

# Astronomy Lab



# Astronomy Lab

*FLORIDA STATE COLLEGE AT  
JACKSONVILLE*



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PART I

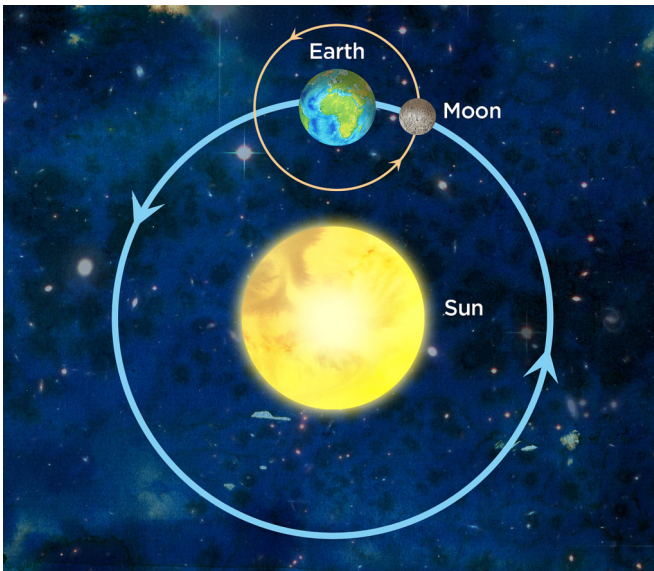
# LAB 1- SUNRISE, SUNSET- MOONRISE, MOONSET



# I. Introduction

## Astronomy Laboratory I: Sunrise, Sunset — Moonrise, Moonset

### Module Introduction



As Earth orbits the Sun, the Moon orbits Earth. [“Earth, Moon and Sun system” by Siyavula Education , flickr commons is licensed under CC BY 2.0 ]

Lab 1 will be completed throughout the term, requiring your work and participation over many weeks. The final submissions for this lab and the quiz will occur at the end of the term. Please, do not

wait to start on this lab, as you will need to record data and take photographs in each week in order to receive a grade.

In this lab, we will explore the day-night cycle, essential knowledge to ancient civilizations as well as indirectly, our modern society. You will first read the Learning Unit below for background information about the location and movement of Earth, the seasons, the orbit of the Moon, and using data to predict the motions of Earth and the moon as well as the effects of the motions on all of us. You will then complete the three lab activities, and quiz.

Note: throughout the term, you will need to do observations outdoors. Be sure to check the weather forecasts ahead of time so that you are able to plan around possible obstructions, such as clouds. Contact your instructor ahead of time to discuss a plan of action, if needed, to work around those obstructions. <sup>(1)</sup>

## Objectives

At the end of this module, students will be able to:

- Navigate the United States Naval Observatory (USNO) website and utilize the tools on the site.
- Analyze data to determine times and locations of Sunrise, Sunset, Moonrise, and Moonset.
- Record data pertaining to the rising and falling of the Sun and Moon.
- Calculate the average change in Moonrise time. <sup>(1)</sup>

## Outcomes

The material in this module includes content designed to meet the following course outcomes:



- Explain and apply major concepts in astronomy including planets, satellites, stars, meteors, galaxies, and theories of the universe.
- Demonstrate knowledge of scientific method.
- Communicate scientific ideas through oral or written assignments.
- Interpret scientific models such as formulas, graphs, tables and schematics, draw inferences from them and recognize their limitations.
- Demonstrate the ability to think critically.
- Demonstrate the ability to use scientific and quantitative reasoning. <sup>(1)</sup>

## Assigned Readings

### Learning Unit 1

## Assignments

- USNO Astronomical Applications Website Summary
- Sunrise / Sunset Activity
- Moonrise / Moonset Activity
- Lab 1 Quiz <sup>(1)</sup>

## 2. Daytime, Nighttime

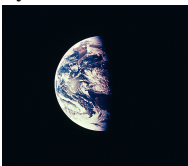
### **Sunrise, Sunset — Moonrise, Moonset**

#### **Daytime, Nighttime**

One of the obvious motions of the heavens is our day and night cycle. Earth turns on its axis in approximately 24 hours. This brings our planet into continuous day and night cycles, where half of Earth is always exposed to sunlight and the other half of Earth is in nighttime, with no sunlight. Note that there are other luminous objects in the heavens, such as the Moon. Yet, by far, the vast majority of our natural lighting comes from the Sun. Even when it is cloudy, we know when it is daytime and likewise nighttime.



Dayside of Earth, including North America. [” Dayside Earth ” by NASA is in the Public Domain ]

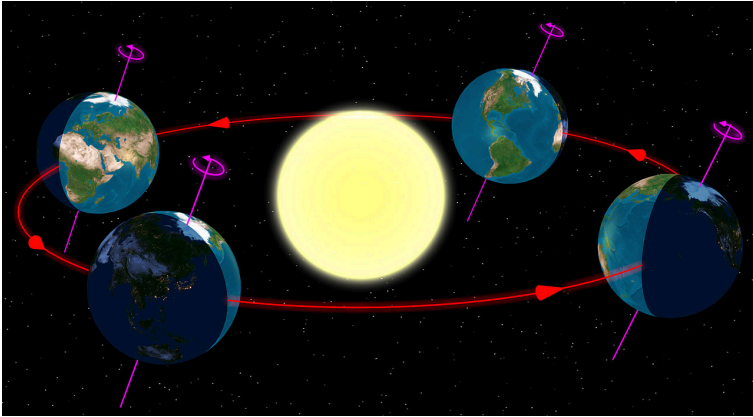


A view of Earth shows part of it is in daylight, part in nighttime; Apollo 8. NASA. [” Half-full Earth ” by NASA is in the Public Domain ]

Understanding the day-night cycle was essential to ancient civilizations as well as indirectly our modern society. The planting of crops or best time to hunt – survival with plenty to eat – was foremost. Today, we take this for granted since the vast majority of

us go to a grocery store to choose the already-cultivated food we want, or go to a restaurant to enjoy an already-prepared meal.<sup>(1)</sup>

## Earth's Motions

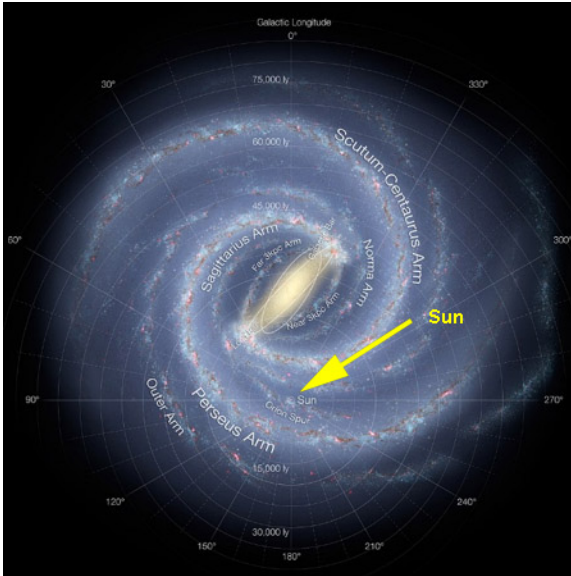


Earth's orbit or revolution around the Sun. [ " North season " by Tau'olunga , Wikimedia Commons is in thePublic Domain, CC0 ]

Our Universe is a Universe of motion. We see and experience evidence of some of the motions, from sunrise to sunset, moonrise and moonset, the seasons, bright planets moving against the background of stars, and even shooting stars — meteors. Earth spins, or rotates, on its axis and it orbits or revolves around the Sun.

Other bodies in our Solar System and other stellar systems undergo such motions. Earth rotates once every 24 hours and revolves around the Sun once every 365.24 days. Mars rotates once every 24 hours 39.5 minutes and revolves around the Sun once every 687 earth days. Jupiter rotates once every 9 hours 48 minutes and revolves around the Sun once every 11.86 earth years.

The Sun is also moving along with the rotating Milky Way galaxy. What is more, the Milky Way is not static; besides rotating, it is also moving through space. It all seems to be a dizzying dance.<sup>(1)</sup>



An artist's concept of our Milky Way Galaxy, from a bird's-eye view. Note the location of the Sun. [ " Milky Way " by NASA/JPL-Caltech/ESO/R. Hurt, Wikimedia Commons is in the Public Domain ]

# 3. Seasons and the Sun’s Location

## Seasons and the Sun’s Location

Seasons occur on a planet or moon because the axis of rotation remains tilted in one direction during its orbit about its star; Earth about the Sun. The tilt is relative to the planet’s or satellite’s orbit. This tilt results in a planet or moon having Seasons. Earth’s axis is tilted about  $23\frac{1}{2}^{\circ}$ . And for comparison, the axis of Mars is tilted about  $25^{\circ}$ . Not all planets are tilted on their axis, for example Mercury’s tilt is  $0^{\circ}$ .

One of the results of Earth undergoing seasons is changes in day and night lengths. In the summer the days are longer and nights shorter. In the winter it is just the opposite.

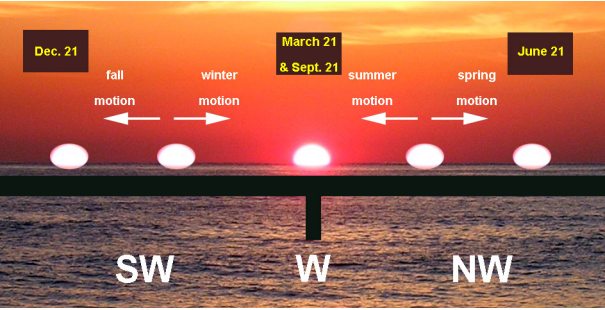
### Day and Night Lengths for Jacksonville, Florida; 2018

Date	Season	Day Length	Night Length
March 20	Vernal Equinox Start of Spring	12 hours 8 minutes	11 hours 52 minutes
June 21	Summer Solstice Start of Summer	14 hours 7 minutes	9 hours 53 minutes
September 22	Autumnal Equinox Start of Fall	12 hours 8 minutes	11 hours 52 minutes
December 21	Winter Solstice Start of Winter	10 hours 11 minutes	13 hours 49 minutes

### Seasonal Position of Sunrise and Sunsets

Season	Position of Sunrise	Position of Sunset
Winter	Southeast	Southwest
Spring	East	West
Summer	Northeast	Northwest
Autumn	East	West

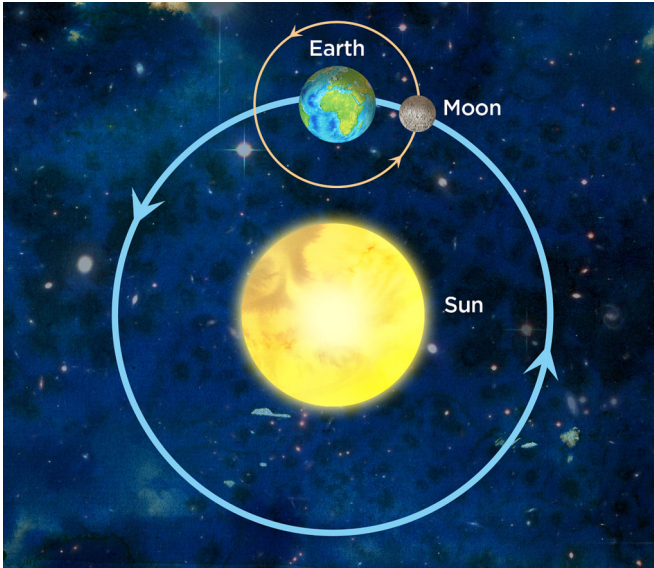
If you watch sunrise and sunset locations over a year, you will also note that the location of where the Sun rises and sets changes. As we orbit the Sun, the rising and setting points are further north in the summer and further south in the winter. There is a variable here: your location on Earth. For example, if you are at far northern or southern latitudes, you will experience extreme day and night lengths, depending on the seasons. And, for those north of the Arctic Circle or south of the Antarctic Circle, you will experience some days with no nights, or some nights with no days. <sup>(1)</sup>



The sunset position changes throughout the year, as does the sunrise position. Note: change “W” (west) to “E” (east) for sunrise position. [“Sunset Cycle”, Florida State College at Jacksonville is licensed under CC BY-SA 4.0 / A derivative from the original work ]

## 4. Moonrise, Moonset

### Moonrise, Moonset



As Earth orbits the Sun, the Moon orbits Earth. [“Earth, Moon and Sun system” by Siyavula Education , flickr commons is licensed under CC BY 2.0 ]

As Earth orbits the Sun, the Moon orbits Earth. It takes about 30 days for one complete phase change (actually  $29 \frac{1}{2}$  days). Compare this to how long it takes Earth to orbit the Sun one time: 365.24 days. Consider our word, “month”, with its roots from the term moonth. As the Moon orbits Earth, its moonrise and moonset times change each day, as does the phase of the Moon we see.





When you check moonrise time over several days or a period of time, you will notice that the Moon rises later each day. That is



because the Moon is orbiting Earth. The difference each day is fairly consistent, but has several variables like your latitude. The time of day that the Moon rises or sets depends on its phase.

If you consider why we see the Moon go through its phases, the time of day when the Moon rises or sets should make sense. The phase of the Moon we see depends on the positions of the Earth, Moon, and Sun relative to each other. So, when the Moon is full, the Earth is between the Moon and Sun; the Sun is setting and the Full Moon is rising. <sup>(1)</sup>

### **Moon Phase versus Moonrise and Moonset Times**

Moon Phase	USNO Image	Moonrise, occurs at	Moonset, occurs at
New Moon		Sunrise	Sunset
1 <sup>st</sup> Quarter Moon		Local Noon	Local Midnight
Full Moon		Sunset	Sunrise
3 <sup>rd</sup> Quarter Moon		Local Midnight	Local Noon

Moon images from the United States Naval Observatory (USNO) “Complete Sun and Moon Data for One Day” website. **Local Noon** refers to when the Sun crosses the meridian at your location. **Local Midnight** is exactly 12 hours after Local Noon[“Moon images” by United States Naval Observatory are in thePublic Domain ]

## 5. Predicting These Motions

### Predicting These Motions



A sundial located in the Forbidden City, Beijing, China.

Construction of the Forbidden City lasted from 1406 to 1420.

[ " Beijing sundial " by Sputnikcccp~commonswiki , licensed under CC BY-SA 3.0 ]

People would use simple markers and sundials in ancient times to determine the time. These devices worked due to the Sun's position in the sky, relative to the individual. A rod, known as a gnomon, projected a shadow onto a base or plate.

The time of day, or night, was also important to sailors and their navigation. Carrying a sundial on a rocking, moving ship was virtually impossible; other methods were required.

Today, finding out the exact time is easy; from depending on

our smartphones to computers, watches and clocks, television and radio. But, what about sunrise and sunset times? Those sunrise and sunset times will vary, depending on where you are on Earth.

One of the most-reliable sites for not only the exact time but other important astronomical data is the United States Naval Observatory, USNO. This observatory was established in 1825 with the original mission of instrument calibration and repair. Establishing precise time, necessary for navigation, became another mission for the USNO. Since those early days, the USNO has been charged with a variety of activities. The two moons of Mars, Phobos and Deimos, were discovered at the USNO. <sup>(1)</sup>

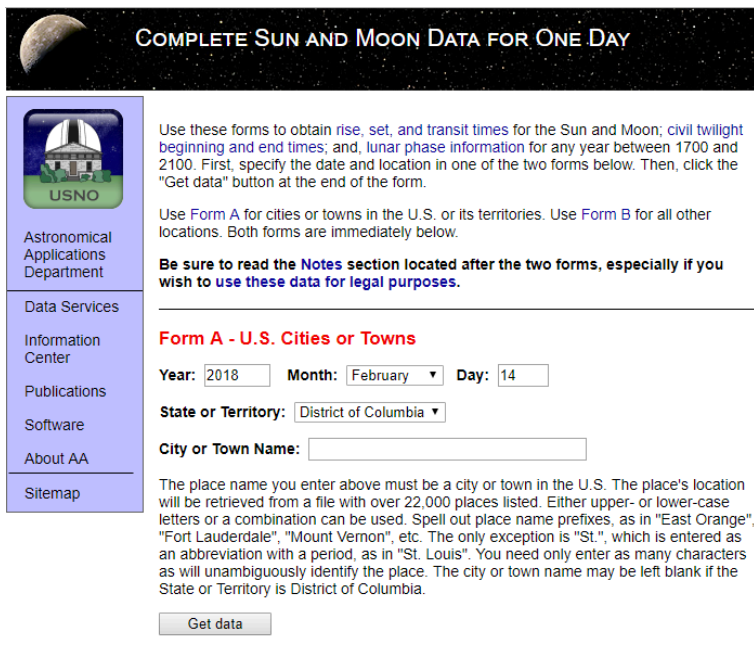


The United State Naval Observatory was first established in 1825 by Congress with President John Quincy Adams encouragement and then signature on the bill. [” USNO Logo ” by USNO is in the Public Domain ]

# 6. The United States Naval Observatory's Astronomical Applications

## The United States Naval Observatory's Astronomical Applications

### USNO Website Screenshot



The screenshot shows the USNO Complete Sun and Moon Data for One Day website. The header features a black banner with a crescent moon and the title "COMPLETE SUN AND MOON DATA FOR ONE DAY". Below the banner is a sidebar with a USNO logo and a list of links: "Astronomical Applications Department", "Data Services", "Information Center", "Publications", "Software", "About AA", and "Sitemap". The main content area contains instructions on how to use the forms to obtain astronomical data for the Sun and Moon, including links to "Form A" and "Form B". It also includes a warning to read the "Notes" section. Below this is a section for "Form A - U.S. Cities or Towns" with input fields for Year (2018), Month (February), Day (14), State or Territory (District of Columbia), and City or Town Name. A "Get data" button is at the bottom.

**COMPLETE SUN AND MOON DATA FOR ONE DAY**

Use these forms to obtain [rise, set, and transit times](#) for the Sun and Moon; [civil twilight beginning and end times](#); and, [lunar phase information](#) for any year between 1700 and 2100. First, specify the date and location in one of the two forms below. Then, click the "Get data" button at the end of the form.

Use [Form A](#) for cities or towns in the U.S. or its territories. Use [Form B](#) for all other locations. Both forms are immediately below.

**Be sure to read the [Notes](#) section located after the two forms, especially if you wish to [use these data for legal purposes](#).**

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**Form A - U.S. Cities or Towns**

Year:  Month:  Day:

State or Territory:

City or Town Name:

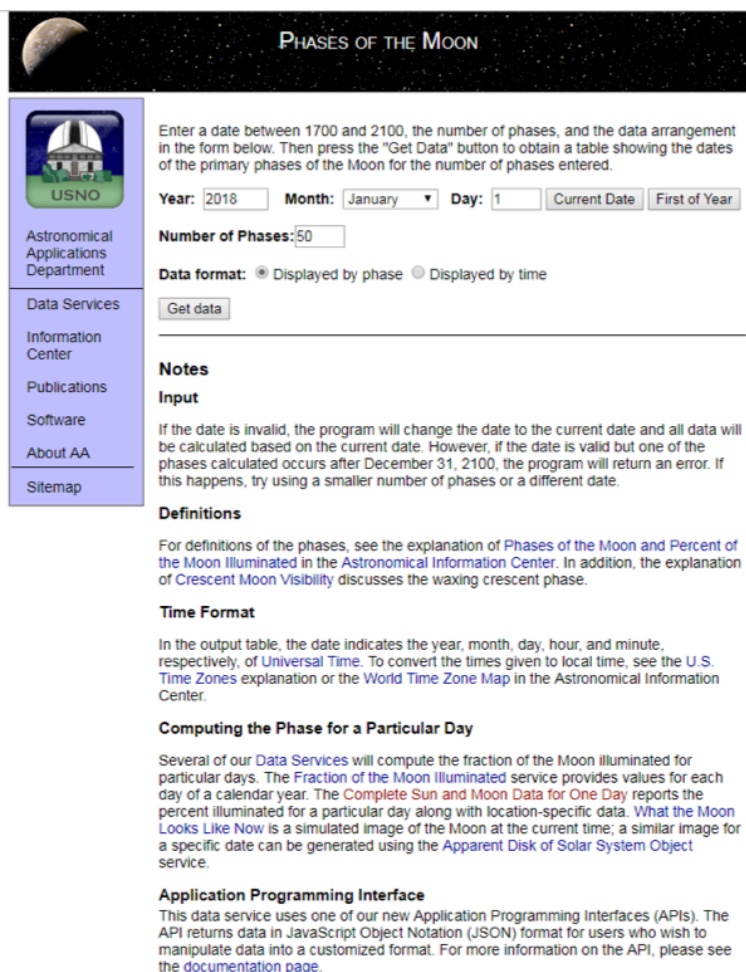
The place name you enter above must be a city or town in the U.S. The place's location will be retrieved from a file with over 22,000 places listed. Either upper- or lower-case letters or a combination can be used. Spell out place name prefixes, as in "East Orange", "Fort Lauderdale", "Mount Vernon", etc. The only exception is "St.", which is entered as an abbreviation with a period, as in "St. Louis". You need only enter as many characters as will unambiguously identify the place. The city or town name may be left blank if the State or Territory is District of Columbia.

The home page for the USNO Complete Sun and Moon Data for One Day website. [” USNO Page ” by Florida State College at

Jacksonville is licensed under CC BY-SA 4.0 ]

One of the contemporary services provided by the United States Naval Observatory to the public is its “Complete Sun and Moon Data for One Day” website. The user can obtain reliable and accurate sunrise, sunset, moonrise, and moonset dates and times for specific locations. Other useful information is also provided about the Sun and Moon’s daily motions specific to the user’s location and desired date.

# Phases of the Moon Screenshot



The screenshot shows the 'PHASES OF THE MOON' web application. At the top is a header with a moon image and the title. Below this is a sidebar on the left with a USNO logo and links to 'Astronomical Applications Department', 'Data Services', 'Information Center', 'Publications', 'Software', 'About AA', and 'Sitemap'. The main content area contains instructions: 'Enter a date between 1700 and 2100, the number of phases, and the data arrangement in the form below. Then press the "Get Data" button to obtain a table showing the dates of the primary phases of the Moon for the number of phases entered.' The form includes input fields for 'Year' (2018), 'Month' (January), and 'Day' (1), with 'Current Date' and 'First of Year' buttons. There is a 'Number of Phases' field set to 50. The 'Data format' section has two radio buttons: 'Displayed by phase' (selected) and 'Displayed by time'. A 'Get data' button is at the bottom of the form. Below the form, there are sections for 'Notes', 'Input', 'Definitions', 'Time Format', 'Computing the Phase for a Particular Day', and 'Application Programming Interface', each containing explanatory text and links.

**PHASES OF THE MOON**

Enter a date between 1700 and 2100, the number of phases, and the data arrangement in the form below. Then press the "Get Data" button to obtain a table showing the dates of the primary phases of the Moon for the number of phases entered.

Year: 2018 Month: January Day: 1 Current Date First of Year

Number of Phases: 50

Data format: ☒ Displayed by phase ☐ Displayed by time

Get data

---

**Notes**

**Input**

If the date is invalid, the program will change the date to the current date and all data will be calculated based on the current date. However, if the date is valid but one of the phases calculated occurs after December 31, 2100, the program will return an error. If this happens, try using a smaller number of phases or a different date.

**Definitions**

For definitions of the phases, see the explanation of [Phases of the Moon and Percent of the Moon Illuminated](#) in the [Astronomical Information Center](#). In addition, the explanation of [Crescent Moon Visibility](#) discusses the waxing crescent phase.

**Time Format**

In the output table, the date indicates the year, month, day, hour, and minute, respectively, of [Universal Time](#). To convert the times given to local time, see the [U.S. Time Zones](#) explanation or the [World Time Zone Map](#) in the [Astronomical Information Center](#).

**Computing the Phase for a Particular Day**

Several of our [Data Services](#) will compute the fraction of the Moon illuminated for particular days. The [Fraction of the Moon Illuminated](#) service provides values for each day of a calendar year. The [Complete Sun and Moon Data for One Day](#) reports the percent illuminated for a particular day along with location-specific data. [What the Moon Looks Like Now](#) is a simulated image of the Moon at the current time; a similar image for a specific date can be generated using the [Apparent Disk of Solar System Object](#) service.

**Application Programming Interface**

This data service uses one of our new [Application Programming Interfaces \(APIs\)](#). The API returns data in JavaScript Object Notation (JSON) format for users who wish to manipulate data into a customized format. For more information on the API, please see the [documentation page](#).

The USNO's Phases of the Moon website. This allows the user to create a calendar or matrix of when each Moon phase will occur – New Moon, 1st Quarter Moon, Full Moon, and Last Quarter Moon. [” USNO Page ” by Florida State College at Jacksonville is licensed under CC BY-SA 4.0 ]

The site provides accurate sunrise and sunset times for the location

and date requested, as well as moonrise, moonset, and moon phase information. The transit information is the time when the Sun or Moon will cross the observer’s meridian — that north-zenith-south line which divides the sky into two halves. One half of the sky is rising, the other half of the sky is setting.

Civil twilight is the time when sunlight is visible, even though the Sun has not yet risen. *Begin Civil twilight* is in the morning before the Sun rises; *End Civil twilight* is in the evening after the Sun sets.

**Sun and Moon Data for One Day**

**U.S. Naval Observatory  
Astronomical Applications Department**

Jacksonville, Duval County, FL (Longitude W81° 39', Latitude N30° 19')

Monday, January 1, 2018		Eastern Standard Time	
Sun			
Begin civil twilight		6:57 a.m.	
Sunrise		7:23 a.m.	
Sun transit		12:30 p.m.	
Sunset		5:37 p.m.	
End civil twilight		6:04 p.m.	
Moon			
Moonrise		4:30 p.m. on preceding day	
Moon transit		11:34 p.m. on preceding day	
Moonset		6:40 a.m.	
Moonrise		5:31 p.m.	

Phase of the Moon on January 1, 2018: Full Moon at 9:24 p.m. (local standard time)

Jacksonville, Florida Sun and Moon data for January 1, 2018.  
[” USNO Page ” by Florida State College at Jacksonville is licensed under CC BY-SA 4.0 ]

The data provided for the Moon covers not only moonrise and moonset, but the current lunar phase, percent illuminated, and a photo of what the Moon will look like in the sky.



Moon	
Moonrise	4:30 p.m. on preceding day
Moon transit	11:34 p.m. on preceding day
Moonset	6:40 a.m.
Moonrise	5:31 p.m.

Phase of the Moon on January 1, 2018: Full Moon at 9:24 p.m. (local standard time)



Jacksonville, Florida Moon data for January 1, 2018. Note the information on the Moon's phase as well as the image of the Moon. The site also provides a Back to form line to click and return the user to the information page, so another date and/or location can be provided by the user. [ " USNO Page " by Florida State College at Jacksonville is licensed under CC BY-SA 4.0 ]

The USNO also maintains a website cataloging the phases of the Moon. This site allows you to find the phases of the Moon for a specific period of time and number of phases.<sup>1</sup>

*Phases of the Moon : U.S. Naval Observatory: Astronomical  
Applications Department*

Date and Time (Universal Time)			
New Moon	First Quarter	Full Moon	Last Quarter
—	—	2018 Jan 02 02:24	2018 Jan 08 22:25
2018 Jan 17 02:17	2018 Jan 24 22:20	2018 Jan 31 13:27	2018 Feb 07 15:54
2018 Feb 15 21:05	2018 Feb 23 08:09	2018 Mar 02 00:51	2018 Mar 09 11:20
2018 Mar 17 13:12	2018 Mar 24 15:35	2018 Mar 31 12:37	2018 Apr 08 07:17
2018 Apr 16 01:57	2018 Apr 22 21:46	2018 Apr 30 00:58	2018 May 08 02:09
2018 May 15 11:48	2018 May 22 03:49	2018 May 29 14:19	2018 Jun 06 18:32
2018 Jun 13 19:43	2018 Jun 20 10:51	2018 Jun 28 04:53	2018 Jul 06 07:51
2018 Jul 13 02:48	2018 Jul 19 19:52	2018 Jul 27 20:20	2018 Aug 04 18:18
2018 Aug 11 09:58	2018 Aug 18 07:48	2018 Aug 26 11:56	2018 Sep 03 02:37
2018 Sep 09 18:01	2018 Sep 16 23:15	2018 Sep 25 02:52	2018 Oct 02 09:45
<b>Universal Time</b> (UT) is also referred to as Greenwich Mean Time (GMT), and is based on the Prime Meridian.			

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Date and Time (Universal Time)			
New Moon	First Quarter	Full Moon	Last Quarter
2018 Oct 09 03:47	2018 Oct 16 18:02	2018 Oct 24 16:45	2018 Oct 31 16:40
2018 Nov 07 16:02	2018 Nov 15 14:54	2018 Nov 23 05:39	2018 Nov 30 00:19
2018 Dec 07 07:20	2018 Dec 15 11:49	2018 Dec 22 17:49	2018 Dec 29 09:34
<b>Universal Time</b> (UT) is also referred to as Greenwich Mean Time (GMT), and is based on the Prime Meridian.			

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## 7. Lab 1 Assessments

### **Discussion: Greetings and Introductions**

Use this forum to introduce yourself to the professor and the class. Tell us a little about yourself, including some of the things you expect to get out of this course.

Students are to post their initial post by 11:59 pm on Wednesday. Be sure to thoroughly address each element of the question, and use the reading and other materials provided to support your discussion. The initial post must be at least 150 words and address all parts of the question(s). In addition, students must respond to the post of at least two classmates. These responses must be substantial, posted by 11:59 pm on Sunday of that week. <sup>(1)</sup>

### **USNO Astronomical Applications Website Summary**

The USNO provides useful information that has a number of applications. Go to the website and explore all of the options available. Write a brief 200 word overview, including one or two things that surprised or enlightened you as you examined USNO's website. Once completed, upload your overview on the submission page by clicking the above link.

Be sure to include descriptive information about the things that surprised/enlightened you including options such as strengths and/or weaknesses of the tools/resources, relevance to your life, relevance to science, how it helped you to overcome misconceptions, how it changed your way of thinking, or how it

supported your conceptions, etc. The assignment should be organized properly. For example:

- Introduction/Overview
- Item of interest 1
  - Supporting Point 1
  - Supporting Point 2
- Item of interest 2
  - Supporting Point 1
  - Supporting Point 2
- Conclusion

This assignment will be graded using the rubric in the syllabus and is worth up to 35 points of your final grade. <sup>(1)</sup>

## Sunrise, Sunset Activity

*Use this linked document to submit your data and responses.*

As Earth revolves around the Sun, the position of sunrise and sunset will change throughout the year. This is easy to track over a period of time if you are looking from the same vantage point. This part of the lab will take place over a number of weeks, the period of which will be determined by your professor.

1. Find a location where you can see where the Sun rises or sets each day. This is important that you find a location where you can see the point on the horizon where sunrise or sunset occurs.
2. Using your smartphone or camera, take a photo once a week of either sunrise or sunset. You may choose any day of the week you wish. **ALWAYS USE CAUTION IN OBSERVING THE SUN!** You only want to observe and photograph sunrise and/or sunset when the Sun is low on the horizon. It is best to stay

with the same day, if the weather allows. You might have to adjust the following week's photo days due to weather; the idea is to photograph the Sun's position weekly to give you a record of how the sunrise or sunset position changes over time.

