______________

Fill in your names below.

10.2.3 Star data

Fill in the data for your stars below.

Name	Spectral type	Luminosity class	Ball colour	Ball size	Parallax (arcsec)	Distance (parsecs)

10.2.4 Constellation sketch

Sketch your constellation below and mark the stars you included in the table.

Original	______ pc away

Which star appears to shift most when you view the constellation 10-20 parsecs from the Sun?

____

11 Lab 11: Structure of the Local Group

11.1 Worksheet

11.1.1 Sizes of Local Group galaxies

Like we did for constellations last week, we'll work in pairs and then as a class to construct a scale model of the Local Group, the small cluster of galaxies which the Milky Way is a member of.

Astronomers have determined the distances to the galaxies in our neighbourhood through a variety of methods. We have also measured their angular sizes, which we will use to estimate their actual sizes.

1. Working in pairs, go to the Galaxy Data Sign-up link for this lab on Moodle and fill out your names at the next available galaxy.
2. Using a scale of 1 m for 500,000 light-years (2 m for 1 million (1,000,000) ly), have one person stand at a distance from the whiteboard corresponding to the galaxy distance.
3. Have the other person stand at the whiteboard and mark out a width that corresponds to 2° of angular width, as seen by the first person. (This is about the width of your thumbnail with your arm fully extended in front of you.)

   Record this width in centimetres: __________

   If your galaxy is at a distance that is too close for you to be able to stretch out your arm fully, move 3 times farther from the board, and then divide your final size by 3.
4. Trade places and repeat, then average your results.
5. Using this scale, mark out the size of your galaxy as estimated from its observed angular size α, e.g. if your galaxy is 0.1° across, it extends 0.1/2 of the width you have marked out. Use the following formula:

$$\frac{\alpha}{2^\circ} \times \text{width in centimetres} = \underline{\hspace{3cm}} \text{ cm}$$

   At this scale, the Milky Way, which has a diameter of about 90,000 ly, is about 18 cm in diameter.
6. Using the same scale of 500,000 light-years per 1 m, i.e. 5,000 light-years per 1 cm, estimate the true size of your galaxy. Fill out the data for your galaxy below.

No.	Galaxy Name	Distance (light-years)	Angular diameter ($\alpha/^\circ$)	Diameter (light-years)

E/Sph	S (a-m)	Irr
Yellow	Green	Blue

7. Using colours to denote galaxy type according to the table, make a model of your galaxy as follows.

   If your galaxy is small enough to fit on a small piece of paper, draw it as a circle of the correct size and colour it in with the right colour. If not, get a piece of paper of the right colour and cut out a circle of the correct size to attach to your paper.

The colours also simulate how the galaxies appear. E (elliptical)/Sph (spherical) galaxies, mostly dwarf (dE, dSph), mostly have older yellow stars. S (spiral) galaxies have older yellow stars in the center and star formation making newer, bluer stars in the disk. Irr (irregular) galaxies usually have lots of star formation, which makes new, bluer stars.