3. Complete the table on the attached document. Copy and paste your photos into the table, and upload into the Lab Blackboard shell using the link above. This exercise will be graded using the rubric in the syllabus and attached document and is worth up to 30 points. <sup>(1)</sup>

## Moon, Moonset Activity

*Use the linked document to submit your data and responses.*

As the Moon revolves around Earth, its rising and setting times will change day to day. This part of the lab will take place over a number of days and perhaps, weeks; the period of which will be determined by your professor. This exercise is also a parallel to AST 1002's *Tracking the Phases of the Moon* project, from Module 2.

1. Find a location where you can see where the Moon rises or sets each day. This is important that you find a location where you can see the point on the horizon where moonrise or moonset occurs.
2. Using your smartphone or camera, take a photo either moonrise or moonset. You will need several days of observations; your instructor will provide you with specifics
3. Complete the table on the attached document. Copy and paste your photos into the table, and upload into the Lab Blackboard shell using the link above. This exercise will be graded using the rubric in the syllabus and attached document and is worth up to 25 points. <sup>(1)</sup>

## Lab 1 Quiz

### Quiz Document Link

This quiz contains five matching items, each worth 2 points, for a total score of up to 10 points. You will have 5 minutes to complete this quiz. You have one attempt. <sup>(1)</sup>

## Lab 13: Event Participation Activity Preview

### Document Link

In lab 13, you will need to attend at least one of the following:

1. Star party observing session
2. Planetarium show
3. Astronomy Club Meeting or sanctioned activity

Details of local events will be provided by your instructor and you can search for similar events in your area. Answer the questions provided for the particular type of event that you choose to attend. Also, be sure to take the Observing Form on page two to have your attendance verified. Please consult your instructor early in the semester if you foresee issues with finding or attending an event. Keep in mind that you are representing the school and yourself, so appropriate attire and behavior are required.

Plan early. Do not wait until the last minute to find an event. Many events will take place over the term but possibly not during the final week. <sup>(1)</sup>



PART II

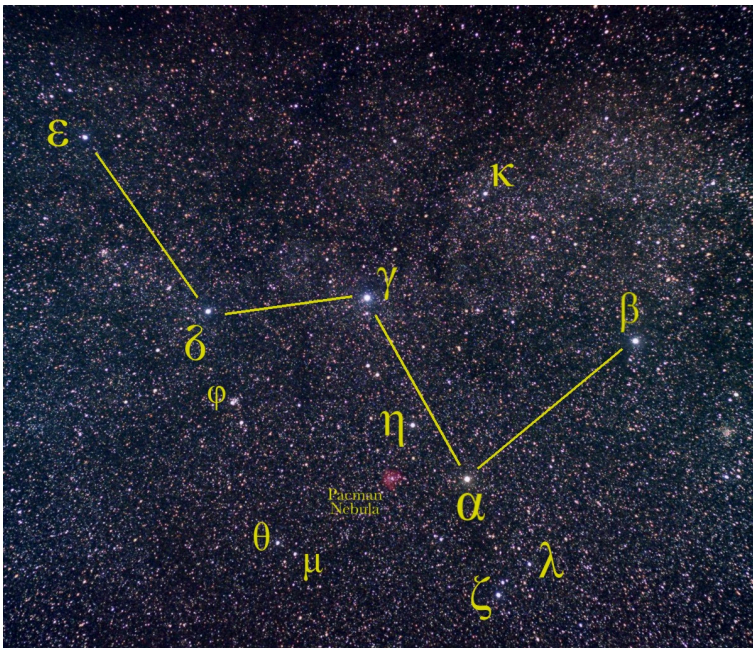
# LAB 2 - CONSTELLATIONS AND THE NIGHT SKY



# 8. Introduction

## Astronomy Laboratory 2 – Constellations and the Night Sky

### Module Introduction



Cassiopeia, named after Queen Cassiopeia from Greek mythology, is seen in the northern sky. [ “Cassiopeia starfield” by Sadalsuud is licensed under CC BY 4.0 ]

The constellations represent groupings of stars that form outlines of animals, objects, mythological people and creatures, or gods.

In this lab, you will learn about historical constellations and myths, do online research into other culture's "non-European" constellations and associated myths, then go outdoors at night and identify/draw specified constellations and bright stars. You will also learn how the modern magnitude system works and will go outdoors at night to identify stars of specific magnitudes, and record data. <sup>(1)</sup>

## Objectives

At the end of this module, students will be able to:

- Record data pertaining to the stars, constellations, and asterisms
- Identify constellations and asterisms
- Discuss the evolution of constellations and their mythologies <sup>(1)</sup>

## Outcomes

The material in this module includes content designed to meet the following course outcomes:

- Explain and apply major concepts in astronomy including planets, satellites, stars, meteors, galaxies, and theories of the universe.
- Communicate scientific ideas through oral or written assignments.
- Interpret scientific models such as formulas, graphs, tables and schematics, draw inferences from them and recognize their limitations. <sup>(1)</sup>

# Assigned Readings

## Learning Unit 2

## Assignments

- Constellations in Mythology Exercise
- Looking Up! Activity
- Lab 2 Quiz <sup>(1)</sup>

# 9. Origins

## Constellations

Looking up... that is exactly what people used to do. The night sky held a fascination for people who told accounts about their experiences, beliefs, or simply stories and myths based on patterns they saw in the stars on the celestial sphere. Many of these constellations and stories are as old as humans; each people group, country, or culture developed their own constellation outlines and accompanying stories. Many of these historical constellations changed over time, or were dropped altogether.

It appears that the term *constellation* came from the Late Latin term *cōstellātiō*, or set of stars. The term constellation was accepted in English sometime during the 14<sup>th</sup> century. Constellations are basically connect-the-dots, where the stars act as the dots and the connections were made by the imagination. The constellations represent groupings of stars that form outlines of animals, objects, mythological people and creatures, or gods. Today we recognize 88 modern constellations, adopted by the International Astronomical Union in 1928. At the same time, the International Astronomical Union adopted constellation boundaries, much like state boundaries within a country like the United States. <sup>(1)</sup>

## Origins

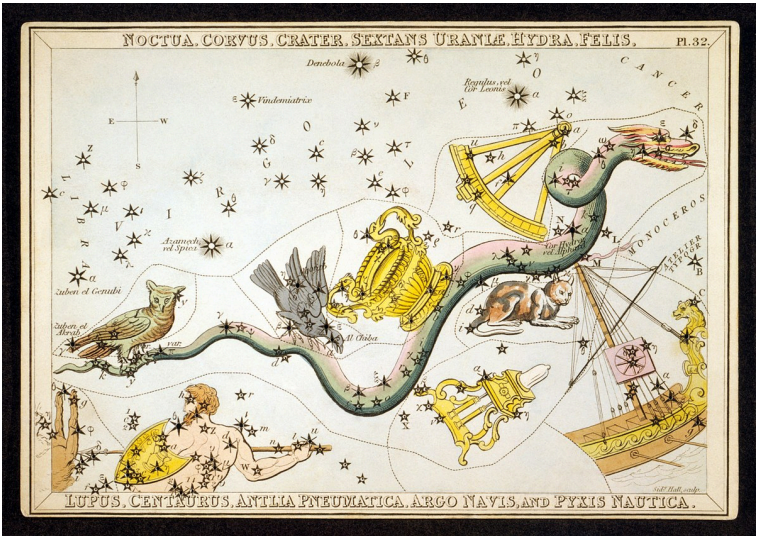
The oldest depictions of shapes go back to the Sumerians, in the Early Bronze age, and the Babylonians, in the Late Bronze Age. These civilizations lived in Mesopotamia, what is today's modern

Iraq. The Chinese, known for their accurate astronomical observations and records, also produced star maps with constellations. Dating back to the 5th century BC, the Chinese divided the sky into twenty-eight mansions. Think of these like the zodiacal constellations, though the twenty-eight Chinese mansions also depicted the Moon's path across the heavens. Even relatively-more modern star maps, like the star maps from the Song Dynasty, kept with Chinese traditions.

Astronomy and the heavens was a center point for ancient Egypt, including Egyptian religion. Egyptian constellations appear to have been original, with no influence from other cultures. Some of the original Egyptian constellations included a lion, crocodile, bull, and a hippopotamus. In the New Kingdom, the constellations were revised. The earliest example, from 1470 BC, is that of Senenmut, an architect who served under the rule of Queen Hatshepsut. <sup>(1)</sup>



The twenty-eight Chinese mansions [ “The twenty-eight mansions of the Chinese astronomy.” by Mysid is licensed under CC BY-SA 3.0 ]



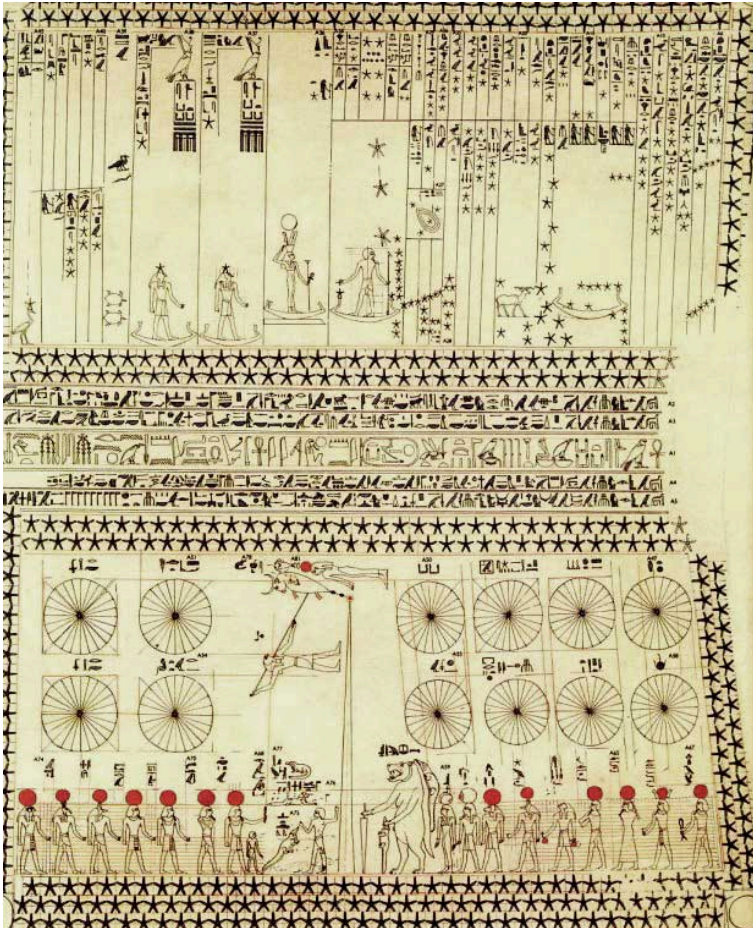
Chinese star map from the Song Dynasty, 11th century AD [ “Su Song Star Map” by PericlesofAthens is in thePublic Domain ]



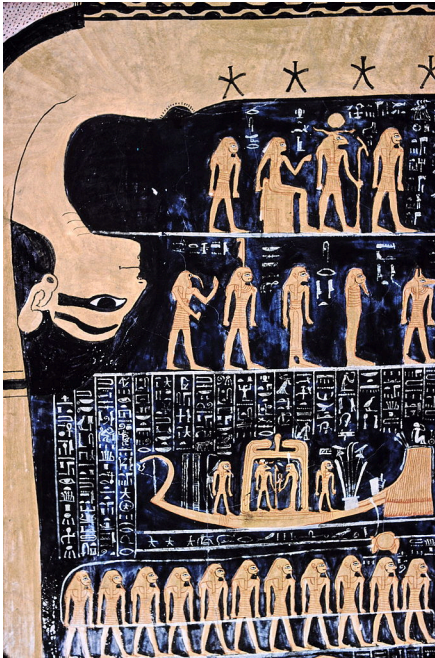
# 10. Egyptians, Greeks, and Hebrews

## Egyptians and Osiris

Perhaps one of the best-known of the Egyptian Constellations is Osiris, god of the dead, underworld, and rebirth. This prominent star grouping, the brightest and most-recognized on the celestial sphere, is today known as Orion. <sup>(1)</sup>



Ancient Egyptian star map and decanal clock on the ceiling from the tomb of Senenmut at Deir el Bahari in Luxor, an architect from the 18<sup>th</sup> Dynasty [ “Senenmut” by SenemmTSR is in the Public Domain ]



Nut, Egyptian goddess of the sky, with the star map found in the tomb of Ramses VI [“Goddess Nut 1” byHans Bernhard (Schnobby) is licensed under CC BY-SA 3.0 ]

## Greeks and Hebrews

The Greeks appeared to have been influenced by a number of the Babylonian and Egyptian constellations. Homer notes in the *Iliad* and the *Odyssey* , written in the 8<sup>th</sup> century BC, the constellations Boötes, Orion, and Ursa Major, as well as a number of bright stars and the Pleiades. Some of the best constellation records are included in Claudius Ptolemy’s 2<sup>nd</sup> century *Almagest* . The oldest known representation of the Zodiac is said to come from Greece, and includes the familiar modern zodiacal constellations.

The Hebrews noted numerous constellations in the *Tanakh* , the

Hebrew Bible, which is the source of the Christian Bible's Old Testament. A number of constellations are noted in the book of Job, in particular Orion and the Big Bear, along with the Pleiades. Job is considered one of the oldest books in the Bible, and many estimates date it to the 6<sup>th</sup> century BC, with some estimates as early as the 7<sup>th</sup> century BC. <sup>(1)</sup>



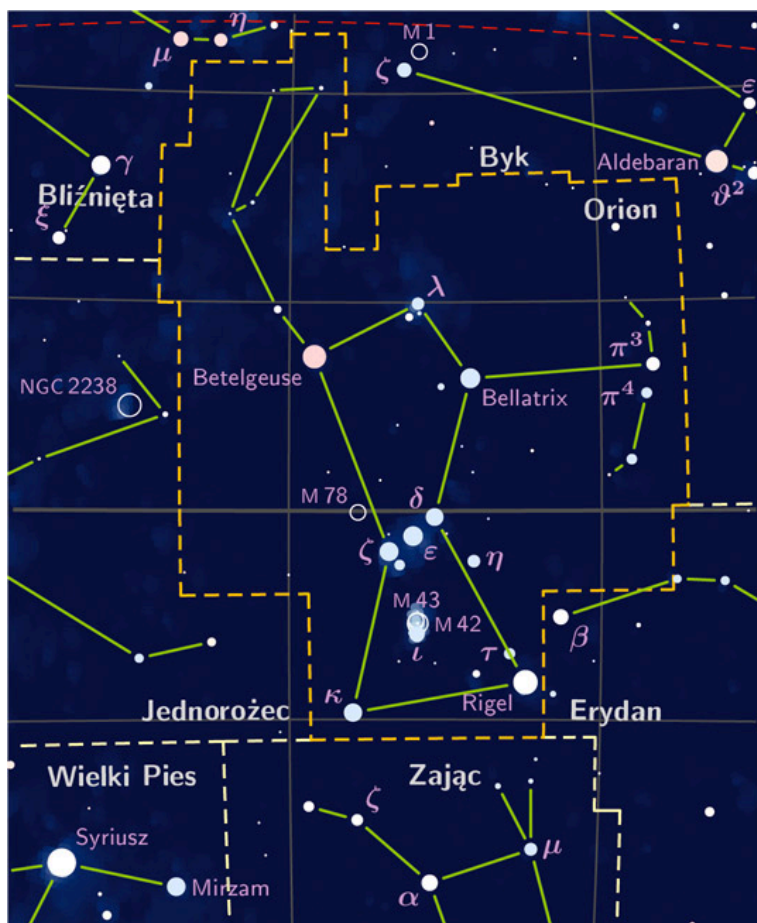
The Farnese Atlas, in Naples, a celestial sphere believed to be from Hipparchus' 2<sup>nd</sup> century BC star map and catalog [ "Atlas (Farnese

Globe)” by Gabriel Seah is licensed under CC BY-SA 3.0 ]

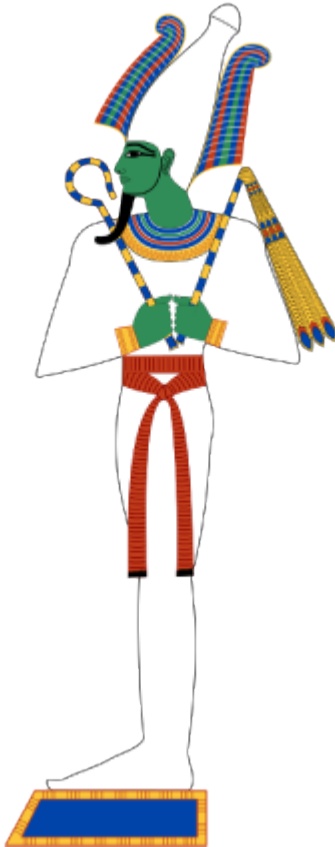
## II. Orion and the Southern Celestial Hemisphere

### Orion

Perhaps Orion is the most-identified group of stars, culturally speaking. The Chinese called the star pattern Shen, a supreme warrior, in India Skanda, a celestial general riding a peacock, Egyptians Osiris, and the North American Lakota Tribe the Hand or arm of a Lakota Chief.<sup>(1)</sup>



A star map showing the constellation Orion the Hunter. Star maps, or star atlases, also include constellation boundaries and objects found within the constellations. [ “Orion constellation PP3 map PL” by Blueshade is licensed under CC BY-SA 3.0 ]



The Egyptians saw the stars which form the constellation Orion as Osiris, the god of the dead in ancient Egyptian religion [ “Standing Osiris edit1” by Jeff Dahl is licensed under CC BY-SA 4.0 ]





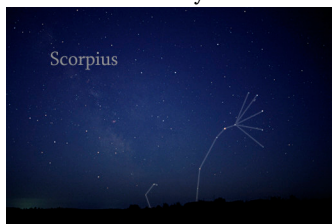
Another shape visualized for today's Orion was Skanda, a celestial general deity riding a peacock, as depicted by Hindus. Skanda was also an important deity in Buddhism. [ "Murugan by Raja Ravi Varma" by Ravi Varma Press, Karla Lonavla is in the Public Domain ]



Orion the Hunter, as depicted in Urania's Mirror, a constellation card set published in London, ca. 1825. ["Urania's Mirror – Orion" by Sidney Hall is in the Public Domain ]

## Southern Celestial Hemisphere

Even though the northern celestial hemisphere and some into the southern celestial hemisphere had been well-charted, albeit with a variety of constellations by different cultures, not as much had been done with the southern celestial hemisphere. Southern hemisphere explorers charted many of these constellations, and a number of them have survived to today. These include a toucan, peacock, triangle, and three constellations that make up parts of a ship. There are many wonderful constellation stories that are unknown to many. In what is New Zealand today, the ancient Maori Tribe noted a constellation they named Maui's hook — what is today's Scorpius. <sup>(1)</sup>

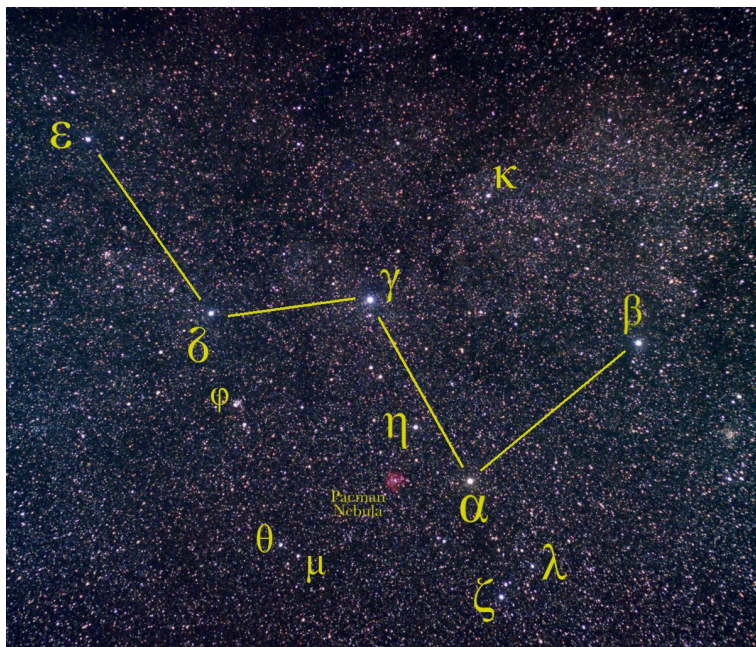


Scorpius, as the Maori Tribe called Maui's hook, shows the shape of a fish hook that was made famous in the recent Disney cartoon, Moana. [ "ScorpiusCC" by Till Credner is licensed under CC BY-SA 3.0 ]

## 12. Native American Stories

### Native American Stories

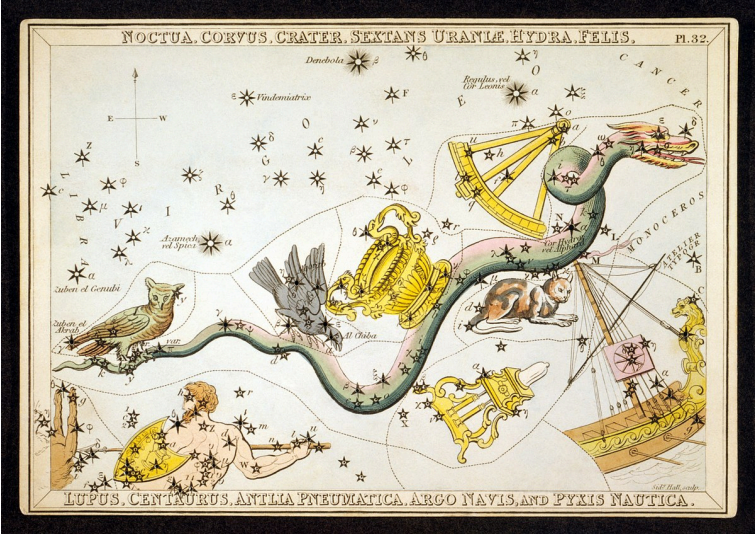
Native Americans have wonderful stories about the night skies and constellations. The Yakima Tribe, from what is today central Washington state, saw Cassiopeia as a stretched, drying elk skin. Cherokees saw two bright stars in today's Canis Major – the great dog – as two dogs guarding the path to the land of souls. That path indicated by the Cherokee? The Milky Way. And, according to the East Coast Mesquakie Tribe and the Great Lakes Iroquois Tribe, the bowl stars of the Big Dipper in the constellation Ursa Major (the Big Bear) form a bear, with the stars of the Big Dipper's handles as hunters. <sup>(1)</sup>



Cassiopeia, named after Queen Cassiopeia from Greek mythology,



is seen in the northern sky. [ “Cassiopeia starfield” by Sadalsuud is licensed under CC BY 4.0 ]



Canis Major as depicted in Urania’s Mirror , a set of constellation cards published in London c.1825. [ “Sidney Hall – Urania’s Mirror, etc.” by Adam Cuerden is in the Public Domain ]

# 13. The Pleiades and The Big Dipper

## The Pleiades

An asterism is a pattern of stars within a constellation, or composed of a number of constellations. The Pleiades, an open star cluster in the constellation of Taurus, is easy to find, and often confused as the Little Dipper. The Greek Pleiades myth is that there were seven sisters who were the daughters of Atlas and Pleione, a sea nymph. Zeus placed the sisters in the sky to protect them.

The Japanese call the Pleiades *Subaru*, Hawaiians *Makahiki* or many little eyes, and the Navajo *Dilyehe* the planting stars which represent youth. <sup>(1)</sup>



A bronze disk, ca. 1600 BC, from Nebra, Germany, is one of the oldest known representations of the cosmos. The Pleiades are at the top right. [ "Nebra Scheibe" by Dbachmann is licensed under CC BY-SA 3.0 ]



The Pleiades, an asterism known as The Seven Sisters. Many mistake the Pleiades as the Little Dipper. [“The Pleiades” by Dr. Mike Reynolds, Florida State College at Jacksonville is licensed under CC BY 4.0 ]



Subaru — the Japanese name for the asterism we call the Pleiades — is the symbol used for the Japanese automaker by the same

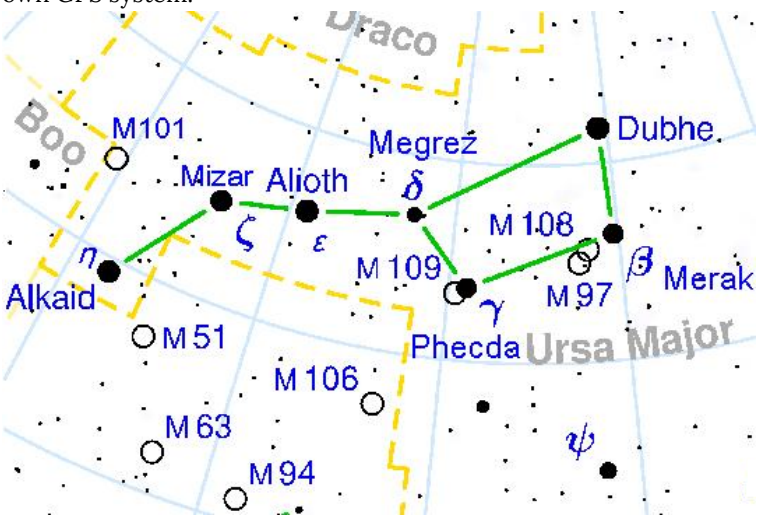


name [“Subaru Pleiades” by Allen McCloud is licensed under CC BY-SA 3.0 / A derivative from the original work ]

## The Big Dipper

Perhaps the best-known asterism, at least in the northern hemisphere, is the Big Dipper, part of the constellation of Ursa Major, the Big Bear. It is easy to recognize, and does look like a dipper. Other cultures have identified it as a plow, wagon, barbeque pit, and perhaps the most meaningful, the drinking gourd.

As escaped slaves were leaving the south during the Civil War, they traveled north at night to try to go undetected. They were given directions to “follow the drinking gourd.” Since the Big Dipper is a constellation near the north celestial pole and the pole star Polaris, they could easily find the asterism and walk towards it; their own GPS system.<sup>(1)</sup>



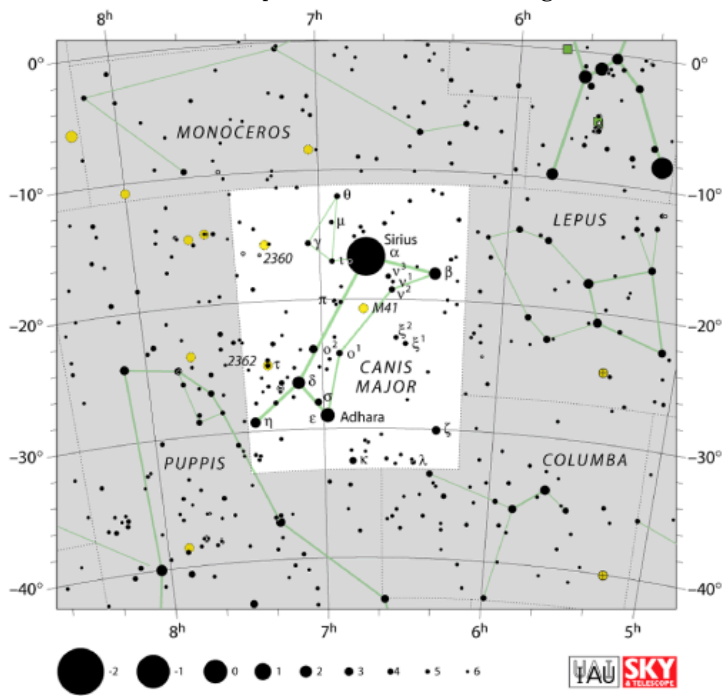
The Big Dipper, made up of four stars for the dipper’s bowl and three stars for the handle [ “Ursa Major constellation detail map” by SAE1962 is licensed under CC BY-SA 3.0 ]

# Modern Constellations

Today we recognize 88 modern constellations, adopted by the International Astronomical Union in 1928. At the same time, the International Astronomical Union adopted constellation boundaries, much like state boundaries within a country like the United States.

Perhaps one of the most-intriguing – and disturbing – modern constellation stories took place in 2013, when a 22-year old New Hampshire woman stabbed her father during a fight outside while trying to identify constellations.

Finding constellations depend on your location; the less lighting you have, the better. Under some city lighting conditions, it is difficult to even find the bright stars, nevertheless many of the fainter stars that make up a constellation's stick figure outline. <sup>(1)</sup>



This star chart shows the modern constellation Canis Major, the Big or Great Dog, as well as its constellation boundaries [ “Canis Major” from IAU is licensed under CC BY 4.0 ]

# 14. Lab 2 Assessments

## Constellations in Mythology

Bernard of Chartres is credited in the 12th century with saying that “we stand on the shoulders of giants.” Even for the seemingly-simple topic of constellations and mythology, this is true. For this generated not only interest and research about the heavens and the science of astronomy, but stoked the imagination.

You will research the myths surrounding one of the less-known constellations. Do not include any of the Zodiacal constellations, or better-known constellations such as Orion, Ursa Major, and Canis Major. Many Southern hemisphere constellations provide great opportunities for less-known constellations.

Use a minimum of two (2) different references about your chosen constellation. Compose an original paper of 200 words about your chosen topic. List your references in standard format. If you cut and paste a quote, provide the proper credit. Once completed, upload your overview on the submission page by clicking the above link.

- Introduction/Overview
- Major Point 1
  - Supporting Point 1
  - Supporting Point 2
- Major Point 2
  - Supporting Point 1
  - Supporting Point 2
- Major Point (etc.)
- Conclusion
- References

This exercise will be graded using the rubric in the syllabus and is worth up to 35 points. <sup>(1)</sup>

## Look Up Activity

*Assignment Document Link.*

*Use the above document to submit your data and responses.*

Each season brings on new constellations due to the Earth's orbit around the Sun. There are four seasonal star maps or star charts. Choose the season star chart appropriate or as directed, make your observations, and record them in the provided table.

This exercise will be graded using the rubric in the syllabus and attached document and is worth up to 30 points. <sup>(1)</sup>

*Quiz Document Link.* This quiz contains five matching items, each worth 2 points, for a total score of up to 10 points. You will have 5 minutes to complete this quiz. You have one attempt. <sup>(1)</sup>



PART III

# LAB 3 - LIGHT POLLUTION AND OBSERVING

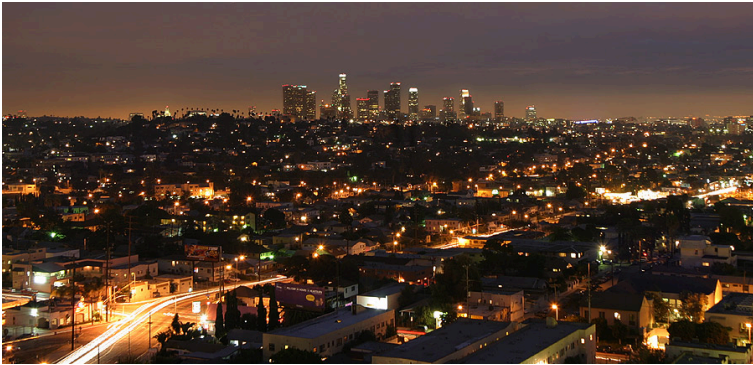




# 15. Introduction

## Light Pollution and Observing

### Module Introduction



The lights of Los Angeles illuminate the sky as well as the streets and neighborhoods [“Lightmatter la at night 001” by Aaron Logan is licensed under CC BY 1.0 ]

Some of your older family members and friends probably tell “tales” of seeing billions of stars, every night, in the nighttime sky. While highly exaggerated, these tales are based in reality. Overall light pollution has dramatically increased over the years, as the pervasiveness of artificial light has brightened our streets, homes, and businesses yet, unfortunately, dimmed our chances of having the spectacular views of yesteryear.