11.1.2 Positions of Local Group galaxies

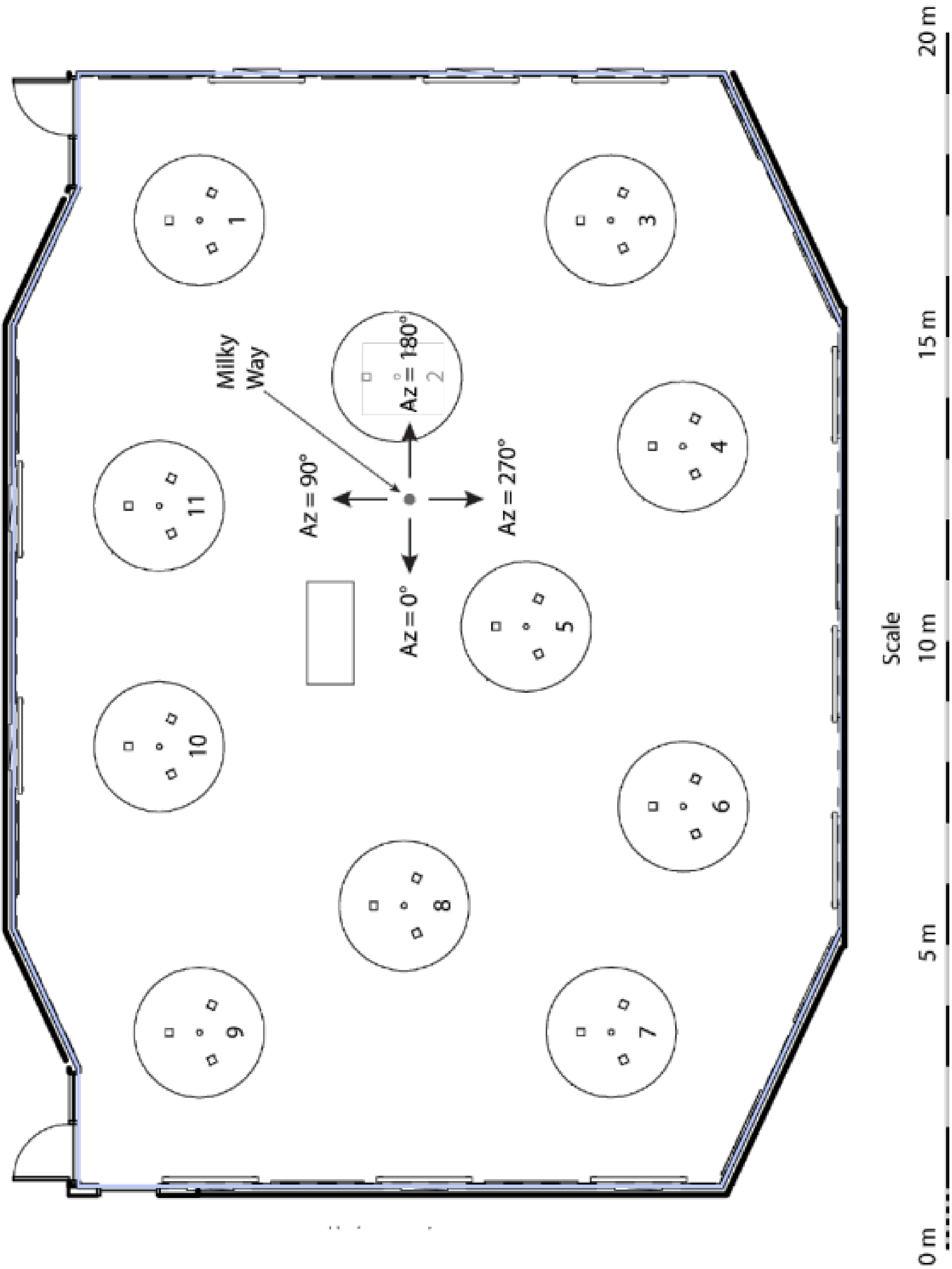
Galaxies in the Local Group mostly lie on a fairly flat plane, so we have assigned them an azimuth according to the direction they lie from the Milky Way. Now, we'll model their positions in space.

1. Your galaxy has an azimuth associated with it. Find the direction of your galaxy relative to the Milky Way. Use the position of the Milky Way we have put up and azimuth values we have marked.
2. In that direction, go out the corresponding distance of your galaxy from the Milky Way, and put it down. Remember that the scale is 500,000 light-years per metre.
3. Mark the position in the diagram.

11.1.3 Moodle Lab Quiz

Go to the section for this lab on the Moodle page and complete the End-of-Lab Quiz.

Be sure to complete the post-lab survey on Moodle before the deadline. Credit is awarded only for completion, not for correctness.


Milky Way
Az = 180°
Az = 90°
Az = 270°
Az = 0°
1
2
3
4
5
6
7
8
9
10
11
Scale
0 m
5 m
10 m
15 m
20 m

12 Project: Movement of the Sunset

12.1 Worksheet

12.1.1 Project overview

For the project, you will be submitting the following:

1. With Lab 2:
   (a) Photo Policy Acknowledgement
   (b) Camera calibration grid photos
2. Project 1st part:
   (a) 1st sunset(/sunrise) photo
   (b) Location documentation photo(s)/information
3. Project 2nd part:
   (a) 2nd sunset(/sunrise) photo
   (b) 3rd sunset(/sunrise) photo
   (c) Annotated photo
   (d) Stellarium screenshots
   (e) Project report

DO NOT WAIT TO TAKE YOUR PHOTOS! The 3rd photo must be at least 4 weeks after the 1st, so if you leave the project to the last minute, you **will** lose points.

12.1.2 Photo Policy Acknowledgement

Make sure you read through the Photo Policy and submit your acknowledgement. Otherwise, you will not get credit for any of your submissions.

Submitting work or pictures that are not your own, or having someone else do it for you, is a violation of academic integrity and will be dealt with harshly.

12.1.3 Camera calibration grid photos

As part of Lab 2, submit photos of the zoomed-in and zoomed-out calibration grids.

The purpose of the activity is to help you work out the angular field of view of your camera, which you will make use of in the project. Hence, it is important that you use the **same** camera for all the sunset(/sunrise) photos, and to do the calibration. If this is not possible, let us know **as soon as you can**.

12.1.4 Sunset photos

The goal of the project is to obtain 3 pictures of the sunset OR sunrise from the exact same location, spaced apart in time. It is important that all 3 photos are consistent, i.e. they must EITHER be of the sunset OR the sunrise, not a mix. If this is not possible, let us know **as soon as you can**.

When you take the picture, ensure that:

1. your camera is zoomed out to zoom factor 1 (if your camera has a wide-angle function that can zoom out to a value lower than 1, e.g. 0.7 or similar, **do not use it**)

2. the Sun is within about 5° in altitude of the horizon

3. the Sun's azimuth can be clearly discerned. Refer to the lecture during lab for examples of acceptable and unacceptable photos.

Don't delete failed pictures! You can still get partial credit for attempts.

For the submission of the 1st part of the project, submit the 1st sunset(/sunrise) photo, along with documentation of the location you took it from.

For the other photos in the project, you must take them from the exact same location. The 2nd photo must be at least 1 week after the 1st photo, and the 3rd photo must be at least 4 weeks after the 1st photo AS WELL AS at least 1 week after the 2nd photo, as per Fig. 9.

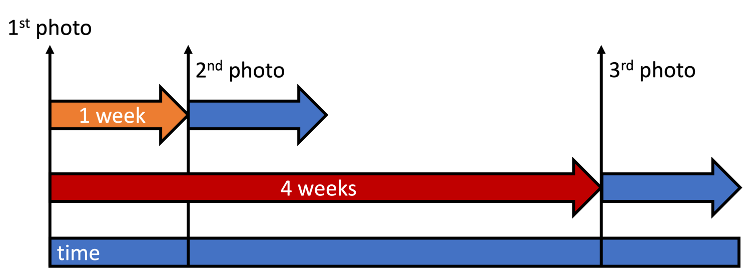


Figure 9: Diagram of time spacing for sunset(/sunrise) photos.

Submit the 2nd and 3rd photos as part of the 2nd part of the project.

12.1.5 Location documentation

All 3 photos must be taken from the same location. Bearing this in mind, we advise you to pick a location where:

1. you can get to the location again regularly later in the semester

2. a clear view of the horizon is visible

3. an area of the horizon is visible along which the sunset(/sunrise) will shift along over time.

   In the spring, the sunset shifts north over time, which is to the right, and vice versa for the sunrise. This is reversed in the autumn.

4. there are features on the horizon that allow you to pinpoint the exact position of the sunset and how it moves over time. Refer to the lecture during lab for examples of acceptable and unacceptable photos.

Additionally, it is important that you precisely document your location. You should provide enough information such that others can return to it and replicate your pictures. You will probably need to include a map along with photos that show clearly where you are standing when you take the pictures. Similar to the sunset photos, make sure features around your location are visible so your precise location can be pinpointed.