In this lab, you will examine light pollution and issues surrounding light pollution, taking photos of light pollution around your home, local shopping centers, and on highways. You will also learn how the

Moon creates a lot of light – natural light pollution – when trying to observe stars and fainter objects. <sup>(1)</sup>

## Objectives

At the end of this module, students will be able to:

- Record data pertaining to light pollution and viewing of stars
- Research the effects of light pollution
- Catalogue sources of man-made light pollution
- Compare and contrast conditions of natural light pollution <sup>(1)</sup>

## Outcomes

The material in this module includes content designed to meet the following course outcomes:

- Demonstrate knowledge of scientific method.
- Communicate scientific ideas through oral or written assignments.
- Interpret scientific models such as formulas, graphs, tables and schematics, draw inferences from them and recognize their limitations.
- Demonstrate the ability to think critically.
- Demonstrate the ability to use scientific and quantitative reasoning. <sup>(1)</sup>

## Assigned Readings

Learning Unit 3

## Assignments

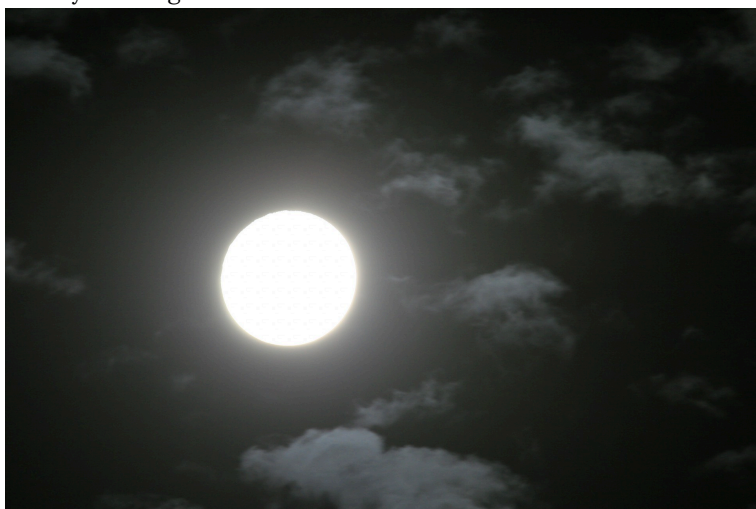
- The Effects of Light Pollution Exercise
- Local Light Pollution and Observing Activity
- Lab 3 Quiz <sup>(1)</sup>

# 16. Streetlights

## Introduction to Light Pollution

When most of us step out on a clear, moonless night and look up, we see... few stars. Many people in industrial or “advanced” countries have never seen the Milky Way, our own home galaxy. And in some large cities, one is fortunate to see the Moon, bright planets, and the brighter stars. Yet, this has not always been the case.

For many centuries, people from around the planet looked up in fascination at the night sky. They passed along stories about the groupings of stars they saw; only the Moon was bright enough to cause fainter stars and the Milky Way to not be visible. And, since the Moon went through its phases, night time darkness would return. So, natural light pollution does occur. You can really see the effects of a bright moon while trying to locate some of the faint constellations or watch a meteor shower. The sky is simply “washed out” by moonlight.



The bright light of the full moon [ “Hazy Moon With Clouds” by Lynn Greyling is in the Public Domain, CC0]

## Streetlights

Streetlights first appeared about 300 years ago as oil lamps. These oil lamps, often mounted on wooden poles or cast-iron fixtures by the early 18<sup>th</sup> century, continued in use until the early 19<sup>th</sup> century, when gas lamps came into use. By the 20<sup>th</sup> century, electric lighting was in use. Today outdoor lighting is used for a number of reasons:

- Streetlights; roadway lighting
- Security
- Buildings
- Advertising
- Ornamental and Decorative <sup>(1)</sup>



The Earth at Night — a worldwide, cloud-free mosaic showing the extent of lighting. The image was taken during 2016 by the Suomi National Polar-orbiting Partnership satellite.

[ “BlackMarble20161km” by NASA Earth Observatory images by Joshua Stevens in the Public Domain ]

# 17. Glare and Shielding

## Glare and Shielding

**Glare** is defined as an intense and blinding light that reduces visibility. Such light produces glare within your field of vision is brighter than the level to which your eyes are adapted. Think of being in a dark room. Someone turns on the lights, and you usually squint. **Sky glow** is a diffuse, scattered light attributable to lighting sources on the ground and not in the air or a significant elevation. And some lighting may be so poorly designed that it leads to confusion; this is referred to as **clutter lighting**.

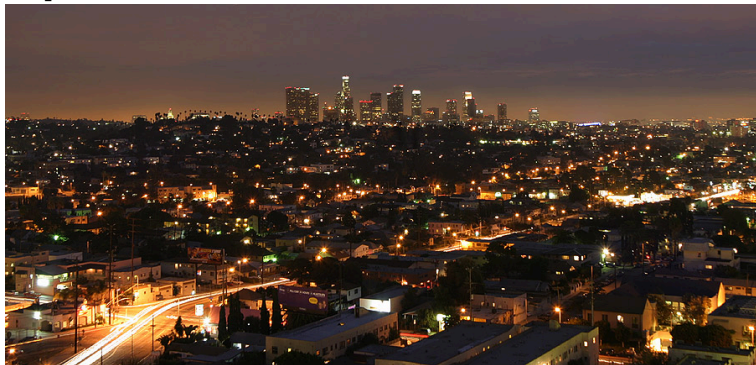
The need for good streetlights and security lighting is understood. However, the usually-poor design and use of such lighting is what is being questioned, not only by astronomers but by biologists, lighting engineers, and even crime and safety experts.

Many of today's outdoor lights are too bright and unshielded, decreasing safety and with other unintentional results. First, the glare from these bright, unshielded lights create shadows, making it more difficult for you to see. The brightness of the light itself, shining into your eyes, constricts your pupils and diminishes your ability to see in low light levels. <sup>(1)</sup>

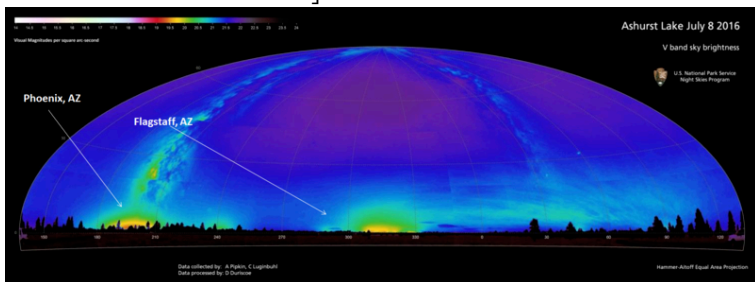


Mexico City at night, showing lights and resulting light pollution

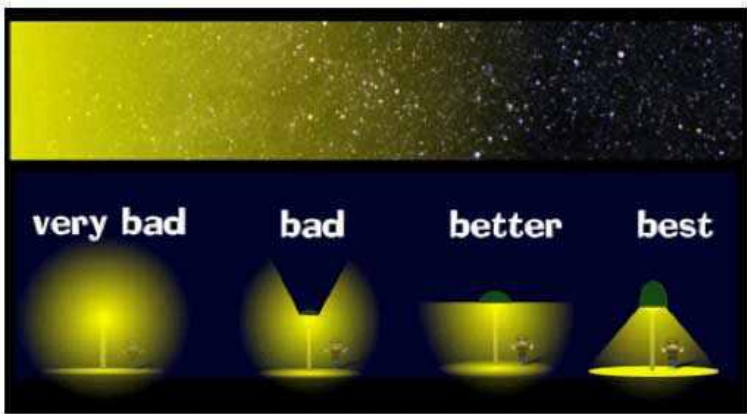
[ “México City at Night 2005” by Quasipalmis licensed under CC BY 2.0 ]



The lights of Los Angeles illuminate the sky as well as the streets and neighborhoods [ “Lightmatter la at night 001” by Aaron Logan is licensed under CC BY 1.0 ]



A calibrated all-sky map shows the skyglow brightness of Phoenix and Flagstaff, Arizona [ “All-sky map of measured skyglow brightness” by Pipkin, A., Duriscoe, D. & Luginbuhl, C. in the Public Domain ]



Streetlight glare can be reduced by shielding, as shown above in a range from unshielded to the most effective shielding. [ “Streetlight Glare” by Futurism is licensed under CC BY 4.0 ]

Shielding refers to an opaque material that blocks light. Many streetlights are made such that the bulb is easily visible, usually in a glass fixture. Instead of directing the light to the roadway, walkway, or the side of a building where it is needed, it shines everywhere, producing glare and sky glow. <sup>(1)</sup>



# 18. Effects of Light Pollution

## Effects of Light Pollution

Government and private studies show that over lighting as well as poorly-directed lighting actually *decreases* safety. According to the International Dark-Sky Association research and references:

- There is no clear scientific evidence that increased outdoor lighting deters crime.
- It makes us feel safer, but bad outdoor lighting can actually reduce safety.
- A study by the city of Chicago actually found a correlation between increased crime and brightly lit alleyways. In fact, glare from bright lights creates shadows where criminals can hide.
- Some crimes, like vandalism and graffiti, thrive on lighting.

*Many species (including humans) need darkness to survive and thrive.* – American Medical Association

What about the effects light pollution has on life? It might surprise you, but a number of studies have been done on this question. Consider the fact that significant artificial light is being added to the environment. Nocturnal animals sleep during the day and are active at night. This significant artificial lighting disrupts their nighttime environment. There are numerous insects that are fatally drawn to light. This might seem good at the surface, but a reduction in insect populations have a negative impact on species that rely on these insects for food or as pollinators. Migratory birds have been significantly impacted, mistiming migration and direction of travel. A study published October 18, 2017 in the *Proceedings of the National Academy of Sciences* looked at the effects of an iconic bright light

source during a specific seven-day period over seven years. The study estimated that about 1.1 million birds were influenced by the specific light source during the study period; that is 49 nights total.

An issue Floridians have become sensitive to for a number of years are sea turtle hatchlings. Turtles come ashore at specific times to lay their eggs. When the hatchlings are ready to return to the sea for safety, artificial lights confuse them and leave them stranded on land. In 2013 the Florida Department of Environmental Protection and the Florida Fish and Wildlife Conservation Commission undertook a study to identify coastal lighting that could threaten the nesting habitats of endangered sea turtles.



Light pollution also has an effect on life, from plants to nesting sea turtles [ “Turtle golfina escobilla...” by Claudio Giovenzana is licensed under CC BY-SA 3.0 ]

There are many other examples of the negative effects of light pollution, from the Great Barrier Reef corals to trees, flowers, and grasses. The lights alter biological clocks of many animals, plants, and yes, even humans.

*Glare from nighttime lighting can create hazards ranging*

*from discomfort to frank visual disability.* – American Medical Association

Humans have specific day-night rhythms, a circadian rhythm, or our biological clock. There are many reports of people not getting a deep sleep, and it is not always the bed or pillow that is the cause.

Then there are the costs of all this lighting. U.S. Department of Energy 2011 data from 2011 estimates that in the United States alone, about \$3 billion each year worth of energy is being lost to skyglow, alone. This comes from the fact that 35&percent; of light is being wasted by unshielded and poorly-aligned outdoor lighting. This is real money out of everyone's pocket. <sup>(1)</sup>

# 19. Potential Solutions

## Potential Solutions

So, what are the solutions? It's unrealistic to think we're going to turn off all of these outdoor nights. Some lighting does serve a good cause. Yet there are a number of ways to significantly reduce light pollution for the benefit of all.

1. Use shielding on lighting to direct the light to the ground. This is effective on streetlights and building lights. The results of shielded lighting are that the light shines down, where it is intended.
2. Do not overdo the amount of light; illuminate with only what is needed. Too much light is a waste.
3. Do not use blue lights; light more towards the red-orange-yellow end of the spectrum is better for health reasons; these are called long-wavelength lights. Bluish lighting is the worst.
4. Use timers and motion detectors for lighting. There are cities and municipalities that are looking at systems that would turn off until needed. Imagine a street lighting system that would only come on when a car travels the road, then turns off when the car is beyond the light.
5. Cities, counties, and municipalities should carefully plan future lighting.

There are organizations that promote good lighting and lighting design. One of the leaders is the International Dark-Sky Association, IDA. The IDA has worked with lighting engineers to design excellent light fixtures, cities, municipalities, and parks on lighting plans, and an overall public education and outreach effort. <http://www.darksky.org/about/>

*I know nothing with any certainty, but the sight of the stars makes me dream. —Vincent van Gogh*

The famous Dutch Post-Impressionist artist Vincent van Gogh painted in 1889 “The Starry Night” while in Saint Rémy de Provence, France. If van Gogh was to try to repeat such a work today from Saint Rémy, few stars and no Milky Way are visible due to light pollution. The starry night is gone.<sup>(1)</sup>



The Starry Night, Vincent van Gogh 1889 [ “Starry Night” by Vincent van Gogh , Google Art Project is in thePublic Domain ]

## 20. Lab 3 Assessments

### **Assignment: The Effects of Light Pollution**

The topic of excess lighting and its effects fills volumes of books, papers, and research, much more than can be presented in an introductory astronomy lab.

Research one of the below topics. Begin your research with the International Dark-Sky Association website . Use a minimum of three (3) different references, including the International Dark-Sky Association website. Compose an original paper of 200 words about your chosen topic. You may also use any counter references you find. List your references in standard format. If you cut and paste a quote, provide the proper credit. Once completed, upload your overview on the submission page by clicking the above link. This assignment will be graded using the rubric in the syllabus and is worth up to 30 points.

- Excess Lighting and Energy Waste
- Florida Sea Turtle hatchlings and poor lighting
- International Dark Skies Places
- Light Pollution Effects on Wildlife and Ecosystems
- Lighting, Crime, and Safety

Be sure to properly organize your writing. For example:

- Introduction/Overview
- Major Point 1
  - Supporting Point 1
  - Supporting Point 2
- Major Point 2
  - Supporting Point 1

- Supporting Point 2
- Major Point (etc.)
- Conclusion
- References <sup>(1)</sup>

## Assignment: Local Light Pollution and Observing Light

### Assignment Document Link

*Use the above document to submit your data and responses. You will also need to upload five iamges in the submission area and label each according to the document.*

1. How much light pollution is in the area where you live, or near where you live? The first part of the lab is a survey of your local light pollution.
2. In the second part of the lab, you will take five photographs at night, as outlined in the document, and upload them to Blackboard.
3. In the final part of the lab, you will observe the moon and respond to the questions as part of your observation report.

This exercise will be graded using the rubric in the syllabus and attached document and is worth up to 35 points. <sup>(1)</sup>

## Lab 3 Quiz

### Quiz Document Link

This quiz contains five matching items, each worth 2 points, for a total score of up to 10 points. You will have 5 minutes to complete this quiz. You have one attempt. <sup>(1)</sup>





PART IV

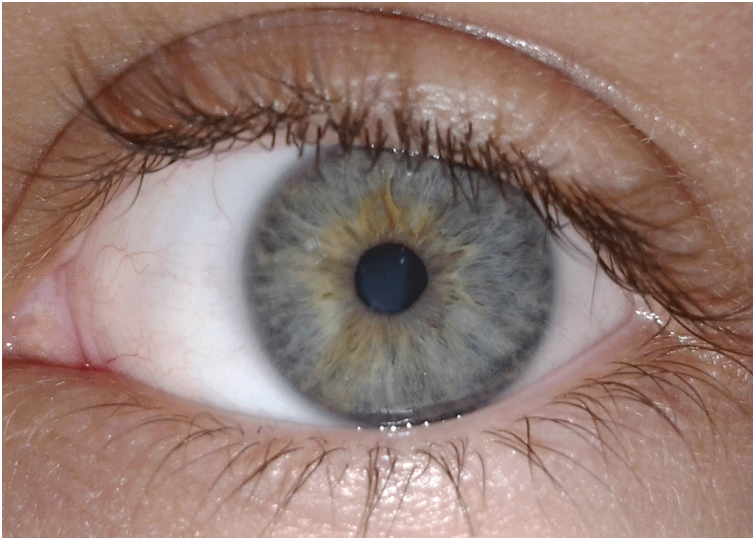
## LAB 4 - ABOUT YOUR EYES



## 2I. Introduction

### Astronomy Laboratory 4 – About Your Eyes

#### Module Introduction



Human eye by by Alexageev is licensed under CC BY-SA 3.0

The eye not only allows us to see our Universe, but to determine color, shapes, basic identifications, and relative sizes of objects. Think of the eye as a sensor that allows our brain to collect, organize, and interpret things around us. The human eye has a number of parts which must function together to assure eyesight. Failure or weakness of any one of these can impair eyesight, or cause blindness.

In this lab, you will explore how your eyes work and identify

the major parts of the human eye, compare the eye to optical instruments such as the telescope or camera, and conduct at-home eye tests which detail near and far sightedness, color blindness, depth of perception, and blind spots. <sup>(1)</sup>

## Objectives

At the end of this module, students will be able to:

- Identify the major parts of the human eye
- Compare the parts and functions of the eye with those of cameras and telescopes
- Perform tests of the eyes for Afterimages, Blind Spots, Eye Dominance, Focus, Color Vision, and Astigmatism <sup>(1)</sup>

## Outcomes

The material in this module includes content designed to meet the following course outcomes:

- Demonstrate knowledge of scientific method.
- Communicate scientific ideas through oral or written assignments.
- Interpret scientific models such as formulas, graphs, tables and schematics, draw inferences from them and recognize their limitations.
- Demonstrate the ability to think critically.
- Demonstrate the ability to use scientific and quantitative reasoning. <sup>(1)</sup>

## Assigned Readings

### Learning Unit 4

## Assignments

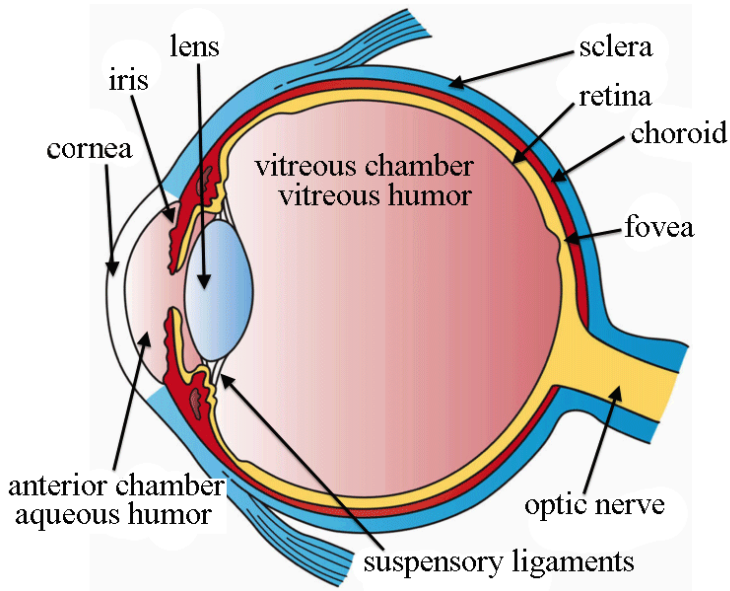
- About Your Eyes Activity
- Lab 4 Quiz <sup>(1)</sup>

## 22. The Human Eye

### **An Introduction to your Eyes**

The eye is a marvelous sensor! With sight as one of our five senses, the eye allows us to experience our world – our Universe. The eye as a sense not only allows us to see our Universe, but to determine color, shapes, basic identifications, and relative sizes of objects. Think of the eye as a sensor that allows our brain to collect, organize, and interpret things around us. What would the beauty of a sunset be without color? Or the distance to a coffee cup as you are trying to pick it up without the eye and brain working together to determine depth perception? Our brain stores these experiences, building on what we see and experience in our universe.

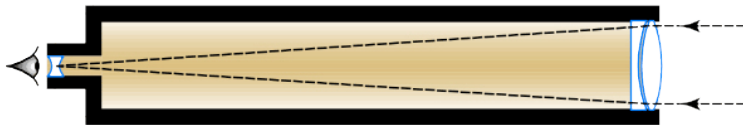
Science has revolved around the human ability to observe, among other things like reasoning, whether it be what occurs when one puts two chemicals together, how the location of sunrise changes over a period of time, the different feather patterns on a male and female bird of the same species, or variations in clouds, shells, and rocks. Astronomy fully used the visual senses to observe the Universe. The eye, as a sensor, is very sensitive to an object's brightness as well as its color.



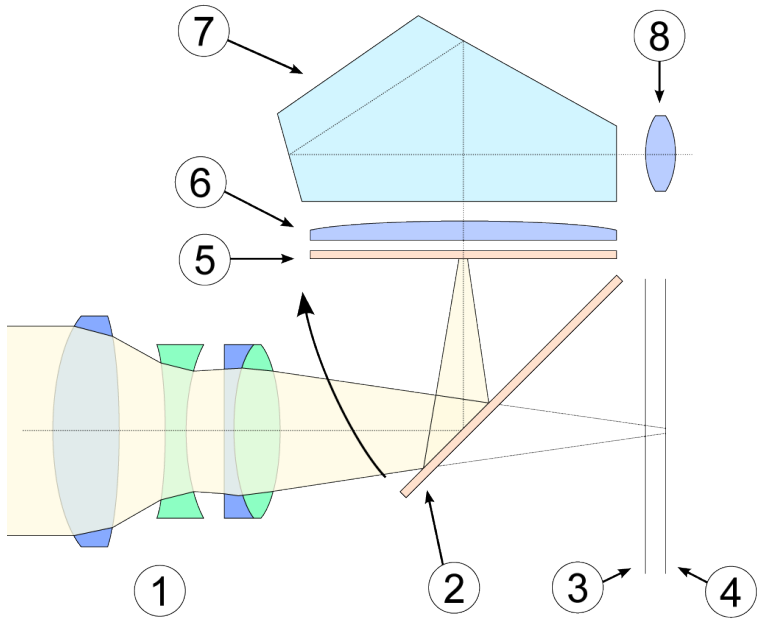
The structure of the human eye. “Three Main Layers of the Eye” by Holly Fischer is licensed under CC BY 3.0

Before the late-19<sup>th</sup> century, all astronomy was visual. Both professional and amateur astronomers used only their eyes to examine the universe around them. And, although the eye is a tiny light-gatherer, it is incredibly sensitive to both brightness and color. It also is adaptable. The human eye can function in bright sunlight and faint starlight – an intensity range of more than 10 million.

Understanding the eye allows one to better understand the workings of optical instruments, such as the telescope and camera. All use a lens to focus, and many of the features of the eye are incorporated in a direct or indirect way into these instruments. <sup>(1)</sup>



The Achromatic Refractor “The Achromatic Refractor” by Dr. Mike Reynolds, Florida State College at Jacksonville is licensed under CC BY 4.0



The Single Lens Reflex Camera “Single Lens Reflex Camera” by Antilived is licensed under CC BY-SA 3.0

## The Human Eye

The human eye has a number of parts which must function together to assure eyesight. Failure or weakness of any one of these can impair eyesight, or cause blindness.





Human eye by by Alexageev is licensed under CC BY-SA 3.0



Calliphora vomitoria Portrait by JJ Harrison is licensed under CC BY-SA 3.0

Note that the human eye is different both functionally and

structurally than most eyes in the Animal Kingdom; for example, many insects feature compound eyes.

### **Cornea**

The transparent “front window” of the eye. It is a thick, nearly circular structure covering the lens. The cornea is an important part of the focusing system of the eye.

### **Pupil**

The round black hole in the center of the iris. The size of the pupil changes automatically to control the amount of light entering the eye.

### **Iris**

The pigmented (colored) membrane of the eye, the iris is located between the cornea and the lens. Its color varies from pale blue to dark brown.

### **Lens**

A transparent biconvex structure located behind the iris. It focuses light rays entering through the pupil in order to form an image on the retina.

### **Retina**

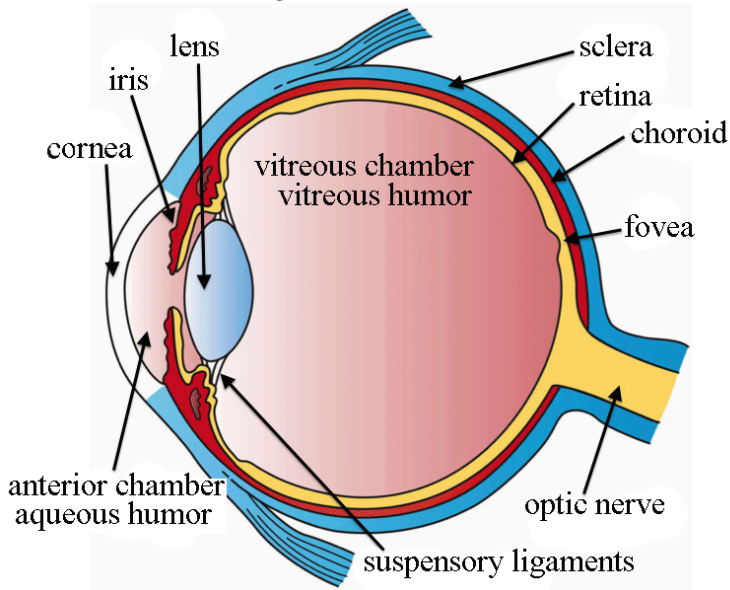
A thin multi-layered membrane which lines the inside back two-thirds of the eye. It is composed of millions of visual cells and it is connected by the optic nerve to the brain. The retina receives light and sends electrical impulses to the brain that result in sight.

### **Macula**

An area of the eye near the center of the retina where visual perception is most acute. The macula is responsible for the sharp, straight-ahead vision that is used for seeing fine detail, reading, driving, and recognizing faces. It is one hundred times more sensitive to detail than the peripheral retina. The macula is sometimes referred to as “the bull’s eye center of the retina.”

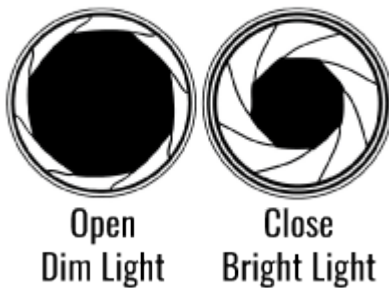
## Optic Nerve

Cable-like structure composed of thousands of nerve fibers that connect the macula and retina with the brain. The optic nerve carries electrical impulses from the macula and retina to the processing center of the brain where they are interpreted into clear, colorful sight. <sup>(1)</sup>



The structure of the human eye. “Three Main Layers of the Eye” by Holly Fischer is licensed under CC BY 3.0

## Diaphragm



The camera diaphragm or aperture – works like the iris in human eyes. Aperture diaframma, Florida State College at Jacksonville is licensed under CC BY 4.0 / A derivative from the original work

## 23. Eye Tests

### Eye Tests

You will conduct a number of eye tests to better understand not only the functions of the eye, but your own eyes.

#### **Afterimages**

Sometimes, when you stare intently at an object and then look away the brain retains an image of what you were viewing. This retained image is called an afterimage and will soon disappear. When an object is observed closely for a long time, the light stimulating the retina eventually causes the cones in that area to become fatigued, desensitizing that part of the retina. After looking away from the image, the less-stimulated cones in the affected area, which are not fatigued, still function. The affected portion of the retina continues to produce the image for up to 30 seconds, but because the stimulation comes only from the less-fatigued cones, it is perceived as a negative image.

#### **Blind spot**

Where the optic nerve penetrates the retina, no vision is possible because there are no rods or cones. This is the cause of the blind spot.

#### **Eye Dominance**

You are all familiar with preferences for using a particular hand for tasks such as writing, batting, and throwing. Our eyes also exhibit right-left dominance in a similar way.

#### **Focus**

How well do your eyes focus. For reading? For distance? This one eye test is the best-known, for many need glasses,

contacts, or even surgery to correct for farsightedness (reading/close objects), nearsightedness (more-distant objects) or both.

**Astigmatism**

The condition in which the cornea or the lens is irregularly shaped is called Astigmatism. This asymmetry causes incoming light rays to refract and converge improperly. Therefore, the light rays do not focus at a specific point on the retina. This results in blurred or distorted images. Many people have some degree of astigmatism, whether they realize it or not.



Astigmatism occurs when the eye does not focus uniformly on the retina. Astigmatism text blur by Tallfred is licensed under CC BY-SA 3.0

**Color Vision**

The retina of the eye possesses two types of specialized nerve cells known as photoreceptors. They are called rods and cones because of their distinctive shapes. Rods function in dim light and perceive shades of gray, like what you see when your eyes adjust to darkness. There are about 120 million rods in each

eye, located at the front of the retina. Cones function in bright light and provide sharp, colorful daylight images. Human eyes contain about million cones concentrated around the center of each retina. There are three different types of cones — red, green, and blue — each sensitive to a different range of wavelengths of light. Different types of cones function together to interpret colors other than red, green, and blue. For instance, in order for the eye to see yellow light, red cones and green cones must work together.

If any of the three types of cones do not function properly, color perception deficiency occurs. Total color perception deficiency is very rare, but partial color perception deficiency is common, especially among men. The most common type is red-green color perception deficiency cannot distinguish between red light and green light. <sup>(1)</sup>

## 24. Lab 4 Assessments

### **Assignment: About Your Eyes Activity**

#### *Assignment Document Link*

Use the above document to submit your data and responses.

In this lab, you will conduct at-home eye tests which detail near and far sightedness, color blindness, depth of perception, and blind spots. Download and complete the attached document.

This exercise will be graded using the rubric in the syllabus and attached document and is worth up to 65 points. <sup>(1)</sup>

### **Lab 4 Quiz**

#### *Quiz Document Link*

This quiz contains five matching items, each worth 2 points, for a total score of up to 10 points. You will have 5 minutes to complete this quiz. You have one attempt. <sup>(1)</sup>



PART V

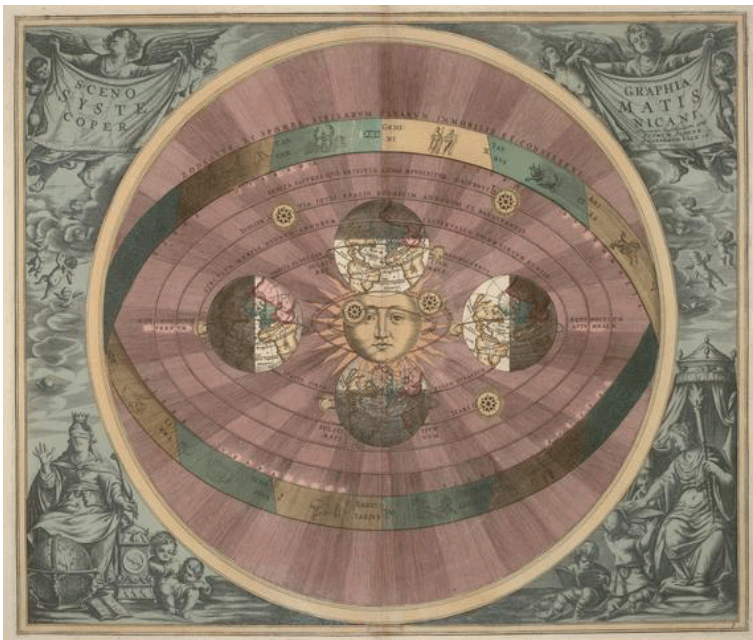
# LAB 5 - SCALING THE SOLAR SYSTEM



## 25. Introduction

### Astronomy Laboratory 5 – Scaling the Solar System

#### Module Introduction



An early Solar System model, based on the Copernican Heliocentric Solar System. Heliocentric by Andreas Cellarius is in the Public Domain

The size of our Universe is hard for one to fathom. In order to get an idea of the size and scale, you will lay out the Solar System –

in miniature and to scale. The model will highlight distances and planet sizes.

You will also model how eclipses occur, both solar eclipses and lunar eclipses, as well as partial and total eclipses. Along with phases of the moon and seasons, this concept is one of the most misunderstood in astronomy. <sup>(1)</sup>

## Objectives

At the end of this module, students will be able to:

- Model the scale of the solar system
- Model solar and lunar eclipses <sup>(1)</sup>

## Outcomes

The material in this module includes content designed to meet the following course outcomes:

- Explain and apply major concepts in astronomy including planets, satellites, stars, meteors, galaxies, and theories of the universe.
- Communicate scientific ideas through oral or written assignments.
- Demonstrate the ability to think critically. <sup>(1)</sup>

## Assigned Readings

### Learning Unit 5

## Assignments

- Scaling the Solar System Activity
- Eclipses Activity
- Lab 5 Quiz <sup>(1)</sup>

# 26. The Center of the Universe

## The Center of the Universe

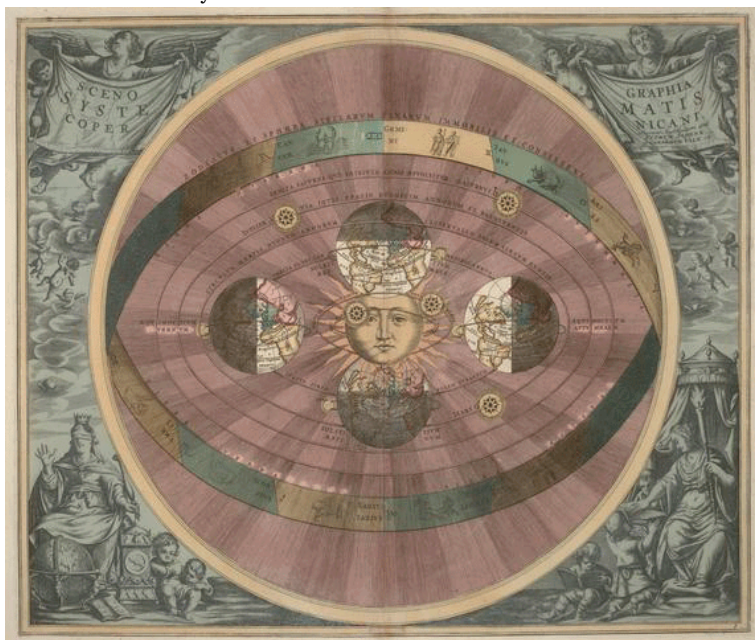
Simply stated, the Universe is huge. It is hard for most of us to comprehend the scale and size of our own Earth-Moon system, the distance to the Sun, our Solar System, or the Milky Way Galaxy. It is understandable that ancient peoples had challenges comprehending the arrangement and make-up of even the Solar System, nonetheless the Milky Way Galaxy and the Universe.

Most early Solar System models placed Earth as the center of the Solar System — and most-often the Universe. The reasoning made sense: everything appeared to go around Earth. Aristotle in the 4<sup>th</sup> Century BC was one of the earliest proponents of an Earth-centered Solar System — a geocentric model. Yet, one of the earliest Solar System models, that of Aristarchus in the 3<sup>rd</sup> Century BC, did correctly place the Sun in the center of the Solar System. Most accepted the Earth-centered Solar System which was refined by the Greek philosopher Claudius Ptolemy in the 2<sup>nd</sup> Century AD. This geocentric Solar System model was accepted by both scientific and religious circles until the work of Nicolas Copernicus (1543) and observations with the telescope of Galileo Galilei (1609) showed the Sun was the center of the Solar System, a heliocentric model. <sup>(1)</sup>

## 27. Sizing Up

### Sizing Up

Once the notion of Earth orbiting the Sun was settled in most arenas, scientists turned in earnest to distances between these bodies. Some of the early notions pictured the stars on glass spheres which turned around Earth; stars beyond the Sun were not pictured to be that far away.

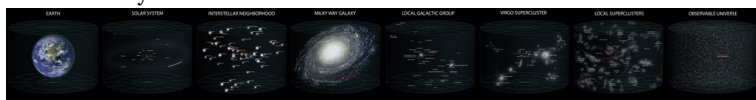


An early Solar System model, based on the Copernican Heliocentric Solar System. Heliocentric by Andreas Cellarius is in the Public Domain

The distance between Earth and the Moon is about 238,855 miles. You might know someone who has put 235,000 miles on their car;

perhaps you have done that yourself. So, imagining 235,000 miles isn't too much a stretch, even though it is a big number. Yet, consider the distance from Earth to the Sun: an average of about 93,000,000 miles. That is 93 million miles – about 400 times further than the distance from Earth to the Moon. Many of us have a bit more of a challenge imagining 93,000,000 miles.

So how far is 93,000,000 miles? Light travels at 186,000 miles per **second** , the fastest speed possible. Our fastest spacecraft are around 75,000 miles per **hour** . Sunlight reflected from the Moon to us seeing it here on Earth takes about 1 ¼ second. When light and energy leave the Sun and heads toward Earth, it takes 8 minutes and 20 seconds to get here. And remember the Sun is the closest star. The next closest? Proxima Centauri – and it takes around 4 ¼ years for the light from Proxima Centauri to get to Earth. The term space is very appropriate when talking about the distances between the stars, between galaxies, and yes, even between the planets in our own Solar System. <sup>(1)</sup>



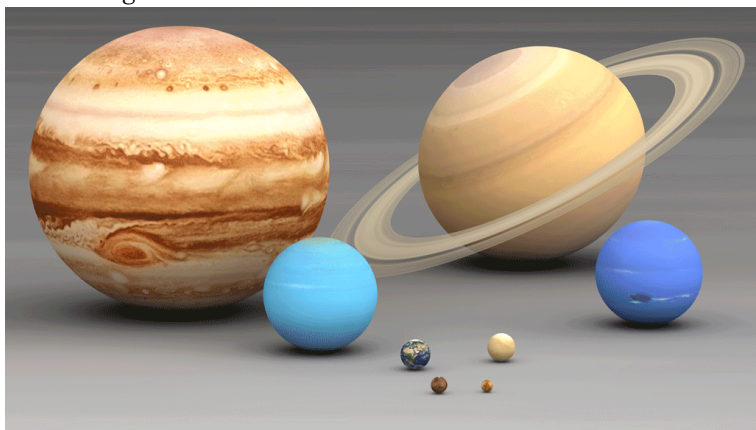
Various segments of the Universe, shown to scale. Earth's Location in the Universe by Andrew Z. Colvin is licensed under CC BY-SA 3.0



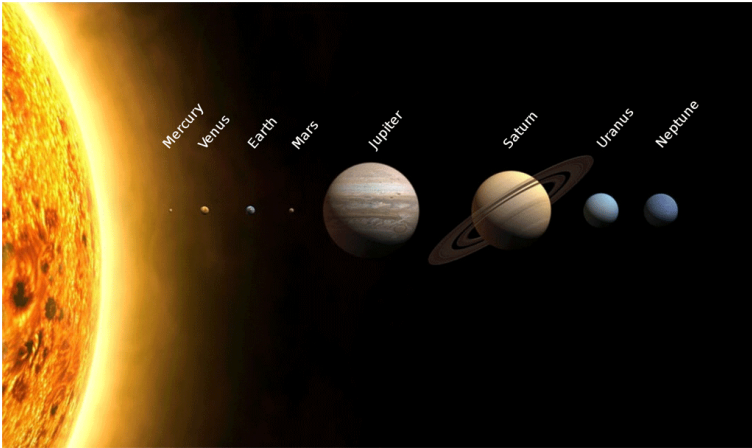
## 28. To Scale

### To Scale

Scaling the sizes of the planets can also be dizzying. Let's call Earth a nice round figure: 8,000 miles in diameter. Comparing Earth to Jupiter, the largest planet in the Solar System, is fairly easy: Jupiter is about 11 times Earth's diameter, or about 88,000 miles. All of the other Solar System planets would fit inside Jupiter. The Sun is about 865,000 miles in diameter, about  $10\times$  Jupiter's diameter. And the Sun is an average-sized star — at best!



Model representations of the planet diameters to scale. 1<sup>st</sup> row: Mars, Mercury (L-R) 2<sup>nd</sup> row: Earth, Venus (L-R) 3<sup>rd</sup> row: Uranus, Neptune (L-R) Back row: Jupiter, Saturn (L-R) Size planets comparison by Lsmpascal is licensed under CC BY-SA 3.0



A Solar System model, with planets and the Sun to scale, but not distances. By the way: what is wrong with this illustration? Planets2013 by PlanetUser is licensed under CC BY-SA 3.0

Add in to all of this the dizzying concepts of distant galaxies, objects in motion, and an expanding Universe and you can see why we call these numbers astronomical. Even when expressing distances in power of ten, such as the speed of light as  $1.86 \times 10^5$  miles per second or the distance to Proxima Centauri is  $2.4961 \times 10^{13}$  miles; that is 24,961,000,000,000 miles.

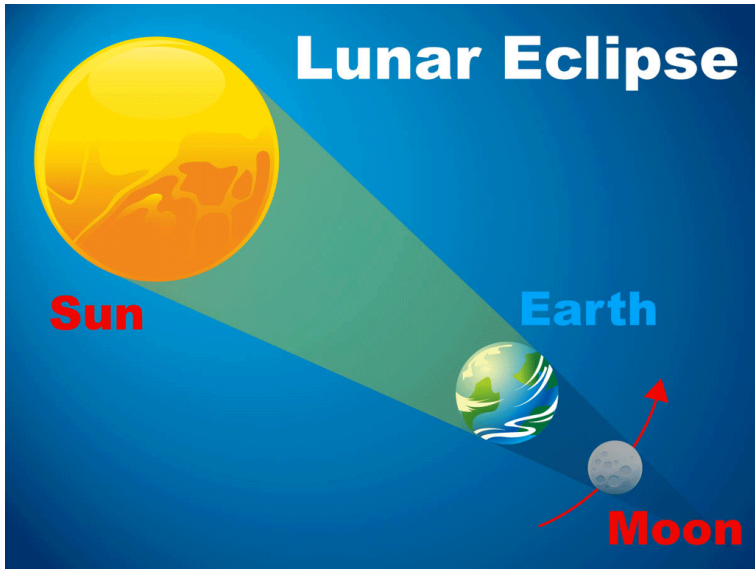
We best see the consequences of the Universe in motion here on Earth through experiencing the seasons due to the revolution of Earth around the Sun. With the rotation of Earth, we have our day and night. And, the revolution of the Moon around Earth allows us to watch the Moon go through its phases. <sup>(1)</sup>

# 29. Earth and Moon

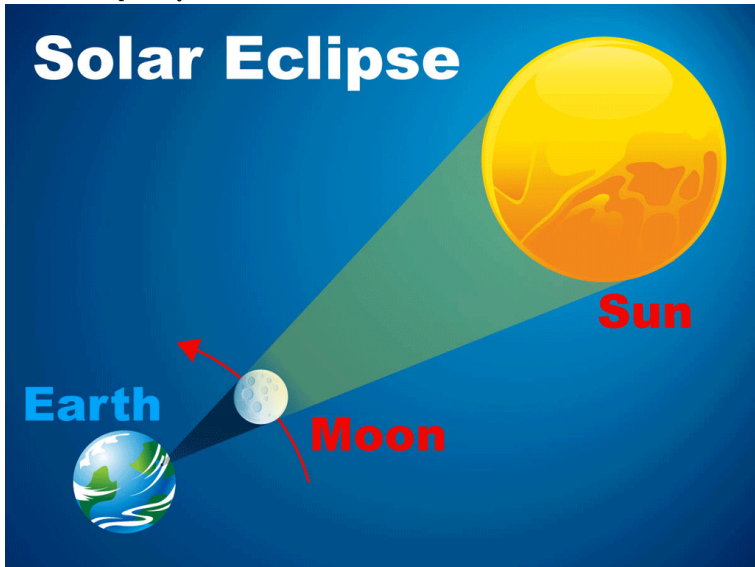
## Earth and Moon

Studying the Earth-Moon relationship gives you one of the best ways to understand distances as well as that special Earth-Moon relationship. For example, many Americans saw the solar eclipse in August 2017; millions traveled to the path of totality. Why do we see solar eclipses? And, how are solar eclipses different than lunar eclipses? Both solar and lunar eclipses depend on the revolution of the Moon around Earth, and that alignment between Sun-Earth-Moon.

A lunar eclipse can only happen at Full Moon, when Earth is directly between the Sun and Moon. The Earth's shadow falls on the Moon, thus eclipsing part or all of the Moon. And, a solar eclipse can only happen at New Moon, when the Moon is directly between the Sun and Earth. In this case the Moon blocks off part or all of the Sun from view on Earth.



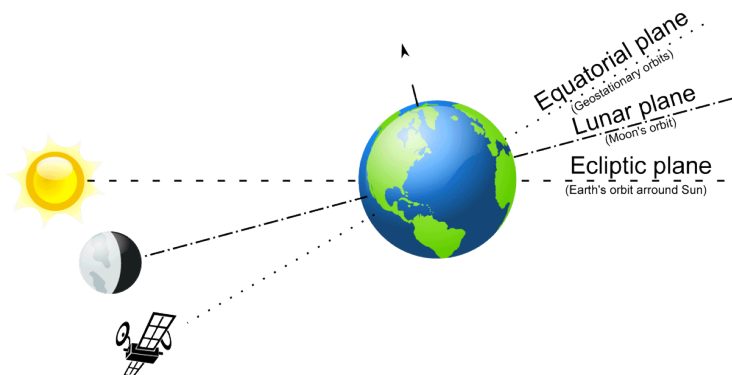
Lunar Eclipse by NASA is in the Public Domain



Solar Eclipse by NASA is in the Public Domain

Why don't we see an eclipse of the Moon and an eclipse of the Sun

once a month? Because, the orbit of the Earth-Moon is slightly tilted to the orbit of the Sun-Earth. Most of the time, Earth's shadow just passes above or below the Moon, missing a lunar eclipse. Thus, the Moon passes just above or below the Sun, thus no solar eclipse. <sup>(1)</sup>



The reason we do not see both a lunar and a solar eclipse each month is because the Earth-Moon orbital plane is tilted about 5 degrees compared to the Earth-Sun orbital plane. Orbital Planes by T3rminatr is in the Public Domain

## 30. Lab 5 Assessments

### Assignment: Scaling the Solar System

#### *Assignment Document Link*

*Use the above document to submit your data and responses. You will need to upload the document and one photo attachment.*

While the immense distances are hard for most of us to imagine, you can lay out an easier-to-visualize Solar System model using ordinary items. For this part of the Lab you will need:

- A ball that's about 3 inches in diameter — or a naval orange
- A roll of 1,000 sheet toilet paper
- A camera to take pictures of your model Solar System; your smartphone camera will suffice

This exercise will be graded using the rubric in the syllabus and attached document and is worth up to 35 points. <sup>(1)</sup>

### Activity: Eclipses Activity

#### *Activity Document Link*

*Use the above document to submit your data and responses. You will need to upload the document and one photo attachment.*

Another relatively-easy to model phenomena are eclipses. For this part of the Lab you will need:

- A yardstick or meter stick
  - The *Lab 5. Eclipses package* in your Astronomy Lab supplies kit.
- This includes the following:

- 1-inch sphere, representing Earth
- ¼-inch bead, representing the Moon
- Two thin sticks
- Two binder clips
- A camera to take pictures of your model Earth-Moon Model and eclipses; your smartphone camera will suffice

This exercise will be graded using the rubric in the syllabus and attached document and is worth up to 30 points. <sup>(1)</sup>

## Lab 5 Quiz

### *Quiz Document Link*

This quiz contains five matching items, each worth 2 points, for a total score of up to 10 points. You will have 5 minutes to complete this quiz. You have one attempt. <sup>(1)</sup>





PART VI

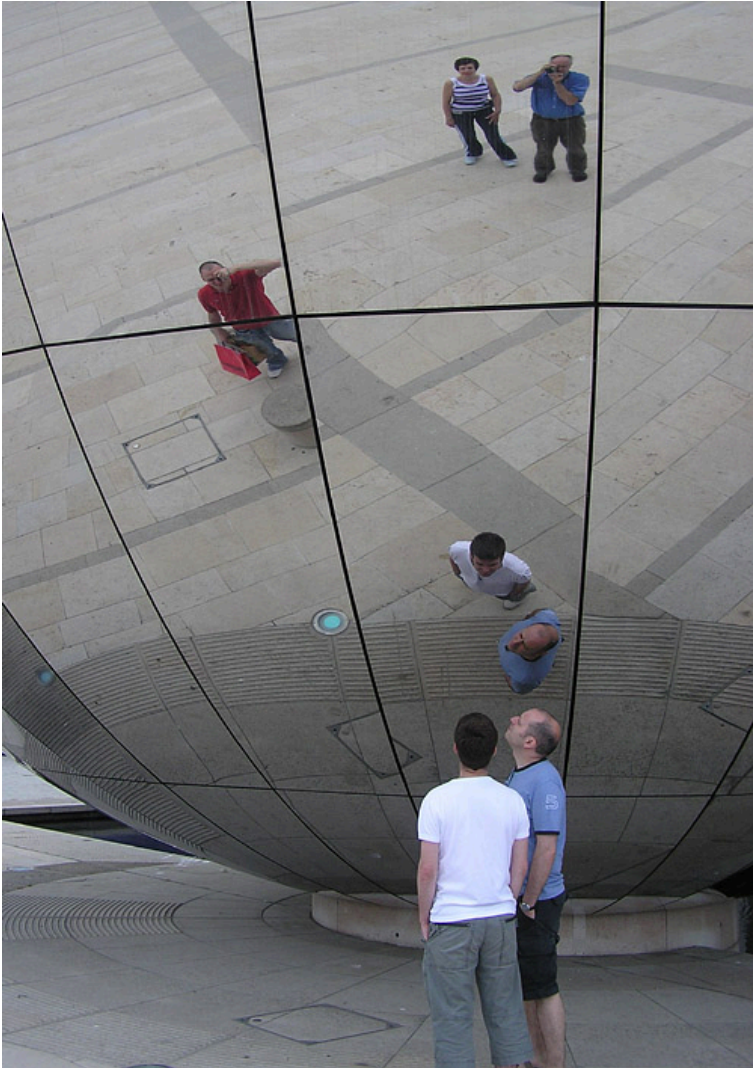
# LAB 6 - OPTICS AND TELESCOPES



# 3I. Introduction

# Astronomy Laboratory 6 – Optics and Simple Telescopes

## Module Introduction



“Mirror.globe.arp.500pix” by Arpingstone in the Public Domain

Optics is the study of light and its interaction with various materials, called medium. We are all familiar with optics in the world around

us. Whether you wear glasses or not, your eyes are a splendid example of optics.

In order to better understand modern optics such as binoculars, cameras, and telescopes, and how lenses and mirrors work, you will conduct specified experiments with lenses and mirrors in this lab. With the supplied lab kit resource, you will assemble a simple refracting telescope. You will take the telescope outdoors and conduct a series of observations with the simple telescope. <sup>(1)</sup>

## Objectives

At the end of this module, students will be able to:

- Describe types of mirrors and lenses, along with their functions
- Compare and contrast types of mirrors and lenses
- Assemble a Simple Refracting Telescope
- Utilize a Simple Refracting Telescope <sup>(1)</sup>

## Outcomes

The material in this module includes content designed to meet the following course outcomes:

- Communicate scientific ideas through oral or written assignments.
- Interpret scientific models such as formulas, graphs, tables and schematics, draw inferences from them and recognize their limitations.
- Demonstrate the ability to think critically.
- Demonstrate the ability to use scientific and quantitative

reasoning.<sup>(1)</sup>

## Assigned Readings

Learning Unit 6

## Assignments

- Optics and Simple Telescopes Activity
- Lab 6 Quiz<sup>(1)</sup>

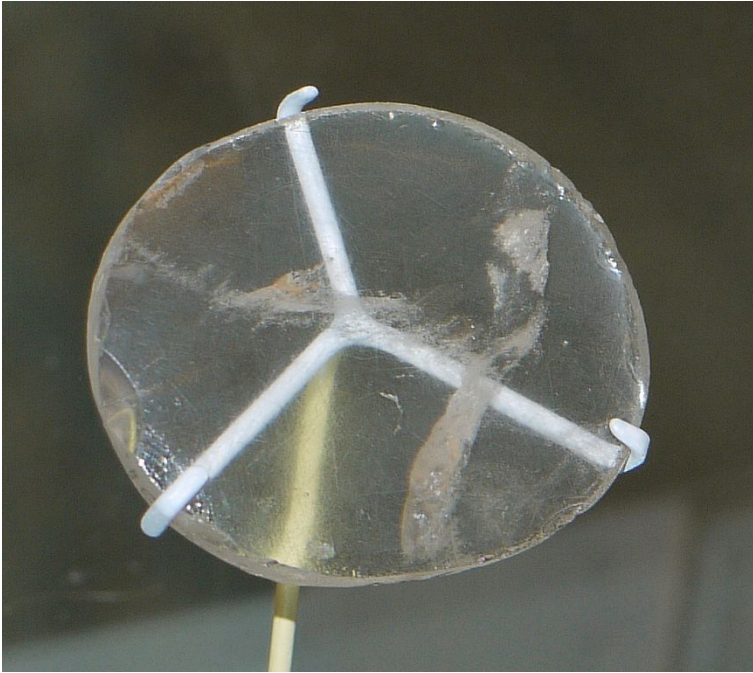
## 32. Lenses

### Optics

Optics is the study of light and its interaction with various materials, called medium. We are all familiar with optics in the world around us. Whether you wear glasses or not, your eyes are a splendid example of optics, as detailed in Lab 4. About Your Eyes. Think of the application of optics; rearview mirrors on cars, lens systems in your smartphone, the atmosphere bending sunlight when the Sun rises and sets.



## Lenses



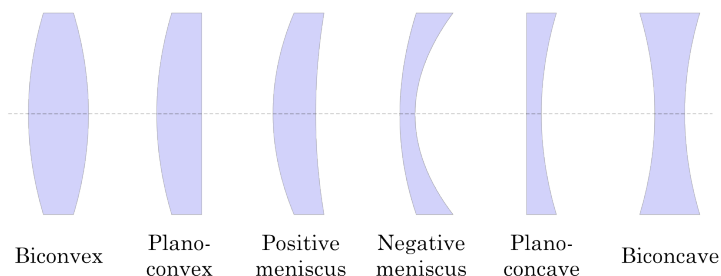
The Nimrud lens is a 3000-year-old portion of rock crystal. It is believed that the Nimrud lens was used as a magnifying glass.  
[ " Nimrud lens British Museum " by Geni, licensed under CC BY-SA 4.0 ]

For this lab, we will first direct our attention to a couple of types of lenses and mirrors. The science of optics can be traced back to the ancient Egyptians and Mesopotamians. Some of the earliest recovered lenses were made from polished crystals, such as quartz.

The ancient Greeks and Romans, such as Pliny and others, wrote about liquid lenses: spheres filled with water. These developments led to furthering ideas about light and what is now called geometrical optics, describing the way light travels in the form of

rays. The term optics is derived from the Greek *optikē*, meaning appearance, look.

You are most likely familiar with the magnifying glass; one is included in the Astronomy Lab Kit for Lab 8. Meteors, Meteorites, and Cratering. Magnifiers are optically known as a convex lens; convex referring to bending outward. Lenses can also be described as concave – caving inward, and plane or plano – flat. Since a single lens has two surfaces, a combination of shapes can occur. Different names are assigned to the lens, depending on the two shapes. For example, if the lens is convex on both sides, it can be called biconvex or double convex. If it is convex only on one side and flat on the other, it is said to be plano-convex.



Types of lenses, lens shapes [” Lenses en ” by ElfQrin , licensed under CC BY-SA 3.0 ]

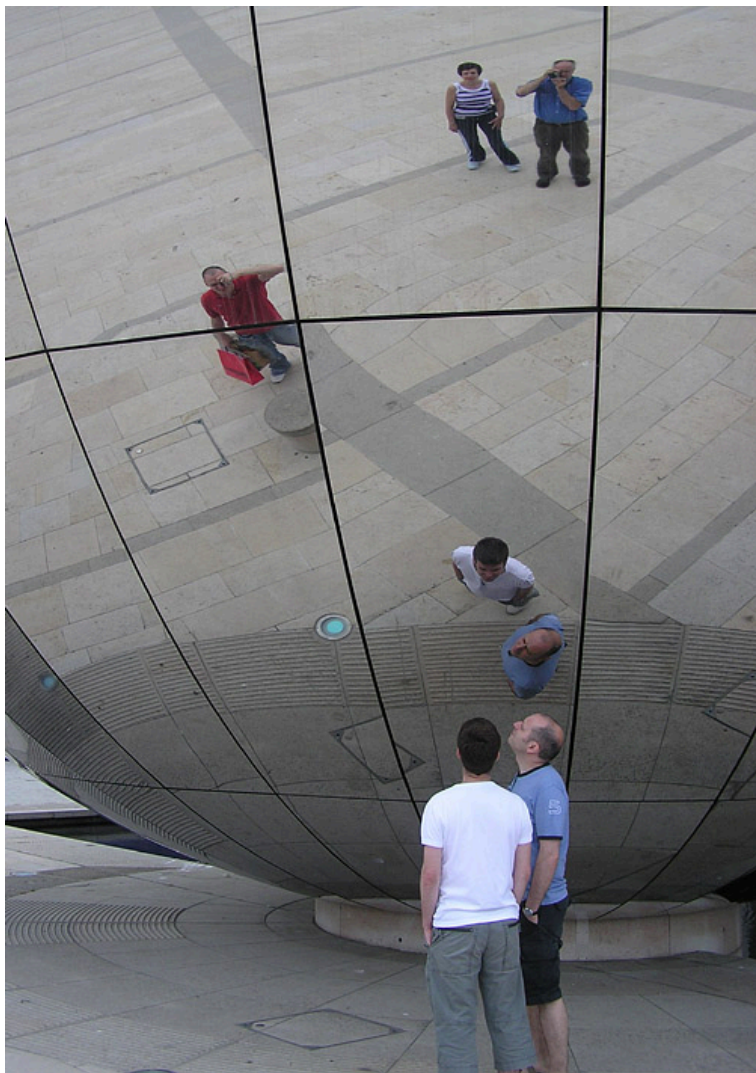
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If a convex lens magnifies, what do you think a primarily-concave lens would do? Consider this for now, and you will cover this as a part of the Lab exercise.

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## 33. Mirrors

## Mirrors



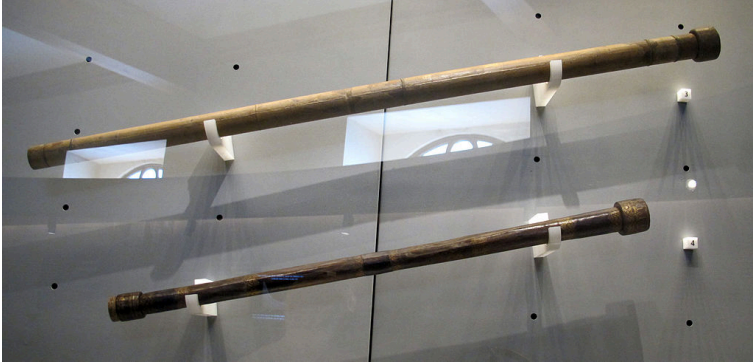
Reflections seen and photographed in a convex mirrored sphere.  
[ " Mirror.globe.arp.500pix " by Arpingstone in the Public Domain ]

Mirror, Mirror on the Wall... Let's now consider mirrors, another

very familiar type of optics in our everyday lives. We should all be familiar with flat mirrors, they hang in our bathrooms, in our cars as the primary rearview mirrors, and in many light fixtures, reflecting and concentrating light for our convenience. Plus, like lenses, mirrors have three shapes: flat, like the plano lens, concave, and convex. Yet, the results of using a convex lens is not the same as a convex mirror.

# 34. The Telescope

## The Telescope



Two of Galileo's telescopes, now on display at the Science Museum in Florence, Italy. [ " Galileo galilei, telescopi del 1609-10 ca " by Sailko , licensed under CC BY-SA 3.0 ]

The main part of this Lab is an introduction to the simple **refracting telescope** , using a combination of concave lenses. The **Refractor** , believed to have been first invented by spectacle makers Hans and Zacharias Janssen, then independently Jan Lippershey of Holland in as early as 1595. The refractor was first used astronomically by Galileo Galilei in 1609.

Like with lenses and mirrors, when telescopes are shown as a drawing or illustration, they are more often shown as a cutaway or cross section. What you will see in these drawings is as if one took the telescope and cut it down the middle of the tube and lenses.

The main lens which focuses the incoming image is called the **objective** . [This is the lens you see on the right side of *The Galilean Refracting Telescope* diagram, below.] Light — shown by the dashed lines [ - - - ] and arrows enters the objective over the entire

surface of the objective. For simplicity, the incoming light is shown as two (sometimes more) lines. Why? Because if you show a solid beam of light incoming — *what really happens* — then you would not see the objective or any lens in a drawing because it would be blocked out by the “solid” line.

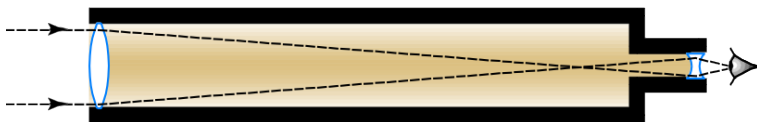
The objective shown here is a double convex lens; that is both sides of the lens shape are outwardly curved. Double convex refers to *double (or two) convex (or out)*. As the light beam travels down the telescope tube (the solid barrel which holds the lenses), it converges or comes to a focus. The objective lens is a converging lens; think of it as a magnifying glass (which it is!).

When the converging light reaches the end of the tube — its **focus** — the light must then be focused for the eye. That is why you see a second, diverging lens (spreads the light out) on the left side of the below diagram. You must use this lens or lens system — called the **eyepiece** — to focus and magnify for the eye. Your eye is one type of detector (shown in the telescope illustrations). Other detectors can include cameras (both film and digital), video camera systems, spectrosopes, photomultiplier tubes (measures the amount of light incoming), etc.