Submit the location documentation along with the 1st sunset photo for the 1st part of the project.

12.1.6 Stellarium screenshots

As we have in other labs, you'll set Stellarium to show the view from the same location and time as your photos, and then take screenshots, which you will submit. You can also click on the Sun to display information about it, including its altitude and azimuth, which we will ask you to report in the project report. These are meant to help you double-check your answers and help you get points.

Submit 1 screenshot corresponding to each of the 3 photos for the 2nd part of the project.

12.1.7 Annotated photo

The annotated photo is a **copy** of one of your photos, on which you will mark the positions of the sunsets from your other photos. Also, based on the angular scale of your camera (from calibrating it in Lab 2), predict where the sunset will shift to on 21 Dec (for fall semester)/21 Jun (for spring semester) and mark this position as well. You can make use of your calibration grid pictures for this. Fig. 10 shows a diagram of how the photo might look.

Submit the annotated photo as part of the write-up of the project report, which is part of the 2nd part of the project.

12.1.8 Project report

The project report consists of a quiz section and write-up section, both on Moodle. You will not have a submit a separate document for it.

The quiz section will have you enter specifics about your photos, including date, time, azimuth of sunset, calibrated angular field of view, and so on. The write-up section

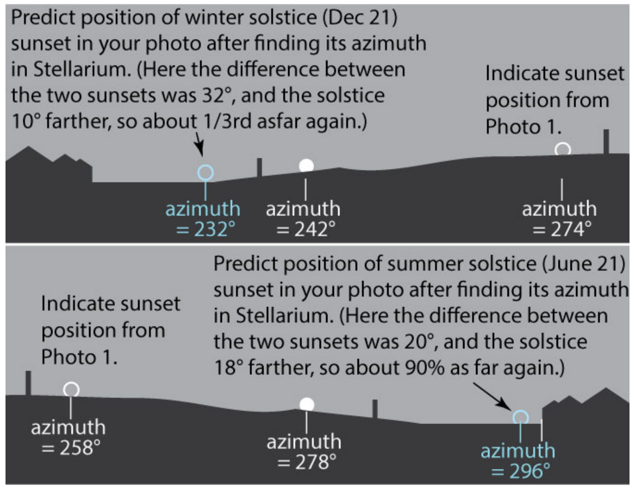


Figure 10:

will ask you to explain the procedure you used for predicting the position of the sunset(/sunrise) on the 21 Dec (for fall semester)/21 Jun (for spring semester) and locating it in the horizon view in your photo.

Note that the annotated photo is part of the submission for the write-up section. This does not, however, mean that either can be substituted for the other, i.e. an annotated photo cannot be taken to replace the write-up, or vice versa.

Happy touching grass!

13 Project: Moon in daytime

13.1 Worksheet

13.1.1 Submission overview

For the project, you will be submitting the following:

1. Zoomed-out photo of Moon in daytime
2. Zoomed-in photo of Moon, taken at same time
3. Zoomed-in photo of golf ball model Moon from scale distance
4. Stellarium screenshot
5. Project report

13.1.2 Moon photos

For this project, get a photo of the Moon during the daytime. You can do this from anywhere, and take two pictures at one time.

1. Take one photo zoomed-out as much as possible (but not past zoom $1\times$, same as for the sunset photos project), showing both the horizon and the Moon visible. (The Moon will look very small in this picture.)
2. Take a second picture zoomed-in as much as possible on the Moon, at the same time (i.e. right before or after the zoomed-out photo).

Reference Fig. 11 for an idea of what the photos might look like.

Submit both the photos as part of the project.

13.1.3 Model Moon photo

In Lab 4, you will have had a chance to take a fully zoomed-in photo of the golf ball, which we are using to model the Moon, from a to-scale distance. As your camera's zoomed-in angular field of view should be consistent (as long as the camera and zoom settings are the same), the size of the golf ball in this photo should be similar to the size of the actual Moon in your zoomed-in photo of it. If you did not have a chance to do so, let us know so you can make it up.