Galileo's observations of the Moon through the simple telescopes he made provided him with an unprecedented view. These sketches by Galileo are of the 1st and Last quarter moon. [ " Galileo's sketches of the moon " by Galileo in the Public Domain ]





The Galilean Refracting Telescope – a single lens each for the Objective and eyepiece [“The Galilean Refractor”, Florida State College at Jacksonville is licensed under CC BY 4.0

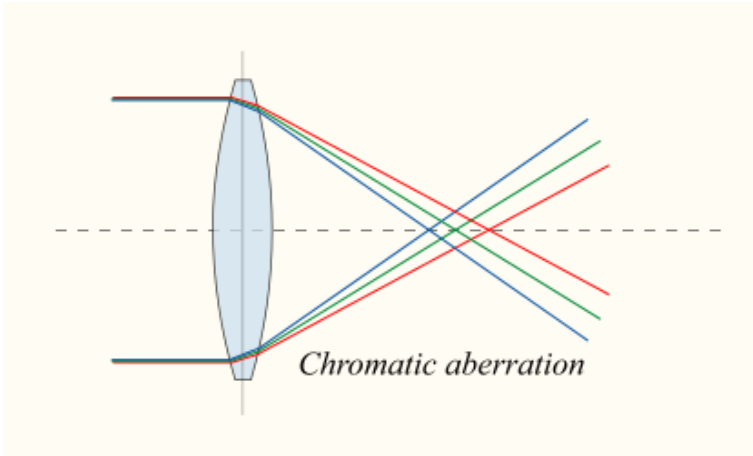
Early telescopes such as the one invented by the Janssens and Lippershey 400 years ago, and the one used by Galileo astronomically, only used one lens for the objective, and a second double concave lens for the eyepiece. Double concave means that both sides of the lens are curved inward, thus *double* (or *two* ) *concave* (or *in* ).

Again, the eyepiece is required to focus and magnify the image for the human eye. An eyepiece might not be required for other “observers,” such as a camera, CCD, or spectroscope. In modern telescopes the eyepiece can be changed, providing different power or magnification.

The telescope you will assemble and test in lab is similar to the ones built by the Janssens, Lippershey, and Galileo, except for the eyepiece lens type.

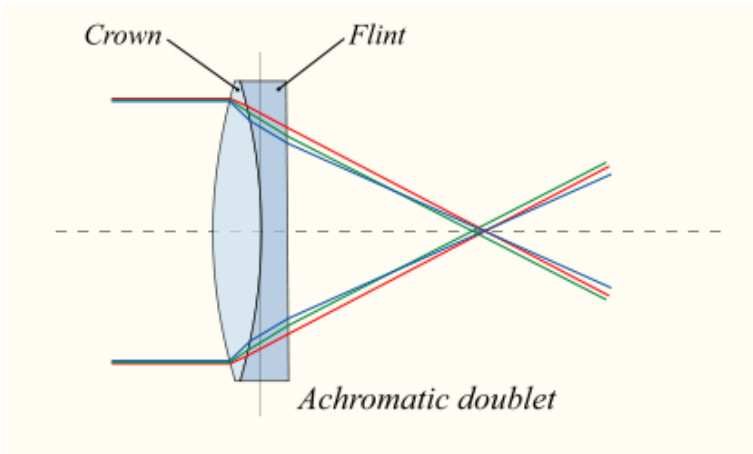
Their telescopes used double concave lenses, making for a long “optik stick.” And even though the parts of this simple lab telescope are inexpensive (the lenses are plastic), they are probably better than those used in early telescopes.

Today’s modern quality refractors use either two ( **achromat** ) or three ( **apochromat** ) lenses for the objective. This combination deals with the major refractor problem: color issues. Think of a lens as a prism (look at the edge of the lens); a single lens does indeed begin to break light into component wavelengths. Achromats take care of this to some degree; apochromats (which are much-costlier) totally eliminate the problem (unless it is a poor set of lenses that make up the apochromat).



Single Lens

[ "Chromatic aberration lens diagram" by Bob Mellish , licensed under CC BY-SA 3.0 ;



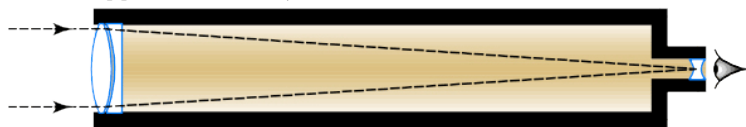
Achromat

" Lens6b-en " by DrBob , licensed under CC BY-SA 3.0 ]

The inside of modern telescope tubes and eyepieces are painted a flat black to avoid internal reflections of light. And most small to moderate-sized objectives and all excellent to high quality eyepiece

lenses are coated to prevent internal reflections within the lenses themselves.

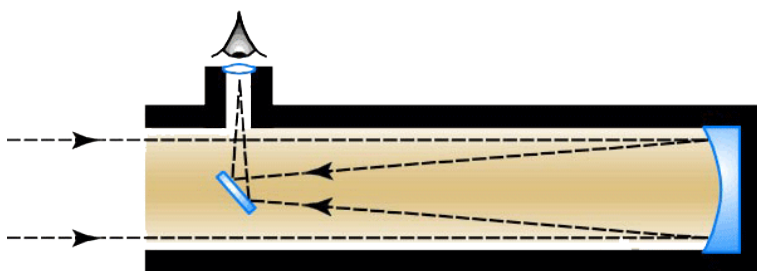
Modern eyepieces are also multi-lens systems. There are eyepieces which can cost hundreds of dollars, based on “exotic” glasses and high-quality barrels (the metal barrels and internal rings which support the lenses).



The Achromat Refracting Telescope — two lens Achromat Objective and eyepiece [“The Achromatic Refractor”, Florida State College at Jacksonville is licensed under CC BY 4.0

## Reflecting Telescope

The other type of telescope used today — now the most-common — is the **reflecting** telescope. The modern **Reflector** uses a concave mirror as its primary objective. A concave mirror has the same basic optical properties as a convex objective lens in a Refractor. There are a variety of Reflector types. These are distinguished by the way the light “exits” the telescope to the detector (eye, camera, etc.). The most common Reflector is the **Newtonian Reflector**, named after its inventor, Sir Isaac Newton. Light enters the telescope tube, is reflected off of the primary mirror (objective) to a smaller flat second (secondary) mirror. The secondary in turn reflects the converging image to the eyepiece and detector.



The Newtonian Reflecting Telescope [“The Newtonian Reflector”  
by Dr. Mike Reynolds, Florida State College at Jacksonville is  
licensed under CC BY 4.0

## 35. Lab 6 Assessments

### Activity: Optics and Simple Telescopes Activity

#### Activity Document Link

Use the above document to submit your data and responses.

For the lab, you will need the *Lab 6. Optics and Simple Telescopes package* in your Astronomy Lab supplies kit. This includes the following:

- Convex lens
- Concave lens
- Convex mirror
- Concave mirror
- Simple Telescope Kit

Using the Convex and Concave lenses and the Convex and Concave mirrors, complete the activities and submit the data and responses on Blackboard. This lab exercise is worth up to 65 points and will be graded using the rubric in the syllabus and attached document.<sup>(1)</sup>

### Lab 6 Quiz

#### Quiz Document Link

This quiz contains five multiple choice items, each worth 2 points, for a total score of up to 10 points. You will have 5 minutes to complete this quiz. You have one attempt.<sup>(1)</sup>



PART VII

# LAB 7 - SOLAR SYSTEM STORMS





# 36. Introduction

## Astronomy Laboratory 7 – Solar System Storms

### Module Introduction



A Martian Dust Devil and its shadow. This dust devil has been nicknamed “The Serpent Dust Devil.” Image captured by the NASA Mars Reconnaissance Orbiter (MRO) spacecraft.

[“The\_Serpent\_Dust\_Devil\_on\_Mars\_PIA15116” by NASA/JPL-Caltech/Univ. of Arizona, in the Public Domain ]

In light of the recent tropical storms and hurricanes, in this lab, you will examine storms throughout the Solar System. Cyclone-like storms rage on Jupiter and Saturn, dwarfing our tropical storms.

More tornadoes occur in the United States than anywhere else in the world. Dust devils on Mars dwarf the dust devils seen here on Earth and can rival EF1-EF2 tornadoes. Lightning has been observed on a number of other planets. <sup>(1)</sup>

## Objectives

At the end of this module, students will be able to:

- Compare and contrast storms on Earth with those in space
- Describe lightning on Jupiter
- Identify storm phenomena <sup>(1)</sup>

## Outcomes

The material in this module includes content designed to meet the following course outcomes:

- Explain and apply major concepts in astronomy including planets, satellites, stars, meteors, galaxies, and theories of the universe.
- Communicate scientific ideas through oral or written assignments.
- Interpret scientific models such as formulas, graphs, tables and schematics, draw inferences from them and recognize their limitations. <sup>(1)</sup>

## Assigned Readings

Learning Unit 7

## Assignments

- Solar System Storms Exercise
- Lab 7 Quiz <sup>(1)</sup>

# 37. Cyclones

## Cyclones

For those who have lived through a hurricane or tornado, you know what these storms can be like firsthand. The devastation from a direct-strike major hurricane can literally erase a city like a huge pencil eraser. Large tornadoes can and have had similar effects. But imagine a cyclone twice the size of Earth that has been going for at least 300 years!



Hurricane Katrina as photographed from Earth orbit, August 2005.  
[ " Hurricane Katrina August 28 2005 NASA " by Jeff Schmaltz, in  
the Public Domain ]

# Cyclones

Tropical cyclones like Hurricanes Andrew, Katrina, Matthew, and Irma show several distinctive characteristics:

- Formation with favorable conditions over warm water, lack of wind shear and land
- Rapidly-rotating storm with a low-pressure center
- Strong winds, heavy rains, storm surges
- Possible outer band spin-up tornadoes

Do tropical storms occur on other planets in our Solar System? Well, first the basis for Earth's tropical cyclones is water; hot water. So, what we know as hurricanes are an Earth-based phenomenon.

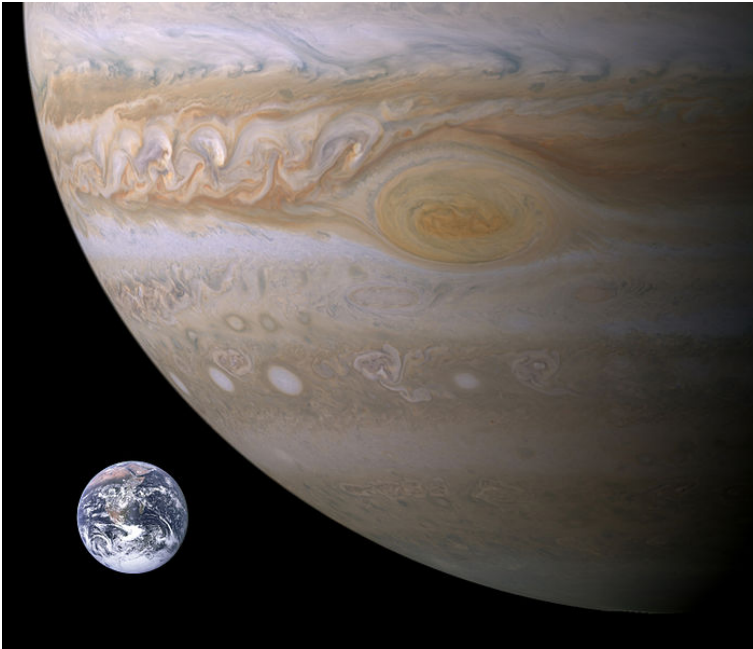
# 38. Storms of Jupiter

## Storms of Jupiter

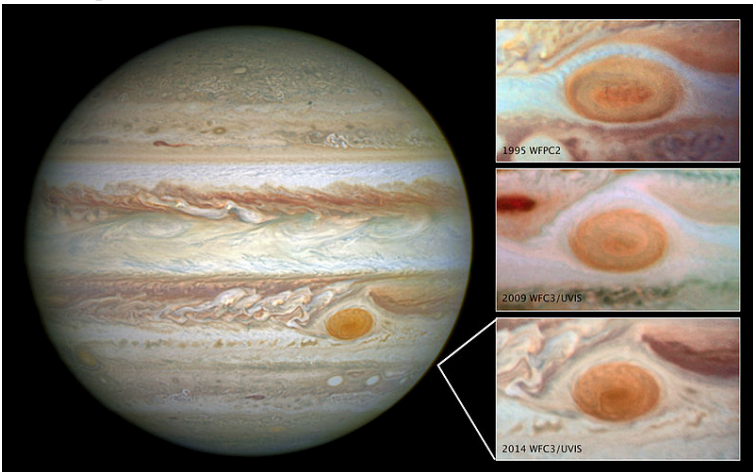
The Gas Giant planets in our Solar System — Jupiter, Saturn, Uranus, and Neptune — are primarily spheres of methane, ammonia, hydrogen sulfide, some water, and helium. Jupiter — our Solar System's giant world — has a variety of strong weather patterns and storms in its atmosphere. The **Great Red Spot**, or **GRS**, was first seen about 300 years ago. So, this feature is one that has been spinning at least 300 years. Imagine any hurricane lasting 300 years!

So, is this a tropical cyclone like we experience on Earth? No... first this is a high-pressure system, versus our low-pressure hurricanes and typhoons on Earth.

There is little water in Jupiter's atmosphere. And, you will note other differences in the GRS compared to tropical cyclones. Besides, a long duration storm with fast winds of 250 to 400 miles per hour, this is truly a GREAT Red Spot. From side-to-side, the GRS is 16,000 miles across. This is TWO EARTH'S. Talk about a serious cyclone... a diameter of 16,000, maximum sustained winds of 400 miles per hour, and storm duration of at least 300 years. Where could you hide from such a monster? And, could you build a shelter or for Jupiter, a spacecraft that would survive these winds?



A to-scale size comparison between Earth and Jupiter's Great Red Spot. [ " Jupiter, Earth size comparison " byBrian0918 , in the Public Domain ]

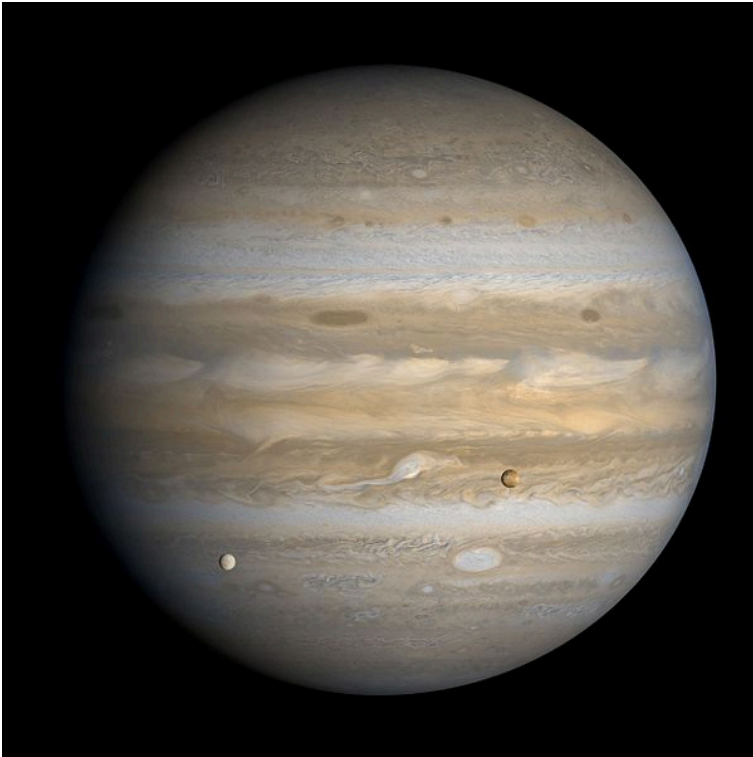


Jupiter and a number of atmospheric storms, including the Great Red Spot; lower right on Jupiter. [ "NASA14135-Jupiter..." by A.

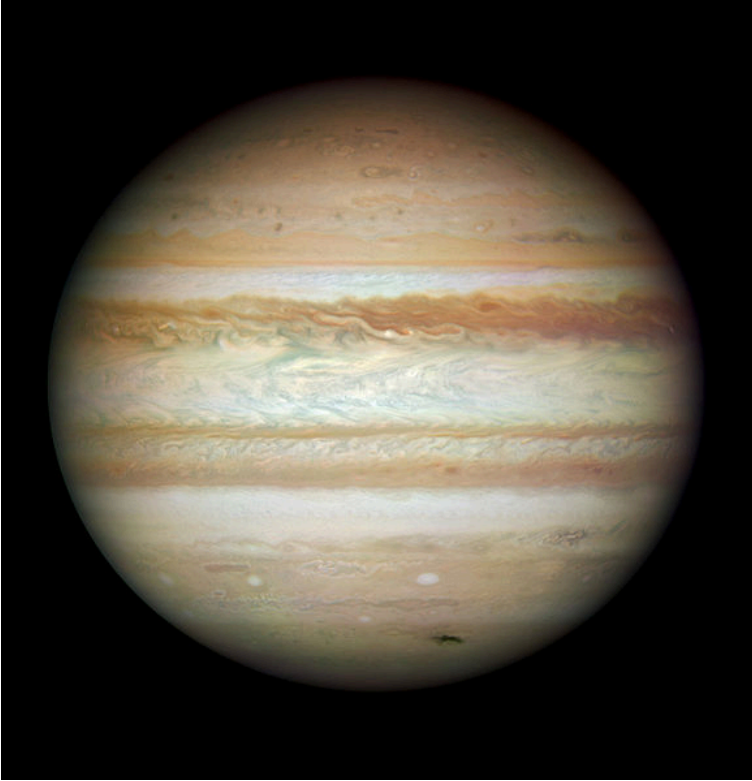


Simon, in the Public Domain ]

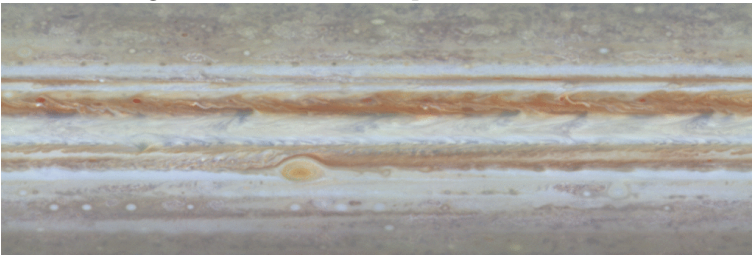
Jupiter's atmosphere is filled with a lot of smaller storms that do come and go, much like our tropical cyclones. You can easily see these festoons, as they are called, in any of the Jupiter images. Festoons look like whirls and waves in the Jovian atmosphere. When we look at Jupiter, we can see these features, even with small telescopes. And you can track these changes over time, like changes in our own weather here in Earth.



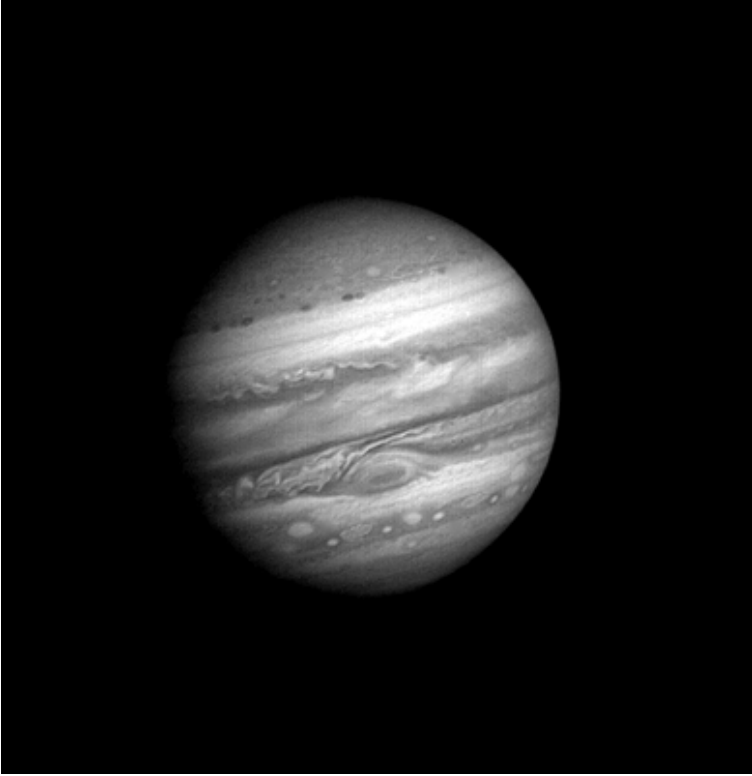
A Voyager 1 image of Jupiter, showing the many storms in the Jovian atmosphere, as well as two of Jupiter's moons (Europa on the left, Io on the right). [ "Voyager 1 Image of Jupiter with Io and Europa " by Björn Jonsson, in the Public Domain ]



A true color Hubble Space Telescope image of Jupiter, showing the numerous Jovian atmospheric storms. [“Jupiter on 2009-07-23 ” by Michael Wong, in the Public Domain ]

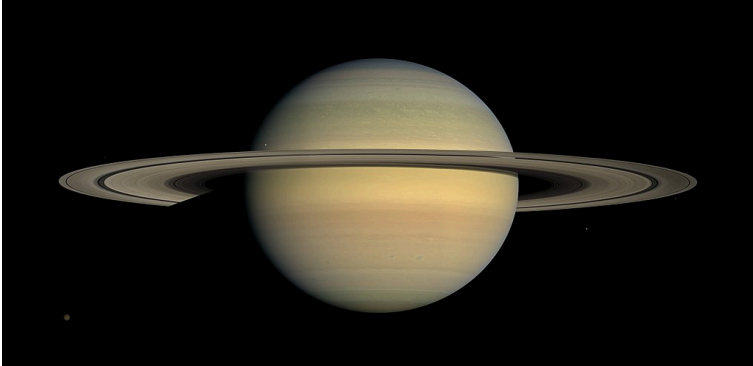


As can be seen by this NASA/JPL/University of Arizona-produced video clip, Jupiter’s atmosphere is always in motion. [” Jupiter surface motion animation ” by NASA/JPL/University of Arizona, in the Public Domain ]



The Voyager 1 space probe captured the images for this time-lapse video of Jupiter's storms over a 28-day period. [ "Voyager 58M to 31M reduced " by NASA, in the Public Domain ]

The other Gas Giant planets in our Solar System — Saturn, Uranus, and Neptune — do not exhibit as strong or numerous storms as Jupiter. This is because these planets are further from the Sun than Jupiter, this receive less heat. Yet all three do occasionally exhibit Jovian-like storms.



The ringed planet Saturn. Storms in Saturn's atmosphere are not as pronounced as in Jupiter's atmosphere. ["Saturn during Equinox " by NASA / JPL / Space Science Institute, in the Public Domain ]

## 39. Tornadoes and Dust Devils

### Tornadoes and Dust Devils

Another type of ferocious storm here on Earth are tornadoes. A tornado is a rapidly rotating column of air that is in contact with both the surface of the Earth and cloud. Tornadoes form when warm, moist air from the Gulf of Mexico and cool, dry air from Canada collide. When these two air masses meet, they create instability in the atmosphere. Sizes of tornadoes average about 500 feet, whereas the largest measured to date was 2.6 miles in diameter. Tornadoes usually travel just a few miles before they dissipate; however, the 1925 Tri-State Tornado traveled some 219 miles.



A classic tornado, near Anadarko, Oklahoma, May 1999. Note the funnel, extending from the cloud to the ground, and the debris or

dust cloud, where the funnel meets the ground. [” Dszpics1 ” by Daphne Zaras, NOAA, in the Public Domain]



A wedge tornado, near Marquette, Kansas, April 2012. Wedge tornados can grow to over a mile in diameter, and exhibit very strong winds. [” April 14, 2012 Marquette, Kansas EF4 tornado ” by Will Campbell, NWS, in the Public Domain ]

A “close cousin” of the tornado is the waterspout. These storms form over water, the ocean, river, or lake, and are primarily made up of water. Waterspouts can move on land; often they degrade but can develop into a tornado.

The Midwestern United States is known as Tornado Alley. More tornadoes occur in this area, by far, than any other place in the world. And, the waterspout capital of the United States? Florida!

Why are tornadoes so devastating, since they are much smaller than a hurricane?

One of the characteristics of many tropical cyclones is that they can spin up tornadoes and waterspouts in the intense bands of wind. This is especially true on the eastern side of Atlantic basin hurricanes. Hurricane-spawned tornadoes are on the weaker side, yet can and do cause significant damage.

Dust devils are related to tornadoes, but do not form the same

way. Dust devils form when hot air near the surface rises quickly through a small pocket of cooler, low-pressure air above it. If conditions are just right, the air will begin to rotate.

They can be powerful, but not as powerful as tornadoes. In fact, a number of dust devils have been imaged in the planet Mars. Perhaps you saw the movie *The Martian*? It did an excellent job portraying Martian dust devils. Let's examine the differences and similarities between Earth's tornadoes and dust devils, and dust devils on the planet Mars.



A waterspout, photographed off of the Florida Keys by NOAA meteorologists, 1969. [” Trombe ” by Dr. Joseph Golden, NOAA, in the Public Domain ]



A dust devil, Ramadi, Iraq, July 2007. [” Dust devil ” by NASA, in the Public Domain ]



A Martian Dust Devil and its shadow. This dust devil has been nicknamed “The Serpent Dust Devil.” Image captured by the NASA Mars Reconnaissance Orbiter (MRO) spacecraft.

[“The\_Serpent\_Dust\_Devil\_on\_Mars\_PIA15116 ” by NASA/JPL-Caltech/Univ. of Arizona, in the Public Domain ]



# 40. Lightning

## Lightning



A very bright yet short duration lightning strike near New Boston, Texas. [” Staccato Lightning ” byGriffinstorm , licensed under CC BY-SA 4.0 ]

Lightning is the discharge that usually occurs during a thunderstorm. This electrostatic discharge occurs between a cloud and the ground, between two clouds, or within a cloud.

- First, the air becomes ionized — a plasma — and this acts as the conductor for the lightning.
- Next, jagged bolts — step leaders — provide the lightning's conductive path.
- Electric current flow, heat, and a shock wave — what we hear as thunder — result.
- Sound thus thunder travels roughly 1 mile every 4.5 second

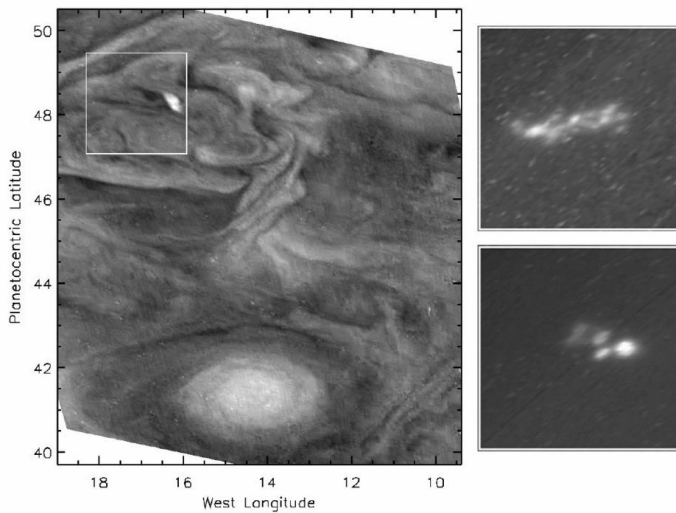
You may have heard that Florida is the lightning capital of the world. More accurately, Florida is the lightning capital of the United States. According to meteorologists, that distinction of lightning capital of the world belongs to the Democratic Republic of the Congo village of Kifuka.



Lightning strike, Ponte Vedra Beach, Florida. [” LightningFL ” by VictorianMutant licensed under CC BY 2.0]

It should be no surprise that lightning has been recorded on other planets. Jupiter and Saturn exhibit lightning, whereas astronomers

believe that have detected lightning in the thick atmosphere of Venus.



These NASA Galileo spacecraft images show thunderstorms during the daytime [left] and nighttime views of the same thunderstorm area on the right; lightning discharges. [” Jovian Lightning and the Daytime Storm ” by NASA/JPL, in the Public Domain ]

# 4I. Lab 7 Assessments

## **Assignment: Solar System Storm Exercise**

*Assignment Document Link*

Use the above document to submit your data and responses.

This exercise will be graded using the rubric in the syllabus and attached document and is worth up to 65 points. <sup>(1)</sup>

## **Lab 7 Quiz**

*Quiz Document Link*

This quiz contains five matching items, each worth 2 points, for a total score of up to 10 points. You will have 5 minutes to complete this quiz. You have one attempt. <sup>(1)</sup>

PART VIII

# LAB 8 - METEORS, METEORITES, AND CRATERING



# 42. Introduction

## Astronomy Laboratory 8 – Meteors, Meteorites, and Cratering

### Module Introduction



Comet Hale-Bopp, Florida State College at Jacksonville is licensed

under CC BY 4.0

The Earth and other bodies in the Solar System have been pummeled since the Solar System's formation. In this lab, you will examine provided meteorites and compare them with terrestrial rocks commonly mistaken for meteorites. Impacts occur on Earth and throughout the Solar System all of the time. You will explore the effects of impacts by simulating impact events, and specifics around impact events.<sup>(1)</sup>

## Objectives

At the end of this module, students will be able to:

- Observe and report back on a meteor shower
- Describe and compare meteorites
- Replicate impacts on Earth and other planets<sup>(1)</sup>

## Outcomes

The material in this module includes content designed to meet the following course outcomes:

- Communicate scientific ideas through oral or written assignments.
- Demonstrate the ability to think critically.
- Demonstrate the ability to use scientific and quantitative reasoning.<sup>(1)</sup>



## Assigned Readings

### Learning Unit 8

## Assignments

- Meteors, Meteorites, and Cratering Activities
- Lab 8 Quiz <sup>(1)</sup>

## 43. Space Vagabonds

### Space Vagabonds

Many of us have looked up at night and seen what is commonly called a falling or shooting star. These usually-fast flashes are particles entering the Earth's atmosphere at tremendous speeds. We see the particle ionize as it travels through the atmosphere, leaving the streak of light. During a meteor shower — such as the Perseids in August and the Leonids in November — Earth passes through dust left behind as comets orbit the Sun. These meteor showers can produce around a hundred falling stars an hour, if conditions are just right.

Occasionally, these space vagabonds make it to the surface of Earth (or other Solar System body). They are now called meteorites. As a review of terms:

**Comets** are best described as snowy dirtballs. They are composed of ices, silicated materials, carbon, and other compounds such as ammonium hydroxide. When a comet approaches the Sun, it can form a tail of gas, dust, or both.



Comet Hale-Bopp [“Comet Hale-Bopp”, Florida State College at Jacksonville is licensed under CC BY 4.0 ]

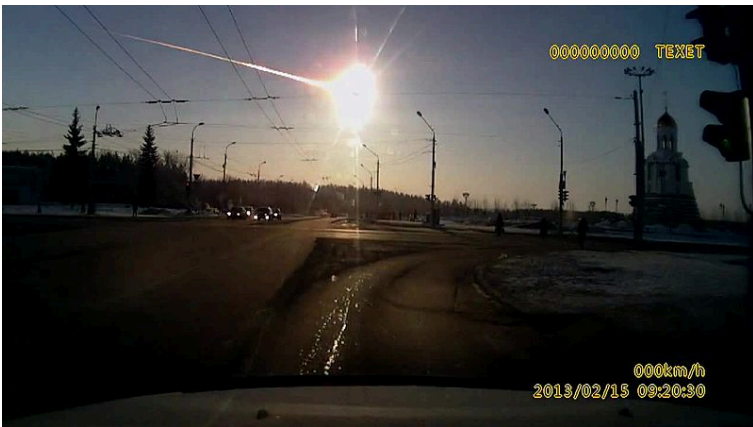
**Asteroids** are a group of the Solar System’s minor bodies that are much like the Rocky Planets in composition: carbon-rich, silicate materials (rock) and/or metal (primarily iron and nickel).



The surface of Asteroid Vesta was taken by NASA's Dawn spacecraft [ " Surface of Asteroid Vesta " by NASA/JPL-Caltech/UCLA/MPS/DLR/IDA is in the Public Domain ]

**Meteoroids** are also materials orbiting in space, and are smaller than asteroids.

**Meteors** are the streaks we see in the sky, commonly called shooting or *falling stars* ; also, can be **fireballs** and/or **bolides**. The root word meteor is derived from the Greek word *meteōros* , which means *high in the air* . Most **meteor showers** are comet dust particles left behind as a comet orbits the Sun. Earth runs into this trail of dust as we orbit the Sun.



A very bright Leonid meteor [left]; and the brilliant and totally unexpected Chelyabinsk fireball, February 15, 2013 [right]. [" Leonid Meteor " by Navicore , licensed under CC BY 3.0 ; " Взрыв

метеорита над Челябинском ” by Daniel Mietchen, licensed under CC BY 3.0 ]



Chelyabinsk meteorites. Note the fusion crust on the exteriors of the meteorites. [” Cheljabinsk meteorite fragment” by Didier Descouens , licensed under CC BY-SA 4.0 ]

**Meteorites** are materials that makes it to the surface of a planet, satellite, etc. There are three major groups or classes of meteorites, based on their make-up.

# 44. Observing a Meteor Shower

## Observing a Meteor Shower

Perhaps one of the easiest and most-exciting astronomy activities is observing a meteor shower. All you need is a lawn chair and your eyes. However, your conditions need to be just right: little street lighting, a clear view of the sky (from trees, buildings, and clouds), and a moonless night. Moonlight can quickly extinguish your view of fainter meteors.

Meteor showers are named after the constellation they appear to come from, called the radiant. For example, the famous August Perseids appear to radiate from the constellation Perseus. There are a couple of showers that do not follow this rule; for example, the Quadrantids are an older constellation that is no longer recognized, yet the shower name is still used.

## Major Northern Hemisphere Meteor Showers

*Each Meteor Shower Constellation for Date Range, Zenithal Hourly Rate, and Parent Body.*

*Quadrantids: Boötes the Bear Driver*

**Date Range** : 12/28 – 1/12

**Zenithal Hourly Rate (ZHR)** : 120

**Parent Body** : Asteroid 2003 EH1 and/or Comet C/1490 Y1

*Shower appears to come from the constellation Boötes, short shower maximum and usually difficult to observe*

### *Lyrids: Lyra the Harp*

**Date Range** : 4/16 – 4/25

**Zenithal Hourly Rate (ZHR)** : 18 – 20

**Parent Body** : Comet Thatcher

*Relatively bright meteors*

### *Eta Aquarids: Aquarius*

**Date Range** : 4/19 – 5/28

**Zenithal Hourly Rate (ZHR)** : 50

**Parent Body** : Comet Halley

*Fast, bright meteors; famous as the source of this shower is Halley's Comet*

### *Southern Delta Aquarids: Aquarius*

**Date Range** : 7/12 – 8/23

**Zenithal Hourly Rate (ZHR)** : 25

**Parent Body** : N/A

*Relatively bright meteors*

### *Perseids: Perseus*

**Date Range** : 7/17 – 8/24

**Zenithal Hourly Rate (ZHR)** : 150

**Parent Body** : Comet Swift-Tuttle



One of the most-famous showers; can produce a bright and magnificent display around the shower's maximum, usually around August 12

### *Orionids: Orion the Hunter*

**Date Range** : 10/2 – 11/7

**Zenithal Hourly Rate (ZHR)** : 15

**Parent Body** : Comet Halley

Not a large number per hour yet very bright and fast meteors. Another shower which is due to Halley's Comet.

### *Leonids: Leo the Lion*

**Date Range** : 11/6 – 11/30

**Zenithal Hourly Rate (ZHR)** : 15

**Parent Body** : Comet Temple-Tuttle

Perhaps one of the fastest of the regular showers; very bright meteors. The Leonids have produced strong storms in the past, with rates up to an incredible 100,000 an hour.

### *Geminids: Gemini the Twins*

**Date Range** : 12/4 – 12/17

**Zenithal Hourly Rate (ZHR)** : 120

**Parent Body** : Asteroid 3200 Phaethon

This shower produces relatively-slow meteors; it's source is unusual in that it is an asteroid, rather than a comet

## *Ursids: Ursa Major*

**Date Range** : 12/17 – 12/26

**Zenithal Hourly Rate (ZHR)** : 10

**Parent Body** : Comet Tuttle

*Slow and medium brightness meteors; included because you might see some of these meteors when watching for the Geminids*

The **date** range of the showers are when members of the shower can be seen. The maximum usually occurs on a specific date and time. The **ZHR**, or Zenithal Hourly Rate, is the expected number of meteors at maximum if the radiant is overhead or at the zenith; if it is towards the horizon, expect to see fewer meteors. And, the Parent Body is the source of the meteor shower; most are comets but at least the Geminids are attributed to Asteroid 3200 Phaethon.

Occasionally, you will see a random meteor, called a sporadic. These are usually not associated with any shower. Sometimes that meteor will be very bright, called a fireball. And, occasionally, these fireballs will break up, called a bolide.

# 45. Meteorites

## Meteorites

*I would more easily believe that (a) Yankee professor would lie than that stones would fall from heaven. — Thomas Jefferson, 1808*

Most meteoritic material that strikes the Earth's atmosphere does not make it to the surface to be recovered. The meteor burns up, or if it makes it to the surface, falls into water, since Earth is a water surface planet.

There is more gold mined each year than the total amount of meteorites found in all collections – museums, universities, and private collections. So, how does one recognize if a rock is potentially a meteorite?

1. **The rock attracts a magnet** – most meteorites have some iron in them. Not all, though.
2. **The rock looks burned**, called a fusion crust. Yet, if the meteorite has been sitting in a desert region for a while, the fusion crust might be weathered away.
3. **The rock looks shaped**, like it's been oriented as it came through the atmosphere. Yet again, this aerodynamic shaping might have been weathered away.
4. **The rock looks like it has thumbprint-like impressions**, called regmaglypts. These impressions are formed as the meteorite comes through the atmosphere, and material is ablated away from the meteorite.

The three major groups or classes of meteorites, based on their make-up:

### **Stones or Stony Meteorites**

These are composed of silicates and other materials. Most stony meteorites contain metal in the form of iron and nickel. Plus, stone meteorites are by far the most common type; some 94&percent; of recovered meteorites are stony. Stone meteorites also include very rare types of meteorites, including lunar, Martian, and possibly even comets.

### **Iron meteorites, or Irons**

These are composed of iron (Fe) and nickel (Ni), with some cobalt (Co) and other trace elements and minerals. Iron is the predominant metal, and the type of Iron meteorite depends on the ratio of iron to nickel. No Earth rock has iron and nickel in combination. Thus a 'rock' recovered with iron and nickel together is a meteorite. Irons are very dense meteorites, in comparison to stony meteorites.

### **Stony Irons**

As the name indicates, they are a combination of iron and stony meteorite properties and the rarest type or class of meteorite.

### **Tektites**

Very dry glasses, and are hypothesized to be meteoritic splash from a large impact. The meteorite strikes Earth, and soil is blown up into the air, almost back into space. Yet, the escape velocity is not high enough, so the now-molten material re-enters and lands, found as the glassy material found in specific areas on Earth.

*Click on the image to view the video.*



Content by Florida State College at Jacksonville is licensed under a Creative Commons Attribution 4.0 International License. ]

Rocks which are not meteorites are referred to as meteorwrongs by those who work in the field. People often find an unusual-looking rock and think it is a meteorite. After testing, which will include the four steps noted and/or chemical testing, many of these are meteorwrongs.

# 46. Impacts and Cratering

## Impacts and Cratering

A crater is a bowl-shaped depression; the word *crater* comes from the Greek for bowl. Craters can form in a number of ways: at the top or side of a volcano, the top of a geyser, from a large impacting meteorite, or even a bomb. For this lab, we will focus on meteorite craters.

Craters are found on every solid Solar System body. If one examines the Moon, many craters are easily visible, even with binoculars. The Moon has no atmosphere, so there is nothing to burn up or slow down the meteoroid, asteroid, or comet.

Crater sizes can go from microscopic to well over one hundred miles across! On the Moon, and other bodies, we observe craters within craters. Occasionally, material is splashed out during an impact, forming what is called rays.



1<sup>st</sup> Quarter Moon. The Moon is littered by thousands of impact craters, easily visible through small telescopes. [”1stQuarterMoon” by Dave Young , Flickr Commons is licensed under CC BY 2.0 ]

## 47. Lab 8 Assessments

### **Assignment: Meteors, Meteorites, and Cratering Activity**

#### *Assignment Document Link*

*Use the above document to submit your data and responses.*

There are three parts to this lab:

- Observing a Meteor Shower
- Meteorites
- Impact Splash

Complete all three sections on the one document then upload by following the link, above. This activities will be graded using the rubric in the syllabus and attached document and is worth up to 65 points. <sup>(1)</sup>

### **Lab 8 Quiz**

#### *Quiz Document Link*

This quiz contains five matching items, each worth 2 points, for a total score of up to 10 points. You will have 5 minutes to complete this quiz. You have one attempt. <sup>(1)</sup>



PART IX

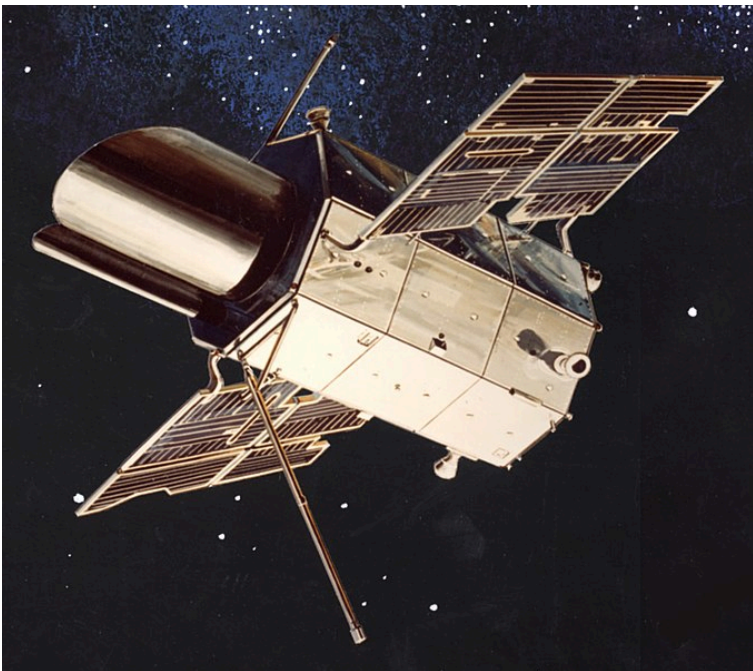
# LAB 9 - THE HUBBLE SPACE TELESCOPE



# 48. Introduction

## Astronomy Laboratory 9 – The Hubble Space Telescope

### Module Introduction



Artist's concept of the Orbiting Astronomical Observatory in orbit. Four OAOs were built and launched as a part of the program. [ "Orbiting Astronomical Observatory" by NASA, in the Public Domain ]

Perhaps the best known unmanned spacecraft is the Hubble Space Telescope, HST, launched in 1991 and still fully operational. Even though the HST was not the first space telescope, it is by far the most famous and productive to date. The images returned by the HST are often beyond words. They give astronomers and stargazers a look at the Universe in detail never seen before.

Using the NASA online Space Telescope Science Institute's (STScI) website, you will explore a number of the Hubble Telescope observations and discoveries to better understand contemporary astronomy. Results from other satellites will also be explored, from planetary orbiters like Cassini (Saturn) to landers and rovers, like Curiosity (Mars). <sup>(1)</sup>

## Objectives

At the end of this module, students will be able to:

- Compare and contrast images from various telescopes
- Describe the advantages of the Hubble Space Telescope
- Research images and information gained by the Hubble Space Telescope for Galaxies, Nebulae, Star Fields, and Globular Clusters
- Explain the impact of current developments in telescope design on future space exploration <sup>(1)</sup>

## Outcomes

The material in this module includes content designed to meet the following course outcomes:

- Explain and apply major concepts in astronomy including

planets, satellites, stars, meteors, galaxies, and theories of the universe.

- Communicate scientific ideas through oral or written assignments.
- Demonstrate the ability to think critically.
- Demonstrate the ability to use scientific and quantitative reasoning.<sup>(1)</sup>

## Assigned Readings

### Learning Unit 9

## Assignments

- Hubble Space Telescope Exercise
- Lab 9 Quiz<sup>(1)</sup>

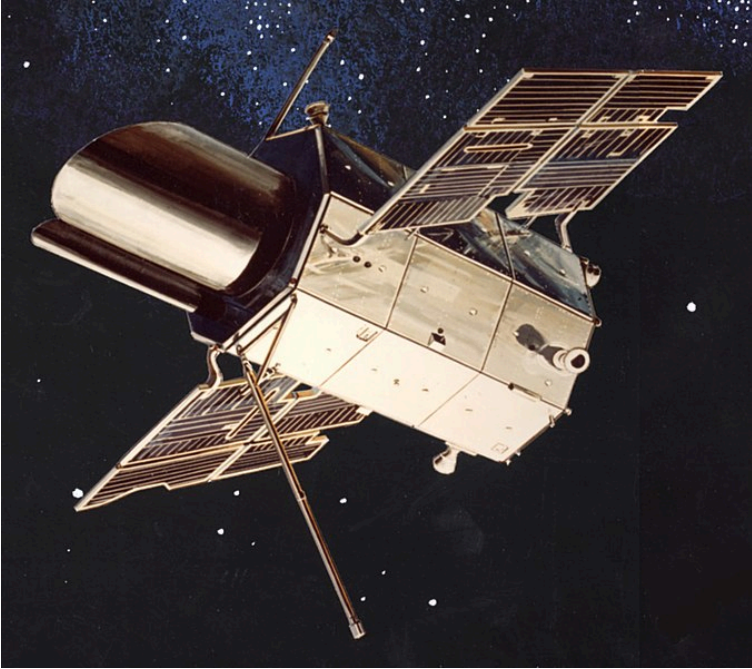
# 49. Hubble Space Telescope

## Hubble Space Telescope

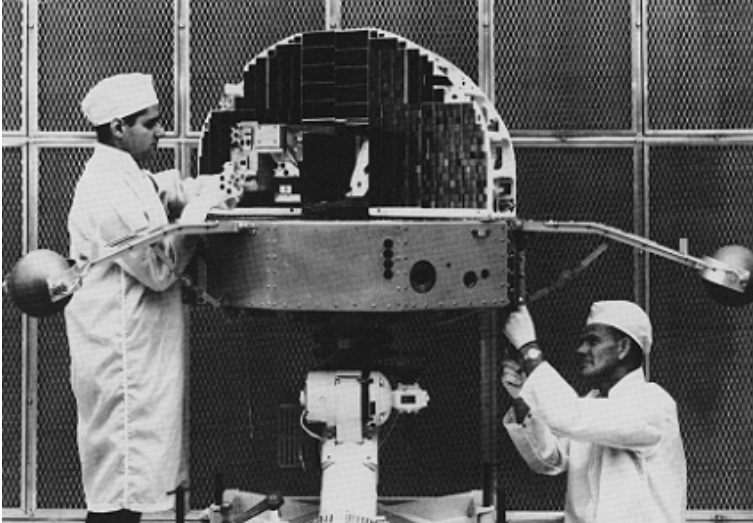
Perhaps the best known unmanned spacecraft is the Hubble Space Telescope, HST, launched in 1991 and still fully operational. Even though the HST was not the first space telescope, it is by far the most famous and productive to date. The images returned by the HST are often beyond words. They give astronomers and stargazers a look at the Universe in detail never seen before.

The idea of a space telescope was first mentioned in writings in 1923 by German rocket pioneer Hermann Oberth. The direct link to what is now known as the Hubble Space telescope can be traced directly to Lyman Spitzer, an astronomer, who wrote in 1946 of the advantages such a space-based telescope would have. Being above Earth's atmosphere would allow such a telescope to "see" without any atmospheric interference. And, the telescope could observe in the ultraviolet and infrared ranges of the spectrum; these wavelengths are mostly blocked by the Earth's atmosphere; a good thing for humans but a bad thing when one is trying to study and understand the Universe.

Progress was made in the 1960's towards the development and launch of a large space-based telescope. First, NASA launched a space telescope 1962 specifically to study the Sun, the Orbiting Solar Observatory. And in 1966, NASA launched the first telescope, the Orbiting Astronomical Observatory.



Artist's concept of the Orbiting Astronomical Observatory in orbit. Four OAOs were built and launched as a part of the program. [ " Orbiting Astronomical Observatory " by NASA, in the Public Domain ]



Two technicians work on the Orbiting Solar Observatory, before launch. [” OSO4 ” by Uwe W ., in the Public Domain ]

With the experience and knowledge from the OSO and OAO missions, NASA began planning for a larger, longer term space telescope. The concept for the Large Space Telescope was that it features a 3 meter-diameter primary mirror (about 118 inches) and be placed into orbit by the under-development Space Shuttle as early as 1979.

As is often the case, funding became an issue, so the Large Space Telescope's primary mirror was reduced in size from 3 meters to 2.4 meters (about  $94\frac{1}{2}$  inches). Additionally, the European Space Agency was brought on as a partner of the Large Space Telescope. The proposed launch was pushed way back from the original 1979 target, due to both Space Shuttle and Large Space Telescope developmental issues.

In 1983, the Large Space Telescope was renamed the Hubble Space Telescope, to honor Edwin Hubble for his work in astronomy and specifically Hubble's discovery that the Universe is expanding. One of the key objectives for the HST was to determine the rate at which the Universe is expanding.



Development and construction of the HST took longer than planned, yet finally a launch date was set: October 1986. With the Challenger tragedy January 28, 1986, all shuttle launches were stopped until the Space Shuttle could undergo major modifications. Finally, on April 24, 1990, the HST was flown into orbit aboard Space Shuttle Discovery and successfully deployed on orbit.



American astronomer Edwin Hubble, at the eyepiece of the 100-inch telescope at Mount Wilson (California, USA). [” Edwin Hubble ” by NASA & ESA is licensed under CC BY 4.0 ]



The HST, after a Space Shuttle Discovery servicing mission, with

Earth in the background. [” Hubble 01 ” by NASA, in the Public Domain ]

# 50. Repairing the HST

## Repairing the HST

One of the HST major design features is the capability of changing out equipment during a Space Shuttle visit. Engineers understood that the technology which supported the HST was changing at a rapid rate. They also understood from previous satellite experience that systems can and do fail. It was fortuitous that HST design engineers had this on orbit servicing mission concept in mind, for it was needed much sooner than thought.

As astronomers checked out their new telescope after launch, it became painfully obvious that something was wrong with the telescope. It was as if the HST was nearsighted; the telescope was not getting a good focus. Stars and galaxies looked fuzzy, something one did not want to see from a multi-billion-dollar telescope. After an investigation, it was found that the HST's primary mirror was shaped to the wrong curve, producing out of focus images.



Hubble's primary mirror during fabrication. [” Hubble mirror polishing ” by NASA, in the Public Domain ]



Wide Field Planetary Camera 1



Wide Field Planetary Camera 2

Hubble without corrective optics (left) – and with corrective optics. After determining the primary mirror was flawed, a corrective optical system – glasses – was designed, built, and flown aboard the Space Shuttle to the Hubble Space Telescope, where it was installed. [” Hubble Images ” by NASA, in the Public Domain ]

During five space shuttle servicing missions over the period of about 16 years, not only was a fix initiated for the out-of-focus issues — the HST basically was fitted with glasses — but solar panels were replaced, new and updated computers installed, and instruments replaced by new instruments.



Hubble's first servicing mission was to install the corrective optics package, along with other repairs and upgrades. The HST was captured by the Shuttle's robotic arm and then placed on an HST-specific base in the Shuttle's Cargo Bay. Astronauts could then take a spacewalk to effect repairs. [” Upgrading Hubble during SM1 ” by NASA, in the Public Domain ]

# 51. HST Achievements

## HST Achievements

So, what are the Hubble Space Telescope's greatest achievements since its 1990 launch? As a summary of some of the many HST achievements:

- Determine the rate the Universe is expanding, and that expansion rate is accelerating
- The range of the age of the Universe
- Discovery and confirmation of galactic nuclei supermassive black holes
- Discovery and observations of proto-planetary disks – called proplyds – in the Great Orion Nebula
- Stellar systems forming, and planets around other stars
- Observations of Comet Shoemaker-Levy 9's collision with Jupiter
- Solar System observations
- The Universe is thick with galaxies

As you can see, the Hubble Space Telescope has had a rich – and sometimes troubling – history.



The Orion Nebula, as captured by the Hubble Space Telescope  
[ " Hubble 2006 mosaic 18000 " by NASA, ESA, M. Robberto, in  
the Public Domain ]

## 52. Lab 9 Assessments

### Exercise: Hubble Space Telescope Exercise

#### *Exercise Document Link*

*Use the above document to submit your data and responses.*

For this lab you will explore some of the Hubble Space Telescope's results, view images from the Hubble Heritage Project, and read and respond to facts about the Hubble Deep Field Project. Provide all of your responses in the attached document. This exercise will be graded using the rubric in the syllabus and attached document and is worth up to 65 points. <sup>(1)</sup>

### Lab 9 Quiz

#### *Quiz Document Link*

This quiz contains five matching items, each worth 2 points, for a total score of up to 10 points. You will have 5 minutes to complete this quiz. You have one attempt. <sup>(1)</sup>



PART X

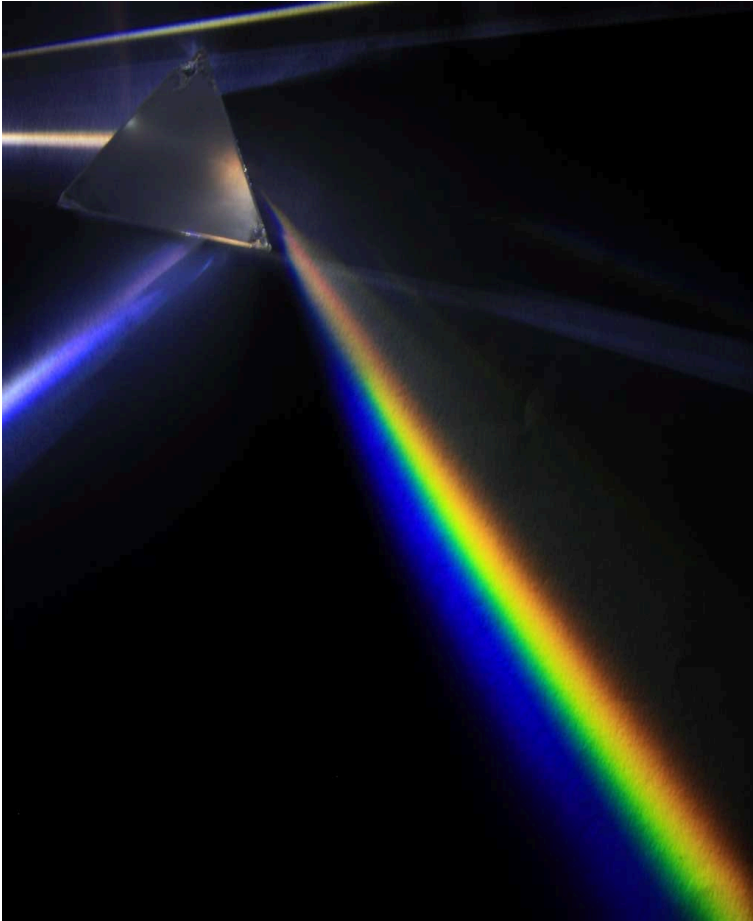
# LAB 10 - STAR COLORS AND SPECTROSCOPY



# 53. Introduction

# Astronomy Laboratory 10 – Star Colors and Spectroscopy

## Module Introduction



When light strikes or enters a prism, it is dispersed into component colors. This is an example of spectroscopy. Light dispersion by D-Kuru is licensed under CC BY-SA 3.0

Spectroscopy is a major scientific tool. In astronomy it allows one to determine precisely the composition of stars, as well as if the star is moving toward or away from Earth.

In this lab, you will explore how spectroscopy works and learn in introduction to astronomy about star color versus star temperature. The lab exercise will take the concept outdoors, where you will visually observe and catalog different stars with varying colors. <sup>(1)</sup>

## Objectives

At the end of this module, students will be able to:

- Identify constellations and the colors of some of the stars within
- Make observations and record data using diffraction grating
- Describe astronomical spectroscopy based on research <sup>(1)</sup>

## Outcomes

The material in this module includes content designed to meet the following course outcomes:

- Explain and apply major concepts in astronomy including planets, satellites, stars, meteors, galaxies, and theories of the universe.
- Demonstrate knowledge of scientific method.
- Communicate scientific ideas through oral or written assignments.
- Interpret scientific models such as formulas, graphs, tables and schematics, draw inferences from them and recognize their limitations.

- Demonstrate the ability to think critically.
- Demonstrate the ability to use scientific and quantitative reasoning. <sup>(1)</sup>

## Assigned Readings

### Learning Unit 10

## Assignments

- Star Colors
- Simple Spectroscopy Exercise
- Astronomical Spectroscopy
- Lab 10 Quiz <sup>(1)</sup>

# 54. Star Color

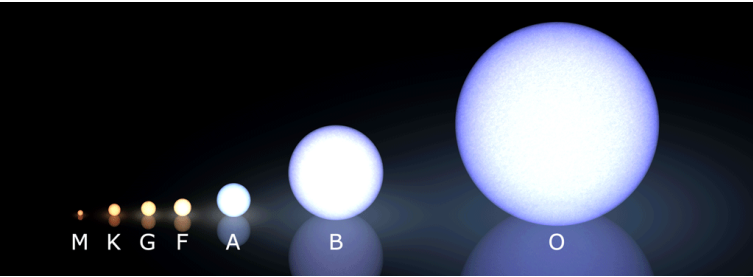
## Stars in the Night Skies

As one looks at the stars in the night sky, a couple of things become obvious, especially if you are observing from a dark sky site. First, you will observe that the stars are of various brightnesses. This is due to two main factors: the distance to the star and the type of star. Second, you will see that not all stars are white in color. You will see red stars, orange stars, blue and blue-white stars. No, your eyes are not playing tricks on you. And, by the way, yellow stars, like the Sun, are a little harder for the human eye to see the star's yellow color. Yet, through a telescope, and for some in binoculars, the yellow color is visible. <sup>(1)</sup>

## Star Color

Astronomers measure a star's surface temperature at its photosphere. Recall that the photosphere is the outer layer of the star from which light is radiated. The star's photosphere temperature dictates its color. Conversely, the color of a star at its photosphere shows its temperature. The hotter the star is, the more blue or blue-white it is. And, the cooler the star, the redder the star will appear in color.

Astronomers classify stars by their color and/or photosphere temperature, called a star's Spectral Type or Spectral Class. An astronomer, Annie Jump Cannon, sorted spectral data and designed the stellar spectral types we still use; O-B-A-F-G-K-M.



Stars – colors with spectral types. Not all of the star types are shown, such as the Red Supergiant stars.Morgan-Keenan spectral classification by LucasVB is licensed under CC BY-SA 3.0

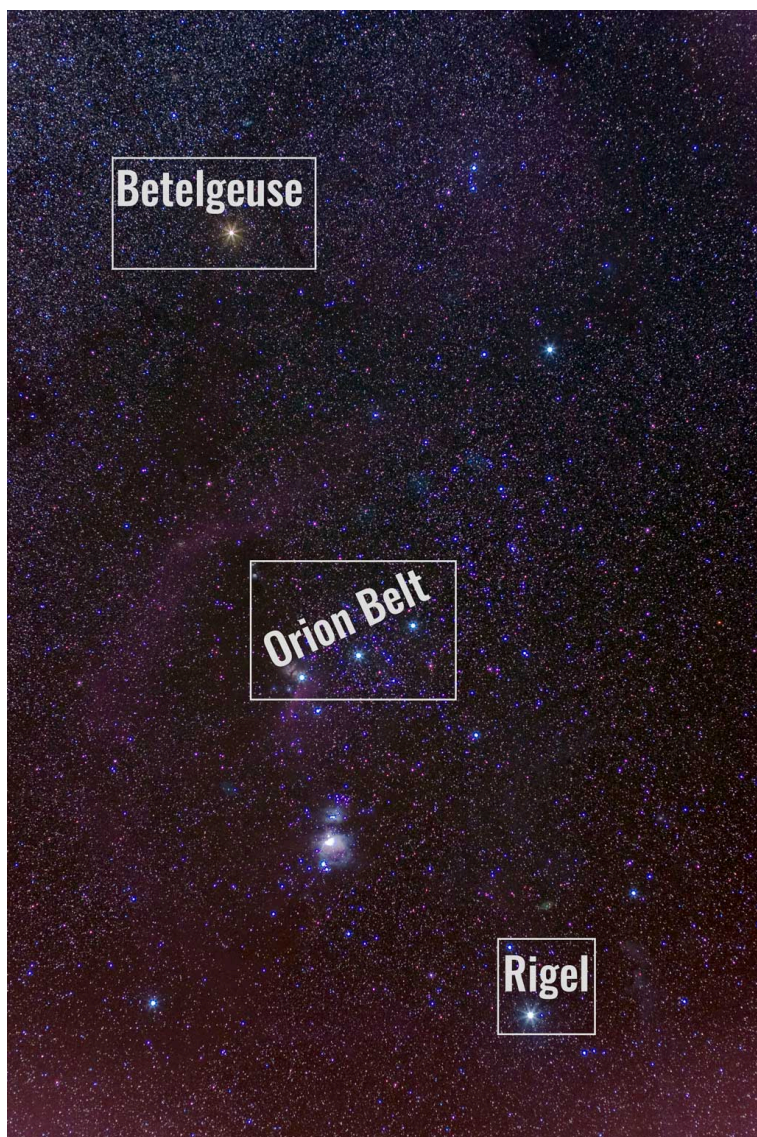
A more-detailed form of Cannon’s classification, the Morgan-Keenan classification, provides more information about each star by adding Roman numerals with the spectral types. See the table, below, for examples of stars, temperature, and color.<sup>(1)</sup>

*Examples of Stars and Spectral Types*

Spectral Type	Star Example	Temperature Range, K	Stellar Color
O	Orion Belt Stars	>30,000	Blue-Blue White
B	Rigel	10,000–30,000	Blue-White
A	Sirius	7,500–10,000	White
F	Polaris	6,000–7,500	Yellow
G	Sun	5,000–6,000	Deep Yellow
K	Arcturus	3,5000–5,000	Orange
M	Betelgeuse	<3,500	Red



## Seeing Star Colors



Orion the Hunter. Note several identified stars; Betelgeuse (red), Belt Stars (blue-blue white), and Rigel (blue-white). Orion 3008 by

Florida State College at Jacksonville is licensed under CC BY-SA 3.0 / A derivative from the original work

Perhaps the best constellation to view various star colors is Orion. This winter constellation includes the stars Rigel (Blue-White), Belt Stars (Blue-Blue White), and Betelgeuse (Red).

You can easily see the star colors without a telescope or binoculars, especially red Betelgeuse and the other blue stars. With a pair of binoculars, star colors become even-more obvious. Many have likened these colorful stars as celestial gems.