Submit the photo as part of the write-up portion of the project.

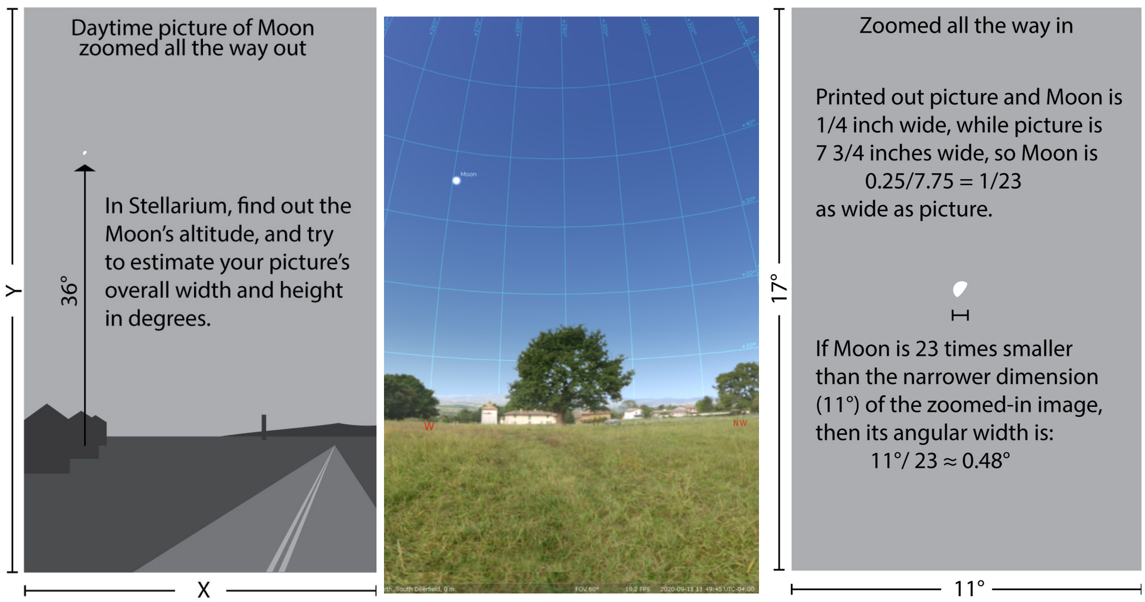


Figure 11:

13.1.4 Stellarium

Similar to the sunset photos project, take a screenshot of Stellarium set to the same location and time as the zoomed-out photo. Make sure to click on the Moon to show its information. It should look something like what's shown in Fig. 11 (which unfortunately does not show the information panel that you should include.)

One of the goals of this project is to learn **when** you can see the Moon during the daytime, and **where** to look. This changes with the phase of the Moon, and Stellarium can be very helpful in figuring this out.

You can also search on the internet for moonrise and moonset times, and then you work out where the Moon will be as it goes from east to west. You will also have to plan around the weather.

Submit the screenshot as part of the project.

13.1.5 Project report

Similar to the sunset photos project, the project report consists of a quiz section and write-up section, both on Moodle. You will not have a submit a separate document for it.

The quiz section will have you enter specifics about your photos, including date, time, azimuth and altitude of the Moon, times of sunrise and sunset, and calibrated angular field of view. The write-up section will ask you to discuss the following:

1. Compare the altitude of the Moon to the height (in degrees) of your zoomed-out calibration picture. Do these values make sense? Explain how they make sense or what might explain any discrepancy.

2. For the zoomed-in picture, how big is the Moon compared to the width (in degrees) found in your zoomed-in calibration photo? Do you get approximately 0.5° for the width of the Moon? Explain how you are making your estimate and/or any problems you had in making the measurement.

3. Place the picture of the golf ball model Moon alongside your zoomed-in photo of the Moon in a document and upload it. Comment in the essay box how similar or different the sizes are in the two photos, and discuss any difficulties.

Note that the 3rd item asks you to upload a separate document containing your photo of the golf ball model Moon and your zoomed-in photo of the actual Moon.