Albireo, also known as Beta Cygni, is a double star system in the constellation Cygnus the Swan. With the naked eye, Albireo looks like a single star. Through a small telescope or even binoculars, one can see two stars that astronomers call Albireo A and Albireo B. The obvious orange and blue stars are occasionally referred to as the “Gator Double.”



The orange and blue stars of Albireo NewAlbireo by Hewholooks is licensed under CC BY-SA 3.0

Polaris, the Pole Star in the constellation Ursa Minor (the little bear), is usually easy to find, unless you have too many streetlights around you or your horizon blocks your view to the north. Polaris is an F

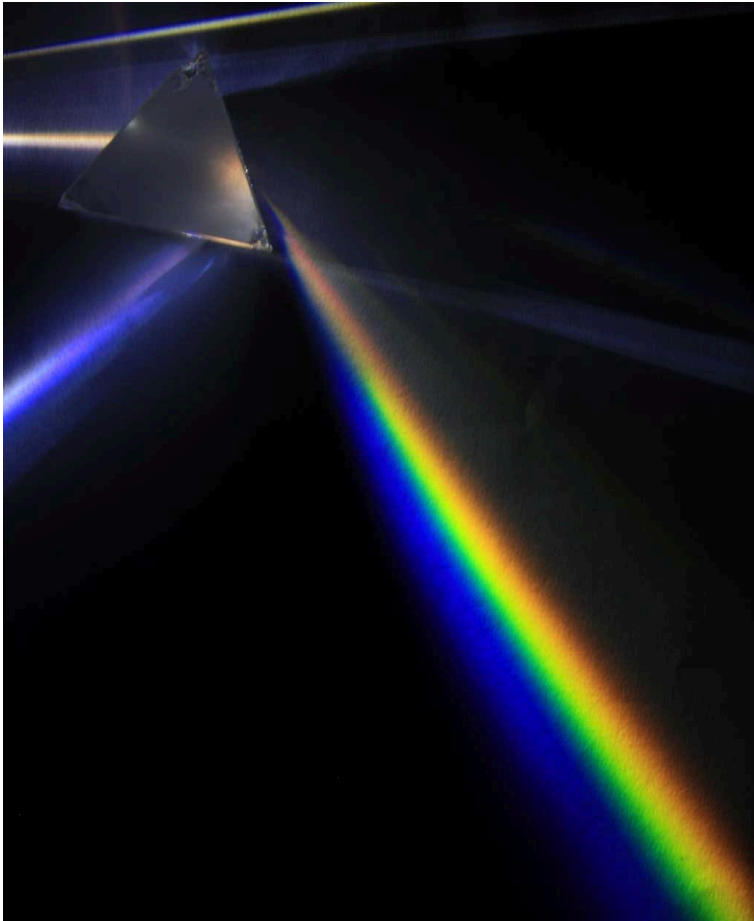
star, based on Annie Jump Cannon's classification. It is a yellow star, and slightly hotter at its photosphere than our Sun. <sup>(1)</sup>



A star trail photograph. Polaris — a yellow star — is at the very center of the photo, indicated by the arrow. Star Trail above Beccles by Florida State College at Jacksonville is licensed under CC BY-SA 4.0 / A derivative from the original work

# 55. The Spectroscope

## The Spectroscope



When light strikes or enters a prism, it is dispersed into component colors. This is an example of spectroscopy. Light dispersion by D-Kuru is licensed under CC BY-SA 3.0

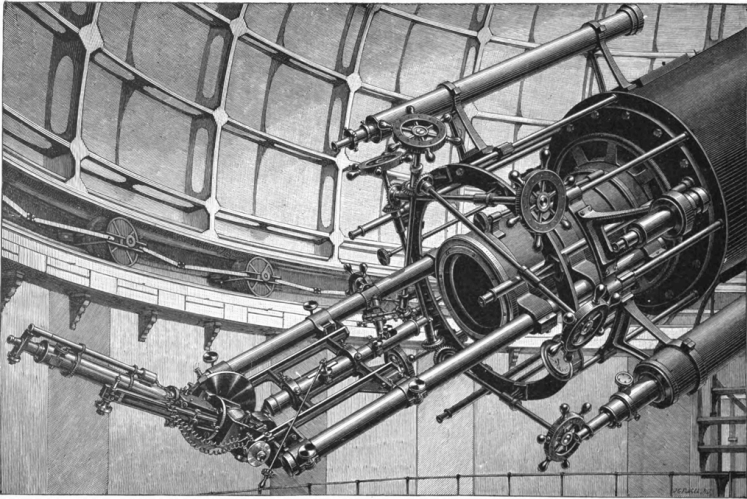
A star's color tells us a lot about the star: its temperature and perhaps even the star's life cycle. But to dig a bit deeper, scientists use a tool called the spectroscope and spectroscopy. In 1814, Joseph van Fraunhofer invented the modern spectroscope. The spectroscope basically uses a prism or diffraction grating to break light into its component colors, producing a spectrum. There is also a slit, where the light enters, and a telescope-like focuser.

The heart of the spectroscope — the component which breaks light into its component colors, is either a prism or a diffraction grating. Think of the diffraction grating as many small prisms on a thin sheet of plastic or glass; 500 or more rulings per inch. The CD is a good analogy to a diffraction grating.



The grooves of a CD can act as a diffraction grating, producing colors when light is reflected off of the CD. Interference-colors by Luis Fernández García is licensed under CC BY-SA 2.0

A spectroscope can be mounted on a telescope, collecting light from one object, such as a star or galaxy, to be passed through the spectroscope for analysis. <sup>(1)</sup>



Lick Observatory's Spectroscope, 1898. The actual spectroscope, which looks like a tube, is attached to the back of the telescope is in the lower left of the illustration. Star-Spectroscope by Julius Scheiner is in thePublic Domain

# 56. Elemental Data

## Elemental Data

When you look at the spectrum of sunlight, you will see a blend of colors. This is called a continuous spectrum. This is like a rainbow, produced when sunlight passes through raindrops, which act as prisms.





A rainbow. Raindrops act as prisms, breaking the sunlight into its component colors. Rainbow above Kaviskis Lake by Arz is licensed



under CC BY-SA 3.0



A continuous spectrum. This is much like the rainbow. Spectral-lines-continuous by Stkl is in the Public Domain

The science of spectroscopy starts in the lab, where scientists observe the spectra of different elements with the spectroscope. What scientists noted is that each element or compound have their own signature spectrum. So, when observing a star, astronomers use a spectroscope to definitively determine what elements make up that star, among other things about the star.

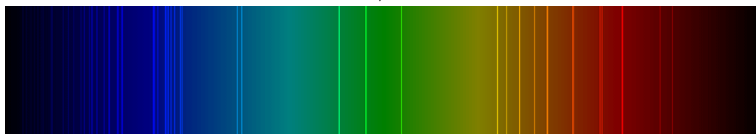
Compare the spectra of hydrogen, helium. Oxygen, and neon, below. Look at the lines; this is the key to determine which element's spectrum you are observing. Each spectrum is specific to that element. It is like fingerprints; no two are alike.



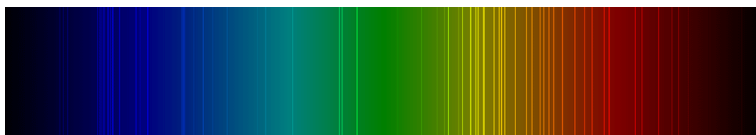
Spectrum produced by Hydrogen, H Hydrogen spectrum visible by McZusatz is in the Public Domain, CC0



Spectrum produced by Helium, He Helium spectrum visible by McZusatz is in the Public Domain, CC0

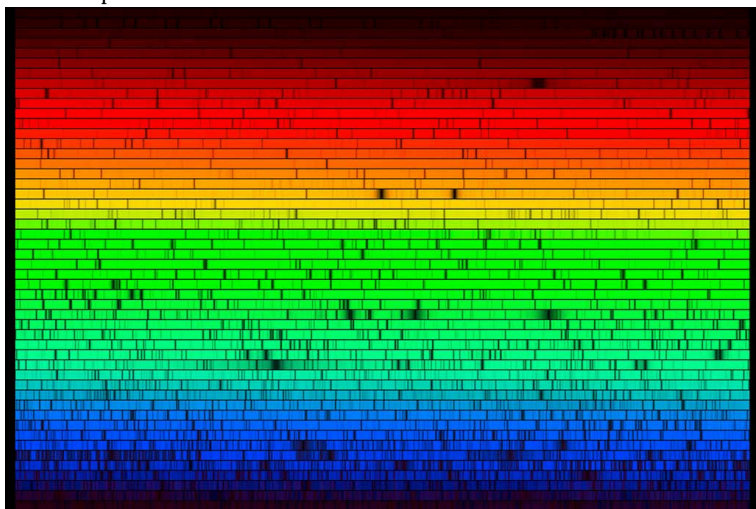


Spectrum produced by Oxygen, O Oxygen spectrum visible by McZusatz is in the Public Domain, CC0



Spectrum produced by Neon, Ne Neon spectrum visible by  
McZusatz is in the Public Domain, CC0

When one captures the Sun's spectra, it includes all of the elements  
and compounds found in the Sun.



The Sun's Spectrum. This image tells astronomers a lot about our  
star, as spectra can about other stars. Included in the stellar  
spectral message is the star's make-up and star type. The barcode  
of the Sun by ESO/José Francisco is licensed under CC BY 4.0

Astronomers employ stellar spectroscopy to study stars, which  
allows them to determine many of the physical and chemical  
properties of the stars and other objects they study in space. <sup>(1)</sup>

# 57. Lab 10 Assessments

## Assignment: Star Colors

*Assignment Document Link*

Use the above document to submit your data and responses. You will need to upload the document and one photo attachment.

At the heart of the spectroscope is a simple optic: either a prism or a diffraction grating. For this part of the lab, you will need the *Lab 10. Stars Colors and Spectroscopy* baggie in your Astronomy Lab supplies kit. This contains a cardboard-mounted diffraction grating. You will also need your smartphone to take photos of your experiments. Use caution when handling the diffraction grating; the surface can be easily damaged. **Do NOT look directly at the Sun with the diffraction grating or any optical instrument.**

This exercise will be graded using the rubric in the syllabus and attached document and is worth up to 20 points. <sup>(1)</sup>

## Simple Spectroscopy Exercise

*Exercise Document Link*

Research and write a brief 200 overview about astronomical spectroscopy, how the astronomical spectroscope works, and how astronomical spectroscopy contributes to the science of astronomy. Use a minimum of three (3) references, listing your references in the proper format. Upload your paper into the Lab 10 Blackboard shell.

Be sure to properly organize your writing. For example:

- Introduction/Overview
- Major Point 1

- Supporting Point 1
  - Supporting Point 2
- Major Point 2
  - Supporting Point 1
  - Supporting Point 2
- Major Point (etc.)
- Conclusion
- References <sup>(1)</sup>

This assignment will be graded using the rubric in the syllabus and is worth up to 20 points. <sup>(1)</sup>

## Astronomical Spectroscopy

This quiz contains five matching items, each worth 2 points, for a total score of up to 10 points. You will have 5 minutes to complete this quiz. You have one attempt. <sup>(1)</sup>

PART XI

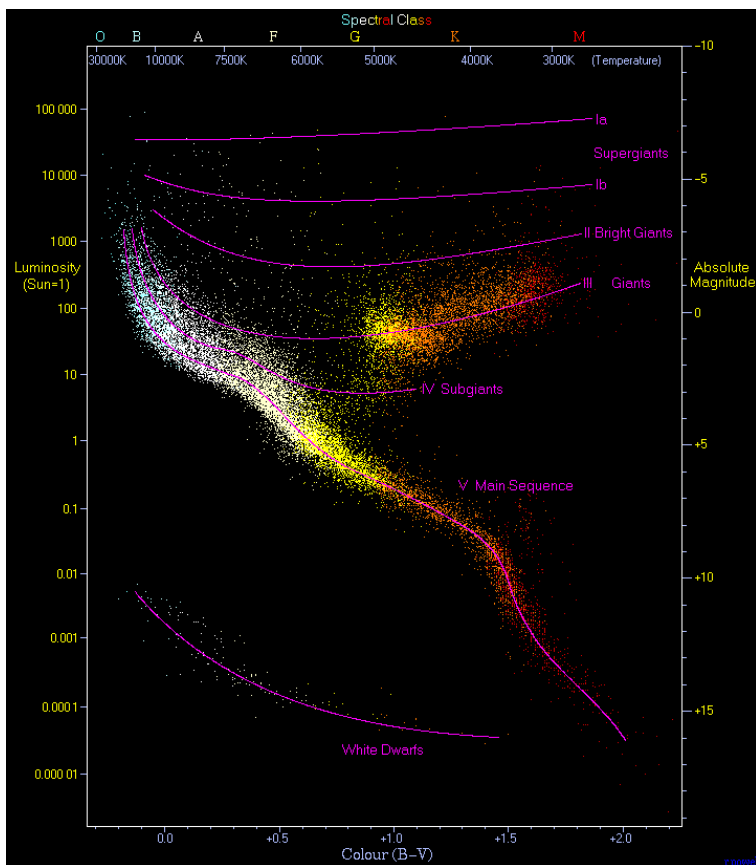
# LAB II - H-R DIAGRAM



# 58. Introduction

## Astronomy Laboratory II – The H-R Diagram

### Module Introduction



Hertzsprung-Russell diagram, or H-R diagram. Some 22,000 stars make up the data for this specific illustration. HRDiagram by Richard Powell is licensed under CC BY-SA 2.5

The Hertzsprung-Russell Diagram, H-R Diagram, is a useful tool which plots stellar luminosity versus temperature. Building on the Star Colors and Spectroscopy lab, you will detail how the H-R Diagram works, and plot some of the stars observed in Lab 10, Star Colors and Spectroscopy. <sup>(1)</sup>

## Objectives

At the end of this module, students will be able to:

- Plot a H-R diagram using provided data
- Analyze the data and make interpretations using the H-R diagram <sup>(1)</sup>

## Outcomes

The material in this module includes content designed to meet the following course outcomes:

- Explain and apply major concepts in astronomy including planets, satellites, stars, meteors, galaxies, and theories of the universe.
- Demonstrate knowledge of scientific method.
- Communicate scientific ideas through oral or written assignments.
- Interpret scientific models such as formulas, graphs, tables and schematics, draw inferences from them and recognize their limitations.



- Demonstrate the ability to think critically.
- Demonstrate the ability to use scientific and quantitative reasoning.<sup>(1)</sup>

## Assigned Readings

### Learning Unit 11

## Assignments

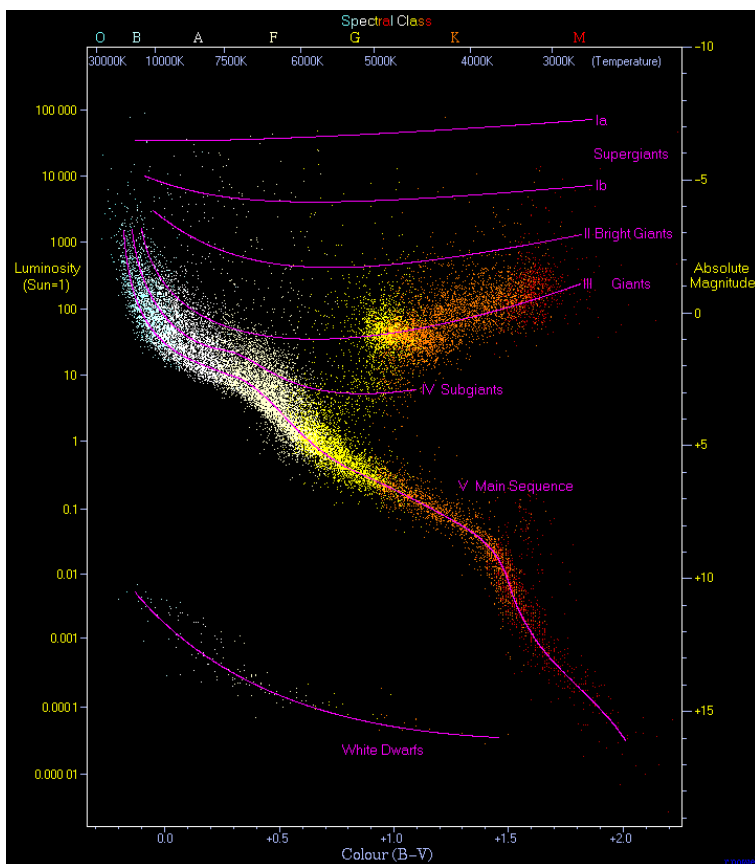
- Plotting a H-R Diagram Exercise
- Lab 11 Quiz<sup>(1)</sup>

# 59. Hertzsprung- Russell Diagram

## Hertzsprung- Russell Diagram

The **Hertzsprung- Russell diagram** , or the **H-R diagram** , is a graph which plots a star's brightness versus its color. This very-useful graphic was developed around 1910 by Danish astronomer **Ejnar Hertzsprung** and American astronomer **Henry Norris Russell** . The H-R diagram groups stars into four major classes, and shows stellar evolution: how stars change as they fuse the elements in their stellar cores.

The H-R diagram itself will appear different than most graphs. Yet, with one glance, you can see stellar groupings, brightness, and colors. The stellar colors are reflective of the star's photosphere, or surface temperature. The hotter the star, the more bluish it will appear. And, the cooler the star, the more reddish in color.



Hertzsprung-Russell diagram, or H-R diagram. Some 22,000 stars make up the data for this specific illustration. HRDiagram by Richard Powell is licensed under CC BY-SA 2.5

Let's first examine closely the above H-R diagram illustration.

**The Y-axis plots the star's brightness.** This particular illustration uses a familiar unit: the Sun. So, with the Sun  $\approx 1$ , stars are plotted when compared to the Sun. This is their absolute magnitude or brightness, not how they look in the sky, or apparent magnitude. (A topic discussed in Lab 3. *Magnitude and Light Pollution*). For those so inclined, the Y-axis is plotted on a logarithm scale. The Y-

axis can also be plotted in absolute magnitude. Most plots are based on the Sun = 1, though.

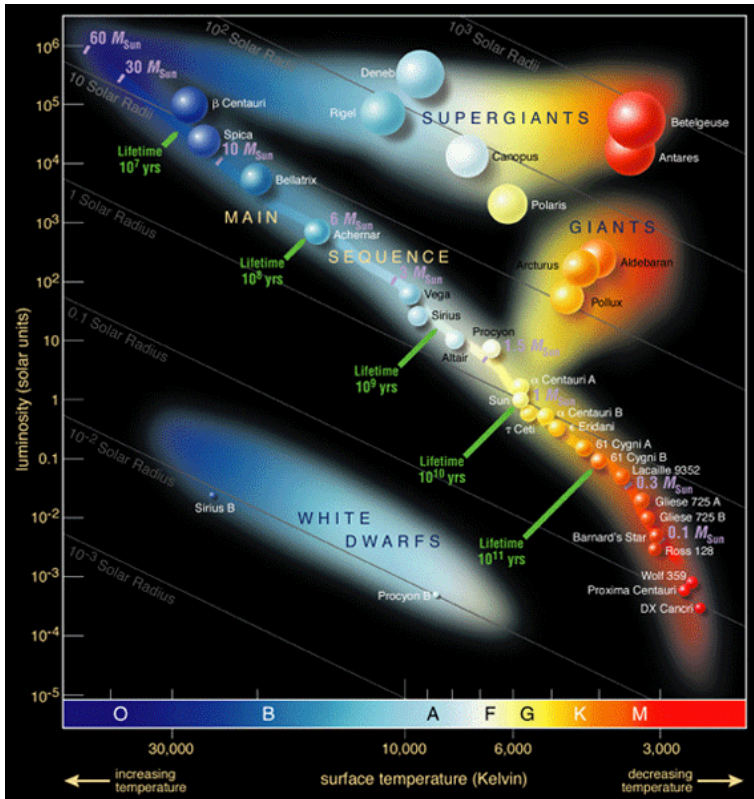
If you also note on the right-hand side of the graph along the Y-axis, you will see numbers and Absolute Magnitude. This is the other way to represent stellar brightness's.

**The X-axis plots the star's temperature.** Look at the values of the X-axis along the top of the illustration (not the bottom – more on that later). You will note at the very top a line of letters; O B A F G K M. Right below that you will also note numbers; 30000K 10000K 7500K 6000K 5000K 4000K 3000K. These numbers will be our primary focus: they are the star's photosphere temperature in the Kelvin temperature scale. You are familiar with the Fahrenheit and most likely the Celsius or Centigrade temperature scales. The Kelvin temperature scale is like the Celsius temperature scale, but starts at zero, called absolute zero. There are no negative temperatures on the Kelvin temperature scale; it always starts at zero. Astronomers prefer the Kelvin temperature scale because there are referrals to the coldest temperature in space – which is just above 0K or absolute zero.

Some astronomers prefer to use what is known as the Color Index – Colour (B-V) – found along the bottom X-axis on the illustration. This is another way to classify a star's temperature and color.

# 6o. H-R Diagram for Milky Way Stars

## H-R Diagram for Milky Way Stars



Another H-R diagram showing a number of specific stars, as well as representative star sizes. The star sizes are somewhat to scale. Hertzprung-Russel StarData " by ESO is licensed under CC BY 4.0

The H-R diagram shown in illustration above provides stellar data in a different way. The four main groups of stars are clearly identified:

1. **Main Sequence:** most stars, like our Sun; this is the area on the H-R diagram where most stars will spend their stellar lives.
2. **Supergiants:** cool stars which are very large and very bright. These stars generally end with a supernova event and many collapse to become neutron stars and even further collapse to a black hole.
3. **Giants:** cool stars which are a little smaller and dimmer than the Supergiants. The Giants have a different stellar ending than the Supergiants.
4. **White Dwarfs:** very, very hot stars which are very small in size.

This particular H-R diagram is very informative in that it graphically shows relative sizes, (though not to scale), colors (thus temperatures), and in some cases masses when compared to the Sun (for example in the upper left-hand corner: 60 MSUN, which means a star 60 times the mass of the Sun). There are also a number of representative stars shown; for example:

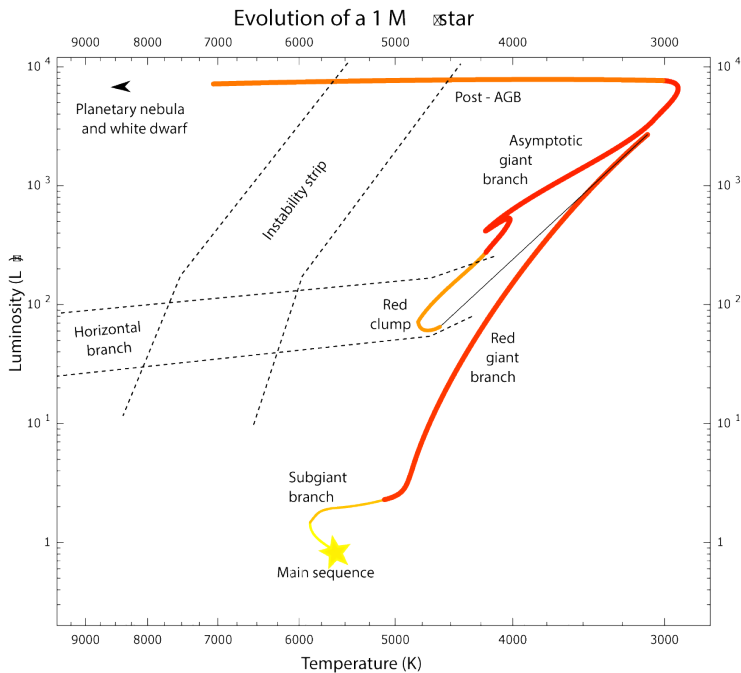
- Betelgeuse in the constellation Orion — X-axis: 3000K, Y-axis  $10^5 M_{\text{SUN}}$
- Polaris, the north pole star — X-axis: 6000K, Y-axis between  $10^3$  and  $10^4 M_{\text{SUN}}$
- Sirius, the brightest star visible from Earth after the Sun — X-axis: 9000K, Y-axis 10 and  $10^2 M_{\text{SUN}}$
- Sirius B, the white dwarf companion of Sirius — o X-axis: ~25000K, Y-axis 0.1 and  $10^{-2} M_{\text{SUN}}$
- The Sun — X-axis: 6000K, Y-axis  $1 M_{\text{SUN}}$

# 6I. H-R Diagram and Star Life Cycles

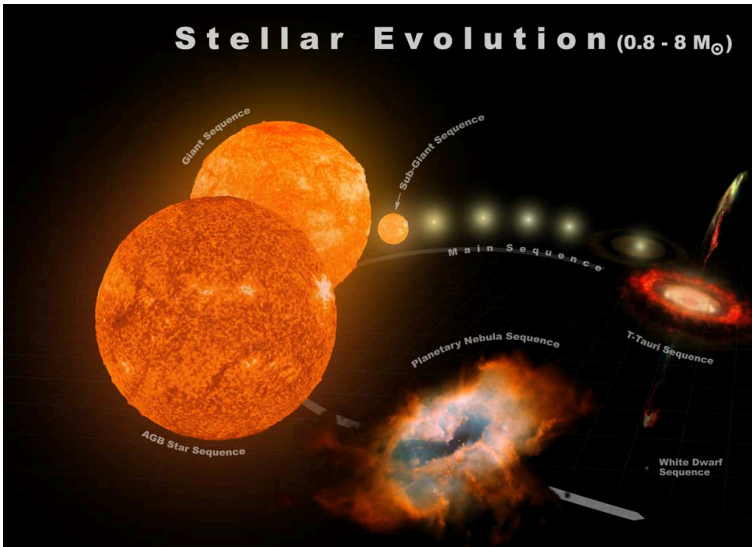
## H-R Diagram and Star Life Cycles

H-R diagrams which show how a star changes or evolves during its stellar life.

The H-R diagram can be used to study and understand how a star will evolve during its life cycle. Stellar evolution is the processes and changes a star undergoes over time.



An H-R Diagram showing stellar evolution of a 1 solar mass star; that is, our Sun and stars like our Sun. Evolutionary track 1m by Lithopsian is licensed under CC BY-SA 4.0

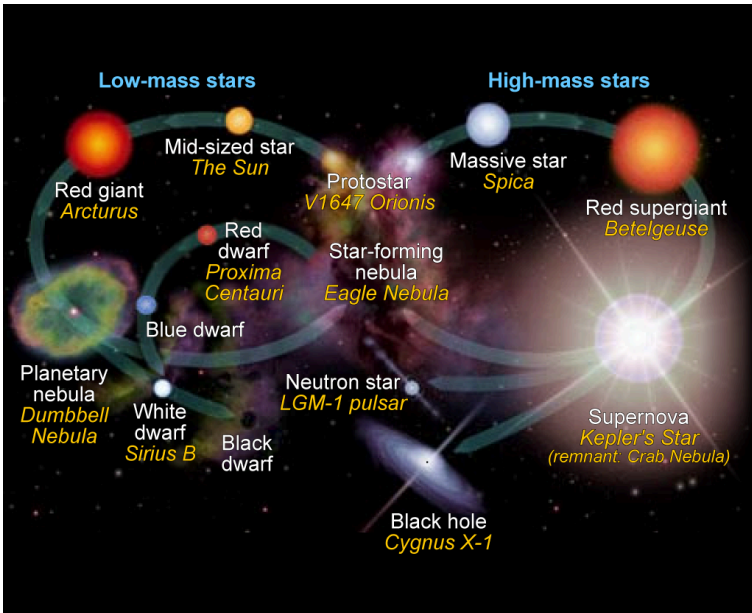


The typical stellar evolution sequence and relative sizes for stars from 0.8 to 8 solar masses. Stellar Evolution by Antonio Ciccolella is licensed under CC BY-SA 4.0

Stars are not all the same mass when their fusion processes begin. So, a star's stellar evolution will vary, depending on the star's stellar mass. High-mass stars fuse their fuel quickly, as fast as a few million years. Low-mass stars like the Sun, are much slower and so evolve much slower, periods of billions to even trillions of years.

Since astronomers cannot track the stellar evolution of one single star, even with a high mass short lived star. So many stars are studied, providing astronomers a good look at the various changes stars go through over time.





Stellar evolution comparison of low mass (left) and high mass stars. Examples of each stage are shown in italics. Star life cycles red dwarf en by NASA Goddard Space Flight Center is in the Public Domain

## 62. Lab 11 Assessments

### Exercise: Plotting H-R Diagram Exercise

Exercise Document Link

*Follow the link above to the assignment.*

*Use the above document to submit your data and responses.*

For this lab you will need:

- Star data, table below
- H-R Diagram Data Graph; print one copy
- Color pencils, pens, or crayons – recommend blue, yellow, orange, and red

You will plot the data points, as advised in the document, then respond to all of the questions with complete answers, written in complete sentences. This exercise will be graded using the rubric in the syllabus and attached document and is worth up to 65 points. <sup>(1)</sup>

### Lab 11 Quiz

Quiz Document Link

This quiz contains five matching items, each worth 2 points, for a total score of up to 10 points. You will have 5 minutes to complete this quiz. You have one attempt. <sup>(1)</sup>

PART XII

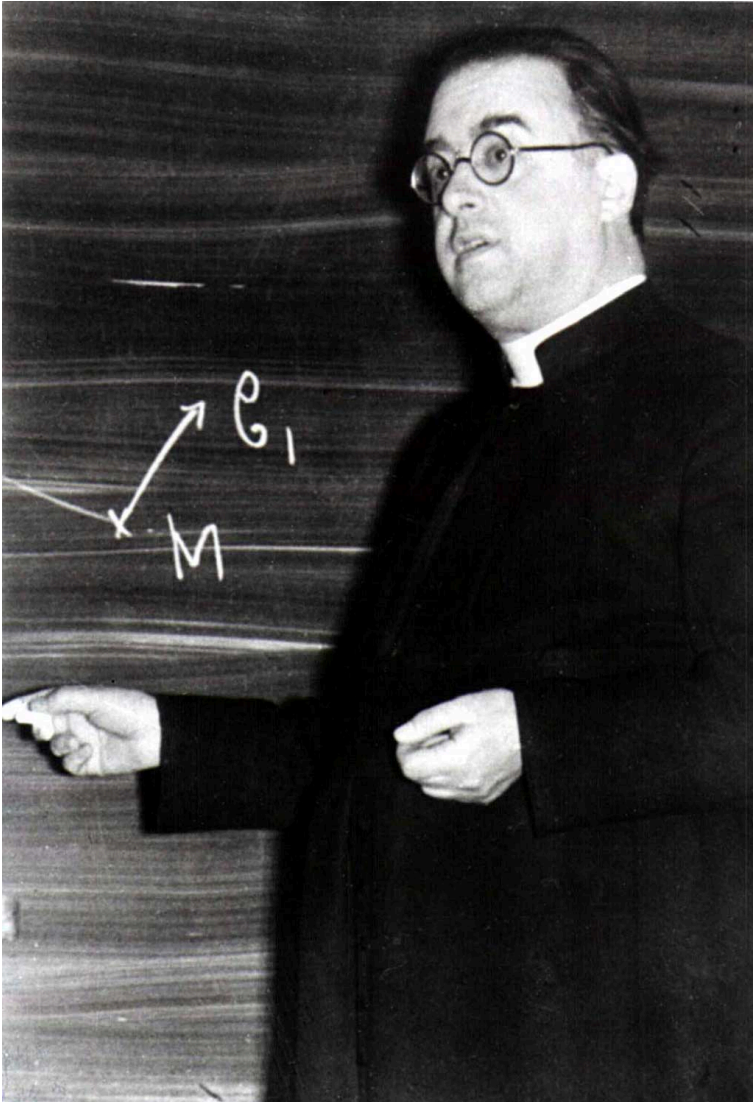
# LAB 12 - HUBBLE'S LAW ORIGINS



## 63. Introduction

## Astronomy Laboratory 12 – Hubble's Law

## Module Introduction



Georges Lemaître, Belgian priest, astronomer and professor of physics at the Catholic University of Leuven Lemaître by huidig is in the Public Domain

Edwin Hubble, of the Hubble Space Telescope fame, developed a relationship between an object's distance and the velocity it appears to be moving away from us that is still in use today. In this lab, you will explore Hubble's Law and implications of the law in understanding the Universe. <sup>(1)</sup>

## Objectives

At the end of this module, students will be able to:

- Calculate the age of the universe using Hubble's Law
- Model the expanding universe
- Make hypotheses based on the model and calculations <sup>(1)</sup>

## Outcomes

The material in this module includes content designed to meet the following course outcomes:

- Explain and apply major concepts in astronomy including planets, satellites, stars, meteors, galaxies, and theories of the universe.
- Demonstrate knowledge of scientific method.
- Communicate scientific ideas through oral or written assignments.
- Interpret scientific models such as formulas, graphs, tables and schematics, draw inferences from them and recognize their limitations.
- Demonstrate the ability to think critically.
- Demonstrate the ability to use scientific and quantitative reasoning. <sup>(1)</sup>



# Assigned Readings

## Learning Unit 12

## Assignments

- Hubble's Law and the Age of the Universe Exercise
- Expanding Universe Model Exercise
- Lab 12 Quiz <sup>(1)</sup>

# 64. Hubble's Law Origins

## Hubble's Law Origins

Hubble's Law is a proportional relationship between a galaxy's distance and that galaxy's receding velocity. This relationship between an object's distance and the velocity it is moving away is a direct observation of the expansion of the observable Universe. Hubble's Law infers that a galaxy that is moving away from an observer twice as fast as another galaxy is twice as far away.

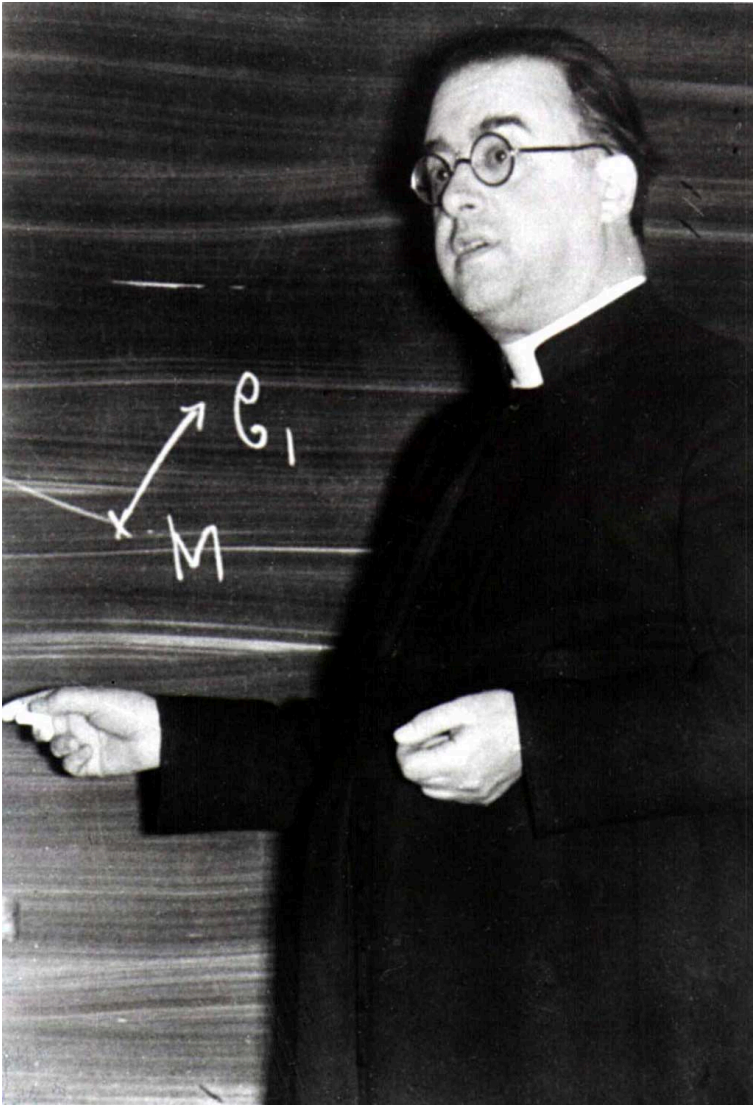
Before Hubble and the early work on modern cosmology, there was much discussion about the size and shape of the Universe. And, questions such as a finite or infinite Universe were often discussed. In 1920, two American astronomers, Harlow Shapley and Heber Curtis, debated over the size of the Universe issue. Shapley thought the Universe was small, about the size of a spiral galaxy. Curtis argued that the Universe was much, much larger. In a few short years after the famous Curtis-Shapley debate, ideas put forth and data collected would begin to resolve these questions.

Even though Hubble's Law is named after American astronomer Edwin Hubble, others worked on this cosmological concept and relationship before Hubble. In 1922, Alexander Friedmann, a Russian physicist, postulated through a set of equations that the Universe might be expanding, and if so, the equations he developed could explain that expansion. In 1927, Father Georges Lemaître, a Catholic Belgian Priest, proposed the theory that the Universe was expanding and not simply set into place. He also hypothesized the rate at which the Universe is expanding. Lemaître was also responsible for the initial concepts of the Big Bang theory. He drew his work from Einstein's Law of General Relativity. His 1927 paper was entitled *UN UNIVERS HOMOGÈNE DE MASSE CONSTANTE ET DE RAYON CROISSANT RENDANT COMPTE DE LA VITESSE RADIALE DES*

NÉBULEUSES EXTRAGALACTIQUES (A HOMOGENEOUS UNIVERSE OF CONSTANT MASS AND GROWING RADIUS ACCOUNTING FOR THE RADIAL VELOCITY OF EXTRAGALACTIC NEBULAE). The problem was that few scientists outside of Belgium read Lemaître's paper.

Lemaître was the first to propose that the expansion of the Universe explains the spectral redshifts being observed in galaxies. There are many who believe Hubble's Law should be called Lemaître's Law.

In addition to being a Catholic priest, Lemaître was an astronomer and professor of physics at the Catholic University of Leuven, Belgium.



Georges Lemaître, Belgian priest, astronomer and professor of physics at the Catholic University of LeuvenLemaître by huidig is in the Public Domain

# 65. Hubble's Law

## Hubble's Law

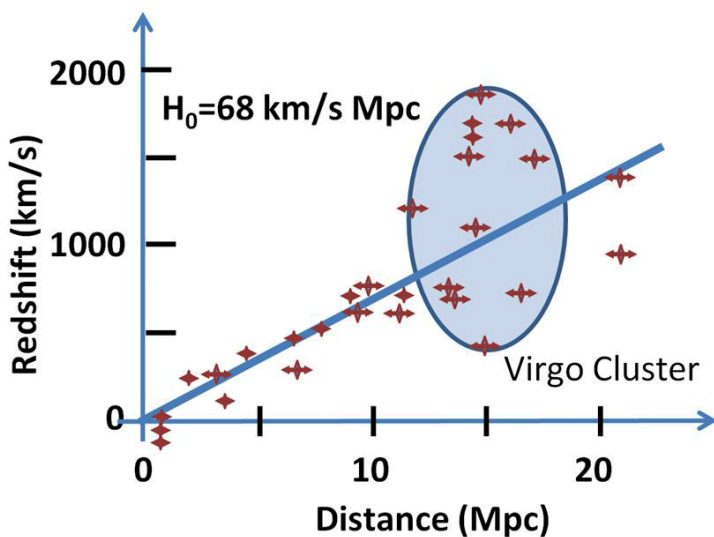
Two years later, in 1929, Hubble confirmed the Universe is expanding. Hubble also was able to infer the recessional velocities of a number of objects from the spectral redshifts he observed.

Hubble's Law states that an object's recessional velocity is proportional to the distance from the observer. In equation form, Hubble's Law is described by:

$$v = H_0 d$$

Where:

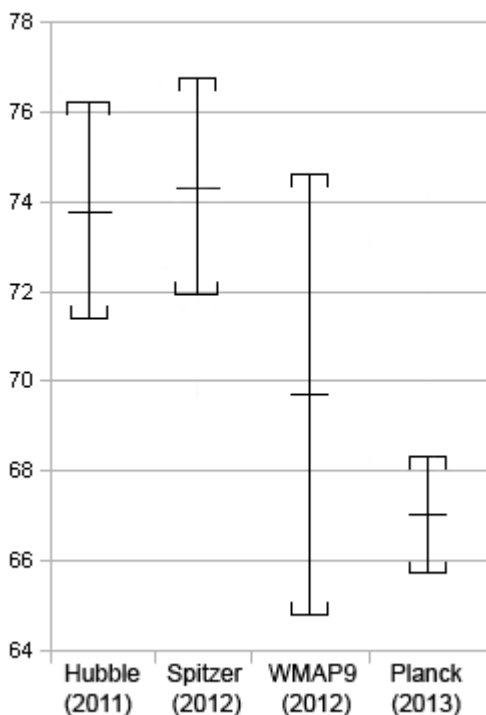
- $v$  is the velocity of the object, in km/s
- $d$  is the distance to the object, in megaparsecs, Mpc, where 1 Mpc equals 1 million parsecs; and
- $H_0$ , the Hubble constant or Hubble parameter, a proportionality between  $d$  and  $v$ ; also known as the rate of expansion, in (km/s)/Mpc or simply km/s/Mpc.



Astronomers take the data they observe — the distance to the object in megaparsecs (Mpc) and the object's speed away from us from their spectral redshifts (km/s) — and plot these values to obtain values needed to determine the Hubble Constant,  $H_0$ . Hubble constant by Brews ohare is licensed under CC BY-SA 3.0

## Hubble Constant

calculated using different survey methods



Different space telescopes have been used to determine the Hubble Constant,  $H_0$ . Each of these space telescopes — Hubble, Spitzer — WMAP, and Planck — look at the universe in different parts of the electromagnetic spectrum. Even though the  $H_0$  ranges for each space telescope vary, the data is more-in agreement than it was 10 years ago. Recent Hubble's Constant Values by Primefac is licensed under CC BY-SA 3.0

What does the km/s/Mpc unit mean? The km/s is a velocity, kilometers per second. Most of us are used to speeds in miles per hour, or mi/hr. A km/s velocity is much faster velocity than we are used to; 1 km/s is approximately 2,237 mi/hr. A megaparsec,

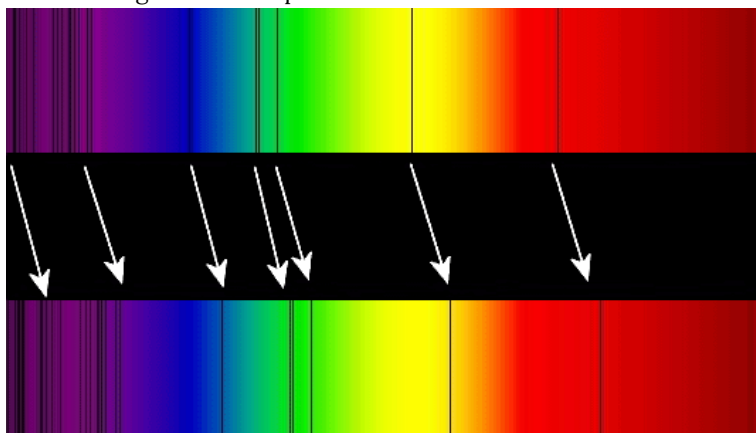
Mpc, is a specific distance, about 3.26 million light years,  $30.86 \times 10^{18}$  kilometers, or  $1.92 \times 10^{19}$  miles. The km/s/Mpc is a unit of velocity per distance, velocity per megaparsec or about 3.26 million light years.

The Hubble's Law equation can be rearranged to solve for an object's distance:

$$v = H_0 d$$

$$d = v / H_0$$

With Hubble's Law arranged in this form, one can determine the distance to an object like a distant galaxy or quasar by determining the object's recessional velocity from the object's spectral red shift and knowing the Hubble parameter.



A red-shifted absorption line spectrum, indicating the object is moving away from the observer (us here on Earth) Redshift horizontal by Georg Wiora is licensed under CC BY 2.5 / A derivative from the original work

With an understanding of the relationship between an object's redshift, its receding velocity, and distance, the work turned to determining the Hubble parameter value,  $H_0$ . A correct, or at least close, Hubble parameter would lead astronomers and cosmologists to not only determining the distances to these galaxies, but the age of the observable Universe itself. Hubble's Law applies to galaxies



and objects that are extremely far away; specifically, more than 10 megaparsecs from the observer.

# 66. The Hubble Parameter

## The Hubble Parameter

So, how did astronomers and cosmologists determine the Hubble parameter? Edwin Hubble first assigned a value in 1929 of 500 km/s/Mpc, based on his observations of extremely-distant objects at Mt. Wilson Observatory in Southern California. Astronomers continued to collect data to revise the Hubble parameter; Allan Sandage achieved a good estimate of 75 km/s/Mpc in 1958. This was a significant change over Hubble's initial estimate. The debate became quite acrimonious, with Sandage revising his estimate to around 50 km/s/Mpc and Gerard de Vaucouleurs proposing a value around 90 km/s/Mpc. This Hubble parameter wide range and debates continued until the mid-1990's, when data from spacecraft such as the Hubble Space Telescope assisted in better values for the Hubble parameter.

Various spacecraft have provided different values for the Hubble parameter. And each of these values are dependent on the type of object being observed or methodology employed. Astronomers and cosmologists have collected data from include Type 1a supernovae, Cepheid variable stars, gravitational lensing, the cosmic microwave background, and most recently gravitational waves.

Let's look at how the Hubble parameter changes things, specifically the age of the Universe. Recall Hubble's Law:

$$v = H_0 d$$

Dividing both sides by  $d$ , solves for  $H_0$ :

$$v/d = H_0$$

Since  $v = d/t$  (velocity equals distance divided by time, e.g. 65 miles/hour) substituting for  $v$ :

$$d/t/d = H_0$$

$$1/t = H_0$$

$$t = 1/H_0$$

This equation —  $t = 1/H_0$  — gives one a direct relationship between the age of the Universe and Hubble parameter. So, let's look at how it works to determine the age of the Universe.

Let's use a value for the Hubble parameter,  $H_0$ , of 70 km/s/Mpc. This gives us:

$$t = 1/H_0 = 1/70 \text{ km/s/Mpc}$$

Yet these units don't look like time, except for the seconds. And we need — *want* — the age of the Universe in years. So first cancel the distance units by dividing  $3.09 \times 10^{19}$  km/Mpc by the selected Hubble parameter:

$$(3.09 \times 10^{19} \text{ km/Mpc}) / (70 \text{ km/s/Mpc}) = 4.41 \times 10^{17} \text{ s (seconds)}$$

There are  $3.16 \times 10^7$  seconds in a year. To convert seconds to years, divide the number of seconds above by  $3.16 \times 10^7$  s/yr:

$$(4.41 \times 10^{17} \text{ s}) / (3.16 \times 10^7 \text{ s/yr}) = 1.396 \times 10^{10} \text{ yr or 13.96 billion years}$$

Let's see one more example, based on Edwin Hubble's original estimate of the Hubble parameter,  $H_0$ , being 500 km/s/Mpc:

$$t = 1/H_0 = 1/500 \text{ km/s/Mpc}$$

$$(3.09 \times 10^{19} \text{ km/Mpc}) / (500 \text{ km/s/Mpc}) = 6.18 \times 10^{16} \text{ s (seconds)}$$

$$(6.18 \times 10^{16} \text{ s}) / (3.16 \times 10^7 \text{ s/yr}) = 1.92 \times 10^9 \text{ yr or 1.92 billion years}$$

So, in comparing the two values for Hubble's parameter,  $H_0$ :

Hubble's parameter, $H_0$	Age of the Universe
70 km/s/Mpc	13.96 billion years
500 km/s/Mpc	500 km/s/Mpc

For a Hubble parameter of 70 km/s/Mpc, close to the range astronomers and cosmologists use today, that is a Universe some 7.27 times older than Hubble's 1929 estimate.

# 67. Lab 12 Assessments

## Hubble's Law and the Age of the Universe Exercise

### *Exercise Document Link*

*Use the above document to submit your data and responses.*

In this lab exercise, you will calculate the age of the universe using the given Hubble parameter then respond to the questions. This exercise will be graded using the rubric in the syllabus and attached document and is worth up to 35 points. <sup>(1)</sup>

## The Expanding Universe Model Exercise

### *Exercise Document Link*

*Use the above document to submit your data and responses.*

In this lab exercise, you will create a model of the expanding universe to utilize for completing the data table and answering the provided questions. This exercise will be graded using the rubric in the syllabus and attached document and is worth up to 30 points. <sup>(1)</sup>

## Lab 12 Quiz

### *Quiz Document Link*

This quiz contains five matching items, each worth 2 points, for a total score of up to 10 points. You will have 5 minutes to complete this quiz. You have one attempt. <sup>(1)</sup>

PART XIII

LAB 13 - PLANETARIUM,  
ASTRONOMY CLUB/  
OBSERVING



# 68. Introduction

## Astronomy Laboratory 13 – Planetarium/ Astronomy Club/Observing

### Module Introduction



A star party in the Grand Canyon National Park 23 Annual Star Party 2013 by Grand Canyon National Park is licensed under CC BY 2.0

Humans have long been looking up at the sky and trying to make sense of what they saw. Methods of observation have evolved throughout the ages, yet access to tools of observation have been slow to follow along. Few could afford the tools while many wanted to use them. Interest in astronomy was strong, so setting up telescopes in public was regularly done. Today, these events are usually called star parties, where the public is invited to come to a

park, museum, or other site to look through telescopes often staffed by amateur astronomers.

In this lab, you will attend a local astronomy club meeting, observing session (star party), or planetarium program, reporting out via specific questions, and sign-off by the club or planetarium. <sup>(1)</sup>

## Objectives

At the end of this module, students will be able to:

- Locate and attend a local astronomy club meeting, observing session (star party), or planetarium program
- Participate in a local astronomy club meeting, observing session (star party), or planetarium program
- Describe the tools used at the viewing event
- Describe the observations made at the viewing event <sup>(1)</sup>

## Outcomes

The material in this module includes content designed to meet the following course outcomes:

- Explain and apply major concepts in astronomy including planets, satellites, stars, meteors, galaxies, and theories of the universe.
- Communicate scientific ideas through oral or written assignments.
- Demonstrate the ability to think critically. <sup>(1)</sup>



## Assigned Readings

### Learning Unit 13

## Assignments

- Event Participation Activity
- Lab 13 Quiz <sup>(1)</sup>

# 69. The Telescope

## Looking Up!

Ever since humans roamed Earth, they looked up. Primarily, they needed to understand the sky — motions of the Sun, Moon, and stars — to know when to plant and pick crops, navigate, or simply as a time keeper. In many cases, their lives depended on their knowledge of the sky. And, many events that took place — meteor showers, eclipse, comets, supernovae — surprised and baffled these ancient peoples.

As technology developed, so did ways to observe and model what people saw in the heavens. Observing included ways to find objects — star maps and globes — as well as ways to track objects, like the astrolabe. The invention of the telescope, and astronomical use by Galileo in 1609, opened up the heavens in a new, exciting way. And, as technology developed, ways to present these astronomical objects became more and more exciting.

## The Telescope

Initially, only those who were well to do or royalty had access to telescopes. And, astronomers were often hired by royalty or rewarded for their discoveries. Yet, as time went on, and methods for producing telescopes became more common, many universities and cities across Europe and the United States in particular saw an observatory with a refracting telescope as a cornerstone. The main challenge was producing excellent — or even good — optics. By the 18<sup>th</sup> Century, refracting telescopes were being produced in some number by opticians like John Dollond. In the 19<sup>th</sup> century, opticians such as Henry Fitz and Alvan Clark produced fine commercial telescopes. Alvan Clark & Sons made what is still the

largest refracting telescope in the world, the 40-inch refractor at Yerkes Observatory, Williams Bay, WI.

Reflecting telescope were not initially popular, due to the difficulties producing the right type of curve on the primary mirror, and keeping the surface reflective. With the development of techniques to deposit a thin coating of aluminum on a surface of glass, the reflector not only became commercially viable, but less expensive to manufacture than the refractor.



1897 photo of the 40-inch refractor at the Yerkes

Observatory Yerkes 40 inch Refractor Telescope-1897 by PD-OLD is

in the Public Domain

# 70. Observatories and Early Astronomy Clubs

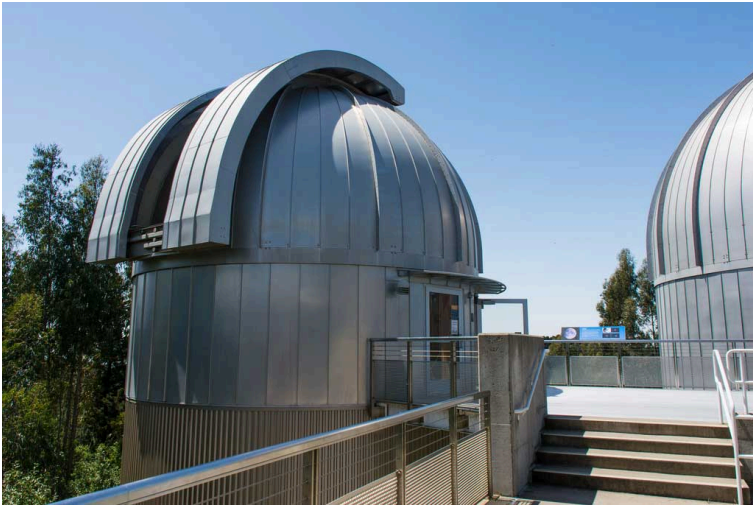
## Observatories and Early Astronomy Clubs

Interest in astronomy was strong, so setting up telescopes in public was regularly done. Today, these events are usually called star parties, where the public is invited to come to a park, museum, or other site to look through telescopes often staffed by amateur astronomers. Perhaps, one of the best known of these groups is the San Francisco Sidewalk Astronomers, started by the late John Dobson.



Sidewalk Astronomy, New York 1921 Telescope on sidewalk by Unknown is in the Public Domain

Many astronomy clubs, colleges/universities, museums/science centers, and even private individuals have observatories: a permanent housing for their telescope or telescopes. A number of these open for the public on regular occasions, or for special astronomical events like an eclipse or when a planet is in the position for optimum viewing.



The dome and building which houses the 8-inch refractor “Leah” at the Chabot Space and Science Center, Oakland, CA. Chabot Dome by Don DeBold is licensed under CC BY 2.0



The 20-inch Refractor “Rachel” at the Chabot Space and Science Center. Rachel by Don DeBold is licensed under CC BY 2.0

# 7I. The Planetarium

## The Planetarium

The planetarium as we know it today is essentially a new technology. Often called the planetarium theater or dome, the room itself is marked by a domed ceiling, onto which astronomical bodies are projected.

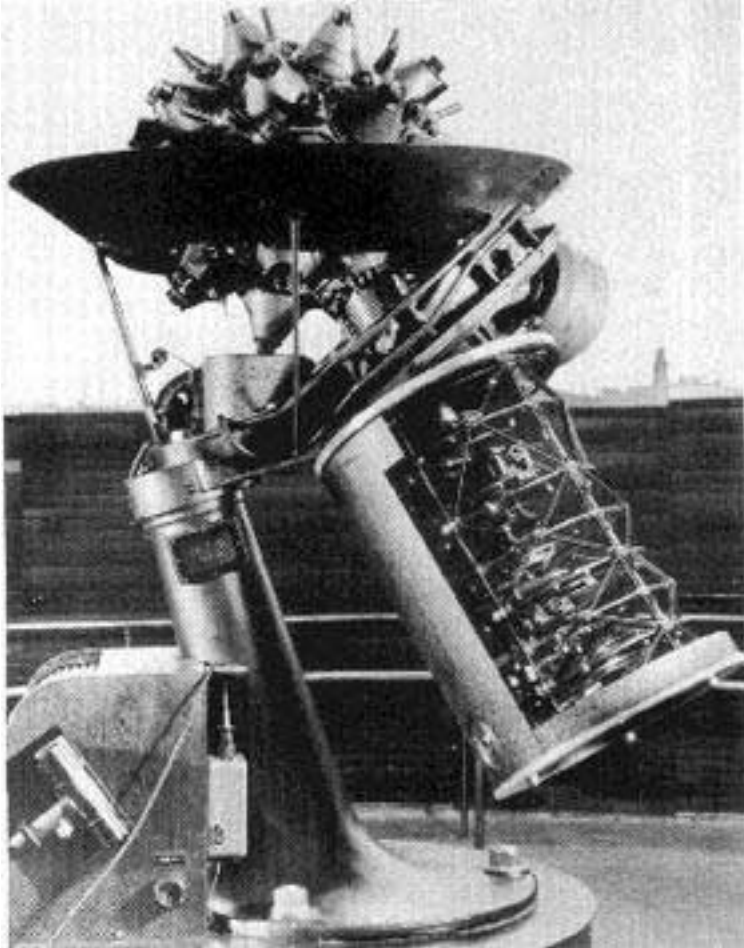
The Greeks are credited with creating a device which could predict the motions of the Sun, Moon, and the planets known at the time (Mercury, Venus, Mars, Jupiter, and Saturn). These devices became known as an orrery. Other early planetarium-like models included the painting of stars and constellations on walls and ceilings, and large domes with theater-like star effects.



A small orrery showing earth and the inner planets Orrery small by Kaptain Kobold is licensed under CC BY 2.0



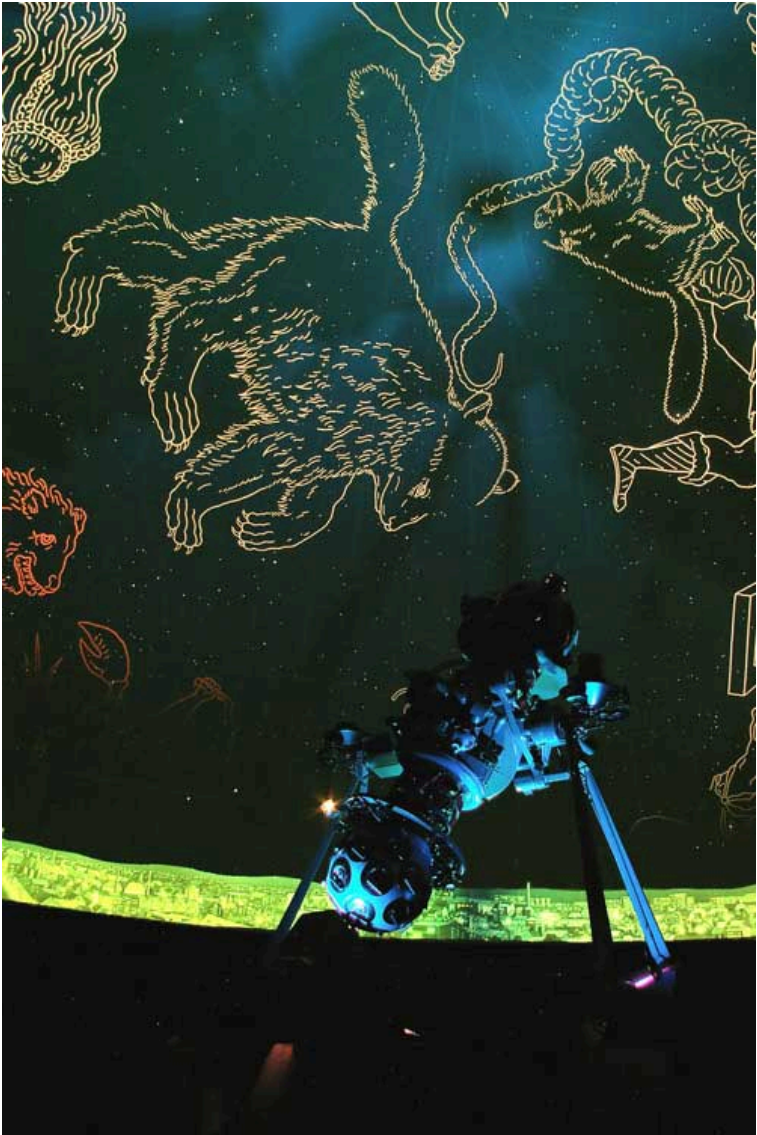
The first modern-era planetarium was designed and built by the Carl Zeiss Company in Jena, Germany and installed in the Deutsches Museum in Munich. The stars were projected onto a plaster dome.



The Zeiss Mark I Planetarium Projector was the first installed planetarium projector; Deutsches Museum Munich, Germany 1923 ZeissMark1 by Unknown is in the Public Domain

Advances in electronics and Space Race demand for science education pushed more museums, colleges and school districts to install planetariums. Over the years, the planetarium has developed

into a multi-dimensional theater, combining all-dome film systems, special effects, and even all-dome planetarium projectors to give students and audiences a modern look at astronomy and the sciences.



A planetarium can also project other graphics, such as constellation outlines. Ncp 2 by Gawin is licensed under CC BY-SA 3.0

## 72. Current Astronomy Clubs

### Current Astronomy Clubs

Like many other hobbies and interests, astronomy clubs can be found throughout the United States. For example, Northeast Florida has the Ancient City Astronomy Club in St. Augustine, the Alachua Astronomy Club in Gainesville, and the Northeast Florida Astronomical Society in Jacksonville.

Many of the United States clubs are members of the Astronomical League, a federation of clubs and societies. You may check their website to see if there is a club in your area.



A star party in the Grand Canyon National Park 23 Annual Star Party 2013 by Grand Canyon National Park is licensed under CC BY 2.0

Astronomy Clubs vary in activities and meetings. Many are observationally-oriented, and a number own their own observatory. For the most part, families and children are always welcome and encouraged; you should check with the local club contact before

attending. A number of the clubs do special activities, such as how to buy a telescope and how to use a telescope. And, a few still offer classes on making a telescope; the Eastbay Astronomical Society in the San Francisco Bay area is well-known for the telescopes attendees make in their Telescope Makers Workshop.

# 73. Lab 13 Assessments

## Event Participation Activity

### Activity Document Link

Use the above document to submit your data and responses.

In this lab, you will need to attend at least one of the following:

1. Star party observing session
2. Planetarium show
3. Astronomy club meeting or sanctioned activity

Details of local events will be provided by your instructor and you can search for similar events in your area. Answer the questions provided for the particular type of event that you choose to attend. Also, be sure to take the Observing Form on page two to have your attendance verified. Please consult your instructor early in the semester if you foresee issues with finding or attending an event. Keep in mind that you are representing the school and yourself, so appropriate attire and behavior are required.

This exercise will be graded using the rubric in the syllabus and attached document and is worth up to 65 points. <sup>(1)</sup>

## Lab 13 Quiz

### Quiz Document Link

This quiz contains five matching items, each worth 2 points, for a total score of up to 10 points. You will have 5 minutes to complete this quiz. You have one attempt. <sup>(1)</sup>